FLAT-PANEL ISSUE

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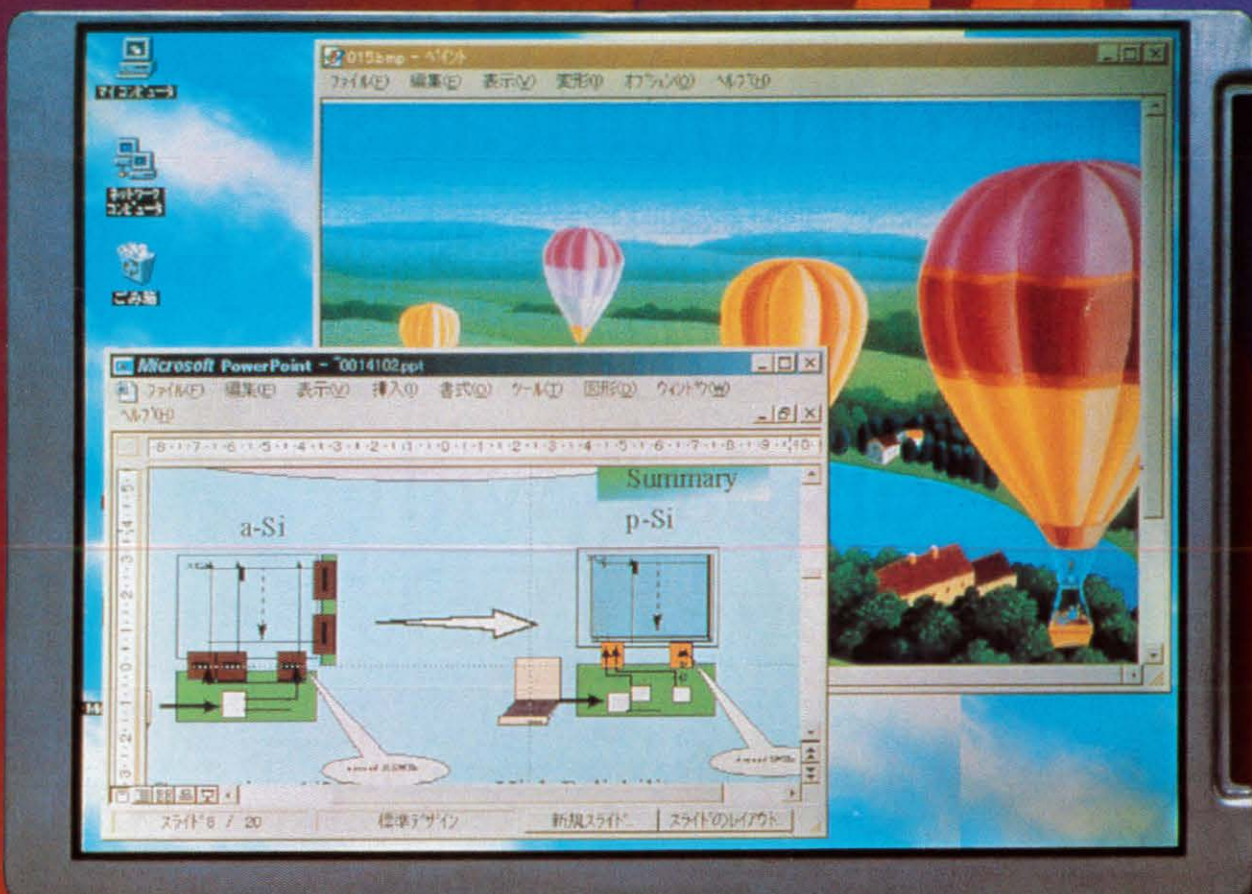

Reflective Color LCDs: Ready for Low-Power Portable Systems

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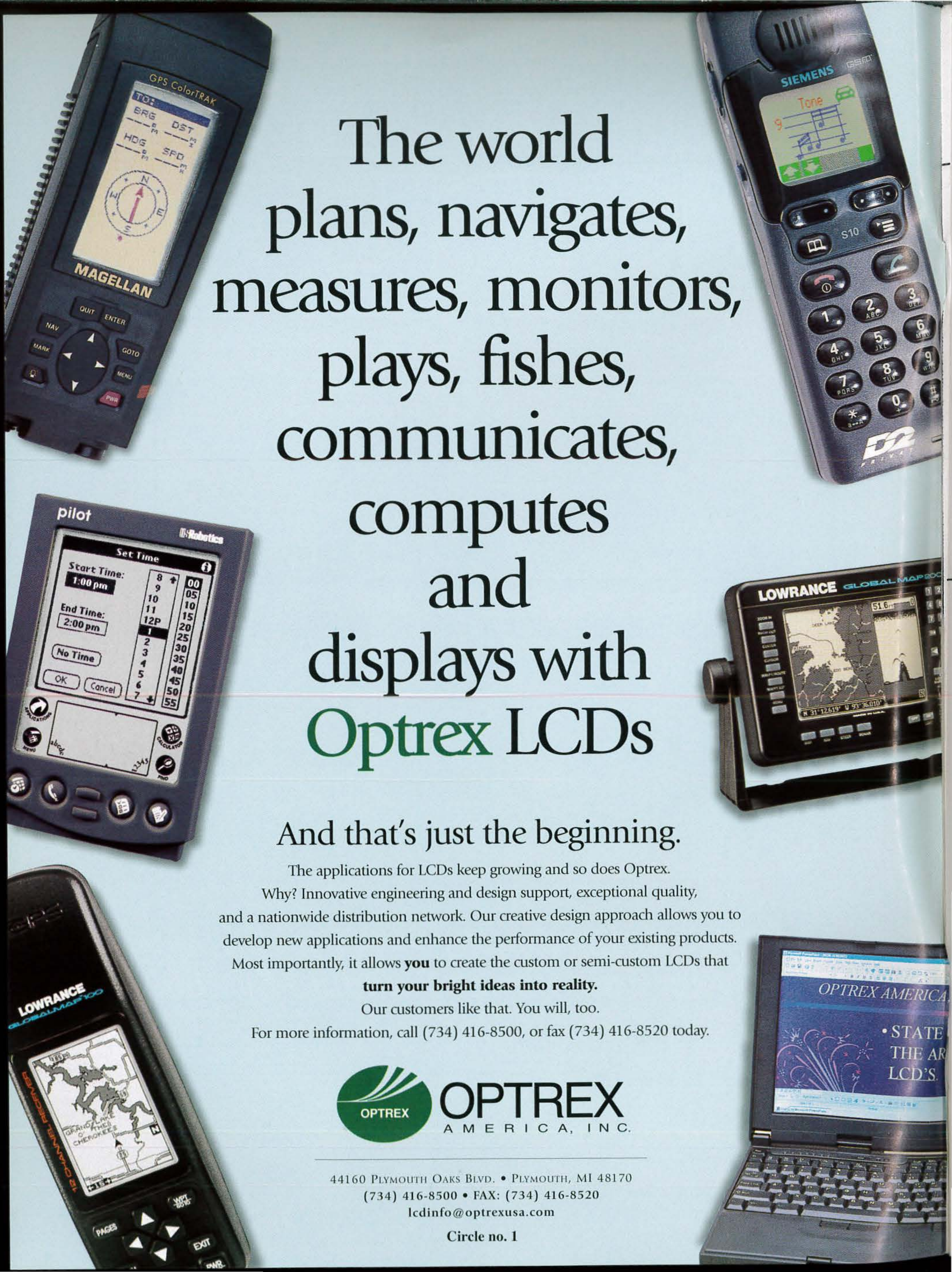

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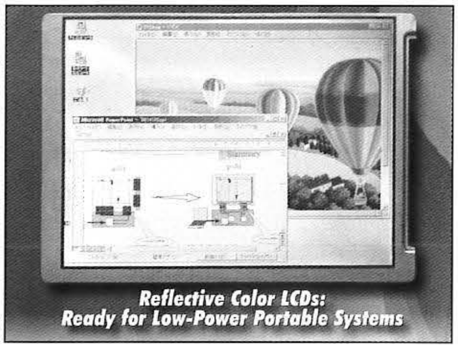
COVER: Reflective color LCDs using several different technologies are now good enough to begin filling a growing demand in a variety of applications that require low power consumption, ranging from cellular phones to notebook computers. This is Toshiba's 8.4-in. AMLCD, which uses polysilicon TFTs and integrated drivers.



Credit: Toshiba America

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Next Month in
Information Display

Manufacturing Issue
- Repair and Rework of FPDs
- Electrostatic Discharge
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Information DISPLAY
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editorial

Information Displayless

The front-page story of *The New York Times* business section on August 19th was "Entertainment in the Skies; Glitches Still Hurting Video With Wings." "Aha!" said I. "Display issues are finally making it into the general business press."

Well, not exactly. The article covered the entertainment-on-demand systems that are being installed in the first-class and business-class cabins on many airlines, and focused on the not-yet-reliable systems, which are essentially video-rate LANs. But other than a passing mention of "personal armrest video screens" in Virgin Atlantic's first and business class and a goggle display made by Olympus Optical for Japan Airlines' first-class cabin that "is like watching a 62-in. screen," displays are barely mentioned. In fact, Virgin Atlantic's in-flight masseuse received more coverage than its in-flight displays. (As this was an article on in-flight entertainment systems, I'm not sure what message the *Times* was trying to deliver, but perhaps we should move on.)

So, what the *Times* gave us was an article on information delivery systems with barely a mention of the devices that must be used to deliver the information. Unfortunately, this seems to reflect the attitude of the people who design in-flight entertainment systems, as any frequent flyer can attest.

I have recently been subjected to flop-down LCD panels that were obviously purchased before wide-angle LCDs became commonplace. None of the several panels within my sight were capable of presenting me with an image that was simultaneously large enough, bright enough, and contrasty enough to offer minimally acceptable viewing.

Was I simply being a display snob? I don't think so. A look around the cabin indicated that an unusually large percentage of people were ignoring the in-flight entertainment.

This isn't rocket science. It is simply designing a system that includes the viewer. It is thinking about viewable display characteristics as a function of viewing angle, and subtended angle as a function of viewing angle and distance.

But there are some human-factors questions that may be more subtle. It seems clear that in-flight entertainment is moving toward individual seat-back and armrest displays. (Perhaps first-class passengers can be trusted with $500 HMDs, but I suspect the cost will have to come way down before the airlines will hand them out to the folks in sardine class.) So, have the people who are proposing 5.6-in. FEDs for seat-back displays made very sure that users think they are large enough? If they aren't, is an 8.4-in. AMLCD large enough? Will a passenger who has just finished using the 13.3-in. display in her notebook PC feel she is being well served with even a 10.4- or 11.3-in. seat-back LCD? Will an FED feel more "cinematic" than an LCD, even if it is smaller? How long will people remain satisfied with VGA/NTSC screen resolution on airplanes after they become used to high-resolution digital TV at home (or at least at the local sports bar)?

The interaction of such human-factors questions with display-design issues and the stringent packaging demands of aircraft installations should keep display people entertained for years to come. Will airline passengers be as lucky?

– Ken Werner

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the display continuum

I Really *Need* to Go to a Meeting ...

by Aris Silzars

It was a few minutes after 3:00 p.m. and I was trying my best to finish up a phone call. I didn't want to be late for the three o'clock staff meeting. While completing my telephone conversation, I did some multi-tasking and prepared my folder with the spreadsheets I thought I might need to have along in case some financial issues came up. At 3:04, I dashed out of my office and did a walk-jog down the hallway to the designated conference room at the far end. I knew that with luck and if no one tried to grab me for a "quick question" I could make it in just over a minute.

And once again, I accomplished my objective. It was 3:06 as I entered the room and I was *on time.* Actually, I was maybe even a bit too early. Of the approximately dozen expected attendees, there were only two in the room - and one of them was the finance person, who was permanently on the schedule as the first speaker. Boss-person had not arrived yet and the only other signs of civilization were a few notepads and "daytimers" left by attendees who presumably were planning to return shortly - right after taking care of just one more vitally important piece of business.

Over the next several minutes, there were more seemingly random entrances and exits, and more notepads were placed at various spots around the table. The finance person had by now adjusted the overhead projector at least six times and positioned and repositioned the first overhead to absolute perfection. Observing this behavior made me wonder if finance people in general have a difficult time with disorder and are slow learners, or if this only applied to the one standing at the front of this room.

Two colleagues and I were the only ones seated at the conference table when boss-person entered at roughly ten minutes after the hour. By now, most of the spots around the table had been "marked" by their future occupants, who were now making their reappearances with increasing frequency and apparent urgency. However, for most of them, after a cursory apology, the first stop was not the spot they had chosen at the conference table but the corner table where the coffee and cookies had been laid out. Finally, after some by-now familiar comments from boss-person regarding how we all need to try harder to get these meetings started on time, the finance person turned on the projector, the lights were dimmed, and the meeting was launched. The time was 3:18. I resolved that next week I would try to do better - no point in being *this* much too early.

By 30 seconds after 3:18, my carefully trained and conditioned psyche had entered that part of the mind-world known to everyone as meeting-land. Meeting-land is unquestionably the greatest blessing bestowed upon us all by the modern corporation. Where else can one go where the mind is so free to wander as during a staff meeting - or any other kind of meeting that involves more than four or five people? It can be mathematically proven that meetings of six or more participants asymptotically approach meeting-land nirvana, and any number above ten participants is a sufficient condition to allow one to be within epsilon of nirvana (the existence of the meeting being the necessary condition).

Even as my physical body assumed that well-trained attentive look and I occasionally nodded with a knowing and approving look toward the screen being

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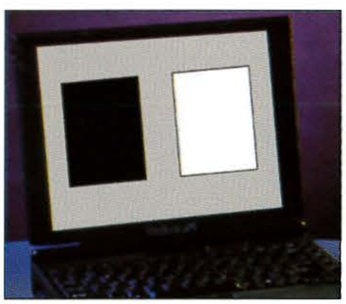

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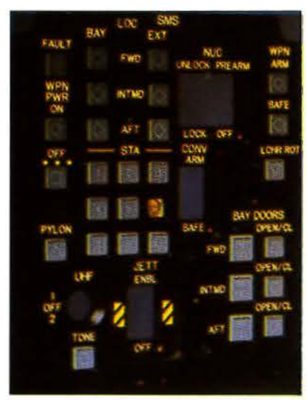

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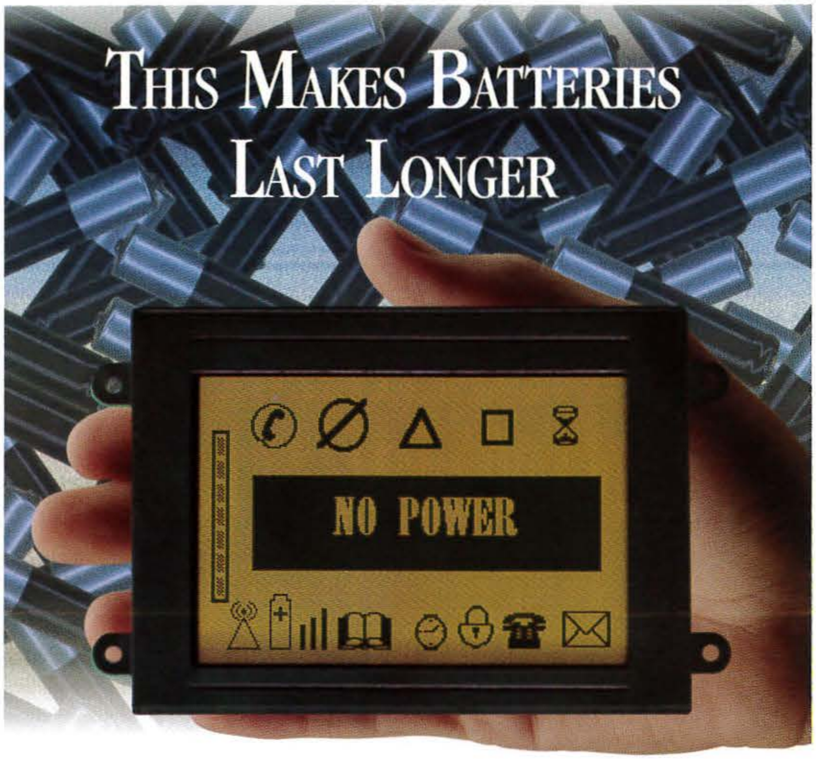

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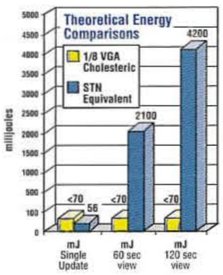

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The "Iron Law" 25 Years Later

Are high-performance addressed STN displays breaking the "iron law" of LCD design formulated by Paul Alt and Peter Pleshko nearly a quarter century ago?

by Terry J. Scheffer

THE QUALITY of the passive-matrix displays found in the current crop of notebook computers has improved remarkably. These 12.1-in. SVGA screens follow the cursor with little or no smearing and are virtually free of crosstalk, mimicking a TFT display of 3 years ago. Most of these recent improvements are a consequence of high-performance addressing (HPA). HPA does not apply to any single addressing technique, but was adopted by the major Japanese display manufacturers to represent new addressing implementations that enable contrast ratios of over 50:1 and combined rise and fall times of less than 150 ms. How do these new schemes work? Have they found a way to break the "iron law of multiplexing"?

