LCD Technology Issue

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Display Procurement for the 21st Century Army

- LED Backlights Usher in Ultra-Slim LCD TVs
- OCB LCDs with Dynamic Backlight Control
- Increasing LCD Energy Efficiency Using Optical Films
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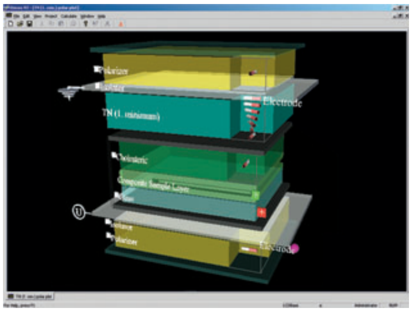

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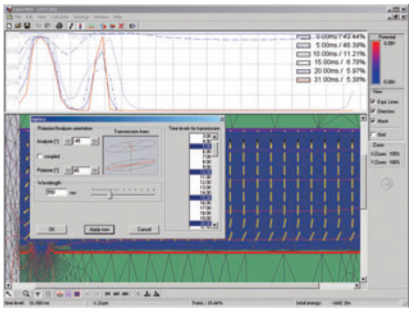

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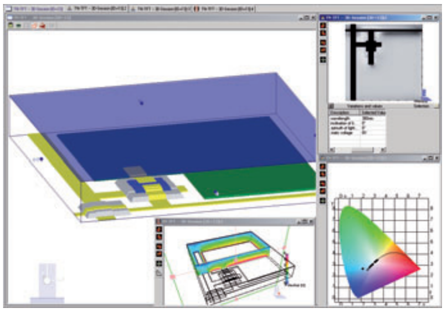

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CREDIT: Cover design by Acapella Studies, Inc. Photo of the TX-338 Ruggedized Analog Resistive (RAR) touch screen courtesy of BARCO.

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Too Many Conferences, Not Too Much Information

Last month, I discussed the strategic side of professional development: advanced degree programs and other professional training programs. I talked about how important it was to offer benefits to employees to take advantage of these opportunities and how important it is for each of us to keep developing ourselves. Advanced degrees and college courses are a long-term path to further development. For most of us in the display business, the short-term tactical path is conferences and seminars. Whenever possible, I try to attend technical seminars and topical conferences so I can keep current on new products and technology innovations. But guess what? There are just too many opportunities. Between September 2007 and September 2008, I counted over 30 meaningful industry-related conference/seminar events with national or international appeal, and I only checked a few popular Web sites. If I also count regional and local events in the U.S., the number is 50 or more. Unless one of these events takes place in your local area, attendance can be a significant expense. Counting airfare, hotel, rental car, registration fees, *etc.*, can easily be more than US$1500 per person. A typical company would need to send at least 2 or 3 people to most events in order to get a comprehensive perspective and cover all aspects. Most companies cannot possibly afford to support more than a few of these events each year with employee attendance, unless they have a specific marketing or promotional interest. But, unfortunately, most of these events are unique and cover somewhat differing aspects of display technology. Even if you further sort the list into markets and technologies, assuming any one of us is not focused on everything, you still get over a dozen in each major category you should be looking seriously at. That's still an impossible number to support.

Overall, attendance at display-industry conferences is down compared to previous years. This seems to correspond coincidentally with the increase in the number of events. Exhibition revenue and marketing spending at these events is also down industry wide. Numerous industry groups including SID organize these events and in many cases they rely at least partially on the income to fund their other endeavors. Some organizers are "for profit" companies, others are not. All of them need industry participation to survive. The problem now appears to be a combination of the sheer number of events combined with continuing reductions in corporate budgets has put an upper limit on what the organizers of these events can expect to accomplish. Only a small number of larger events such as FPD International and DisplayWeek actually turn a profit and are showing sustained growth. Most others either cover their expenses or operate at a loss for the betterment of the industry. Of course, organizers cannot afford to subsidize all of their events and unless some make money, they will not survive.

The display industry needs much of the content at many of these events. Designers and researchers need to be at these events to keep pace. Marketing groups need these events to promote their products and grow their businesses. Organizers need these events to fund their other endeavors. So, with all of us having complimentary needs it seems logical that we need to find a solution together. I think the most obvious one is collaboration among organizing groups to combine content and reduce the total amount of independent events. While I do not expect competing marketing firms to team up, non-profit- and profit-focused groups can certainly partner in some form,

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guest editorial

Synergy through System-Level Considerations Gives LCD Technology a New Edge

by Jim Anderson

For years, liquid-crystal-display (LCD) research has focused on the challenges of the liquid-crystal panel. Performance improvements have focused on improving viewing angle, contrast, and switching speed by improving the liquid-crystal material, alignment, and electrical driving. The significant advances in manufacturing technology have enabled larger and larger panels while still driving the price down at an amazing pace.

Thanks to creative scientific work in the industry, each component of an LCD module now achieves such a level of performance and price as to enable everything from low-cost gas-pump displays, to energy-efficient mobile devices, to the huge full-HD TV sets with wide viewing angle that are becoming common in households around the world.

The primary focus of the effort has been on the LCD panel itself. Early super-twisted-nematic (STN) LCDs enabled laptop computers into the marketplace, but had poor viewing angle, poor response time, and limited display resolution. Through improvements in manufacturing technology, active-matrix backplanes became cost effective, thus enabling new LC designs. The 90° TN mode, used most commonly today, gave significant improvements in viewing angle and response time, and removed the barriers to high resolution. To continue the improvements to create super-wide viewing angles and high contrast, new LC modes using different alignment (vertically aligned or in-plane-switching) were developed. By increasing the drive frequency of the LCD panel to 120 Hz, researchers have achieved new levels of performance for image-blur reduction. However, performance progress has slowed as the concepts became more difficult to manufacture in the LCD panel and drive electronics.

Similarly, early direct-lit backlights were very simple devices with a large number of CCFL bulbs designed to give uniformity and brightness through the highly inefficient LCDs available then. Researchers at 3M along with other institutions realized brightness gains in the system by placing prismatic and then reflective polarizer films between the backlight and the LCD panel. As these new films became available and work progressed to improve the efficiency of the LCD panel, bulbs were removed. Work in the past few years on wide-color-gamut CCFLs and now LED-based lighting have further improved the performance of LCD modules by making the colors more vibrant.

To enable LCD modules to take the next step in performance, the components must be optimized together. Researchers in the industry have begun doing exactly this and have come up with many creative and exciting new devices. By coupling the way the backlight is driven to the way the LCD image is created, for example, contrast, image blurring, and power efficiency can be significantly improved. The articles in this issue highlight some of these improvements. By utilizing a holistic approach to system design, these researchers have developed amazingly thin, power-efficient, and high-performance designs.

The ability to create an LCD-TV set that is only 10-mm thick by Samsung Electronics was only possible by utilizing the properties of an LED backlight with new techniques in LCD design, as well as overall TV-set design and optimizing these as a system.

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president's corner

Investing for the Future

The past few months have shown huge volatility in the international financial system, with many indicators pointing toward economic slowdown. The natural tendency for most companies and individuals is to hunker down, cut back on expenses, and to wait for better times. At times like these, investment for the future usually takes a back seat to other concerns because it's easier to worry simply about the here and now.

Even in tough times, though, most people will find money for an investment if the opportunity looks like a sure thing, especially if the returns are potentially large. With this in mind, I would like to bring to your attention a relatively low-cost investment that invariably leads to a set of assets that can provide returns that could last for decades. I'm talking about investing in people and, in particular, students, who are in the process of plotting their career trajectories.

The strength of any endeavor ultimately depends on the quality of its people, and the electronic-display industry is no exception. All companies rely on smart, dedicated, innovative people to imagine, develop, manufacture, and sell the products that delight customers and provide profits back to the company. Whether it is the company leadership, the scientific and engineering development staff, marketing team, or manufacturing group, at one point all of these people were students.

Students have a lot of uncertainty in their lives, particularly regarding career choices. What makes a student choose one particular field over another? What makes a student in a particular field choose one company over another? The reasons are many and often subtle, but there is one element that is certain: For a student to choose a particular field, or a particular company, they must have some exposure to that field or company. This exposure is particularly important for the electronic-display industry, as many universities do not have specific departments or programs that will naturally provide training or exposure to our industry. Allow me to offer two ways for companies to provide this exposure.

Internships are a great way for a company to engage students as they are forming their career choices. Often done in conjunction with a local university's career center, the student is given work that is useful for the company and is appropriate to the student's level of training. This is great for the students, who get a glimpse what it is like to work in the "real world" and, in particular, begin to identify the traits, habits, and skills that enable success. Internships in different cities and/or countries give students valuable life experience that they likely will never forget. They also get to earn a bit of money, which is nearly always in short supply at that age.

For the company, it can be great as well. Interns work cheaply compared to regular salaried staff. They are motivated to work hard in order to impress their hosts. While the students may lack experience (and perhaps some judgment), sufficient oversight from a regular employee can ensure that useful work is completed. Interns develop tremendous gratitude for the sponsoring companies and spread that word to their friends. Most importantly, though, the company gets to identify some highly talented workers that they can engage again once they graduate.

There are other ways that our industry can support students as well. Think back to the first technical conference that you attended, early in your career. Rubbing shoulders with experienced scientists and engineers, getting to present a paper or explain a poster presentation, and just learning about the state of the art can leave quite an

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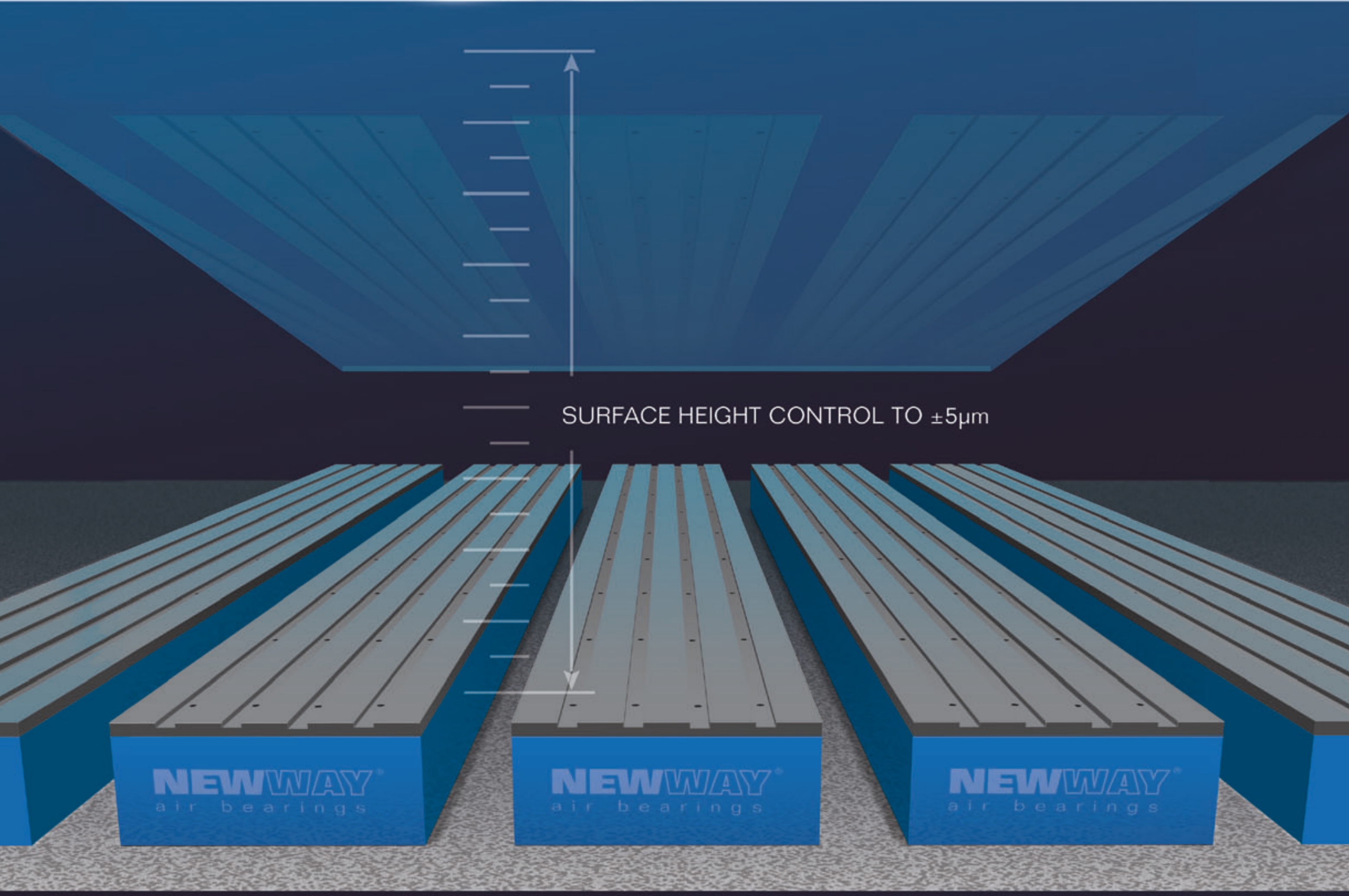

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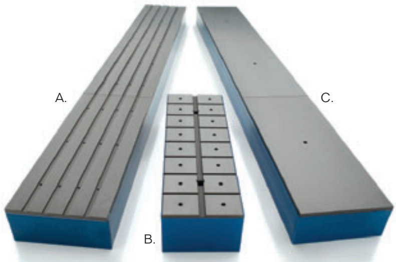

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Ultra-Slim LCD TV Enabled by an Edge-Lit LED Backlight System

As always, thin is in when it comes to flat-panel TVs. LCD designers and engineers have been striving to make their TV sets thinner and thinner, especially as the threat from OLED TV looms. This article examines the problems encountered when trying to develop an edge-lit LED backlight and how Samsung overcame these hurdles to introduce its 10-mm-thick 40-in.-diagonal LCD-TV prototype in late 2007.

by Taeseok Jang

THE ANSWER seemed to be so simple. LCD designers and engineers knew that they had to keep making their modules thinner and thinner, especially once it became apparent that OLED TV was on a path to commercialization. The backlight seemed to be the logical place to slim down the LCD-TV form factor without sacrificing image quality, and the best way to do this was to shift from a direct LED backlighting unit (BLU) to an edge-lit BLU, as had been done in the notebook-PC and desktop-monitor sectors.

However, it was quickly determined that such an edge-lit structure could not be directly applied to large-sized TVs without a number of careful considerations. Difficulties arise due to lowered mechanical rigidity and insufficient luminous flux. Samsung has overcome these issues, as demonstrated by their 10-mm-thick 40-in.-diagonal LCD TV with an LED edge-lit backlight system (Fig. 1, Table 1) that the company first demonstrated at FPD International 2007.

In this article, we will discuss these issues as they relate to ultra-slim technology for large-sized TVs.

Taeseok Jang *is Vice-President of the Backlight Technology Team, LCD Business, Samsung Electronics Co. Ltd., Asan-City, Chungcheongnam-do, Korea 336-841; e-mail: jangt@samsung.com.*

Module Design and Thermal Management

When designing an extremely slim LCD-TV module, the first consideration must be the design of parts such as the top and bottom chassis, which are the external metal frames surrounding the panel, and all optical components because these can make the module more vulnerable to deformities such as bending and warping. When slimming down a large module, it is difficult to maintain a flat shape even in the absence of external force. This situation worsens when the power is on. Heat is generated from the LED light source and concentrated along the edges before being transferred to other parts such as the light-guide plate (LGP), optical sheets, and top/bottom chassis. In the steady state, a non-uniform temperature distribution is established, which causes local variations in thermal expansion. Eventually, this will result in complex mechanical distortion. A simulation showing the result of thermal distortion is shown in Fig. 2.

Fig. 1: *The 10-mm-thick LCD-TV module.*

Table 1: Key specifications of the LCD-TV module

Item	Specification
Display size	40 in.
Resolution	FHD (1920 × 1080)
Mode	S-PVA
Module thickness	10 mm
Bezel size	14.6 mm
Luminance	450 nits
Color gamut (NTSC)	92% (CIE 1931)

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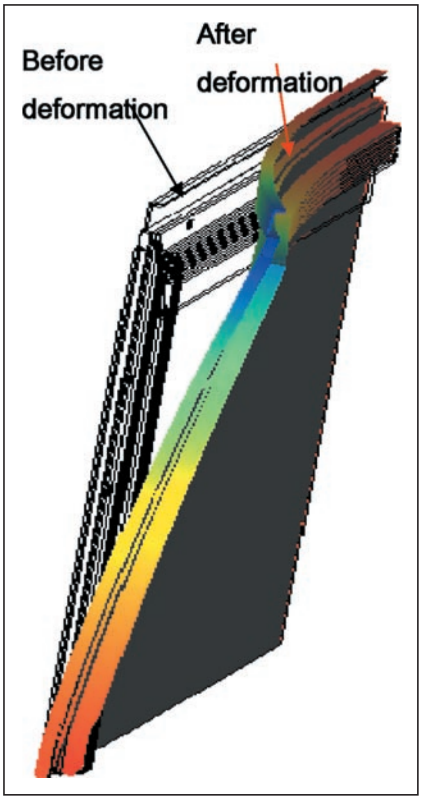


Fig. 2: *Simulated thermal distortion of an edge-lit LED module.*

For a rough estimate of the thermal deflection, consider a disk of radius R with a linear temperature gradient from T_0 (center) to T_R (edge). The amount of distortion (ℓ) (depth of dish) can be calculated after some simplification as

$$\ell = \pi R[6\beta(T_R - T_0)]^{1/2} ,$$

where β is the thermal-expansion coefficient. This equation states that the distortion is proportional to the module size and the square root of both the material property (thermal coefficient) and the temperature difference. Usually, the larger the module size, the larger the variation in temperature, so overall distortion occurs readily with larger modules. As an example, Fig. 3 shows the LGP's temperature distribution when the LEDs are placed along the circumference of the LGP. The actual amount of module distortion is derived from the vector sum of each component, including the LGP, the bottom and top chassis, and the LCD panel.

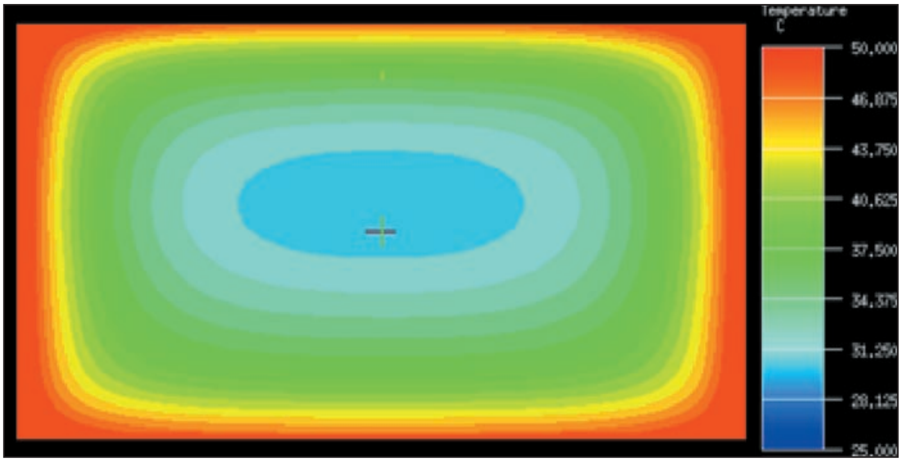


Fig. 3: *Temperature distribution of the LGP.*

It is very difficult to circumvent this problem with an acceptable increase in cost. For example, aluminum could be considered for use as the bottom chassis material because it has an higher thermal conductivity compared to electro-galvanized steel (SECC) and can provide benefits for heat dissipation. However, use of aluminum inevitably results in increased cost and reduced mechanical strength. Some auxiliary parts need to be added to supplement the mechanical strength while maintaining a high level of heat dissipation. Aside from the mechanical rigidity, a thermal spreader is of great help in preventing deterioration of the liquid crystal and for avoiding wrinkles in the optical sheets.

