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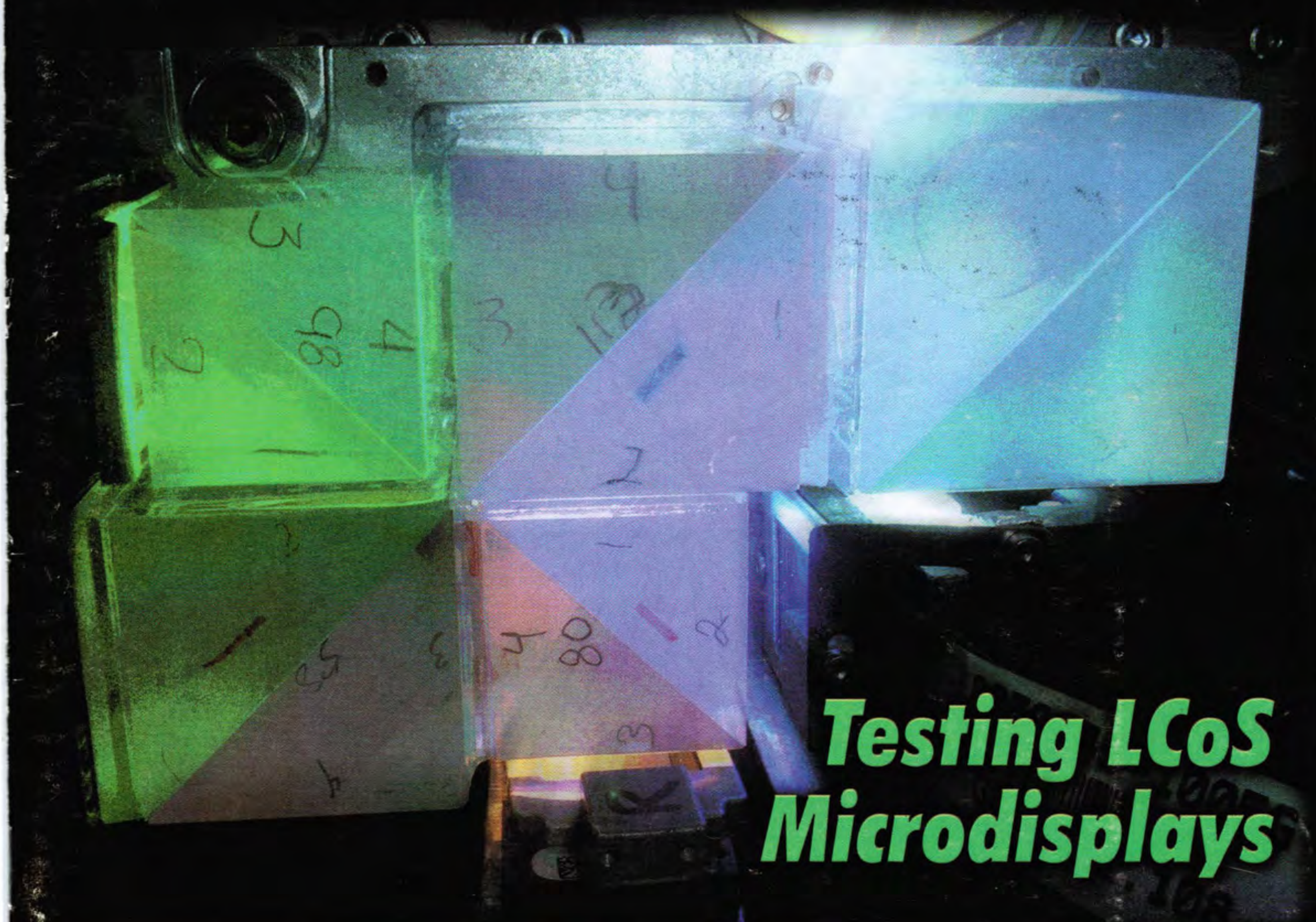

Testing LCoS Microdisplays

- *Testing LCoS Devices*
- *High-Efficiency AMOLEDs*
- *Rotating Drum Improves LCoS Projector*
- *OLED Encapsulation*
- *A Survey of Vehicular Displays*

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LCoS-microdisplay test results depend sensitively not only on the testing conditions, but also on the design of the optical engine in which the microdisplay will be used, which must be reflected in the tester's architecture.

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Next Month in
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Industry Directory Issue
- Display Industry Annual Directory
- Five-Wire Touch Screens
- Flexible Transistors
- Drivers for Novel Displays
- CeBIT 2002 Report

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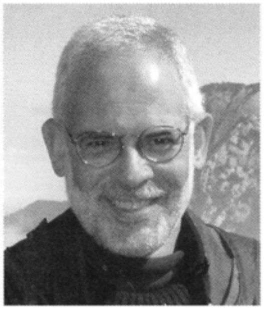

A Drink in Shanghai

Shanghai, China, February 22 — It is a little before midnight in a lounge on the 39th floor of the Shanghai Hilton. Sungkyoo Lim – a Professor at Dankook University and CEO of General Lighting and Display of Seoul, Korea – and I are lazily sipping our drinks and commenting on the city's skyline when Sungkyoo says something that snaps me to attention: "George Bush talks about the 'axis of evil.' I prefer to think about the 'axis of wealth' – New York, Tokyo, Seoul, Shanghai. It is clear that the axis of wealth now extends firmly into China."

It was my second visit to Shanghai. Sungkyoo and I were part of a team introducing a Korean company and a Shanghai company, with the hope of bringing the two together for a display-related joint venture. The talks had gone well, and executives of the two companies were coming to the conclusion that their individual strengths, requirements, and strategies meshed very well indeed. So Sungkyoo and I were feeling satisfied with our day's work.

The day of meetings, plant visits, Shanghai banquets, and viewing the early-20th-century European buildings on the Bund from the 88-story post-modern Hyatt on the east side of the Huangpu River had left me with a strong impression: Shanghai is a modern city-state that is rich, powerful, flamboyant, optimistic, and international. It is surely Chinese, but it is not like much of the rest of China. It has its own energy, its own style, and its own sense of mission. That mission is to increase its own power and wealth through international business. And part of that business is in displays.

The preferred way for many Shanghai companies to get into the FPD business (as well as other businesses) is to form joint ventures with foreign companies who supply the product and manufacturing technologies – at least for the moment. Not only does this provide a convenient and reasonably secure mechanism for the foreign company to transfer its technology and manufacturing know-how to the Shanghai company, but joint ventures also get preferential treatment under Chinese law. (That preferential treatment will phase out now that China is part of the WTO, but years of full and partial benefits remain.)

What fuels such ventures is exactly what you would expect. The foreign company supplies its technology and know-how so that a manufacturing facility can be built and start producing quickly. The Shanghai company provides an inexpensive, often dedicated labor force; often-favorable import duties; access to the world's largest market; and, ironically, a vibrant business culture.

So what kinds of displays are currently made in the Shanghai area? CRTs and CRT-based television sets have long been important products. Now, there are companies to make small STN-LCDs, VFDs, PDPs, and LCoS projectors and projection TVs, among others. The Chinese market for many goods is already large, and it will continue to grow for decades to come as some measure of prosperity finds its way to different categories of people in different geographical regions.

Although an ancient city, Shanghai seems new and sometimes raw. The prosperous live well here, and unskilled labor is cheap. The city has a spirited contemporary architecture unlike any I have seen in New York, Tokyo, or Seoul. "The axis of wealth," Sungkyoo had said, "now extends firmly into China." There are great opportunities in the PRC generally, and in Shanghai in

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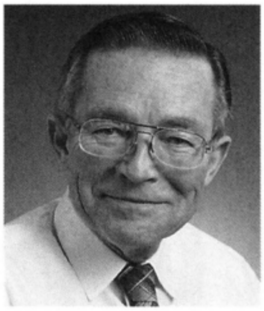
a view from the hilltop



Trends in Time Management . . .

by Aris Silzars

"Welcome ... Welcome ... Please do come in. I'm so glad you could join me for this month's column. As I told you when we spoke briefly by phone, this month I am going to write about how the latest developments in 'wearable' electronics are improving everyone's productivity. As we delve into this topic, I think you will see that technology has just begun to scratch the surface of new opportunities. With further improvements in cell phones, PDAs, and portable computers with wireless modems – and the displays that we will use to interface with them – there will be no end to what we can do. Oh, sorry, I'm getting way ahead of my story.

"Let's back up a little and begin with what we can already do today. But before I do that, would you like a cup of coffee or may I offer you something else? OK, well let me just take a moment to put a cup of tea in the microwave and then we will begin. Oh, excuse me, I hear my cell phone ringing. Let me just take this one call. OK – now where were we? Oh yes, the current capabilities of computers and communications are just the beginnings of what we will be able to do to improve our abilities to keep in touch with our colleagues and various databases. As you know, the present capabilities are rather rudimentary. We can communicate by voice and most of our laptop computers work with relatively slow modems – excuse me, let me just get my tea.

"Oh, by the way, I hope you don't mind if we continue this conversation as we drive to the airport. I promised Ernst that I would pick him up when he arrives on the 10:30 flight from Phoenix. But before we leave, let me just take a few minutes to check my e-mail and see if there is anything that is really urgent – Oh, please excuse me, I really do need to take care of this one e-mail that came in from England. It's almost the end of the day there and they are waiting for my response.

"OK, let me just grab my cell phone and briefcase and we will be on our way. Well, as I was saying, our abilities to communicate information will grow dramatically over the next decade. The next major step will be that we will be able to connect to the Internet through the cellular-telephone network, and those connections will become faster and more reliable. Of course, the voice channels will no longer drop calls as they do today. The quality and reliability will improve to the point that we will no longer have to think about them. Once in a while, it still impresses me that the traditional telephone system is now so good that it is often not possible to tell the difference between a local call and an international one.

"Oh, by the way, do you mind if I make a quick stop at the computer store to pick up a printer cable? As long as we are out and about, it's a much better use of my time than making a special trip later on. Please wait ... I'll be back in just one minute ... Yes, Peter, I did send you that information by fax. Perhaps you can check with your fax operator to see if it has come in yet. Can I call you back later? I'm in a meeting with a colleague right now ... OK, here we are. Sorry for the interruption. Peter was calling me to check on a fax that I had sent him. Well, as I was saying, once a more reliable and higher capacity cellular network comes on line, it will greatly expand our communications capability

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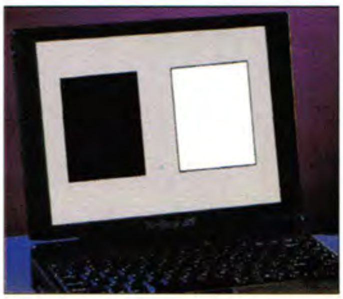

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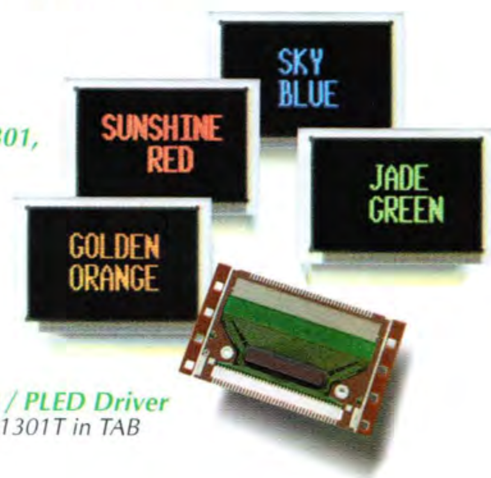

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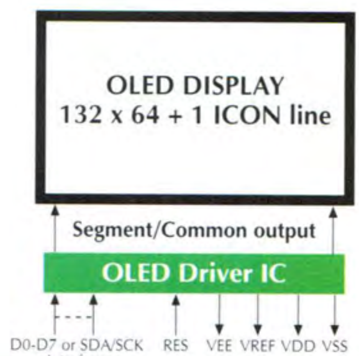

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The Challenge of Testing LCoS Devices

Optimizing test parameters for each application is critical to the accurate identification of pixel defects and the adoption of LCoS technology for display-system applications.

Peter A. Smith and Q. Jason Yang

LIQUID-CRYSTAL–ON–SILICON (LCoS) microdisplay panels have the potential to dramatically alter the way we receive visual information. Designs ranging from head-mounted displays to large projection systems may find applications in everything from portable telephones and computers to home entertainment.

In order to deliver on this promise, however, LCoS panels must work, and work reliably. Testing is a key to creating products that users will accept, and one of the most important tests is to find pixel-scale and sub-pixel defects because these result in visible flaws.

LCoS technology makes it relatively easy to create displays with a high pixel count. With more than 1.3 million pixels in a single SXGA-resolution panel, it is clear that an automated test solution is required. To ensure that a manufacturer of LCoS displays can meet the performance requirements specified by the light-engine builder, the two parties must first agree on the defect nomenclature that will be used. This makes it possible to describe the potential defect tests.

The test system, display system, and device characteristics must then be considered, so that defect information is correlated. For a device, these characteristics include the contrast as a function of optical-axis rotation, the luminance as a function of voltage, and the defect intensity as a function of applied voltage.

Defect Nomenclature

Pixel functionality can be tested for any gray shade within the display. The potential tests include dark defects on a white image, bright defects on a black image, differences in gray shade from a nominal gray value, and the distances between defects. Each defect can be described as a percentage difference between the measured gray-scale value and the nominal value. In addition, each defect can be described in terms of defect area per unit pixel size. The defect area and the difference in gray shade have an additive effect in producing an unwanted characteristic in the display.

To illustrate the defect testing, consider the bounding cases of bright and dark defects

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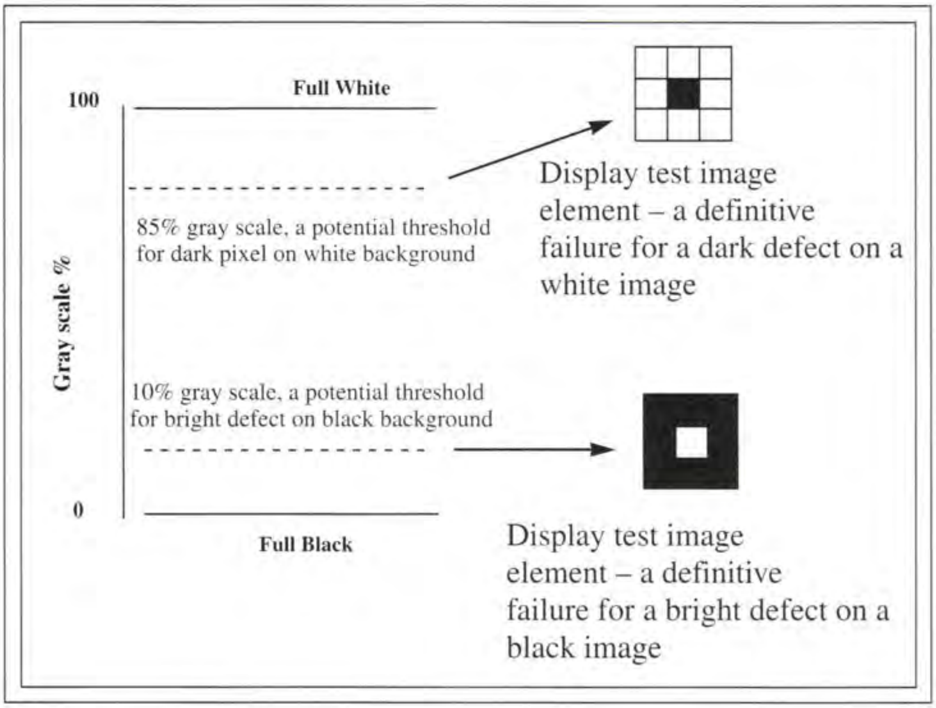

Fig. 1: Threshold values can be used to identify dark or bright defects in LCoS microdisplays.