A Brief History of Multiplexing

The emergence of the CMOS LSI process in the early '70s made it practical to consider replacing LED, vacuum fluorescent, and EL displays with LCDs in various applications. Watch manufacturers were the first to seize this opportunity, using 3½-digit static-drive LCDs. In these displays, each of the 23-odd-segment electrodes and the single common backplane electrode were connected to their own dedicated drivers.

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While feasible for simple watch displays, static drive was impractical for 8-digit calculator displays because of the sheer number of drivers required, not to mention electrode routing complexity and fine interconnect pitch. In order to reduce the number of drivers required, manufacturers developed multiplexing techniques for LCDs based on the 3:1 selection scheme used for driving EL displays, which was modified with alternate-frame voltage inversion to eliminate damaging net dc voltages.

In the multiplexed EL display, the matrix rows are sequentially selected or pulsed from zero voltage to an amplitude $S = 2D$, while the columns are driven with control voltages of $-D$ or $+D$, depending upon the data. On- and off-pixels receive pulses of $3D$ and $\pm D$, respectively, hence the name 3:1 selection. If the voltage D is adjusted to be at, or just slightly below, the EL threshold voltage, then only the on-pixels light up during their selection interval.

This multiplex drive scheme worked reasonably well for multiplexing a few lines of

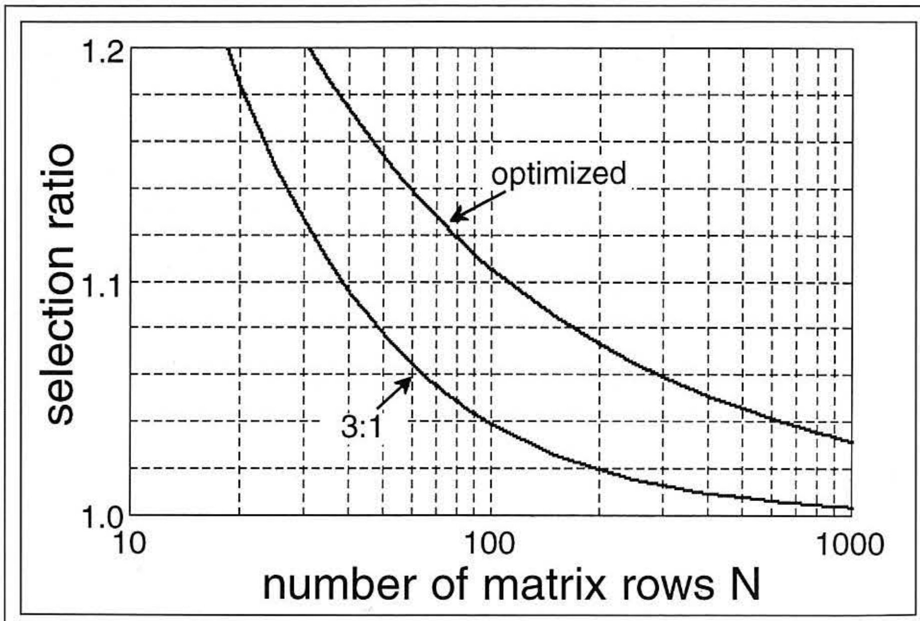

Fig. 1: Alt and Pleshko addressing provided a higher selection ratio compared with the 3:1 selection scheme.

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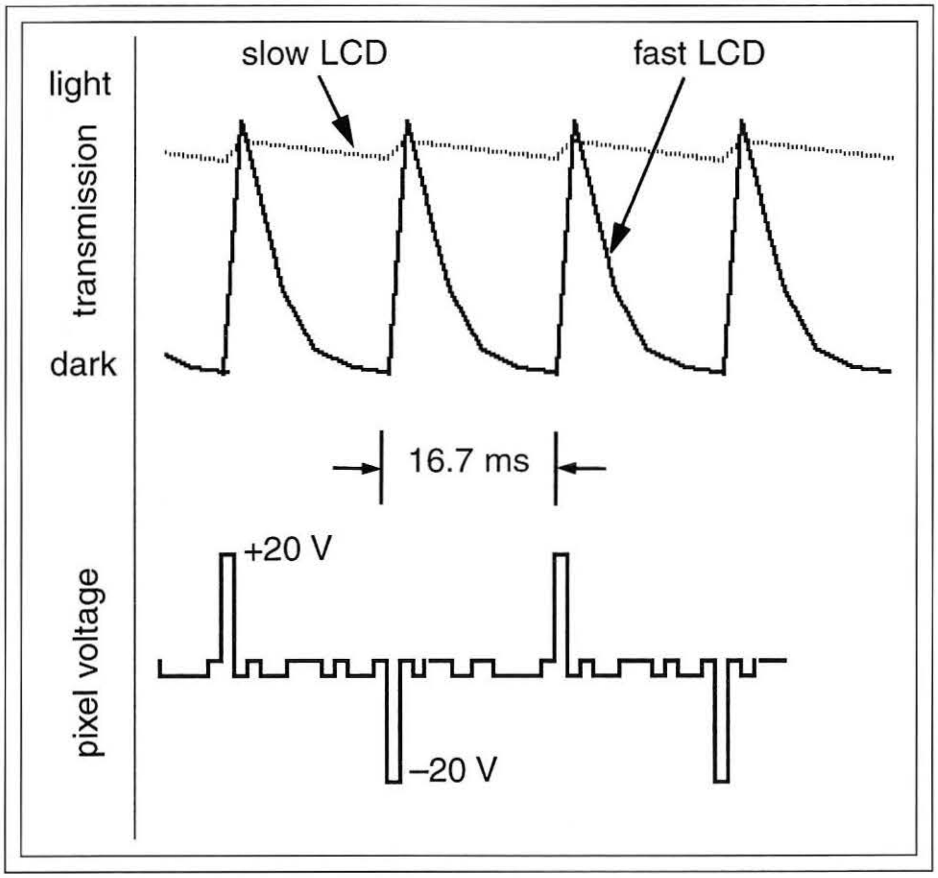

Fig. 2: The on-pixel waveform of a conventionally addressed slow-responding STN display drives the pixel to a constant "white" state. But in a video-responding STN display the rapid decay of transmitted light intensity after the select pulse results in significantly less brightness.

dynamic-scattering-mode (DSM) LCDs, but there was a significant loss in contrast ratio when attempts were made to multiplex the greater number of lines that were usual for the LED and EL displays of the time. In order to understand this performance falloff, Kawakami and co-workers at Hitachi undertook some experiments to investigate the fundamental differences between the response of EL and DSM displays to multiplex drive signals.

Applying a series of pulses to a DSM cell, these researchers expected to see rapid response to each individual pulse, but instead were surprised to see what they referred to as "accumulated pulse response." To learn how the DSM effect responded to actual multiplexing waveforms, they built simple matrices with differing numbers of rows N and then drove them with the 3:1 selection technique. By slowly increasing the supply voltage U and noting the threshold values, Uth_{on} and Uth_{off}, where the on- and off-pixels first turned on, they were able to establish the empirical expression

$$Uth_{off}/Uth_{on} = (1+8/N)^{1/2}.$$

These experiments were repeated using the newly reported twisted-nematic (TN) effect with the same results. Attempting to understand this relationship led them to discover that the same expression could be obtained by assuming that the liquid crystal (LC) responded to the root-mean-square (rms) voltage of the pixel waveform. It was only many months later that they realized that they could optimize the selection ratio of on- to off-pixel rms voltages, $<V_{on}>/<V_{off}>$, and derive what is now known as the "iron law" expression

$$<V_{on}>/<V_{off}> = \{(N^{1/2}+1)/(N^{1/2}-1)\}^{1/2},$$

where S/D is now equal to $N^{1/2}$, a function of the number of multiplexed rows N, instead of the fixed value of $S/D = 2$ for 3:1 selection. Closer examination of the optimized drive reveals that the instantaneous pixel voltage during the selection time of an off-pixel is higher than the LC threshold voltage, but the pixel does not turn on as it would in an EL display because of the LC's slow response.

Several semiconductor manufacturers developed chips first for $N = 2$ and then for $N = 3$ after lower-threshold LCs and higher-voltage CMOS processes had evolved. The increase in contrast ratio and brightness for $N = 2$ and $N = 3$ displays using the optimized scheme was actually quite small. The real significance of optimized addressing came later when matrices with much larger values of N were used in high-information-content (HIC) displays. A first step in this direction came in 1978 when Hitachi developed an optimized driver LSI (HD44100) which was used in TN modules with 16 characters and $N = 16$.

Also in the early '70s, Paul Alt at IBM's T. J. Watson Research Center in Yorktown Heights, New York, was independently investigating what factors controlled the electro-optic (EO) behavior of single-pixel and small-matrix DSM displays. Although IBM had no LCD products planned at the time, there was the sense that LCDs could become important. At that time, there were confusing and conflicting ideas about multiplexing LCDs, one of the more popular beliefs being that the limits of multiplexing were determined by the ratio of the LC fall time to the rise time. Alt did not agree with this assessment and was eager to make a fresh start in the laboratory.

Alt began his investigations with DSM cells of different materials, geometries, and temperatures, and measured their EO behavior with a wide variety of voltage excitations, including single unipolar pulses, single bipolar pulses, multiple pulses, dc with pulses, and so on. In looking over the data taken with the different excitations that produced the same EO result, it became evident that the cells were responding to the rms value of the excitation voltage. Alt then addressed the pixels with actual multiplexing waveforms and used the rms response to correctly predict the EO behavior, realizing that the pixel voltage over the whole frame period – not just the instantaneous voltage when the pixel is selected – had to be considered.

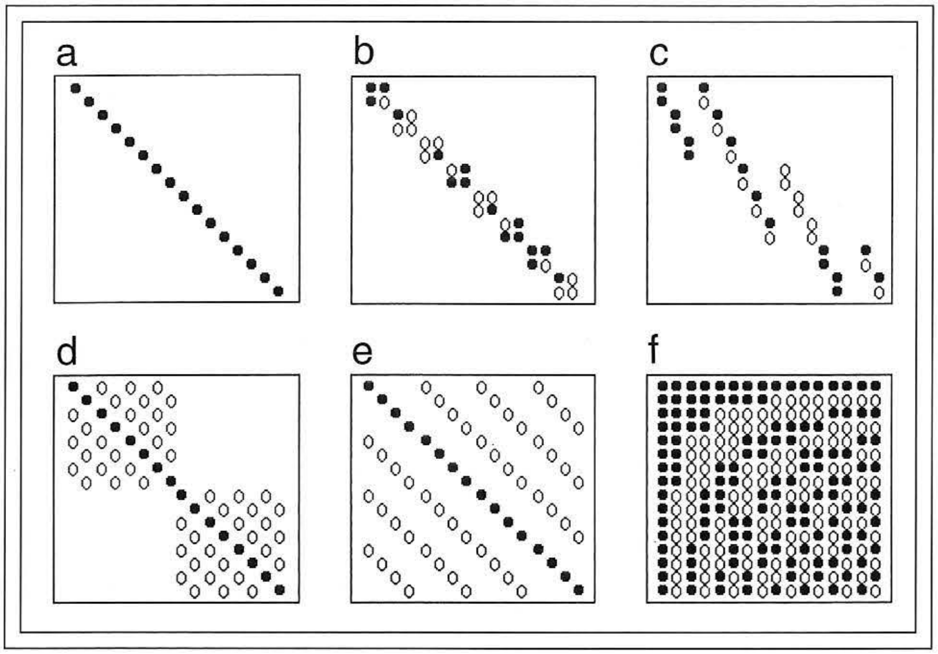

Fig. 3: Orthogonal row functions for driving a simple 16-row matrix include (a) Alt and Pleshko, (b) two-line selection, (c) Enhanced Hi-Addressing, (d) HC-Addressing, (e) four-line MLA, and (f) the Walsh function. In these examples, the horizontal axis represents row number and the vertical axis, time. The symbols • and ○ indicate positive and negative selection voltages. Blank regions indicate where the row voltage is zero.

How to write the general equations for the on and off rms voltages across a pixel then became obvious, and the parameters for maximizing the contrast ratio emerged (Fig. 1). Alt's group soon built a 40 × 40-matrix display, and it worked wonderfully.

Strangely enough, Alt found the final result rather disappointing. Anticipating writing a lengthy scientific paper with many complex equations, it was difficult for Alt to resign himself to the fact that the EO response of such a complex electro-hydrodynamic system - with charge flow, light scattering, and electrical and optical anisotropy - could be reduced to the same rms response as the heat from a resistor. The idea of writing a paper was shelved for some time.

Fortunately, Peter Pleshko - Alt's manager at the time - had a better perspective of just how un-obvious this result was. He convinced Alt to write the paper, and contributed to it himself. The result was the classic 1974 paper "Scanning Limitations of Liquid Crystal Displays." After the paper was published, conventional passive-matrix addressing forever became known as Alt and Pleshko addressing.

Breaking the Iron Law?

In investigating a simple two-line matrix and relaxing the condition that the column signal be determined only by the desired pixel value of the selected row, Nehring and Kmetz were able to obtain a selection ratio of 3.0, which was significantly higher than the value of 2.414 obtained by Alt and Pleshko addressing. This discovery raised a whole set of new questions. For a given matrix size *N*, what was the real optimum selection ratio? Could the selection ratio be made large enough to significantly improve the performance of a high-resolution TN matrix display, and what would these addressing waveforms look like?

These and other questions were answered in Nehring and Kmetz's pioneering paper "Ultimate Limits for Matrix Addressing of rms-Responding Liquid-Crystal Displays." Nehring and Kmetz proved that the Alt and Pleshko selection ratio could be exceeded whenever the number of multiplexed matrix rows was not a perfect square - 4, 9, 16, and so forth - but that the increase was negligible for matrices with more than three rows. At this point, the Alt and Pleshko selection-ratio equation became known as "the iron law of multiplexing." This result of Nehring and Kmetz meant that researchers would have to look elsewhere to improve the performance of HIC LCDs. The iron law could not be broken.

In their generalized matrix analysis, Nehring and Kmetz also proved that iron-law performance could be achieved with any set of orthogonal functions driving the matrix rows, not just the sequential Alt and Pleshko block functions. In this general case, the column voltages are determined from an inner-product computation of the row voltages and the pixel input data. This proof opened up a new research area known as multiple-line addressing (MLA).

Multiple-Line Addressing

A requirement for rms response is that the characteristic response time be much longer than the frame period of the display. For typical 60-Hz frame rates, this rms behavior breaks down in a display with a characteristic response time short enough to display video images. This breakdown is manifested by a phenomenon known as frame response, in which the liquid crystal reacts strongly to voltage changes occurring within the frame period (Fig. 2). Frame response can significantly reduce the brightness and contrast ratio because of the rapid decay of the optical transmission that occurs after each high-voltage select pulse in the pixel waveform.

Frame response is clearly related to the Alt and Pleshko row-selection pulse. New addressing techniques have been developed that replace this single high-voltage selection pulse with a number of lower-voltage selection pulses distributed over the frame period to minimize frame response. The lower voltage reduces the intensity of the frame response, and the distribution prevents the optical state of the pixel from significantly decaying before it receives another selection pulse.

According to the generalized matrix analysis, any set of orthogonal row functions may be used to address the matrix rows and still preserve the iron-law selection ratio. A subset of these will have the qualities that effectively reduce frame response. An important consideration in choosing functions from this subset is the hardware complexity associated with their implementation. Not only must the row functions be generated, but they also must enter into the determination of the column voltages through the inner product computations. Examples of sets of orthogonal row-selection waveforms for MLA of a 16-row matrix are compared in Fig. 3.