These types of problems for a slim-edge module quickly become more serious for increasing screen sizes. An optimal corrective approach must be taken from a holistic-system perspective in order to pass the various types of reliability tests required for mass production. If possible, it is highly advisable to work with the set manufacturer from the beginning of the design stage. Thermal issues are closely related to overall light efficiency and the level of power consumption. Development and use of highly efficient LEDs and optical components, such as the LGP and the system's optical sheets, are key factors for guaranteeing a sufficient level of commercial quality. Active backlight driving is also useful for reducing power consumption and heat generation. These points are discussed below.

Light Source and Optical System Efficiencies

LEDs are selected as the optimal light source over conventional cold-cathode fluorescent lamps (CCFLs), which present serious electrical and optical challenges in an ultra-slim LCD-TV module. Unlike a conventional direct-lit-type module, the light sources in an ultra-slim panel can only be placed along the edges of the module. However, tight spacing of CCFLs causes current leakage and a resultant severe decrease in electrical/optical efficiency. Furthermore, discharge instability can result.

When applying LEDs to edge-lit large TV modules, efficiency must be the first criterion considered, due to space constraints for LED placement and potentially severe thermal issues. There are many factors affecting the efficiency of the LEDs, such as the LED die (size, manufacturer, design, *etc.*), the package design, and the opto-mechanical characteristics of the module. While LED manufacturers are working diligently to increase the performance of their LED chips, it must be noted that packaging technology also has significant influence on the performance of the device. A package with low thermal resistance is critical for best efficiency, control of color shift, increased reliability, and longest life. For edge-type applications, the slug-type package, in which the LED chip is mounted on a metal slug for heat removal, needs to be widely adopted. Packaging with ceramic material is also highly recommended, even in view of increased cost.

Table 2: Comparison of light efficiency and color gamut for different methods of white-color production

Case	White LED	Efficiency	Color Gamut (CIE1931)	Main Applications
1	Blue chip + Yellow phosphor	100%	<70%	Notebook PC
2	Blue chip + Red/Green phosphor	~75%	~83%	TV
3	Blue chip + Green/Orange phosphor	>90%	~72%	—
4	Blue/Red chip + Green phosphor	>90%	~92%	—
5	Red/Green/Blue chip	~60%	>100%	Notebook PC, Monitor, TV

In addition, the method by which white color is produced is critical because this decision can have a significant effect on color gamut and light efficiency. Table 2 shows a rough estimate of the projected efficiency and color gamut derived from the various methods of producing white light. Note that the efficiency is normalized to the case of the blue chip plus yellow phosphor combination. Each method has its own strengths and weaknesses; therefore, selection should be based on the target application and required specifications. For the edge-type TV application, the designer's first priority should be in maximizing efficiency as emphasized above. Case 2 might be most common, due to its simple driving circuit and reasonable color gamut. However, Cases 3 and 4 represent better choices in terms of efficiency. Case 4 looks superior to Case 3 in that it has better efficiency and a wider-color-gamut. However, Case 4 may require a color-control circuit, as would Case 5 (RGB LEDs) because the blue and red chips age at different rates and the time required for blue versus red chips to reach steady-state emission levels differs significantly.

The same argument applies to the LCD's optical components including the LGP and optical sheets. The light-extraction pattern of the LGP is formed by a CO_2 laser – an improvement compared to the typical "scattering ink" pattern in screen-printing. The resulting microgroove is carefully controlled to provide about 10% higher efficiency, due to its reduced optical loss. As shown in Fig. 4, the microgroove has a well-defined shape that reduces the scattering properties. The amount of light extraction is controlled by the pattern pitch, the duty ratio, and the width. Also, the angle of the groove will determine the angular profile of the extracted beam. The proper combination of optical sheets is followed by careful application of the LGP to maximize efficiency and to provide best overall appearance.

Global Dimming

As a non-emissive display device, an LCD backlight typically consumes constant (maximum) power over time and emits a constant amount of light regardless of the final image seen by the viewer. Even from an early stage, active driving of the backlight has drawn considerable attention, and it has already been adopted for use in some high-end TVs. This technology adjusts the backlight luminance according to the image depicted, which results in reduced power consumption and a great deal of enhancement to the contrast ratio. Active-driving technology can be classified by the control method as global dimming, 1-D local dimming, 2-D local dimming, or three-

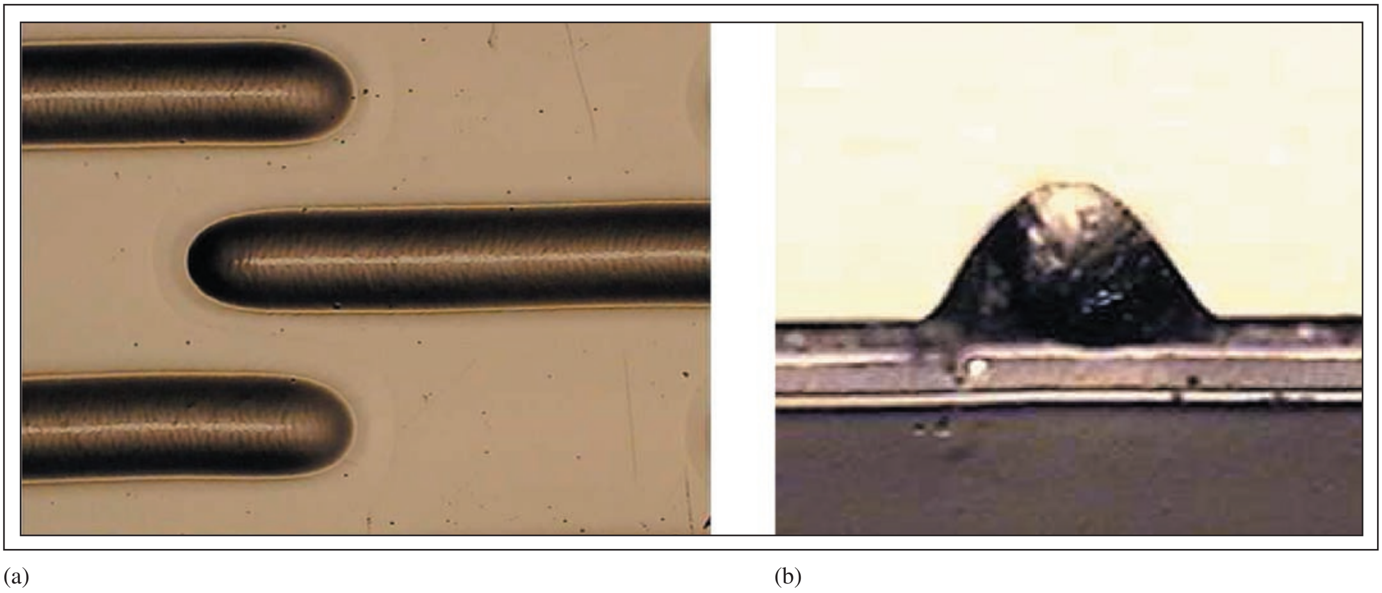
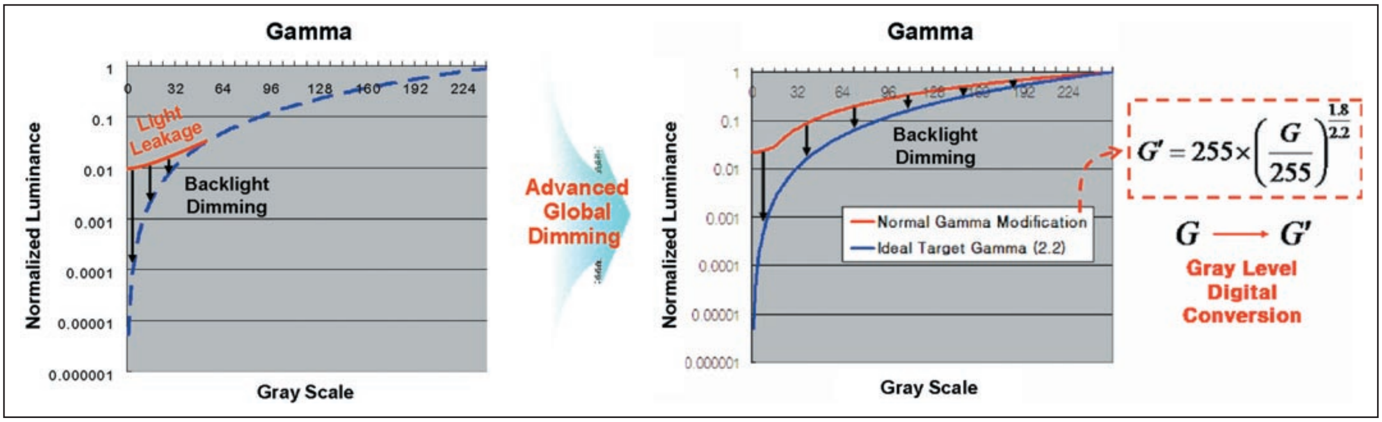

(a)
(b)

Fig. 4: Magnified view of the microgroove patterns of the LGP formed by a CO_2 laser: (a) top view; (b) side view.



(a) (b)

Fig. 5: Operating principle of the global-dimming technique: (a) conventional global dimming; (b) advanced global dimming.

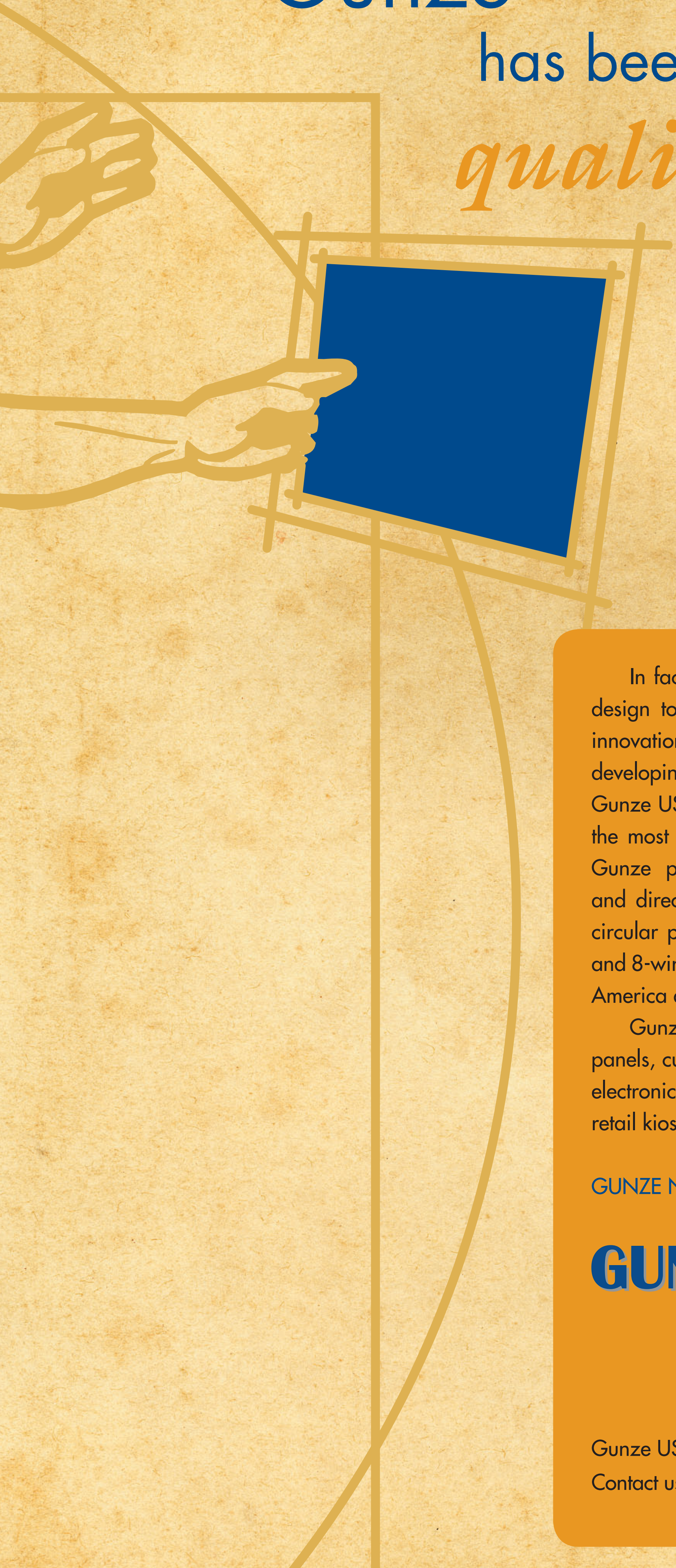
way local dimming (color dimming). For an ultra-slim module with an edge-lit backlight, global dimming is most appropriate due to its relatively simple dimming algorithm and driving circuit, in addition to consideration of the physical layout of the light source.

Figure 5 shows the working principle behind the global-dimming technique being used in our edge-lit TV module design. Figure 5(a) shows the gamma curve of conventional global dimming. Without dimming, the gamma curve follows the red curve at low gray levels due to considerable light leakage, which can cause significant loss of contrast ratio. Conventional global dimming works in the low gray region mainly for the purpose of increasing contrast ratio, so the amount of power savings is not significant overall.

With the advanced global dimming shown in Fig. 5(b), the input image data is converted and then transferred to the timing controller just as if the gamma curve were changed to, *e.g.*, 1.8 (red curve) from the ideal value of 2.2 (blue curve). The ideal gamma level is achieved by backlight dimming over the entire gray-level range. The difference between the two curves corresponds directly to the amount of power reduction at a given gray level. When this technique is applied, the final gamma curve nearly coincides with the ideal (2.2) gamma curve and results in much higher (dynamic) contrast ratio. Compared to the pixel-compensated global-dimming algorithm, which needs memory to store the gray-level value for each pixel, this algorithm only requires gray-level averaging with some attention to maximum data level. Therefore, advanced global dimming provides a highly cost-effective performance-enhancing solution compared to the pixel-compensated global dimming technique. Of course, modifications may be needed to eliminate certain types of artifacts, including darker images in the low gray range and flickering due to abrupt changes in backlight luminance. Importantly, the power savings attained by the advanced global-dimming technique will also result in a substantial decrease in the temperature of the module.

Conclusion

Although edge-lit backlighting technology is mature in smaller-sized applications such as notebook PCs and desktop monitors, until now it has not been scalable to large-sized LCD TV. Significant technical barriers must be overcome in order to be able to mass-produce an edge-lit ultra-slim TV module. First, the module needs to attain a sufficient level of mechanical strength and thermal reliability. Accomplishing this will require panel makers to cooperate more closely with set makers. Secondly, the edge-type TV module must be energy efficient. To achieve this, it is more cost effective to employ an efficient light source and improved optical components than to try to solve the problem simply by way of thermal management. With this point in mind, the edge-lit ultra-slim TV can indeed contribute toward a green TV solution. Finally, the advanced global-dimming technique plays a particularly useful role in reducing overall power consumption, hence increasing efficiency and improving reliability. This technique also provides considerable enhancement to the contrast ratio and results in nearly ideal gamma characteristics. Therefore, it is expected that the ultra-slim edge-lit TV module will become increasingly popular with ongoing improvements being made in panel transmittance and LED efficiency. ■



OCB-LCDs

High-Contrast Low-MPRT OCB-LCD with Dynamic-Backlight-Control Technology

Slow response time and low contrast ratio still plague the performance of many TFT-LCDs. Solving one issue does not necessarily address the other. This article puts forth a potential solution: an OCB-mode LCD with dynamic-backlight-control technology.

by Shigesumi Araki, Kenji Nakao, Seiji Kawaguchi, Yuuki Nishimoto, Kazuhiro Nishiyama, Ken Shiiba, Akio Takimoto, Ryosuke Nonaka, Masahiro Baba, and Go Ito

WITH ALL THE PROGRESS MADE in the performance of TFT-LCDs, there are two important performance measurables that still need improvement: slow response time and low contrast ratio. Many improvements have been proposed to address these subjects. Among these, high frame rates, overdrive, and optically compensated bend (OCB) mode[1] are used to improve slow response time. Of these techniques, dynamic-backlight-control technology dramatically improves contrast ratio.[2] This article proposes a new dynamic-backlight-control technology for the high-speed OCB-mode.

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Conventional LCDs

Dynamic backlight technology controls the backlight luminance and signal gamma data according to input images. For example, the backlight luminance is dimmed for dark scenes and the white luminance is optimized

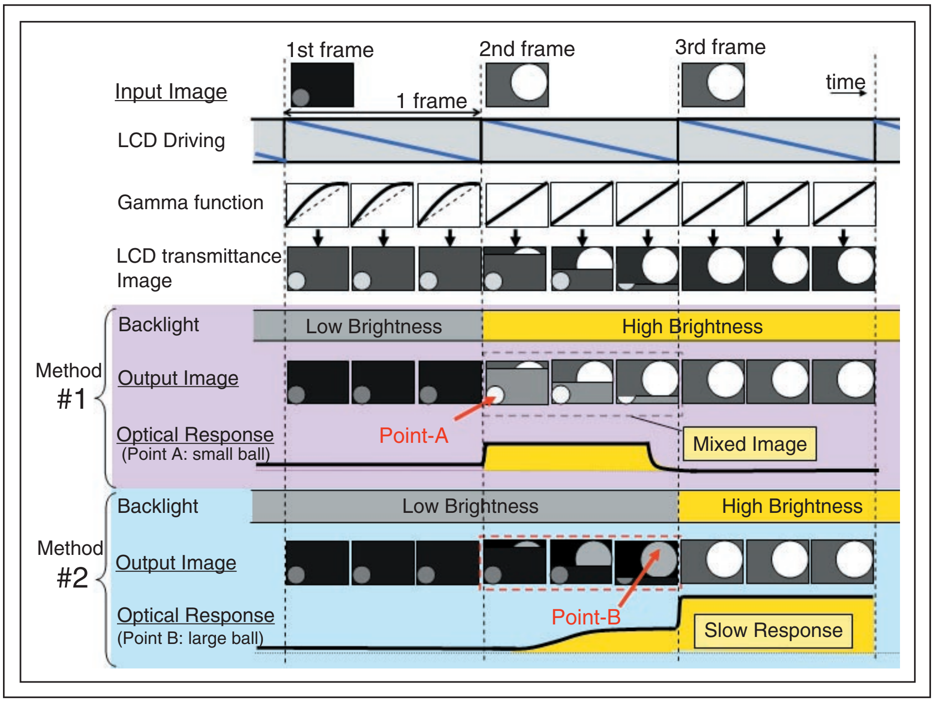

***Fig. 1:** Driving scheme of conventional dynamic-backlight-control technology.*

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by adjusting the signal gamma data; therefore improving the contrast ratio.

Figure 1 shows a simple concept of a conventional LCD with dynamic-backlight-control technology illustrated with examples of a sequence of input images: the first frame is a dark image with a gray ball, the second frame is a bright large ball that suddenly appears on screen, and the third frame holds the previous image. Each frame's images are analyzed, and then the gamma function and backlight brightness are adjusted.