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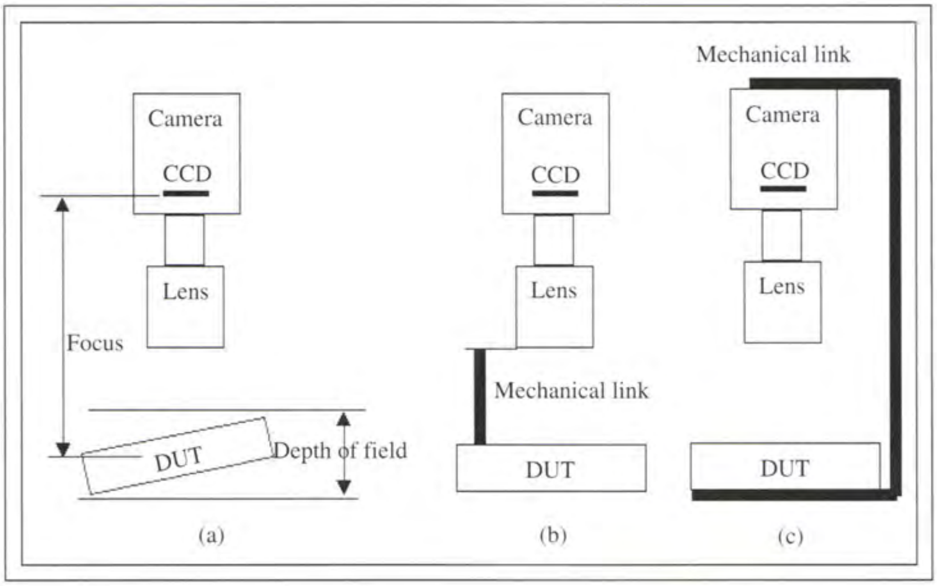

Fig. 2: *(a) Tilting of the DUT should be minimized to be within the depth of field of the sensor optics in order to keep the device relatively parallel with the camera's focal plane in either (b) a top-mounted or (c) a bottom-mounted configuration.*

(Fig. 1) (we will not consider area effects in this article). Testing for black defects requires a white image to be displayed on the LCoS panel. Perturbations, or "non-white responses," in the white image are measured with respect to the surrounding eight pixels. The difference in luminance is calculated and compared to a threshold value. If the difference is greater than the threshold value, the pixel is recorded as defective. This process is carried out over the entire pixel array of the imager.

Sampling Requirements

For camera-based test systems, the sensor optics are designed with sufficient resolution to detect the defects of interest. The sampling rate of the sensor must satisfy the Nyquist sampling criterion to accurately represent the real features in the display. Typically, a spot defect of the smallest size being looked for is covered linearly with three camera pixels. In other words, the ratio of camera pixels to the spot defect is 9:1 in two-dimensional camera images.

By knowing the dimension of a camera pixel, one can determine the magnification of the camera lens. If the minimum size of spot defects is 6 μm, and the camera pixel pitch equals 7.5 μm, the magnification of the lens will be 3.75×, *i.e.*, $M = (3 \times 7.5)/6$. For a 12-μm display pixel pitch, this translates to a 36:1 ratio of camera pixels to display pixels.

What determines the minimum size of the defect that must be measured in the test system? This is established by the modulation transfer function (MTF) or the contrast transfer function (CTF) of the display system that incorporates the tested imagers. In general, an engine with better optics, *i.e.*, a higher CTF, will make it necessary for the test system to measure and resolve smaller defects. The test system's designers must take the optical characteristics of the display system into account if they are to succeed in developing a test solution that ensures that parts are tested to the appropriate defect specification.

Z-Height Effects

From the sampling requirements and defect sizes described, it is inevitable that the typical test-system optics are characterized by a small field of view and a high *f*-stop value. Consequently, the sensor optics will have a limited depth of field (DOF), and the presentation of a device under test (DUT) to the sensor will be critical. The plane of the display must be parallel to the plane of the sensor over the inspection area.

The parallelism in the test system is very important. To guarantee that the DUT is in focus everywhere, the tilting should be controlled within the DOF [Fig. 2(a)]. The two possible designs of the DUT presentation

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Fig. 3: *Shown is an LCoS panel in a top-mounted configuration in a display system.*

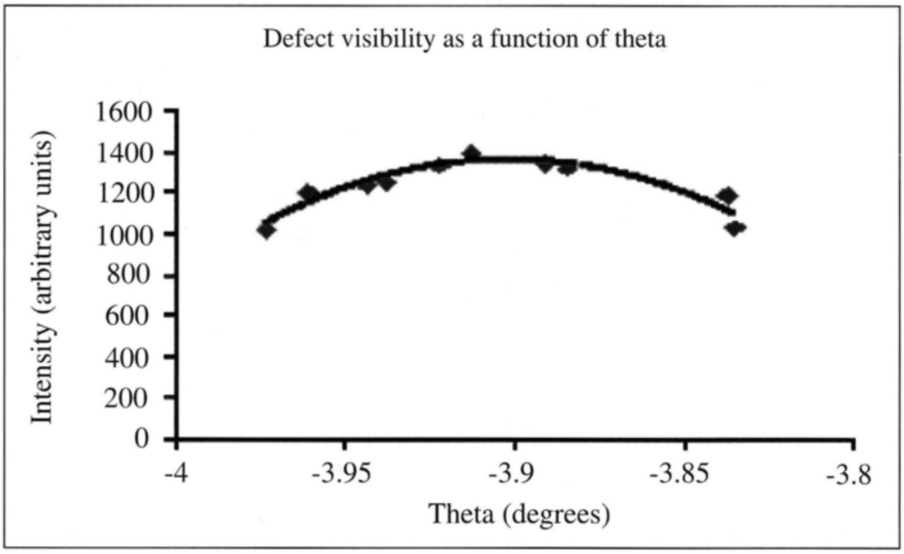


***Fig. 4:** LCoS-panel contrast is a function of optical-axis rotation; finding the optimal angle makes it easier to identify bright defects.*

mechanism are either a top- or bottom-mounted configuration [Figs. 2(b) and 2(c)]. The top-mounted design has a short mechanical link between the top of the DUT and the camera (Fig. 3), while the bottom-mounted configuration has a long mechanical link. When a very tight tolerance for the DOF is specified, the short mechanical link of the top-mounted design will introduce less tolerance stack.

The top-mounted configuration is generally preferred because it produces a geometry that mimics the light engine's mounting and depth of focus. (A properly designed display system does not need to address the challenge of a variable DOF.) The bottom-mounted design, however, is easier to implement. In either case, the reference plane – whether it be at the top or the bottom of the DUT – should be leveled to be parallel to the sensor plane of the charge-coupled device (CCD), which can be done by observing the focus in acquired images.

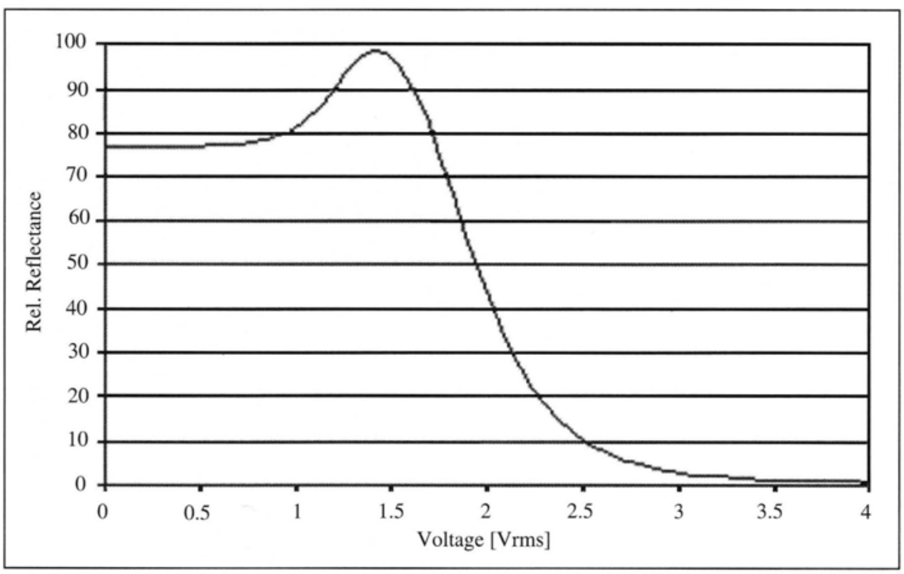


***Fig. 5:** The reflectance of LCoS devices peaks as a function of applied voltage, making dark defects easier to identify.*

Optical-Axis Effects

LCoS devices are subject to a peak in contrast as a function of the optical-axis rotation (Fig. 4). For a normally white liquid-crystal mode, this peak is largely a function of setting the black state for minimum brightness. This behavior has a large impact on contrast measurement and pixel testing. Equally important, this behavior affects defect visibility in the dark state within the test environment. In display systems that use a quarter-wave plate to maximize contrast, the effective optical axis is varied.

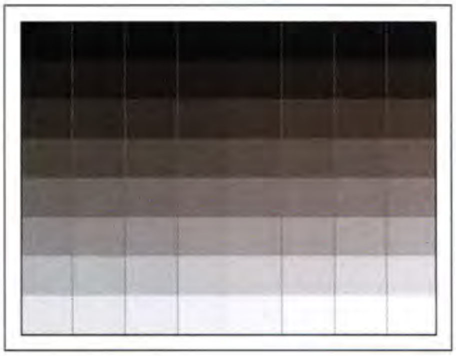
To successfully test bright defects for normally white LCoS devices, the defect test must include a planar theta adjustment. This theta adjustment essentially maximizes the defect visibility (defect contrast). If this is not done in the test system, the LCoS-imager manufacturer runs the risk of having the customer discover a defect after the imager has been aligned and mounted.

Voltage Effects

Dark Defects. LCoS devices are subject to a peak in reflectance as a function of applied voltage (Fig. 5). This behavior affects defect visibility in the bright state because a defect will have a different contrast, depending on the voltage used to set the white state. In the display system, the user optimizes the voltage to achieve peak brightness. In most instances, the brightness-optimization scheme will enhance defect visibility.

To successfully account for the LCoS-device behavior and test dark defects, the test system must include a peak brightness– voltage routine to determine the reference white state. The shape of the curve requires the splicing of three curve fits and, correspondingly, defines the need for seven data points to start an iterative search routine for the peak voltage. However, incorporating the display into the test system permits the peak voltage to be found rapidly by utilizing a specific test image that covers the range of voltages through the peak in the electro-optic response curve (Fig. 6).

Bright Defects. The reference voltage also impacts the ability to observe bright defects in



Three-Five Systems

Fig. 6: This sample test image is used to find the peak brightness as a function of voltage.

the test system. In the Three-Five Systems LCoS device, we have observed the following relationship in defect intensity (arbitrary units) for comparing 375 ($R^2 = 0.92$) defects as a function of voltage:

- Intensity of defect at 6.00 V = 0.95
- Intensity of defect at 3.75 V = 7.90

In addition, we observed five times more defects in the deep gray state. In developing test routines, it is crucial to relate the test-system black level to the display-system black level because defects may be more or less visible, depending on the test-system voltage and the display-system voltage.

Through a Lens Darkly

It is easy to state that LCoS devices should be tested before delivery to light-engine manufacturers, but execution is more difficult. As described above, test-camera geometry, test voltage, and optical-axis control can all have a major impact on the success – or failure – of adequately identifying pixel defects without falsely identifying pixels that are not defective. Optimizing these test parameters will be critical to the adoption of LCoS technology for display-system applications. ■

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High-Efficiency AMOLEDs

Phosphorescent OLEDs are much more effective than their fluorescent predecessors. Combined with flexible substrates and advanced active-matrix arrays, they provide a compelling vision of the "display of the future."

by Mike Hack and Julie J. Brown

ORGANIC LIGHT-EMITTING DIODE (OLED) technology is making tremendous progress towards becoming the display technology of choice for a wide range of product applications. Almost 100 companies are engaged in OLED development, driven by the promise of thin, lightweight products with wide viewing angle, high brightness, low power consumption, full color, and video speed. Although initial market opportunities are for mobile products, such as games, cellular phones, and personal digital assistants (PDAs), there is considerable interest in applications for larger products, such as monitors and TVs.

DisplaySearch estimates that worldwide sales of OLED displays will grow from $1.7 billion in 2005 to $2.8 billion in 2007. These estimates do not account for new product applications based on the novel OLED features of transparency and flexibility or their possible entry into new markets in the areas of lighting and wearable electronics.

Mike Hack is Vice-President of Strategic Product Development and Julie J. Brown is Vice-President of Technology Development at Universal Display Corp., 375 Phillips Blvd., Ewing, NJ 08618; telephone 609/671-0980, fax 609/671-0995, e-mail: mikehack@universaldisplay.com. *The authors acknowledge the contributions from Professors Stephen R. Forrest and Mark E. Thompson, the UDC engineering team, and colleagues at PPG Industries. They also acknowledge DARPA for their partial support of this work.*

The first commercial product containing OLED technology was a small-molecule passive-matrix monochrome display made by Tohoku Pioneer Corporation in 1997 for automotive radio applications – a display that won the SID/*Information Display* Display of the Year Gold Award for 1998. In 1999, Kodak and Sanyo announced a full-color active-matrix OLED (AMOLED) prototype. In 2000, Sony Corp. first demonstrated a 13-in. SVGA AMOLED display, followed by Samsung SDI with a 15-in. XGA AMOLED display.

In 2001, SNMD (a joint venture between Samsung SDI and NEC Corp.) started manufacturing a full-color passive-matrix 2.2-in. OLED cellular-phone display, and SK Corp. (a joint venture between Sanyo and Kodak) announced that AMOLED displays would be available during 2002. To date, all commercial products are based on small-molecule OLED technology. In 1999, Seiko-Epson demonstrated a monochrome polymer AMOLED display, and at the 2002 SID exhibition Toshiba demonstrated a 17-in. polymer AMOLED display. Several companies have now announced the launch of monochrome polymer OLED (PLED) products for 2002. The first efficient small-molecule OLED devices were reported by Tang and his colleagues at Kodak in the 1980s, and in 1990 light emission from large-molecule PLED devices was reported.

In both of these conventional fluorescent OLEDs, light emission occurs as a result of the recombination of singlet excitons, and the internal quantum efficiency is limited to approximately 25% for small-molecule devices and reportedly up to approximately 57% for polymer devices. In 1998, researchers at Princeton University and the University of Southern California demonstrated phosphorescent OLEDs, in which light emission occurs from the radiative recombination of triplet excitons, formed as a result of inter-system crossing of singlet to triplet states through the presence of a heavy-metal atom. This results in internal quantum efficiencies approaching 100%.

Table 1: Current Status of UDC's Phosphorescent Devices

EL color	Red	Blue*	Green
Peak wavelength (nm)	620	474	515
CIE (x, y)	(0.65, 0.35)	(0.16, 0.32)	(0.30, 0.63)
Luminance efficiency @ 1 mA/cm^2 (cd/A)	10	11	24
Operational lifetime (hours)	15,000 @ 300 cd/m^2	> 200	10,000 @ 600 cd/m^2

*An aggressive development program is under way to achieve a high-efficiency, saturated, stable blue PHOLED.