The first Active Addressing™ prototype developed by Motif used bi-level Walsh-function waveforms [Fig. 3(f)] that selected all the matrix rows all of the time. These functions were very effective in eliminating frame response, but their use required a high degree of computational complexity. Furthermore, this type of function required double-buffering the input image data because a complete frame of input data had to be stored unchanged for an entire frame period in order to correctly compute the inner product.

During this time, another memory buffer had to be simultaneously present to store the incoming image data stream for the next frame. This implementation became too costly in a market of drastically reduced TFT prices, and Motif ceased to be an active player. Motif has, however, retained the intellectual property rights to this technology and is now managing a successful MLA licensing program.

Asahi Glass independently invented the four-line MLA scheme [Fig. 3(e)], whose computational complexity is considerably reduced over that of the Walsh-function approach, yet frame response is still strongly suppressed because the selection pulses are uniformly distributed over the frame.

At IDRC '97, Sharp presented the four-line MLA scheme called High-Contrast Addressing [Fig. 3(d)]. According to Sharp's presentation, the single matrix is divided into two equal sections, with the four selection pulses distributed in the first half of the frame for the upper display section and in the second half of the frame for the lower display section. A big hardware advantage of this scheme is that it only requires a single frame-buffer memory because the information in the memory portions corresponding to the upper and lower display sections can be alternately discarded after only half a frame, and these memory portions can then be reused to load the next frame's data for the other panel section.

In the two-line MLA schemes developed by Hitachi, referred to as Hi-Addressing [Fig. 3(b)] and Enhanced Hi-Addressing [Fig. 3(c)], the additional hardware complexity of MLA is kept to an absolute minimum, requiring only line buffers for additional memory, since the two selection pulses are separated by only one (b) or two (c) selection intervals. Because the selections are not uniformly distributed, this method is less effective at reducing frame response, so the frame frequency must be increased. For comparison, Fig. 3(a) shows the Alt and Pleshko row-function matrix, which is identical to the unit matrix. Displays using the MLA schemes shown in Fig. 3 have contrast ratios and response times that are significantly improved over conventionally addressed displays.

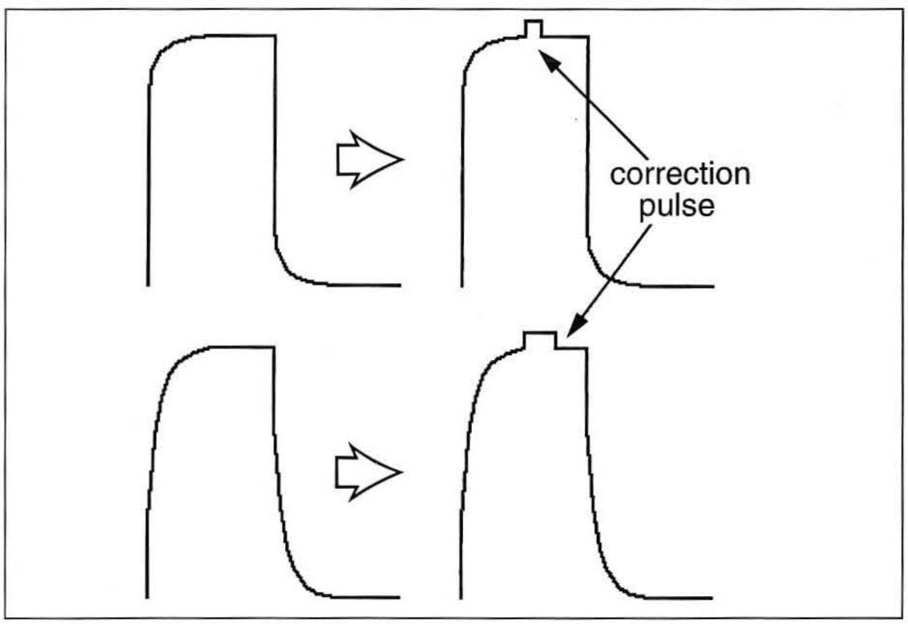

Fig. 4: Horizontal shadowing can be eliminated by compensating for variable distortion of row-selection pulses, as described by Hitachi at IDRC '97.

Combating Crosstalk

The trends toward higher resolution, larger size, and faster response in notebook-computer displays all exacerbate crosstalk effects. Crosstalk occurs when the optical states of individual pixels in a display are collaterally affected by the optical states of other pixels, and generally appears as vertical and horizontal streaks emanating from displayed patterns. Crosstalk can be traced to non-ideal conditions, such as the finite sheet resistance of the transparent ITO electrodes and output impedance of the row and column drivers. These impedances act in combination with the pixel capacitance to distort the addressing-voltage waveforms and cause pixel voltages other than the desired ones.

The first multiplexed LCD matrices used frame inversion to prevent damaging net dc voltages on the pixels. These panels exhibited particularly intense vertical streaking above and below horizontally striped patterns. This crosstalk was traced to the panel's low-pass filtering action, which rounded off the sharp voltage transitions in the column-drive waveforms. The round-off would not cause visible artifacts if it occurred to the same degree at every pixel, but the degree of rounding off is pattern dependent. Thus, the pixel voltages in a nearly all "on" column will be very close to their expected values because there are few transitions in the column waveform to be rounded off. However, in a column displaying a dotted pattern, there are many on and off transitions, and the round-off distortion will noticeably decrease the rms pixel voltages, causing the streaking under these patterns. The streaking has been reduced in conventional displays by inverting the polarity of the row and column waveforms more frequently than once per frame. This has the effect of making the number of transitions in the column waveforms less dependent upon the image pattern.

In order to reduce the voltage required of the row drivers, the Alt and Pleshko method was initially modified by applying an offset voltage to both row and column electrodes

LCD technology and history

during one phase of their polarity sequence. This became known as the Improved Alt and Pleshko Addressing Technique (IAPT). An undesirable consequence of this method was the introduction of transient voltages on the pixels, which degraded the contrast ratio. Sanyo was first to remove this "improvement" with their "Smart Addressing," which used tri-level row drivers capable of a $2S$ voltage swing instead of the traditional bi-level row drivers with the lower $S + D$ voltage requirement. The added cost of the high-voltage drivers in the Sanyo approach can be partially offset with cheaper, lower-voltage column drivers. It seems that the IAPT method cannot meet the performance targets of HPA.

To achieve acceptable image quality in notebook screens, it has been necessary to develop more-sophisticated crosstalk-elimination schemes. Recently, Hitachi, Sharp, and others have published elegant methods that actively eliminate crosstalk, as opposed to the conventional passive methods described above. At least three different origins of crosstalk have been identified: vertical stripe shadowing, vertical block shadowing, and horizontal shadowing.

The cause of vertical stripe shadowing was discussed earlier in connection with the frequent polarity inversions. Sharp has developed an active method that corrects for this particular distortion, rather than having it apply to all images. The method determines whether or not there is a voltage transition on the column by comparing the image data of the selected row with that of the previous row. If a transition has occurred, a small correction pulse is applied to the column voltage in a specially developed column-driver chip to compensate for the loss in rms pixel voltage associated with the rounding off of that transition. If there is no transition, then no correction is applied. Thus, virtually all stripe shadowing is eliminated, while at the same time the contrast ratio appropriate to the iron-law selection ratio is restored.

Vertical block shadowing is caused by voltage switching transitions on the column electrodes inducing waveform-distorting voltage spikes on the row electrodes *via* the differentiation effect of a series RC circuit. This is a global coupling phenomenon, where the same distortions are simultaneously induced on all the row electrodes. These voltage transients can become particularly large if many column electrodes simultaneously switch in the same direction, as can easily happen if the display shows a similar pattern across many columns. Several schemes are now in use which detect these global transients upstream at the row-driver voltage source and apply an appropriately sized counter-pulse to compensate for the transients (Fig. 4).

Crosstalk associated with both vertical stripe shadowing and vertical block shadowing concerns waveform distortions that occur the majority of the time, when the pixel is not selected. Horizontal shadowing, on the other hand, is introduced by distortion of the row-selection pulse, which occurs during the relatively short period of time when the pixel is selected. The pixel capacitance in a super-twisted-nematic (STN) display depends upon the orientation of the liquid crystal because its dielectric constant is anisotropic. An on-pixel could have three times the capacitance of an off-pixel, so a matrix row with many on-pixels will round off the selection pulse more strongly than a matrix row with only a few on-pixels. Counting the number of on-pixels in the selected row and applying an appropriate compensation voltage to the selection pulse eliminates this type of crosstalk.

Outlook

HPA schemes have kept STN displays viable in the notebook-computer market. Because of their simpler construction, STN displays will always be cheaper to manufacture than their thin-film-transistor (TFT) counterparts. STN displays are therefore likely to dominate in price-sensitive areas for the foreseeable future. The emergence of LCD desktop monitors presents a new opportunity for STN displays because of the ease at which they can be adapted to larger sizes compared with TFTs. The availability of larger STN panels at significantly lower costs than TFTs will be a strong driving force for this new market.

HPA will also be widely applied to mobile applications using reflective STN-LCDs because of its significantly lower power dissipation compared with conventional addressing. ■

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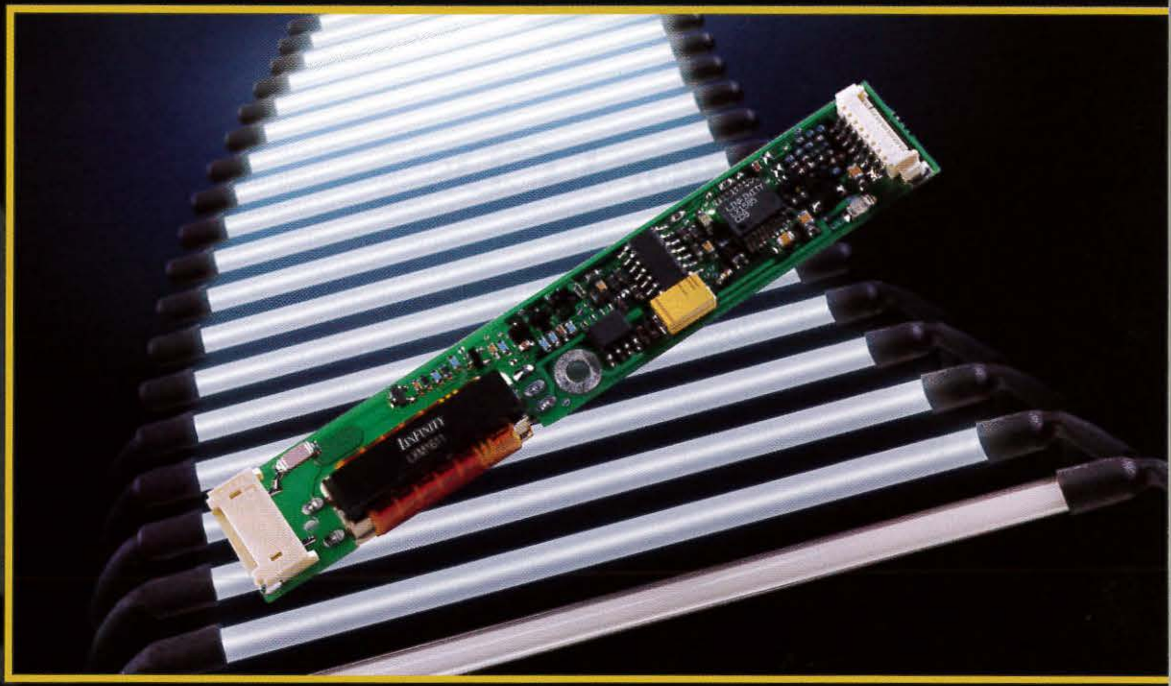

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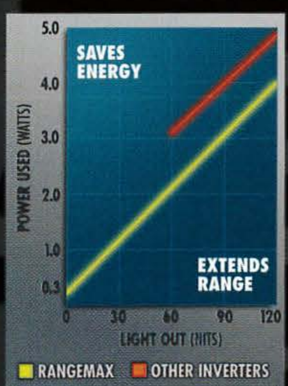

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Circle no. 14

Reflective Color LCDs

The market for reflective color LCDs is very active, but which technology will prevail?

by Alan Mosley

BACKLIT color active-matrix LCDs (AMLCDs) and supertwisted-nematic liquid-crystal displays (STN-LCDs) are widely used in notebook computers and are now being introduced as displays for desktop monitors. The present value of the worldwide markets for these two backlit technologies is around $10 billion and is predicted to grow to around $25 billion by 2003.

Almost since the introduction of STN-LCDs and AMLCDs in the late 1980s, manufacturers have continually sought to reduce the power consumption and bulk of their display modules. Although they have achieved remarkable reductions in both areas - typical values of power consumption and depth are now 3 W and 7 mm, respectively - there is still a demand for further improvements. It is now recognized that in order to meet the demands of the marketplace for reduced power consumption and bulk, it will be necessary to remove the backlight from the display module.

These market demands are centered around the large range of handheld computing and telecommunications products, including palmtop computers, mobile phones, pocket organizers, and personal digital assistants. Until recently, the LCDs used in these products were reflective monochrome supertwisted displays. These display modules are thin (about 5 mm) and have a very low power consumption (about 0.3 W), but their functionality - and market value - is limited by the absence of color. To overcome this deficiency, LCD manufacturers have begun to develop reflective color LCDs.

The first examples of this class of displays, which operate in the electrically controlled birefringence (ECB) mode, are already in the marketplace. Presently, the optical performance of these displays is limited because they are only able to provide four to eight colors, including black and white. In view of the present situation, many LCD manufacturers, particularly in Japan, are developing new types of reflective color LCDs. Some of the various approaches that have been reported will be described below.

Technologies

The ideal reflective color LCD would have multicolor single pixels, since this would avoid the light losses associated with dividing each pixel into red, green, and blue sub-pixels, each of which transmits (and subsequently reflects) only one-third of the entering light. But this ideal approach is very difficult to implement because each pixel must provide a range of colors and gray levels. A technique that avoids this difficulty is to use a stack of

Sharp

Fig. 1: Sharp's reflective HR TFT-LCDs deliver enhanced performance despite using polarizers and color filters.

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three displays, with each display providing a single primary color. The main disadvantage of this method is the cost of three displays.

Consequently, some manufacturers are continuing to use color filters, but are finding ways in which to increase the brightness of the LCD. An obvious approach is to use a liquid-crystal effect that does not use polarizers, such as the dye phase-change, also known as the guest-host effect. In spite of this analysis, some manufacturers - most notably Sharp - have developed reflective color LCDs that employ both polarizers and color filters (Fig. 1).

Reflective Color ECB STN-LCDs

Simple reflective color ECB-type STN-LCDs - such as the 80 × 64-pixel plus icons, four-color displays produced by Varitronix - are already in the marketplace (Fig. 2). The technology results in multicolor single pixels that not only enhance the brightness of the display but also remove the need for expensive color filters. However, typical optical performances are relatively poor:

- Contrast ratio, 2.5:1
- Viewing angle in the vertical direction, ~30°
- Reflectivity relative to white paper, ~20%
- Number of colors, 4

The operation of these displays is based on the electrical control of the effective birefringence of the liquid-crystal material.