In method #1, in which the backlight brightness is changed at the beginning of the second frame, gamma functions are changed at the beginning of the second frame. And the dark small-ball image is rewritten with the bright large-ball image. The scanning is performed from the top to the bottom of the screen. The mixed images appear in the second frame because the first frame image remains until it is rewritten by the second frame image. The optical response of the small-ball image shows that the brightness of the second frame is higher than that of the first frame. Therefore, the bright small ball appears for a moment, which creates a flashing problem.

Gamma functions are changed at the beginning of the second frame in method #2, in which the backlight brightness is changed at the end of the second frame. Since the driving mode is the same as that of method #1, the mixed images appear in the second fame. However, the flashing problem caused by the small-ball image does not occur in this method because the brightness of the small-ball image remains low during the second frame. However, it is also necessary to pay attention to the brightness of the large-ball image; during the second frame, it keeps its dark state and reaches its real brightness level in the third frame. The optical response of the large-ball image requires two steps, which makes the response time slower than that for a conventional LCD without dynamic-backlight-control technology.

Essentially, both methods weaken the picture quality compared to that of a conventional LCD without dynamic-backlight-control technology. Method #1 causes flashing problems, so this is not a suitable option. On the other hand, method #2 causes slow response time. Despite this and the fact that this method requires a very complex algorithm to prevent the flashing problem, this method has been applied to conventional LCDs.

Since the flashing problem and slow response problem are caused by the mixed images in the second frame, we came up with the concept of separating each sequence of frame images such as seen on a movie projector.

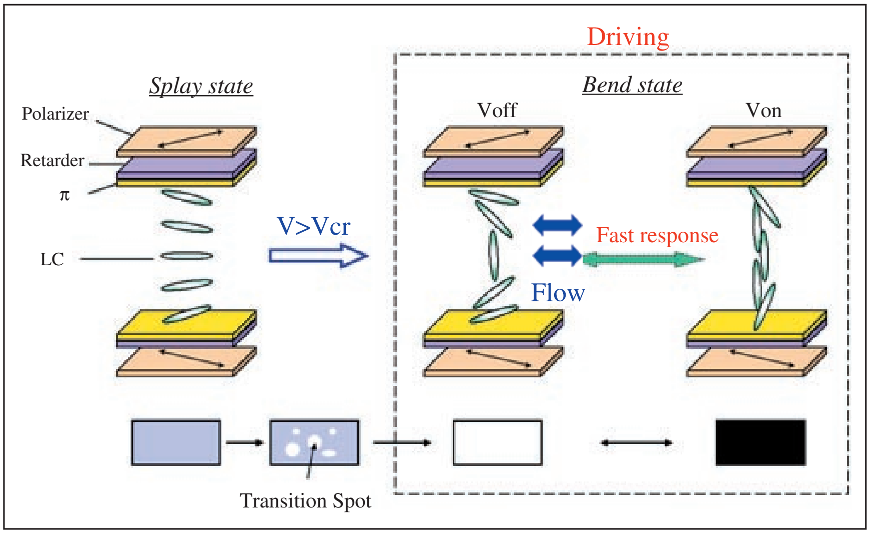
Conventional OCB-LCDs

The first version of our OCB-LCD, which we call "OCB-I," has adopted pseudo-impulse driving (also referred to as black insertion driving).[3-6] With this driving, a black zone of constant width is running on the LC panel to separate optical outputs of consecutive frames and reduce motion blurring. The typical value for the moving picture response time (MPRT) is 8.2 msec. However, OCB-I had a low contrast ratio due to leakage of non-modulated light during the black-insertion period.

To overcome the trade-off between moving picture quality and contrast ratio, we developed a second version (OCB-II) using a CCFL blinking backlight.[7] This driving

What You Should Know about the OCB Mode

As Szu-Fen F. Chen et al. explained in the November 2006 issue of *Information Display* magazine, the term "optically compensated bend (OCB) mode" was coined by Tatsuo Uchida in 1993. By employing biaxial compensation film, the required driving voltage becomes much lower than that for the original "π-cell" – the use of an electrically controllable half-wave plate, as proposed by Phil J. Bos *et al.* earlier. The π-cell was designed to enhance the LC response time by reducing the backward flow of the fluid by using surfaces that were treated so that their orientation was in the same pretilt direction. As illustrated here, the OCB mode, or π-cell, transforms the splay state into the bend state when the applied voltage is higher than the critical voltage (V_{cr}). The white and dark states can then be switched in the bend state while increasing/decreasing the voltage.



In an OCB-LCD driving scheme, the LC phase transforms from the splay state into the bend state when a voltage level higher than the critical voltage is applied (V_{cr} is about 2 V). The voltage continues to increase in order to control the white and dark images in the bend state.

The LC molecules in the bend state are oriented 180° (π) and vertically rotate between parallel rubbing directions within the OCB cell. The optical retardation of the upper and lower LC molecules compensates each other in the OCB cell. Therefore, the same optical retardations at different viewing angles can be seen. This intrinsic characteristic enables the OCB mode's wide-viewing-angle property. The bend-state orientation also enhances the LC switching speed to less than 4 msec between the ON and OFF states.

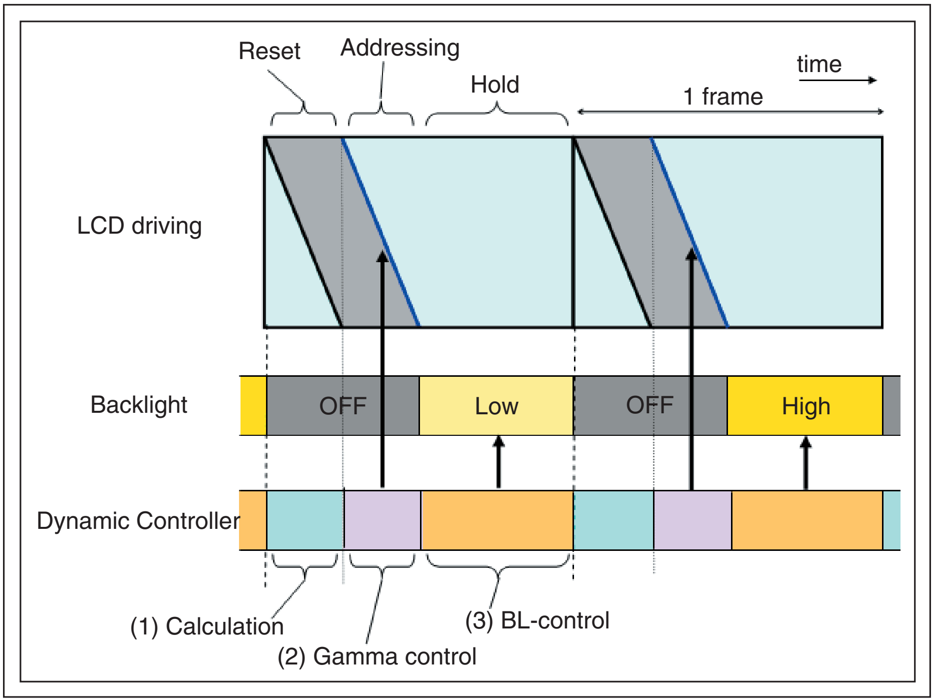


Fig. 2: *Design of OCB-III LCD with dynamic-backlight-control technology.*

method enables the reduction of the black image's luminance – without lowering the luminance of the white image – by turning off the backlight in sync with the black zone, thus improving contrast ratio. This improvement has already been incorporated into the mass-production of OCB-LCDs.

Furthermore, we have proposed a third version of the new driving method using an LED backlight (OCB-III).[8,9] OCB-III includes a technology that can simultaneously improve moving picture quality (as fast as 2.0 msec) and contrast ratio.

Design of OCB-III with Dynamic-Backlight-Control Technology

Among conventional OCB driving methods, OCB-III driving is most suitable for dynamic-backlight-control technology because it separates each sequence of frame images. Figure 2 shows the driving scheme of OCB-III with dynamic-backlight-control technology. In this driving method, one frame is divided into three periods: (1) reset period, (2) addressing period, and (3) hold period. In the reset period, whole data are reset; in the addressing period, new data are written in each pixel by scanning in a similar manner. After whole data are written, the display data are held while the LED backlight turns on. Additionally, a dynamic controller has been added to the OCB-III driving. The dynamic controller first calculates gamma level and backlight level from the brightness level of an input image before addressing. Secondly, it controls the gamma level in the addressing period. Finally, it controls the backlight brightness by dimming in the hold period.

Theoretically, the driving method of OCB-III with dynamic-backlight-control technology causes no flashing problems. A diagram of the image operation is shown in Fig. 3. If the input images suddenly change between two frames – for example, from a dark image to a bright image – OCB-III with dynamic-backlight-control technology enables the display of the bright image by completing the image operation before turning on the LED backlight; thus, the mixed image does not appear during the second frame. Therefore, this driving method does not create the flashing problem and keeps its fast response time. In addition, this driving method was realized by a simple algorithm.

The response-time property of a conventional LCD and the prototype OCB-III were measured with an oscilloscope and a luminance meter with a photomultiplier tube. Input images are switched from full black to full white.

The measurement results are shown in Fig. 4. The response time of the conventional LCD with dynamic backlight control became slower than that of the LCD without dynamic backlight control. On the other hand, the OCB-III with dynamic backlight control

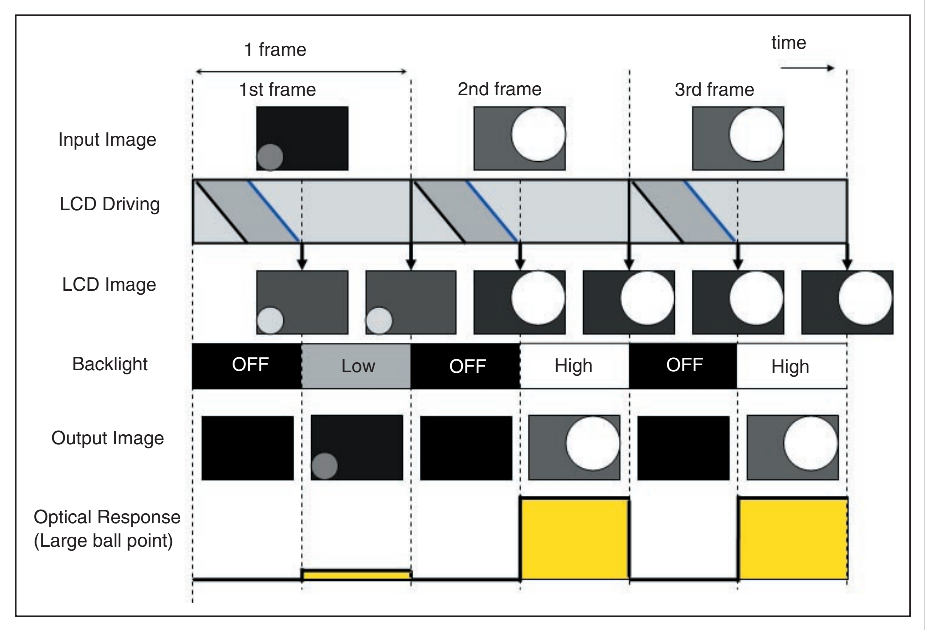
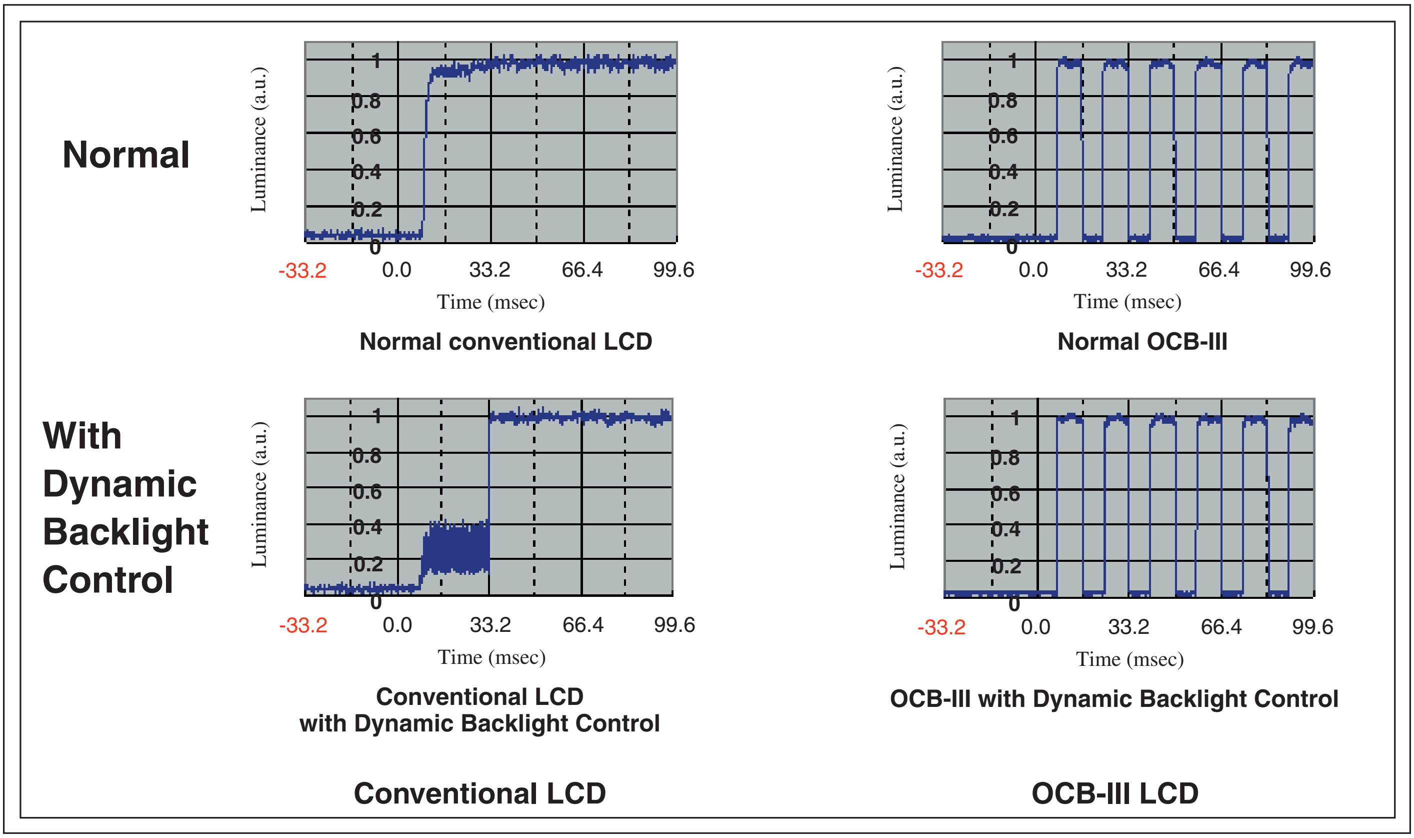


Fig. 3: *Driving scheme of OCB-III LCD with dynamic-backlight-control technology.*



Normal conventional LCD

Normal OCB-III

Conventional LCD with Dynamic Backlight Control

OCB-III with Dynamic Backlight Control

Fig. 4: *Measurement result of response time.*

shows the same response time as that of the OCB-LCD without dynamic backlight control.

Conclusion

The prototype 32-in. (1366 × 768) OCB-III LCD with dynamic-backlight-control technology features a maximum contrast ratio of 1,000,000:1 and an ultra-fast MPRT of 2.0 msec. High contrast ratio is consistent with high response time. Additionally, this LCD has a wide viewing angle of over 160° with a CR>50 and $\Delta u'v'$<0.02. Four additional prototype models have been developed: an 8-in. WVGA, 9-in. WVGA, 12.3-in. double-VGA (1280 × 480), and 12.1-in. SVGA. This shows that OCB-III with dynamic-backlight-control technology is also suitable for other OCB-LCD products.

OCB-III with dynamic-backlight-control technology achieves both high contrast ratio and fast response time. It shows high performance that exceeds that of CRTs in motion picture quality and almost the same performance in terms of contrast ratio. The combination of OCB-mode and dynamic-backlight-control technology provides the best solution for high-performance displays in various applications such as television, professional use (including medical and broadcasting equipment), and automotive.

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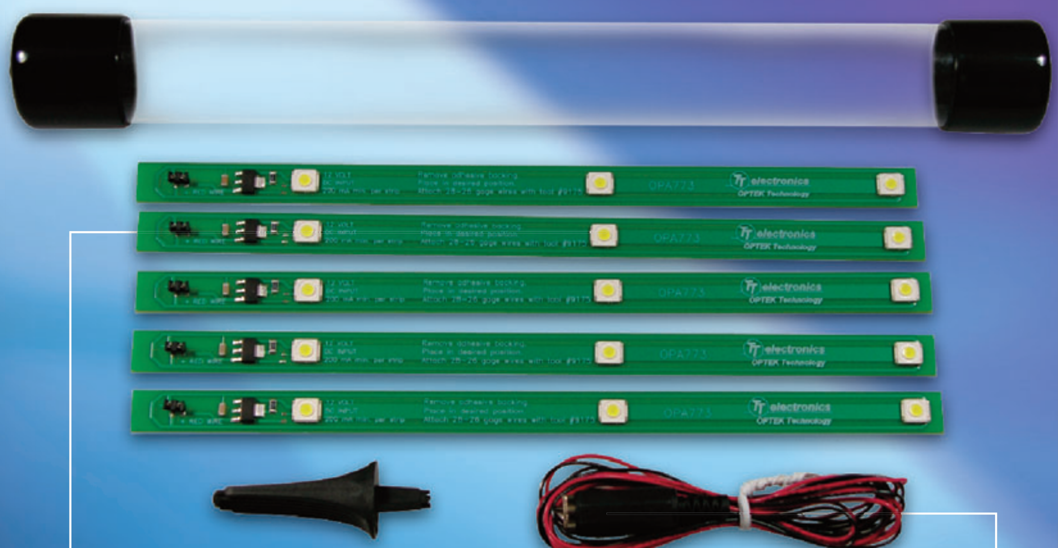