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H. K. Chung, Samsung SDI

Fig. 1: This 2.2-in. QCIF AMOLED fabricated by Samsung SDI incorporates UDC's red and green phosphorescent-materials system.

Based on these inventions, Universal Display Corp. (UDC) is developing a new generation of high-efficiency phosphorescent OLED materials and devices. The high efficiency of phosphorescent OLEDs provides significant performance advantages for both full-color passive-matrix OLED (PMOLED) and AMOLED displays, and may even allow OLEDs to be used someday for general lighting purposes.

Moving to Active Matrix

Early OLED displays were passive matrix, consisting of a series of patterned orthogonal row and column lines, with the organic devices placed at pixels defined by the intersection of these lines. While this simple architecture avoids the use of an electronic backplane, it is inefficient because the OLEDs must be pulsed with very high drive currents over a short duty cycle. This results in lower OLED efficiencies, significant I^2R power losses in the row lines, and the need for relatively expensive current-sourced drive electronics.

By employing an active-matrix backplane, the OLEDs can be driven with drive electronics similar to those used in AMLCDs up to a 100% duty cycle, enabling displays with much lower power consumption. In fact, it is likely that AMOLED cellular-phone modules will be cost-competitive with their PMOLED counterparts because the lower driver-chip costs for an AMOLED will offset the higher display cost of incorporating a thin-film-transistor (TFT) backplane. Power analysis shows that PMOLEDs will not be practical at sizes greater than 2–3 in. or at row-line counts greater than 100.

High-Performance AMOLED-Display Requirements

The fabrication of a high-performance AMOLED display requires the integration of OLED technology on a TFT backplane. The OLED requirements include chromaticity and lifetime specifications, high efficiency (low power consumption), ease of manufacture, and low cost. From a backplane perspective, the TFTs need adequate mobility, low leakage, low threshold voltage, and good uniformity and stability – again with ease of manufacture and low cost. In the future, we believe that displays will no longer be based on glass substrates, but instead will use thin, lightweight, flexible materials providing new functionality and compatibility with low-cost roll-to-roll manufacturing techniques.

There have been tremendous advances in the overall performance of both small-molecule and polymer OLED devices over the last few years, but the challenge of developing low-power-consumption products still remains. UDC's proprietary small-molecule phosphorescent OLED (PHOLED™) technology has the highest efficiency of any OLED technology developed to date, and has a comparable lifetime (Table 1). While there is considerable interest in obtaining phosphorescent emission from polymer OLEDs, the reported efficiencies are still lower than those achieved in small-molecule systems.

From a manufacturing perspective, as of June 2002, Philips has announced shipments of monochrome polymer-based displays and full-color displays are now commercially available (from SNMD). Samsung SDI has demonstrated a 2.2-in. AMOLED that incorporates a poly-Si backplane and UDC's red and green phosphorescent-materials system (Fig. 1).

Comparing the luminous efficiency of PHOLED™ technology with both conventional fluorescent small-molecule and polymer OLEDs shows that phosphorescent emission can achieve significant improvements in luminescent efficiencies (Table 2). In a full-color AMOLED, the red pixels consume more power than either the green or blue pixels, so an efficient red is critical to achieving low power consumption. UDC's newly announced phosphorescent red devices with CIE coordinates of (0.65, 0.35) has three to four times the efficiency of the best red fluorescent OLED.

Simulating the power consumption of a 2.2-in. QCIF full-color OLED display by using three different OLED technologies – PHOLED devices, conventional small-molecule fluorescent devices, and polymer OLEDs – and comparing them with the power consumed by an AMLCD backlight (Fig. 2)

Table 2: Comparison of Luminance Efficiencies of Phosphorescent OLEDs (PHOLEDs™), Fluorescent OLEDs [OLED (F)], and Polymer OLEDs (PLEDs)

Comparison (cd/A)	Green	Red	Blue
PHOLED™	(20 – 27) **23**	(6 – 25) **11**	(6 – 11) **6**
OLED (F)	(7 – 15) **15**	(2 – 4) **3**	(3 – 10) **5**
PLED	**13**	(1 – 2) **2**	**3**

Note. Numbers shown in bold are used in the power calculations of Fig. 2.

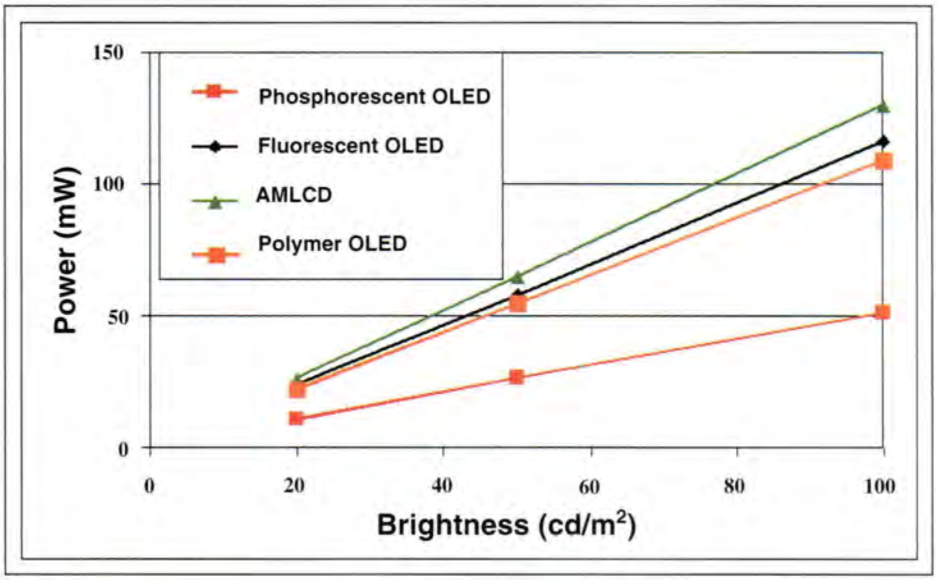


Fig. 2: Shown are simulations of the display power consumption of three OLED technologies compared with that of an AMLCD backlight.

indicates that PHOLED technology leads to a 100-cd/m^2 display that consumes only 50 mW (assuming a 50% polarizer efficiency and full illumination of 30% of the pixels) compared with 110–130 mW for the other OLED technologies and the AMLCD backlight. These simulations take into account that the polymer OLED devices have approximately half the drive voltage of small-molecule devices.

Backplane Technologies for AMOLEDs

Unlike an AMLCD pixel, which contains a single TFT acting as a pass transistor to charge the capacitive liquid-crystal cell, an efficient OLED pixel requires a minimum of two TFTs. OLEDs are current-driven devices whose brightness is proportional to current flow, so gray scale is usually enabled by placing a driver TFT in series with the OLED to control the drive current. Gray-scale information is multiplexed to the driver-TFT gate from the data drivers through a second TFT whose gate electrode is connected to one of the scan lines.

The performance requirements of TFTs for OLED displays are therefore more stringent than those required to drive an AMLCD. The pixel luminance in an AMOLED is strongly dependent on the TFT threshold voltage (V_{th}), which is not the case in an AMLCD, so display image uniformity requires good V_{th} uniformity and good stability to bias stressing across the array.

The key TFT performance requirements for OLEDs are

- ***Mobility***: Sufficient to provide the necessary OLED current at less than 10-V gate-to-source voltage.
- ***Leakage***: Ability to hold charge on driver-TFT gate for one frame time (< 1 pA).
- ***Threshold Voltage***: Low to minimize TFT power losses (|1 V| to |3 V| NMOS/PMOS).
- ***Stability and Uniformity***: Sufficient to ensure pixel uniformity across an array over the lifetime of the product.

Calculations of the minimum driver-TFT mobility required to drive an AMOLED pixel for a range of display sizes and resolutions, assuming phosphorescent OLED devices and a 300-cd/m^2 display brightness, are shown in Table 3. The analysis is based on calculating the current for the red pixel, assuming that this requires the most current. If fluorescent OLEDs were used, the calculated mobility would need to be three to four times higher – or a larger TFT or higher gate voltage would have to be employed. These simulations indicate that PHOLEDs open up the possibility of using amorphous-silicon (a-Si) TFTs, or possibly even organic TFTs, in AMOLED pixels.

With appropriate threshold voltages, and leakage currents less than 1 pA, the next criteria for assessing the viability of a TFT technology to drive AMOLEDs are uniformity and stability. At the relatively low gate-to-source voltages used for the driver TFT, the drive current is strongly dependent on the device threshold voltage. In low-temperature polysilicon (LTPS) TFTs, device stability is good, but the laser-crystallization processing often produces threshold-voltage non-uniformities across an array, leading to brightness non-uniformities.

For a-Si TFTs, threshold-voltage uniformity across an array is good, but the TFTs undergo threshold-voltage shifts after bias stressing, which leads to variations in image uniformity. For a 10% non-uniformity in pixel brightness, we estimate that for a poly-Si TFT AMOLED pixel, the uniformity of V_{th} across an array must be better than 100 mV; and for an a-Si TFT, the V_{th} shift after stressing should be less than 500 mV. Table 4 shows a comparison of the key performance metrics for a range of TFT technologies for driving OLED pixels.

Poly-Si technology allows for the integration of CMOS drive circuitry on the TFT plate, which could be advantageous for small-sized displays. Amorphous-silicon TFTs, if

Table 3: Maximum Pixel Currents and Minimum Driver-TFT Mobilities for a Range of AMOLED Displays, Assuming a 300-cd/m^2 Luminance

Display size (in.)	Resolution	Max pixel current (μA) for red PHOLED (11 cd/A)	Minimum driver-TFT mobility (cm^2/V-sec) for W/L=16 and V_{gs}-V_{th}=5 V
2	160 × 120 × 3	0.53	0.37
5	320 × 240 × 3	0.82	0.57
10	800 × 600 × 3	0.53	0.37
20	1024 × 768 × 3	1.29	0.89

Universal Display Corp.

***Fig. 3:** A flexible AMOLED could enable a multipurpose communications device, such as this "pen communicator" concept from UDC.*

shown to be sufficiently stable, offer the benefit of lower production costs than their poly-Si counterparts. Organic TFTs are still in the research phase, but are beginning to show promise, while renewed R&D on stable CdSe TFTs suggests that they may also become a viable backplane technology.

The Future Is Flexible

Although most of the current flat-panel-display industry is based on glass substrates, there is considerable interest in using flexible substrates. This design will offer the user a display that is significantly lighter, thinner, less susceptible to breakage, and more rugged – all important features for mobile applications.

One flexible substrate system we are pursuing at UDC is plastics. OLEDs are an ideal display medium for use on plastic substrates because of the OLED's very low deposition temperature (<100°C) and extremely thin form factor. Plastic-based OLED displays offer the additional features of being conformable and even flexible.

We believe that flexible display technology will enable advanced communications devices, such as our extendable universal communications device concept (Fig. 3). Such a product could offer a full range of communications features and benefit from a low power consumption, high brightness, roll-up capability, and full communications and GPS capabilities, all in a "pen-like" package that houses all the components.

We believe that this product concept is a compelling vision on which to base our aggressive efforts in developing the technology components necessary to make it a reality. ■

Table 4: Applicability of Different TFT Technologies to AMOLED Displays

	Poly-Si	a-Si	Organic TFT	CdSe
Type	PMOS/NMOS	NMOS	PMOS	NMOS
Performance				
Mobility	Very good	OK for PHOLEDs	OK	Very good
Leakage	OK	Very good	OK	OK
Stability	Good	Issue	Issue	TBD
Uniformity	Issue	OK	Issue	TBD
Manufacturability	Maturing	Excellent	N/A	TBD
Cost	> Medium	Medium	Low ??	Potentially low
Plastic compatibility	Under development	Good	Excellent	Good

Marching to a Different Drum

A transmissive rotating drum provides a more efficient and more easily realized LCoS projection engine than other color-sequential approaches.

by Matthew S. Brennesholtz

MICRODISPLAYS have revolutionized the projection industry, making it possible to create brighter and lighter projectors than ever before. Unfortunately, designers must choose among a bewildering array of single- and three-panel optical architectures, each with its own cost/efficiency/image-quality trade-off.

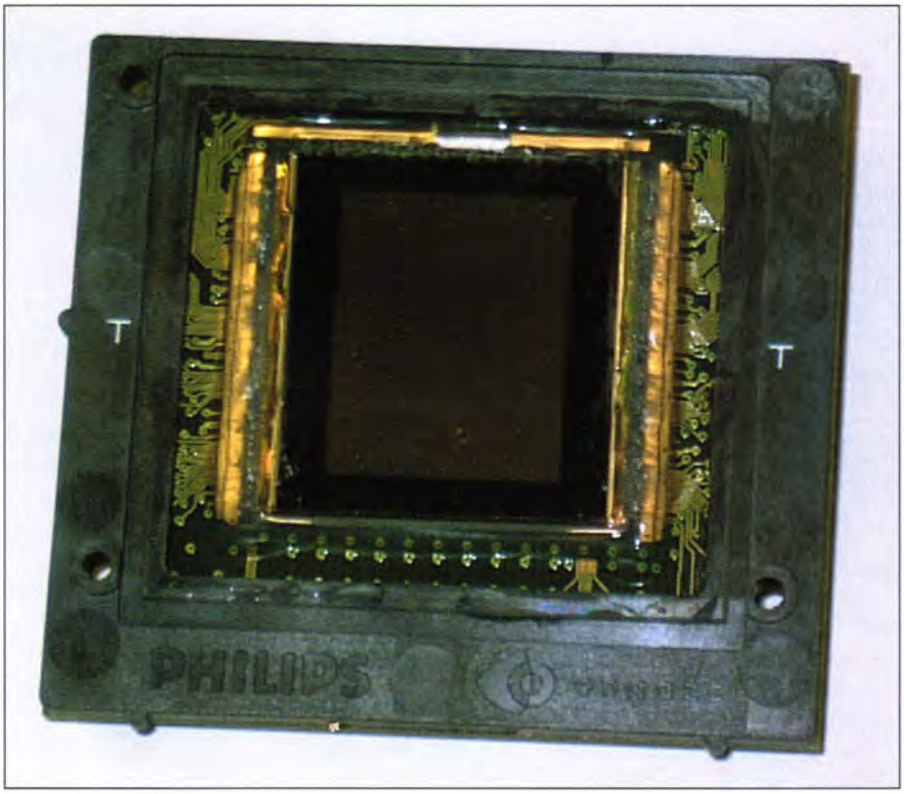
A new approach using a rotating drum offers some significant improvements over these previous approaches. It is simple to design, build, and operate, and makes efficient use of the panel and the available light.

LCoS Makes It Possible

The images produced by liquid-crystal–on–silicon (LCoS) microdisplays (Fig. 1) with analog gray scale can be updated quickly enough to support color-sequential operation. Philips has designed and demonstrated a projection engine that uses three rotating prisms to illuminate a single microdisplay with scrolling bands of colored light. The optical system includes a color-splitting section to separate red, green, and blue; three rotating prisms to scan these colors; and a color-combining system to illuminate the single LCoS panel. The result is that all the light is delivered to the panel all the time, which increases efficiency, but the optical system is somewhat complex. As a result, we at Philips conducted experiments to find a simpler way to achieve similar ends.

The Color-Drum Concept

A generic liquid-crystal (LC) display is addressed with image data row by row, starting at the top. Each row overwrites the data from the previous field (Fig. 2). As soon as one field is loaded on the panel, the next field starts again at the top row. Therefore, image data from both the current and the previous fields appear on the LCD simultaneously.