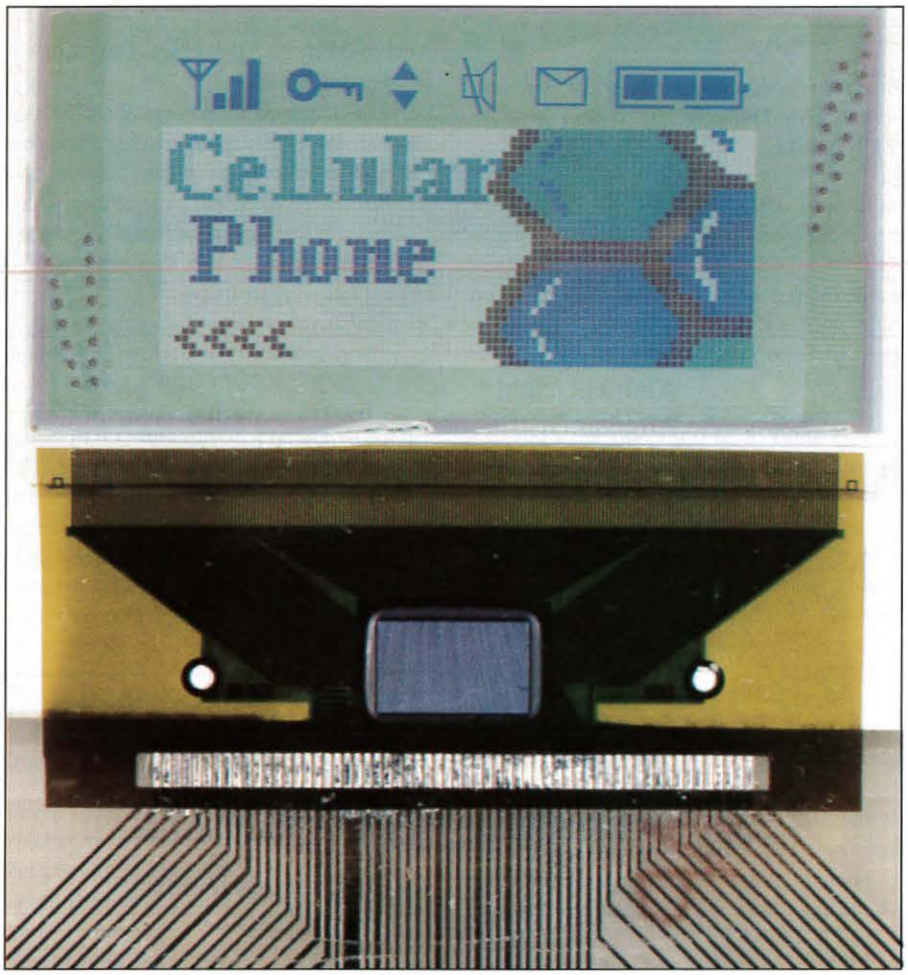
The wavelength of the light transmitted by an ECB STN-LCD having essentially crossed polarizers depends on the birefringence (Δn), thickness (d), and twist angle of the liquid-crystal layer. In a reflective color ECB STN-LCD, the effective value of Δn is changed by varying the data voltage applied to a particular display column, leading to a change in the peak wavelength of the transmitted light. The value of the product Δnd is chosen so that the peak wavelength transmitted in the non-select voltage state is in the red part of the visible spectrum.

As the data voltage is increased, the effective value of n decreases, which decreases the peak transmitted wavelength, moving it toward the blue end of the spectrum. Applying the maximum permissible data voltage produces a black pixel.

At present, it is hard to see how reflective color ECB STN-LCDs will be able to produce more than eight colors and acceptable values of contrast ratio and viewing angle. On the other hand, they are relatively low in cost and are already in the marketplace, generating revenue for their manufacturers. Nevertheless, it must be concluded that these reflective color STN-LCDs are unlikely to survive and will be replaced by one or more of the other reflective color LCD technologies that are now under development.

Table 1: Performance Specifications of the Sharp Polarizer-Based Reflective Color LCD

Dimensions (W × H × D)	210.7 × 152.8 × 2.4 mm
Pixels	[640 × RGB] × 480
Reflectivity	30%
Contrast Ratio	10:1
Viewing Angle for CR > 2:1	100° (V), 120° (H)
Number of Colors	260,000
Response Time	50 ms
Power Consumption	0.3 W
Weight	190 g



Varitronix

Fig. 2: The first examples of this class of displays, which operate in the electrically controlled birefringence (ECB) mode, are already in the marketplace.

Reflective Color AMLCDs

The great power of active-matrix addressing is its ability to address a wide variety of liquid-crystal materials. The only limitation is that these materials should have very high resistivities, typically 10^{14} Ω-cm.

A key parameter of every AMLCD technology is its aperture ratio, the percentage of the nominal pixel area through which light can pass. The larger the value of this ratio, the brighter the display. In reflective AMLCDs,

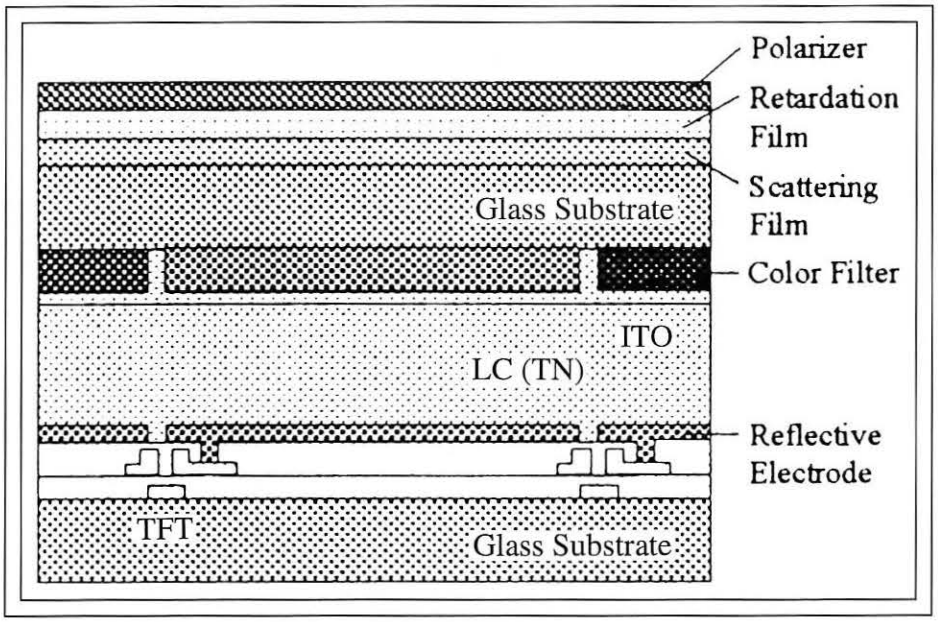


Fig. 3: In reflective AMLCDs, it is possible to increase the value of the aperture ratio dramatically by using a planarized electrode that also acts as an internal reflector. [Courtesy of Ogawa et al., SID Intl. Symp. Digest Tech. Papers, *217 (1998).]*

it is possible to increase the value of the aperture ratio dramatically - from 60 to 85%, for example - by using a planarized electrode that also acts as an internal reflector (Fig. 3).

Current work on reflective color AMLCDs can be divided into three areas: AMLCDs with polarizers, active-matrix-addressed dye phase-change displays, and active-matrix-addressed polymer-dispersed LCDs.

AMLCDs with Polarizers

One of the first approaches to reflective color LCDs was simply to use twisted-nematic (TN) displays with less efficient, and hence more transmissive, polarizers and less absorbent color filters - which is possible because in a reflective LCD the light passes through the color filter twice. But these displays were far too dark and led to the development of displays with internal reflectors, high aperture ratios, and a single polarizer.

Then, Sugiura and Uchida of Tohoku University improved the performance of the internal reflector by building a microstructure into its surface. This led to the fabrication of acceptable reflective color LCDs, such as Sharp's 8.4-in. VGA display (Table 1).

The advantage of this technology - a single polarizer with color filters and an internal reflector with a microstructured surface - is that it uses materials and processes very similar to those used for more conventional transmissive AMLCDs. But, ultimately, we should be able to produce a superior display based on a liquid-crystal effect that does not use polarizers.

Active-Matrix-Addressed Dye Phase-Change Displays

Dye phase-change LCDs, which were first reported around 1970, can provide bright images in a reflective display because they do not require polarizers. By blending appropriate red, green, and blue dichroic dyes, we can produce a black-on-white display that can be combined with RGB color filters, an internal reflector, and active-matrix addressing to provide a reflective color LCD.

The main problem with this approach is that it is difficult to obtain dyes with high resistivities, and low-resistivity dyes lead to low holding ratios and increased power consumption.

Active-Matrix-Addressed Polymer-Dispersed LCDs

Polymer-dispersed liquid-crystal (PDLC) displays are well known and provide a polarizer-free optical effect that switches between clear and scattering states. Because of these characteristics, PDLC materials have been used in projection systems, where they can provide a bright high-contrast image.

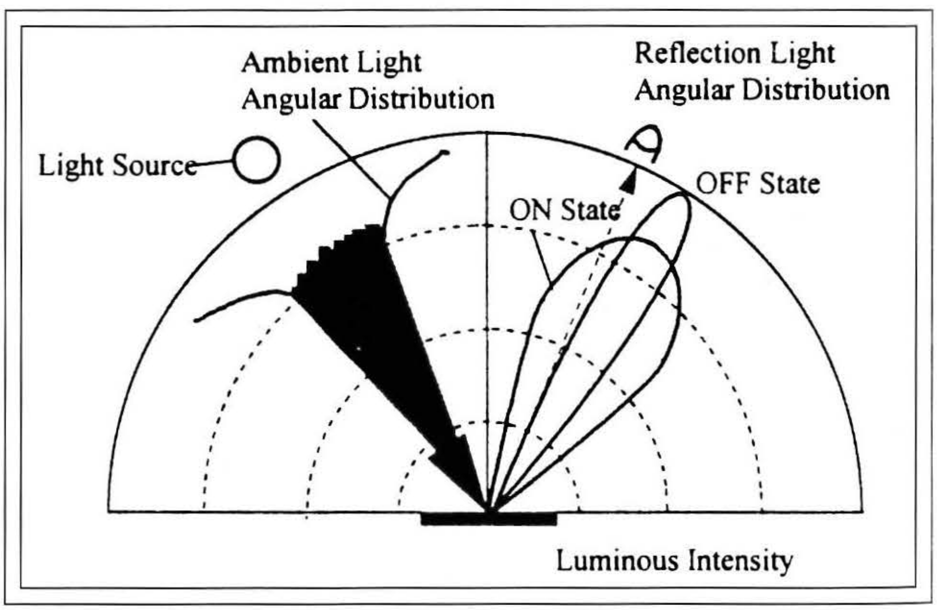


Fig. 4: In the PDLC display's non-select state, the PDLC material scatters light into the eye of the viewer. In the selected (high-voltage) state, the material is transparent, so incident light is specularly reflected from a mirror-like internal reflector and passes beyond the viewer's line of sight. [Courtesy of Sonehara et al., SID Intl. Symp. Digest Tech. Papers, *1023 (1978).]*

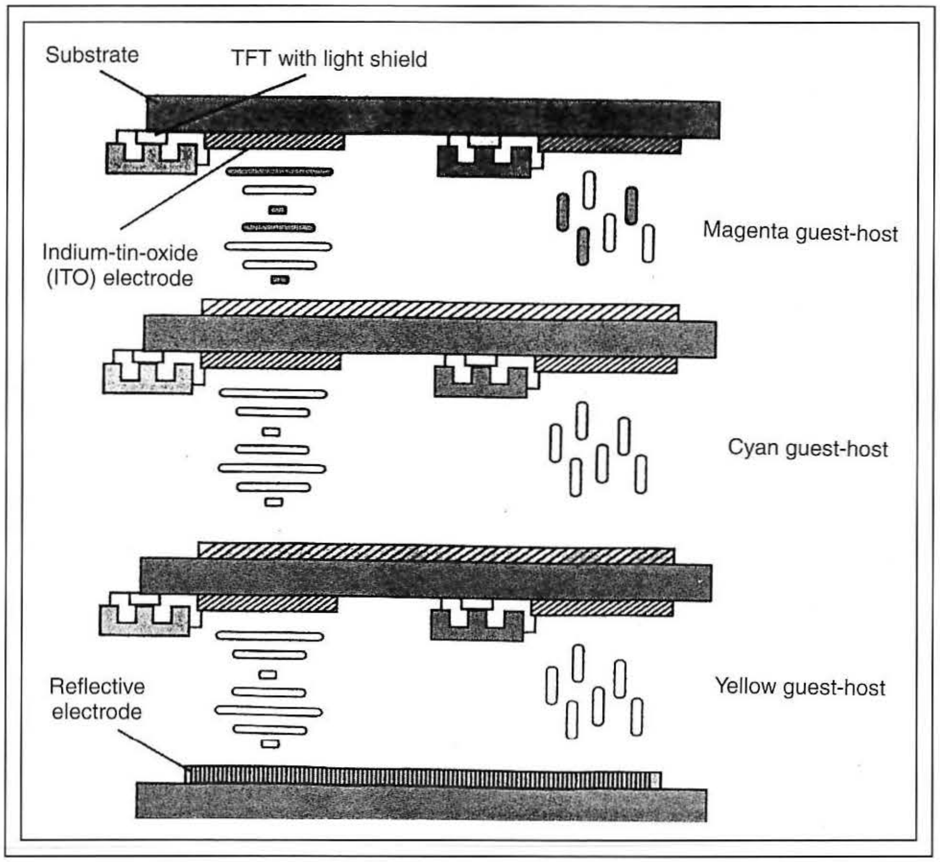


Fig. 5: In a triple-layer dye phase-change display, the dyes are subtractive rather than additive and parallax is reduced by selecting the order of the dye layers. (Courtesy of Toshiba.)

In 1997, Seiko reported using an active-matrix PDLC structure in a reflective color LCD, with MIMs being used as the switching elements. In this display's non-select state, the PDLC material scatters light into the eye of the viewer. In the selected (high-voltage) state, the material is transparent, so incident light is specularly reflected from a mirror-like internal reflector and passes beyond the viewer's line of sight (Fig. 4, Table 2).

Table 2: Performance Specifications of the Seiko PDLC-Based Reflective Color LCD

Size	5.6-in. diagonal
Pixels	[320 × RGB] × 240
Reflectivity	8%
Contrast Ratio	10:1 with collimated light 5:1 with diffused light
Number of Colors	4096
Response Time	50 ms (rise + decay)
Power Consumption	0.12 W

At present, we do not appear to have a universal method for measuring the reflectivity of LCDs. Therefore, purchasers must be careful when using published figures to judge the performance of reflective color LCDs. Subjectively, the Seiko and Sharp displays appear equally bright.

In its present form, the Seiko display has the disadvantage that it requires high voltages (of the order of 20 V) to switch the PDLC layer, but switching voltages in the range of 7–10 V have been reported elsewhere. Although the Seiko display has the advantage of being polarizer-free, it has the disadvantage that it uses color filters, which immediately reduce the level of the reflected light to 33%.

Multi-Layer Displays

By using a stack of three displays it is possible to produce a display with multicolor single pixels, thereby avoiding the light losses associated with using RGB sub-pixels. As stated above, the main disadvantage of this method is cost. Two techniques have been reported: one based on active-matrix-addressed dye phase-change LCDs and one based on the stabilized cholesteric-texture displays developed by Kent State University.

Table 3: Performance Specifications of a Three-Layer Dye Phase-Change LCD

Size	3.4-in. diagonal
Pixels	240 × 160
Reflectivity	35%
Contrast Ratio	4:1
Viewing Angle	140°
Number of Colors	512
Response Time	?
Power Consumption	?

Two significant points concerning a triple-layer dye phase-change display are that (1) the dyes are subtractive rather than additive and (2) parallax is likely to be a problem (Fig. 5). To overcome parallax, Toshiba has used 0.4-mm glass substrates and carefully selected the order of the dyes in the stack. Toshiba found that the lowest level of parallax was obtained by placing magenta at the top and yellow at the bottom. While it appears that the parallax problem is virtually solved, the fundamental problem of the relatively high cost of three displays remains. The performance of a prototype display reported by Toshiba is summarized in Table 3.

The response time of dye phase-change displays can be long, over 100 ms, because of the increased viscosity of the liquid-crystal material caused by the addition of 3–5% of dye. Toshiba did not provide a value for the power consumption of this display in a paper delivered at the 1997 SID Symposium, but they did report that the dyes had been purified to increase their resistivities.

Multi-Layer Stabilized Cholesteric-Texture LCDs

The polymer- and surface-stabilized cholesteric-texture LCDs developed by Kent State University are able to switch between reflecting a narrow band of circularly polarized light and transmitting all light. The peak wavelength of the reflected light is the product of the pitch of the cholesteric texture and its average refractive index.

By changing the pitch, we can produce structures that reflect red, green, or blue light. A 3-in.-diagonal 240 × 160-pixel two-layer device consisting of blue and yellow reflecting layers and a black light absorber was described by Kent Displays at the 1997 IDRC in Toronto. Although stabilized cholesteric-texture LCDs are able to show gray scale, the reported display did not have this capability and was therefore limited to four colors: blue, yellow, white, and black.

