CRT ISSUE

Information DISPLAY

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SID

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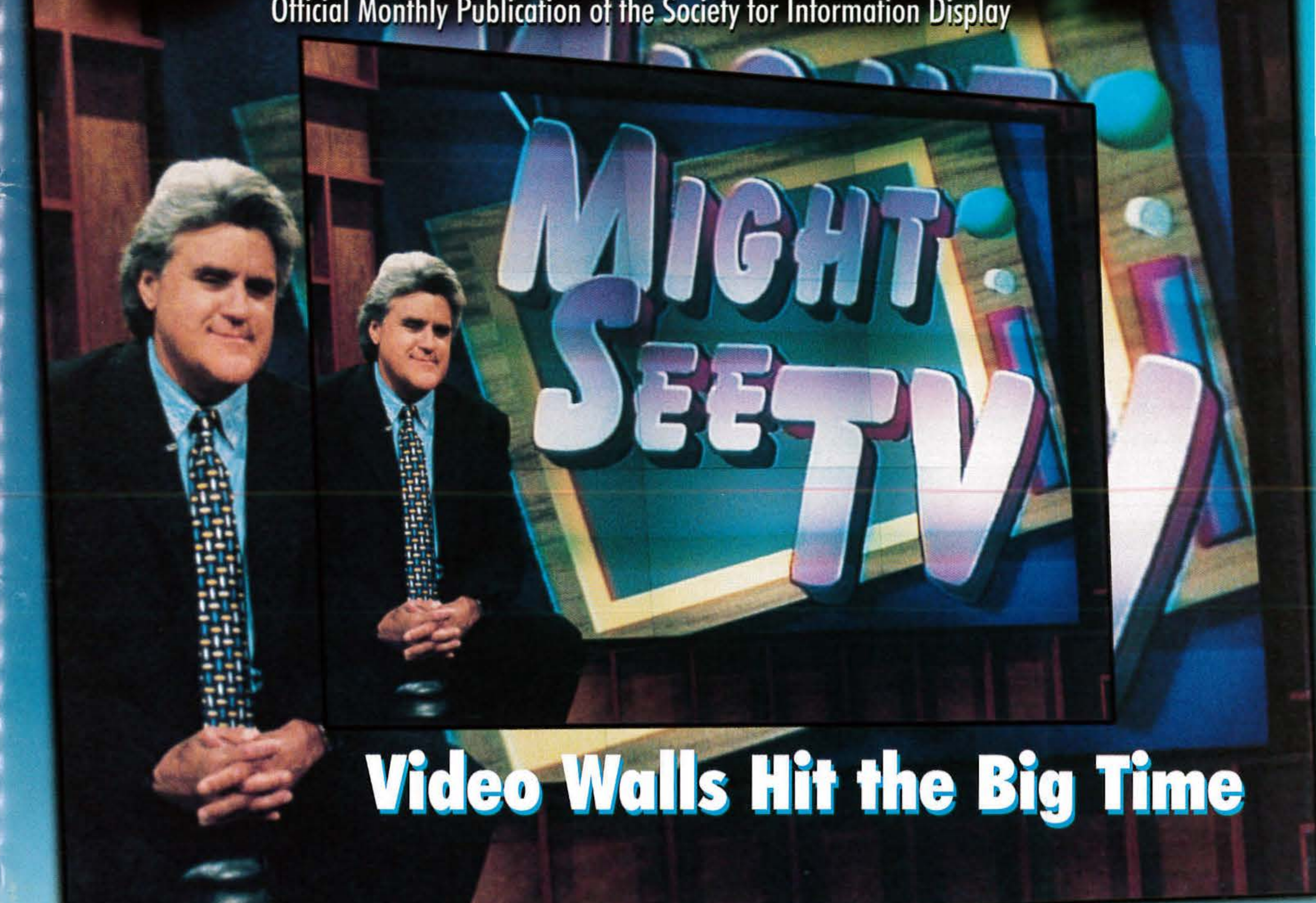

Video Walls Hit the Big Time

- *Improving the Quality of Medical Images*
- *Color CRTs Without Shadow Masks*
- *Video-Wall Cube Systems*
- *Industry News*
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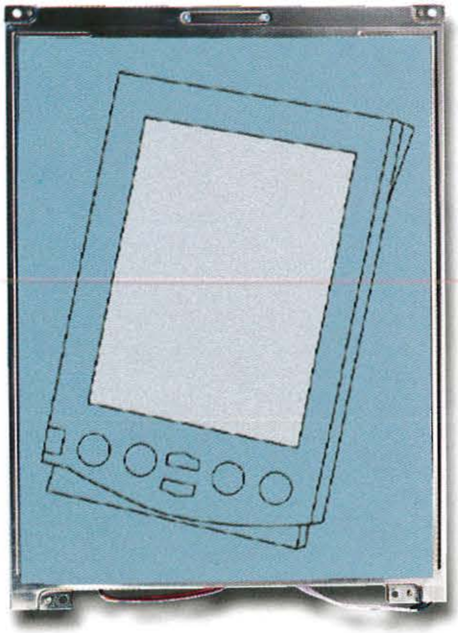

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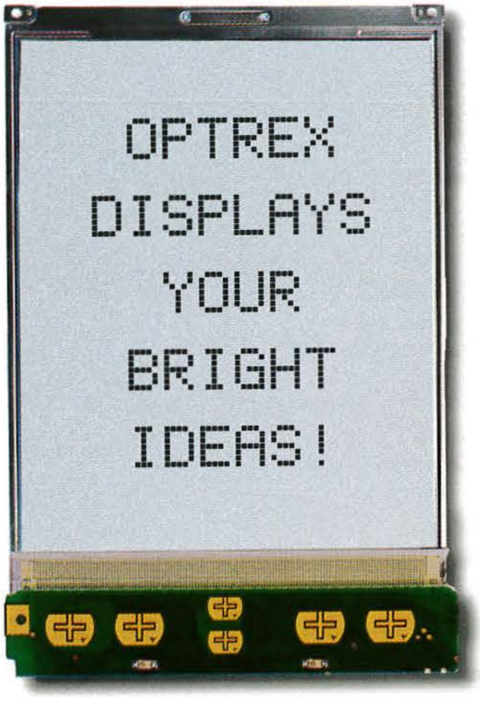

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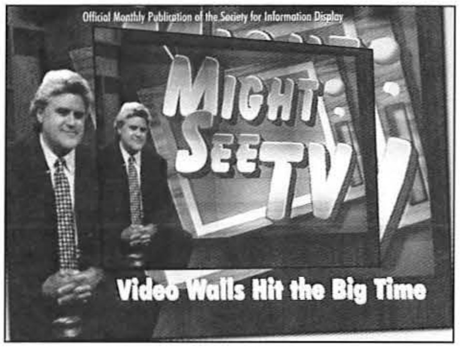
COVER: As video-wall technology improves dramatically and becomes increasingly cost effective, it is finding new applications. Jay Leno's version – as seen on "The Tonight Show" on NBC TV – presents a 10-ft.-diagonal image on a 3 × 3 array of video-wall "cubes." Remarkably, there is virtually no image gap between cubes and no brightness fall-off toward the edges of each cube.



[CREDIT:] Pioneer New Media Technologies

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Next Month in *Information Display*

Display-Business Issue

- The New Monitor Market
- Good Display Measurements
- Pioneering the Right Technology
- Why Do PDPs Cost So Much?
- Riding Moore to Market in 3-D

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Information DISPLAY

JUNE 1998
VOL. 14, NO. 6

guest editorial

LCDs: Ready for Naval Operations?

by Kenneth E. Sola

Just over a year ago, Tom Holzel wrote a guest editorial for this magazine [see "The Emperor and His Flat-Panel Displays," *Information Display,* March 1997 - *Ed.*]. The theme, that flat-panel displays could not handle commercial video, provoked a great deal of reaction. I read the editorial and some of the responses to it that subsequently appeared in the August issue of *Information Display.* The idea intrigued me, but I did nothing with it; that is, not until late November of last year.

At that time, as a civilian employee of the U.S. Navy, I was called upon to prepare for two important visits to the Naval Air Warfare Center at Patuxent River, Maryland, which were scheduled for early December. The first was by the Military Applications Users Group of the U.S. Display Consortium. The second was by members of the Office of the Secretary of Defense.

My task was to poll engineering support personnel and military users of FPDs for information regarding the performance of the technology and the general level of satisfaction with FPDs. What I learned disturbed me. While there was some satisfaction with the performance of cockpit displays of text, graphics, and low-update-rate information, there were many complaints about backlighting, reliability, off-axis viewing, glare, and the display of video. The problems with "dynamic contrast" mentioned by Holzel were evident. There was general user dissatisfaction with the display of video from military sensors, such as forward-looking infrared (FLIR). This feedback prompted me to draft a very negative position paper.

In view of the stated problems and the rapid advances being made in the FPD industry, it was time to have a look at these FPDs. In a study conducted by the Crew-Systems Integration Department at the Naval Air Warfare Center at Patuxent River Naval Air Station, we concentrated on LCDs, primarily because this was where most of the problems were being reported, but also because these were the most "fleet-ready" FPDs, with enormous pressure for their being installed to replace the bulky, heavy CRTs currently in use.

From January through March, we had opportunities to evaluate a large number of FPDs, most of which were LCDs built up from the common 20.1-in. glass substrate being offered by NEC. This normally white glass had solved the off-axis viewing problem with the use of in-plane crystal switching. But this method of switching did not come free. It reportedly reduces switching speed, which would be expected to worsen video-smearing and image-retention problems. In addition, the turn-on time (t_{on}) is significantly longer than the turn-off time (t_{off}), which leads to problems such as "waterfall gram blink," in which a display filled with pixels of contrasting luminance levels wink noticeably as they are updated by writing the new data to the bottom row and moving each of the older rows up by one.

These problems diminish the utility of LCDs for military use, but they were not generally known in the military community when we started our evaluations. What was known - and acted upon - was that the FPD industry had finally produced a large-area 1280 × 1024 color LCD that could replace the 19-in. CRTs in

continued on page 47

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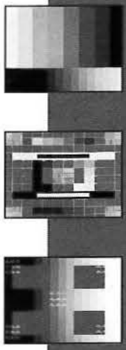

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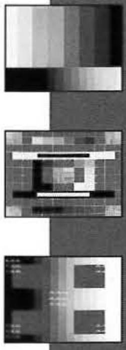

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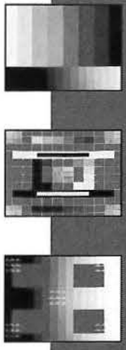

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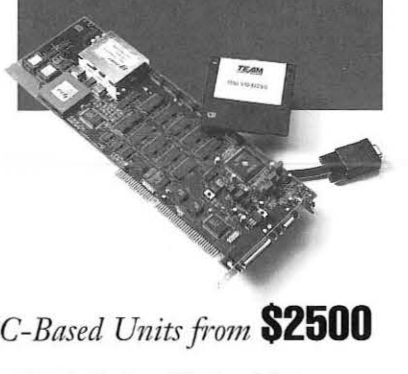

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Circle no. 2

the display continuum

The Wiggly Green Worm ...

by Aris Silzars

"Hey guys, come look. I've got the green worm!" shouted Gary, with obvious excitement in his voice. The other engineers immediately rushed over to Gary's bench, and sure enough, there on the screen was a green glowing thing about 10 cm long, 0.5 cm wide, and wiggling in a distorted sort of sine-wave fashion at roughly 10 Hz. Both ends of this worm had fat little blobs brighter than the main body. Nevertheless, all the engineers gathered around the crude metal box containing this newborn wiggler were clearly impressed. Congratulations were offered all around. Later, after work, they would go to the local pub and properly celebrate the birth of this, the company's latest product.

Of course, it would be several more months before this fat little worm would learn to focus itself into a respectable thin, bright, and uniform trace across the new oscilloscope's screen and would learn to wiggle at several hundred megahertz instead of just 10 or 20 Hz. And perhaps to the casual and unknowing observer, this first sign of life would not have been very impressive. Yet, to those who truly understand the challenges of making new technologies play together, such events are always momentous occasions.

Taking new technology to market is a very non-trivial and usually underappreciated undertaking.

My own love affair with green worms and other glowing things began quite innocently in a high-school science class when an engineer from Tektronix stopped in one day and gave us a demonstration of how an oscilloscope can show such things as voices and musical sounds, what a sine wave and square wave look and sound like, and how one can trace the signal through a television set. That one event, perhaps more than any other, was my inspiration to become a scientist and engineer. Then and there, I decided that I too wanted to learn a science discipline and perhaps eventually create something that would be worthy of displaying on such a marvelous instrument.

What would have been my reaction that day if I could have seen 15 years into the future to a time when I would not only be working with these marvelous instruments but also managing the design of far more sophisticated high-speed displays than the one that awed me in that high-school science class? Well, reality can sometimes exceed even our visions and our dreams. Now, isn't that a thought worth keeping for future reference, especially when one hits that occasional bump in the road of life?

Can you imagine anything more unlikely than a CRT? Oh, you think it's perfectly obvious? Well, then, let's see you explain the workings of a rudimentary CRT to someone who doesn't already know what you are talking about.

"Well, first you take a glass bottle and you pump most of the air out of it. Next, you stick this coated wire-thingy in it and you heat it up so it's glowing red hot. Then, you put some special powder somewhere on the surface of this bottle, such as the flat bottom part, and call it the screen. To operate it, you put a high voltage between the hot wire-thingy and the powder - and it lights up. Then, if you want to get really clever, you can also put some metal plates inside and put some varying voltage on them, and then you can move the glowing spot all over the screen faster than the eye can see."

continued on page 46

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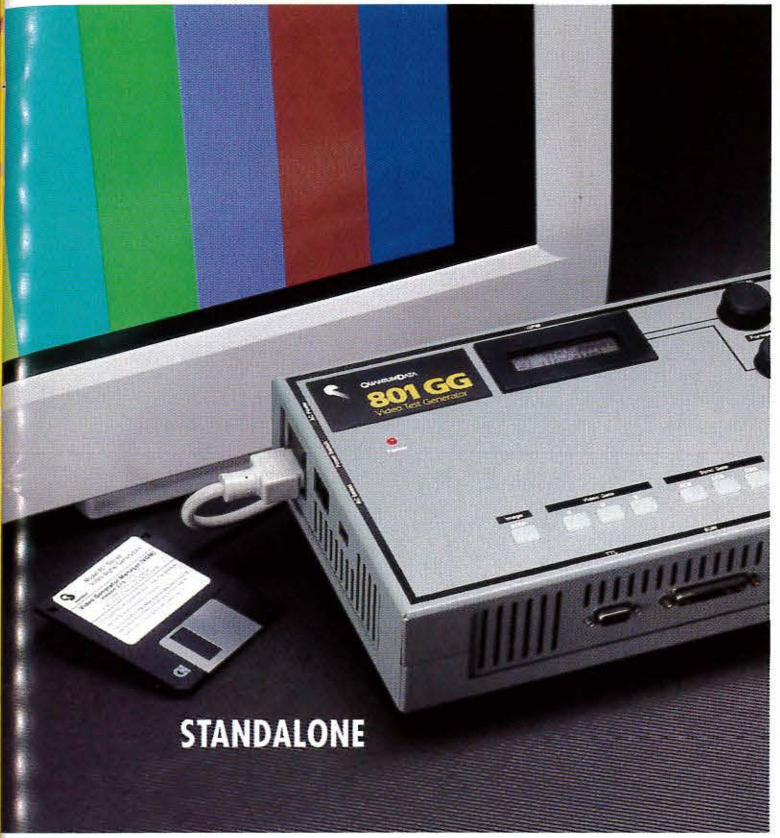

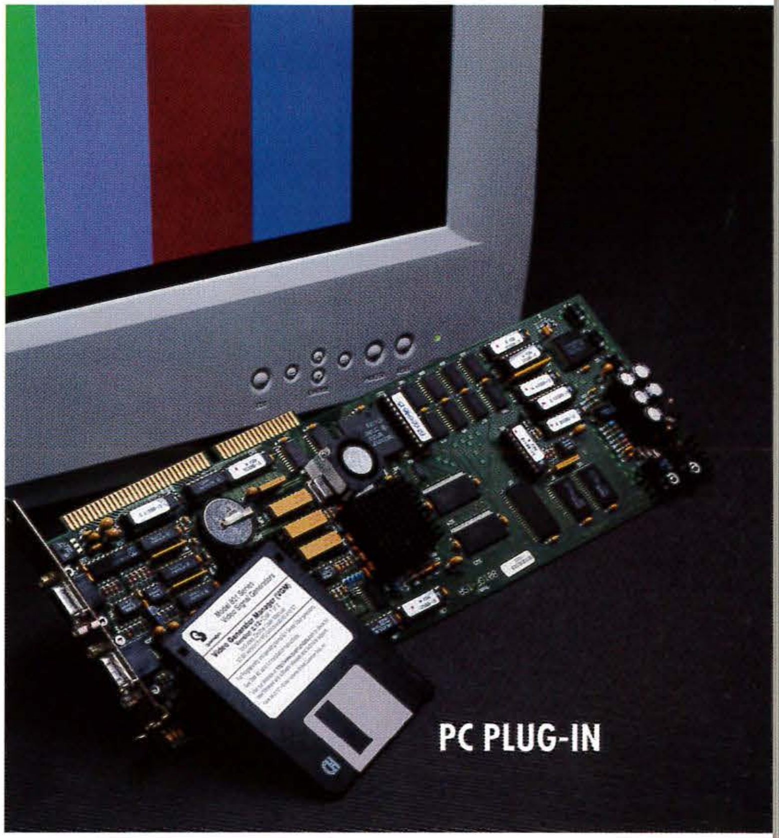

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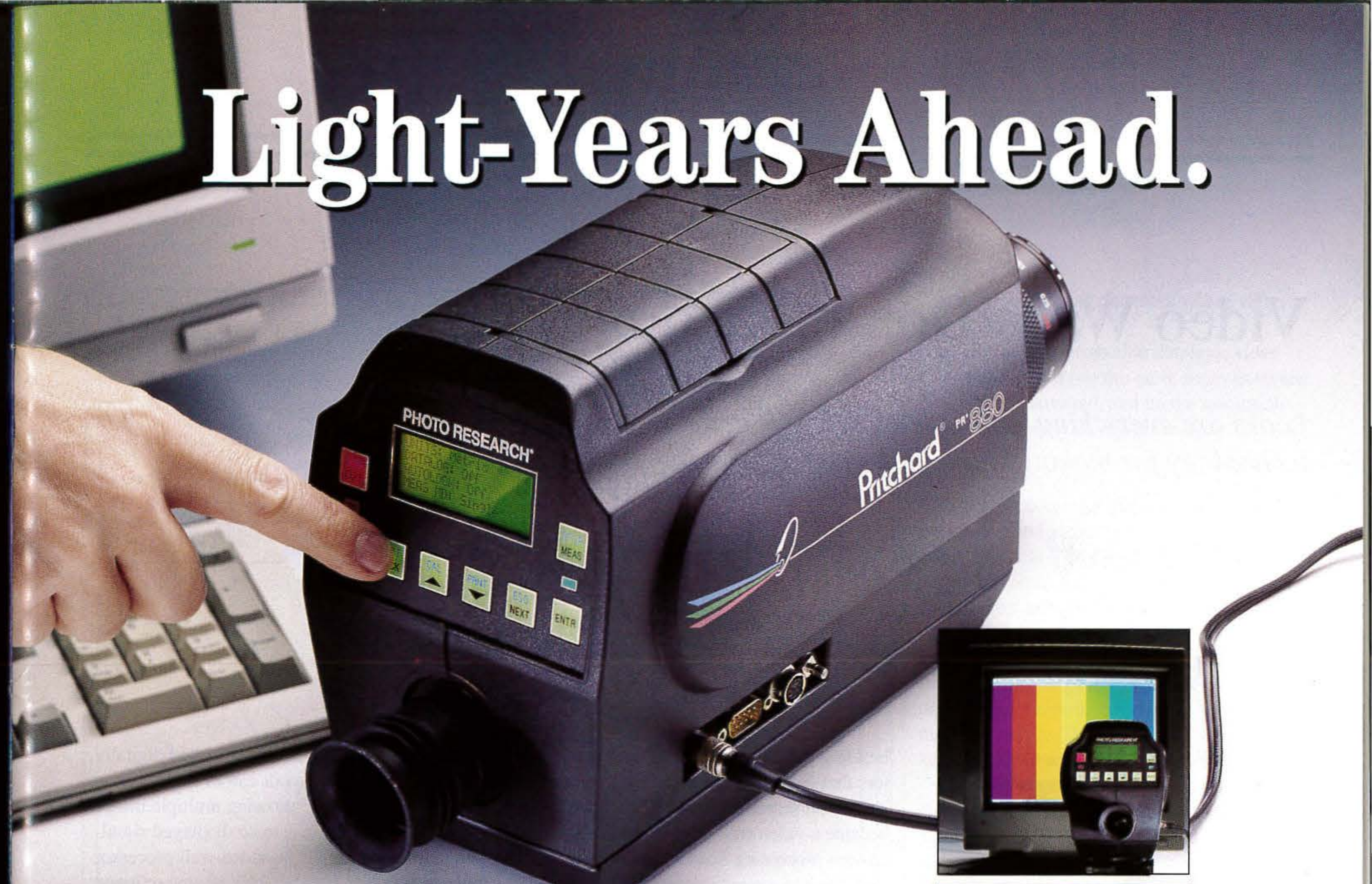
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Video Walls Don't Stand Still