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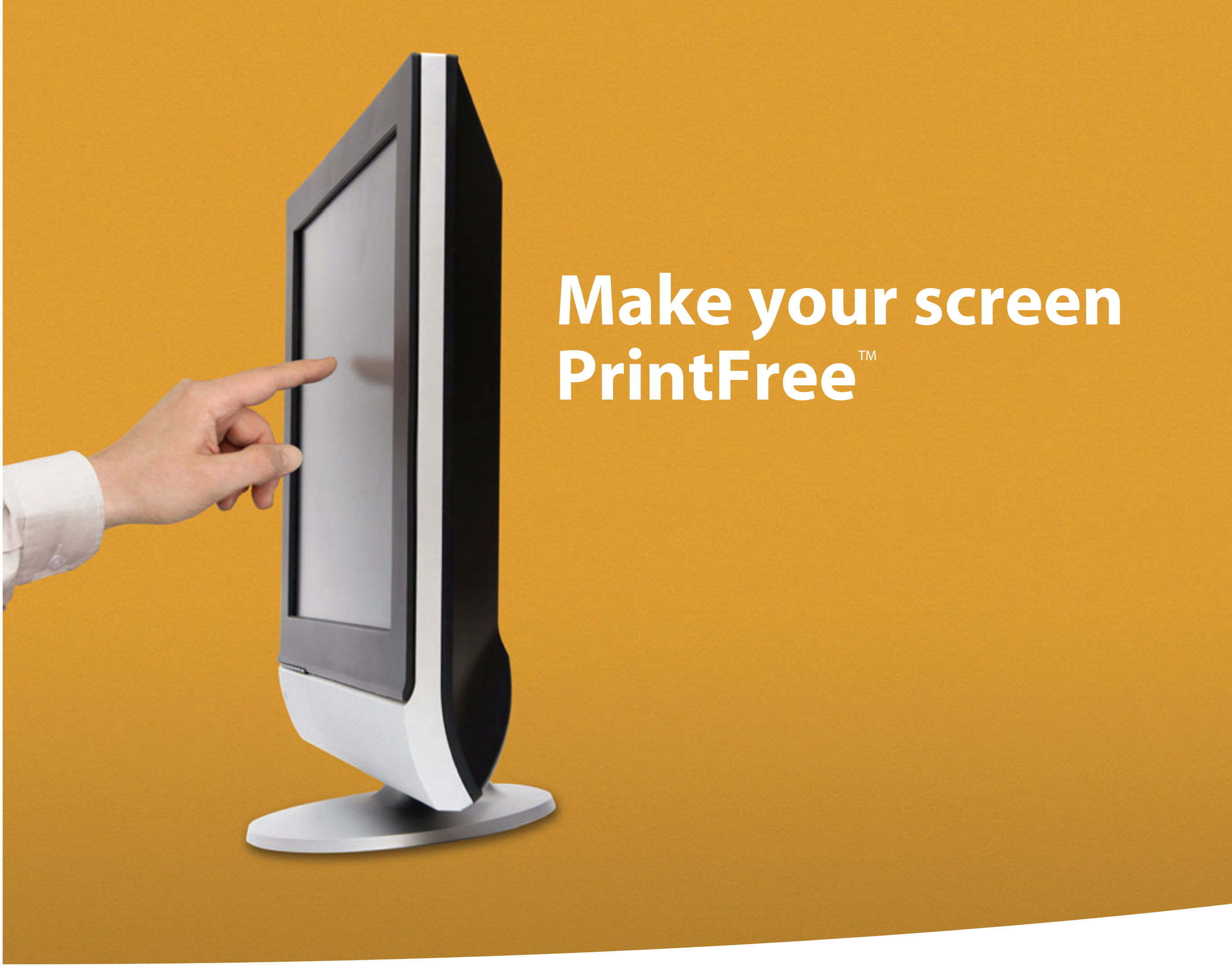
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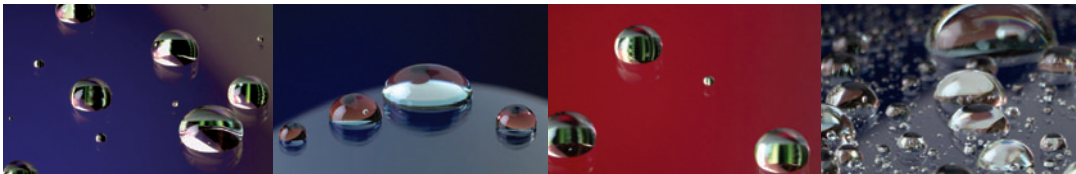

Increasing LCD Energy Efficiency with Specialty Light-Management Films

With increasing focus on the demand and costs of energy, LCDs must become more efficient in terms of utilizing light and energy. Low-loss components in LCDs can greatly improve system efficiency and help address the need to reduce power consumption. This article describes tests that show that LCD efficiency can be improved 50% or more by using a reflective polarizer and high-efficiency reflectors.

by Tao Liu and Mark O'Neill

UNLIKE other display devices, liquid-crystal-display (LCD) devices are predominantly transmissive devices. A backlight placed behind the LCD is used to illuminate the image formed by the display pixels. An LCD is inefficient, as typically less than 10% of the available light passing through the display and less than 1% of the total input electrical power to the display is emitted as usable optical power.[1]

With increasing global demand for energy resulting in rising energy costs, consumer awareness of energy use is increasing, and energy consumption has become a key purchasing factor for items ranging from vehicles to LCD TVs. In addition, global energy regulations are focused on addressing the increasing power consumption in consumer electronics.

Improving the efficiency of LCDs has been an industry trend for years. Improved manufacturing of the LC cell, light sources, and image-processing schemes have all enhanced the performance of LCD panels. 3M is continuously developing low-loss reflective polarizers and high-efficiency reflector components that work in concert with these improvements to further increase LCD energy efficiency.

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Efficiency Improvements

To date, LCDs have mainly relied on cold-cathode fluorescent lamps (CCFLs) as the backlight source. Because newer technology light sources such as light-emitting diodes (LEDs) offer improved efficiency, the electrical-to-optical power-conversion efficiency is improving. More light is generated at lower power.

Geometric-enhancement films, such as prismatic films and gain diffusers, can be used to further improve efficiency by concentrating more of the backlight angular distribution toward a centralized viewing region, resulting in more light toward the viewer. However, the luminance outside of the centralized region is compromised, which reduces viewing-angle performance. Moving the light from one region to another results in more light energy for viewers in the central region, but the net overall efficiency is often lower due to losses in the added films. In addition, the concentration of light toward the central region may result in a viewing region too narrow for the intended application.

LCD-panel transmission has improved through manufacturing improvements. LC-cell architecture and smaller transistors (such as the use of poly-Si TFTs) have increased the aperture of each pixel, allowing more light to be transmitted through the panel. Some wide-view technologies counteract this improvement. As cell structures get more complicated to provide wider viewing angles, the amount of light transmitted through the panel may suffer.

Active dimming of the backlight has become increasingly prevalent. 0-D dimming, where the entire backlight is modulated as the local-scene luminance changes, reduces the power consumption on an overall scale. Local dimming, where localized areas are modulated as its average luminance requirements change, can further reduce the power consumption of LCDs. But while these techniques reduce power consumption, neither improves optical efficiency.

Low-loss components can be applied with all these techniques to enhance display efficiency. Reflective polarizers, such as Vikuiti™ Dual Brightness Enhancement Film (DBEF), are low-loss components that pass one polarization of light and reflect the orthogonal polarization of light.[2] When aligned with the LCD panel's rear polarizer, the reflected polarization is recycled in the

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backlight cavity for further use instead of being absorbed in the rear display polarizer, resulting in efficiency improvements of 30–50%. High-efficiency reflectors, such as the Vikuiti™ Enhanced Specular Reflector (ESR), have high reflectivity over all angles of incidence, resulting in low absorption losses.[2] Because recycling elements such as geometric-enhancement films, reflective polarizers, and diffuser plates are used, the benefit of high-efficiency reflectors increases.

Power that is saved by using a more-efficient LCD can be applied to different areas of a device, benefiting other consumer needs. Mobile devices including cell phones, music players, and notebook computers run on batteries that can limit their operation. 3M's measurements indicate the LCD module consumes 25% or more of the total system power in portable electronic devices. Efficiency gains can enable such devices to run longer between charges, increase display luminance without added power consumption, reduce the battery size for display-performance requirements, or allow the power budget to be re-distributed to other device needs.

Plug-in devices such as computer monitors, TVs, and digital signs also benefit from more-efficient LCDs. The backlight consumes 70% of the power needed to run these devices. Improvements in display efficiency can be used to increase the luminance without additional power consumption, or reduce total power consumption and energy costs with the same luminance, or reduce the device's heat load.

System Design and Supply-Chain Considerations

All displays have some basic requirements, including proper luminance level, luminance angular profile, and uniformity. In addition, the form factor, battery life (for mobile devices), power consumption, and general viewing perception must be considered. Meeting all these requirements is challenging because some specifications counteract others. One tenet in system design is using low-loss components to improve system efficiency. Managing improved efficiency is left to the display designer. By altering the stack of optical films used in the backlight, designers can improve the efficiency by achieving the following:

- Higher luminance at the same power consumption.
- Reduced power consumption for the same luminance.
- Lamp-count reduction for the same luminance, reducing the bill of materials of the backlight maker.
- Lower display temperatures with different thermal-management requirements, which may allow for less-expensive options or even different design considerations.

The above can accomplished while maintaining visual quality standards, product reliability, and lifetime. However, changing backlight components has multiple impacts on the supply chain. The addition or substitution of films may increase the cost at one level, such as the backlight supplier, while simultaneously lowering the total bill of materials and operating cost.

As the film configuration changes, luminance and optical efficiency improvements can be implemented in various ways that can affect the entire supply chain.

- Fewer CCFLs or LEDs reduce the bill of materials of the backlight maker.
- Fewer light sources may require fewer inverters.
- Fewer light sources may also allow replacement of power supplies or other electrical components to less-expensive options at the system integrator.
- Lower system temperatures may allow for changes in the thermal management to less-expensive options or even different design considerations
- Lower power draw will reduce energy consumption for the end user.

The benefits of reflective polarizers and high-efficiency reflectors can easily be characterized in terms of luminance and power consumption. The total cost of a display device is realized throughout the value chain with the final decision at the brand.

To investigate how much the film stack can affect the power budget of a mobile device, we conducted experiments comparing displays using reflectors and reflective polarizers against those that did not. The results are presented here.

Results: Mobile Devices

The run time of mobile devices can be enhanced by using high-efficiency reflectors and reflective polarizers. The film stack of a 3.5-in. mobile entertainment system was modified to demonstrate the benefits of low-loss components. The luminance of the device was measured using various film stacks as listed in Table 1.

The device backlight was further modified to control the power to the LED sources and monitor luminance. Luminance as a function of power was mapped for each device in Table 1 with results shown in Fig. 1. Each device can now be set to the same luminance level by controlling the power settings for the sources.

Run time was evaluated each time a single modification was made. After each modifica-

Table 1: Film-stack modifications to a mobile entertainment system and the recorded luminance values and simulated run times. Luminance as a function of backlight power was recorded for each device. To simulate each configuration, backlight power was adjusted to provide a 249-cd/m2 display. Run time was then monitored.

Device	Reflector	Film #1	Film #2	Film #3	Luminance (nits)	Projected run time (min)	Projected run time increase
#1	Silver	diffuser	TBEF2-T-i	TBEF2-M-i	249	232	—
#2	Silver	high haze diffuser	BEFRP2-RC	—	280	249	7%
#3	ESR	high haze diffuser	BEFRP2-RC	—	327	278	20%
#4	Silver	diffuser	TBEF2-T-i	BEFRP2-RC	419	322	39%
#5	ESR	diffuser	TBEF2-T-i	BEFRP2-RC	493	343	48%

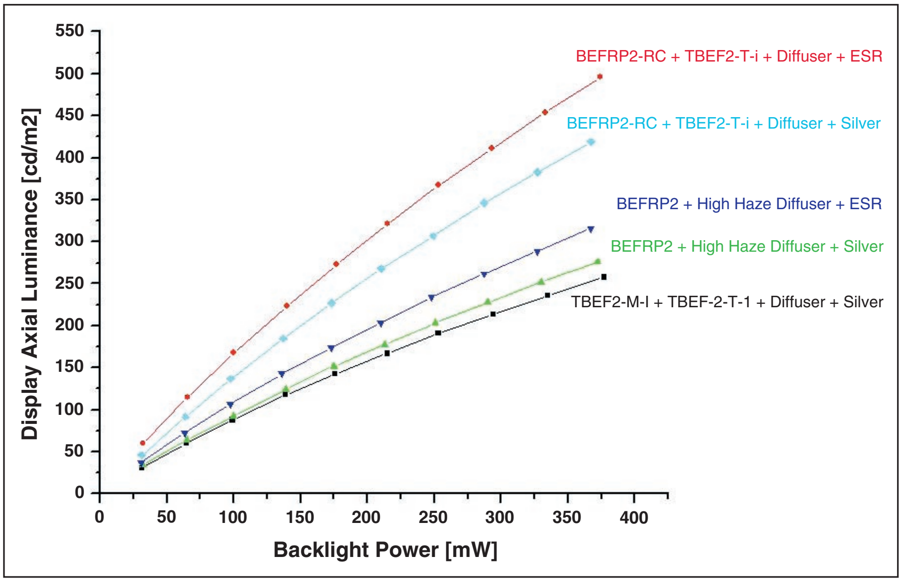

Fig. 1: Luminance as a function of backlight power for the each modification listed in Table 1.

tion, the backlight power settings were adjusted to produce the same luminance as was present before the modification. The savings in backlight power required, caused by an increase in light efficiency after each modification, thus enabled a net increase in run time.

The display power settings were modified to simulate each film stack. To evaluate device #1, the backlight was set to full power. To evaluate device #2, the backlight settings were changed to 84% power (the setting if film stack #2 was in the device under test). Similar adjustments were made to evaluate devices #3–#5. A video was played on continuous loop with the backlight on. Run time was measured from fully charged battery to when the device shut down from lack of power.

Modifying device #1 to device #2 eliminated one component, modified the diffuser level, and added the reflective polarizing capability of Vikuiti™ Multifunctional Film BEF RP2-RC (BEF RP2-RC), increasing run time by 7%.[2] The luminance profile for device #2 is broader than that for device #1. Typically, this decreases the peak luminance. With the addition of the reflective polarizer, polarized light is emitted from the backlight, resulting in higher transmission through the LCD panel. In device #3, the reflector is changed from silver (device #2) to ESR. The improvement in reflectivity results in lower absorption losses in the reflector. The higher peak luminance translates to an additional 13% improvement in run time. In device #5, the addition of Vikuiti™ Thin Brightness Enhancement Film II (TBEF2-T-i) compresses the luminance profile of device #3 to be comparable to device #1.[2] The geometric enhancement further improves the peak luminance resulting in a 48% increase in run time of device #5 as compared to device #1. Table 1 lists peak luminance and run-time improvements for various reflector/film combinations in this experiment.

By changing to low-loss components and maintaining the same display luminance, a mobile entertainment system's run time increased 48%, from 232 to 343 minutes.

Results: Notebook Computer

The power allocation of notebook computers can benefit from using high-efficiency reflectors and reflective polarizers. The film stack of a 15.4-in. notebook computer was modified to demonstrate power savings. The backlight power was regulated by external control. Power and luminance levels were recorded for the film stacks in Fig. 2.

The power to the backlight was modulated to provide an axial luminance of 195 cd/m^2 for each film-stack configuration. Power draw for the backlight at this luminance and the associated power savings are listed in Table 2. Modifying the enhancement films from crossed Vikuiti™ Brightness Enhancement Film II (BEF2) to Vikuiti™ Brightness Enhancement Film II (BEF2 G2) and Vikuiti™ Dual Brightness Enhancement Film II (DBEF II) allows removal of the coversheet while adding the reflective polarizer capability.[2]

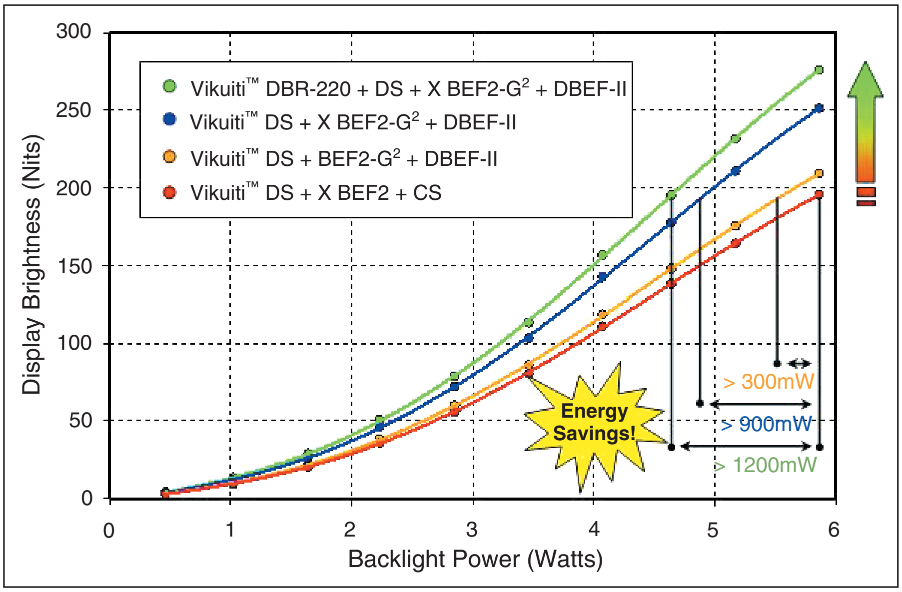

Fig. 2: Luminance as a function of backlight power for the modifications listed in Table 2. Energy savings is shown for a luminance of 195 cd/m^2 in each device.

Table 2: Film-stack modifications to a notebook computer and the recorded luminance and power consumption for 195 cd/m^2.

Device	Reflector	Film #1	Film #2	Film #3	Film #4	Luminance (nits)	Backlight power for 195 nits (W)	Backlight power decrease (W)
#1	diffuse white reflector	diffuser	BEF2	BEF2	coversheet	195	5.86	—
#2	diffuse white reflector	diffuser	BEF2 G2	DBEF II		209	5.54	0.316
#3	diffuse white reflector	diffuser	BEF2 G2	BEF2 G2	DBEF II	251	4.93	0.935
#4	DBR-220	diffuser	BEF2 G2	BEF2 G2	DBEF II	276	4.66	1.205

The subsequent luminance profile of device #2 is broader than device #1 because only a single prism film is used. The reflective polarizer more than compensates for the expansion of luminance profile from the change in geometrical enhancement. The power required for a luminance of 195 cd/m^2 decreases by more than 300 mW (>5%). Further modification to include a second sheet of BEF2 G2 in device #3 (to obtain a crossed BEF2 G2) compressed the luminance profile to be slightly less than that for device #1. This geometrical enhancement permits an additional power reduction of more than 600 mW while maintaining a luminance of 195 cd/m^2. Finally, replacing the diffuse white reflector with the Vikuiti™ Durable Back Reflector (DBR-220), a modification of ESR for notebook computers, results in less light absorbed by the reflector component.[2] Device #4 further reduces power consumption of the backlight by more than 250 mW as compared to device #3 and more than 1.2 W (20%) compared to device #1.

Changing the film stack of a notebook computer to include low-loss components and maintaining the same luminance decreases the power consumption of the backlight by 1.2 W or 20%. This power can be reallocated to add functionality such as increasing processor performance, cameras, or fingerprint readers. Alternately, the portability of the computer can be improved by reducing the battery size and computer weight.

Results: LCD Monitors

The energy consumption of LCD monitors can benefit from using high-efficiency reflectors and reflective polarizers. Benefits from improving the efficiency of an LCD can result in reduced power use by reducing light source and power-supply components.[3]

Two mainstream Lenovo monitors (models L174 and L197w) clearly demonstrate power savings using a reflective polarizer in their backlights and half the number of CCFLs as their original counterparts (models L171 and L194w). Vikuiti™ Diffuse Reflective Polarizer Film (DRPF2) was added to the L174 model.[2]

Vikuiti™ DBEF-D2-280 (DBEF-D2-280) was added to the L197w model.[2] With the addition of the reflective polarizer, the backlight emits polarized light to the LCD, resulting in less absorption by the rear polarizer. Optical-efficiency improvements allowed the removal of two CCFL lamps and their associated electronics from each monitor. The modified displays meet luminance and uniformity specifications while enabling power savings of 6 W or more than 30%.[3]

The addition of a reflective polarizer results in energy savings and fewer components, including some that contain mercury. These new Lenovo monitors are Electronic Product Environmental Assessment Tool (EPEAT) Gold qualified. EPEAT is among the tech industry's most coveted environmental designations.[4]

Results: LCD TV

The energy consumption of LCD TVs can be reduced by using reflective polarizers. Benefits from improving LCD efficiency can reduce power consumption, the number of light sources, and TV temperature.