A Reflective Future – but with What Technology?

There are many different approaches to reflective color LCDs. At the present time, reflective color LCDs derived from ECB STN-LCDs are already in the marketplace, while those based on conventional AMLCDs are about to begin production. This is not too surprising, given the infrastructure supporting STN-LCDs and AMLCDs. It is clear that there is a very strong demand for reflective color LCDs, but it is difficult to predict which of today's technical approaches will ultimately be the most successful. ■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The Three Components of Reflection

The ambient light that reflects off a display screen can affect image quality more than the light intentionally produced by the display – but which type of reflection is the most important? This is the second in a series of articles from NIST.

by Edward F. Kelley, George R. Jones, and Thomas A. Germer

"BEAUTIFUL DARKS IN BRIGHT LIGHT." That's another way of saying that reflections from the display surface are under control. Perhaps we will see advertisements making this statement in the future (Fig. 1). But the actual meaning of such claims is vague unless the reflection properties are clearly indicated.

If we were to state only the familiar diffuse and specular reflection properties, would the specifications be adequate? Not really: we might still not know how the display will look to the eye. There are actually three components of reflection with which we must contend in order to properly describe display reflection as it is perceived by the eye.

This is not a criticism of existing reflection-measurement methods and recommended practices. Defining how an electronic display actually appears to the eye may require a more complete description than is needed for fabric or paint.

When considering reflection properties, specular (mirror-like) reflection and diffuse reflection (as seen with surfaces like common copy paper and walls painted with flat, or matte, paint) are often thought of. With specular reflection, the observed luminance in the virtual image is proportional to the luminance of the source. The luminance of reflected images in a mirror doesn't depend upon their distance from the mirror, just as the luminance of objects does not vary with distance when we observe the objects directly.

With the so-called diffuse reflection, many people think in terms of Lambertian reflection - the luminance of the surface is independent of the direction from which the surface is observed and depends only upon the illuminance of that surface. (A nearly perfect Lambertian surface is not common and is difficult to produce in practice.)

The problem here is that the display industry sometimes think that the terms "diffuse" and "Lambertian" mean the same thing, and that is generally *not* the case for displays. According to the American Society for Test-

Edward Kelley

Fig. 1: *This fictional advertisement, which specifies three kinds of reflectance, could not honestly be used to describe any display that exists today.*

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ing and Materials (ASTM), a diffuser is a surface that takes light energy away from the specular direction and distributes it in many other directions.[1] The term is not constrained to refer only to a Lambertian surface. So, it makes sense to use the term "Lambertian" for reflectance properties associated with a perfectly diffuse reflection.[2]

Four different screens showing the same-sized text with a black-and-white metal target on the front surface, to assure they are rendered equivalently in the reproduction, are shown in Fig. 2. The screens are illuminated by a 60-W light bulb in a small aluminum shade, and the bulb has a small opaque black square on its surface.

Figures 2(a) and 2(b) show cathode-ray tubes (CRTs), and Figs. 2(c) and 2(d) show flat-panel displays (FPDs). Figure 2(a) is an older CRT monitor that appears to have a medium-gray screen when turned off; the CRT in Fig. 2(b) appears dark gray when turned off. When the FPD screens are turned off, the surface of the FPD in Fig. 2(d) will appear darker than that in Fig. 2(c). Unfortunately, the limitations of the camera used and the printing of the images on paper severely restrict the range of contrast that is rendered here for all the displays, especially for the CRT in Fig. 2(b) and the FPD in Fig. 2(d).

How should these reflection properties be described so that we can understand how usable a display would be in a particular envi-

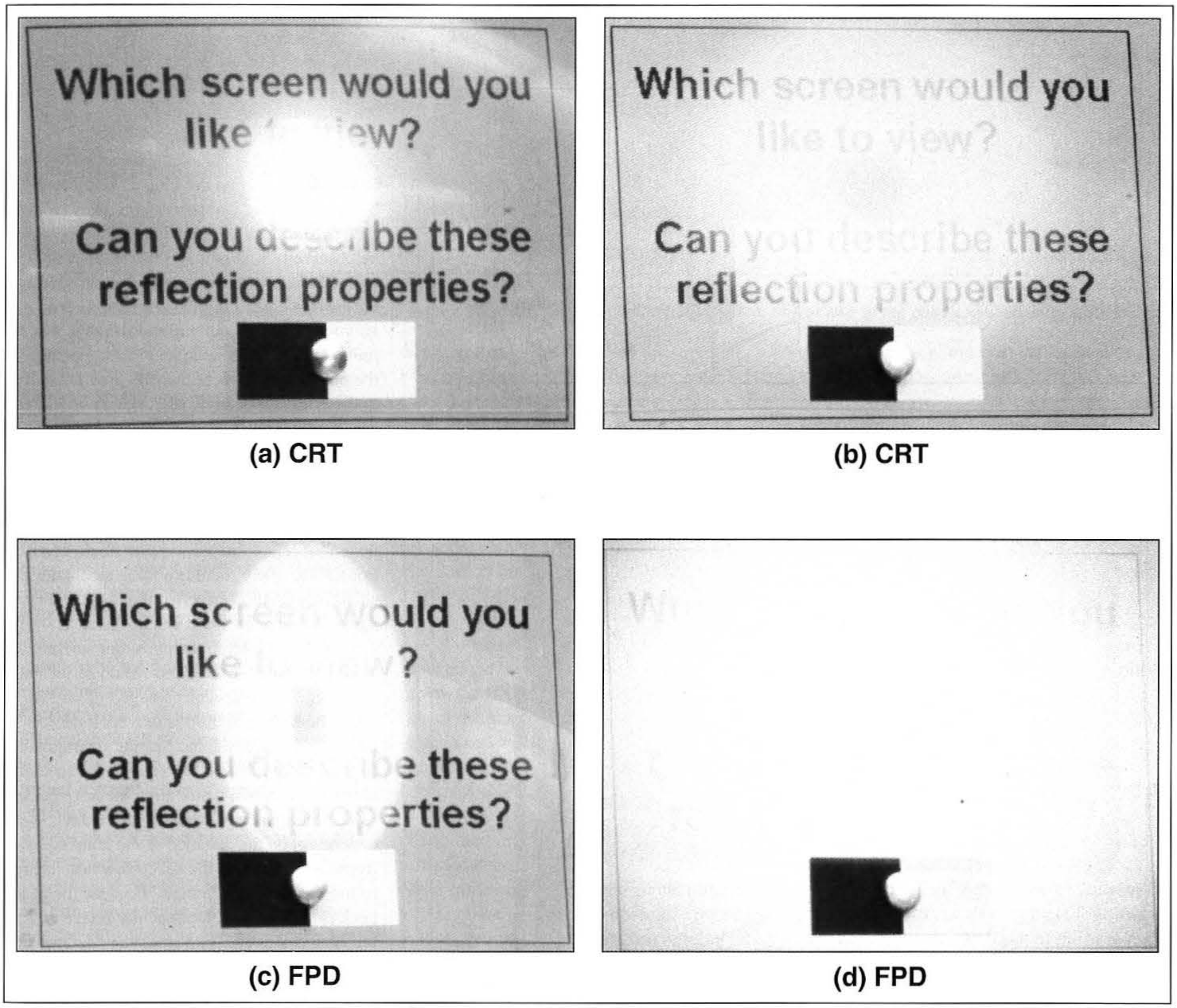
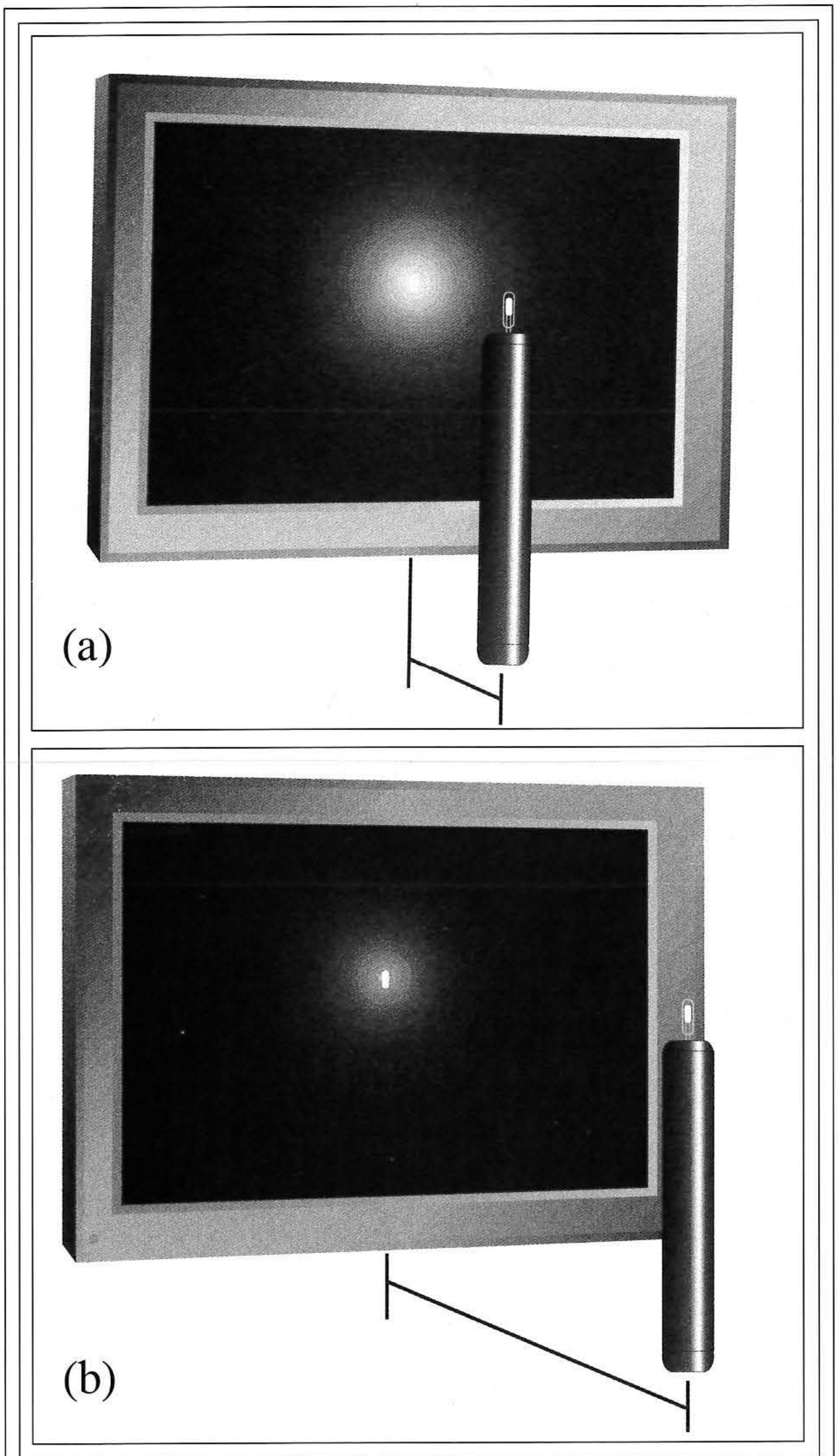


Fig. 2: These four displays exhibit very different reflection characteristics, each one representing a different combination of specular, Lambertian, and haze reflectance.



ronment and how it would appear to the eye? Would specifying the specular and Lambertian (or diffuse) components convey enough information to describe the reflected image? Probably not; something more is needed.

The best way to observe the reflection properties of a display surface is to look at the reflection of a point source of light. (With some flashlights, the head can be removed to expose the small high-intensity bare bulb. This will serve well as a point source of light.) In general, and with most CRT screens, three manifestations of the reflection of the point source can be observed (Figs. 3 and 4).

If there is a specular component, as is the case with most CRT computer monitors, a distinct virtual image of the point source will be observed. The brightness of the virtual-image point source will remain constant as the point is moved away from the screen. A general background gray that persists far away from the virtual image of the point source may also be observed. Again, this is especially true with CRTs, in which that gray background is the surface containing the phosphors. It is very much like a Lambertian surface in that its luminance remains relatively independent of the observation direction and is proportional to the illuminance upon its surface – it will get darker as the point source is moved away from the screen. If the screen has a front-surface semi-diffusing treatment, a fuzzy ball of light that surrounds the specular image can be observed. This is referred to as the haze component of reflection for want of a better term.[3] For CRTs, where there is a thick faceplate, a small fuzzy ball of haze without a specular image centered within it can be seen. This haze ball comes from the phosphor surface behind the front surface and would be located to the side of the specular image.

As the flashlight bulb is moved, it can be positioned so that the haze peaks are aligned. If a flat screen is used, decreasing the specular viewing angle will better align the haze peaks.

The luminance of the haze reflection depends upon the distance of the point source from the screen, but the haze reflection itself follows the specular image. Because the haze peak is aligned with the specular image and the luminances add, and since the haze peak

Fig. 3: *The reflection of a point source changes depending upon its distance from the display.*

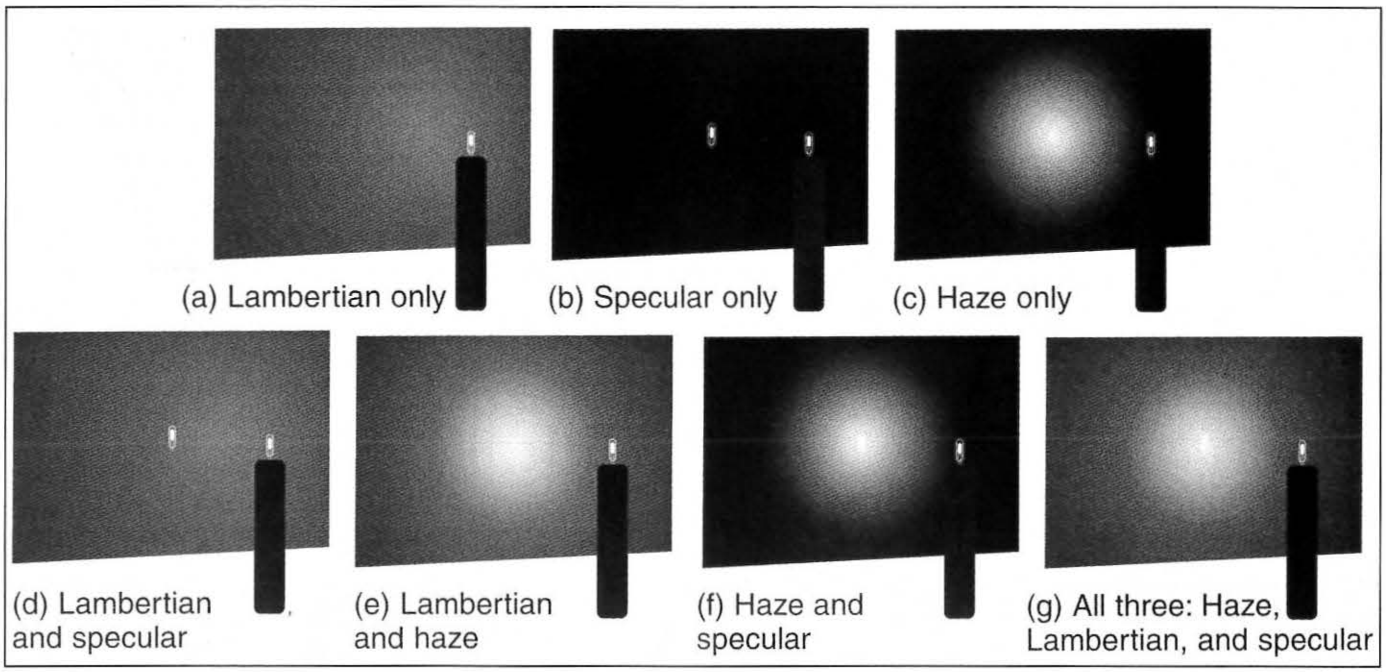


Fig. 4: Displays can have various mixtures of the three different reflection components. Often, one or two of the components can be made trivial.

decreases as the source is moved away while the specular luminance remains constant, a viewer can get the impression that the specular image is decreasing in luminance as the source image moves away, which is not the case.

So three types of reflection associated with displays can be seen: the general background-gray Lambertian component, the specular component having a distinct image of the source, and the haze component - the fuzzy ball of light that follows the specular image. The haze component is like the Lambertian component in that it is proportional to the illuminance, but the haze component is also like the specular component in that it is peaked in the specular direction. The haze is the reflection property that exists between the two extremes represented by specular (with a distinct image) and Lambertian.