Philips Components

Fig. 1: LCoS microdisplays can be the foundation of small, bright, and efficient projection engines.

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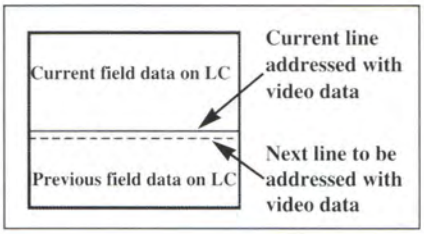

Fig. 2: *LCoS panels are addressed row by row.*

In a three-panel system, the previous and current fields represent the same color, so the panel can be under constant illumination. In a color-sequential projector, the color must change with each new field, so the two portions of the panel must be illuminated with two different colors of light at the same time. The division between the two colors must be straight and horizontal, and must move down the panel in sync with the image data.

The entire panel is illuminated with a single color at any given time when using a typical color-wheel design. The color of the light then changes rapidly to the next color over the entire panel simultaneously. In order to use a color wheel in an LCoS projection system, the lamp must be turned off while the LCoS display is addressed with the next field. After all the rows are addressed, then the lamp can be turned on to illuminate the LCD with the appropriate color of light. With a high row count – such as the 720 rows minimum needed for HDTV – and a high frame rate to minimize color-sequential artifacts, addressing the LCD requires most of the available time, leaving little time to illuminate the LCD.

Spiral color wheels are a better match for LCoS devices, but the division between colors is neither straight nor horizontal, making it difficult to coordinate the changing colors with the changing video data.

In contrast to these approaches, a rotating drum can produce a straight and horizontal

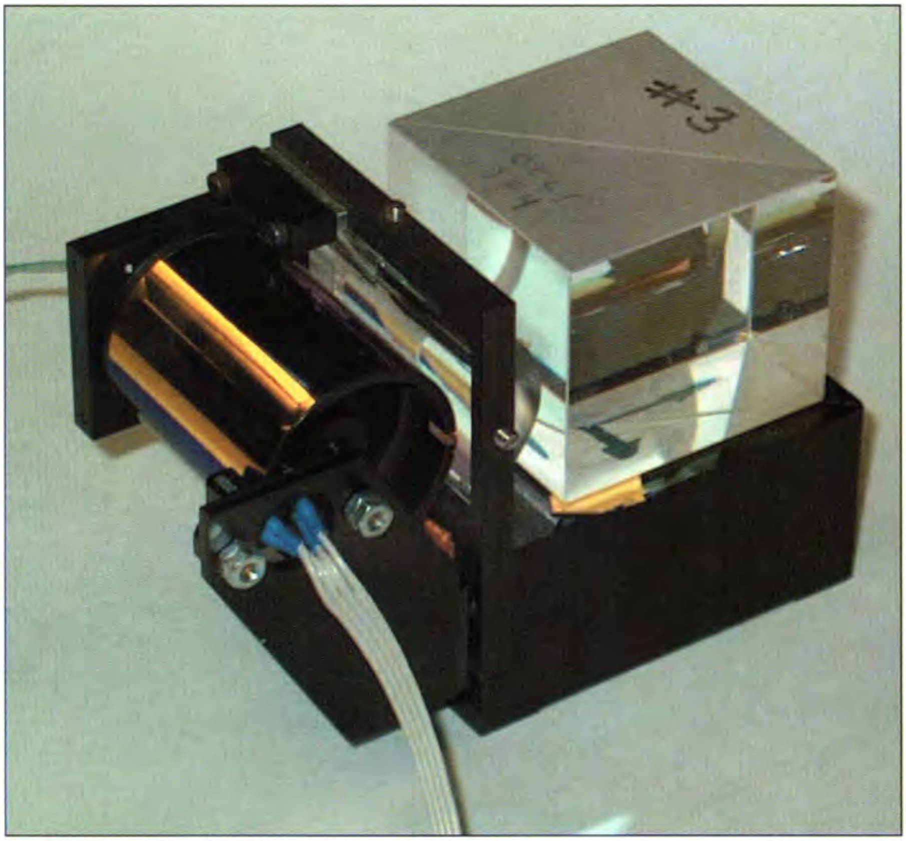

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Fig. 3: *This reflective-color-drum assembly has two segments each of red, green, and blue dichroic material.*

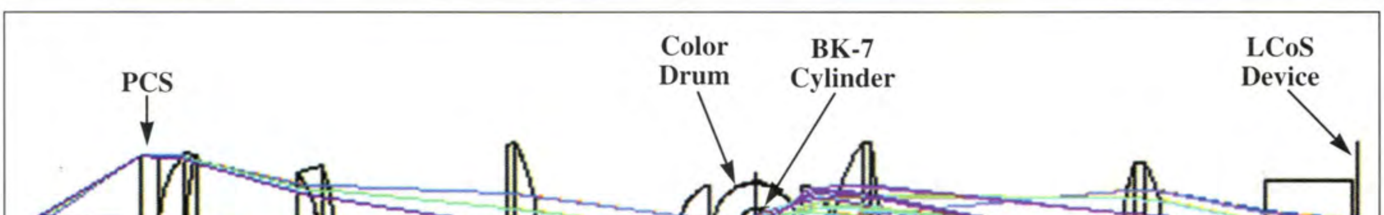

Fig. 4: *This ray-trace diagram shows the optical design of the prototype transmissive-color-drum projector.*

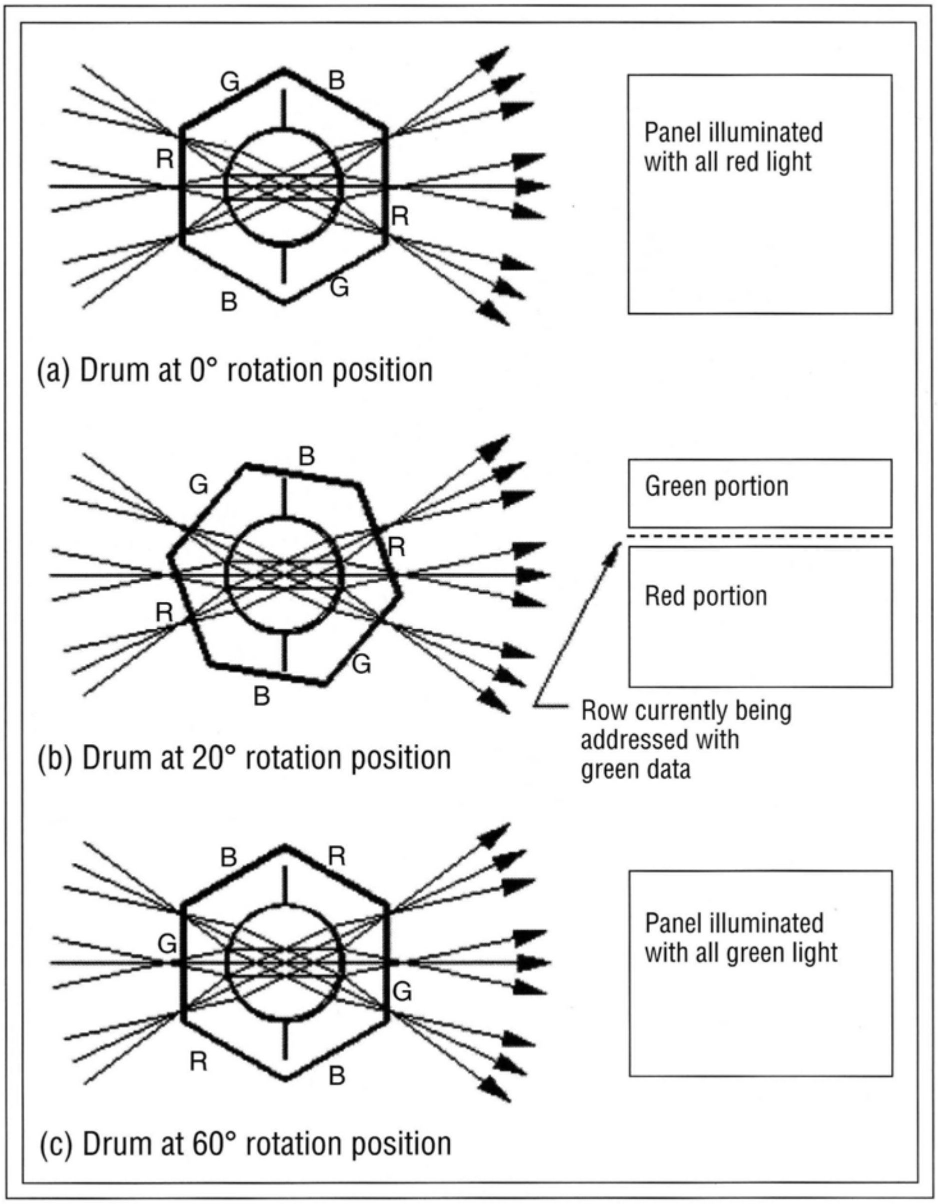

Fig. 5: *This diagram of the operation of the transmissive color drum shows how the positions of red, green, and blue dichroic filters direct colored light to the LCoS panel as the rows are addressed.*

line separating two colors. But previous drum designs were too bulky for production projectors.

A Reflective-Color-Drum Projector

To explore ways to improve drum designs, we built and tested a projector based on a reflective color drum, using an LCoS microdisplay with a 1-in. diagonal and 4:3 aspect ratio. The 30-mm-diameter drum has six segments: two each of red, green, and blue reflective dichroic material (Fig. 3). The incident white light and the reflected red/green/blue light are separated by a quarter-wave plate and a polarizing beam splitter (PBS). When tested, this system suffered from several problems:

1. Additional cost due to the presence of an extra PBS.
2. Manufacturing difficulties in depositing dichroic filters onto a curved surface.
3. Poor light efficiency.
4. Poor colorimetry due to the nature of reflective dichroic filters.

Still, this system did produce an image of sufficient quality to encourage further investigation of rotating drum systems.

A Transmissive-Color-Drum Projector

In an attempt to resolve the problems of the reflective color drum, we designed and tested a transmissive-color-drum projector. The hexagonal transmissive drum is also 30 mm in diameter. A series of axially symmetrical and cylindrical lenses guide the light along the illumination path (Fig. 4). Lenses L1 through L4A map the light body from the integrator to the front surface of the drum. On the axis of the drum is a cylinder of glass that maps the light body on the front surface of the drum to a second light body on the rear surface of the drum. Lenses L4B through L6 map the light body on the second surface of the drum to the LCoS device. In this design, lenses L4A and L4B are identical cylindrical lenses with plano-surfaces on one side, the cylinder on the axis of the drum has a circular cross section, and the rest of the lenses are rotationally symmetrical about the optical axis.

A transmissive color drum with six flat dichroic segments can illuminate a single LCoS-display panel with different colors as the panel's rows are addressed with new field data (Fig. 5). When the drum is at the nominal 0° position, light coming from the left forms a light body on the front side of the drum [Fig. 5(a)]. Here, all light encounters a red dichroic filter. The front surface is re-imaged on the rear surface of the drum. Since the imaging is done with a cylindrical lens, a point on the front surface is re-imaged to a line parallel to the line between the dichroic segments on the rear surface. At the second drum surface, all the light encounters a second red dichroic filter and forms a second light body. This light body is re-imaged onto the LCoS device and eventually onto the projection screen. At this instant of time, all the video data on the LCoS device is red data.

As the drum rotates, the division between the red and green dichroic filter comes into the light body [Fig. 5(b)]. When the drum is at a 20° rotation angle, a portion of the light passes through the green dichroic filter – first on the front surface, then the rear surface – and is finally imaged onto the top portion of the panel. The remainder of the panel is illu-

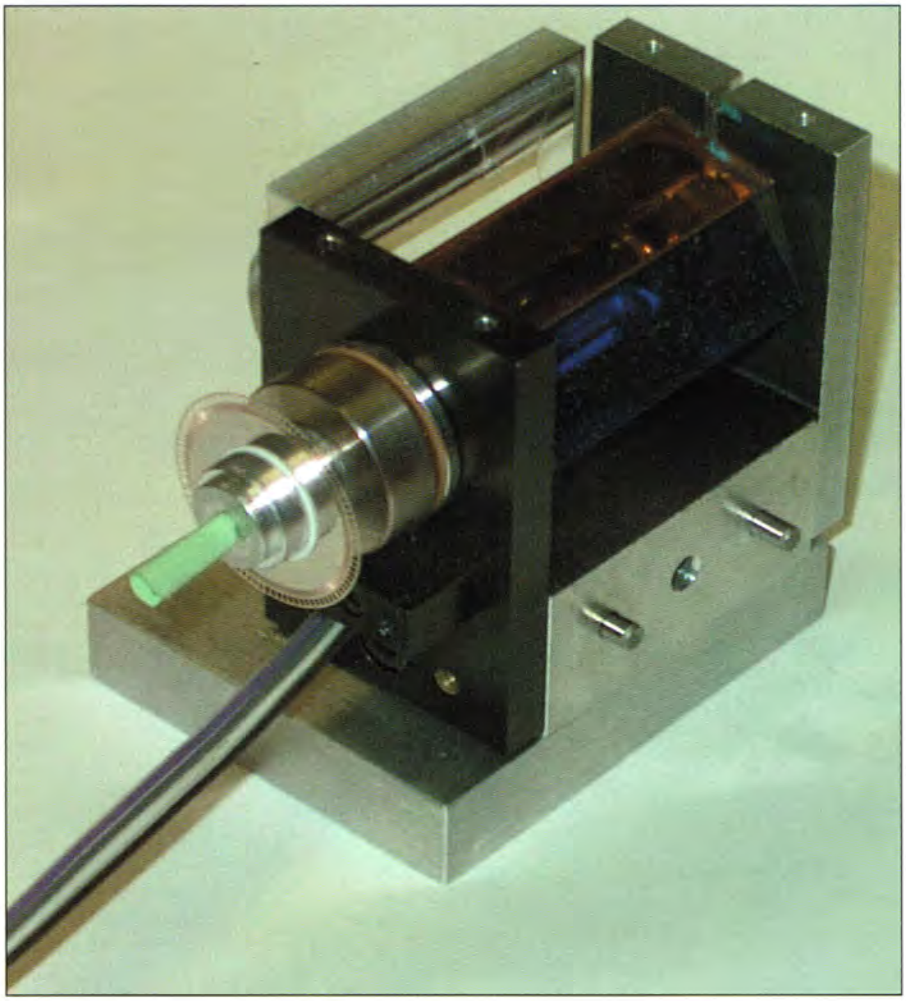

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Fig. 6: *This six-segmented transmissive-color-drum assembly, including cylindrical lenses, motor, and encoder, was one of the designs tested.*

minated with red light as before. The electronics load green video data into the row at the division between the red and green light. After the drum has rotated a full 60°, the entire panel is illuminated with green light and the entire LCoS device contains green video data [Fig. 5(c)].

The focal length of the cylinder on the axis of the drum is chosen so that the corners of the hexagonal drum image on each other. This produces a sharp line of demarcation between two colors at the device. In the flat areas between dichroic boundaries, imaging from the front to rear of the drum is not perfect because the dichroics are not at the correct distance from each other. This does not affect the color on the screen, however, since all light still hits the appropriate dichroic filter.

One of the prototype drums has six dichroic segments (Fig. 6). Other drums, with three and 18 segments, were also built and tested. A three-sided drum is also hexagonal, but with only one filter of each color. The second filter of each color is omitted for increased light efficiency. The 18-segment drum produces a pattern of three color bars on the screen that duplicates the pattern produced by the Philips three-prism scrolling-color architecture.