Looks are everything with video-wall cube systems, and the technology for making walls look good is evolving steadily.

by Josh Kairoff

Over the last 50 years, the display industry has developed a variety of technologies for the cost-effective presentation of information, ranging from desktop-computer displays and portable flat-screen LCDs to plasma panels and projection systems. Of the many video technologies introduced in the professional display marketplace over the last 15 years, the video wall has been one of the most versatile and popular.

Introduced in the mid-1980s, video walls first caught the attention of trade-show and facility managers wanting to deliver video information to large audiences. Eventually, the video-wall concept became cost-effective in a variety of applications, including retail stores, restaurants, sports arenas, corporate command-and-control settings, and many public forums (Fig. 1).

Video walls became an attractive solution by offering an image area that could be expanded to almost any size without increasing depth and while offering programming features not available in other display media. The technology has maintained its benefits into the digital age and promises to be a leader in high-definition broadcast applications.

What Is a Video Wall?

The first video walls were formed simply by building a wall of traditional television monitors that displayed the same image on each individual screen. This "wall of video" became a video wall with the introduction of a custom processing box to matrix the image so that it would appear as one (or more) large image(s) spanning all of the displays. The concept evolved even further when display boxes became controllable so that a programmer could manipulate the video wall in a presentation environment.

Today, video walls are controlled digitally, and the central processor can even interact with "smart cubes," allowing multiple images from different sources to be displayed simultaneously (Fig. 2). The video-wall processor accepts signals from any AV source or input and can convert them into separate data streams that can be sent to specific cubes. This makes it possible to project a different image on each screen, the same image on each screen, one giant image across the entire

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Fig. 1: *This Bloomberg Financial Television sign located in the main concourse of New York City's Pennsylvania Station is one example of a video-wall application. Each of the two video walls, separated by the concave fixed-image Bloomberg sign, contains 16 40-in. Pioneer cubes and is 11.1 ft. wide by 10.3 ft. high. The entire assembly is 101 ft. long.*

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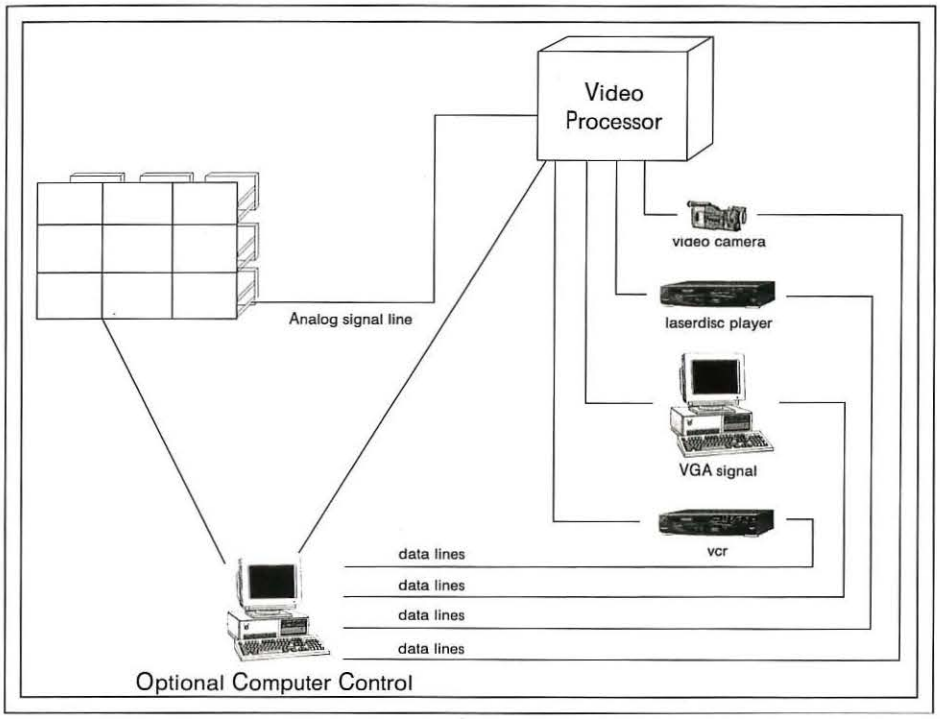

Fig. 2: *In today's video walls, the central processor can digitally interact with "smart cubes," allowing multiple images from different sources to be displayed simultaneously.*

group of screens, or any combination of the above.

The direct-view monitors used in the first video walls have long since been replaced by rear-projection units - or cubes - that create a virtually seamless presentation of information because there is very little separation between the screens. Today, cubes are designed specifically for video walls, incorporating a custom rear-projection system within a specially designed frame assembly. With each of the cubes having matched phosphors, fine manufacturing tolerances, and precision adjustments to obtain compatible video characteristics, today's video walls are able to deliver high image quality and space efficiency while providing levels of brightness and resolution superior to anything previously produced.

Video walls can form an image area of almost any size or configuration without compromising the integrity of the image, as may happen with a projector.

The increasing popularity of video walls is based on several characteristics:

- Unlike front projectors, video walls do not require a dark environment and a significant amount of space in front of the screen to project the light.
- Direct-view displays, while ideal for large outdoor stadiums, exhibit pixelated images and poor viewing angles at the shorter viewing distances where video walls excel.
- Unlike rear-projection displays, video walls do not require more room as screen size is increased, and image resolution and intensity do not decrease.

Video Cubes

Video walls comprise two main elements: display cubes and signal processors. Video cubes typically include a projector (or engine), screen, and lens mounted in a frame (or chassis), and are stacked together to form a large image area (Fig. 3). The units can be either stacked on the floor or hung suspended from a ceiling or gantry. Current video walls use polymer screens to focus the light and make an image. These screens have played a key role in recent wall advancements.

In early video walls using direct-view CRT displays, the screens were made of glass. Their size and weight contributed to a large separation, or mullion, between screens. These days, the mullion between video cubes is roughly 5 mm wide, with some as small as 3 mm. And with the new mullionless screens recently introduced by several manufacturers, the separation is virtually unnoticeable to the viewer.

Projection screens consist of two lenses - a Fresnel lens and a lenticular lens - that together focus images and distribute them

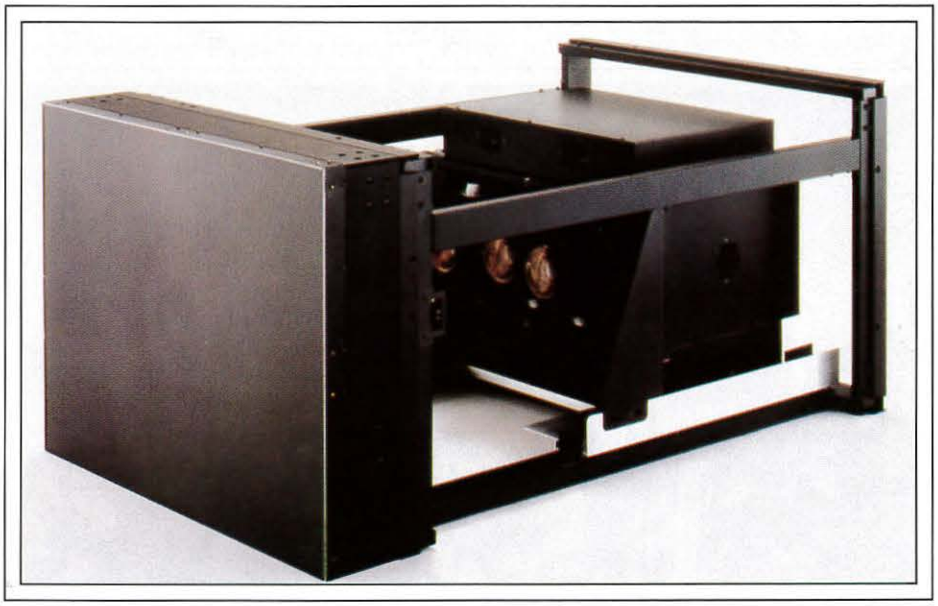

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Fig. 3: *Video cubes typically include a projector (or engine), screen, lens group mounted in a frame, and a case. The cubes are stacked together to form a large image area.*

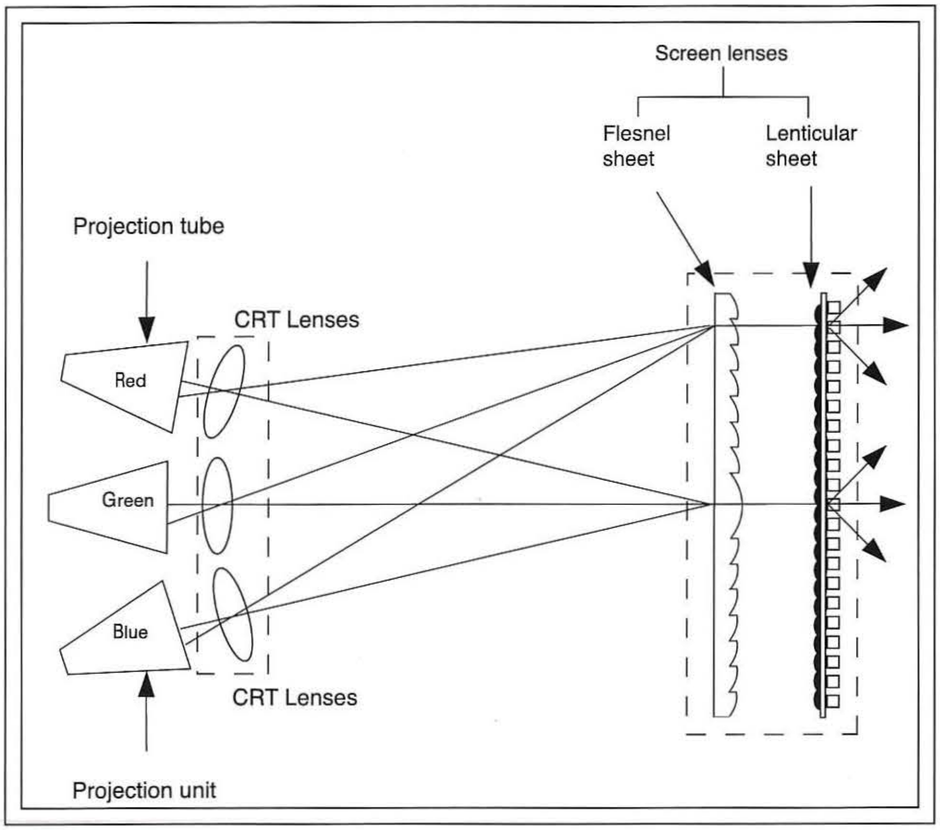

Fig. 4: *Using a two-lens system in a cube produces bright images and even color balance out to the very edges of the screen.*

across the entire viewing area (Fig. 4). The primary function of the Fresnel lens is to direct the light from the projector toward the front of the screen. The lenticular lens, located in front of the Fresnel lens and characterized by vertical black stripes, then forms the actual image while reducing reflections of ambient light. Consequently, there is very little image reflection in projection systems, unlike direct-view television, where images are often reflected from the screen surface, especially in brightly lit rooms.

Video-Wall Processors

The second component of a video wall is the video processor. As a rule, cube systems operate on the same principle - a processor feeds video signals to each screen independently. With recent developments in processor technology, a video wall can be easily operated by manipulating a mouse or touching the keys on a basic laptop computer. Some processors easily interface with AMX, Crestron, and other control systems.

Video processors can accept many types of video inputs; most are equipped to handle four or more simultaneously and are capable of showing each image at a different magnification level. Early processors required all video signals to be synchronized or genlocked, but modern processors can accept non-synchronous mixed material and output synchronized images. The most recent developments are giving processors the ability to accept and output high-frequency computer and high-definition TV signals.

A processor can customize images of any size across the video-wall display, and can also output the same image on each cube. A standard video processor is capable of addressing cube matrices of almost any size, the most popular being 2 × 2, 2 × 3 high definition, 3 × 3, 3 × 4 high definition, and 4 × 4. The images on these matrixed displays can be normal or anamorphically stretched to any desired configuration.

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Fig. 5: *Video walls made General Colin Powell bigger than life at the 1996 Republican Party Convention, but each individual cube showed dark edges around the screen. This problem, which was characteristic of cubes from all manufacturers for years, has now been eliminated.*

Advances

In earlier video walls, the image on each monitor appeared darker around the edges of the screen (Fig. 5). To combat this problem, images today are internally pre-equalized before projection modifies the intensity of the light.

New hardware and software features continue to be introduced into the video-wall market. Programmers can now upload and download data sets, as well as obtain data from the display devices. This helps greatly during installation, servicing, and trend forecasting. Computer software designed to set up, control, and maintain video walls is readily available in Windows and DOS formats, and internal diagnostics systems are being built into new video-wall products.

Color and Resolution

During video-wall installations, technicians concern themselves with matching colors and reaching a desired brightness range. This process, which used to require bulky test equipment and an "artist's touch," is now carried out through the use of a simple computer-software program on a laptop computer.

Convergence and geometry methods differ slightly, based on the specific manufacturer. The goal remains the same, though, which is to align and adjust each display cube so that it produces clear, sharp images that are uniform in size, color, and position. Standard video signals - crosshatch, color bars, flat fields, and gray scales - are used, as well as some special signals, such as tilted crosshatch, spirals, and sizing grids.

Applications

Applications for video walls are as diverse as the organizations that use them. Retailers and malls use them for display purposes and to execute directed, on-premises marketing. Sports bars use them to entertain patrons, while sports arenas can advertise to fans and entertain them with instant replays. Museums and public facilities can use a video wall to provide information to visitors. Corporations can use them to monitor large amounts of data at one time. Video walls are also used in television broadcasting, and they currently provide an excellent way of taking the Internet beyond the single-user interface for exposure to much wider audiences.

The Future of the Wall

Video walls are by definition matrices of video screens controlled by central processors. The most popular form of cube has been the rear-projection CRT, which has a record of performing successfully over years of 24-hour-a-day operation in rugged environments.

But new technology is or soon will be complementing current cube products. Plasma-display panels (PDPs) currently entering the market might well represent the "cubes" of the future. Development of PDPs for use in video walls will have to include extensive testing, as well as reduction of the mullion associated with the glass chambers containing the gas.

Since the video-wall architecture can incorporate all appropriate developments in display technology, its future seems bright. ■

opinion

End of the Shadow Mask?

Dynamic color separation can replace the shadow mask, deliver better performance, reduce size and weight, and lower costs.

by Clayton A. Washburn

NOW THAT the HDTV-signal question has been formally settled in the U.S., the consumer-electronics industry finds itself in the kind of turmoil not seen since the early days of color TV produced a similar profusion of display alternatives. Which of the many species of displays will survive as alternatives for digital advanced television (ATV)? Will the cathode-ray tube (CRT) really become obsolete? Will the flat-panel display (FPD) really become the dominant consumer-entertainment display?

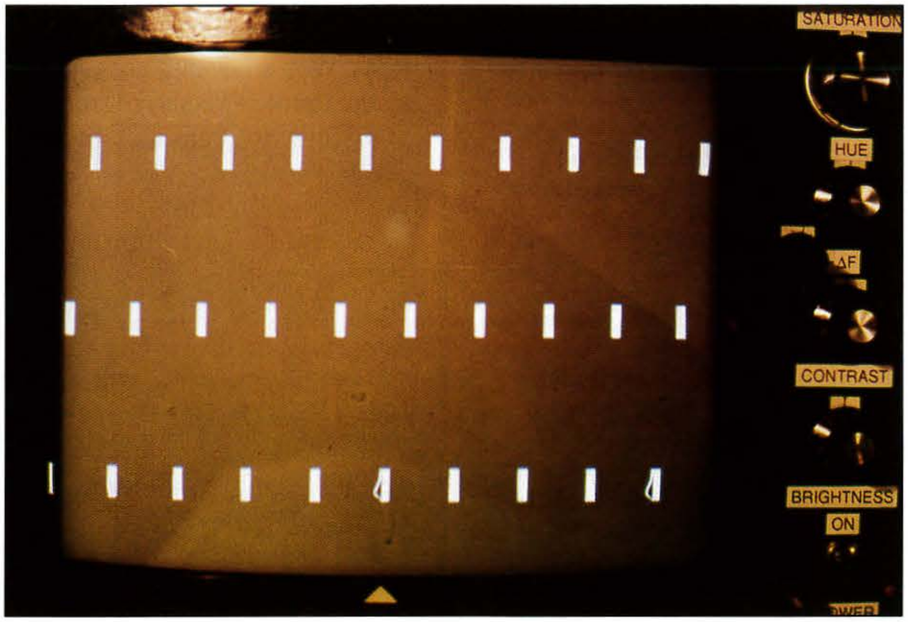
In this article, I wish to add an alternative but neglected CRT architecture to the mix. Because the industry appears to have concluded that there are no alternatives to the color shadow-mask CRT, introducing one now requires more than a glowing description. The alternative must be assessed against FPD expectations and the shadow-mask benchmark.