Another way to see the three distinct reflection components is to direct a laser beam at the surface and allow the reflected light to illuminate a large white card - all in a very dark room (Fig. 5). The general, usually very soft, illumination of the whole card is the Lambertian component. The sharp point of light is the specular component, and the fuzzy ball of light around the specular point is the haze component.

Measuring What We See

Observing the three reflection components is one thing; measuring them accurately is another matter. If all we had to deal with were the specular and Lambertian components, reflection characterization would be simple. However, the existence of haze requires us to employ more sophisticated methods, such as the bidirectional reflectance distribution function (BRDF).

The BRDF is the directional dependence of the ratio of the reflected luminance to the incident illuminance. Since the observation direction and the illumination direction can be different, the BRDF is a four-dimensional function of the incident and reflection angle. If we were to add wavelength dependence and polarization dependence, the BRDF would become a six-dimensional function.

When we look at the reflected luminance distribution of a point source or observe the reflected distribution of a laser beam on a white card, we are viewing a geometrical distortion of the BRDF. It is obviously possible to look through a small-aperture viewing tube fixed in space (to make sure we only look at the same point on the screen) and move a point light source around (Fig. 6). Suppose we constrain our apparatus so that the tube and source are in the horizontal plane.

If the eye could measure the luminance and all three components of reflection that were present, we could measure the in-plane BRDF and get results similar to those shown in the plot of Fig. 6. As the point source approaches the specular direction, the luminance dramatically increases as we move up the haze peak - note the log scale - until the bright specular image of the bulb comes into view. To turn this conceptual apparatus into an instrument, we would need to replace the eye with a detector, calibrate the apparatus, and apply a cosine correction to the point-source illuminance as it is moved away from the specular direction.

But using a point source is not the best way to measure the BRDF. If we can account for (or avoid) the effects of veiling glare in a camera system, a photograph of the reflection of a point source might be a useful way to supply a measurement of the shape of the BRDF. The best methods, however, use lenses and practical light sources.[4] If these goniophotometric methods are not followed carefully, however, the result of the haze measurement may be ambiguous because the result can depend upon the distances of the source and detector from the screen, apertures of the source and detector, and the foci of the detector and source.

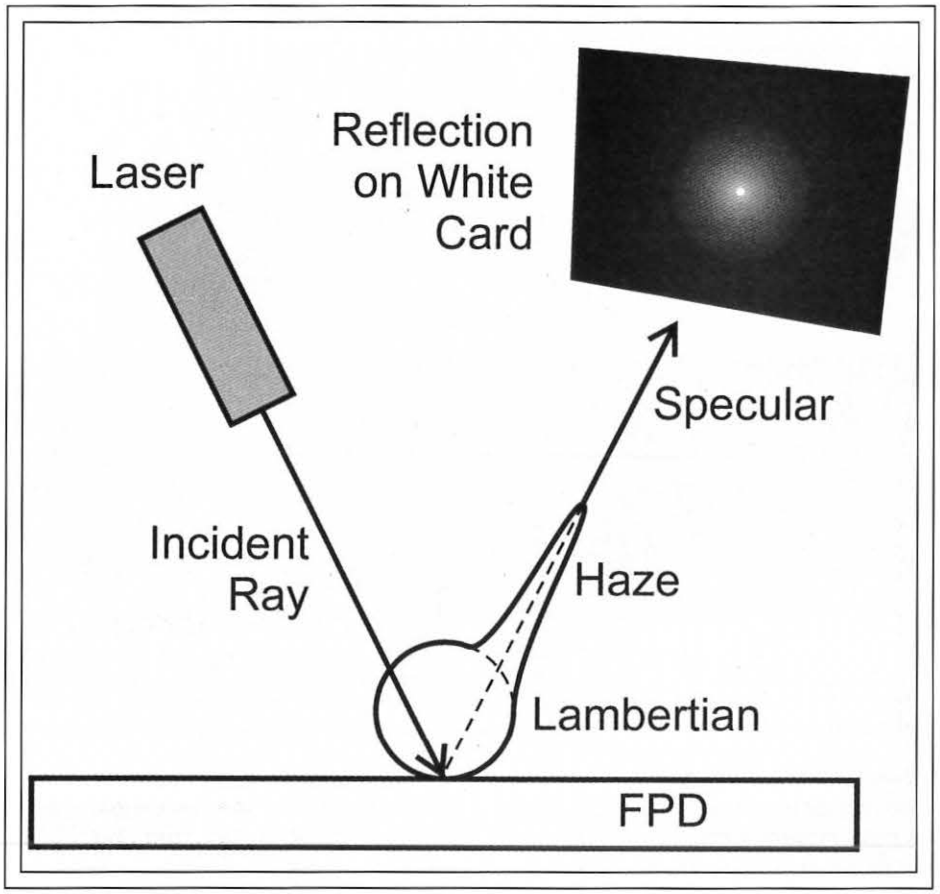


Fig. 5: The different reflection properties can also be manifested by the reflection of a laser beam onto a white card in a very dark room.

Those who measure BRDFs often fix the light source and move the detector. There is little difference in the BRDFs obtained by moving the source or moving the detector as applied to displays, provided that the specular angle - the angle from the normal - of the fixed part of the apparatus is small. When measuring the BRDF in a plane, the light source will obscure the detector (or the detector will obscure the light source) for some range of angles, and no data will be obtained. An idealized apparatus would be obtained if the detector and source were so infinitesimally small that they would not interfere with one another, and a BRDF could thus be obtained based on the normal direction and not some off-normal specular configuration.

For displays, the BRDF is almost always symmetric in any single plane aligned with the normal of the screen, but the haze need not be rotationally symmetric about the specular direction. If there is a pixel matrix beneath the front surface, the haze may have spikes in several planes (most often either the horizontal or vertical planes, or both, and sometimes in planes at 45% from the horizontal plane).

One advantage of displays is that the haze profile doesn't change dramatically as it is viewed from different angles. This can be seen by moving the flashlight point source around (keeping the head fixed at the normal of the display) so that the haze reflection is viewed in all parts of the screen. Thus, a center-screen measurement of the BRDF is a sufficient specification of reflection in most cases.

The beauty of the BRDF is that, once obtained, it permits the calculation of how a display will appear in its environment, based upon the distribution of light sources in the room. In fact, that is the goal of this research: to provide a method of characterizing the BRDF parametrically in order to permit an adequate characterization of the three components of reflection so that the performance of a screen can be calculated for any given environment. Research is currently under way to provide simple methods to parameterize the BRDF using simple instrumentation that does not require complicated goniophotometric data collection.[5]

Ultimately, we might expect to see four or five parameters required to specify reflection: the Lambertian component, the specular component, the peak of the haze component, some width measure of the haze component, and perhaps a shape parameter associated with the haze component. Probably the first three parameters will tell the main story, as in the fictitious advertisement at the beginning of this article, but three parameters are insufficient to permit a calculation of the reflected luminance in a given ambience.

If we were to go back to Fig. 2 and try to describe the reflection properties, this is what we would say. In Fig. 2(a), the CRT has a moderate Lambertian component, with a strong specular component and a front-surface treatment that produces some haze. In Fig. 2(b), the CRT has a much lower - but still not trivial - Lambertian component, very little haze, and a reduced but significant specular component. The reduction in the specular component from Fig. 2(a) to Fig. 2(b) is accomplished by a multi-layer anti-reflection coating applied to the front surface. The FPD in Fig. 2(c) does not display well in the photo, but it has only a haze component. The specular and Lambertian components are at least four orders of magnitude lower than the haze peak. The only non-trivial component in the FPD in Fig. 2(d) is also the haze component, but the peak of this haze component is reduced by the application of a multi-layer anti-reflection coating.

All of the preceding tells us that the metrology of display reflection is not a simple matter. We have discovered something disturbing but extremely useful: it is no longer adequate to limit our thinking to two types of reflection, diffuse and specular. Rather, there are three distinct components of reflection perceived by the eye when using electronic displays. Further research should clarify and simplify the complications associated with display reflection metrology.

References

[1]*ASTM Standards on Color and Appearance Measurement,* American Society for Testing

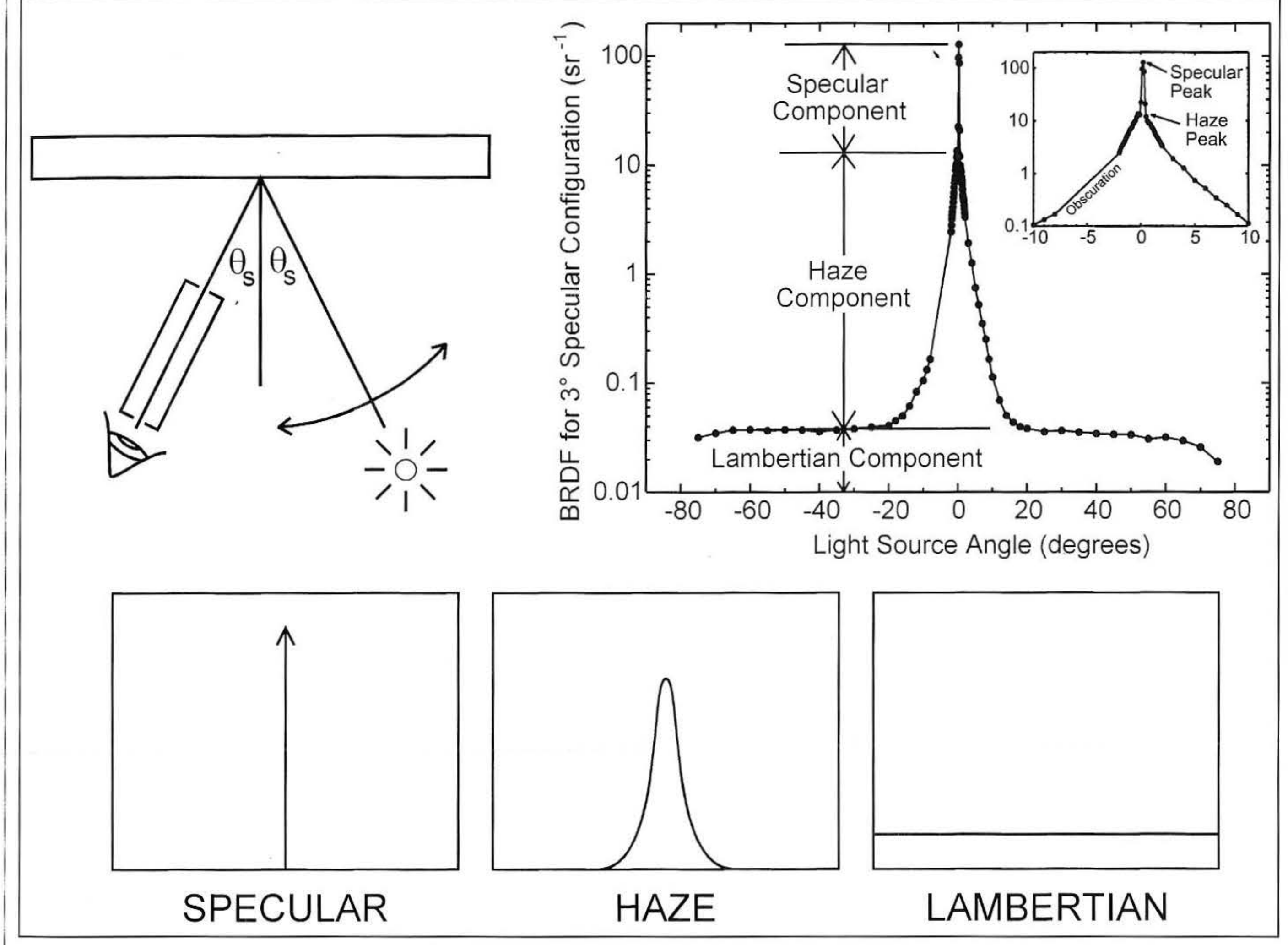


Fig. 6: This simple apparatus can be used to observe the reflection characteristics from a point source of light. Just as the three different components are distinctly visible to the eye, they are readily apparent in a bidirectional reflectance distribution function (BRDF).

and Materials, "Standard Terminology of Appearance," E284 95a, pp. 235-252.

[2]Michael Becker has recommended the use of the term "Lambertian" in this three-component model to avoid any confusion that may arise with using the term "diffuse." See Michael Becker, "Evaluation and Characterization of Display Reflectance," *Displays* **19**/1, 35-54 (June 30, 1998).

[3]ASTM, *op. cit.*, "Standard Test Method for Visual Evaluation of Gloss Differences Between Surfaces of Similar Appearance," D4449-90 (reapproved 1995), pp. 178-182.

[4]ASTM, *op. cit.*, "Standard Practice for Goniophotometry of Objects and Materials," E167-91, pp. 206-209.

[5]E. F. Kelley, G. R. Jones, and T. A. Germer, "Display Reflectance Model Based on the BRDF Displays," *Displays* **19**/1, 27-34 (June 30, 1998). Also see the VESA (Video Electronics Standards Association) *Flat Panel Display Measurements Standard* (FPDM), sections 308 and A217 for more details on the complications of display reflection metrology (www.vesa.org). ■

Temperature-Compensating Shadow-Mask Mounting

As high-performance CRTs are produced in increasing numbers and in geographically diverse locations, advanced mounting technology is helping CRT makers achieve better images at lower cost.

by Keith Wheeler

THE CONTINUING GROWTH OF CRTS is being fueled by advanced digital television (ADTV) and high-resolution computer-monitor applications. Cost considerations dictate that a growing percentage of these units will be built in Asia and along the Pacific Rim. For example, current CRT market share for countries such as China, India, and Mexico is about 19%. This share is expected to grow to 29% by 2006.

The manufacturing technology for producing cathode-ray guns and tubes is widely known. But a problem arises when CRTs with lower color-purity performance are used in more demanding applications, such as color computer monitors.

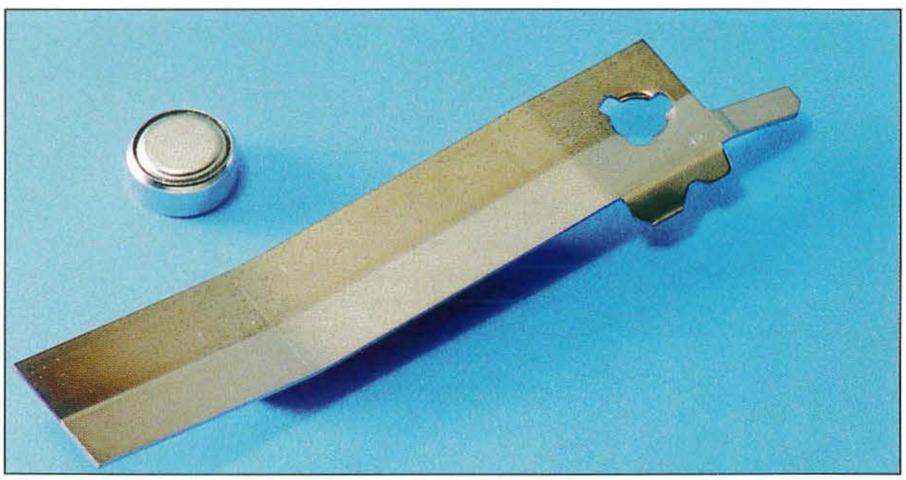
Solving Color-Purity Problems

Color-purity problems arise as a result of the mismatch in the temperature coefficients of expansion of the metal used in the CRT aperture mask and frame, and the glass of the CRT itself, all of which expand as the CRT heats up in service. This is a major issue in color purity because the metal mask controls the landing positions of the electron beams from the electron guns.

The mask contains fine apertures through which the electrons must pass to illuminate the screen. The phosphor dots or stripes on the screen glow when excited by the electron beam, thus forming the screen image. CRTs heat up in use, and most metals expand faster than glass. If the metal mask and frame assembly expands in a way that causes geometric distortion, color purity is affected.

An early solution to the thermal-expansion problem was to use a special high-nickel-content low-expansion alloy called Invar for the mask. Invar was the common choice of mask material when thermal compensation was first used as a solution for the mask/panel distortion problem, and its good thermal-expansion match with glass often meant that no additional compensation was needed.