The drums all have non-rotating baffles inside them that are attached to the glass cylinder. These baffles prevent stray light from reaching the LCoS device and the projection screen.

For a given frame rate, the transmissive-color-drum projector requires the same line-address frequency and LC response speed as the Philips three-prism scrolling-color system. The prototype transmissive drum projector used the same T3 LCoS device developed for scrolling-color projectors.

The Efficiency of LCoS Systems

A comparison of relative efficiency as a function of panel diagonal for the single-panel transmissive-color-drum shows that it exceeds the performance of the single-panel scrolling-color design for smaller panel sizes, although a three-panel projector is more efficient than either (Fig. 7). The lumens per square inch of silicon area for the three designs were compared for a 1.18-in.-diagonal panel (Table 1). These results were generated using lumen *versus* étendue techniques and measured component-efficiency data using a UHP 120-W 1.3-mm-arc-length lamp and a 16:9 1280 × 720 LCoS panel.

While the total lumen output of a three-panel projector is significantly higher than the output of a drum or scrolling-color projector with panels of the same size, the three-panel projector has three times the amount of silicon and is less efficient in terms of lumens per square inch of silicon area. Therefore, if a projector manufacturer had a certain specification for lumen output, a single larger panel would be more cost-effective than three smaller panels because the one larger panel would have less silicon than the total of the three smaller panels.

We believe that the 420 lm produced by the transmissive-color-drum projector with a 1.18-in. panel would be sufficient for an HDTV rear-projection system up to about 40 in. For larger screen sizes, the projector manufacturer would have the option of going to a higher-power lamp with the drum or continuing to use the long-lived 120-W lamp and

Table 1: Projector Throughput with a 1.18-in.-Diagonal 16:9 Panel

Architecture	Lumens (lm)	Lumens/ square inch (lm/sq. in.)
Transmissive drum	420	706
Scrolling color	564	948
Three panel	926	519

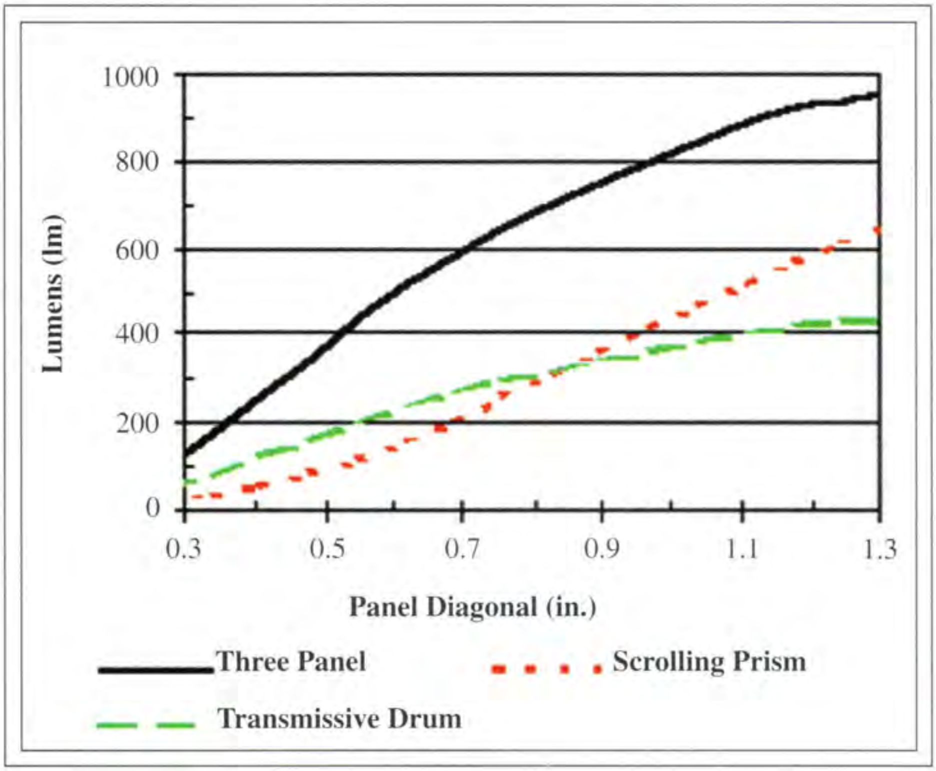


Fig. 7: *Lumens* versus *panel diagonal for LCoS systems with three different optical architectures.*

going to the more complex, but more efficient, three-prism scrolling-color architecture.

For small panels, the drum architecture is actually more efficient than the three-prism architecture. The crossover point occurs at a panel diagonal of about 0.85 in. for a 1.3-mm-arc-length lamp, and the other assumptions described above apply. In a different simulation, using a 1.0-mm arc length and slightly different assumptions, the crossover point where a color drum becomes more efficient than a three-prism projector was at about a 0.55-in. panel diagonal. With this lamp and panel diagonal, both the color drum and three-prism scanner would produce about 190 lm.

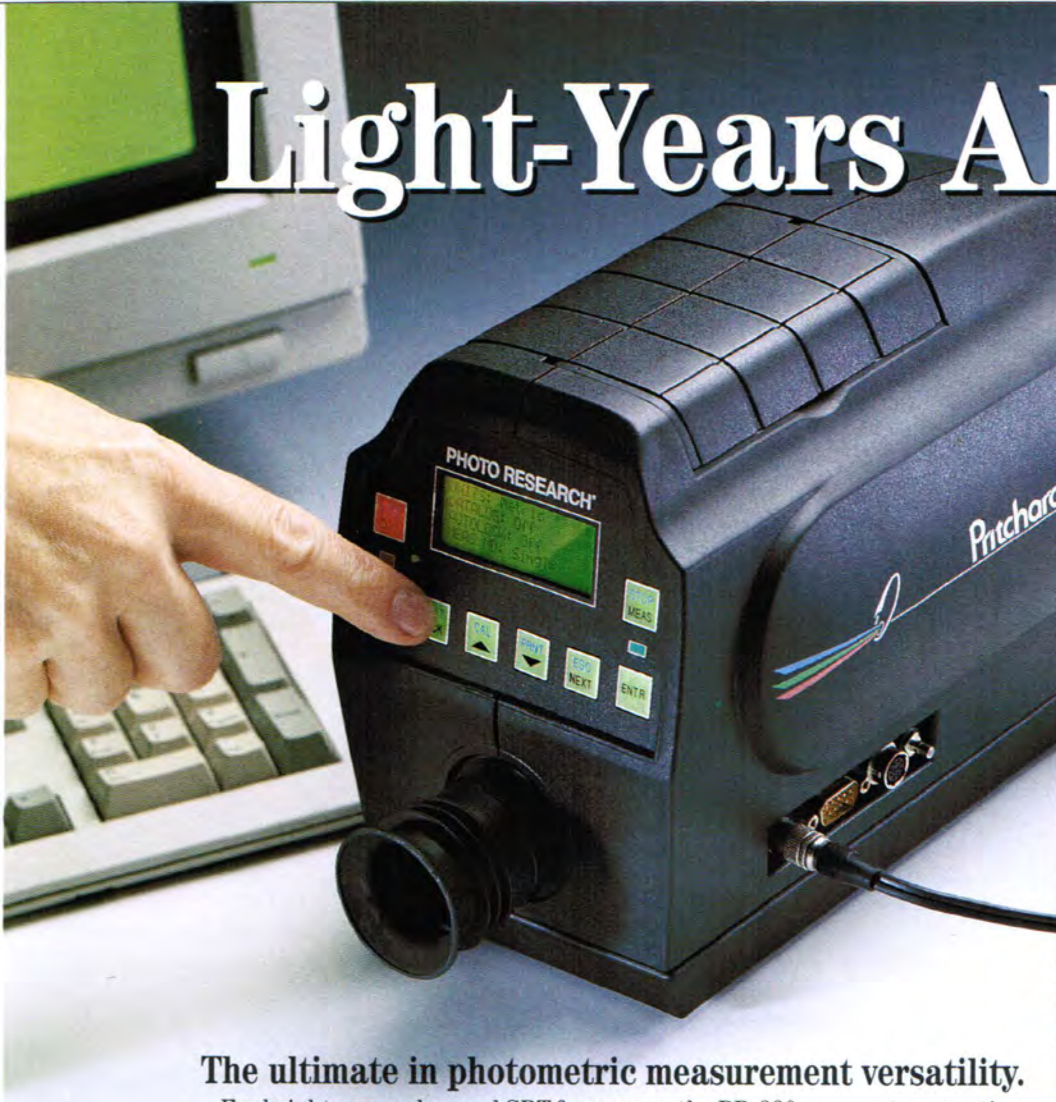
Colorimetry

We measured the primary colors and the white point of both the reflective- and transmissive-color-drum systems. The reflective-drum color primaries are quite far from the recommended European Broadcasting Union (EBU) primaries, but the primary colors of the transmissive drum are close to the target primaries, even though stock dichroic filters were used. The white point achieved by each projector is "greenish" compared to the target white point (D65) for video. This must be corrected to a point on or near the blackbody line before the projector is acceptable for video applications.

When the transmissive-color-drum design is used, there is an instant when the LCoS device contains video data for only a single color and is illuminated by only a single color of light [Figs. 4(a) and 4(c)]. This vertical blanking time depends on the details of the optical design and represents about 0.7 msec in the reflective-color-drum projector when running at a 60-Hz frame rate. During this brief period of time, the power of the UHP lamp can be increased or decreased to increase or decrease the intensity of one color. At intermediate angles [Fig. 4(b)], the lamp must be run at the nominal power because two colors are present. Roughly speaking, during the 0.7 msec when the full frame was illuminated with a single color of red, green, and blue light, the 100-W UHP lamp used in this prototype projector was driven at 300, 10, and 200 W, respectively, in the prototype reflective-color-drum projector. Lamp power over the frame time – 16.7 msec in this case – must average to the nominal lamp power of 100 W for correct lamp operation. A three-position switch was used to switch between 5400K, D65, and D85 white points.

The transmissive rotating drum holds great promise for projection engines for smaller displays up to about 40 in. on the diagonal. It is a relatively simple, efficient, and cost-effective solution for field-sequential illumination of single-panel projectors. ■

Light-Years Ahead.



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Circle no. 11

OLED Encapsulation

Protecting active OLED layers from a hostile world is critical for display lifetime; achieving it in a slim, reliable package is crucial for maximizing some of OLED's inherent advantages.

by Kimberly Allen

ORGANIC LIGHT-EMITTING DIODE (OLED) displays are now familiar in display circles as visually attractive flat panels that overcome key liquid-crystal-display (LCD) disadvantages such as poor viewing angle and insufficient brightness. But during every second of an OLED's lifetime, that attractiveness is threatened by the water and oxygen in the air.

One of the most troublesome steps in OLED manufacturing is proper encapsulation of the device to prevent damage from moisture and oxygen. Too much exposure to moisture and oxygen results in a display with noticeable dark spots. The organic materials and the cathode, which is often made of a reactive metal, are fatally susceptible to air damage. It is generally agreed that the sealed OLED device should allow no more than 10^{-5}- or 10^{-6}-g/m^2-day water penetration and 10^{-3}-cc/m^2-day oxygen penetration.

Lifetime issues are a key limitation in OLED market development. End-product manufacturers follow the standard set by the LCD: unblemished performance over the lifetime of the product. In many cases, this means about 10,000 hours, but sometimes even longer lifetimes are necessary.

OLED lifetime can be improved in several ways, including materials development and modification of the device structure. But encapsulation remains the most direct means of protection. So, solving the encapsulation problems of OLED displays is of primary importance for closing sales of these panels to OEMs and other buyers.

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The Submarine Solution

One approach to encapsulation is to treat the OLED as a voyager in a poisonous atmosphere. The delicate device is sealed in a metal can that acts as a submarine or spaceship. A getter material provides an extra precaution against the corrosive agents that leak into the cell. The epoxy that bonds the OLED's glass substrate to the metal can allows for some penetration, and it also gives up some water vapor itself.

Pioneer, the first commercial producer of OLEDs, used this technique successfully. Subsequent OLED makers adopted it also (Fig. 1), and it is currently the most common method in production. In such displays, the flat metal can forms the back side of the display; the raised area in the middle houses the getter material. Samsung-NEC Mobile Display (SNMD), TDK, RiTdisplay, and Philips all employ this technique.

The metal can has the advantage of successfully protecting the device, a big plus in an infant manufacturing industry in which process steps are still far from being optimized, but the disadvantage is that it is quite large. If an optimum encapsulation solution could be found, OLEDs would have a slimmer profile than LCDs with an attached backlight, but because of the metal can the depth of the two devices is currently approximately the same. As a consequence, many companies are pursuing alternative encapsulation techniques. The two most popular are a glass-to-glass seal and a true thin-film layer such as the Barix™ layer made by Vitex Systems.

Portelligent

Fig. 1: *This display module for an NEC cellular phone incorporates an OLED panel made by Samsung-NEC Mobile Display (SNMD). The display's glass substrate is epoxy-bonded to a flat metal can, which forms the back side of the display; the raised area in the middle houses the getter material.*

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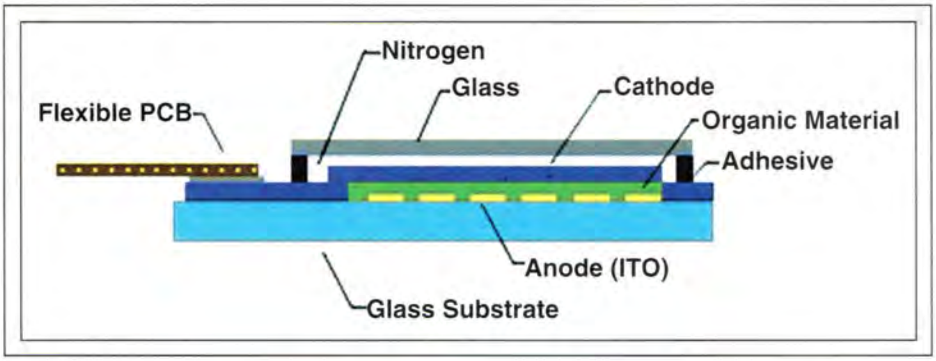


Fig. 2: Elimination of the metal can and getter in favor of a glass-to-glass seal results in a slimmer OLED device.

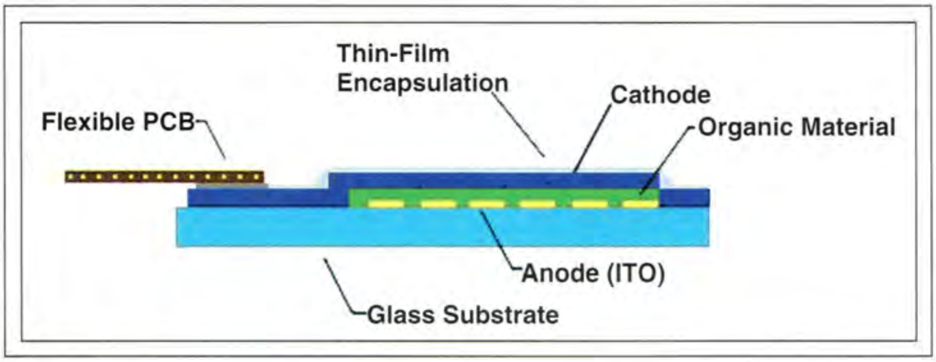


Fig. 3: The ultimate goal for OLED device packaging is to use thin-film encapsulation.