The film stack of a standard 40-in. LCD TV having a diffuser plate, gain diffuser, Vikuiti™ Brightness Enhancement Film III (BEF3-10T), and gain diffuser was modified to a diffuser plate, crossed BEF2 G2 and Vikuiti™ LED Efficiency Film (LEF-D), and a reflective polarizer.[2,5] The combination of the geometrical-enhancement films and reflective polarizer recycle much more light than the original film stack. This results in higher peak luminance from the prism films as well as light polarized for the LCD from the reflective polarizer. Luminance levels were recorded and total power monitored with a plug-in watt meter. Internal temperatures of the TV backlight cavity were also measured.

The TV settings were adjusted to best match the luminance levels of the TV in each configuration. The increase in efficiency and luminance due to the prismatic enhancement films and reflective polarizer allowed removal of eight CCFLs from the backlight without

Table 3: Film-stack modifications to a 40-in. television and recorded luminance, power, and internal temperature.

Configuration	Component #1	Film #1	Film #2	Film #3	# CCFLs	Luminance (nits)	Backlight power (W)	Backlight internal temperature (°C)
#1	diffuser plate	gain diffuser	BEF3-10T	gain diffuser	20	350	195	44.0
#2	diffuser plate	BEF2 G2	BEF2 G2	LEF-D	12	350	92	34.0

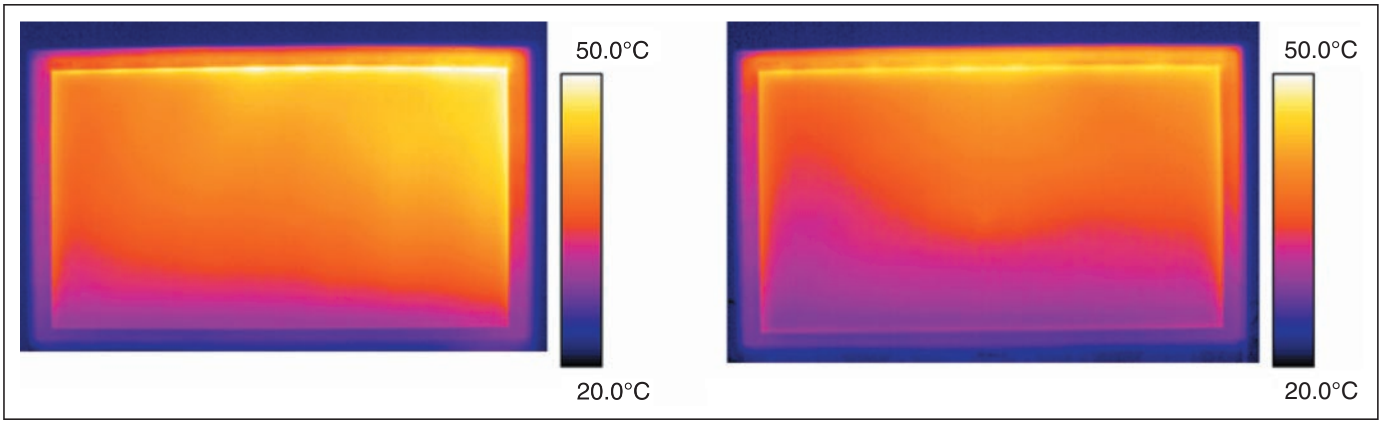

Fig. 3: Thermal images of a 40-in. LCD TV with modifications as listed in Table 3. With the use of low-loss components, the front-panel temperature decreased from 37.8 to 30.1°C.

affecting system uniformity. The results are listed in Table 3. Thermal images are shown in Fig. 3 showing a temperature drop of more than 7°C.

The use of a reflective polarizer in a TV application improves the optical efficiency of the TV. Less light is absorbed by the LCD. The efficiency improvement can be used to reduce the number of CCFLs from 20 to 12. In addition, a power savings of 102 W (52%) and a 10°C lower internal temperature can be realized.

Conclusions

LCDs are continuing to proliferate throughout electronic applications. This is occurring as concerns for energy demand and costs are increasing. Regulatory guidelines for energy consumption are beginning to appear. Low-loss components in LCDs can greatly improve system efficiency and help address the need to reduce power consumption. Tests show that LCD efficiency can be improved 50% or more by using a reflective polarizer and high-efficiency reflectors.

Benefits of the efficiency boost can be used in a variety of ways across the applications of LCDs. Mobile devices may have extended the battery life to provide up to 48% longer run time in mobile entertainment systems. The power budget of notebook computers can be reallocated to improve functionality as the power consumption is decreased by up to 20%. Cameras, fingerprint readers, and processor speed can use the power redirected from a more-efficient display. Monitors can reduce power consumption by eliminating light-source components, saving more than 30% of the energy consumption. Finally, power consumption of TVs can be reduced by more than 50% while simultaneously reducing heat load and removing components from the bill of materials.

Acknowledgments

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Information Dominance, Situational Awareness: The U.S. Army's Requirements and Methods for Procuring Displays

The U.S. Army of the 21st century is almost as dependent upon state-of-the-art displays as it is on trained soldiers. This means there are tremendous opportunities for display manufacturers to have their wares integrated into Army equipment. Here, a retired Army general gives a glimpse of what the Army demands from its displays and how it goes about securing the best equipment to support its missions.

by Ed Harrington, Brigadier General, U.S. Army (Retired)

DISPLAY TECHNOLOGY is a part of every soldier-operated system in today's U.S. Army, whether the soldier carries it as an individual or is part of a crew in a tank, artillery system, helicopter, radar site, command post, intelligence/electronic-warfare staff, missile system, or a supply, maintenance, or logistics planning cell. Displays of all sizes are sought: 8-in. handhelds for individual use to large screens of 60 in. and more for mobile command posts. In every field-mission scenario, the Army will expect displays to be operational when needed, viewable in a wide range of lighting conditions, and extremely rugged, including maximum shock and electromagnetic resistance.

With all of this in mind, it becomes critical for all in the display field to understand how the Army sources and procures its display systems. This article offers a glimpse behind the curtain, looking at how the Army is structured and how that affects decisions on displays, the opportunities for new display technologies, *etc.*

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Information Dominance

Determining the main applications for display technology in the Army requires an understanding of the Army's doctrinal priority for the 21st century: Information Dominance providing continuously improved Situational Awareness at every level of operation, from the individual soldier to the greater Army as a whole. This is true at the Army-only level as well as for "Joint and Combined Operations" (integral with the other military services). The Army's strategic mission is to engage in the full spectrum of operations, ranging from humanitarian assistance and special operations to counter-insurgency, the global war on terrorism, and full-scale world war. Implicit in this mission and doctrinal focus is the requirement to operate in every location of the globe, under all types of weather conditions, 24 hours a day, 7 days a week. Information Dominance/Situational Awareness in a worldwide environment frames the Army's requirements for main applications that utilize display technologies.

The structure of the Army drives how it is equipped (what it buys) to accomplish Information Dominance and Situational Awareness. The Army force structure is made up of branches responsible for providing personnel, training, and equipment to Army units for specific overarching mission areas. These branches/mission areas comprise the "users" of Army equipment, *i.e.*, the soldiers who become qualified in operating the many types of weapons and supporting systems the Army employs to accomplish its missions. The Army's Acquisition Corps is a newer component whose responsibility is to manage the process of developing, producing, fielding, and sustaining Army equipment and information systems.

Each branch of the U.S. military is responsible for defining the mission requirements for personnel, doctrinal guidance, education/training, and the technologies and equipment to remain at the forefront of the mission area. The Army is developing its Future Combat System (FCS) to integrate new technologies as rapidly as possible. The operational focus for the FCS is to optimize the Army's role in Joint "Network Centric Warfare." The foun-

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dation for effective Network Centric Warfare is Information Dominance and continually enhanced Situational Awareness at every level of organization.

Within the Army, the Acquisition Corps is responsible for the full range of materiel functions to develop, design, engineer, integrate, test, contract for, produce, deploy/field, and sustain and improve Army equipment and systems. These systems range from ground and aerial combat and transportation (*i.e.*, tanks/tracked vehicles, trucks, watercraft, and helicopters) to missiles, artillery and mortar systems, and small arms to radar, communications, application software systems, night-vision devices, sensors of all types, and medical to water and petroleum systems, construction equipment, ammunition, clothing, shelters/tents, and food equipment and food. A large majority of these systems have integrated processors and displays

"Users" are represented by the Training and Doctrine Command (TRADOC). TRADOC's mission is to develop the doctrine, education, and training of soldiers (users) from each of these branches, and each of these branches play a large role in defining what is needed in their mission areas relating to how they perform their combat mission.

Display Deployment

Displays are deployed in configurations designed to provide Situational Awareness for military units varying in size from one soldier to many thousands of soldiers operating over large land masses and often over the world's oceans. The range of functions displays perform are keyed to the size of the military unit, its designated mission, and how it integrates with other military units.

A single soldier will have small eye-sized displays for night vision. Ground vehicles, aircraft, helicopters, and command posts utilize multiple displays to guide, control, and provide direction. Staffs of fighting units at each level use displays to organize, manage, and sustain the military unit in its mission, analyzing and moving information from as well as to subordinate units and taking direction from the Commander. Vehicles ranging from the HUMMWV equipped for mobile "Command and Control" (C2) of military units to tanks, fighting vehicles, artillery/missile systems, radar, and intelligence, reconnaissance, and target-acquisition platforms will feature 1–5 displays.

> “ ***Determining the main applications for display technology in the Army requires an understanding of the Army's doctrinal priority for the 21st century: Information Dominance providing continuously improved Situational Awareness at every level of operation.*** ”

Examining the displays in the C2 HUMMWV serves as a useful exercise to demonstrate all the tasks that displays are given in military applications. This vehicle will have a display used to present Situational Awareness from several applications to guide and control (process information to and from lower units and report to higher headquarters) the military unit in accomplishing its mission. The "Commander's Display Unit" (CDU) display in this vehicle will show the latest situation, *i.e.*, locations of each friendly unit reporting to that Commander (teams, squads, platoons, companies, or even battalions), and/or other units operating with that Commander's unit. This Situation Overlay will also show the latest enemy locations, the terrain, road network, if any, and geographical features such as hills, rivers, marshes, valleys, and washouts.

The "Intelligence" overlay will show more details of enemy concentrations and estimates of enemy strength, weapons, reinforcements, aviation, and higher-level headquarters. This overlay will provide weather estimates, locations of enemy supply routes, and supply locations. The "Aviation" overlay will show friendly aircraft and helicopters that may be able to provide close air support to that Commander's units if they become engaged with the enemy. The "Logistics" overlay will provide the status of food, water, ammunitions, fuel, medical, and other support needed for that unit to enable it to fight and sustain itself.

This HUMMWV will also have additional displays for staff members to receive information, evaluate it, and update each of the applications above. This "suite" of applications, using the displays at each station, will provide a comprehensive picture for the Commander and enable coordination, communication, and execution of mission, including enabling that Commander to judge how to adapt the mission to the continual changes that occur when engaged with the enemy.

Display sizes can range from approximately 6–18 in. in the close confines of a military vehicle. Displays must be light in weight, compact for their screen size ("low space claim"), and operate in extreme environmental conditions withstanding maximum shock and vibration; enabling sunlight viewability; operating across temperature ranges from desert heat to arctic freeze; emitting low/no infrared signals; not be reflective; and using as little

> “ ***Lessons from present warfighting and deliberate analyses of the future point to the need for advanced types of displays and processors designed to better integrate and array more complex critical, essential elements of information.*** ”

power as possible – all while achieving maximum reliability.

Displays are deployed in similar configurations for larger "Command Posts" (CPs), stationary shelter units with individual workstations for staffs with specialists for each major function noted above. These CPs will have larger screen sizes (18–60 in.) with the larger screens used to present the situation to the Commander and his/her staff, including linkage to streaming video from manned or unmanned aircraft to have a real-time interactive view of the mission/battle. The CP will have multiples of the workstations seen in vehicles; for example, the Intel function will have 4–5 displays each serving a specific need, *e.g.*, the specialist for enemy troop locations will have a separate display, as will the specialist for enemy air support. The Operations function will have similar workstations to collect data and array it as part of a larger analysis for a current mission, or to assess contingencies that might arise as the current mission continues. The Logistics staff will be equipped similarly with workstation/displays for transportation, fuel, food/water, ammunition, maintenance/repair actions and parts sourcing, and medical support. CP displays will need to be unpacked, set up, and in operation quickly, and then shut down, broken down, and packed up just as fast because CPs in modern warfare must be moved quickly either to stay in pace with the battle or to constantly change locations to avoid receiving enemy artillery fire. CP displays need similar light-weight and low-space claim.

Lessons learned from present warfighting and deliberate analyses of the future conclude that newer types of vehicles are needed along with advanced types of displays and processors designed to better integrate and array more-complex critical, essential elements of information for the Commander at each level. Military units are being redesigned to take advantage of technologies such as autonomous or robotic ground and air vehicle operation, automated artillery fires, interactive intelligence collection and analysis, and enhanced video. Displays that can enable the management of multiple unmanned aerial vehicles is an emerging requirement. Warfare doctrine recognizes the need for better "battle command on the move." Vehicles such as the Joint Light Tactical Vehicle (JLTV) are required to have processing and display capability well above what is used today, primarily to enable "on the move" C2. The JLTV will be produced in 10 variants, several of which will have displays deployed much like the HUMMWV C2 described above. The C2 JLTV may have four or more displays providing situational inputs in real time for the Commander. Logistics vehicles from transport trucks to maintenance teams to fuel transports to medical aid teams will require information from route and alternate planning to parts sources on the move to patient status to identification of possible enemy ambush points during mission execution.

New Display Technologies: Challenges and Opportunities

The overarching justification for the increased use of electronic displays is to continuously improve Situational Awareness at every level in the Army's organizational structure. Relevant information – displayed faster, with more clarity, in all types of climatic and sunlight conditions – is the central thrust Army users and system program managers (PMs) are pursuing. Such mandates mean that there are hundreds of opportunities for new display technologies in today's U.S. Army.

The users in the Army have a continuing (daily) exchange of requirements, technical information, and ideas/concepts with their counterparts in the Acquisition offices. This exchange is focused on finding the latest technology, identifying its status in terms of readiness for operational use (suitability and effectiveness), and the cost and availability as well as the ability to produce at the scale the Army requires. User and Acquisition offices are oriented to each branch's functional needs and also to functional requirements applicable to all mission areas.

Acquisition Corps program managers and research and development offices, in consonance with TRADOC user representatives in each branch, collaborate to find better display solutions for the systems they manage. They are guided by three important criteria in the selection of a display: cost, schedule, and performance. Each acquisition program manager assesses alternatives using these criteria and develops "trade-offs" related to cost, or schedule needs, or performance demands to find the optimal solution for each functional need.

TRADOC users from each of the branches and Acquisition managers for their branch and Army-level systems work together to assess these solutions for adoption. Program managers decide on the best technical and functional solution and approve the budget and program plan for the system. It is important to understand that program managers are seeking solutions at a technical level ready for engineering integration into a larger system, or complete and "ready to go," not those that require further R&D. Upon the program manager's decision, a system will be developed, tested, and produced, then deployed to Army units worldwide. The systems noted in this article include displays as components; additionally, program managers will acquire displays (usually integrated with processors) as solutions by themselves.

New entrants can gain traction for their unique solutions in a variety of ways and by placing emphasis on using several approaches simultaneously. The key trait to promote is the uniqueness of a solution, as there are hundreds of vendors with myriad solutions. Acquisition managers and the Army's "buying commands" [Tank-Automotive and Armaments Command (TACOM), Warren, MI; Communications Electronics Command (CECOM), Ft. Monmouth, NJ; and Aviation Missile Command (AMCOM), Huntsville, AL] now have a full "life cycle" responsibility for system management, which includes finding improved technologies and less costly, more reliable solutions throughout the life cycle of a system.

> "*Program managers are seeking solutions at a technical level ready for engineering integration into a larger system, or complete and "ready to go," not those that require further R&D.*"

> *“Displays must be light in weight, compact for their screen size (“low space claim”), and operate in extreme environmental conditions withstanding maximum shock and vibration; enabling sunlight viewability; operating across temperature ranges from desert heat to arctic freeze; emitting low/no infrared signals; not be reflective; and using as little power as possible — all while achieving maximum reliability.”*

In conjunction with acquisition managers, these buying commands conduct “Industry Days” or “Advanced Planning Briefings for Industry” (APBIs) that serve to inform interested vendors of the future requirements for each system. Industry Associations such as the Association of the United States Army (AUSA), National Defense Industry Association (NDIA), Armed Forces Communications Electronics Association (AFCEA), Army Aviation Association of America (AAAA), and Simulation, Training, and Instrumentation (STRI) conduct annual meetings and several conferences and symposiums throughout the year to bring government and industry together to present products and technologies. These events are excellent forums to initiate entry and outreach.

The bottom line is to understand the competition’s offerings and find a way to answer what will almost always be the first question asked by a PM, Lead Engineer, R&D Manager, or user rep: “What makes your product unique?” The next question will be, “How much does it cost?” After that, “How many and how soon can you deliver?” The next comment will be, “Show me.” When you say, for instance, your display is an extreme rugged-type display, you can expect an Army PM or user rep to drop it, or if the display is “sunlight readable,” to take it out into sunlight and try to read the screen. Always use your display in front of a military audience. Put your capabilities briefing on it and demonstrate its unique advantages. Refrain from using a separate laptop to make a presentation – military users want to see, feel, and handle a product.

Conclusion

The focus for warfare in the 21st century is to be “Information Dominant” in any scenario, from counter-insurgency to full-scale world war. Information has become as critical as trained soldiers, tanks, artillery, aircraft, warships, and ammunition. Soldiers need smaller displays for individual Situational Awareness – who is on the right, who is on the left, who is backing them, and where is the enemy? Larger units need information interactively now to continue to stay at least one step ahead of the enemy. Situational Awareness will mean synthesizing an expanding body of knowledge to be able to “see first, act first, and defeat the enemy decisively.” Without properly performing displays, none of this would be possible. As the military continues to adapt and transition to a 21st-century fighting force, the opportunities for display manufacturers to get their products into military applications will only continue to grow, but knowing how to get your foot in the door will help give you a leg up on the competition. ■

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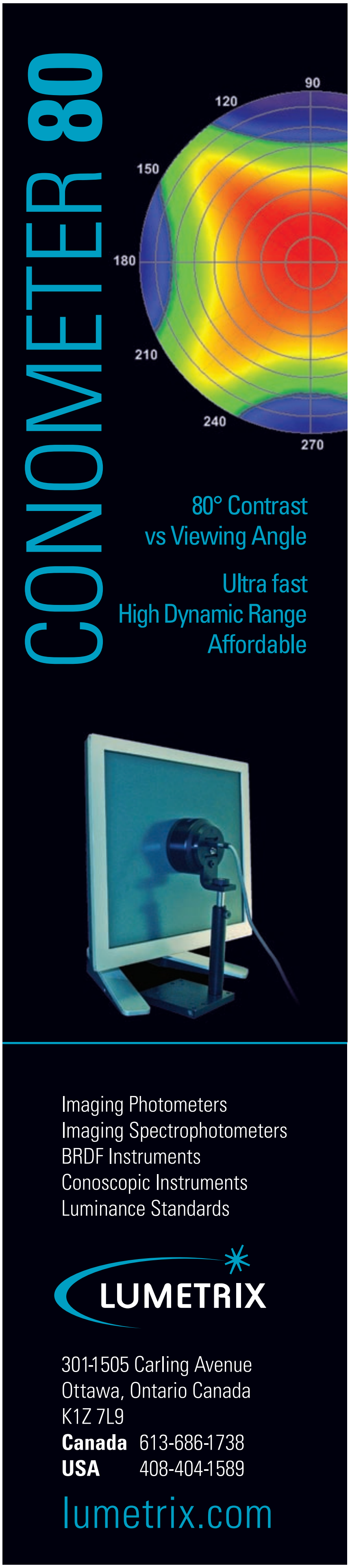


In a World of Ubiquitous Mobile Displays, New Technologies Continue to Emerge

From OLEDs to pico projectors to LCDs, displays for mobile devices are currently receiving a great deal of attention. At SID Mobile Displays 2008, attendees learned of the latest state-of-the-art mobile displays and applications and got a glimpse at future technologies that will shape the market for years to come.