But with customers demanding sharper pictures, color-TV screen sizes growing larger, and CRTs finding broader use in computers, even the close match of Invar's temperature



TI CRT Components

Fig. 1: In clad bimetal-strip thermostats, each of the two metals thermally expands at a different rate, causing the composite device to bend at a predetermined rate and force for any temperature. In CRT applications, the separate metal elements are electron-beam welded side by side.

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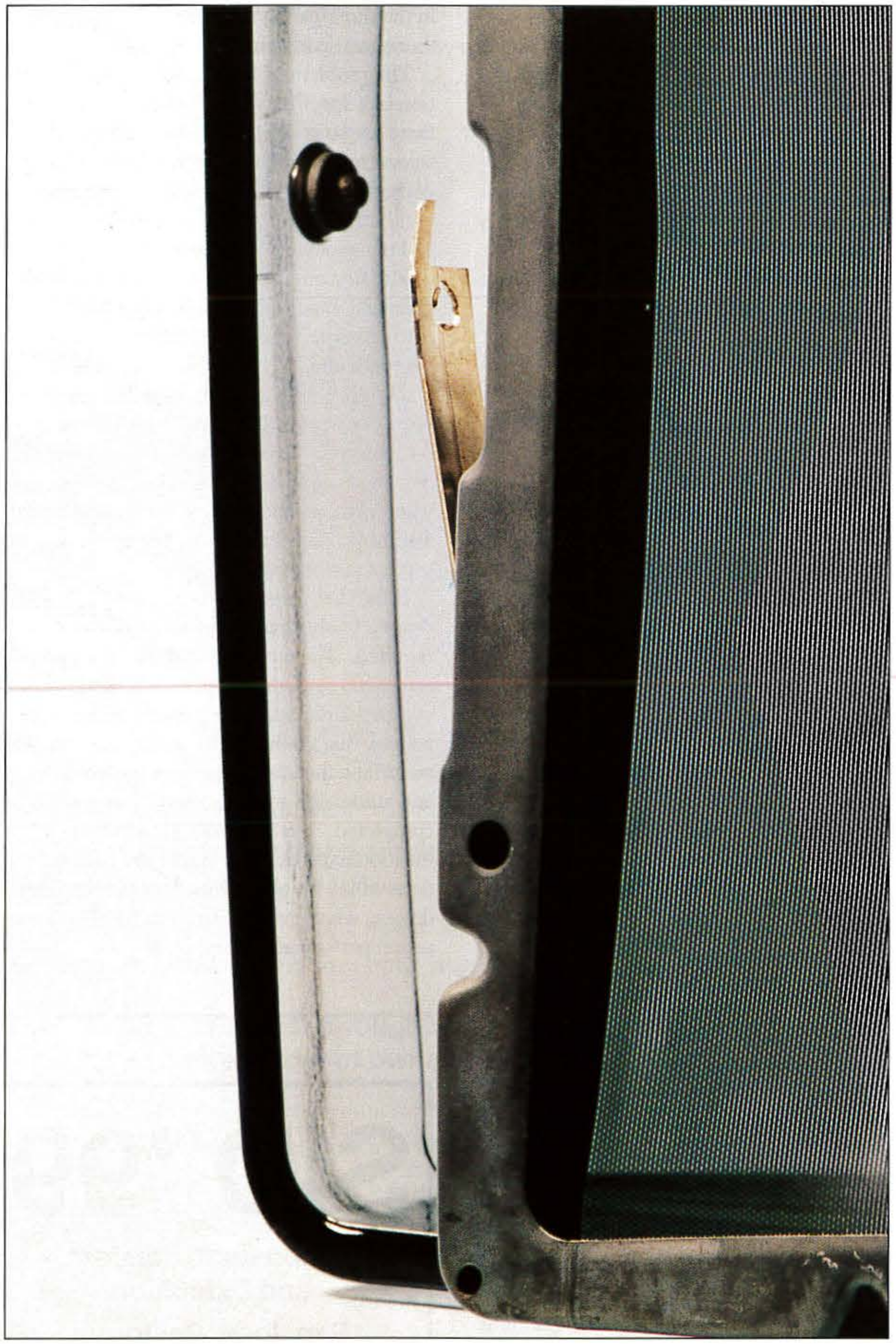
coefficient of expansion to glass became inadequate to meet the demands for greater color purity. Initially, stainless-steel clips were used at the sides or corners of the masks to solve the problem. To achieve even higher image quality, manufacturers began to use thermostatic metal components, which provide more precise dimensional control.



TI CRT Components

Fig. 2: This bimetallic temperature-compensating clip has been fastened to the mask frame and will be attached to the mounting lug on the CRT prior to final assembly and sealing of the CRT bulb.

CRT manufacturers, particularly new or inexperienced ones, sometimes copy a successful compensation design from another manufacturer who has already solved the thermal-expansion problem. Unfortunately, these designs may be out of date and may continue to use Invar for the mask material.

Experienced CRT manufacturers have sought less-expensive alternatives, such as substituting aluminum-killed (AK) steel as the mask material. But AK steel has a much higher thermal-expansion coefficient than glass, so using it usually calls for sophisticated design measures to compensate for the increased thermal-expansion mismatch.

Makers of high-quality CRTs have developed a wide knowledge of compensation technologies over the years, but newer manufacturers are often not aware of these techniques. In fact, only a few companies are familiar with sophisticated engineering approaches to the thermal-mismatch problem. They are usually large, high-quality manufacturers of television sets and computer monitors who have had the time and resources to devote to these engineering solutions. This engineering knowledge invariably includes an understanding of bimetallic thermostats.

"As CRTs have faced constant pressure to increase color purity and lower costs, knowledge of thermostat compensation technology has had to keep pace," says Paul Galipeau, product engineer at Texas Instruments' CRT Components business unit. "Many new tools, such as mathematical criteria to predict the performance of various thermostat-metal combinations, are now available to take advantage of years of development experience."

Different Solutions for Different Problems

Thermal-compensation designs generally vary from manufacturer to manufacturer. Some use Invar masks with or without thermostatic devices in the mask/frame assembly. Other manufacturers use AK-steel masks, which require thermostatic compensators with varying levels of sophistication.

Older designs usually fall into one of two general categories:

- Invar is used as the mask material, with or without compensation clips.
- An AK-steel mask is used, but the compensation device is either too costly or does not meet the customer's current image-definition quality requirements.

A CRT manufacturer satisfied with its Invar screen can often achieve some material cost savings and/or superior performance by updating its stainless-steel-spring design. This will sometimes require relocation of the spring in the mask/frame assembly. It is possible to further increase savings by a complete redesign, including replacement of the Invar mask by an AK-steel mask.

A manufacturer that already uses AK-steel masks may encounter problems because the design of the thermostatic compensation device does not provide adequate color purity for its customers' applications.

There are several levels of engineered solutions, from the simplest to the most complicated. It depends on the goal of the CRT manufacturer and the extent of the "purity drift" and/or reject rate he is able to tolerate. Purity drift refers to how far away the electron beam's landing point has wandered from its initial target. This is measured over time as the CRT heats up. Acceptable purity drift is measured in microns and varies according to application: less than 6 μm is a common goal for a computer monitor; 20 μm may be tolerable for a color TV.

CRT manufacturers whose purity-drift performance is outside of acceptable limits sometimes seek outside design help. TI's CRT Components business unit is one source of such services. (TI invented the first thermal-compensation device in cooperation with RCA.) TI's Galipeau says, "After we have completed the appropriate engineered solution, the CRT manufacturer typically gains a net cost savings of 20–30% over his previous compensation device." Savings as high as 40–45% have been achieved when the CRT manufacturer is able to move from an Invar to an AK-steel mask as well, he added.

An effective compensator design involves the selection of a thermostat-material combination, general design, and appropriate clip locations based on analytic techniques and design experience.

The Design Cycle

Most engineers are familiar with thermostats as clad bimetal-strip devices. Each of the two metals in the composite thermally expands at a different rate, causing the composite device to bend at a predetermined rate and force for any predetermined temperature. These devices have been widely used for many years in household thermostats, temperature controllers for appliances, over-voltage protectors for motors, and many similar applications.

In CRT devices, the separate metal elements are electron-beam welded together side by side to become the critical thermal element in the three-part system of mask, frame, and thermostat compensator (Fig. 1).

The problem of finding an appropriate solution in a specific case is formidable because there are so many thermostat materials to select from, and actual performance also depends on factors such as the length and width of the part, the location in the assembly, and the geometry of the compensator.

The first engineering step is to analyze the present compensator in terms of spring force, material type, hardness, thickness, spring length, width, and location in the overall mask/frame assembly. Acceptable results are often possible by selecting a more suitable compensation material or by redesigning the device to achieve more accurate compensation – and perhaps relocating it in the mask/frame assembly. This may be all that is necessary to solve a customer's problem.

If the first-stage effort does not achieve the desired goals, thermostat-metal designs are required. The customer can then use prototype parts to evaluate the results in terms of compensation and spring force. From these results, fine tuning of the compensator design, material adjustments (perhaps alloy ratios), and automated-manufacturing features can be completed. The compensator attachment location is particularly important because it determines the active length of the thermostat device, which permits fine tuning of compensation performance (Fig. 2). ■

It Takes a Worried Man to Sing a Worried Song

Worried songs were sung as the Taiwanese dollar and stock market fell in value daily during Computex Taipei 1998 – but local monitor manufacturers put on a brave face and showed off their new products.

by Bryan Norris

THE GLOOMY ECONOMIC CLIMATE of Taiwan was reflected in the statistics for Computex Taipei '98, held this year June 2-6. When applications for a stand at the show closed back in October 1997, 996 companies had applied. In the end, there were only 892 exhibitors.

This number actually constituted an increase of 3.1% over the previous year, when 865 companies were present. But since the rise was markedly smaller than the double-digit increase expected - the number of exhibitors in 1997 was up 20% from the previous year - the organizers were still disappointed. And the disappointment nearly turned into despondency when visitor numbers for the first day were down by about 2000 from 1997.

But it wasn't only the organizers who went home feeling depressed after the first day. The demise of the magazine *Byte* meant the absence of the prestigious "Best Products at Show" awards, normally announced at a presentation on the first day. This absence meant that certain members of the press were equally down, since they had become accustomed to having the "noteworthy" exhibits found for them and realized this year they would have to do some real work to come up with their articles.

But for the organizers at least, spirits rose later in the week when visitor numbers for the first 3 days (13,281) exceeded those of the preceding year (12,373), and 16,225 "overseas" visitors (viewed as potential buyers)

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CETRA Press Office

***Fig. 1:** A number of the monitor suppliers at Computex Taipei grouped together in Section D of the main exhibition hall.*

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Fig. 2: *Proview's stylish MT-500, a forthcoming entry in the 15-in. category, was exhibited in a special grouping of Taiwan's "most prestigious IT companies" in Stella Hall.*

attended the show overall compared with 15,761 in 1997. The number of overseas exhibitors was down only slightly (by 6) to 87, representing 15 countries: the largest contingents from the U.S.A. (45 companies), Singapore (12), Hong Kong (11), and Japan (5).

The Gloomy Economic Background

The Taiwanese dollar (NT$) fell continually during the show week on its way down to an 11-year low against the U.S. dollar in mid-June – a 20% plunge since the Asian crisis began last summer. Taiwan's TWSE Index also fell to a 5-month low on expectations of poor earnings from Taiwan Semiconductor Manufacturing Co. and other computer-related companies. And the all-important electronics sub-index – the IT sector is the largest industry in Taiwan – had its biggest fall in eight months!

Compared to the other countries affected by the "Asian crisis," the circumstances in Taiwan are still relatively favorable because the country is debt-free and has a strong manufacturing base. Nevertheless, the economic situation remains precarious, especially since Taiwan's manufacturers are heavily dependent on demand from U.S. PC houses, and cutbacks there are of major concern. The U.S. is Taiwan's largest IT export market, accounting for 41% of the total (followed by Europe with 29% and the Asia-Pacific region with 19%), and forecasts of cutbacks by major U.S. players, such as Intel, Compaq, Dell, and IBM, directly affect the Taiwanese electronics industry.

Monitors make up the largest share of Taiwan's total IT hardware production: In 1997 they accounted for 28.1% of production by value (with notebooks next at 22.5%). According to figures gathered by the Taiwanese CRT producers, 1997 monitor production in Taiwan reached 43.1 million units, an increase of over 19.6% compared to 1996. Around 55% of these units were made in overseas plants, compared with around 48% in 1996.

The monitor manufacturers in particular are looking nervously at the U.S. situation – and not simply because of U.S. cutbacks. They are also worried that OEM orders from U.S. and major European PC houses will be transferred to Korean suppliers as a result of the huge drop in the won against the U.S. dollar.

In 1997, Taiwan's monitor companies enjoyed a 33.6% share of the world computer-monitor market compared to the 20.9% taken by the Korean suppliers. But in 1998, the Korean share is expected to increase by at least another 5%! This expected transfer to Korea's manufacturers will make the task of increasing own-brand model sales in the U.S.A. and Europe even harder for Taiwanese suppliers. And this is already a challenge, even for the established Taiwanese monitor suppliers.

So how are the Taiwanese manufacturers faring so far this year? In terms of U.S. dollars, for Q1 '98, Taiwanese monitor sales

CETRA Press Office

Fig. 3: SlimAge showed its 14-in. Model 610A and 15-in. Model 710A TFT-LCDs in contrasting modern and traditional cabinet designs.

were down in value by 13% (to US$1.9 billion) compared to the same period in 1997, according to the government and industry-backed research group Market Intelligence Center. This is despite a 12.6% increase in sales volume, which is explained by the fact that prices have continued to plummet. According to an article in the *Asian Wall Street Journal* that appeared on May 4, 1998, prices in Q1 '98 fell by 22% on average. This, together with oversupply and the popularity of cheap products, has led to the fall in profits. Actually, in Taiwanese dollar terms, Q1 '98 sales were slightly up on the same period last year, albeit by just a few percent. But even this was disappointing compared to the usual double-digit year-on-year growth.

Down – But Not Out

Because of the economic worries, monitor exhibitors at the show were more reserved than in previous years and were devoting most of their headline promotions to other products - such as notebooks, scanners, digital cameras, and LCD projectors - which will hopefully command greater profit margins. Having said that, the manufacturers were not going to miss the opportunity of showing off their newest monitor offerings. Therefore, Computex Taipei still proved the best venue to learn in detail what the Taiwanese VDU makers are offering.

Most of the monitor suppliers were located together in the first part of the D section of the main exhibition hall in the Taipei World Trade Centre (TWTC), where a newly reorganized stand area had been created (Fig. 1). But Taiwan's "most prestigious IT companies" were allocated large rooms in the Stella Hall - Home of the Stars - of the Taipei International Convention Centre (TICC), located across the road from the TWTC. These included the display manufacturers ***Action (Axion), AOC, Chuntex (CTX), Compal, GVC, Mitac, Proview, Tatung,*** and ***Teco*** (Fig. 2).

On the Computex Taipei Web site, 64 exhibitors were listed as supplying color CRT monitors. The catalogs and product brochures collected from the booths of 43 of the Taiwanese CRT-monitor makers list some 435 different models. Of these, just 15% (67) were 14-in., 29% (125) were 15-in., and 30% (129) were 17-in. This was the first year in which 17-in. models constituted the largest sector of monitors on offer. A further 5% (21) were 21-in. models, and 8% (33) were current (or expected) 19-in.!

Will 19-in. Models End the Worries?

The future definitely holds out the promise that CRT units with larger screen sizes will increase in importance. In a pattern seen at CeBIT '98 in Hannover, Germany, in March, the trend was definitely toward models with larger CRT screens - notably the 19-in. In fact, last year's show had seen the advent of the 19-in. CRT monitor in prototype form, so by this year's show companies were able to promote second-generation 19-in. versions.

The more established 19-in. suppliers - such as ***Acer, ADI, CTX, Forefront, MAG, Royal,*** and ***Sampo*** - were displaying their models, all using the ubiquitous tube from ***Hitachi.*** Indeed, most of the forthcoming 19-in. models from Taiwanese suppliers will employ the Hitachi tube, though some new models, particularly those destined for the OEM market, can also be fitted with alternative 19-in. tubes. For example, ***Compal***'s M990, which had previously been sold with an Hitachi tube, was fitted with a microfilter tube from ***Toshiba*** on the company's stand. (Compal is promising three new 19-in. models by Q1 '99.)