Glass to Glass: A Slimmer Solution

The next step in encapsulation is elimination of the metal can and getter in favor of a glass plate so that the device resembles a sandwich, like an LCD. This is a much slimmer solution (Fig. 2). The challenge is to create a glass-to-glass sealing material sufficiently impermeable to air that the OLED can be protected without any desiccant.

But sealing glass to glass is not a simple matter. A limited number of materials bond well to the glass surface and are simultaneously compatible with other aspects of OLED manufacturing. The material would most likely be a UV-curable epoxy. Development work so far suggests that the same classes of materials used in LCD sealing, such as various silanes, should also work for OLEDs. Finding an adequately impermeable material that is also common enough to be inexpensive is an important development goal.

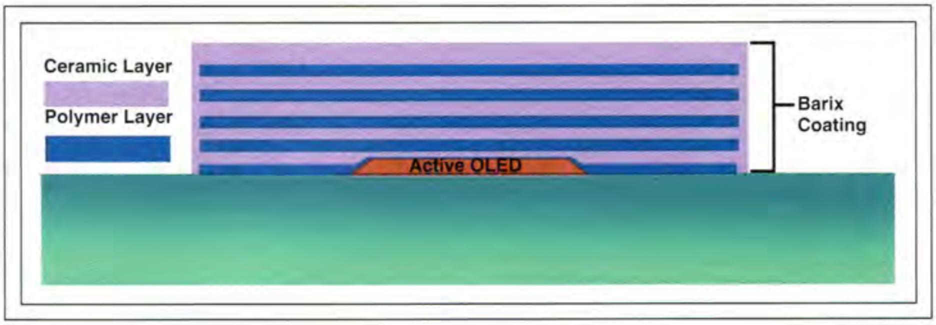
Glass-to-glass sealing techniques are being developed by several companies, including Delta Optoelectronics, Opsys, and Philips Mobile Display Systems. Dow Chemical has also done work in this area for other applications. The first commercial OLED product using a glass-to-glass seal is a portable MP3 player from GoDot, which uses a polymer panel from Delta Optoelectronics. It reached the market in June.

Just a Wetsuit

Rather than sealing the OLED into a separate structure, the ultimate goal is to create an encapsulating layer that can be applied as a final step in the thin-film process of making the OLED device, be it either the small-molecule or polymer type (Fig. 3). Many companies have their eyes on this prize, but so far only one has offered a satisfactory solution to the OLED industry. Vitex Systems' Barix™ encapsulation layer is being tested and refined through evaluation by industry players. Fresh competition is arising from Symmorphix and some materials players, but Vitex Systems' development is the farthest along.

A typical Barix layer is a series of dyads consisting of a polymer and an oxide (Fig. 4). About five dyads successfully protect a Ca cathode from degradation. The polymer is applied by a technique called vapor polymer deposition (VPD), in which the monomer adheres to the surface as a liquid, which is then polymerized by UV light. VPD is essentially a form of physical vapor deposition (PVD), and the fact that the material is applied as a liquid means that it can flow all over the device surface to coat every crevice, such as those under the pillars that define the pixels. The oxide is then deposited by straightforward evaporation to complete one dyad. Currently, the system is set up as an in-line process, but it could be tuned to work in a cluster environment.

Vitex Systems has equipment to perform a number of tests on its layers in house. These



Vitex Systems

Fig. 4: The Barix™ product from Vitex Systems is a multilayered thin-film protection scheme with alternating insulator (polymer) and oxide (ceramic) layers. At their current level of development, five of these dyad layers provide almost enough protection from moisture and oxygen to be considered for commercial devices.

include optical measurements of the index of refraction and dielectric constant, thermal shock, and various environmental tests. It is worth noting that Barix is relatively transparent in the visible spectrum – a transparency greater than 85% – meaning that it could serve as a protective layer in up-emitting OLED displays. The effectiveness of Barix is usually checked with a pure Ca layer, which can be deposited in the same chamber as the polymer and oxide (Ca becomes transparent when it reacts to form calcium oxide or calcium hydroxide).

Tests on cathode materials are good indications of Barix's effectiveness, but the best tests come from applying it to actual OLED devices. Vitex Systems has worked with many companies to try Barix in their prototypes. Philips has made devices on a Vitex Systems substrate called Flexible Glass™, which is a plastic substrate coated with Barix (and any other layers the customer desires – it is a custom product). Philips reported at the October 2001 Asia Display/IDW Conference in Nagoya, Japan, that over a period of 14 days the Flexible Glass performed nearly as well as glass, allowing water vapor to penetrate at a rate of about 8×10^{-5} g/m^2-day. Compared to the requirement of 10^{-5} or 10^{-6} g/m^2-day, this is still not quite adequate, but further refinements are expected.

Vitex Systems has an agreement with equipment maker Tokki to sell the Barix capability along with Tokki's OLED equipment systems. Customers get the necessary machinery for depositing the polymer and oxide dyads as the final step in the manufacturing process. Barix can work with both small-molecule and polymer OLEDs.

The Future Is Sealed

With so much effort going toward the development of a thin-film encapsulation layer for OLED devices, significant progress is expected in 2002. Whether Barix or some other single solution comes to dominate the industry, or whether many options are adopted, it is likely that OLED devices will see improved lifetimes and thinner packages in the near future.

iSuppli/Stanford Resources forecasts that the OLED market will reach $112 million in 2002 (*Organic Light Emitting Diode Displays, 2002*, iSuppli/Stanford Resources, March 2002, http://www.stanfordresources.com), fueled by increasingly reliable manufacturing on the supply side and increased customer confidence on the demand side. Improved encapsulation helps both. Stanford Resources expects the OLED market value to rise to $2.3 billion in 2008, for a compound annual growth rate of 65%. Such rapid growth will be possible in part due to continous manufacturing improvements. OLED's early track record in encapsulation will pave the way. ■

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Circle no. 13

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Looking Beyond the Dashboard

As "telematics" finally moves to the center of the automotive-technology stage, a review of the specifications, developments, and measurement issues of vehicular displays will describe how and why it got there.

by Robert L. Donofrio

WHEN WE TALK ABOUT an "information display," most people think about computer screens or televisions. Yet we rely even more on displayed information when we get behind the wheel of an automobile. As the Digital Age progresses, we have begun to move beyond the traditional "steam gauge" analog dials and on to displays that are, in varying degrees, digital and are capable of conveying more than just numeric information.

Automotive technology in the past – and in the near future – falls into three categories. From 1949 to the 1970s, technology development was focused on high-compression engines. From about 1975 to 1995, microprocessor control took the spotlight. From 1995 to 2015, the important automotive technology is and will be "telematics," which is the combination of computers and communications. In automotive applications, this encompasses functions such as navigation, intelligent transportation systems (ITS), and Internet access, as well as future types of connectivity.

Still, the fundamental concept of driving remains "eyes on the road and hands on the wheel," which determines the types of technologies that are best suited for displays in automobiles. We are already seeing center-console liquid-crystal-display (LCD) panels and audible prompt systems used in navigation applications.

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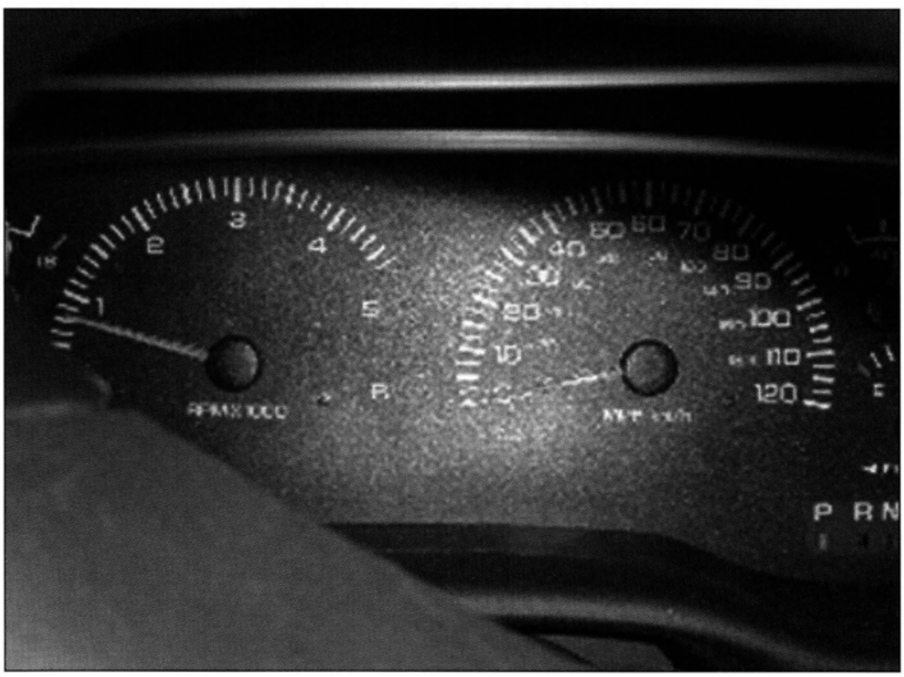
As this evolution of automotive-instrumentation proceeds, many factors must be considered. What specifications for displays should be required, and how can we best measure performance? There are many developing technologies; how do we best evaluate them for automotive-instrumentation applications?

Over the past 5 years, automobile-industry enthusiasm for the different display technologies has waxed and waned. The enthusiasm seen in 1996 for field-emission displays (FEDs) has cooled. Now we see the rise of organic light-emitting diodes (OLEDs) as a serious contender for automotive displays, although, at present, it is still an add-on and not original equipment in production automobiles. A range of other display technologies – STN-LCD, bistable LCD, AMLCD, EL,



R. L. Donofrio

***Fig. 1:** The instrument cluster in the author's 1999 Dodge Dakota truck is relatively basic, with electro-mechanical gauges and a VFD odometer (not visible in photo).*

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Fig. 2: *The 2002 Mercedes 320 CS has mechanical analog gauges and a digital display which is a backlighted LCD.*

TFEL, VFD, and projection – are still areas of interest for automotive-display applications.

Recent History

Perhaps the best place to start is to look where we have been. The technologies used in automobiles and trucks up to the present time include electro-mechanical (EM) displays, electroluminescent (EL) displays, vacuum fluorescent (VF) displays, passive super-twisted-nematic (STN) liquid-crystal displays (LCDs), active-matrix liquid-crystal displays (AMLCDs), light-emitting-diode (LED) displays, cathode-ray-tube (CRT) displays, and incandescent illuminated displays (IID). Backlights use incandescent, fluorescent, and LED illumination.

Displays are used in three primary areas: the instrument cluster (typically the speedometer, tachometer, fuel gauge, and various engine operating-condition indicators); the center panel (entertainment and cabin-environment controls, frequently used for navigation information); and back-seat passenger services (which may be overhead, on the back of the front seats, or on a console between the front seats – generally used for passenger entertainment).

Today, the instrument cluster is usually a mix of display technologies, including mechanical dial gauges with fluorescent lights, LCDs, and/or VF displays. For example, the 1999 Dodge Dakota truck has a basic instrument cluster with electro-mechanical gauges and a VFD odometer (Fig. 1). The 2002 Mercedes 320 CS has both mechanical analog displays and a digital display which is a backlighted LCD (Fig. 2). The 2002 Volkswagen instrument cluster features mechanical gauges with LCD inserts (Fig 3). The center display is a negative-mode LCD with LED backlights. The center panel is also becoming more complex in terms of display technology. The Lexus 2002 CS has an LCD as an integral part of its center console (Fig. 4). At this point, no single technology dominates automotive-display applications.

CRTs

The cathode-ray tube (CRT) was first used as an automotive display by General Motors Corp. about 17 years ago in the Buick Riviera (see *Information Display*, January 1987.) The display was made by Zenith and used a 5-in. green monochrome tube. The multifunctional display covered a range of applications – including air control, fan speed, and radio – using pages that could be selected by the driver. In 1986, Toyota used a CRT for navigation and diagnostics in the center console of the Toyota Soarer. In 1987, Toyota had a "Multivision" CRT system in the Crown, and in 1989, Nissan sold a "Multi-AV" CRT system as an option in some models. By 1992, more than 200,000 cars in Japan used a CRT for navigation systems offering various navigation aids, including static turn-by-turn graphics, a moving map with and without voice, a paper map, and text directions.

VFDs

Vacuum-fluorescent-display (VFD) technology is a close cousin to CRT technology, in

Fig. 3: *This 2002 Volkswagen instrument cluster includes LCD inserts, one of which has an LED backlight.*

Fig. 4: The Lexus 2002 CS includes an LCD panel in its multifunctional center console.

which electrons bombard a phosphor screen, and it is widely used in domestic automobiles. The Futaba VFD has an interesting history. In 1970, VFD technology consisted of cylindrical single-digit vacuum tubes with thick-film phosphor on ceramic and cylindrical multiple-digit vacuum tubes with thick-film wiring, both of which were generally used in calculating machines. In the late 1970s, Futaba made the transition to flat front glass, and manufacturers started using VFDs in vehicles. The mid-1980s saw the use of thin-film internal wiring. In the 1990s, Futaba developed 5 × 7 dot-matrix and graphics VFDs. In 1996, Futaba was advertising FEDs.

FEDs

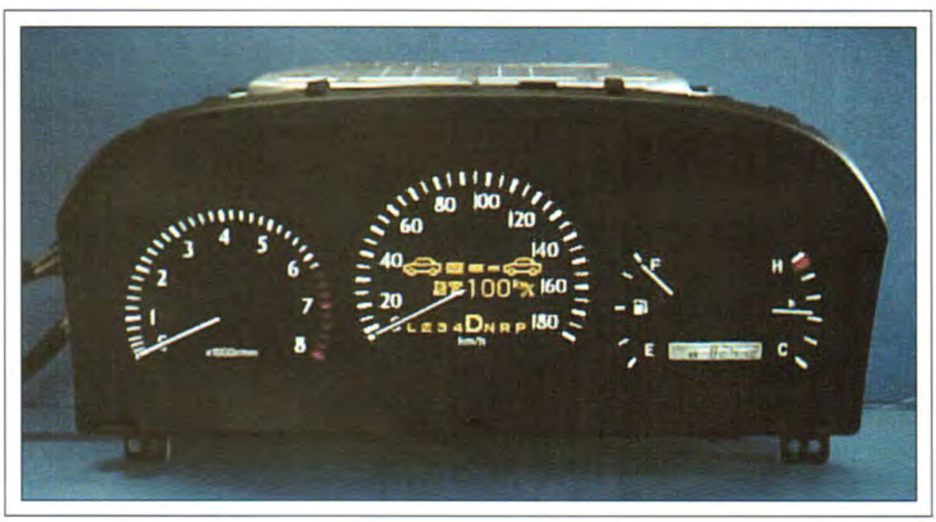
Field-emission displays (FEDs) initially showed great promise. Emissive like a CRT, yet flat like an LCD, they were the focus of intense research worldwide by a number of large and small corporations. To date, only Futaba and PixTech have had FED products on the market, and recent financial woes at PixTech call into question their continued participation in the market. Candescent Technologies was another company that had hoped to have volume production by 2003, but it recently suspended manufacturing operations and is currently reorganizing, according to CEO Duke Amaniampong. (Candescent's supporting partner, Sony, has the opportunity to pursue the technology further.) Work on carbon-nanotube (CNT) emitters for FED use continues at some companies, but no products suitable for automotive displays are available yet. As a result, the future of FEDs in any application, and not just automotive displays, is not particularly bright.