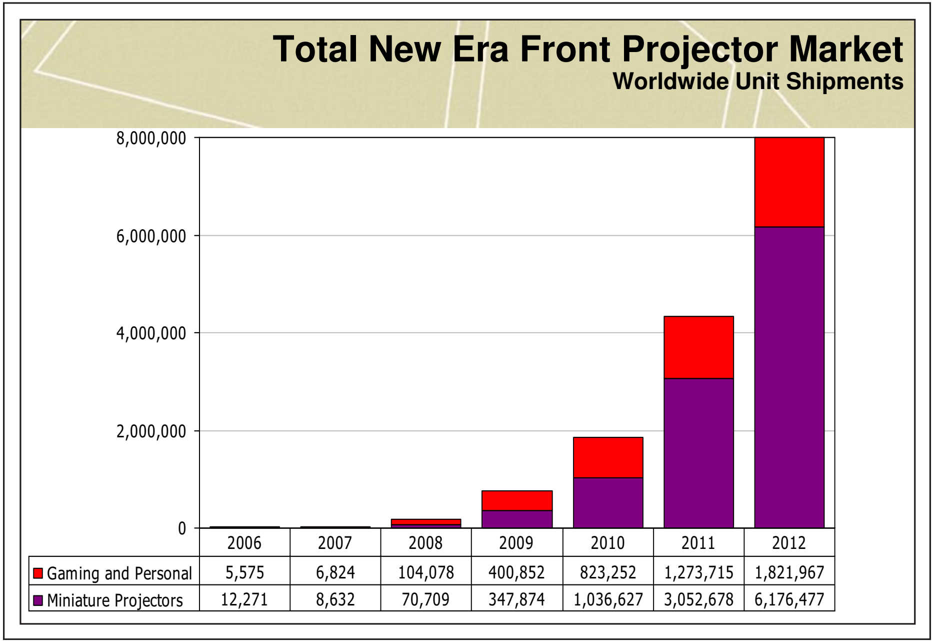
by Alfred Poor

LOOK UP "ubiquitous" in the dictionary and you might see a picture of a mobile display. From mobile phones to MP3 players, and from personal navigation devices (PNDs) to notebook computers, small–to–mid-sized displays designed to go with the user are everywhere. Many devices even sport more than one display. So it should come as no surprise that an attentive audience gathered for the third annual SID Mobile Displays Conference (part of the SID Hot Topics Conference Series) held on September 23 and 24, 2008 in San Diego, California.

At first glance, you might wonder what the hubbub is all about. According to Vinita Jakhanwal of iSuppli Corp., the mobile-display market is forecast to grow at about only 5% CAGR through 2012. Sure, the 5 billion units predicted to ship that year is a large number and many companies would be happy to have even a small share of that, but that does not explain the excitement in this field.

Growth through New Applications

Part of the interest is driven by the new applications that are becoming possible as a result of technology advances. The most inspiring message on this topic was delivered by the keynote speaker, Mary Lou Jepson of Pixel Qi, a spin off from the One Laptop Per Child (OLPC) project. She described how an LCD design could provide a high-resolution monochrome image in bright-light settings and full-color images in dim light, meaning that the energy budget for a notebook computer can be greatly reduced. The result is a low-cost computer design currently in production and being delivered to third-world students around the globe.



	2006	2007	2008	2009	2010	2011	2012
🟥 Gaming and Personal	5,575	6,824	104,078	400,852	823,252	1,273,715	1,821,967
🟪 Miniature Projectors	12,271	8,632	70,709	347,874	1,036,627	3,052,678	6,176,477

Pacific Media Associates

***Fig. 1:** According to Pacific Media Associates, projectors with outputs less than 500 lum will be responsible for the major growth in front-projection display technologies.*

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But other applications are on the way that could signal remarkable growth opportunities. William Coggshall of Pacific Media Associates led the session on projection technology for mobile devices and explained that novel applications will be responsible for nearly all the growth in the front-projector market. According to his forecasts, the typical 500–4999-lum projector market will grow at about an 8% CAGR from 2006 to 2012, but for the same period the growth rate for projectors with less than 500-lum output will be nearly 140% (Fig. 1).

The growth in these tiny "pico" projectors will be driven by devices that will either be companions to mobile phones or built into the phones themselves, and several approaches were presented at the conference. These are made possible by advances in microdisplay imagers and new lighting sources. 3M relies on an LCoS imager, while Samsung uses an array of micromechanical diffractive elements and Microvision has a single reflective element that can scan a light beam in two dimensions to create a full image. One key advantage to the Microvision approach is that increasing the resolution of a display does not require any increase in the projection-engine size.

Another factor that makes these new pico projectors possible is the availability of low-cost and low-power microlasers. The coherent light beam greatly simplifies the optics design, eliminating the need for focus elements. Among the advances in small-laser technology that were discussed at the conference, the DeCIBEL design from Epicrystals was one of the most interesting. The light output is highly polarized, making it suitable for LCD-based imagers, and the short coherence length reportedly helps reduce speckle. According to Janne Kontinen, CTO of Epicrystals, the devices will have operating voltages of 1.7 V or less and will have a flat package that could be used to create a light engine as small as 1 cc.

3-D displays are also finding their way into portable devices, according to the presentation by Steve Sechrist of Insight Media. Technology solutions range from a simple pair of LCD panels that provide images on two planes to autostereoscopic panels using lenticular arrays to a system under development by DoCoMo that actively tracks the viewer in order to adjust the "sweet spot" dynamically.

Old "New" Technologies

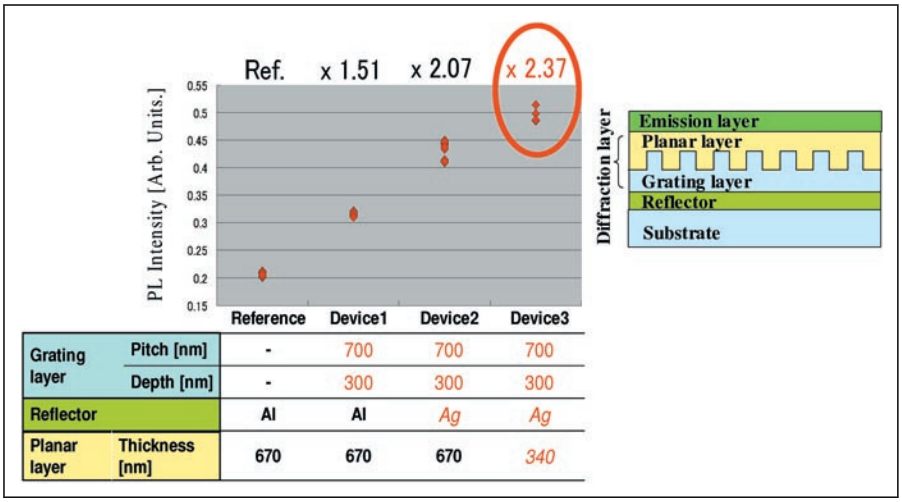
While LCDs continue to dominate small–to–mid-sized displays, others continue to work toward gaining a foothold in the market. OLEDs continue to move forward with increasing commercial production. Nokia's recent pronouncement that it wants its display-panel providers to be capable of supplying OLED panels is noteworthy, especially in light of the fact that the company purchases more than half a billion displays annually. As a result, OLEDs were a major topic at the conference, even though they are forecast to remain a small portion of the total mobile-phone-display market; according to iSuppli's Jakhanwal, OLEDs will represent less than 15% of the mobile-display revenue through 2012.

DuPont and Universal Display Corp. (UDC) made presentations about their progress in OLED production processes and materials. Of particular interest was the talk by Hiroshi Maeda of Toshiba America Electronic Components (TAEC), who pointed out that as much as 70–80% of the light produced by the emissive layer of an OLED device can become trapped within the device layers as a result of waveguide behavior. TAEC has been working to develop "microbumps" that can be created below the anode layer of the OLED stack, which can help scatter the light in such a way that better manages to escape the display. TAEC's research has also shown that this out-coupling approach can also be achieved using a separate substrate that is connected to the OLED device by a layer of oil. A third approach is the use of a diffraction-grating layer within the OLED device, which has shown that it can more than double the output efficiency of an OLED stack without making any changes to the stack materials (Fig. 2).

The Magic Touch

Thanks to the iPhone's success, everyone seems to know about the "pinch" gesture and how to use it. As a result, touch-screen technology is currently a major focus of the mobile-display industry. Geoff Walker of Tyco Electronics' Elo TouchSystems gave the conference attendees an excellent overview of the various touch technologies and their relative advantages and weaknesses (Fig. 3). One of the often-overlooked details about touch screens is the need for a user interface that is both intuitive and suitably versatile. Stantum is a company that has developed a new software interface for mobile devices designed for multi-touch screens. As described at the conference, it uses a combination of tree-structured menus and context-sensitive gestures that make it easier for a user to navigate and perform common tasks such as taking written or pictorial notes.

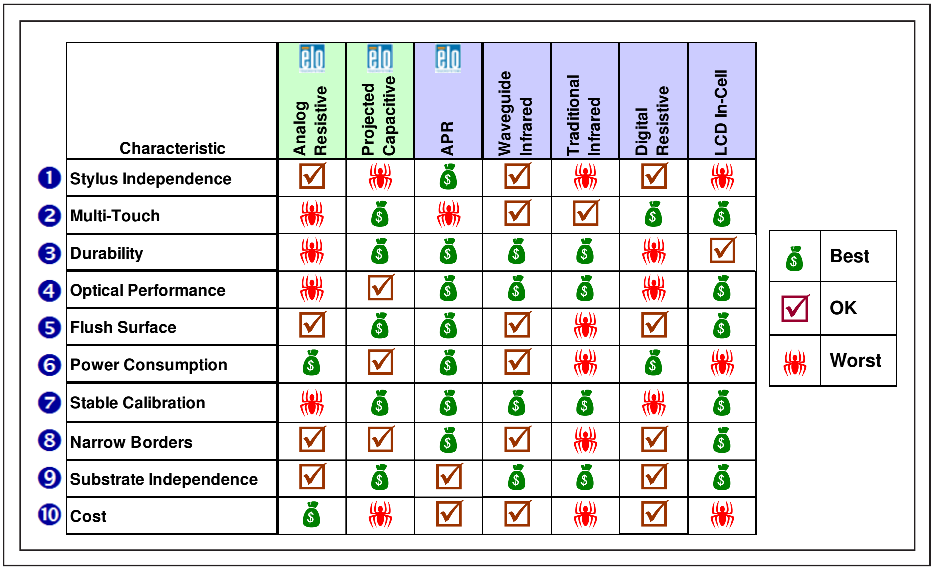
Perhaps the most engaging part of the touch-screen segment, however, was a presen-



		Reference	Device1	Device2	Device3
Grating layer	Pitch [nm]	-	700	700	700
	Depth [nm]	-	300	300	300
Reflector		Al	Al	*Ag*	*Ag*
Planar layer	Thickness [nm]	670	670	670	*340*

Toshiba Matsushita Display Technology Co., Ltd.

Fig. 2: *Toshiba's improved outcoupling technology for OLED devices has more than doubled light output.*



	Characteristic	Analog Resistive	Projected Capacitive	APR	Waveguide Infrared	Traditional Infrared	Digital Resistive	LCD In-Cell
①	Stylus Independence	☑	🕷	$	☑	🕷	☑	🕷
②	Multi-Touch	🕷	$	🕷	☑	☑	$	$
③	Durability	🕷	$	$	$	$	🕷	☑
④	Optical Performance	🕷	☑	$	$	$	🕷	$
⑤	Flush Surface	☑	$	$	☑	🕷	☑	$
⑥	Power Consumption	$	☑	$	☑	🕷	$	🕷
⑦	Stable Calibration	🕷	$	$	$	$	🕷	$
⑧	Narrow Borders	☑	☑	$	☑	🕷	☑	$
⑨	Substrate Independence	☑	$	☑	$	$	☑	$
⑩	Cost	$	🕷	☑	☑	🕷	☑	🕷

$	Best
☑	OK
🕷	Worst

Tyco Electronics

Fig. 3: Mobile-device designers can choose among a variety of touch-screen technologies, each of which has its own advantages and disadvantages.

tation about the digital waveguide technology from RPO, Inc. Other companies have attempted to use infrared emitters and sensors to create a touch-screen system, but these have had serious limitations in terms of complexity, part count, and low resolution. The RPO system described at the conference manages to create a system using just two IR emitters – one for each axis – and a single sensor. Parabolic reflectors create a plane of light across the face of the panel, while fiber-optic waveguides carry the received light to a single CCD sensor. The result is a system that needs no calibration, has no moving parts, and can be used with any pointing device from a gloved finger to a stylus. Given the fine resolution of the system, it can even tell the difference between the pointed end of a pencil and its eraser, making it possible to create context-sensitive actions in the user interface, based on the size of the touch device. RPO has pilot production running at 250,000 units per year and will be in full production in 2009 through a partner in China.

Full Measure

When there is more than one solution available for an application, you have to be able to compare them in order to choose the most suitable. A number of speakers addressed the complex issue of display metrics and how to make sure you are measuring what you intend.

James O. Larimer of ImageMetrics set the table with an excellent treatise on issues of brightness and contrast, starting from their origins in biological vision systems and carrying through to performance of different display technologies. Even more provocative, however, was the presentation by Chang Hoon Lee of Samsung Mobile Displays. He made the case that conventional contrast measurements are not adequate at predicting panel readability under harsh conditions, such as direct sunlight. A simple measure of light is not enough; the difference in hue is also an important factor. He made the point that OLED panels have a far wider color gamut than the typical LCD panel and, as a result, perform better in bright light than their contrast measurements might indicate. He presented a "patch level" contrast measurement that relies on human observers to measure display performance under controlled conditions, which demonstrated that OLEDs perform 18% better than LCDs and up to 30% better when the image includes a color background.

Other highlights ranged from improvement in LCD-panel backlights and heat dissipation to new circuitry and interfaces intended to increase reliability while decreasing power consumption to ways to include touch-like capabilities into a mobile flat-panel display by using part of the active-matrix backplane as optical sensors. The end result was an event that kept participants in their seats right through to the end of the last session on the second day. The conference was rich in both content and context and worth putting on your calendar for next year. ■

We are always interested in hearing from our readers. If you have an idea that would make for an interesting Business of Displays column or if you would like to submit your own column, please contact Mike Morgenthal at 212/460-9700 or email: mmorgenthal@pcm411.com.

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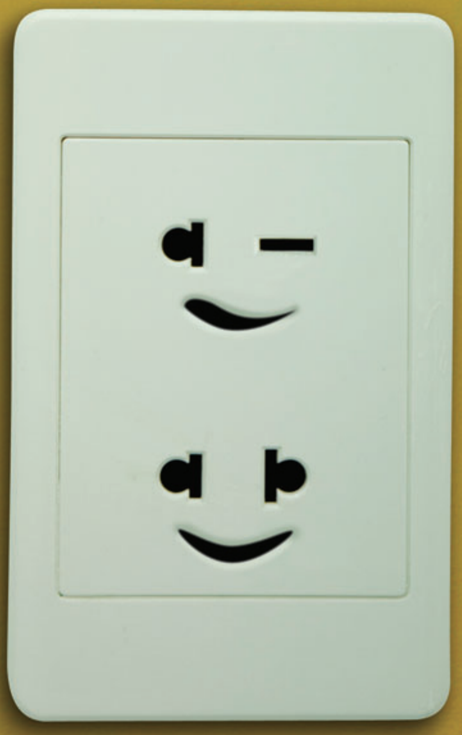

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Edited by Aris Silzars

Influence of the monocular near-to-eye display position on the visual system during dual-task performance

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Abstract — In this research project, the influence of different monocular near-to-eye display (NED) positions on user comfort has been investigated. In total, 43 subjects participated in tests; 22 used above and 21 below NED positions during dual-task performance for 40 minutes. SSQ and VSQ questionnaires were used to compare the eyestrain and other sickness symptoms before and after the task performance for both display positions. According to the subjective test results, the NED position above the eye causes more symptoms than the position below the eye.

People repeatedly face situations where they need or could benefit from more information. One possibility to gain additional information is to exploit an NED. NEDs could be used in very different environments with different applications without outside interruptions. A type of NED, monocular, bi-ocular, or binocular, on one hand sets limits, but on the other hand gives the user freedom to choose the most suitable presentation mode for a specific media. Like standard monitors, NEDs could also cause unwanted consequences if they are not used appropriately.

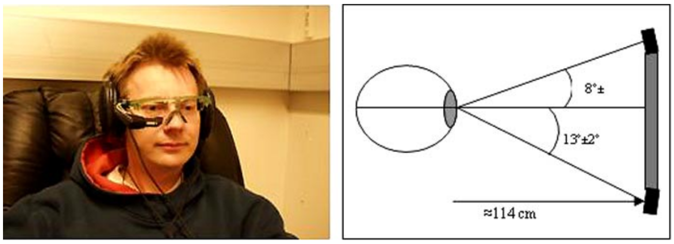

FIGURE 2 — The participants viewed a small NED placed either approximately 5° above or approximately 15° below the horizon line of sight. The ViewSonic display's middle point was approximately 5° below the horizon line.

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Application of radial basis functions to shape description in a dual-element off-axis eyewear display: Field-of-view limit

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University of Central Florida

Abstract — Previously, it was demonstrated that radial basis functions may be preferred as a free-form shape descriptor for a single-mirror magnifier, justified by a performance increase measured by the MTF, when compared to other conventional descriptions such as multivariate polynomials (*e.g.,* Zernike polynomials or *x– y* polynomials). The benefit in performance increase can be used to expand the pupil diameter from 8 to 12 mm given a 20° field of view and a 15-mm eye clearance or to increase the field of view. The main contribution in this paper is the investigation of the field-of-view limit in a dual-element magnifier where the free-form mirror is described with radial basis functions. Our main result in this paper is an estimate of the field-of-view limit of the dual-element magnifier to be approximately 25° full-field diagonal, given the specific geometry described in the paper. The impact of the astigmatic node placement in a rectangular image field on the modulation transfer function is also analyzed for the particular dual-element magnifier geometry.

Regardless of complexity (*i.e.,* types or number of surfaces), an optical system can always be characterized by an effective focal length along with principal planes and nodal points. A *magnifier* forms a virtual image when the object lies inside of its focal length as shown in Fig. 1. Our approach is to consider one or two element magnifier designs and investigate their performance, field of view, and pupil-size limits.

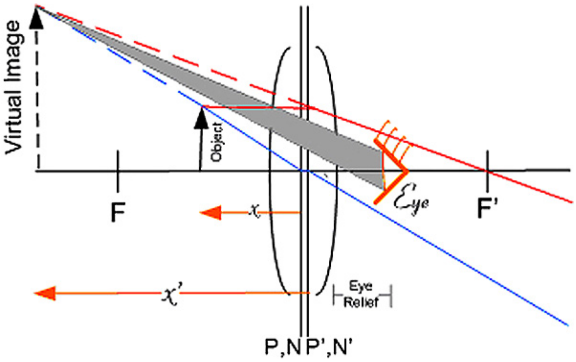

FIGURE 1 — Illustration of the principle of operation of a magnifier.