The early days of television produced a variety of color-display concepts. The possibilities were eventually reduced to two, and the shadow-mask CRT is the one that prevailed. Despite all its accomplishments, the shadow mask – which is used to provide both color separation and color position control – limits both the CRT's resolution and beam efficiency (to about 20%).

The alternative was "indexing," which used sequential color separation (SCS). SCS switches color signals in correspondence with beam scan across sequential color phosphors in response to an indexing signal for controlling switching frequency. In this way, it provides color position control. SCS beam efficiency is about 50%, but best beam utilization is only one-sixth in time and in space at each color. Because of these basic limitations – and despite revolutionary advances in the electronics for controlling the switching and indexing functions – a re-examination in the 1980s still found SCS indexing inadequate. In particular, it can't meet most display-brightness requirements.

In early attempts to improve SCS, investigators examined beam-velocity modulation. Beam arrest – stopping the beam at a particular location – could double the effective pixel resolution, and it showed promise in relieving the basic time and space limitations of SCS.

Clayton A. Washburn *is President of Washburn Laboratory, 24 Andrea Lane, Thornwood, NY 10594; telephone 914/769-5774. He has had a long career in CRT tube and system technology, including experience at the MIT Radiation Laboratory, Rauland Corp., Syntronic Instruments, and General Precision Laboratory.*



Washburn Laboratory

Fig. 1: *DCS works. This subraster pattern is presented on a 12-in. color DCS CRT demonstration display. The saturation control is set at maximum to produce a white pattern. The demonstrator uses off-the-shelf components and is not employing indexing.*

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But there were problems. In particular, attempts to implement the beam-arrest approach pressed then-current technology. Beam-velocity shifts were in direct conflict with the attempts of the automatic-frequency-control (AFC) circuit in beam-indexing systems to correct the beam's position. Indexing was then abandoned before velocity-modulation concepts could be developed. Finally, as color gained acceptance, shadow-mask technology began its climb up the manufacturing-productivity curve, and television-manufacturing companies saw little reason to pursue alternatives.

A New Wave: Dynamic Color Separation

The revival of indexing in the late 1980s paid scant attention to the earlier work on velocity modulation. But developments in other areas over the last two to three decades have advanced the art required to implement updated velocity-modulation systems (Fig. 1).

An examination of beam-velocity control concepts has revealed that the technology – called "dynamic color separation" (DCS) – provides color-separation behavior that is distinctly different and substantially improved when compared with that of SCS. DCS methods eliminate the time and space constraints of SCS. They dynamically apportion beam energy across the color triad at successive pixels in proportion to signal chromaticity and independently, in general, of beam-current control of display luminance.

DCS eliminates the beam-current loss of both shadow masks and SCS indexing. Its efficiency compares to that of monochrome CRTs, but the perceived resolution is two to three times higher. Like SCS, DCS can use indexing to control beam position in relation to the color triads across the display area, but there are more options for control of color position:

- Simplified index detection may be selectively applied.
- Geometric error correction greatly reduces the requirements for indexing.
- Beam-spot control can assure faithful color rendition.
- Error corrections can be automated.

DCS concepts have been demonstrated, and they work. But are DCS displays manufacturable and do they offer a competitive advantage over shadow-mask CRTs? Indeed, do they represent a technology breakthrough that will enhance the CRT's competitive position *vs.* FPDs? These questions require answers at the beginning. No one is interested in new CRT ideas that can not survive for the long haul.

Counterpoint

The views expressed by Mr. Washburn in his article are controversial, despite having been moderated – perhaps more than he would have liked – by *Information Display*'s editor. Because the ideas expressed are interesting as well as controversial, *ID* is publishing the article and accompanying it with our reviewers' comments. The reviewers will remain anonymous, but their conclusions are synthesized here by *ID*'s editor.

This article proposes a new and genuinely interesting way of modulating the beam. But although it asserts that appropriate electron guns exist for start-up production of DCS tubes for large-scale applications, it does not make a convincing case that this is actually so. And a convincing case must be made because maintaining the focus of a beam that must have a much smaller spot size and higher current density than the beam in a shadow-mask tube has been the downfall of beam-index approaches in the past – even after ICs made the necessary control electronics possible.

In a shadow-mask tube, the diameter of each of the three electron beams is such that it excites the phosphors in several RGB triads on the screen. In the case of a typical desktop-computer monitor, the pitch of those triads is 0.28 mm; in the case of a typical NTSC TV receiver, it is about 0.60 mm.

Television receivers have two to three times the luminance of a desktop monitor, and that is not coincidental. The greater luminance of the TV receiver is produced by a beam with higher beam current, and the higher current density in the beam forces the beam to spread (electrons repel each other). Looking at the situation from the other direction, the higher definition (smaller beam diameter) of the desktop monitor is purchased at the expense of reduced beam-current density and luminance.

Beam diameter is a much more critical factor in a DCS tube than in a desktop monitor. In a DCS tube, the beam must be small enough to strike only one red, green, or blue phosphor stripe at a time, and must still have enough current density to create a sufficiently bright spot. Maintaining the focus and beam shape gets harder away from the center of the tube (especially in the corners), and it gets harder as image brightness increases, as tube size increases, and as deflection angle increases.

There are some offsetting considerations. Because the percentage of the beam's cross section that actually impinges on the phosphor is perhaps three times what it is in a shadow-mask tube, the beam current can be reduced by a factor of three. Also, since the beam is impinging on only one sub-pixel at a time, rather than several, one might be able to obtain a similar image resolution with larger sub-pixels – and that would allow the beam to have a larger diameter. This brings us to the basic question: Does the required beam current permit a beam diameter that is consistent with an increased – but not excessively increased – phosphor-stripe size?

It is not easy to quantify these factors on the back of an envelope. Is it possible to make a 17-in. DCS desktop monitor with the required screen resolution and luminance? or a 27-in. TV receiver – which has a higher deflection angle than the monitor?

Fortunately, today's beam-design software tools can provide unambiguous answers to these questions. Anyone who is drawn to Mr. Washburn's attractive modulation scheme should use those tools and obtain those answers.

– KIW

How DCS Works

There are a variety of ways to implement DCS concepts. For convenience, think of a conventional NTSC horizontal line scan across vertical color triads (although DCS is certainly not limited to this format) and imagine that beam intensity is constant while the beam is exciting a particular pixel.

In an early approach to DCS, beam arrest occurs at each color stripe in sequence, but the dwell time for each color is modulated proportionally to that signal's amplitude ratio. If

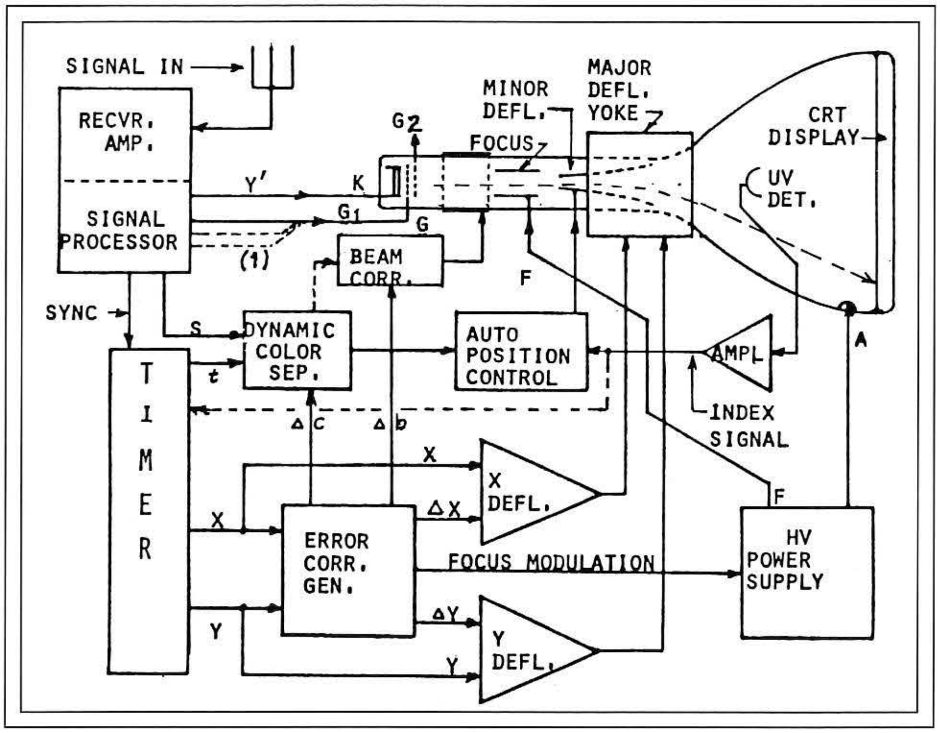


Fig. 2: A dynamic color CRT television receiver implements all the functions usually found in a NTSC/PAL/SECAM receiver, but some are implemented in strikingly different ways.

a particular color's ratio goes to zero, that color is jumped over. Equal time intervals produce white. This is the most complicated of all DCS approaches, and implementation was far from feasible when it was conceived. We have now implemented the approach with off-the-shelf parts, and have found that it requires adroit component selection to match circuit requirements. Practical slew-time loss is 5–10%.

Another DCS approach arrests the beam at the dominant hue to be produced at each triad. For NTSC this corresponds to synchronization at chrominance (C) phase. The arrest time is modulated in proportion to the ratio of the saturated dominant hue to white, *i.e.,* to the degree of saturation of the color. Between arrest positions, the beam travels at uniform velocity. The DCS signal goes to zero for producing white and to full beam arrest for producing a selected saturated hue. This method is substantially less demanding of high-slew-speed components than the previous one.

In a third approach, the system need only provide continuous full beam arrest at dominant hue position on successive triads. Distribution of beam energy over the primaries (color desaturation) is then accomplished by control of beam size, shape, and/or distribution. This method is shown in Fig. 1, but has yet to be fully implemented.

In summary of DCS methods: Control rates are those of the color signals, not video or triad rates. The examples have described time modulation, but there are corresponding velocity-modulation methods. Selective combination of these methods can be beneficial.

DCS opens "indexing" to practical commercial implementation because it is highly efficient, has eliminated the SCS time and space constraints, and has raised beam-current utilization to nearly 100%.

Implementing DCS

The characteristics of a typical DCS display - reception, signal processing, sync timing, high-voltage-electrode power supply, video, and deflection - will all be recognized as common to NTSC/PAL/SECAM monochrome and color displays (Fig. 2). While the first three items may be identical to those in an NTSC receiver or its ATV replacement, demands on the others will be different.

In general, subsystem power requirements will be lower and performance demands will be higher. An appropriately designed DCS HV power supply is critical. The limitations of earlier approaches have been overcome by adding error-correction, focus-modulation,

Author's Response

First, my thanks to the Editor for gleaning from my submission the essentials to an easy understanding of DCS behavior. The article does not delve into enough detail to provide "convincing" proof. That kind of detail is to be found in the references and it is supported by the photographs. The *Consumer Electronics* reference discusses the aspects that pertain to DCS deflection and beam control. The reference listed first, written in anticipation of publication before this article, provides a stringent comparison of DCS to other color-separation methods. Since this article has not become available, I will provide copies to those who have interest in further details.

The references plus long experience viewing CRT spots and designing the components/circuits for their correction provide the basis for my "controversial views." They are also supported by a range of information which this article can not cover. These views, however, do not oppose - rather, they confirm - the general counterpoint description of beam behavior. The trouble is in the numbers and in opinions which I find run counter to facts. My impression is that the counterpoint discussion pertains to SCS, not DCS.

There is no way to resolve this controversy in the time and space available herein. I suggest, in the interest of the CRT industry, that a meeting with *ID*'s critics be arranged to sort out and to report the facts pertaining to DCS.

Respectfully,
- Clayton A. Washburn

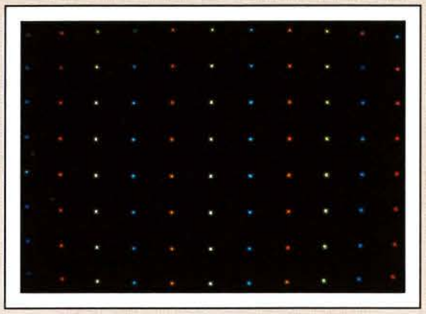
A DCS Demonstration

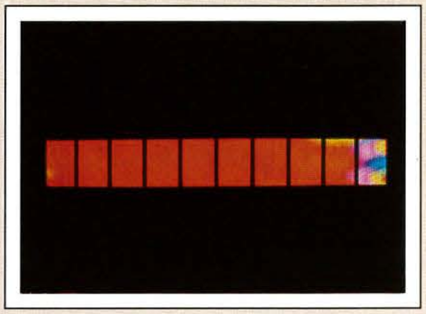
Our 12-in. DCS demonstrator has a timer that provides several distinctly different types of operation. Here are two of them.

First is a pattern of pixel positions - a dot pattern (Fig. A). This pattern avoids transient errors to show the residual errors after geometric-distortion correction. Hue is shifted in this example to change primary colors at successive dot columns.

The second pattern provides a strip sequence of large-area uniform color blocks across the tube (Fig. B), which checks the effects of all errors on color uniformity and indicates the uncorrected defects that must be dealt with by indexing or some other position-control method. It is impressive that, without indexing, the beam position has been nearly corrected to impinge on only single primary stripes over the full-format area of a large-viewing-angle display.

- CAW


(A)


(B)

and beam-control components, which have made high-performance DCS practical.

The corrections, high voltage, and deflection beneficial to DCS have evolved in other applications and have been widely used by Washburn Laboratory (Thornwood, New York) and others over the past 30 years. There have been commercial, industrial, and military applications which have typically involved resolutions and precision substantially above those of standard TV. It is fair to say they now represent mature art.

Because the technology has been used for low-volume applications with specialized requirements, it has been expensive compared to consumer products. As a result, the technology has gained a reputation for having high costs. But in fact, it is susceptible to the same economies of volume as other display technologies.

The two remaining blocks (DCS and APC) in Fig. 2 provide what is unique to DCS. These blocks and their control elements replace the shadow mask of conventional direct-view CRTs or the three-tube assembly of projection-CRT displays.

The function of the DCS block is to generate a minor deflection waveform to produce color separation. The automatic color-position-control (APC) block controls beam position *vs.* time as directed by the timer at sequential pixel addresses.

This points up another essential distinction of DCS: Color depends not on beam current, but on the location (address) of pixels on the color screen's format area. Error correction provides precise address location. The timer is the element that must - and can, whether it is analog or digital - provide precise address information. The resulting display, like FPDs and unlike shadow-mask CRTs or CRT projectors, provides a faithful duplicate of any signal, including stored or archival information, which makes the technology compatible with whatever media the future may hold.

DCS Performance

DCS matches or exceeds the performance of shadow-mask CRTs. A major performance parameter for any color display is color fidelity, which can be verified in an appropriate DCS demonstration.

DCS can provide a bright display because the technology relieves the time and space constraints of SCS and the beam inefficiencies of SCS, shadow-mask, and color projection-CRT displays. The beam current for primary colors is only one-third of that for producing white, which is a substantial advantage in producing a bright image without degrading color.

Current CRT displays perform at limiting (5%) pixel MTF, but DCS performs at an MTF close to 100% (as do FPDs if they can use the full pixel area). This produces a threefold increase in perceived detail. For a shadow-mask CRT to provide the same results would require more than a doubling of the scan speed.

The direct-view CRT display has established a substantial reputation for long life and high reliability, but shadow-mask power consumption, weight, and bulk are all high. DCS removes the shadow mask and supporting glass structures from the bulb, which together account for an appreciable fraction of the CRT's weight.

The NTSC version of a DCS receiver requires two-thirds the power of a shadow-mask receiver and cuts out more weight. The DCS gun development promises a reduction in depth and an additional reduction in weight.

The potential weight and power decreases can amount to 50%, to create a CRT package that is more appealing than a shadow-mask CRT's and to make the FPD's advantages in this area less compelling.

The Bottom Line

DCS offers an impressive display technology, but does it make a business? Will transition costs be prohibitive? DCS will require substantial changes in circuitry, but circuit-board changes are a yearly routine. They do not require the disposal of capital equipment. The change to DCS circuitry should not entail high costs or disruption, although it will require changes in some alignment and test equipment. But this is not entirely bad. DCS testing is easier: it's automatic.

The real question to be examined is the CRT and its tooling. Certainly, the shadow mask and its investment disappear when and where DCS is proven superior, but there is no alternative element to finance. The alternate already exists, mainly as IC circuitry. It only needs future improvement - application-specific integrated circuits (ASICs) - as justified by cost savings.

So we are down to the bulb. The gun will be changed. But suitable guns for start-up exist, and the bulbs and their components exist.

At the end of the DCS implementation-requirements list, there are no huge start-up costs and the CRT's past investments are not summarily thrown out. There is a significant improvement in resolution and packaging and lots of room for justifiable follow-on advances to match varied market demands.

Is the CRT still doomed to obsolescence? Maybe. But DCS could substantially lengthen its life expectancy. While there are many applications where FPD technology is to be welcomed, there are others that offer no reason for CRT obsolescence in the foreseeable future if the most appropriate CRT technology is used.

Notes

C. A. Washburn, "Dynamic Color Separation for Color CRT Displays" (available from the author).

C. A. Washburn, "A Magnetic Deflection Update - Field Equations, CRT Geometry, the Distortion and Their Corrections," *Consumer Electronics* **41,** No. 4, 963-978 (Nov. 1995).

V. K. Zworykin *et al.,* "Color Receiver Utilizing Velocity Modulation in Display Tubes," U.S. Patent #2 989 582, 06/20/61.

