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INFORMATION DISPLAY

November 1987
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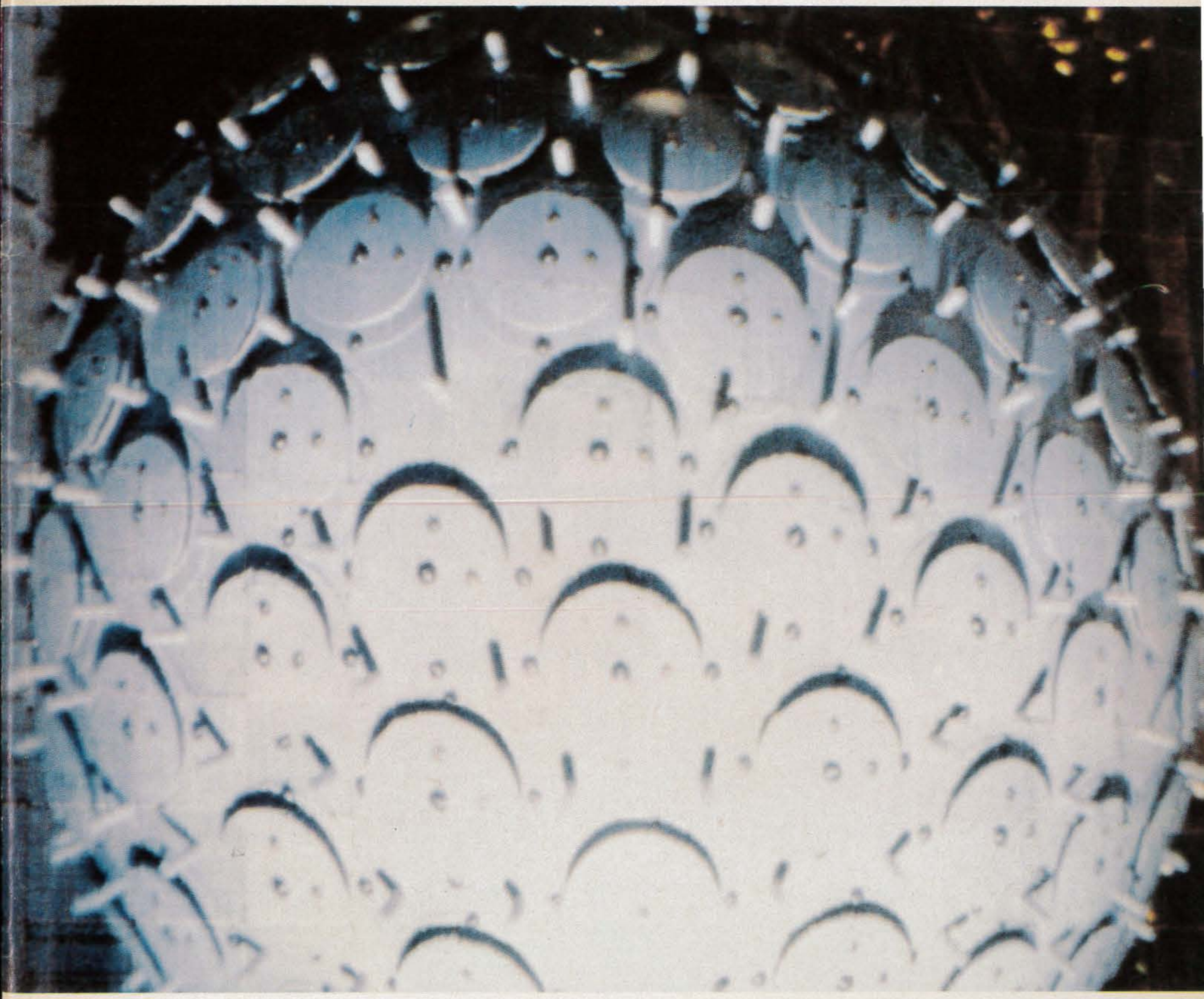
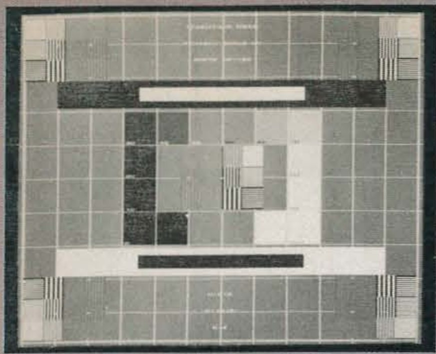