Reading experience with curved hand-held displays

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Marja Salmimaa (SID Member)
Jukka Hautanen (SID Member)

University of Helsinki

Abstract — The aim of this study was to measure reading experiences on curved paper-like displays. The experimental materials were mockups that consisted of printed paper attached to a curved plastic surface. The experiment participants held the mockups in their hands and evaluated the reading experience with them. Twelve font sizes, two curvature magnitudes, and two curvature directions were used in the experiment. The results showed that reading text on a curved surface was easier when the curvature direction is perpendicular to the text direction. It was also found that concave surfaces were regarded as better in cases where the text direction was the same as the curvature direction.

The anchoring stimuli were flat and had stimulus text in 12 different font sizes starting from 6 and ending at 22 [Fig. 1(a)]. The text was printed on a gray background. After the initial anchoring stimuli, we presented the curved stimuli [Figs. 1(b)–1(e)], which consisted of five different font sizes that were chosen based on pilot experiments, which indicated that the greatest change in the subjective opinion changes between font sizes 6 and 12 after which the subjective reading experience did not increase and even decreased with larger fonts.

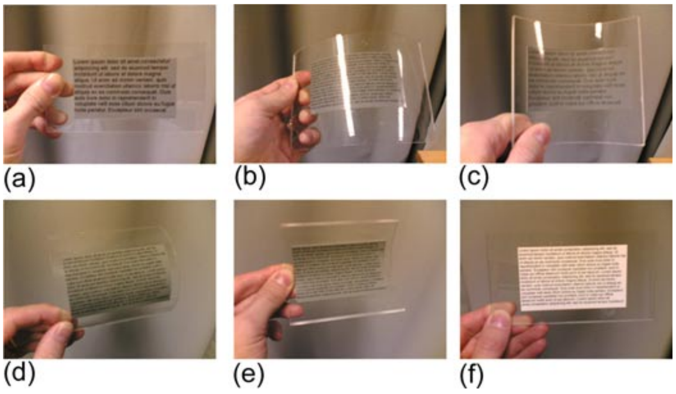

FIGURE 1 —Stimuli used in the experiment. (a) Anchoring stimulus with flat plastic background, (b) convex stimulus with equal text and curvature direction, (c) concave stimulus with equal text and curvature direction, (d) convex stimulus with opposite text and curvature direction, (e) concave stimulus with opposite text and curvature direction, (f) comparison stimulus with flat plastic background.

The effect of stereoscopic viewing in a word-search task with a layered background

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Erkki Heinonen
Johan Bergquist (SID Member)
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Keio University

Abstract — The benefits of stereoscopic viewing were explored in searching in words superimposed over a background. In the first experiment, eight participants searched for text in a normal 2-D display, a 3-D display using a parallax barrier, and a darkened 2-D display of equivalent brightness to the 3-D display. Word-search performance was significantly faster for the bright 2-D display *vs.* the 3-D display, but when brightness was controlled, performance on the 3-D display was better relative to the 2-D (dim) display. In a second experiment, the effect of floating text *vs.* sinking background disparity was assessed across four background conditions. Twenty participants saw only the floating-text (FT) condition and 20 participants saw only the sinking-background (SB) condition. Performance of the SB group was significantly better than that of FT group, and the advantage of SB disparity was greater with the more-complex backgrounds. Thus, when a parallax-barrier 3-D display is used to view text or other figural information overlaid on a background, it is proposed that the layer of primary interest (foreground) should be displayed with zero disparity (on the physical display surface) with the secondary layer (background) appearing to be sunk beneath that surface.

Multiple layers of information within a fixed area theoretically multiply that area by the number of layers. However, problems such as visual parallax and limited visual attention for simultaneous multi-level viewing mean that the measurable benefit of layered 3-D interaction is likely to be much less than might be predicted by simply summing the areas of the multiple layers in the display.

FIGURE 1 — The concept: Layering application information on a handheld device.

Motion-blur characterization with simulation method for mobile LCDs

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Yiqin Xu
Yabin Shi
Wen Song
Wei Lei

Southeast University

Abstract — A simulation method based on measured liquid-crystal responses and human-vision properties was proposed to characterize the motion blur of LCDs. A perceptual experiment was implemented to validate the simulation model within different viewing conditions by changing the visual angle. The results indicate that the smaller visual angle of the mobile display has no statistic significant effect on smooth-pursuit eye tracking when perceiving a moving block on a screen. The calculation process of quantitative metric was presented based on the measured light behavior and the simulation model. In the end, the different motion-blur reduction approaches were evaluated for mobile LCDs.

Motion blur is caused by the combination of light behavior of the LCD and the human-vision property. Consider a one-dimensional image displayed on a screen. For a sample-and-hold type display, the light emission will hold on for one frame period. When the image moves on the screen from left to right at the speed of 2 ppf (pixel per frame), the image content will hop from left to right immediately at the beginning of each frame and then hold for one frame period. So the signal in a LCD is discrete in both spatial domain (quantified in pixels) and temporal domain (quantified in frames).

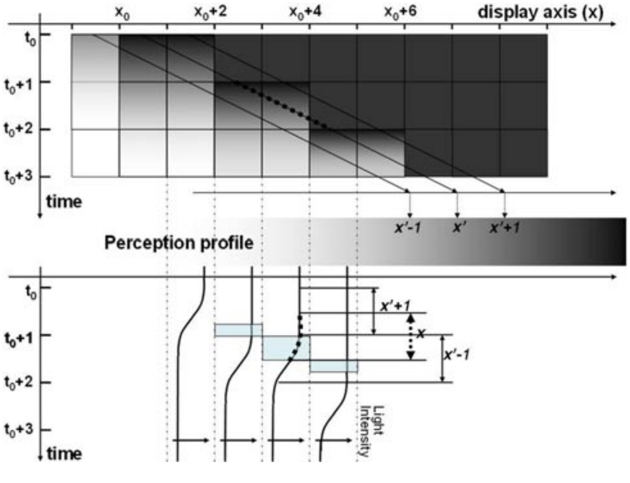

FIGURE 2 — Motion-blur generation when liquid-crystal response delay is taken into account. The lower part indicates the liquid-crystal response and the integration region with the eye is smoothly tracking.

OLED lifetime issues from a mobile-phone-industry point of view

Antti Laaperi

Nokia Device R&D

Abstract — Lifetime issues have been a hot topic throughout the history of OLEDs. The rapid development of lifetimes since 2002 has enabled OLED displays to become acceptable for mobile phones. The lifetime requirements of 30,000 hours expressed by the representatives of mobile-phone-terminal makers were felt to be unrealistic to be obtained in 2003, since the lifetime of the blue color was below 1000 hours. Today, 5 years later, lifetimes of AMOLED panels are over 50,000 hours. OLED displays are suffering from a burn-in effect due to limited lifetime. After 2003, it was understood by the panel and terminal makers that instead of lifetime, burn-in sensitivity became the limiting factor from an AMOLED-panel usability point of view. The burn-in effect becomes visible at 2–3% luminance degradation levels between adjacent pixels. To take this effect into account in mobile-phone applications, the lifetime needs to be increased from 30,000 to 60,000 hours, and suitable algorithms need to be used for the display of the terminal. There is also pressure to double the peak luminance values used in the terminals in order to improve the performance of the screen in outdoor environments. The roles of the material developers, panel makers, and terminal makers are reviewed in this paper from a lifetime perspective.

TABLE 1 — Development of the lifetime (hours) for small-molecule OEL materials during 2004–2007.

	2004	2005	2006	2007
Fluorescent red, 150 cd/m^2 from panel	10,000	37,000	52,000	
Fluorescent green, 150 cd/m^2 from panel	14,000	49,000	65,000	
Fluorescent blue, 150 cd/m^2 from panel	3700	13,500	35,000	60,000
Phosphorescent red, 1000-cd/m^2 emission		10,000	80,000	200,000
Phosphorescent green 1000-cd/m^2 emission	20,000	40,000	110,000	250,000
Phosphorescent blue, 500-cd/m^2 emission		1660	3000	9000

TABLE 2 — Development of lifetime (hours) of polymer-OEL material during 2002–2007. The luminance reference for all the values in Table 2 is 1000 cd/m^2.

	2002	2003	2004	2005	2006	2007
Fluorescent red	450	1100	2100	3000		
Fluorescent green	300	900	2700	6000		
Fluorescent blue	100	300	800	2000		
Phosphorescent red	30	200	250	4800	24,000	67,000
Phosphorescent green	3	20	25	3180	35,000	78,000
Phosphorescent blue				1660	1700	10,000

Power-saving primary design for displays enclosing a target color gamut

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Chung Hua University

Abstract — Display primaries are optimized for the trade-off between the total primary power and color gamut under the requirement that a target color gamut is enclosed by the color gamut of the display. LED displays and HDTV color gamut are taken as examples. Compared to the display using a set of typical commercial RGB LEDs, it was found that a total optical (electrical) power of 23.6% (15.6%) can be saved for the display using optimal RGB LEDs. Although the size of the display color gamut is sacrificed, the color gamut of the display using optimal RGB LEDs still encloses the HDTV color gamut. The combined effect of the LED luminous efficiency and white-point condition on the determination of the optimal LED wavelengths and bandwidths is also studied.

For the display where its chromaticity triangle encloses the HDTV chromaticity triangle, its color gamut may not completely enclose the HDTV color gamut in a perceptual color space. Thus, we represent the color gamut of a display in the CIELAB color space in this paper. Figure 2 shows the HDTV color gamut. The color-gamut size is represented by a discernible color number instead of the chromaticity triangle area. The discernible color number represents the number of discernible colors as defined based upon calculations using the CIE94 color-difference formula in the CIELAB color space.

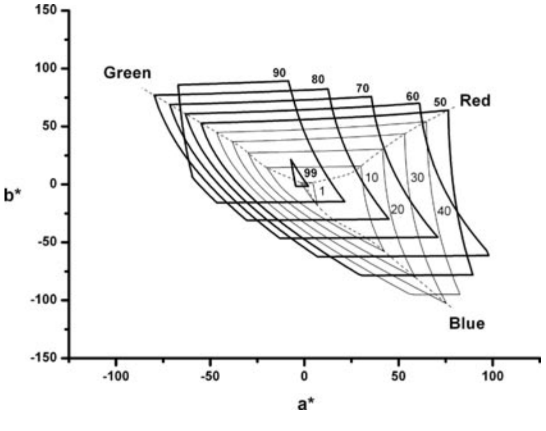

FIGURE 2 — Color-gamut cross sections of constant lightness (L^*) in CIELAB color space for the HDTV color standard. The corresponding values of L^* are shown near the boundaries of the cross sections. Dashed lines show the loci of primary ramps.

Color performance of an MVA-LCD using an LED backlight

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Abstract — The color performance, including color gamut, color shift, and gamma curve, of a multi-domain vertical-alignment (MVA) liquid-crystal display (LCD) using an LED backlight are calculated quantitatively. Simulation results indicate that an LED backlight exhibits better angular color uniformity and smaller color shifts than a CCFL backlight. Color gamut can be further widened and color shift reduced when using a color-sequential RGB-LED backlight without color filters, while the angular-dependent gamma curves are less influenced using different backlights. The obtained quantitative results are useful for optimizing the color performance and color management of high-end LCD monitors and LCD TVs.

In evaluating the color uniformity of an LCD monitor or TV, the observers care more about the color performance in the horizontal and vertical directions. Therefore, the color shift in the horizontal direction is usually measured. Figure 5 shows the simulated angular dependent $\Delta u'v'$ of an MVA-LCD backlit by different light sources as observed from the horizontal ($\phi = 0°$) viewing direction at G63 and G255, respectively. The RGB curves are more or less symmetric along $\theta = 0°$ and the $\Delta u'v'$ value increases as θ increases. It is interesting to note that no matter which backlight is used, blue color always has the largest $\Delta u'v'$ value, followed by green and then red.

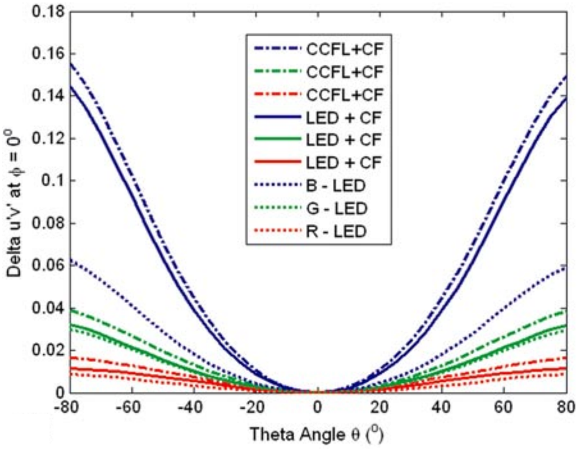

FIGURE 5 — Color shift for RGB primaries at the different gray levels under different backlights along the horizontal direction. Gray level, G255.

Compact modeling of amorphous-silicon thin-film transistors with BSIM3

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Sameer Venugopal (SID Member)
Korhan Kaftanoglu
Lawrence T. Clark
David R. Allee (SID Member)
Edward Bawolek

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Abstract — A novel approach of modeling a-Si:H TFTs with the industry-standard BSIM3 compact model is presented. The described approach defines the a-Si:H TFT drain current and terminal charges as explicit functions of terminal voltages using a minimum set of BSIM3 parameters. The set of BSIM3 parameters is chosen based on the electrical and physical characteristics of the a-Si:H TFT and their values extracted from measured data. By using the selected BSIM3 model parameters, the a-Si:H TFT is simulated inside SPICE to fit the simulated *I–V* and *C–V* curves with the measured results. Finally, the extracted BSIM3 model is validated by simulating the kickback voltage effect in an AMLCD pixel array.

The modeled a-Si:H TFT is fabricated with a low-temperature, 180°C process compatible with a flexible transparent substrate.The gate metal is molybdenum patterned on the substrate and is placed underneath the a-Si:H. The gate dielectric is silicon nitride and the active layer is hydrogenated amorphous silicon deposited with plasma-enhanced chemical vapor deposition. The source/drain metal is sputtered on as an N^+ a-Si/Al bilayer. Depending on the application, another metallization step using indium tin oxide and molybdenum (ITO) is carried out [see Fig. 1(a)]. Figure 1(b) shows the cross-sectional view of a three-terminal *n*-channel a-Si:H TFT used in the measurements and model fits.

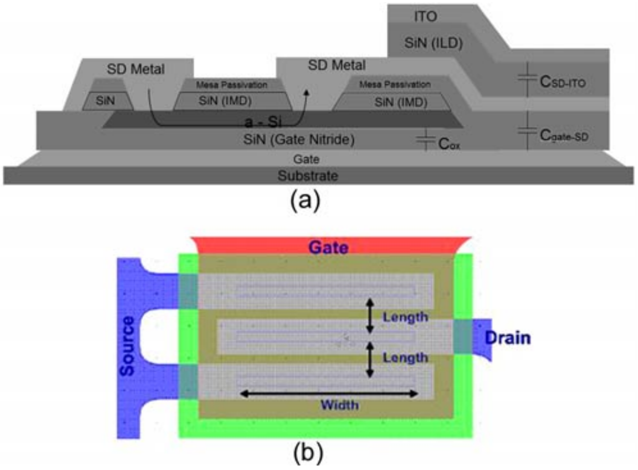

FIGURE 1 — (a) The channel passivated bottom-gate inverted-staggered a-Si:H TFT fabricated at the Flexible Display Center. (b) Cross-sectional view of the reflective (REFL) type a-Si:H TFT with *W* = 96 μm, *L* = 9 μm, and fingers = 2.

Single-cell-gap transflective liquid-crystal display using double- and single-mode approaches

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Tao Du (SID Student Member)
Vladimir G. Chigrinov (SID Fellow)
Hoi-Sing Kwok (SID Fellow)

Hong Kong University of Science and Technology

Abstract — In this paper, many popular methods to study transflective liquid-crystal-displays (LCDs) have been discussed, and several new transflective LCD configurations with a single cell gap have been proposed. The traditional double-cell-gap method gives the best match of the transmittance/reflectance voltage curve (TVC/RVC) and also the widest viewing angle, but also brings the highest fabrication complexity. The single-cell-gap transflective LCD is much easier to fabricate and also shows a good match of TVC/RVC. A new methodology has been shown to find optimal configurations for single-cell-gap transflective LCDs. New configurations using multimode in a single pixel include twisted-nematic (TN) optically compensated bend (OCB), TN electrically controlled birefringence (ECB), and TN low-twisted nematic (LTN). TN and hybrid-aligned nematic (HAN) modes have been investigated for single-mode transflective LCDs. The results exhibit high contrast ratio, a good match of TVC/RVC, as well as wide viewing angle.

Figure 17 shows the schematic diagram of the HAN-mode transflective LCD. The top and bottom substrates are antiparallel rubbed. Horizontal polyimide is spin-coated on the top substrate during preparation, while vertical polyimide is on the spin-coated bottom substrate. The LC molecules are parallel aligned at the top substrate with a preferred tilt angle of about 2°. The preferred tilt angle of the LC molecules at the bottom substrate is around 88°. An ordinary polarizer coated with an anti-reflection layer is used for both transmissive and reflective regions to improve the dark-state performance.

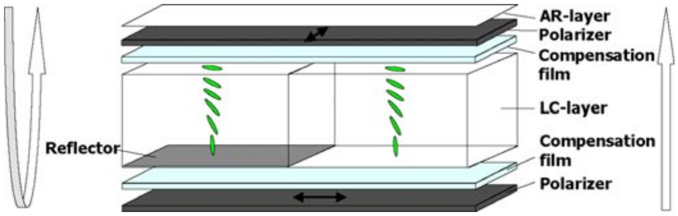

FIGURE 17 — Scheme of the transflective LCD: reflective part and transmissive part, HAN mode.

A touch-sensitive display with embedded hydrogenated amorphous-silicon photodetector arrays

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Tae-Jun Ha (SID Student Member)
Yongtaek Hong (SID Member)
Jae-Hoon Lee
Byoung-Jun Lee
Bong-Hyun You (SID Member)
Nam-Deog Kim (SID Member)
Min-Koo Han

Seoul National University

Abstract — A new touch-sensitive hydrogenated amorphous-silicon (a-Si:H) display with embedded optical sensor arrays is presented. The touch-panel operation was successfully demonstrated by fabricating a prototype of a 16-in. active-matrix liquid-crystal display (AMLCD). The proposed system, obviating the need for the extraction of information from the captured images in real time, provides the location of the finger touch. Due to the simple architecture of the system, the touch-panel operation can be readily integrated within large-area displays.

An a-Si:H TFT with an etch-back structure on a glass substrate was fabricated by employing a standard commercial process in order to investigate the possibility of using the a-Si:H device as a photosensitive element. After a 250-nm-thick gate metal layer (Mo/AlNd) was sputter deposited and patterned on the glass substrate, a 450-nm-thick silicon nitride (SiN_x) layer as a gate insulator, a 200-nm-thick a-Si:H film and a 50-nm-thick n^+ silicon layer were deposited by PECVD at 400°C without breaking vacuum.