C. A. Washburn, "Color TV Image Reproduction System," U.S. Patent #3 312 779, 04/20/69.

C. A. Washburn, "Dynamic Color Separation Display," U.S. Patent #5 291 102, 03/01/94. ■

Circle no. 11

Circle no. 12

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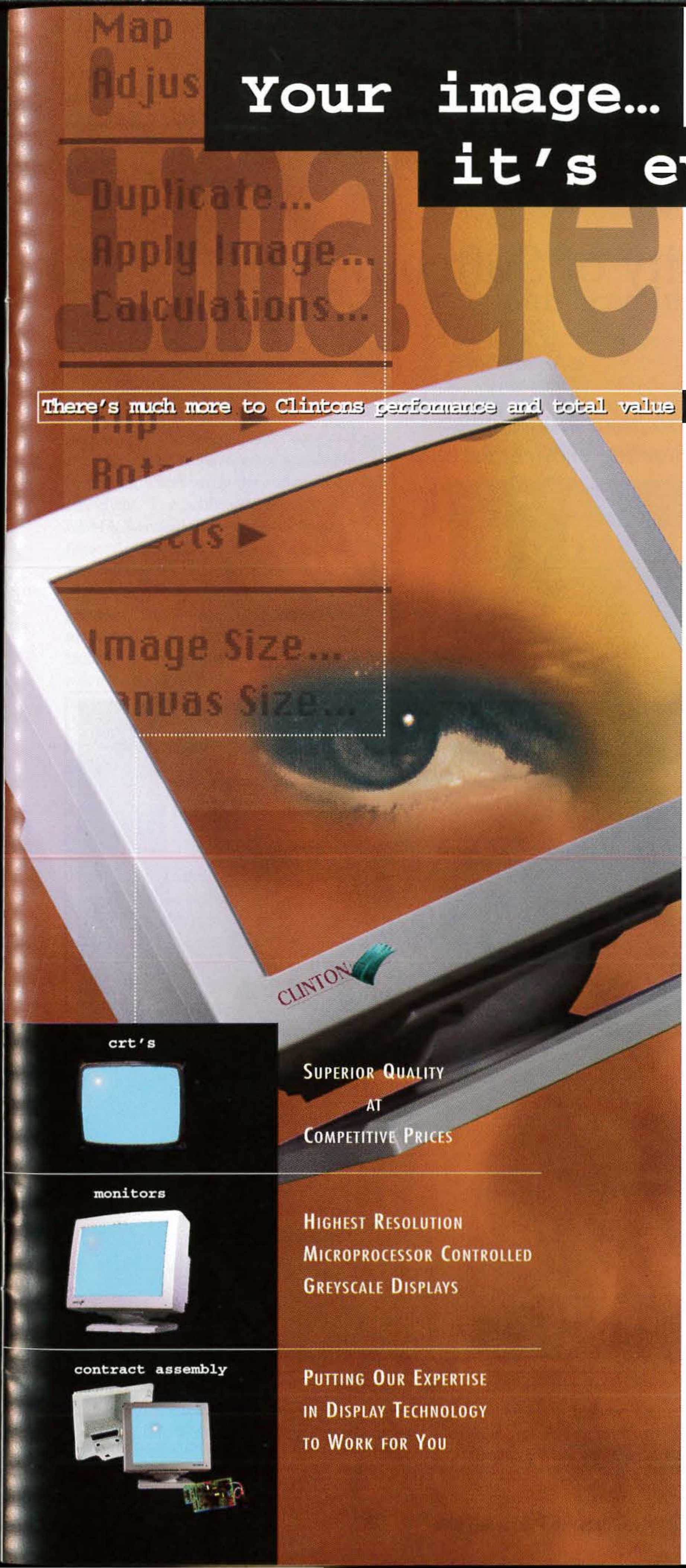

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Circle no. 13

Improving the Quality of Softcopy Medical Images

Making monitors that are good enough to please radiologists is one of display technology's most demanding challenges, and recent developments are helping monochrome CRTs do the job.

by Ken Compton and Don Hirsh

PICTURE ARCHIVING AND COMMUNICATIONS SYSTEMS (PACS) are the electronic vehicle by which hospitals and medical centers plan to replace film-based x-rays and other hardcopy medical images. Monitors represent as much as 40% of any PACS purchase, and monitor calibration and maintenance accounts for the largest portion of system maintenance costs.

Consequently, there is growing interest in the difficult but potentially rewarding business of making high-quality medical monitors (Fig. 1). Within the past year, softcopy image quality control has become the subject of increasing technical and marketing interest throughout the medical-imaging industry.

Hardcopy (film-based) systems remain the gold standard to which softcopy systems aspire. Radiologists perceive that most films are adequately exposed, can be read on any light box, and achieve sufficient quality for diagnostic purposes. Image consistency and

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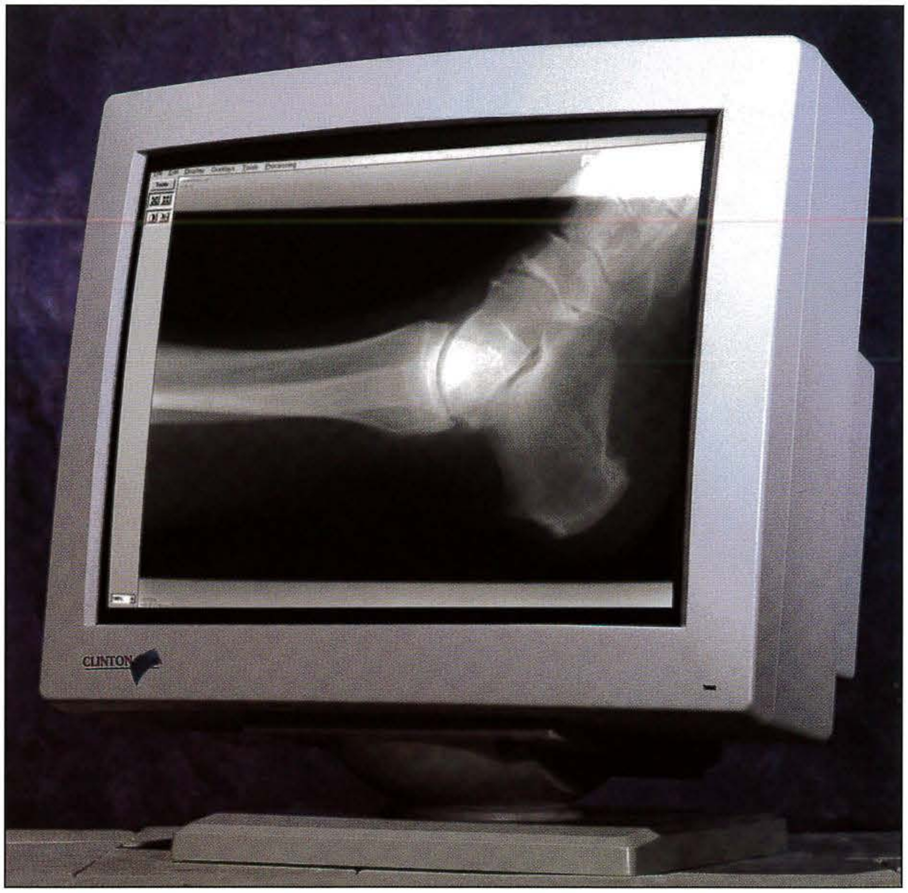
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***Fig. 1:** Creating medical monitors good enough for radiologists to use in making diagnoses requires high-performance design, high-quality components, precise fabrication, and an effective program of softcopy quality control.*

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reproducibility are not significant concerns for hardcopy but are concerns for softcopy. This difference is partly a matter of technological maturity. Quality-control technology and procedures have long been a staple of film-based imaging, and these procedures are performed by professionals when the image is generated and when the film is processed.

In softcopy imaging, quality control is practiced primarily in the monitor and display controller, which are at the end of the technology chain. The publication of the draft ACR-NEMA Standard Display Function has focused efforts on softcopy tone reproduction and consistency of image presentation. But even as engineers begin developing useful product enhancements, advocates of electronic radiology are coming to terms with the fact that softcopy quality control is more difficult to achieve on a system-wide basis than is hardcopy quality control. The reasons are clear: softcopy reading stations are more diverse and ultimately require more preventative maintenance than their hardcopy analogs.

Approaches to Softcopy Display Quality

There are several currently available systems that attempt to improve tone reproduction and gross luminance performance. Without great fanfare, monitors from Siemens Medical Systems (Iselin, New Jersey) have had the ability to compensate for ambient lighting for more than a decade. A sensor in the bezel of Siemens SimoMed monitors measures ambient light near the cathode-ray-tube (CRT) face, and this information is used to make changes in the luminance and contrast of the display. (Similar systems have been used in other monitors and high-end television receivers.)

Since 1995, DOME Imaging Systems (Waltham, Massachusetts) has systematically marketed the virtues of the Luminance Calibration System in the company's Md series of video controllers. This system consists of an external calibrator that is placed against the face of the CRT, along with associated software. DOME's video controllers are novel in that they include a calibrator port on the card itself for the semi-automatic luminance measurement and a 10-bit digital-to-analog converter (DAC) for tone-scale adjustment.

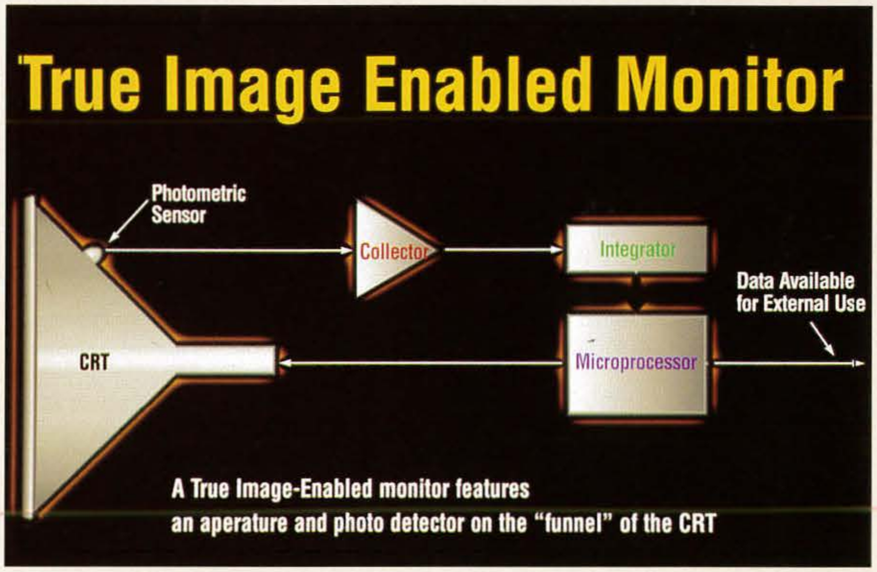
The Luminance Calibration System applies an appropriate correction to the native gamma response of a given display monitor. These corrections are applied to the video signal of the controller before it is sent to the monitor. For the correction to be consistently successful, all monitors must be operating within functional specifications.

The system can quantify the inevitable luminance changes, but cannot perform corrections at the monitor. Thus, intervention is required to effect the necessary minimum and maximum luminance at the display. Maintaining an array of monitors by periodic external calibration is the current state of the art for softcopy display.

The TrueGrey® Medical Workstation Display from BARCO, Inc. (Kennesaw, Georgia) is a 21-in. color monitor that combines ambi-

The True Image™-Enabled Monitor

True Image, LLC, has developed a system for automating crucial calibration and compensation functions. The True Image™-enabled monitor has a photometric sensor integrated into the CRT during the manufacturing process. When the phosphor in any monitor is excited by an electron beam, photons are emitted in all directions, not just outwardly through the face of the CRT. Therefore, an integrated sensor can take measurements from "behind" the face of the CRT, with results that are proportional to standard measurements made from the front. Further, when the phosphor is not excited, the same sensor produces a signal that is proportional to the ambient room light. This measured value can be used to restore just-noticeable differences in the low end while simultaneously maintaining the dynamic range of the image. This problem has been historically addressed by depending upon progressively brighter monitors, but simply maintaining a useful dynamic range may be sufficient for the human visual system.



A True Image-Enabled monitor features an aperature and photo detector on the "funnel" of the CRT

When a typical CRT is manufactured, the interior surface of the faceplate is coated with phosphor, followed by a controlled thickness of aluminum. The aluminum conductor extends over most of the interior surface of the CRT envelope. In a True Image™-enabled CRT, a translucent aperture is created in the funnel and a photometric sensor is attached to it (see figure). From this vantage point - behind the face of the CRT, rather than in front of it - measurements can be made much more conveniently than with the current generation of external photodetectors. Furthermore, the single detector can be used to make precise measurements of both the luminance of the monitor and the ambient lighting conditions in which the monitor operates.

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Trade-offs: The Video Engineer's Quagmire of Opposing Goals

The black art of monitor design resides in the complementary matching of highly specialized components. The video amplifier is designed to be as close to linear as possible and drives the CRT, which is inherently non-linear. Add the human visual system, another non-linear system, and the task of optimizing a display system becomes even more complex. The solution does not lie within any one component of a display subsystem, but in the accumulation of many engineering compromises. Let's look at some of those compromises.

The video preamplifier of the monitor receives an industry-standard signal (from the video source) of 0–0.7 V peak-to-peak, which represents minimum to maximum luminance. If the video signal differs from the 0.7-V excursion or 0-V_t offset, the display loses dynamic range.

The monitor's preamplifier and final drive circuit amplify the video signal to approximately 38 V at the CRT to achieve maximum luminance on a mid-range display. On a high-luminance monitor, maximum luminance is achieved with closer to 42 V. Amplifiers with a non-linear response could be designed to better match the CRT, but the variations between CRTs preclude a consistent result.

The preferred scenario is for the video amplifier's gain to be held to a known constant. To accommodate CRT variability, the biasing circuits for the electron gun are designed to be adjustable. This permits consistent results from the electron gun – but not necessarily on the screen.

The CRT, specifically the cathode current, has a logarithmic response with cathode drive over a major portion of the drive range, but as the drive approaches its upper limit, the response changes to a power law.

Another important response is light output *vs.* current density to the phosphor. This appears quite linear up until saturation, which means that if the current density is doubled, the luminance will double. But even this factor is influenced by phosphor-density variations among CRTs and center-to-edge variations on individual CRTs.

The observed image also passes through the glass faceplate of the CRT. Faceplate-thickness variations – a normal consequence of the faceplate's typical wedge-shaped cross section – affect transmittance from 7 to 15% from center to edge. This all adds up to a lot of variables with different response characteristics. Compensating for one problem does not always benefit the others.

The human visual system generally exhibits logarithmic response over the range of luminance seen in radiological imagery. Just-noticeable changes in gray tones at the low end are perceptible with smaller video-signal changes than are just-noticeable changes at the brighter white levels, which require dramatic changes in video signal.

Of the ambient influences, glare from room light has the most impact on image fidelity and perceived dynamic range. The typical black level is set to a luminance of less than 1 cd/m^2 to less than 2 cd/m^2 – we set clinical medical monitors to 0.5 fL and diagnostic medical monitors to less than 0.03 fL. A light box placed opposite a bank of monitors can wipe out the black level, causing part of the available dynamic range of the monitor to be ineffective in overcoming ambient light. Ambient glare that cannot be eliminated at its source is best controlled with a high-quality anti-reflective coating, which enhances contrast. Contrast modulation (modulation transfer function, or MTF) is sometimes compromised in the quest for higher light output. (MTF decreases with increasing spatial frequency and light output.) A strong case can be made for designing a monitor system based on the optimum MTF for image fidelity and then scaling/zooming the image to fit the available pixel format.

Virtually all the aforementioned items can be addressed by the monitor designer, but not totally and simultaneously corrected. The most significant step is contained in the digital LUT that tailors the video card's output to a specific display. When the LUT is combined with reasonable design criteria for the display, closed-loop monitoring, feedback, and regulation, it makes an effective solution possible.

– KC

ent-light compensation and luminance/color calibration in a single product. As in the Siemens monitors, a front-mounted sensor automatically compensates for changing ambient light. Luminance and color calibration are still performed with an external sensor, but the sensor information is delivered to a microprocessor within the monitor itself. In addition, BARCO recently introduced a 5-Mpixel monochrome display with similar control features.

This approach offers several potential advantages. Most important, the monitor's video-signal-to-luminance characteristics can be modified so that component aging can be included in the calibration/compensation process. Here, the signal from the video card does not have to be modified to compensate for luminance drift; rather, the system can recalibrate the monitor itself. With a system like BARCO's, a technician is still required, but his or her role is simplified.

A novel approach to image quality assurance was developed by Imatec Ltd. (New York, New York) and called the 20/20 System. Imatec claimed that the system provided image reproduction fidelity for both hardcopy and softcopy displays, but the company is no longer marketing the display actively. In the DOME and BARCO calibration systems, measurement and calibration are made with respect to the physical characteristics of each monitor; the goal of uniform performance is implemented one monitor at a time. Imatec took a broader look at image reproducibility by identifying a master image or master monitor. Compensation of other screens, locations, and film printers is then implemented with respect to the master image.

The system involves pairwise measurements and pairwise compensation that is transmitted from master system to remote with the image to be viewed. Like DOME's, the Imatec system attempts to modify the signal that will be delivered to the monitor, but on an image-by-image basis prior to video-card processing. All these approaches have positive attributes, but only Siemens and BARCO are able to modify the crucial brightness and contrast settings at the monitor without user intervention.

We believe a superior closed-loop system can be provided by measuring and re-establishing the maximum and minimum luminance within the display itself. To some degree, modifying the look-up table (LUT) or performing other image-data remapping can compensate for sub-optimal settings on the display, but more often the monitor must also be routinely adjusted to achieve complete luminance quality control. The DOME system cannot modify the monitor. The Imatec philosophy implies that every series of transmitted images should be subject to a recalibration routine if there is a significant difference in ambient lighting, image content, or image source, or if there is additional manipulation of the displayed image at the source. To guarantee fidelity, all these systems require that their external calibration procedures be practiced regularly across the entire population of monitors. That's demanding.

We believe marketplace requirements for softcopy fidelity include not only the need for accuracy and reproducibility, but also ease of use. Ultimately, calibration must become automatic and continuous, and maintenance must be minimized. With respect to tone-scale reproduction, softcopy image quality needs to become a non-issue because display subsystems "just do it."

Any system of quality control that imposes a burden of scheduled maintenance can only be implemented in organizations that have access to a skilled technical staff. In the pressured atmosphere of managed care, maintenance is likely to be overlooked until it is too late. If this seems unlikely, ask any radiologist who has a teleradiology system at home, "When was the monitor last calibrated?" We believe the marketplace will ultimately demand truly automated image fidelity.

Automating Quality

Is it possible to remove the need for user intervention and still assure calibration? We believe that several design ideas taken together can substantially automate major aspects of softcopy quality control.

Monitor calibration addresses the inevitable long-term aging of analog components: the cathode within the electron-gun assembly depletes over time, the phosphor loses efficiency, and CRT glass darkens through continual electron bombardment. All of this must be accommodated in the quest for long-term image stability.

The first requirement for a monitor that will automatically compensate for aging of analog components is to employ a microprocessor-based system design. Access to adjustable characteristics of the monitor must be removed from the analog domain. Compensation - increasing brightness, for example - must become a matter of changing a value in memory or in a system register.

Next, the monitor requires that a photodetector be integral to the system design. In True Image's innovative approach, a detector is applied to the funnel of the CRT over a specially prepared aperture (see The True Image™-Enabled Monitor). From the back of the CRT, the sensor can make precise observations of monitor luminance. The sensor is completely inconspicuous and data is available on demand, so the calibration process can be simplified considerably.