STN-LCDs

While supertwisted-nematic liquid-crystal-display (STN-LCD) technology can be used for high-density information displays, it is generally used for fixed-segment displays for letters and numbers. It remains one of the most economical technologies available.

AMLCDs

Active-matrix liquid-crystal-display (AMLCD) technology has become the workhorse of the laptop-computer market because of its relatively light weight, thinness, fine resolution, and high-quality images. It is also finding use in automotive applications. AMLCDs have some significant operating-condition limitations, but through the use of heaters and backlights, AMLCDs are able to approach the required automobile display-performance specifications. The big issue of cost has prevented the wide use of AMLCDs in U.S. automobiles. However, BMW used



Silviu Pala, Denso-International

Fig. 5: The Denso-Toyota instrument cluster includes a yellow transparent EL display.

Planar Systems

Fig. 6: The Johnson Controls–Planar steering-column display utilizes a futuristic transparent yellow EL device, with a blue alphanumeric gauge beneath it.

100,000 AMLCDs in their vehicles in 1999 and predicted the use of 150,000 in 2000.

EL Displays

Electroluminescent (EL) technology has had a long history in vehicular displays; EL displays flew in the Mercury Space Capsule. They are now used in some GPS systems, buses, and farm and excavation equipment.

OLEDs

There are basically two classes of organic materials used in organic light-emitting diode (OLED) displays. The first class consists of small-molecule (sm-OLED) materials of the Alq_3 type and the use of fluorescent dyes developed by Kodak. These materials produce light from the generation of singlet excitons. In OLED operation, the carriers form electron-hole pairs, or excitons, which recombine and emit light. These excitons are either "singlets" or "triplets".

The phosphorescent materials made by Universal Display Corp., emit light from triplet excitons. Applications for these phosphorescent dyes were developed by Steve Forrest of Princeton University and Mark Thomson of the University of California. Polymer-based OLED (PLED) devices were first built by Richard Friend of Cambridge University in 1990.

We can achieve a contrast ratio of about 300:1 – suitable for an automotive application – using a green passive-matrix OLED (PMOLED) with an anti-reflection-coated circular polarizer, assuming an output of 110 nits and an ambient-light level of 500 lux. Such a cell can achieve a 4:1 contrast ratio at an ambient illumination of 50,000 lux.

OLEDs can be made on flexible substrates, in which case they are called FOLEDs. Top-emitting cathodes have been enabled by the development of transparent OLEDs (TOLEDs).

The first OLED display used in an automotive product was a passive-matrix segmented display developed by Pioneer and used in the audio system. Ford Motor Company recently showed a white OLED display in a concept car. This concept includes a "reconfigurable" instrument cluster which is made up of a number of 5 × 8-in. displays across the instrument panel.

Optical Enhancements

When an OLED stack consists of indium tin oxide (ITO), organic LED material, and a transparent substrate, the light is emitted from both sides of the display with a transmission of 70–85%. (This could be useful for through-windshield applications.) Alternatively, if an absorber, such as Luxell's optical interference element, is used on the anode side and a transparent OLED (TOLED) on the cathode side, we have enhanced contrast.

Reflective and Transmissive Displays

An interesting development is the introduction of displays that are transmissive or both transmissive and reflective (transflective). The advantage of transflective LCDs is that they will have improved contrast at higher ambient-light levels (because the image is enhanced by controlled reflection of that ambient light) while still having an acceptable contrast at low light levels (by transmitting the light from a conventional backlight). Transparent self-luminous displays also have interesting automotive applications. Four recent approaches are embodied in an Optrex STN display, a Sharp AMLCD, the Denso-Toyota display, and the Johnson Controls–Planar display.

Optrex STN-LCDs. The Optrex method uses a semitransparent mirror instead of a zero-transmission mirror, as would be used with a purely reflective LCD, and then adds a backlight. This system shows improved high-ambient contrast while still giving acceptable low-ambient contrast.

Sharp AMLCDs. The Sharp AMLCD also provides good contrast for both high- and low-ambient illumination. The company calls this "Advanced-TFT" technology, and it has a number of interesting features. Each pixel is divided into a reflecting and a transmissive area. A transparent layer of ITO is used for

Table 1: Optical Requirements

Display luminance	150 fL
Contrast ratio (CR)	100:1
Dimming ratio	100:1
Viewing angle	±60°
Response time	50 msec @25°C
Defective pixels	1 per display "on" 1 per display "off"
Resolution	80 color groups/in.
High-ambient CR	10:1 min white CR @ 3000 fC

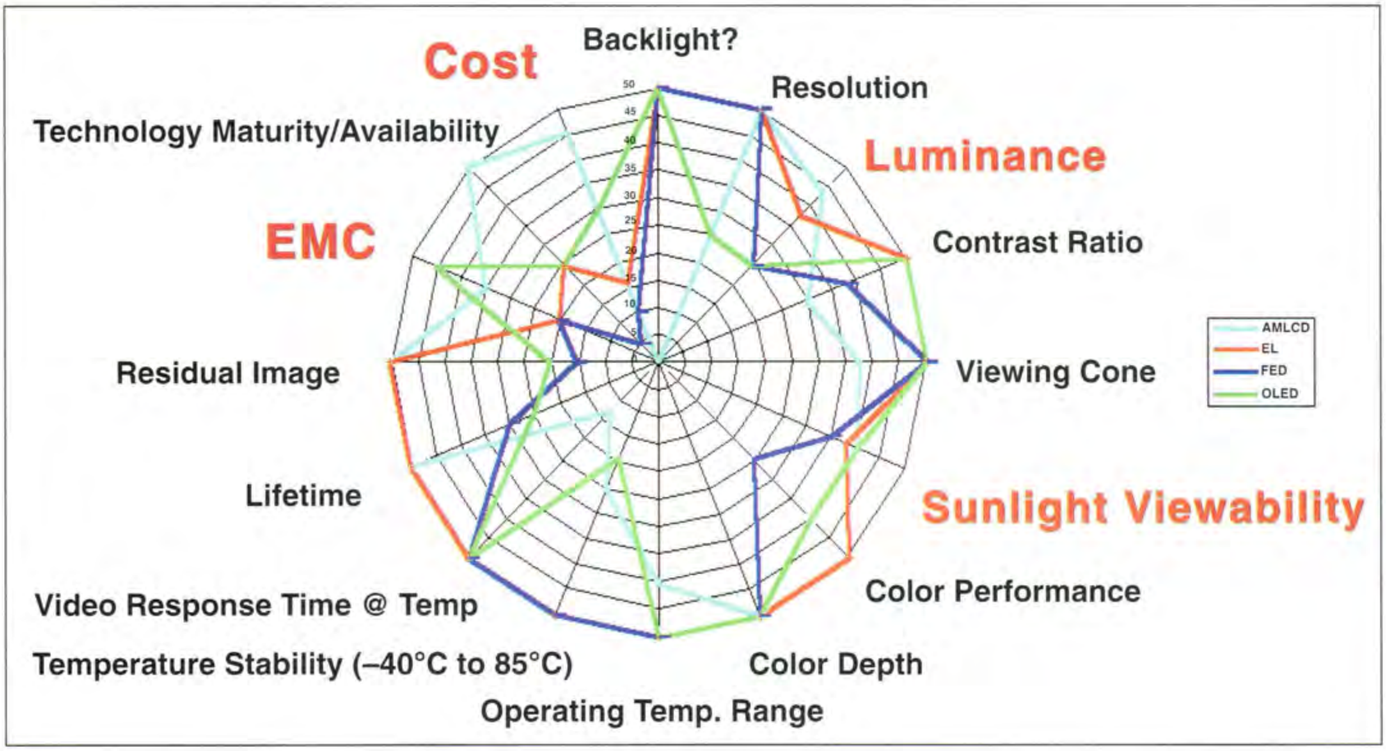


Fig. 7: Shown is a Spider Chart developed by Delphi-Delco to make multi-variable comparisons of displays easier. (Courtesy of Robert Schumacher, Delphi Automotive Systems.)

the transmissive area, and an aluminum reflective layer is deposited on top of an unevenly shaped acrylic-resin layer in what is called a micro-reflective structure for the reflecting area. Both of these LCD layers, which have different thicknesses, are driven at the same time. The optical properties of the two areas are optimized for different cell-thickness conditions.

Table 2: Environmental Requirements

Temperature range (operating)	–40 to +80°C
Temperature range (performance)	–20 to +70°C
Storage temperature	–40 to +95°C
High-temperature endurance	86°C, 250 hours
Humidity	65°C at 94% RH
Vibration	3.2 g, multi-axis
EMC	GM 9114P
Ultraviolet exposure	500 hours (xenon light exposure)

Denso-Toyota EL Displays. Toyota has developed an instrument cluster with a transparent EL display called Optitron. This dual-vision concept has been in production since 1999 and is used on the 2000 Toyota Crown Majesta and Crown Royal Sallon G. This transparent self-luminous display allows digital data to be superimposed over an analog dial display (Fig. 5). Visual testing showed that the luminance of the display has to be 80 cd/m^2. Since the black filter in front of the black-faced dial gauges has a transmission of 20%, the initial luminance of the EL display must be 400 cd/m^2 if it is to be used in bright sunlight (50,000 lux).

Johnson–Planar Transparent EL Displays. The Johnson Controls–Planar transparent EL display is a combination of a transparent yellow EL speedometer dial gauge with a blue alphanumeric gauge under the speedometer (Fig. 6).

Specifications and Comparisons

In 1996, Delphi-Delco presented a list of optical and environmental requirements for automotive displays (Tables 1 and 2). Different display technologies have different strengths and weaknesses in these optical and environmental areas, so automotive display engineers must choose the ones that have the optimal set of characteristics for a particular application. One method that is used in the auto industry to compare these parameters is the spider chart (Fig. 7). This type of chart gives the user a visual tool for comparing displays in terms of several important parameters simultaneously.

Into the Future

The demand for more information – for both driver and passengers – dictates that automotive displays will become even more important and more complex. New developments, such as flexible substrates and compact projection light engines, ensure that automobile interiors will be substantially different from those available today, offering vivid displays with richer information content. ■

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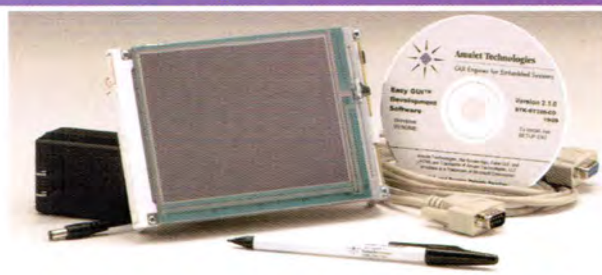

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editorial

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particular, for companies in the display industry if we are flexible, imaginative, and leave our old nationalistic and cultural limitations at home. The people of Shanghai are proud of their city's international orientation, and we are the "internationals" they would like to welcome as their partners.

Sungkyoo and I sip our drinks on the 39th floor and listen to the ice cracking in the ice bucket. We both have flights from the new Pudong Airport in the morning, and it is after midnight. Soon we will say our good-byes, but we're sure that more visits to Shanghai are in store for both of us.

— KIW

We welcome your comments and suggestions. You can reach me by e-mail at kwerner@nutmegconsultants.com, by fax at 203/855-9769, or by phone at 203/853-7069. The contents of upcoming issues of *ID* are available on the *ID* page at the SID Web site (http:// www.sid. org).

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units in Q3 '01 compared with Q3 '00, and a 22% drop in revenues. Still, with CRT monitors at the 19-million-unit and $5-billion marks for Q3 '01, and LCD monitors at 4 million units and about $2.7 billion, the quarter saw the LCD monitor carve out about a 17% market share of the units and a 35% share of the revenue. That didn't take too long.

Clearly, the next big opportunities for LCDs have the biggest potential volumes yet: in large sizes, the TV; in small and medium sizes, the cellular phone, the PDA, and whatever other handheld consumer gear catches on within the next few years. But the big-screen arena is fraught with uncertainty and will take some time to play out. What screen sizes and price points will play in what parts of the world, for example? How will the seemingly never-ending unfolding of the HDTV market progress? In the small sizes, similarly unclear is the price/performance mix that will really catch on. And in both the large- and small-to-medium-screen arenas, there are some serious competitors to the LCD.

Tomorrow's large-screen phenomenon may, indeed, ride on the back of an LCD, but the PDP is also a strong contender, as is the rear-projection display in all its many variations, including high-temperature polysilicon AMLCDs, LCoS microdisplays, the Digital Micromirror Device of Texas Instruments, and the D-ILA projector technology of Hughes-JVC Technology Corp. There will also be some new contenders in this space, with possible future TVs based on the electroluminescent display technology of iFire Technology, Inc., the novel rear-projection screen technology of SCRAM Technologies, Inc., or some alternative big-screen technology of the many now in development.

The small- and medium-sized display arena has likewise attracted the attention of display interests beyond conventional passive and amorphous-silicon AMLCDs, including low-temperature polysilicon AMLCDs, OLEDs in passive and active-matrix varieties, the microcapsule displays of E-Ink Corp., LCDs or OLEDs based on the Fluidic Self-Assembly process of Alien Technology Corp., the reflective IMods displays of Iridigm Display Corp., and others.

In both cases, LCDs may not find the going as easy in the future as it has been in the past, when they first made the portable-computer market their own and then swept the FPD action on the desktop. Certainly, they will not have the small-, medium-, and large-screen markets all to themselves. ■

David Lieberman is a veteran display journalist living in Massachusetts.

SID 2003 honors and awards nominations

As the new chairman of the SID Honors and Awards Committee (H&AC), I, Larry F. Weber, would like to thank Andy Lakatos for his outstanding service as chairman of the H&AC for the last 5 years. My hope is that I can perform as well as Andy. On behalf of the H&AC, I am appealing for your active participation in the nomination of deserving individuals for the various SID honors and awards. The SID Board of Directors, based on recommendations made by the H&AC, grants all the awards. To begin with, these awards include four major prizes that are awarded to individuals, who are not necessarily members of the SID, based upon their outstanding achievements. The **Karl Ferdinand Braun Prize** is awarded for ***"Outstanding Technical Achievement in Display Technology."*** Scientific and technical achievements that either cover a wide range of display technologies or the fundamental principles of a specific technology are the prime reasons for granting this prize to a nominee. The **Jan Rajchman prize** is granted for ***"Outstanding Scientific and Technical Achievement or Research in the Field of Flat-Panel Displays."*** This prize is specifically dedicated to those individuals who have made major contributions to one of the flat-panel-display technologies or, through their research activities, have advanced the state of understanding of one of those technologies. The **Johann Gutenberg prize** is awarded for ***"Outstanding Technical Achievement in Printing Technology."*** This prize is specifically devoted to those who have excelled in the field of hardcopy printing. Each of these above-mentioned prizes carry a $2000 stipend sponsored by Thompson Consumer Electronics Inc., the Sharp Corporation, and the Hewlett-Packard Company, respectively. The fourth major society prize, the **Lewis and Beatrice Winner Award,** is awarded for ***"Exceptional and Sustained Service to the Society."*** This award is granted exclusively to those who have worked hard over many years to further the goals of the Society.

The **SID Fellow Award** is given each year to a number (up to 0.1% of the membership in that year) of **SID members** in good standing for at least five years at the time of the nomination, who have demonstrated ***"Outstanding Scientific or Technical Engineering Achievements in the Field of Displays over a Sus-***

SID honors and awards nominations

Nominations are now being solicited from SID members for candidates who qualify for SID Honors and Awards.