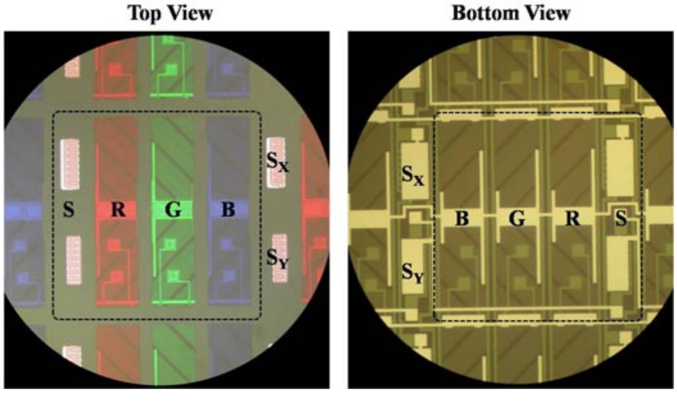


FIGURE 6 — The micrographs of the unit pixel in the fabricated AMLCD panel.

New driving scheme for intelligent power-efficient high-voltage display drivers

Ann Monté
Pieter Bauwens
Stefaan Maeyaert
Jan Doutreloigne

University of Ghent

Abstract — A new bistable-display driver is presented. The innovation in the developed driver is the addition of a new logical block that calculates the most energy-efficient driving waveforms. In this paper, the algorithms being applied to the row and column waveforms in order to reduce the power consumption are discussed. Some theoretical as well as experimental results are shown, proving a reduction in the power consumption by about 50%. The proposed algorithms are especially important for battery-powered applications.

By short-circuiting row i and row $(i + 1)$ for a short period of time, before making the transition from one voltage level to the other, part of the otherwise wasted charge can be recuperated. Row i and row $(i + 1)$ are charged to 20 V when both rows, which were at 40 V and 0 V are short-circuited, respectively. As a result, the voltage source only has to deliver the power needed to increase the voltage level of row $(i + 1)$ from 20 to 40 V and not from 0 to 40 V, implying a big power savings. This principle is demonstrated in Fig. 3.

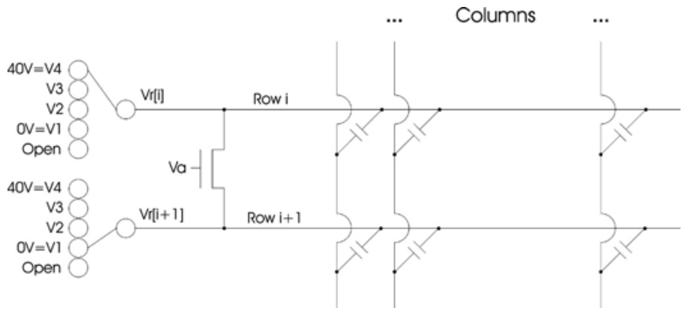
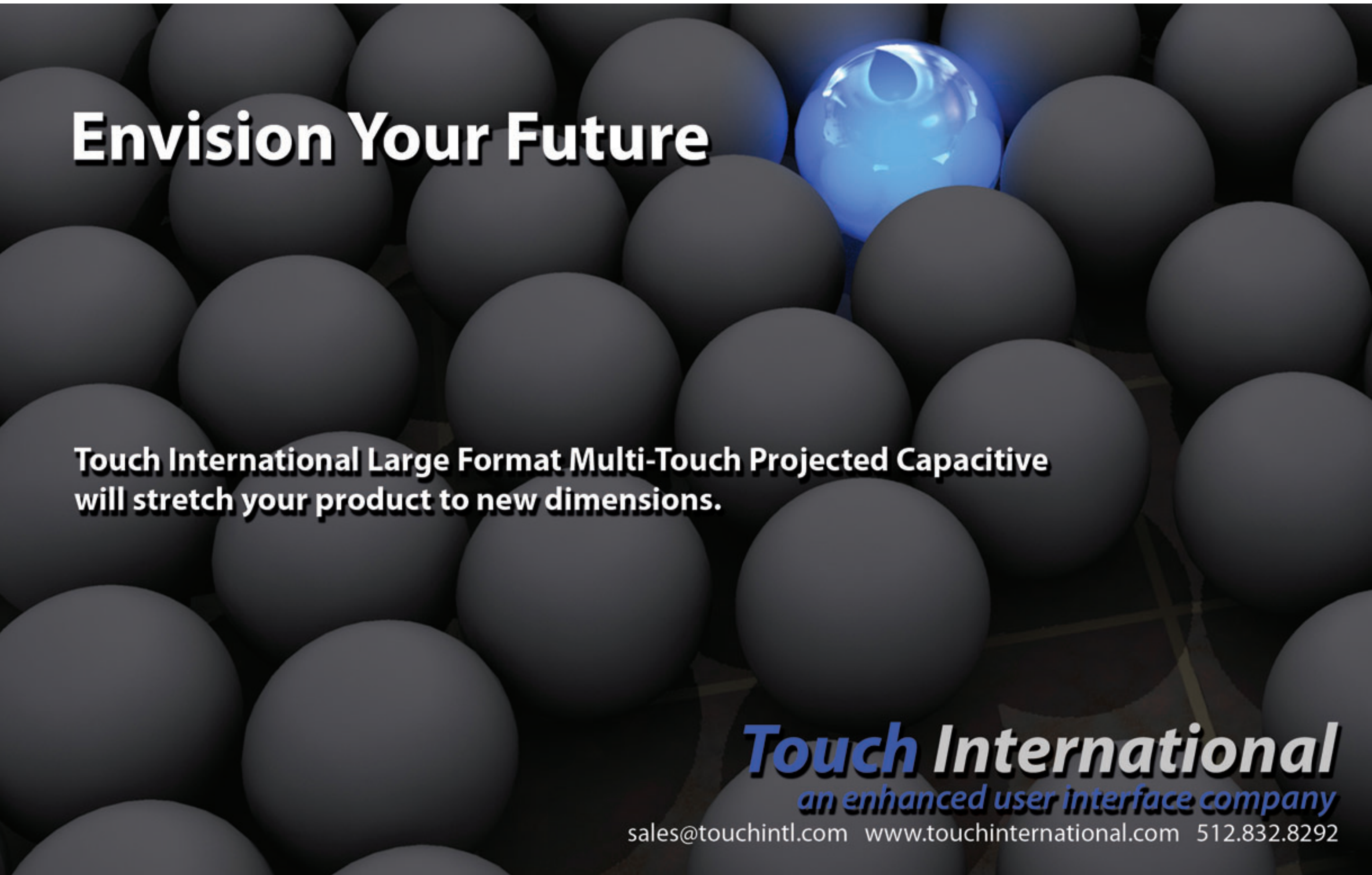


FIGURE 3 — Charge recycling by short-circuiting rows.

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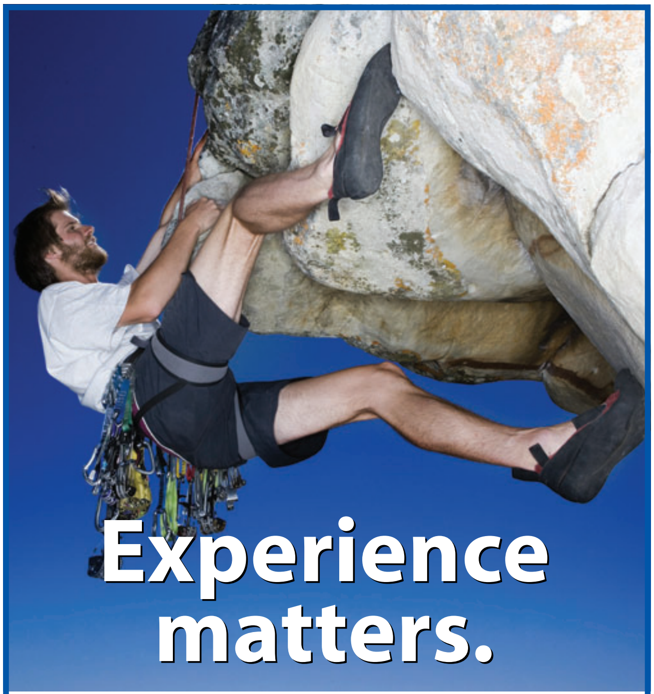
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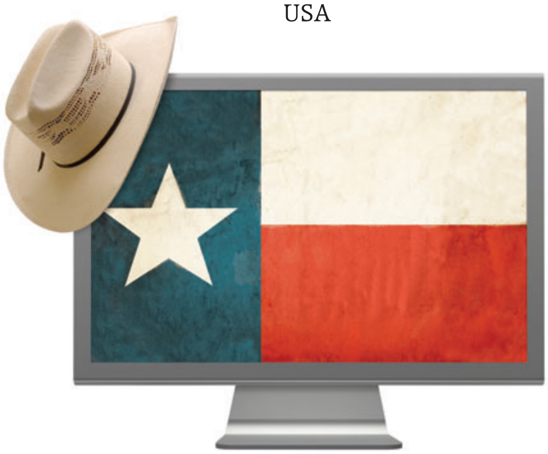

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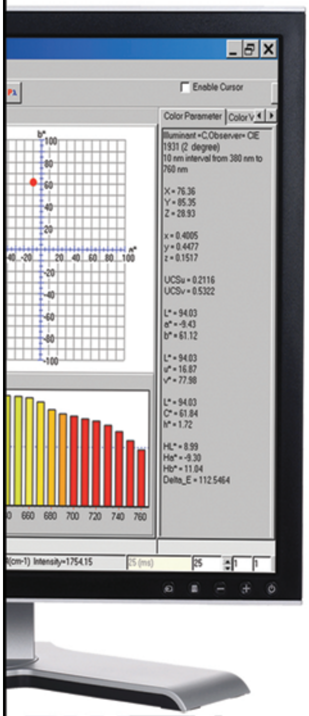
Building Blocks for LED/LCD Measurement Systems



Illuminant =C,Observer= CIE 1931 (2 degree)
10 nm interval from 380 nm to 760 nm

X = 76.36
Y = 85.35
Z = 28.93

x = 0.4005
y = 0.4477
z = 0.1517

UCSu = 0.2116
UCSv = 0.5322

L* = 94.03
a* = -9.43
b* = 61.12

L* = 94.03
u* = 16.87
v* = 77.98

L* = 94.03
C* = 61.84
h* = 1.72

HL* = 8.99
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Information DISPLAY

September 2007 Vol. 23, No. 9

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- Evolution in LTPS AMLCD Manufacturing
- Fast-Switching LC Effects
- Nanoparticles and LCDs
- Progress in High-Brightness LEDs
- Building an Effective Patent Strategy: Part 1
- Journal of the SID September Preview

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In this case, Samsung did not just combine the components needed to meet the goal of a 10-mm-thick TV set; it took advantage of the properties of those components to create an even better product. Samsung utilized an edge-lit architecture with a light-guide plate, and then took the design further by utilizing the other advantages of LEDs to improve display performance. Dr. Jang clearly describes how they used the fast switching of the LEDs to modify the gamma of the device to enable improved picture quality over the entire range.

In another article, the combination of technologies by Toshiba Matsushita Display (TMD), resulting in a very high-performance display, is described. By choosing the most advanced technology for each component, TMD had an impressive toolset with which to create a state-of-the-art display. By choosing the OCB LC mode, TMD was able to have inherent fast response time to reduce the Motion Picture Response Time (MPRT). By using an LED-based backlight, the company improved the contrast ratio to 1,000,000:1 and viewing angle to more than 160° with a CR>50. By using the inherent fast switching of the LCD and the LEDs, TMD coupled the drive scheme of the LEDs to the drive of the LCD panel to further reduce the MPRT down to 2 msec. This combination of technologies along with utilizing the synergistic advantages truly makes this display one of the highest performing LCD modules ever created.

Finally, an article from 3M clearly demonstrates the ability of film technologies, when coupled with the design of the backlight and the LCD, to enable significant efficiency boosts. When a recycling film, such as a prism film or reflective polarizer, is added to a system, the efficiency of the backlight cavity becomes even more important. Realizing this and designing the system as a whole can yield extra performance increases than optimizing the components alone. A 48% increase in the battery life of a mobile entertainment system was achieved by 3M by increasing the reflectance of the back reflector and replacing a sheet of prism film with a reflective polarizer. These modifications lead to a total battery life for this 3.5-in. display unit of almost 6 hours. The results in a TV set were even more impressive, reducing the power by 102 W (over 50%) as well as reducing the internal temperature by 10°C.

It is clear that by coupling the technologies available to TV-set designers today, new breakthroughs in display performance are being achieved. I look forward to the creative combinations that will be coming out in the future to enable new benchmarks for TV-set design, power efficiency, and overall set performance. ■

Jim Anderson *is an Advanced Physics Specialist, 3M Projection Systems Department, 3M Center, Bldg. 235-25-62, Saint Paul, MN 55144-1000; telephone 651/737-0717, e-mail: jeanderson@mmm.com.*

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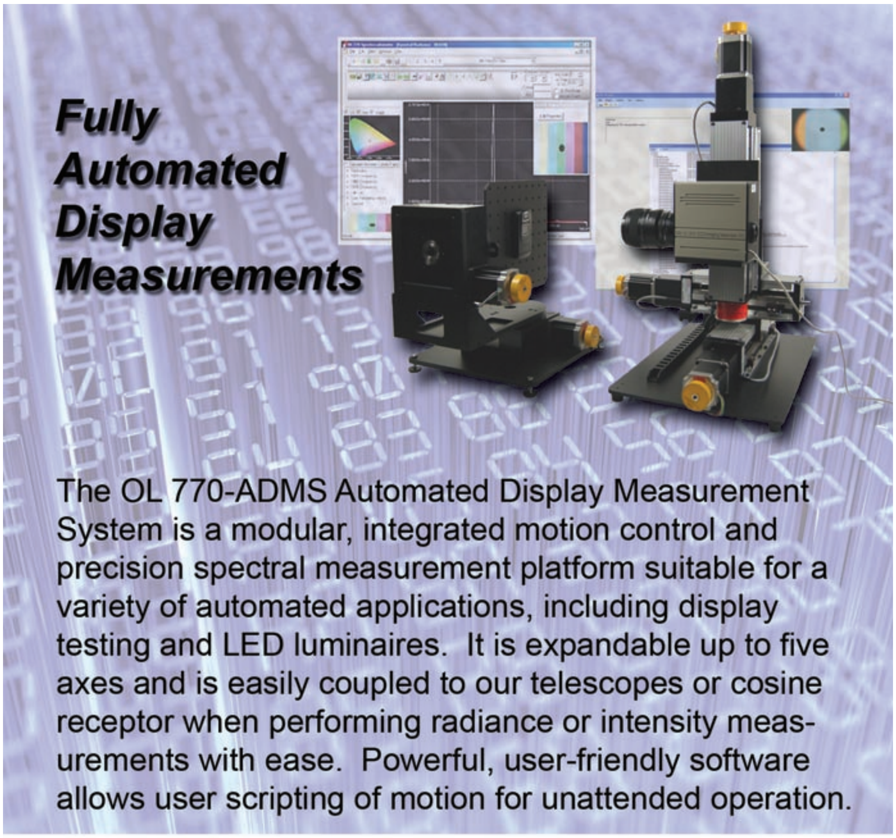

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impression on people early in their careers. While some university faculty may have limited capability to send their students to conferences, it is rarely possible to enable all deserving students to participate.

SID tries to do its part. For many years, the Society has provided numerous travel grants for deserving students to attend SID-affiliated conferences. Companies with a major stake in the electronic-display industry may consider sponsoring students to attend conferences as well. While there may not be as much direct contact as with an internship, the student (and their associated faculty member) will be highly grateful for companies that can provide this sort of support.

In times of tight money, it's expedient to cut as many expenses as possible. Companies should remember, though, that their ability to withstand hard times and excel during good times is directly related to the quality of their people. Is your workforce as talented and innovative as it could be? If not, it might be worth spending a bit of money and time on students now to reap those great rewards down the line.

Paul Drzaic
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Now in its 14th year, the annual **Display of the Year Awards** are the industry's most prestigious prize. Both SID members and non-members can nominate a product, as long as it was introduced into the marketplace between January 1, 2008 and December 31, 2008.

All nominations will be considered – display companies are encouraged to self-nominate their own products. Gold and Silver Awards will be awarded in three categories:

Display of the Year Award
Granted for a display with novel and outstanding features.

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To submit a nomination, visit www.sid.org/awards.dya.html, download an application for the appropriate category, and follow the instructions for submission.

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Award winners will be profiled in the SID Show Issue of *Information Display Magazine*.

continued from page 2

sharing expenses and income in a mutually beneficial way. Combining the content into bigger and fewer events will almost certainly reduce total expenses and maximize attendee value. Organizers should also be exploring opportunities for virtual seminars and exhibitions over the internet, which eliminates the need for attendee travel. These events could be held in the evenings, produced in TV studios, and piped to major sponsors via dedicated satellite feeds and to individual attendees over the Internet. The technology is all available, the model has not yet been tested that I know of.

Provided we do see some voluntary consolidation in upcoming years, I think it is critical that industry companies make the commitment to send their employees to these events and support them with marketing money. These events are vital and everyone benefits from the concentrated know-how that is available. Without these events, I believe our entire industry will suffer. So, please work in whatever sphere of influence you can to help partnerships, consolidation, and support of these important assets to our industry.

This issue is our annual LCD Technology issue and I'm very pleased to welcome first-time guest-editor Jim Anderson, Advanced Physicist from 3M Project Systems Division. Jim brought a fresh and creative perspective to the role and I believe each of the articles presents a unique and important aspect of LCD technology. The topic, of course, is so broad that almost anything could be considered as relevant, but we tried to bring you three specific articles that represent core opportunities for achieving a performance improvement in mainstream products.

We're also featuring this month a contribution from Brigadier General Edward Harrington, U.S. Army retired. General Harrington is a colleague of ours at Crane Corporation and he and I have had many discussions about the advancement of display technology specifically for military applications. While it may seem obvious at first how soldiers can use electronic displays and what technologies would be valuable, the process to go from an idea to a practical implementation is very complex. Ed uses the term "situational awareness" to describe what the U.S. army is trying to achieve in every aspect of their deployment of advanced systems. The best displays are those that provide sufficient information content in extreme operating environments over very long periods of time. Working as part of very complex information systems, they provide the right amount of information to protect the soldier without overloading them or producing needless distractions of extra content. In this world, "best" is not always better and reliability and utility really define the best criteria for success. I hope you will enjoy his contribution and maybe it will spark new ideas to enhance products or accelerate the deployment of new technology into this complex marketplace.

Stephen P. Atwood

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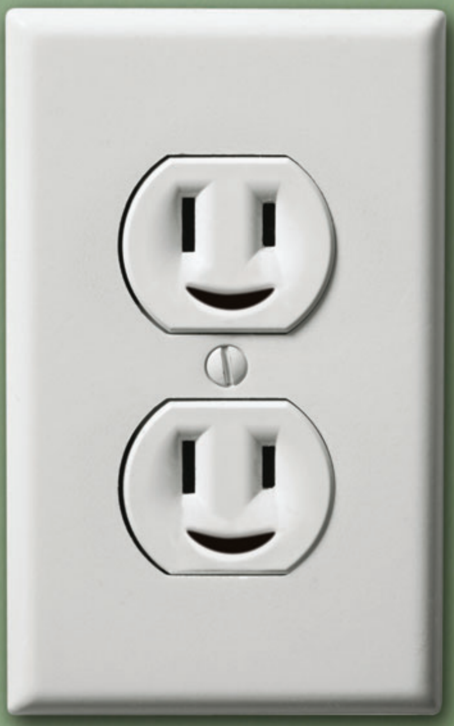

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