A second benefit is available from the internal sensor. When the display is black the same sensor can be used to take measurements of the ambient light that is striking the face of the CRT. A microprocessor-based monitor with such a detector can implement monitor calibration and compensation automatically, and transfer this information to a database. The same is true of ambient lighting measurement. Intervention is required only if the monitor can no longer achieve calibration or if the ambient light exceeds the maximum level for which compensation is possible.

We are confident that the vendors who can economically automate softcopy quality control will be well received because it is the lack of uniform image presentation and system-wide consistency that has impeded the adoption of softcopy radiology. We are also confident that automated, monitor-based, closed-loop feedback and control systems will have a significant role to play in raising the standards of softcopy image presentation.

A truly self-calibrating monitor will eliminate recurring quality-control expenditures and finally allow the same level of confidence in image presentation that has been an unquestioned feature of film-based interpretation. ■

Impending expansion of LCD acquisition for anti-submarine warfare

According to sources at the Naval Air Warfare Center, Patuxent River, Maryland, the U.S. Navy has accelerated its "buy" decision for flat-panel-display replacements for the current color and monochromatic CRTs at the five tactical crewstations on board fleet P-3 Orion aircraft, which are used for anti-submarine warfare (ASW).

Kenneth E. Sola, an engineering psychologist in the Crew-Systems Engineering Division at Patuxent River, has been asked to form a team to define minimum display-performance requirements for this large-scale display replacement. The Navy side of the integrated product team (IPT) has already been formed and has started its "high priority/maximum speed" task.

The specification produced by the IPT will clearly state, both to the Navy acquisition managers and to potential suppliers, what is minimally necessary to effect a successful swap-out of the CRTs on board the P-3s.

Potential suppliers are invited to communicate with Ken Sola at 301/342-9261, fax 301/342-9305; e-mail: sola_ken%PAX5@mr.nawcad.navy.mil.

Boards for multisync displays

Genesis Microchip, Markham, Ontario, Canada, has implemented its video/graphics processing technology into two reference design products. The boards drive flat-panel displays with substantial integration and minimal cost. One of the boards, the Z1FCMP, includes the new gmFC1 frame-rate conversion chip and the gmZ1 Advanced Image Magnification IC. The gmFC1 chip converts the frame rates of incoming signals to the fixed frame refresh rate used for output at the timing required by the display. The chip is part of Genesis Microchip's strategy of solving the problems associated with multisync displays.

continued on page 32

conference report

International Display Workshops Big in Nagoya

When Japan Display became Asia Display, Japan had to create an annual conference to support its domestic display community – but it's become international.

by Ken Werner

EVEN BEFORE "Japan Display" was changed to "Asia Display," in recognition of an industry that was spreading throughout Asia, the Japanese display community had a problem. Japan Display was the name given to the International Display Research Conference (IDRC) every third year when it was held in Japan and typically drew over 1000 attendees. In between its triennial appearances in Japan, the IDRC was held in Europe (where it was called "EuroDisplay") and North America (where it was simply called the "IDRC"), drawing between 400 and 600 attendees.

But Japan, the country with the largest number of display researchers, was finding that even a triennial display research conference was not frequent enough, especially for the majority of researchers, who did not have the travel allowance to fly overseas 2 years out of three. Then, the Society for Information Display (SID), with full support from its large Japan Chapter, decided to turn Japan Display into Asia Display, with sponsorship cycling through the interested Asian Chapters. (Asia Display '98 will be in Seoul, Korea, from September 28 to October 1. For information, e-mail: idrc@ns.dankook.ac.kr or log onto Web site http://tftlcd.kyunghee.ac.kr/idrc98.) Now, Japan's display research community could only look forward to a major conference 1 year in six - or even less frequently.

The solution, implemented 1 year before the last Japan Display in 1995, was to establish the International Display Workshops (IDW), the fourth of which was held November 19-21, 1997, at the handsome Nagoya Congress Center in Nagoya, Japan (Figs. 1 and 2). Interestingly, the IDW quickly became an international event in its own right - in stature, content, and mix of attendees. Of the 890 registrants at IDW '97, 220 came from outside Japan, *ID* was told by Shigeo Mikoshiba, a well-known professor at the University of Electro-Communications in Tokyo and the Chair of the IDW Steering Committee.

In his opening comments, Heiju Uchiike, Professor at Hiroshima University and Chair of the Organizing Committee, said in the manner of a workman whose efforts had produced a satisfying result, "IDW is now almost a new Japan Display. We are up to 10 workshops this year from 8 last year in Kobe."

It is not possible to provide an exhaustive report of a large meeting like IDW in a short article. What follows are some personal selections from the formal presentations, as well as from informal conversations.

Keynote and Invited Addresses

The first keynote, "Policy of Information and Telecommunication in Japan," by Akio Motai, Deputy Vice-Minister of Technology and Policy Coordination of the Ministry of Posts and Telecommunications (MPT), was delivered by K. Suzuki, Director of Technology Development for MPT when Motai could not attend. In the written version of his paper, Motai emphasized the importance of info-communications as the key to industrial growth. The second phase of info-communications reform will be characterized by the creation of dynamism through competition, the revolution in broadcasting through digitalization, and the establishment of a new communications infrastructure. As part of MPT's deregulation strategy, NTT will be reorganized into one long-distance and two regional carriers, and the linking of new telecom carriers to NTT at low rates will be encouraged. (For more information, see the editorial in the February 1998 issue of *ID*.)

Toshiba's S. Takenaka opened by dismissing the long formal title of his keynote address and saying the real title should be "Can the CRT Survive Against Strong, Growing Enemies." His answer was to outline the extent to which the CRT is a moving target, and describe in some detail how specific improvements can be realized in luminous efficiency, contrast, beam size, and deflection power. Techniques for reducing deflection power include going to 22.5-mm necks and the incorporation of Toshiba's rectangular cone (RAC) deflection yoke, he said.

***Ken Werner** is the editor of* Information Display Magazine.

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Ken Werner

Fig. 1: IDW '97 was held at the handsome Nagoya Congress Center under mostly cloudy and rainy skies.

One of the CRT's great and enduring strengths is its format flexibility. LCDs and PDPs have a fixed native format and can not easily produce high-quality images in any other format - which is a problem the CRT simply does not have.

Takenaka's personal goal for the CRT of the future, he said, was a device with a 60-in. diagonal, a depth of one-half to one-third the current one, twice the brightness and contrast ratio, and with a 30–50% reduction in deflection power. It might be possible to realize such large, thin CRTs, by having a multi-neck structure on a single screen.

In the first invited address, Donald Bitzer, now Distinguished University Research Professor in the Computer Science Department at North Carolina State University, recounted the history of the invention of the ac plasma panel, and illustrated his talk with contemporary slides of early PDPs. The ac plasma display was invented by Bitzer, Gene Slottow, and one of Bitzer's graduate students, Robert Wilson, in 1964 at the Coordinated Science Laboratory (CSL) at the University of Illinois. The basic approach was laid out by Bitzer and Slottow in a 15-minute conversation as they waited for their wives to arrive and drive them home. Both wives were late, and a technology was created. When the first 1 × 1 matrix was fabricated from three microscope cover slides, it worked immediately - but only because a scrounged vacuum system had a leak that mixed a fortunate amount of nitrogen with the neon gas.

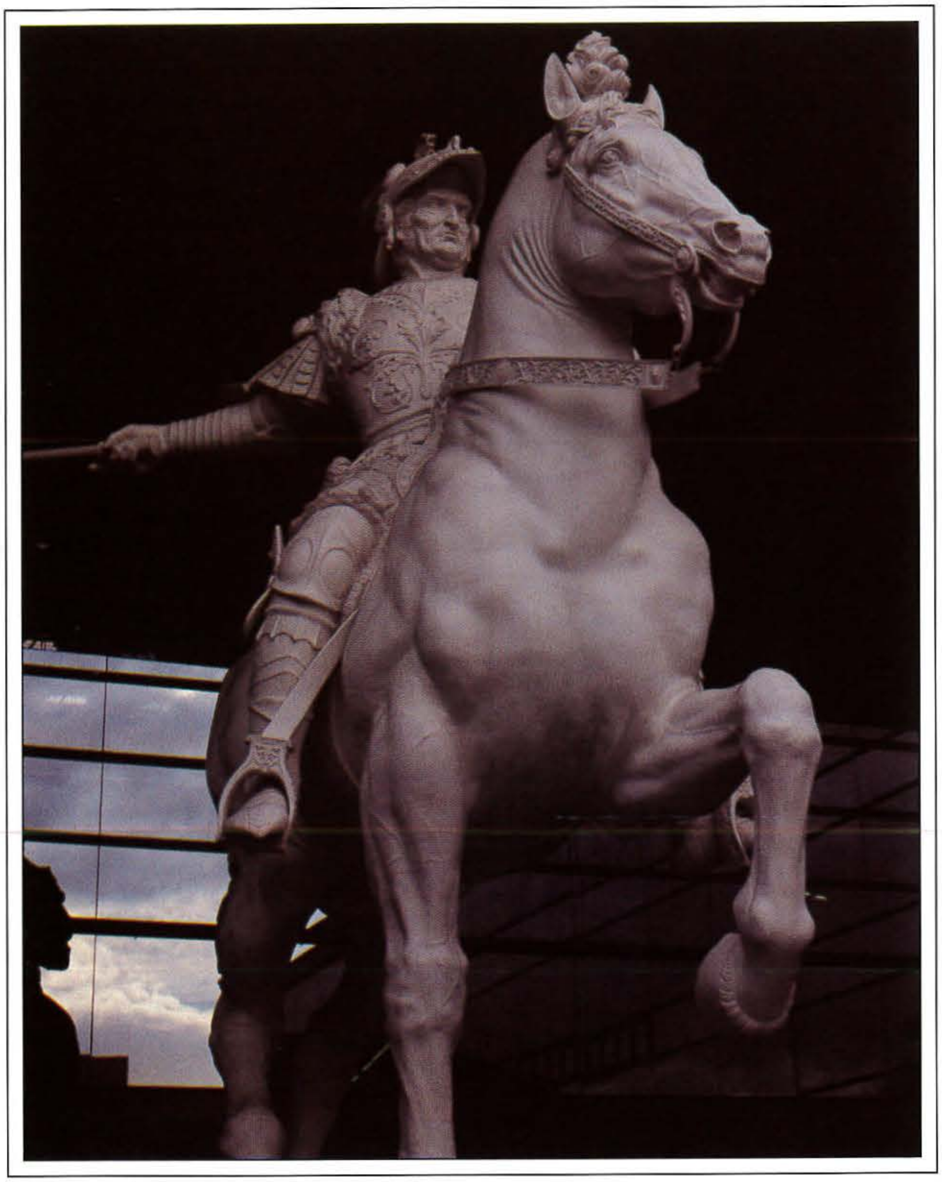
Among Bitzer's and Slottow's graduate students were Larry Weber (now President of Plasmaco) and Roger Johnson (now CEO of Information Technology Limited), both of whom had many students of their own and helped populate the field. Both Heiju Uchiike and S. Andoh of Hitachi spent a year at CSL in the '60s, and were instrumental in transferring the technology to Japan.

At the end of his talk, Bitzer fought back sobs as he said, "My only regret is that Gene Slottow could not be here to see what all of you have done with this technology. It would have meant everything to him."

Three more invited papers were presented on Thursday evening. Ernst Lueder of the University of Stuttgart presented "Progress and Future Trends of LCDs" with his usual clarity, breadth of view, and good humor. Among his picks for significant areas of development are:

- TFT displays with even larger aperture ratios and decreased parasitic couplings.
- Sharp's development of ITO with a sheet resistance as low as 15 Ω/□, making it suitable for data bus lines and allowing the saving of a mask step.
- MIMs and amorphous TFTs prepared at less than 150°C.
- One-shot laser annealing of poly-Si TFTs.
- Addressing schemes with decreased power consumption.
- Reflective displays with only one polarizer.
- Guest-host and PDLC cells without polarizers.
- Bistable cells with plastic substrates.

Arto Pakkala of Planar International (Espoo, Finland) reviewed the status of electroluminescent (EL) displays based on phosphor and insulator thin films grown with



Ken Werner

Fig. 2: *This equestrian statue of Francesco Sforza, one-time duke of Milan, which is the centerpiece of the Nagoya Congress Center, was designed by Leonardo da Vinci to be the biggest statue ever constructed. Leonardo created a clay model of the horse by 1493, but war intervened. The model was destroyed and the bronze casting never performed. But Prof. Hidemichi Tanaka of Tohoku University uncovered manuscripts in Madrid in 1967 that permitted the construction of a 2-m model of the statue, which was scaled up using computer techniques. The statue was finally cast in fiber-reinforced polymer when it was calculated that the horse's legs would not be able to support the statue's weight if it were cast in bronze.*

atomic-layer epitaxy (ALE). One-third of EL displays are currently made using ALE techniques, with a complete ALE insulator-phosphor-insulator deposition taking 20 hours.

Robert Meyer of LETI-CEA (Grenoble, France) in the final invited paper discussed "Anode Voltage, Architecture and Performances of Field-Emission Displays." "The production of large-sized cathodes at low cost must be considered as the key technical challenge for the field-emission display, but performances are mainly dependent on anode voltage and display architecture." During his talk, Meyer described a transparent cathode structure for FEDs that allowed the phosphor to be viewed from the cathode side of the display, resulting in enhanced luminance (200–300 cd/m^2) and luminous efficiency (2–2.5 lm/W).

As far as the FED anode-voltage debate is concerned, Meyer took the position that the selection is to be based on appropriateness: "Low-voltage FEDs with a simple structure and a low cost are especially suitable for small-to-medium-sized displays requiring high resolution and color brightness up to 300 cd/m^2.

"Medium-voltage FEDs are especially attractive for large-sized displays with low resolution. The structure remains very simple and the brightness can be increased up to 1000 cd/m^2. Is it necessary to have a focus electrode for medium voltage? It looks as though a good 'spot size' can be achieved without a focus electrode at 2 kV with an efficiency of 3 lm/W. High-voltage FEDs requiring a complex structure are the only solution for very bright displays up to 10,000 cd/m^2."

Gettering is a sensitive issue for FEDs, where the combination of large internal surface area and small internal volume makes adequate gettering difficult. During the question period, Meyer refused to comment on the getter process being used at LETI.

The Workshops

Here are some quick takes from the 10 workshops.

In the Workshop on FPD Materials and Components, T. Taminato, President of K&T Institute in Tokyo, said that lower-cost ink-jet matrix color filters will come into play in the next year or two, but with a different colorant system than has been used until now.

E. Ohmori (Nomura Securities, Tokyo, Japan) commented that the weak demand for notebook-type LCDs was similar to the way things were in "nightmarish 1995." In '95, demand for 10.4-in. displays was weak; now the demand for 12.1-in. displays is weak. He also predicted that STN-LCDs will "roll back" because of the advent of high-performance addressing.

Price trends will be down until the year 2000 and beyond. The situation would be okay if not for the new fabs coming on line. Without them, a healthy supply-and-demand situation would exist, with 51% of the output being 13.3-in. panels. With the new fabs, it would take 60% - and that won't happen. Under current circumstances, 13.3-in. TFT panels are not profitable, he said.

A recovery in 2000 will be helped by low prices, which will stimulate the desktop-monitor market - which will be very important for the LCD business. "But, please," said Ohmori, "we don't need any new Taiwanese fabs." However, it is clear that several Taiwanese companies are looking at the situation from a different viewpoint.

In "Technology Trends of Materials and Parts for LCDs," Yasoji Suzuki and Hitoshi Hatoh noted that materials cost for an LCD is 60% of what it was in 1993, and early in the next century it must drop to half of what it is today. Many technological innovations will be needed if this is to be accomplished.

Five authors from Schott Glass (Mainz, Germany), Deutsche Spezialglas AG (Grünenplan, Germany), and Sony's Atsugi Technology Center described a unique component in plasma-addressed liquid-crystal (PALC) displays: the "microsheet," a very thin glass sheet that separates the plasma part of a PALC display from the liquid-crystal cell. The authors reported that 620-mm-wide sheets of the 50-μm-thick AF45 glass have been produced for the first time in a down-draw process, resolving a major materials issue for 40-in. PALC displays.

In the April-May issue of *ID*, proponents of PALC technology expressed the conviction that it is all but inevitable that PALC displays will seriously challenge PDPs. But in a private conversation with *ID* and Roger Stewart of Sarnoff Corp., Fujitsu's legendary Tutae Shinoda expressed a different opinion. He noted that the hardest part of making a PDP is fabricating the barrier ribs. PALC technology must do much the same thing - and it then must add an LCD. Therefore, Shinoda does not see how PALC can compete on price, not to mention viewing angle.

The image quality of a PDP is much better than that of a CRT rear projector and somewhat better than that of an LCD rear projector such as Sony's Flight 37, said Shinoda, and PDP's motion artifacts are mostly solved. Indeed, the only real technical problem PDPs continue to have *vs.* CRT rear projectors is luminous efficiency.

N. J. Koh of LG Electronics' Display Device Research Lab in Kumi City, Korea, described the design of a 17-in. perfectly flat CRT called the "Flatron," which will use interchangeable flat tension masks (FTMs) having a 0.24-mm pitch in production. With the Flatron, LG has solved the hardest problem with FTMs, Koh said, which is focus, but he would not describe how at this time.

During the Q & A session, Hsing-Yao (Jimmy) Chen, Senior Consultant at Chunghwa Picture Tubes Ltd. (Taoyuan, Taiwan), asked for confirmation that a manufacturing system using interchangeable FTMs had actually been achieved. When Koh confirmed it, Chen congratulated him and said, "We have not been able to attain this."

In describing the field-sequential-color silicon-backplane microdisplay made by Displaytech (Longmont, Colorado), M. D. Wand noted that backplane size must be kept small for costs to be kept down. A 0.5-in. display costs $30; a 0.7-in. display, $90. With 8-μm design rules, one can get to SXGA on a 0.5-in. display.

Displaytech uses a ferroelectric liquid-crystal (FLC) mixture for its high speed and other characteristics that are well-matched to the silicon backplane. The FLC mixture typically contains 10-15 components, including the host and the chiral additive.

Ken Werner

Fig. 3: *Roger Johnson, CEO of Information Technology Limited, provided commentary that enriched* ID*'s reporting of PDP technology at IDW '97.*

Workshop on Plasma Displays

The mood was decidedly upbeat at the Plasma Display Workshop. NEC's K. Nunomura stressed recent advances in picture quality for

Yokogawa M&C Corp.

***Fig. 4:** Yokogawa's economical shading-cylinder colorimeters were shown in the small exhibition at IDW '97.*

TV applications. NEC's capsulated color filter (CCF), which places a red, green, or blue color filter in front of each color sub-pixel, substantially improves chromaticity and gives a broader color gamut than an LCD or CRT, he said; using 12 sub-fields for 8-bit gray scale, along with dual scan, improves motion quality at the cost of increased data-driver-circuit cost; and a single priming sequence drastically improves contrast ratio.

I. Kawahara and K. Wani of Matsushita (Osaka, Japan) discussed the simulation and reduction of motion-picture disturbance (MPD) in AC-PDPs, and joined their PDP colleagues in stating that most of the motion problems have already been solved.