- KARL FERDINAND BRAUN PRIZE. Awarded for an outstanding *technical* achievement in, or contribution to, display technology.
- JAN RAJCHMAN PRIZE. Awarded for an outstanding *scientific* or *technical* achievement in, or contribution to, research on flat-panel displays.
- JOHANN GUTENBERG PRIZE. Awarded for an outstanding *technical* achievement in, or contribution to, printer technology.
- LEWIS & BEATRICE WINNER AWARD. Awarded to a SID member for exceptional and sustained service to SID.
- FELLOW. Conferred annually upon a SID member of outstanding qualifications and experience as a scientist or engineer in the field of information display, and who has made a widely recognized and significant contribution to the advancement of the display field.
- SPECIAL RECOGNITION AWARDS. Granted to members of the technical, scientific, and business community (not necessarily SID members) for distinguished and valued contributions to the information-display field. These awards may be made for contributions in one or more of the following categories: (a) outstanding technical accomplishments; (b) outstanding contributions to the literature; (c) outstanding service to the Society; (d) outstanding entrepreneurial accomplishments; and (e) outstanding achievements in education.

Nominations for SID Honors and Awards must include the following information, preferably in the order given below.

1. Name, Present Occupation, Business and Home Address, Phone and Fax Numbers, and SID Grade (Member or Fellow) of Nominee.

2. Award being recommended:
   Fellow*
   Jan Rajchman Prize
   Karl Ferdinand Braun Prize
   Johann Gutenberg Prize
   Lewis & Beatrice Winner Award
   Special Recognition Award

*Fellow nominations must be supported and signed by at least five SID members.

3. Proposed Citation. This should not exceed 30 words.

4. Name, Address, Telephone Number, and SID Membership Grade of Nominator.

5. Education and Professional History of Candidate. Include college and/or university degrees, positions and responsibilities of each professional employment.

6. Professional Awards and Other Professional Society Affiliations and Grades of Membership.

7. Specific statement by the nominator concerning the most significant achievement or achievements or outstanding technical leadership which qualifies the candidate for the award. This is the most important consideration for the awards committee, and it should be specific (citing references when necessary) and concise.

8. Supportive material. Cite evidence of technical achievements and creativity, such as patents and publications, or other evidence of success and peer recognition. Cite material that specifically supports the citation and statement in (7) above. (Note: the nominee may be asked by the nominator to supply information for his candidacy where this may be useful to establish or complete the list of qualifications).

9. Endorsements. Fellow nominations must be supported by the endorsements indicated in (2) above. Supportive letters of endorser will strengthen the nominations for any award.

Send the complete nomination – including all the above material by **October 11, 2002** – to Larry F. Weber, Honors and Awards Chairman, Society for Information Display, 610 South 2nd Street, San Jose, CA 95112 USA; e-mail: sidawards@sid.org.

tained Period of Time," and who are recognized as significant technical contributors to knowledge in their area(s) of expertise by SID members practicing in the field. For this reason, five endorsements from SID members are required to accompany each Fellow Award nomination. Each Fellow nomination is evaluated by the H&AC, based on a weighted set of five criteria. These criteria and their assigned weights are creativity and patents, 30%; technical accomplishments and publications, 30%; technical leadership, 20%; service to SID, 15%; and other accomplishments, 5%. When submitting a Fellow award nomination, please keep these criteria with their weights in mind.

The Special Recognition Award is given annually to a number of individuals (membership in the SID is not required) of the scientific and business community for distinguished and valued contribution in the field of displays. These awards are given for contributions in one or more of the following categories: (a) ***Outstanding Technical Accomplishments,*** (b) ***Outstanding Contributions to the Literature,*** (c) ***Outstanding Service to the Society,*** (d) ***Outstanding Entrepreneurial Accomplishments,*** and (e) ***Outstanding Achievements in Education.*** When evaluating the Special Recognition Award nomination, the H&AC uses a five-level rating scale in each of the above-listed five categories, and these categories have equal weight. Nominators should indicate the category in which a Special Recognition Award nomination should be considered by the H&AC. More than one category may be indicated. The accompanying nomination should, of course, stress accomplishments in the category or categories selected by the nominator.

While individuals nominated for an award may not submit their own nomination, nominators may ask a nominee for information that will be used in his/her nomination. The selection and nomination process is relatively simple, but requires that you and perhaps some of your colleagues devote some time to preparation of the supporting material that the H&AC needs in order to evaluate each nomination for its merit. It is not necessary to submit a complete publication record with a nomination. Just list the titles of the most significant half a dozen or less papers and patents authored by the nominee, and list the total number of papers and patents he/she has authored.

The selection of nominations for SID honors and awards is a highly selective process. Each year only about 30% of the nominations are selected to receive one of the awards. Some of the major prizes are not awarded every year due to the lack of sufficiently qualified nominees or, in some cases, because no nominations were submitted. On the other hand, once a nomination is submitted, it will stay active for three consecutive years, and will be considered three times by the H&AC. The nominator of such a nomination may improve the chances of the nomination by submitting additional material for the second or third year that it is considered, but such changes are not required. If a nomination is not awarded an award over this three-year period, the nominee will not be considered again.

Since 1997, nominations can be entered through the Internet simply by logging in at www.sid.org. At the SID Web site click on ***Awards.*** This action opens the Honors and Awards section of the SID site. Then click on ***Award Nominations*** found at the top of the page, *i.e.,* the display screen, to open the Nomination Form. The SID H&AC encourages the use of this electronic version. Volunteer labor is used to process all the nominations. Electronic filing saves a lot of administrative work, and helps with reducing the workload on our volunteers. In 2000, all award nominations were submitted over the Internet. But we will still accept hardcopy nominations. The associated text box appearing in this column contains a complete description of each of the prizes and awards, along with a detailed description of the information that is asked for in support of each nomination. *Please note that with each* ***Fellow Award nomination,*** *only five written endorsements by five SID members is required.* These brief endorsements – *a minimum of 2–3 sentences* to a maximum of one-half page in length – *must state why, in the opinion of the endorser, the nominee deserves to receive the Fellow Award. Identical endorsements by two or more endorsers will be automatically rejected* (no form letters, please). Please send these endorsements to me either by e-mail (preferred) or by hardcopy to the address stated in the accompanying text box. Only the Fellow Award nominations need these endorsements.

All 2003 award nominations are to be submitted by October 11, 2002. We strongly encourage the submission of nominations *via* the Internet as described above. Or you may e-mail your nomination directly to *sidawards@sid.org*. If that is not possible, then please send your hardcopy nomination to the address appearing in the associated text box.

The Honors and Awards section of the SID Web site contains all this information along with the names of previous award winners.

Last year the H&AC received a good selection of well-qualified nominees for the Fellow and Special Recognition Awards, but there were very few nominees for most of the major awards. I am especially appealing to you and urge you to nominate worthy candidates for all the major prizes as well as candidates for the Fellow and Special Recognition awards.

As I state each year: "In our professional lives, there are few greater rewards than recognition by our peers. For an individual in the field of displays, an award or prize from the SID, that represents her or his peers worldwide, is a most significant happy and satisfying experience. In addition, the overall reputation of the society depends on who are the individuals who are in its 'Hall of Fame.'

When you nominate someone for an award or prize, you are bringing happiness to an individual and his or her family and friends, and you are also benefiting the society as a whole."

Thank you for your nomination in advance.

– Larry F. Weber, Chairman
SID Honors & Awards Committee

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a view from the hilltop

continued from page 4

and, as a result, we will be able to make further dramatic increases in our productivity.

"For example, consider the ... Wow! Look at that accident over there! And look at the traffic jam that it's created! I wonder what that person was thinking to make that stupid move? It sure seems that people don't pay attention when they are driving. I've learned that from my morning runs. I can never trust people to look when they pull out of their driveways or make turns at intersections. They are usually too distracted with a cell phone at their ear or music blasting from their 500-W stereo systems.

"Well, as I was saying, consider the possibilities of how we can make use of these new communications capabilities when they come on line. Consider the possibilities of having computer and communications power that is better adapted to carry around with us embedded in wearable electronics. We could, for example, have displays that are mounted for near-to-eye viewing. The conventional head-mounted ones that have their origins in military applications may not be the best way to do this. We may instead develop something that is easier to wear and that doesn't cause feelings of nausea. Perhaps the solution will be something that is a few inches from the eye and allows the user to still observe his or her surroundings.

"Well, here we are at the airport. Let me just take care of parking the car, and then we can continue our discussion. While I am doing that, I'll just make a quick call to see if I have any messages that need immediate attention ... Also, could you look up Ernst's cell phone number on my PDA here so we can see how his flight is doing? We can try to call him to see if his plane is on the ground yet. I'm sure he will have his cell phone on as soon as the wheels touch ground. Yes, yes, I know that it's against the rules to use a cell phone before the plane is at the gate and the door is open, but you and I both know that almost no one pays any attention to that minor detail.

"There he is! Ernst, so good to see you. How was the flight? I agree that on Sundays it sure seems that there are more vacationers than on a typical weekday. However, with our busy schedules, today was the only day that I could arrange for us to meet. By the way, let me introduce you to my colleague Steve. Steve joined me this morning to participate in this month's column on how new developments in communications and display technology will improve our productivity and time utilization. Well, let's get going. I only have a few more hours before I need to participate in a conference call with a company in Korea. As you know, by then it will already be early Monday morning there and they want to get my inputs as soon as possible.

"As I was telling Steve, we are just at the beginnings of a revolution in location-independent communications. I can hardly wait until the day when I can have an Internet viewer with me wherever I go – positioned for instant access. Can you imagine how convenient it will be to be able to do e-mails during airplane trips and maybe even while driving using a heads-up display and voice-activated word processor? Also, I'll be able to do useful work while standing in line at the bank or grocery store. And whereas today I can only work by telephone while watching my daughter's soccer game, soon we will also be able to do e-mails. Won't that be great!

"By the way, do either of you remember those ridiculous predictions that futurists were making not so many years ago about how we would have more leisure time and the work week would drop to 35 or even 30 hours? How did they think the business world would function under such a concept? How can anyone win in business without total dedication? Well, anyway, I love these new directions. I can't wait to get my hands on the next generation of computers and communications devices. Location-independent connectivity is what it's going to be all about.

"Ernst, I hope you don't mind if I just drop you off at your hotel. I've got a couple more appointments to get in before my conference call. And, Steve, I'm so glad you could join me today to participate in person in this month's column. As I told you when we made the appointment, Sunday is always a better day for these more contemplative topics because there aren't the interruptions that we all get on a typical workday. Well, it's been great talking to you both. Ernst, I'll call you later to see what we can set up for tomorrow. "Bye."

Are you ready for the evolution of the 24/7 workweek? As the saying goes, Be careful what you wish for, for you may get it." There may be more to life than 24/7 business-related communications. Some time for peaceful contemplation may be even more important than getting in one more phone call. How do you plan to balance your work and relaxation time in a world where the two are becoming ever more intermixed? I would like to hear your thoughts – that is if you are not too busy answering other e-mails and telephone calls. You can reach me by e-mail at silzars@attglobal.net, by telephone at 425/557-8850, by fax at 425/557 8983, or by taking the seriously leisurely method of writing a letter addressed to 22513 S.E. 47th Place, Sammamish, WA 98075. ■

Aris Silzars is the Past-President of SID and lives on an hilltop overlooking Issaquah, Washington.

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backlight

Whither the LCD?

by David Lieberman

Back in the early 1980s, a class of products arose called portable computers. They were large, unwieldy, CRT-based machines adapted for businessmen from the systems that were being carried around by the roving technical specialists of the day. It wasn't long before flat-panel-display makers saw the opportunity to bring new meaning to the concept of portability, and multiple FPD technologies contended as the laptop computer was born. Nor was it very long before the LCD drove the EL display and the PDP out of the portable-computer business, despite the aesthetic superiority of the latter two emissive displays. The LCD simply had the best power and pricing story, as well as being the first of the alternatives to offer color.

Today, according to DisplaySearch, the laptop/notebook market, based on 2001 figures, is about a 25-million-unit market, and, with about a $200 average selling price (ASP) for the active-matrix LCDs (AMLCDs) primarily used there, that's about a $5 billion display opportunity. That's a nice market size if it's not carved up among too many competitors, and many LCD makers old and new are now focusing on sizes below and above the notebook realm. It is not a market that is going to grow explosively, however, although DisplaySearch sees some encouraging trends.

Last year was "the first year in which aggregate volume growth for notebooks will exceed that of desktop computers," said DisplaySearch analysts, despite relatively "sluggish" growth in notebooks. Notebook computers accounted for 20% of all computer sales in 2001, according to DisplaySearch figures, up from about 18% in the year 2000 and projected to reach nearly 28% by the year 2006. The relentless trend to larger notebook screens, the company speculates, indicates that users "are using notebooks to replace their desktop computers rather than to serve as an adjunct computer for travel purposes."

What's more, the LCD has begun to make impressive and accelerating progress against the CRT in the desktop-computer market, and the monitor opportunity represents a far larger available market than do notebook computers. And here, there are no real competing FPD technologies to seriously hinder the LCD's conquest.

According to DisplaySearch, LCD monitors hit record high shipments in Q3 of last year of about 4 million units – a 143% leap over the previous year's Q3; and the company was predicting that Q4 would bring another record, with 6 million units shipped. The driver behind the LCD-monitor growth has been, of course, "significant price erosion," reflecting the dramatically downward trend of LCD-module prices.

DisplaySearch reports that the ASP for a monitor-grade LCD "fell at a double-digit rate for five consecutive quarters from Q3 '00 to Q3 '01," while overall price tags plunged 55% over those of the previous year. The entrenched leader in the desktop monitor market clearly suffered thereby, although CRT prices continued to decline.

"While LCD-monitor shipments soared, CRT-monitor shipments fell," DisplaySearch analysts said. Specifically, CRT monitors suffered a 21% drop in

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calendar

The 7th Asian Symposium on Information Display (ASID '02). Contact: ASID '02 Secretariat, M. Toh, +65-790-4237, fax +65-793-0997, e-mail: sid-smc@ntu.edu.sg.
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Microdisplay 2002. Sponsored by SID. Contact: Danielle Rocco, Palisades Convention Management, 212/460-8090 x218, fax -5460, e-mail: drocco@pcm411.com.
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2002 International Conference on the Science and Technology of Emissive Displays & Lighting. Contact: K. Neyts, fax +32-9-264-3594, e-mail: EL2002@elis.rug.ac.be.
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Twenty-Second International Display Research Conference (Eurodisplay '02). Sponsored by SID. Contact: Janine Verdez, Le Club Visu, +33-1-53-17-11-42, fax -45, e-mail: jverdez.clubvisu@wanadoo.fr.
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Tenth Color Imaging Conference: Color Science, Engineering, Systems & Applications. Sponsored by IS&T and SID. Contact: SID HQ, Dee Dumont, 408/977-1013, fax -1531, e-mail: office@sid.org, www.sid.org.
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The 9th International Display Workshops (IDW '02). Contact: SID HQ, Dee Dumont, 408/977-1013, fax -1531, e-mail: office@sid.org.
December 4–6, 2002 Hiroshima, Japan

The Third International Display Manufacturing Conference & Exhibition 2003. Contact: SID HQ, Dee Dumont, 408/977-1013, fax -1531, e-mail: office@sid.org.
February 19–21, 2003 Taipei, Taiwan

SID 2003 International Symposium, Seminar, and Exhibition (SID '03). Contact: SID HQ, Dee Dumont, 408/977-1013, fax -1531, e-mail: office@sid.org, www.sid.org.
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