Leading-edge OEM-only supplier ***AmTRAN*** offers a variety of tubes in its models. In its Grand Hyatt Hotel suite, AmTRAN showed off two 19-in. models: the AT1097F with an Hitachi tube and the AT1097D with ***Mitsubishi***'s "Natural Flat" Diamondtron™ aperture-grille tube (available in Q4 '98). And in one of the product lists obtained in the suite, a future NEC 19-in. CromaClear™ tube was introduced. MAG confirmed that it will have a 19-in. with the Mitsubishi tube available by the end of 1998.

As at CeBIT, non-Taiwanese exhibitors ***Samsung*** and ***Panasonic/Matsushita*** showed their own models that use their own-make 19-in. tubes. Some Taiwanese makers are expected to take advantage of these tubes. For example, ***ViewSonic*** is to have the 100% "short-neck" - more accurately, "reduced-length" - Panasonic/Matsushita 19-in. tube in its PS790 model. The short length allows this monitor (and others) to offer an extremely small footprint. And ***Teco*** is planning to produce a second 19-in. model as a basic low-end unit that will probably use the Samsung tube. At the time of the show, this would reduce the selling price from the current US$460 to US$410. ***Proview***'s current 19-in. uses the Hitachi tube but may also house the Samsung in the future.

Abandoning CRTs?

Apart from parading the 19-in. CRT models, the manufacturers were also getting down to the show's other main monitor business: the promotion of LCD monitors, especially 14- and 15-in. models. As witnessed at CeBIT, Taiwanese monitor makers are looking to LCDs to provide them with a worthwhile return on their investment.

A few of the exhibitors at the show talked about the possibility of withdrawing from the manufacture of CRT monitors altogether in order to concentrate on making LCD models. One company which has already done this is ***Mitac,*** which confirmed that its production of CRT monitors had now ceased and its displays department will now concentrate on building and selling a range of LCD models.

Although some suppliers still offer STN units, most are backing TFT-AMLCDs. On the Computex Taipei Web site, 60 exhibitors were listed as supplying some kind of LCD, and approximately 30 of these were promoting current or promised TFT-AMLCD monitors. A look at those listed reveals that the 15- and 14-in. units are by far the most popular LCD screen sizes. Over a third of the LCDs (47, or 35%) fell into the 15/15.1-in. category and 19, or 14%, fell into the 14/14.1-in. category (Fig. 3).

In addition, Computex Taipei held out the promise of 18-in. LCD models before the year is finished, though the facts concerning the forthcoming 18-in. models were somewhat tentative. Prototype units could be seen on the stands of ***AmTRAN, CTX, Singaporean DMC/GES, Lite-On, MAG, Mitac, Teco, Topvision,*** and ***ViewSonic.*** On the ***Samsung*** stand, an 18-in. was on show as well as a 17-in. LCD monitor, both fitted with Samsung panels. Stand personnel were unable to clarify whether both sizes would become commercial items, but the 17-in. may well be quietly dropped.

The growing popularity of LCD monitors is clearly tempting new players into the business. ***Topvision*** is a newcomer to the displays industry, having been founded in April 1997. In a presentation introducing the company, Topvision declares itself to be "the company that is dedicated to the LCD monitor and flat-panel display technologies." Another new player on the scene was ***Twinhead,*** the well-known notebook maker, which was also showing a forthcoming 15-in. TFT-LCD model. As a senior figure on the Twinhead stand commented, "We have been used to assembling LCD panels into notebooks, so putting them into monitors is a logical and easy thing to do to extend our product range."

But if PC manufacturers are looking at monitors, the monitor suppliers are also looking at PCs, and there were a number of LCD-PCs being displayed at the show. ***Mitac*** has been making all-in-one LCD-PCs for a considerable time. In Taipei, Mitac positioned its latest LCD-PC, the ECO, in a prominent position on the center stand of the room. The new model has the option of a rotating 15- or 13.8-in. TFT-LCD screen and a variety of Pentium® processors. (The Fujitsu LCD-PC sold in Europe is recognizable as a Mitac-made product.) And a ***VGO*** LCD-PC model was widely advertised in various magazines as "the most powerful all-in-one LCD PC in the world." (VGO is the brand name of notebook manufacturer ***Y.C.L. International Technology*** and the model itself was on display in a Grand Hyatt Hotel suite.

What's Coming?

The VDU suppliers of Taiwan are not blind to the signs that indicate they will face extremely difficult trading conditions in the year ahead: intense competition in the OEM sector, where low-priced won-based products are now available from Korean suppliers; greatly reduced markets in the troubled Asia-Pacific region; restrained "branded" markets in Europe and the U.S.A.; and the resulting sharp fall in prices!

But Computex Taipei demonstrated that despite difficult times the Taiwanese monitor manufacturers are still keenly researching, designing, producing, and presenting a multitude of monitors - both CRT- and LCD-based - in a sustained effort to maintain their position as suppliers of over half the world's monitors. We will no doubt find out how well they have managed to maintain this position at next year's show, to be held June 1–6, 1999. Still, at the very least, the organizers, CETRA, are optimistic that the local IT industry will weather any current storms. They talked of adding another exhibitor hall for next year! ■

calendar

Display Technology

The Sixth Color Imaging Conference. Sponsored by IS&T and SID. Contact: IS&T, 7003 Kilworth Lane, Springfield, VA 22151; 703/642-9090, fax 703/642-9094, e-mail: info@imaging.org.
Nov. 17-20, 1998 Scottsdale, AZ

Flat Panel Display Devices Symposium at LEOS '98. Contact Paul E. Burrows, Princeton University, 609/258-4454, fax -1954, e-mail: burrows@ee.princeton.edu.
Dec. 1-4, 1998 Orlando, FL

7th International Symposium on Advanced Display Technologies. Organized by the Belorussian and Ukrainian Chapters of the Society for Information Display in cooperation with the Belorussian Ministry of Education, Belorussian State Committee on Science and Technologies, the State University of Informatics and Radioelectronics, and the Scientific Production Corp. "INTEGRAL." Contact: Prof. A. Smirnov, tele/fax +375-17-239-88-58, e-mail: smirnov@display.rei.minsk.by.
Dec. 1-5, 1998 Minsk, Belarus

The 15th Annual Flat Information Displays Conference. Contact: Stanford Resources, Inc., Attn: Laura Barretto, P.O. Box 20324, San Jose, CA 95160; 408/448-4440, fax -4445, e-mail: www.stanfordresources.com.
Dec. 2–3, 1998 Monterey, CA

The Fifth International Display Workshops (IDW '98). Sponsored by SID/Asia Region, Japan Chapter, and the Institute of Image Information and Television Engineers (ITE). Contact: IDW '98 Secretariat, c/o The Convention Annecy; phone/fax +81-3-3423-4180.
Dec. 7–9, 1998 Kobe, Japan

Display Works 99: Display Manufacturing Technology Conference. Co-sponsored by SID, SEMI, and USDC. Contact: Mark Goldfarb, Palisades Institute for Research Services, Inc.; 212/460-8090 x202, fax -5460, e-mail: mgoldfar@newyork.palisades.org.
Feb. 2–4, 1999 San Jose, CA

The 1999 SID International Symposium, Seminar & Exhibition (SID '99). Sponsored by SID. Contact: Mark Goldfarb, Palisades Institute for Research Services, Inc.; 212/460-8090 x202, fax -5460, e-mail: mgoldfar@newyork.palisades.org.
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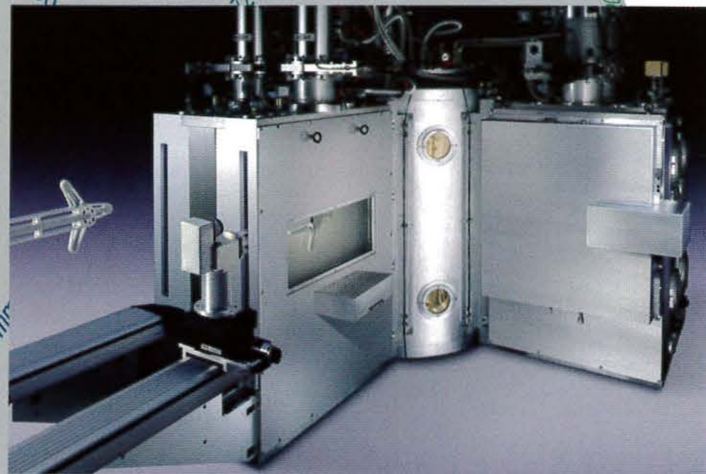

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continued from page 4

illuminated by that wonderful presentation device known as the overhead projector, there were other *very important* things going on. Since the incoming information rate during a typical presentation seldom exceeds 10 bytes per second, one is left with at least 99.99% of one's mind free to wander through all those creative and private thought-places in meeting-land – wanderings that one would occasionally not wish to share even with one's closest colleagues.

We've all heard the saying that "A mind is a terrible thing to waste." Since intuitively we already know that, we have all learned to use this opportunity for many good and sometimes even noble causes. One of my favorites has always been to use this time to do the detailed problem solving on one of my weekend projects. Perhaps, it could be working out the next steps in restoring a piece of antique furniture, or how to best position my darkroom equipment for optimum printing efficiency, or which digital camera and color printer I should buy, and so on and so forth – you get the idea.

Let's add all this up. ***As an attentive meeting attendee, I am accomplishing all of the following: I am absorbing all the information that is being presented to me, I am physically comfortable and resting while seated in a transcendentally meditative posture, I am using most of my mind's capabilities to work on problems of my choosing, and I am getting paid my full salary by the company for doing this.*** This is great stuff!

Is it any wonder that managers spend most of their days in meetings? In fact, have you noticed that the percentage of the day spent in meetings seems to have a direct correlation with the level of the manager. (In this case, there is no asymptotic behavior; it increases linearly by roughly 24% per management level and then simply goes flat at 96%. Apparently, the remaining 4% is the irreducible residual time needed to do some other important work-related activities.)

However, I must confess that for me there was always a down side to all this. Once the presentations were finished, there would usually be a discussion period with the intent of reaching some kind of a decision. Now, since most boss-subordinate interactions occur during these meetings, this time is one's optimum opportunity to make the "right" kind of impression on the boss. My problem was that I was never very good at that. Others beat me at this game time and again.

For many years, I kept thinking that if I produced world-class technical results my contributions would be recognized and the "results would speak for themselves." It took longer than I would like to admit to realize how naive a concept that really is.

Since most technical innovations, new product developments, or project management accomplishments have few comparisons by which to measure their true significance in the short term, ***it's the perceived success that matters and not the actual result.*** Let me explain. Let's say you've just invented a new flat-panel display that requires no matrix addressing. How does your management decide if this is a significant result or not? They would have to be very knowledgeable about display technology and would have to know how many others have tried and not succeeded. But they most likely aren't that knowledgeable and don't know about the many prior attempts. So until your product is a marketplace success ten years from now, only your peers will know what an incredibly significant result you have achieved. But, unfortunately, your peers may also be your competitors for corporate budgets, the next promotion, lab space, and/or the boss's attention. So do they really want you to get all the recognition you may deserve? Hmmm… .

Well, as I told you, I was never very good at this stuff. But others were, and after a while I started observing that there were certain personality types which seem to populate staff meetings everywhere. So I took the scientific approach and started to create categories for some of these characters. The behaviors were sufficiently distinct that I decided to keep separate dossiers on bosses and colleagues. Perhaps, I thought, that way I could at least learn from their successes, and even if I chose not to emulate them, I could at least understand how they were able to pull off their feats of persuasive legerdemain.

Think of the list that follows as the introductory program to a play you are about to enjoy. Unfortunately, in this month's column, I won't be able to entertain you with the play itself. (That will have to wait for a future column.) In any case, each of these characters would be worthy of an entire play (or column) - in at least three acts.

Therefore, let me welcome you to the Issaquah Village Theater, where tonight's play, *The Meeting,* is presented with the generous support of high-technology corporations everywhere. The cast of characters you will meet is the following, in alphabetical order:

The Bosses:

Consensus Builder - This boss-character you will quickly recognize as seeking agreement from all his employees before he makes a decision, even when that decision involves making a change that will negatively impact one of those whose consent the boss is seeking.

Controller Queen - Her dictatorial majesty will impress you with her ability to ask the most detailed question, especially when it comes to keeping track of orders and sales and other financial matters. The controller queen does not wish her subjects to present reasonable explanations - only favorable results.

Duke of the Inner Circle - The duke you will quickly spot by his entourage of loyal followers. His inner circle follows him from company to company and from job to job. If you are not one of the inner circle, your influence will be immeasurably small.

Entrepreneurial Inventor - When you see him make his entrance, you will quickly note that he tries to solve all the world's problems with his technology and will tolerate no thought that his germinating ideas are not ready for immediate scale-up to high-volume manufacturing.

Maker of the Numbers - This character will entertain you with her single-minded objective of beating each week's, each month's, and each quarter's financial plan. Unfortunately, you may find her a bit one-dimensional.

Promoter of Thyself - Let's give credit where it's due - to the boss. If you don't, he will take it anyway. His presentations are a sight to behold. Search we high or low, a more self-proclaimed capable individual is not to be found anywhere.

The Whiz - Such a smart one is he that all sorts of problems will yield to a purely analytical approach. The intellect side of his brain is so dominant that the emotional side has had no chance to develop, and all people problems are either ignored or "solved" by writing an algorithm.

The Colleagues:

Entertainer - What a charmer you will find this character to be, one so endearing to his colleagues and his boss. Many promotions and other blessings have come as a result of such a wonderful ability to keep everyone so up to date on the latest of humorous stories.

Follower of the Party Line - Ah, it's all in the timing. One must listen to all opinions and then wait to see what the boss is thinking. Then just before the decision is to be announced, one must jump up as if inspired from the heavens above and quote said decision. You will be amazed at how this ability will be demonstrated time and again during Act II.

Manipulator - Such a well-behaved individual is he - never a discordant word during the meetings. But, there is an ominous air about this character. His turf is the back alley and the one-on-one encounter. You will note the excessive attention lavished upon the boss by this individual. And you will also note that the boss always seems to have a less than accurate slant on the facts after a meeting with the manipulator.

Problem Solver - Poor problem solver, she takes the meeting agenda at face value. She assumes that the problems are really as presented and offers up logical solutions. Why won't anyone listen? Why won't the others believe her when she describes how other companies at which she has worked resolved similar situations?

Rainmaker - Whatever it is, it just won't work. Be it a new company policy or a new product idea, it just won't work. Everything is getting worse. Rainmaker will make you oh so sad with her soliloquy of problems - problems at work and problems at home.

Traditionalist - Well, after more than 25 years at the same company wouldn't you also try to resist change? In fact, would you even know what change is? This character lives out his final corporate days pursuing the thankless task of trying to preserve what little is left of past grandeurs - at least as remembered by this old-timer.

Waffler - This character, you will discover, is right out of *Fiddler on the Roof.* Tevye could also see both sides of every issue and finally made only one decision - and then lived to regret it. Waffler has a real problem with decisions because he can see the nearly infinite positive and negative possibilities in every situation. Such brilliance would be great if only it could be harnessed for some useful purpose.

Well, my goodness, we seem to have come up with about the same number of boss and colleague categories for our play. Certainly this does not mean that we have exhausted the possibilities. In fact, we most likely have just scratched the surface. So let's get on with our play and enjoy watching what happens as these characters interact.

Oh, I'm sorry! I forgot that you don't live here in Issaquah. That will certainly make it harder for you to make it in time for tonight's performance. But please don't despair. I have a perfectly adequate alternative to offer you. Tomorrow, when you go to work, you will almost surely have some kind of a meeting. Now that you know the cast of characters, you can experience theater-in-the-round as you've never experienced it before. Welcome to the play.

Should you want to provide me with a critical review of your personal theater experiences, or perhaps others, please contact me by any of the following methods: e-mail at silzars@ibm.net, telephone at 425/557-8850, fax at 425/557-8983, or by mail at 22513 SE 47th Place, Issaquah, WA 98029. ■

2 99

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17 NOVEMBER **98**

Sixth Color Imaging Conference: Color Science, Systems & Applications

SCOTTSDALE, ARIZONA
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16 MAY **99**

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  - Author Interviews – Evening Panels
  - Short Courses – Applications Seminars
  - Technical Seminars – Applications Sessions
  - Product Exhibits - Executive Poster Sessions
  - Display Technology Showcase

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