H. Ando and his colleagues from Pioneer's Koufu Plasma-Display Panel Center described the development of signal-processing ICs for ac plasma displays. Plasma displays, they said, "are expected to be the displays of the next generation … but more cost reduction is necessary for the popularization of the PDP." To reduce cost and power consumption, the authors have integrated the signal-processing functions of a PDP on three ICs: PD4800A does video processing; PD4801A performs sub-field memory control; and PD4799A controls the driver ICs. The chips have been used in a 40-in. 640 × 480 Pioneer PDP that displays NTSC, VGA, MAC, and PC98. It was not stated whether the ICs would be commercially available.

F. Namiki and a large team of co-workers from Fujitsu described the fabrication and characteristics of the company's experimental 25-in. SXGA PDP with 0.39-mm pixel pitch intended for engineering-workstation (EWS) or PC applications. The key technologies needed for such a high-resolution PDP are fabrication of fine-pitched barrier ribs, the formation of uniform phosphor layers between the ribs, and high-speed addressing of at least four times the number of pixels used in entertainment-grade PDPs. The ribs were formed by dry-film resist and sandblasting, with the 30-μm-wide ribs set at a 130-μm pitch (for a cell gap of 100 μm). A 640 × 480, 0.39-mm test panel was fabricated and produced a luminance of 190 cd/m^2 and a contrast ratio of 60:1 or better.

According to Information Technology Limited CEO Roger Johnson (Fig. 3), a prototype panel shown at the 1997 Japan Electronics Show prior to IDW looked excellent - and better than the test panel shown by these authors at the author interviews. Johnson had had extensive conversations with Fujitsu's Tutae Shinoda, who predicted sample prices equivalent to those for the NEC 20.1-in. LCD. But Shinoda realizes the price must go down to $4000–5000, or about twice the price of a 25-in. professional CRT monitor.

As Johnson and I were talking, Dr. Shieh of Acer joined the conversation. He is working on a 34-in. PDP, which, he said, needs more work. Johnson: "Acer is known for computers. Is that the focus of your display?" Shieh: "No. TV first."

Workshop on Field-Emission Displays

Chun-Hui Tsai of Taiwan's Electronics Research and Service Organization (ERSO) led off the FED Workshop by describing a high-voltage FED structure he called "a breakthrough in FED development." A 3-in. test panel with reduced driving capacitance is producing 20 lm/W at 5 kV, and uses focus electrodes. Life testing has now reached 10,000 hours. A light spot of 0.4 mm at 3000 cd/m^2 has been obtained with a cathode-anode gap of 5 mm. The test panel has 150 × 90 pixels, with each pixel being 330 × 330 μm. The lifetime issues, said Tsai, relate to maintaining an ultrahigh vacuum in the FED's tiny volume.

With proper design, Tsai concluded, FEDs have extraordinary performance and will penetrate into portable applications.

Jong Duk Lee and his colleagues from Seoul National University discussed some of the benefits - enhanced emission uniformity and stability - of MOSFET-controlled field-emitter arrays (MCFEAs) and presented carefully measured characteristics of the particular structure they have fabricated. Multiple-gate structures, as presented by Itoh and Kanemaru at IDRC last September in Toronto, were not discussed.

Toshio Yamagishi and a team from NHK Science and Technical Research Laboratories (Tokyo, Japan) and Futaba Corp. (Chiba, Japan) described a new type of image sensor that combines an FEA and a high-gain avalanche-rushing amorphous photoconductor (HARP) target. An image from an experimental field-emitter image sensor (FEIS) using this architecture was presented. The FEIS, said the authors, "opens up the possibility of a new class of image sensors having ultrahigh sensitivity with wide dynamic range."

But the research is only beginning, cautioned the authors, "and many important phenomena related to the FEIS may not yet have been identified."

In an invited paper, R. A. Tuck and W. Taylor of Printable Field Emitters, Ltd. (Harlepool, England) and R. V. Latham of Aston University (Birmingham, England) reported on early work in developing printable field-emitting materials for large-area low-cost FEDs. The authors spent the most time discussing a material with a high density of metal-insulator-metal-insulator-vacuum (MIMIV) sites, but it does not appear on the surface that these sites are inherently uniform.

When this comment was made during the Q & A session, the authors answered that a ballast resistor is built into each site for feedback to assist uniformity. In addition, the degree of uniformity varies with coating technique. Now, 10 μm are used; it is necessary to go to 1 μm so that the emitting sites will be small relative to the cell structure.

Another approach to creating FEAs was described by Masayuki Nakamoto and his colleagues from Toshiba (Kawasaki, Japan). They used transfer molding to create very uniform tip arrays with a resistive core layer at a high density of 7,840,000 tips/cm^2.

Ken Werner

Fig. 5: These experimental TV receivers were used by the NHK Science and Technical Research Laboratories in 1947-48. They appeared in a display at IDW celebrating the 100th anniversary of the CRT and the 30th anniversary of the Sony Trinitron™.

Exhibits

A small but interesting exhibition accompanied the technical workshops. ***Fujitsu FQS*** (Fukuoka, Japan) was promoting LiqCryst 3.0, a Windows-based application that permits convenient access to the structures and associated data of 72,000 thermotropic liquid-crystalline compounds. LiqCryst 3.0 is distributed in Asia by Fujitsu FQS and in the rest of the world by LCI Publisher GmbH. A trial version is available. For additional information, access http://liqcryst.chemi.uni-hamburg.de or http://www.fqs.co.jp/CCS/.

Hamamatsu Photonics (Shizuoka-ken, Japan) showed one of its high-speed gated image-intensifier units, and demonstrated its capabilities with a series of images of PDP photo emissions as a function of increasing sustain voltage.

Yokogawa M&C Corp. (Tokyo, Japan) showed its 520-01 and 520-02 shading-cylinder colorimeters (Fig. 4). (The 520-02 includes internal reference object-color data and five silicon photodiodes instead of three to provide more accurate chromaticity measurements: ±0.01 max *vs.* ±0.03.) Introduced in Japan in late 1996 and scheduled to be introduced in the U.S. market in October 1997, Yokogawa's colorimeters cut costs by replacing expensive lenses with two irises to define the viewing cone - the shading cylinder. The acceptance angle is about 30°. The price of the 520-01 is $3458, $3913 for the 520-02. Windows-based color-management software is $728. For information in North America, contact Yokogawa Corporation of America at 770/251-8700 or http://www.yca.com.

Sanyo Electric Company (Osaka, Japan) and ***Sanyo Multimedia Center U.S.A.*** (San Jose, California) showed a very impressive autostereoscopic display based on a 15-in. XGA LCD, which used double-image-splitter technology and a head-tracking system. (The screen resolution was half of XGA in the horizontal direction.) The demo unit was not equipped with the head tracker; still, it was not hard for a viewer to position his or her head in one of the sweet spots. When there, the fanciful (but not rapidly moving) animated world presented by the software was remarkably enveloping and effective. Engineering samples were to be available in April 1998, per Chief Researcher Atsuhiro Yamashita.

Nissho Electronics (Tokyo, Japan), Japanese distributor for ***Displaytech*** (Longmont, Colorado), showed two of that company's reflective field-sequential-color microdisplays mounted to simulate goggles or glasses. The displays looked good but the optics needed work, exhibiting curved fields and loss of definition toward the corners. Nissho's Nobuaki Nagai said that the demonstrated 0.4-in. VGA displays were just for glasses-type applications and viewers; 0.85-in. XGA and SXGA panels would be used for projection. SXGA samples were scheduled to be available to qualified customers in Japan by the end of Q1 '98 and XGA three months later.

Why SXGA before XGA? The original plan was to produce VGA and SXGA panels only, but there was lots of demand for XGA panels from Japanese customers, Nagai said. Seiko-Epson's Kamakura-san was observed to be in an apparently serious conversation with a Nissho sales rep.

Nichia Chemical Industries (Tokushima, Japan) was showing a selection of full-color dot-matrix LED modules incorporating, of course, Nichia's path-breaking bright blue LEDs. For more information, access http://www.meshnet.or.jp/nichia/.

Fuji Manufacturing Company (Tokyo, Japan) was providing information about the company's "Pneuma-Blaster" sandblasting system for forming PDP barrier ribs. Sales Engineering Manager Tadashi Sone showed *ID* a photomicrograph and an actual sample of

100-µm-pitch ribs sandblasted with Fuji S8 abrasive that would be suitable for SXGA and UXGA panels. The ribs were 30 µm wide with 70-µm spacing. The system can produce 16 40-in. panels per hour, Sone said. NEC, Hitachi, Mitsubishi, Samsung, LG, and Acer are all using the machine.

Tokyo Cathode Laboratory (Tokyo, Japan) showed its Cathode Emission Profiler for CRTs, which generates its cathode-emission information in a variety of graphics formats. A version for FEDs is under development, and a prototype is anticipated by mid-1998. Sony, Canon, and NEC have all expressed interest in the FED version - and serious interest isn't cheap. The CRT version costs about ¥25 million ($200,000). The FED version is likely to cost twice as much, said Marketing Manager Takashi Araki.

Otsuka Electronics Co. (Osaka, Japan) showed its LCD-7000/5100 LCD-evaluation system for panels and modules, which has a lamp and sensor on adjustable arms. The flexible system measures luminance, contrast ratio, chromaticity, *etc.,* and it is available with a temperature chamber. This is the standard system for Asian manufacturers, said Acting Marketing Manager Hiromu Fujii, and about 130 have been sold.

Lasertec (Yokohama, Japan) presented information about its LCD mask and color-filter inspection stations and its confocal laser scanning microscopes for LCDs and PDPs.

Sumitomo Chemical (Tokyo and Osaka, Japan) was promoting its liquid-crystal chemicals, and polarizing, retardation, and anti-reflecting films. For information: access http://www.sumitomo-chem.co.jp/kiso/optical.html.

Noritake (Nagoya, Japan) showed a variety of its itron monochrome and multicolor dot-matrix VFDs. "The market wants thin and compact," said a Noritake representative, "and the internal memory in these displays permits 256 × 32 pixels to be addressed through only 12 pins." The company also showed the very bright picture-element tubes used by Mitsubishi in its Tokyo Dome display - which utilizes 60,000 of them.

Lodic Co. (Tokyo, Japan) was showing black-and-white polymer-network LCD (PNLCD) modules. These are light-scattering opaque/transparent switching displays that do not use polarizers and transmit more than 85% of light in their transparent state. The company claims a wide viewing angle and greater than 10:1 CR even in direct sunlight. Lodic, which is now a subsidiary of Dai-Nippon, makes a variety of LCD materials, said President Akio Nagashima. The PNLCD material is the company's latest product, which is used by Spoon in that company's low-cost, highly styled, and widely advertised wristwatches, which seemed to be ubiquitous in Japan around the time of IDW.

Mitani Electronics Corp. (Tokyo, Japan) showed a 55-in. mask for PDP fabrication. Both glass and chrome masks were to be available by early 1998, said Senior Managing Director Kiyoharu Hashimoto.

The Past and the Future

Even as it works to shape the future, the display industry has developed an inclination to honor its past. One of the IDW exhibits did just that by celebrating the 100th anniversary of the CRT and the 30th anniversary of the Sony Trinitron™ by showing historical items borrowed from Japan's National Science Museum.

Among the items on display were a replica of the 1897 Braun tube, an example of the first Trinitron TV receiver (the KV1310, a 13-in. table-top set that sold for ¥118,000 in 1968), and two wooden-cabinet receivers used by NHK for experimental work in 1947-48 (Fig. 5).

The future of display technology is even richer than its past, as indicated by the varied work discussed at this IDW. To get an idea of what's coming next, make your reservations in Kobe for IDW '98, December 7-9, 1998. ■

continued from page 25

New plasma monitor

QFTV, San Francisco, California, and Photonics Systems, Northwood, Ohio, have announced the availability of the QFTV/Photonics 42-in. FlatScreen™, a digital 4-in.-thick full-color plasma monitor. The product specifications include SVGA/XGA resolution, portrait/landscape options, a 400:1 contrast ratio, a field-upgradable RGB interface, and digital video inputs. The digital monitor incorporates many advanced state-of-the-art technologies, including digital video cards, ImageSite glass substrates, and color-corrected front glass. The full-color monitor also includes a proprietary cooling system that allows the unit to be installed within a 4-in. wall or hung flat against a wall. Next-generation designs are being developed that will provide better definition and picture quality for professional multimedia and computer-workstation applications.

Plastic display screens

Cambridge Display Technology, Cambridge, U.K., and Seiko-Epson Corp., Nagano, Japan, have unveiled a joint development program to produce plastic television and computer-monitor screens based on CDT's patented Light-Emitting Plastic (LEP) technology. Measuring 50 mm square and only 2 mm thick, the black-and-white prototype screen can display full television pictures. Unlike LCD screens, the prototype display screen has no restrictions on viewing angle, nor is there blurring of fast-action shots. The black-and-white screen has the potential to be used as a monitor for portable VCRs and digital cameras. The joint development program is expected to deliver futher benefits later this year with the announcement of a full-size color display screen. ■

Please send new product releases or news items to Information Display, c/o Palisades Institute for Research Services, Inc., 411 Lafayette Street, 2nd Floor, New York, NY 10003.


1948
1998

conference report

Strategic Perspective and Vehicular Displays Draw over 200 to Ypsilanti

The unique orientation of this regional meeting attracted a number of international attendees.

by Samuel Musa and Robert L. Donofrio

THE FPD STRATEGIC FORUM is not a large meeting, but with its emphasis on global flat-panel-display (FPD) technology and manufacturing strategy, and with CEOs conversing *sotto voce* in the hallways, it has become a valued one. The Metropolitan Detroit Chapter of the Society for Information Display and the University of Michigan's Center for Display Technology and Manufacturing sponsored the third annual forum in Ypsilanti, Michigan, on September 22, 1997, and followed it on September 23 with a technical symposium having a special focus on vehicular displays (Fig. 1). The keynote address, given by Doug Rothwell, CEO of the Michigan Jobs Commission, detailed Michigan's interest in supporting the display industry.

The first session addressed the next generation of display manufacturing, and included presentations by several leaders of the FPD industry. They covered the challenges in technology, manufacturing, markets, location, and timing. The U.S. role in displays was discussed in relation to infrastructure as well as display manufacturing.

Ross Young of DisplaySearch kicked off the session with "Fourth Generation Challenges and Opportunities," which treated the issues involved in fabricating 17- and 19-in. LCDs. Among the challenges are developing a robust hillock-free Al-deposition process, minimizing equipment failures, maintaining uniformity over a larger area, simplifying TFT structures, and increasing process integration.

Mr. Hideaki Kawakami, Senior Chief Engineer at Hitachi, discussed next-generation in-plane-switching (IPS) nematic LCDs addressed with a TFT matrix. This technology was selected, Kawakami said, because conventional TFT production lines can be used and very wide viewing angles can be achieved for monitor applications.

Next, Hiroshi Hayama, Research Manager at NEC, spoke about next-generation TFT production lines and technologies as proposed by the TFT-LCD Technology Committee of the Ultra Clean Society. The committee has proposed a 960 × 1100-mm glass substrate for next-generation production lines. These lines must surmount significant technical challenges, which include reducing TFT photo-

***Samuel Musa** is Executive Director of the Center for Display Technology and Manufacturing at the University of Michigan, Ann Arbor, MI. **Robert L. Donofrio** is President of Display Device Consultants, 6170 Plymouth Rd., Ann Arbor, MI 48105; telephone 734/665-4266, fax 734/665-4211, e-mail: rldonofrio@aol.com.*

Detroit Marriott Ypsilanti

***Fig. 1:** For two days last September, the Detroit Marriott Ypsilanti was home to the third annual FPD Strategic Forum and Technical Symposium.*

0362-0972/98/1406-034$1.00 + .00 © SID 1998

mask process steps, reducing film thickness, implementing fast substrate transfer, performing uniform deposition and etching at higher rates, and incorporating high-speed coating, developing, and exposure.

Todd Yuzuriha, Director of LCD Technology R&D at Sharp Microelectronics Technology, was concerned with next-generation AMLCD issues, as was Donggil Kim, Vice President of Frontec. Kim addressed three major TFT-LCD projects being tackled by LG Electronics:

- A high-quality thin-film-deposition process based on ultra-clean technology.
- UV photo-alignment of liquid crystals.
- Integrating driving circuits using low-temperature poly-Si TFTs.

Michael Ciesinki, CEO of USDC, began the second session by appealing for a new FPD initiative. He cited some goals for 2001, including robust domestic manufacturers and suppliers, university-based research and development, and technician-level and continuing professional education.

Motorola's Tom Credelle was next with an overview of the Motorola field-emission-display (FED) pilot line's capability and the company's plans for commercial production. Then Steve Depp of IBM discussed the history, formation, and operation of DTI, the joint-manufacturing venture between IBM and Toshiba; and Norman Turner of Applied Komatsu Technology gave an overview of AKT products and markets.

Turner was followed by Stefanie A. Lenway and Tom Murtha of the University of Minnesota, who presented a strategic analysis of current markets and future opportunities for U.S. display manufacturers.

Vehicular Displays

On the second day of the event, several automobile manufacturers discussed future directions in vehicular displays. It's very clear that American automobile manufacturers believe that automotive FPDs will first be used in Japan, then in Europe, and finally in the U.S. W. F. Powers of Ford stated that two promising displays for autos are the FED and the organic light-emitting diode (OLED). Both could possibly be made at the low cost required by the American market. Futaba discussed their vacuum-fluorescent displays (VFDs) and FEDs.

An exciting automotive display was described by John Troxell of General Motors. In conjunction with Futaba and Delco, General Motors Research Center has developed a reconfigurable active-matrix VFD for heads-up applications - a display that uses the VFD technology that is well known in the auto industry.

A paper by Sarnoff Corp., Planar Systems, USARL, and Computing Devices of Canada reported a new multi-layer ceramic-on-metal technology in which the display, drivers, and functional electronics are all part of the display package. General Dynamics Land Systems described the new M1A2 Main Battle Tank AMLCD, and Teltron Technologies discussed their new 2-in. CRT and monitor, all housed within a 2.9 × 12-in. tube, which was developed for use in the M-2 Bradley Fighting Vehicle.

In the Emerging Technologies Session, Rebecca Jordan previewed the light-emitting-diode (LED) displays being developed at Eastman Kodak, and Ronald Gale described the CMOS displays being developed by Kopin Corp. A sizable poster session covered many topics, including university research and the activities of companies currently discussing new display-related developments and applications. ■

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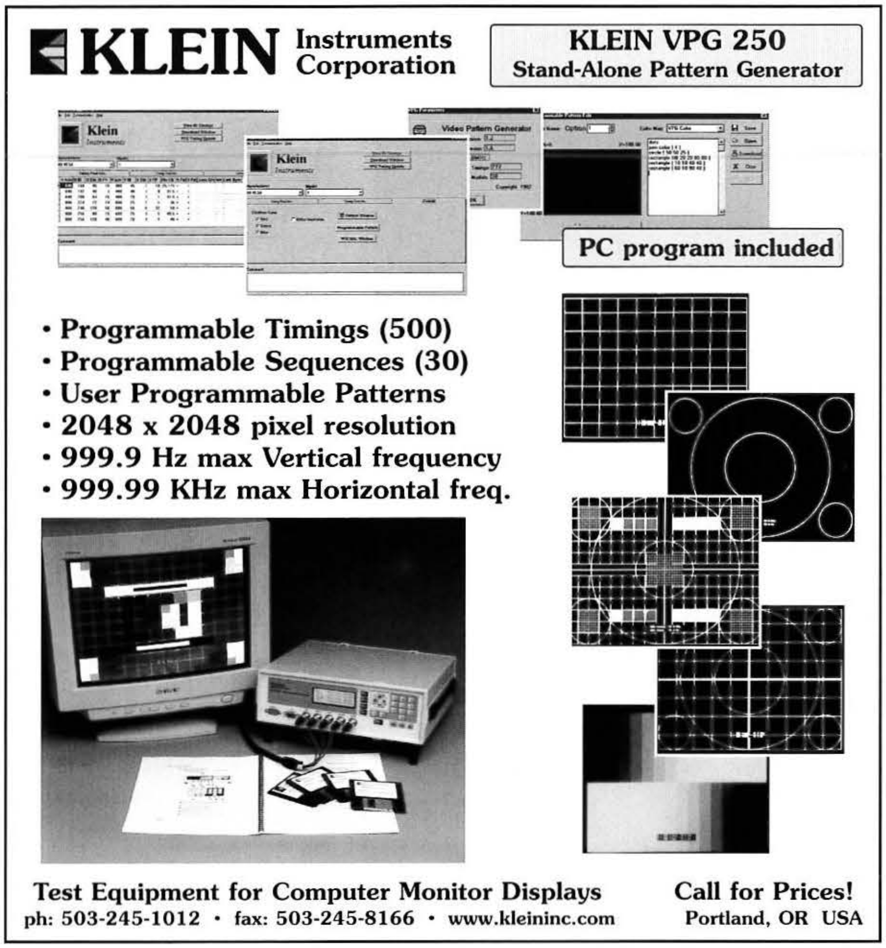

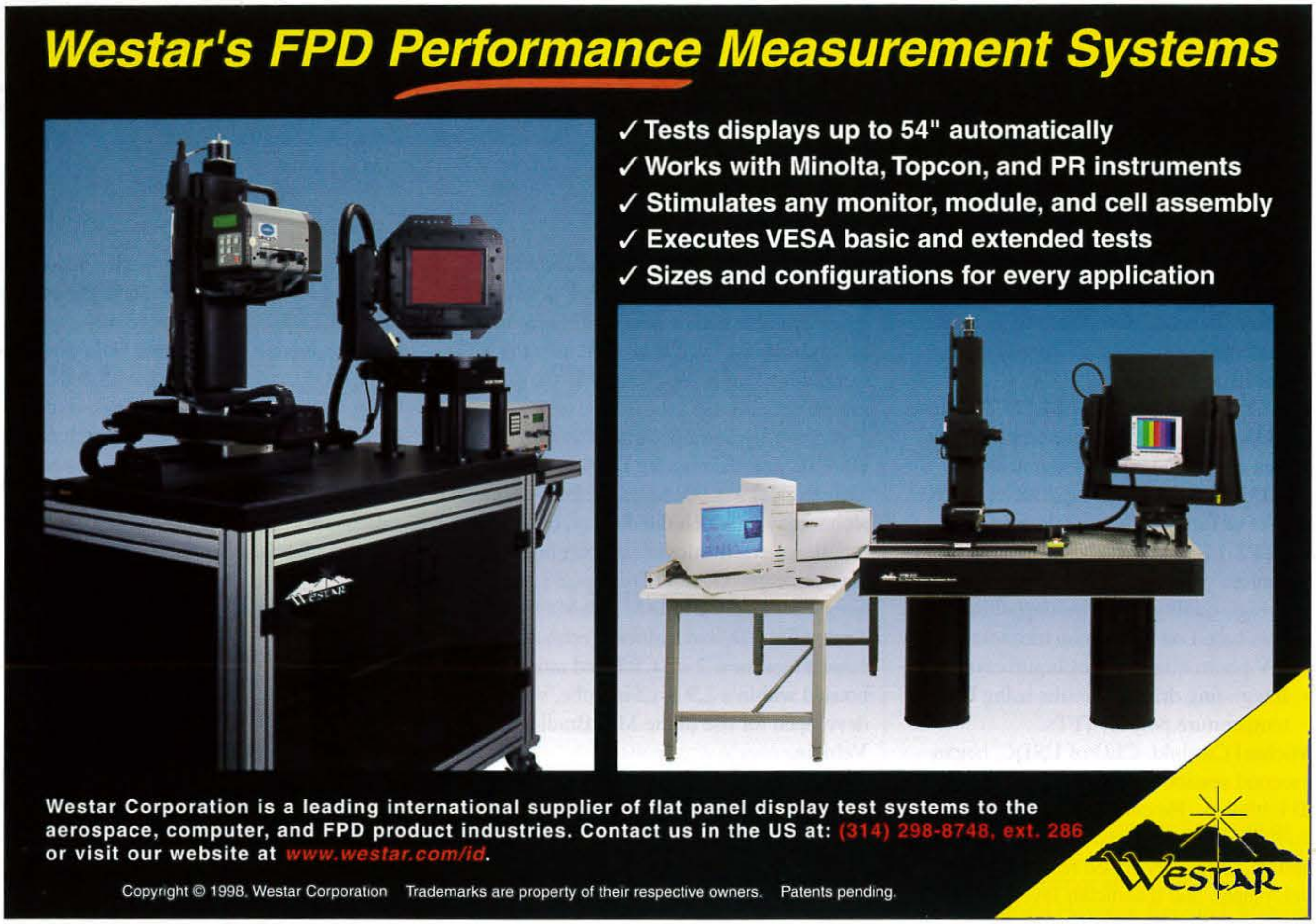

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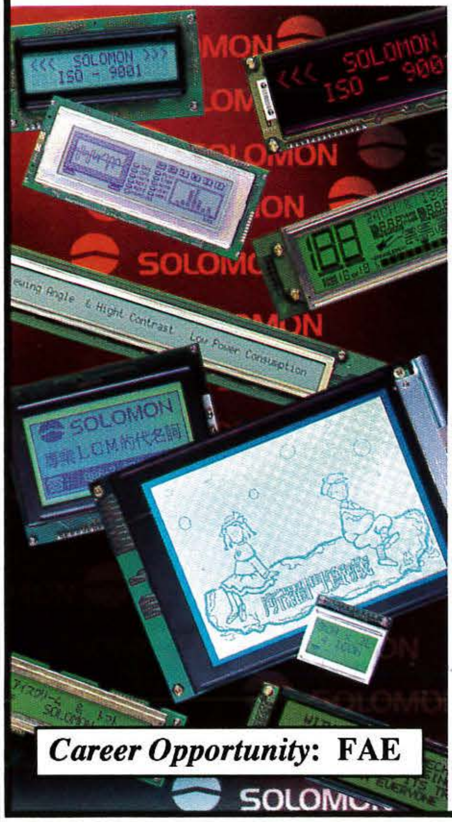

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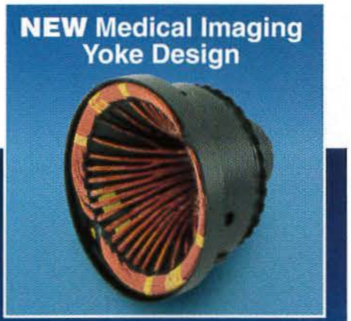

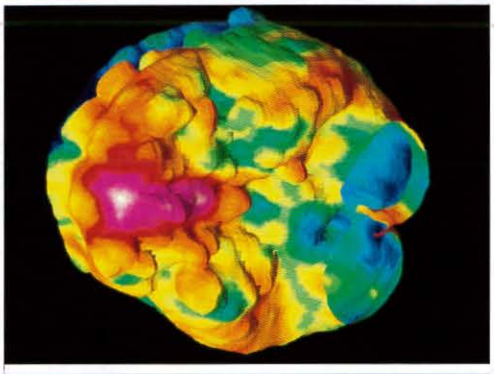

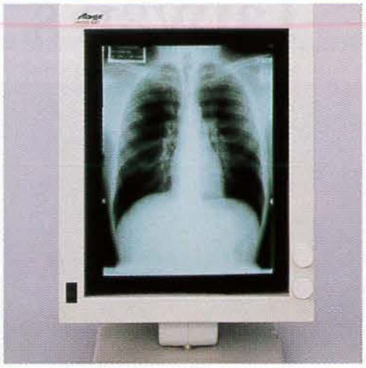

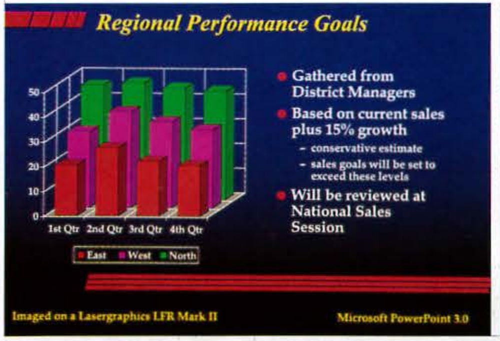

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9 98

SEPTEMBER

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  - PL Devices – LC Backlights

28 98

SEPTEMBER

18th International Display Research Conference (Asia Display '98)

SEOUL, KOREA
SEPT. 28 – OCT. 1, 1998

- An international conference on display research and development aspects of:
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  - Hard Copy & Storage, Input Systems,
  - Integrated Devices and Applications,
  - Image and Signal Processing,
  - Color Perception, Human Factors

17 98

NOVEMBER

Sixth Color Imaging Conference: Color Science, Systems & Applications

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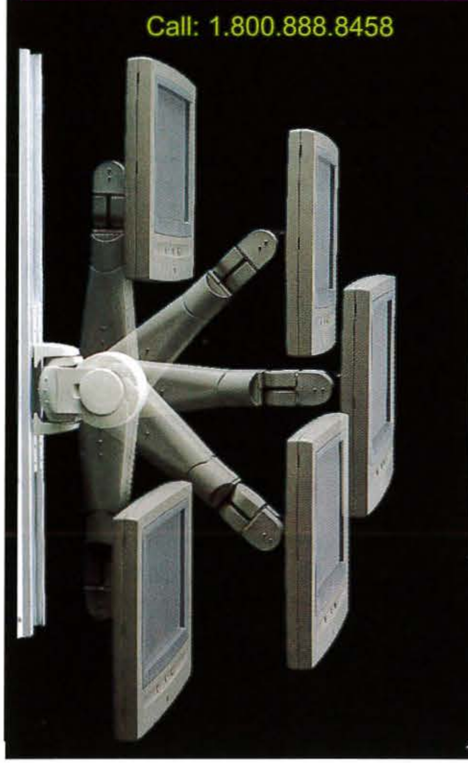

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Wiley Launches Wiley-SID Series in Display Technology

MacDonald and Lowe's Display Systems *and Keller's* Electronic Display Measurement *kick off the new series with strong sales.*

by KEN WERNER

John Wiley & Sons and the Society for Information Display have launched their new *Series in Display Technology* with the publication of two books. The first is *Display Systems: Design and Applications,* edited by Lindsay W. MacDonald and Anthony C. Lowe (Wiley, 1997; ISBN 0-471-95870-0; $95.00, $70.00 for SID members ordering from SID Headquarters). Although the book is a symposium volume whose chapters are based on the papers given at the international two-day conference, "Getting the Best from State-of-the-Art Display Systems," held at the National Gallery, London, in February 1995, the volume has far more coherence than the typical symposium product.

This coherence is due to the fact that the conference was designed from the beginning to be made into a book, with both conference and book adhering to a predetermined plan. As the editors say in their preface:

> For any display-based product to be successful, the needs of the application must be properly matched to the capabilities of the display system. This match can only be made in the context of the whole product design and development process. It must start with the analysis of market requirements including an understanding of the tasks and needs of the users.
>
> ... Recognizing these issues and realizing the need to create a forum where representatives of the wide range of disciplines encompassed by this subject could meet and interact, the European Region of the Society for Information Display (SID) organized [this] international two-day conference.
>
> ... The objective of this volume is to extend the discussion to a wider audience.

Many of the contributors are distinguished. "Part I: Applications - What drives the requirements for displays?" contains chapters by Carl Machover ("How applications have driven display requirements"), Lindsay MacDonald ("Display requirements for desktop electronic imaging"), and Richard Holmes ("Head-mounted display technology in virtual reality systems). Other distinguished authors appearing in this section include Ben Shneiderman, Dick Bosman, and Lou Silverstein.

"Part II: Technology - What can current displays deliver?" includes "Matching display technology to the application" by Anthony Lowe, "Active-matrix addressing of LCDs: merits and shortcomings" by Ernst Lüder, "The structure, performance and future of passive-matrix LCDs" by Alan Mosley, and "Projection Systems" by Patrick Candry, along with several other contributions.

A final section on metrology contains seven chapters covering measurement principles, optical characterization of LCDs, CRT colorimetry, low-cost color-measurement techniques, dynamic performance of displays, evaluating stereoscopic displays, and evaluating the usability of workstation displays in the real world.

With its systems orientation, and with its editors' commitment to provide a comprehensive and balanced treatment, *Display Systems* is a far more useful volume than its symposium origin would indicate.

Electronic Display Measurement: Concepts, Techniques, and Instrumentation by Peter A. Keller (Wiley, 1997; ISBN 0-471-14857-1; $70.00, reduced price for SID members ordering from SID Headquarters, $60.00) is a unique practical guide to display measurements. It starts with the basics - "Light and Color," "Light Sources, Filters, and Detectors," and "Displays." The book then moves on to the nitty-gritty: measurement instrumentation, luminance and contrast measurement, color measurement, resolution measurement, geometry measurements, time-related measurements, calibration, and display standards. The many appendices include CIE tristimulus values, radiometric and photometric conversions, standard illuminants, WTDS phosphor designations, instrument manufacturers, calibration services, and standards organizations.

Keller has had a dual career at Tektronix, first as a CRT designer and now as the manager of Tek's instrumentation product line. His extensive experience shows in this book's emphasis on what practical people really need to know. It will not surprise readers of Keller's previous book, *The Cathode-Ray Tube: Technology, History, and Applications* (Palisades Press, New York, 1991) that the current work is clearly written and exhaustively referenced.

It is worth noting that the review copy of Keller's new book immediately became an important reference for a research project I was working on at the time. I recommended it highly.

This series is truly international, not only because of its SID sponsorship and the nationalities of its authors, but also because the volumes are issuing from Wiley's offices in both Chichester, England, and New York City. This is an unusual arrangement that has produced a peculiarity in the first two volumes: except for the varnished paper on their hard covers, the two books look nothing alike. The cover designs are different, as are the books' trim sizes and typographic designs. The chapter titles in one volume are presented with only the first letter of the first word capitalized; the titles in the other volume have the first letter of each word capitalized.

Does this matter in the greater scheme of things? Not to most people, but it gives the impression that Wiley's American hand doesn't know what its English hand is doing. And that's unfortunate because, in all other ways, *The Wiley-SID Series in Display Technology* is off to a fine start. ■

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SOCIETY FOR INFORMATION DISPLAY NEWS

SID Headquarters moves to San Jose

In May, at the annual SID International Symposium, incoming President Tony Lowe and outgoing President Web Howard announced that the SID Headquarters was being moved from Santa Ana to San Jose, and that a new staff had been appointed.

The new SID Executive Director is Dee Dumont, who worked extensively with longtime SID member and Past-President Gus Carroll. The new Executive Assistant is Jenny Needham, who previously worked for Apple Computer. Trisha Maniscalco, a staff member at Santa Ana, is helping with the transition. "The new staff and HQ will bring SID members an improved range of services," said President Lowe.

Contact information for the new SID HQ is:
SID Headquarters
31 East Julian Street
San Jose, CA 95112
phone: 408/977-1013
fax: 408/977-1531
e-mail: office@sid.org
Dee Dumont, Executive Director,
dee@sid.org
Jenny Needham, Executive Assistant,
jenny@sid.org

Redesigned SID Web site

SID's recently redesigned website (http://www.sid.org) now contains the titles of forthcoming articles scheduled for *Information Display Magazine,* the current *ID* editorial, and news releases from the SID Press Relations Office. You can also use the site to locate selected back articles from *ID* and *The Journal of the Society for Information Display (JSID),* and to order SID books, Digests of Technical Papers, and other publications.

A great deal of information is available on the SID Web site, and the site and *ID* magazine are intended to complement each other.

Invitation to Asia Display 98

It is a great pleasure to invite all of you to attend Asia Display 98, which will be held for the first time in Korea. You can enjoy the several events at Asia Display 98 and the beauty of the autumn season, tours, shopping, and the friendliness of the Korean people. You can make many friends in the display companies and research institutes of Korea. You can also find important business partners in Korea because people in the Korean display industry need strong cooperation with you and your company.

I will do my best along with my staff to make Asia Display 98 a very successful event for you, and I am sure that Asia Display 98 will be remembered by all the attendees and exhibitors for a long time. I look forward to seeing all of you soon in Seoul, Korea.

Sincerely,
C. Lee
Conference Chair
Asia Display 98

M. H. Oh
Chair, Executive Committee
Asia Display 98

Seoul to host first Asia Display conference held outside Japan

Asia Display 98, the first Asia Display conference to be held outside Japan, will be held September 28 - October 1, 1998, at the Sheraton Walker-Hill Hotel in Seoul, Korea. Asia Display 98 is a vertically integrated international opportunity expected to draw over 1500 attendees from around the world. The event is sponsored by the Korea Chapter of the Society for Information Display and the Korean Physical Society. SEMI Korea is managing the exhibition.

You can present your research results, share the most recent achievements in information-display research and development, explore market opportunities, and interact with industry people at Asia Display 98. You can also exhibit your products and view state-of-the-art display technologies at the vendor exhibition, which will include information displays, production equipment, materials, and components.

Asia Display 98 will enable you to keep abreast of the growing flat-panel-display technologies and industries in Korea. The global flat-panel-display market will be US$15.2 billion in 1998 and it will grow to US$21.5 billion in the year 2000. A healthy portion of this market increase will be due to the plans of Korean and other Asian companies to make multibillion-dollar investments in the information-display industry within the next few years.

Technical program

Conference topics include active-matrix LCDs, applications, applied vision/human factors/3-D displays, CRTs, display manufacturing, display measurement, display systems, plasma-display panels, electroluminescent displays, field-emission displays, large-area displays, and liquid-crystal technology.

Asia Display 98 also offers a series of technical workshops given by experts in the field of information displays. The workshops will be held on Monday, September 28, 1998, and will cover AMLCDs/LCs, FEDs, PDPs, and phosphors.

Keynote and invited addresses will be given by Mr. Y. W. Lee, President of Semiconductor Business, Samsung Electronics, Co., Ltd.; Dr. S. Kobayashi, Professor, Science University of Tokyo in Yamaguchi; and Dr. Larry F. Weber, President of Plasmaco.

The schedule for Asia Display 98 is as follows:

Workshop	Sept. 28
Technical Conference	Sept. 29 - Oct. 1
Vendor Exhibition	Sept. 29 - Oct. 1
Reception	Sept. 28
Exhibitors' Reception	Sept. 29
Banquet	Sept. 30

Hotel and travel information

Because the value of the U.S. dollar has increased by more than 50% since last year, visitors to Asia Display 98 will be able to enjoy the very nice hotels, restaurants, transportation, and shopping. The Sheraton Walker-Hill Hotel in Seoul, Korea, is the conference site (+82-2-453-0121, fax +82-2-452-6867, e-mail: hotel@pretty.walkerhill.co.kr). The hotel is located on attractive, wooded, lakeside grounds outside of Seoul. There are several other hotels, such as Lotte World Hotel, Han Kang Hotel, and Olympic Parktel, located near the conference site, where there will be special discounted room rates available for attendees.

Access to the hotel is easy. From Kimpo International Airport, Korean Air Limousine buses leave for the Sheraton Walker-Hill Hotel every 15 minutes. Free shuttle buses between the Sheraton Walker-Hill Hotel and the Kwangnaru subway station (Line 5) are available. For more information, e-mail: idrc@ns.dankook.ac.kr.

Tours and activities

One of Korea's TFT-LCD manufacturers has agreed to open its TFT-LCD development line to Asia Display attendees. Reservations for the industry tour can be made at the conference registration desk during conference hours.

The weather in Korea during early autumn is mild, and the countryside is beautiful. There will be several social and spouses' programs, such as a city tour and shopping at Itaewon and Namdaemoon. There also will be many programs prepared by Kim's Travel Services Co., Ltd., including tours to a traditional ceramics-making village and a Korean Folk Village, and an evening cruise on a Han River Pleasure-Boat, with Korean dishes and a traditional Korean dance performed on board. The evening view along the Han River is memorable.

For more extended trips, there is a three-day tour of the beautiful and unspoiled Cheju Island, and a two-day excursion of the ancient buildings and temple of Kyongju, the "Museum without walls," which was the capital of the Shilla Kingdom for a thousand years. You can feel the history of Korea by just walking in the city of Kyongju.

Information

For general information, contact S. Lim, Secretary General, Dankook University; +822-709-2979, fax +822-792-5857, e-mail: idrc@ns.dankook.ac.kr.

For Technical Conference and Workshop information, contact Jin Jang, Program Co-Chair, Kyung Hee University; +82-2-961-0270, fax +82-2-968-6924, e-mail: jjang@nms.kyunghee.ac.kr.

For information on the Asia Display 98 Exhibition, contact H. C. Kim, SEMI Korea; +822-551-3041, fax +822-551-3406, e-mail: hkim@semi.org or semikorea@semi.org., Web site http://tftlcd.kyunghee.ac.kr/idrc98.

Minsk '98

The 7th International Symposium on Advanced Display Technologies (MINSK '98) will be held December 1–5, 1998, in Minsk, Belarus. The symposium is sponsored by the Society for Information Display, Belorussian and Ukrainian SID Chapters, in cooperation with the Belorussian Ministry of Education, the Belorussian State Committee on Science and Technologies, the State University of Informatics and Radioelectronics, and the Scientific-Production Corporation "INTEGRAL."

This symposium will be the seventh in a series of annual meetings and will provide an international forum for presentation and discussion of new results in the field of design, manufacturing, and applications of modern information displays. Particular emphasis will be given to novel materials, technologies, and display applications. The following topics will be covered:

Active- and passive-matrix LCDs.
LC materials and phosphors.
Technological equipment, materials, and components for display manufacturing.
Public information displays and projection devices.
Cathode-ray tubes and TVs.
Emissive displays (ELs, PDPs, VFDs, and FEDs).

The symposium program will consist of oral and poster presentations along with short communications, author interviews, a SID Belarus business meeting, and round-table discussions. The symposium's official language will be English. Simultaneous interpretation will be provided.

The registration fee is $US300 (10% lower for SID members) and includes admission to all sessions, light refreshments, a copy of the Symposium Proceedings, hotel accommodation with full board, reception, banquet, local transportation, and social programs.

The cost of local transportation is included in the registration fee. Pick up of all foreign participants will be arranged at the international airport or railway stations. The same procedure will be followed for departure.

For more information, please contact A. Smirnov at:

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Display Technology

5th Annual Flat Panel Display Strategic and Technical Symposium 1998. Sponsored by the University of Michigan (Center for Display Technology and Manufacturing) and the Metropolitan Detroit Chapter of the Society for Information Display. Contact: Robert Donofrio; 734/665-4266, fax -4211, e-mail: rldonofrio@aol.com
Sept 9-10, 1998 Ypsilanti, MI

9th International Workshop on Inorganic and Organic Electroluminescence (EL 98) and The Fourth International Conference on the Science and Technology of Display Phosphors. Sponsored by SID, PTCOE, DARPA, and the Oregon Center for Advanced Technology Education. Contact: Mark Goldfarb, Palisades Institute for Research Services, Inc., 201 Varick St., Suite 1006, New York, NY 10014; 212/620-3380, fax 212/620-3379.
Sept. 14-17, 1998 Bend, OR

The 18th International Display Research Conference (Asia Display '98). Sponsored by KPS and SID. Contact: Prof. S. Lim, Secretary General; +82-417-550-3542, fax +82-417-551-9229, e-mail: limsk@ns.dankook.ac.kr, Internet: http://tftlcd.kyunghee.ac.kr/idrc98.
Sept. 28-Oct. 1, 1998 Seoul, Korea

The 42nd Annual Meeting of the Human Factors and Ergonomics Society. Contact: HFES, P.O. Box 1369, Santa Monica, CA 90406-1369; 310/394-1811 or 310/394-9793, fax 310/394-2410.
Oct. 5-9, 1998 Chicago, IL

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

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

continued from page 4

"Sure, when pigs fly," might be the well-considered response, followed by: "And by the way, what is this special powder that you claim puts out light but no heat, and what is this wire-thingy that you say makes invisible electrons?"

"Oh, you mean the phosphor screen and the cathode?"

"I don't care what you want to call them; I don't exactly see these items on the shelf in my local hardware store. So where do you find these magical materials that emit invisible particles and which you then claim cause light to be created? Next, I suppose you're going to try to tell me that you talk to aliens that come in spaceships and impart this knowledge to you on a regular basis."

But magical materials they are. And they typically determine when and how a new display technology will make it to market. Oliver Dalton, one of the really classy product-development managers at Tektronix, who retired some years ago, used to remind us more ambitious display-device developers that, no matter what we promised, his assumption would be that it would take us at least 10 *years* to develop a new cathode. Needless to say, his estimate was always more accurate than ours. The materials development and life testing invariably kept the new cathodes from being introduced until much more time had passed than we had estimated. The story was not much different for phosphors. The initially promising results were usually followed by many months and often years of hard work to improve life, repeatability, and to develop a predictable manufacturing process. No matter how we tried, we could never find any shortcuts. New materials took considerable development time and extensive experience before they could be reliably used in new products.

Is it because the CRT is such a peculiar device that it suffers from this seeming snail's pace in the development of new materials? Is it perhaps because we have to work in a vacuum that we have these difficulties? Then consider the following: liquid crystals were first developed for displays in the mid-60s, plasma panels have been around for about as long, and work was being done on field-emitter arrays 30 years ago.

No, I don't think that working in a vacuum is the problem. The problem is that unraveling the complexities and unexpected behaviors of new materials takes time and extensive experience. The learning process must typically start with a simple product and gradually progress to the more complex applications. Consider liquid crystals: the first applications were in watches, then came calculators, then low-resolution passive-matrix-addressed displays, and then larger monochrome displays and so on until today we have some really great-looking flat panels for computer and video applications. This development cycle spans a period of over 30 years. Thus, when we talk about the CRT being an old and venerable technology, in its 100th year, it's really not all that ancient when compared to the LCD or to plasma displays.

Why did the LCD take so long to develop into the full-color video-capable flat-panel displays of today? I would suggest that progress in understanding material properties was and is the time-limiting obstacle. This includes everything from the liquid crystals themselves, through the color-filter materials used to create the full-color displays, to the understanding of how to deposit the active-matrix arrays. Once the materials understanding was there, the overall device design became relatively obvious.

Plasma panels have followed a similar path. After the base technology was established in the glowing neon-orange monochrome version, color was difficult to achieve until a materials system was developed to create a backplane that provided adequate isolation between the color cells. There was a period of over 10 years when progress seemed to have stopped. In fact, the materials work was progressing but wasn't yet far enough along to be used to make a practical color panel.

Some time ago, I was invited to visit a start-up company developing a new display technology. The company was reasonably well-funded and had put in place all the typical corporate functions of finance, human resources, marketing, sales, manufacturing, and, of course, new-product development. However, as my visit-day progressed and I circulated from department to department, I learned that there was a product introduction planned for a major trade show in about 9 months. As I inquired about the status of the various pieces of the new display technology, I began to realize that there were still some very basic unanswered questions regarding the materials system and the fabrication process. Uh-oh! The caution lights went on in my head. I asked more questions. The answers were not encouraging. Some life testing had been done, but not under realistic conditions - and for hours instead of weeks or months. The process yield looked to be at zero. There were still basic materials issues for which there were no apparent answers. However, no one wanted to hear my cautionary comments and my skepticism about the product's introduction just 9 months away.

By the end of the day, as I said my goodbyes and walked to my rental car, a big sign was flashing in my head. On the first line was the name of the company just the way it was over the entrance door. But, on a line right below the real sign, I could picture (virtual reality-like) in even brighter letters the words "Pretend Company - OPM." In case you haven't seen this before, OPM stands for Other People's Money, *i.e.,* a company that has no product revenue and instead lives off of its investors. Of course, that's quite acceptable for some predetermined start-up period, as long as the revenue generation commences roughly when promised. But it can't continue indefinitely, especially if the product can't be developed because there are basic materials limitations. Unfortunately, hoped-for products or the inventing of new materials on an investor-promised schedule are unrealistic ways to try to build a real company. You guessed it: the company mentioned above has had quite a rough ride that started about 8 months after my visit. They have yet to introduce their product. Those darn materials problems just don't seem to respond to the threats of unhappy investors.

The more experience I've gained with electron devices of various kinds, the more respect I've ended up having for the materials that go into them. Without understanding how these wonderful substances emit their electrons, convert them to light, filter and modify the light, interconnect the bits, stimulate the pixels, and work their magic in yet other ways, we are either asking for trouble or already deep in it.

Now, here is my concern. Materials development takes time and resources. And more often than not, throwing extra resources at a problem does not reduce the time to solve it. In fact, from experience, I can say that ***beyond some adequate level of funding, more money does not help to get results any faster.*** In these days of instant investor gratification, who is going to do the sustained funding of materials research that is needed over periods typically spanning decades in order to create the new results that are needed for us to develop the future generations of displays? Who will have the patience to allow the careful exploration of "parameter space" so that new phenomena can be understood and optimized?

In the "good old days," we could count on the major research labs, such as RCA, Bell, IBM, and others, typically at large U.S. corporations. Today, there are fewer of these, but some of this work has been picked up by our colleagues at such world-class companies as Sharp, NEC, Sony, Thomson, Matsushita, Philips, Toshiba, LG, Samsung, and others.

The U.S. still leads the world in having an environment where venture capital and technology start-ups seem to go hand in hand. However, venture capital is not very patient. A product must be developed in a year or less, and revenue generation must begin so that a public offering can be made in about 3 years. That excludes any possibility of materials development. The materials technologies must, therefore, come from somewhere else. So here is the puzzle. If the U.S. is the venture-capital center of the world, but all the materials developments are occurring somewhere else, how do we start new ventures with the objective of creating new display products? Do we need a path for materials technologies from the Pacific Rim and Europe to be made available to the U.S. venture community? Is there a new global business model that we need to consider to assure the most rapid and efficient transfer of materials know-how into creative new display products that serve the many new opportunities with which the information society is presenting us?

Personally, I'm anxiously anticipating a new-technology sunlight-readable laptop-computer display that will allow me to sit under a tree or on a park bench at the lakeshore and write my next column. Can you not imagine how much more inspired my writing will be when done in such an idyllic setting?

In the meantime, I would very much like to hear your thoughts on the questions posed above. Could there even be a role for SID to promote a global matchmaking of talents? To send me your comments, you can use the most popular method, e-mail, at silzars@ibm.net, or by phone at 425/557-8850, by fax at 425/557-8983, or via the Post Office at 22513 S.E. 47th Place, Issaquah, WA 98029. ■

guest editorial

continued from page 2

the military inventory. The LCDs promised us substantial space and weight gains, but what about image quality, resolution, video display, and user acceptance? These performance measures were virtually being ignored. We focused our work on them, and what we found was quite surprising.

In an extensive evaluation that will be reported in detail in *Information Display* later this year, we found that although there were problems with military use of LCDs, none were overwhelming. But we confirmed what the FPD industry has grown tired of hearing: our performance and preference scores by military evaluators still favored the CRT.

Smearing was confirmed as an operationally significant issue. The current generation of NEC's 20.1-in. LCD glass cannot be used to display data from Navy fleet sensors that provide high-resolution high-rate-of-change video input for target detection and classification - at least, not without changes in the tactical use of these sensors or other workarounds.

Backlight problems also persist. High background luminance levels, either from backlight leakage or reflection from the glass, degraded contrast and the detection of low-resolution signals. Backlight non-uniformities were noted in the way most suppliers integrated the NEC glass.

Waterfall gram blink was also flagged as an operationally significant problem. There is no way a military operator can stare at a blinking display for hours on end, searching for targets. However, during the course of our evaluation, we found evidence that the waterfall-gram-blink problem was on the verge of being eliminated. In fact, in our acoustic laboratory studies, we were able to reduce this problem (as well as improve contrast levels) by manipulating the impedance, voltage, and current levels to the display from our video-interface unit.

Despite the problems noted above, these LCDs were judged favorably by the military evaluators in the study. Also, there were some areas where the LCDs were rated superior to the CRTs. These included text size and quality, videotaped synthetic aperture radar (SAR), and radar-scan video. The larger display area and flat surface of these NEC LCDs, as well as their wide-angle off-axis viewing capability, are positive factors for Navy fleet operations. Our evaluation found some positive areas and tester attitudes, as well as confirmation of the continued existence of known LCD problems with this glass. Our report to the program offices that funded the study emphasized that the problems noted were either fixed, fixable, or could be reduced in impact. In the final analysis, we recommended that the NEC 20.1-in. glass, properly packaged and driven, and secured from an accredited supplier, be fielded as a CRT replacement in applicable U.S. Navy air, surface, and subsurface platforms. ■

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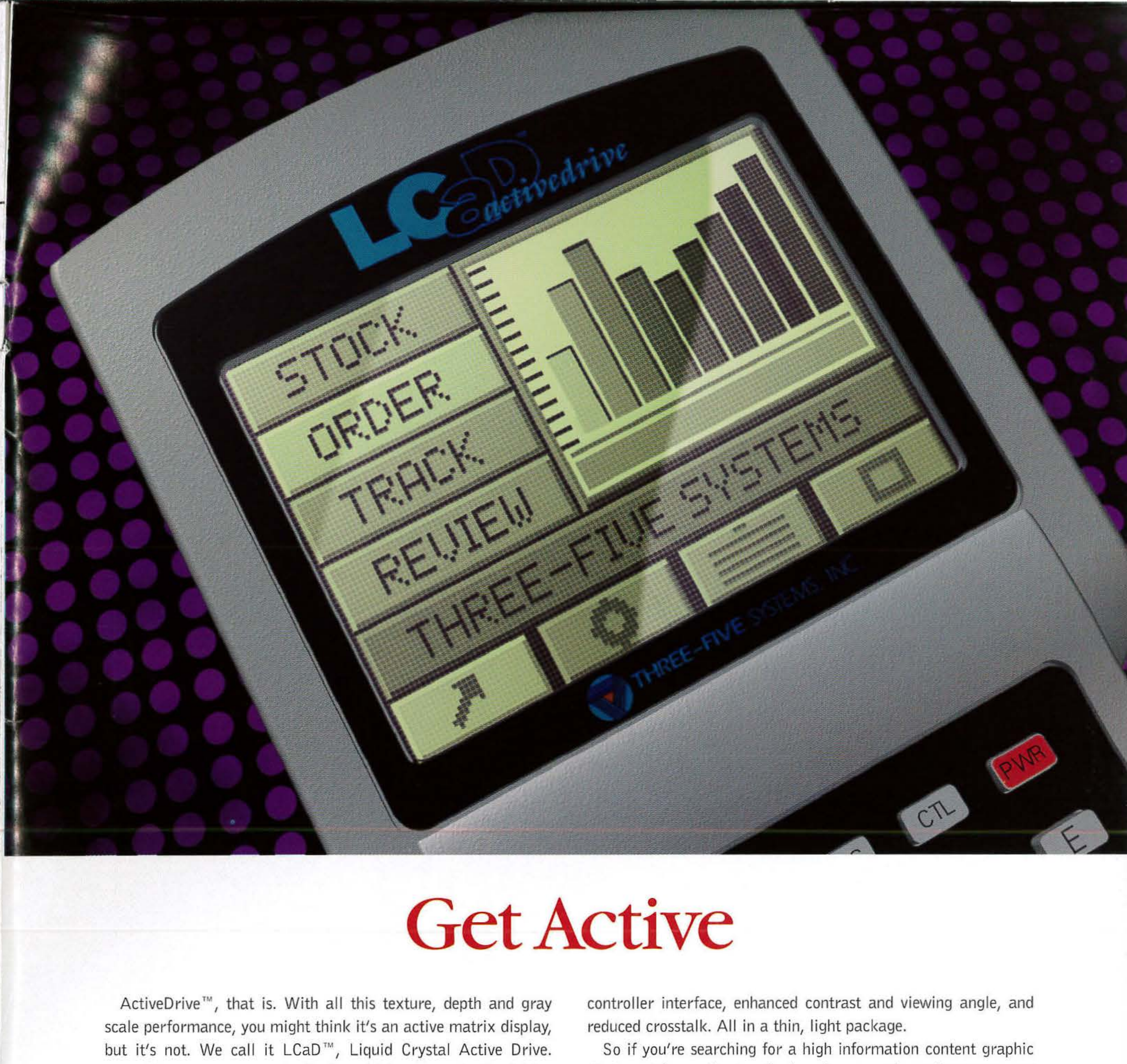
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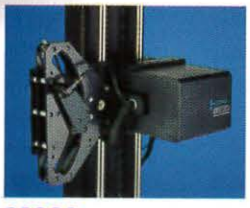

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