Large-screen fiber optic display
Active-matrix TFT-LCDs
Color LCDs for avionics



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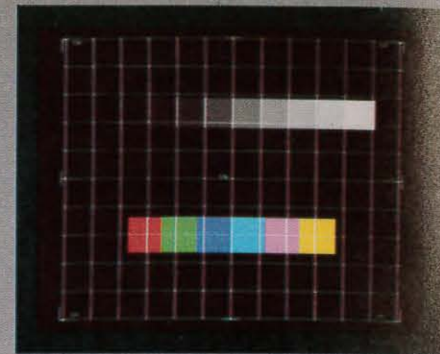

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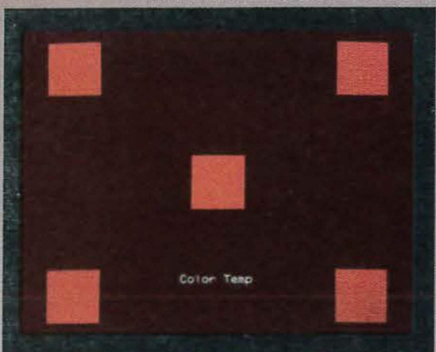

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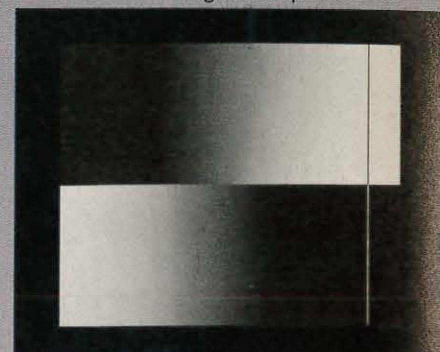

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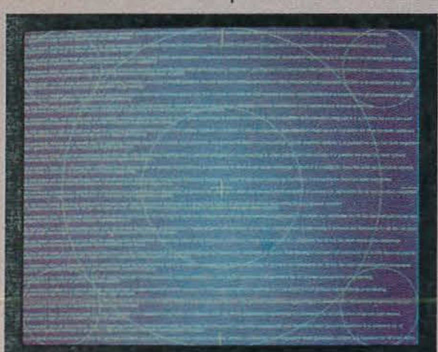

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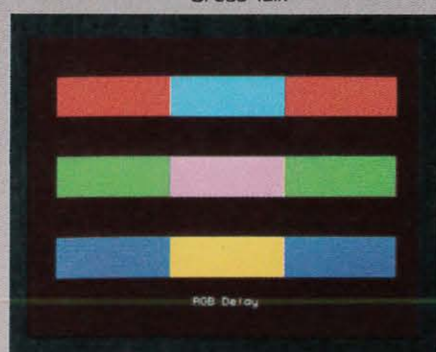

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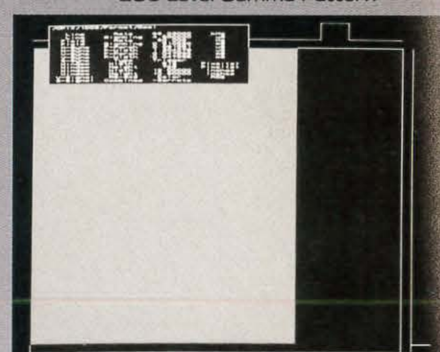

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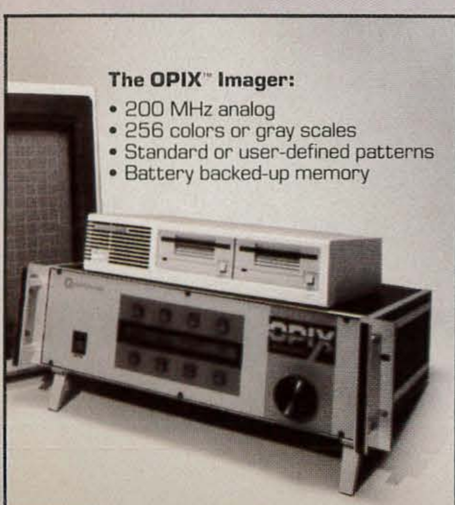

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INFORMATION DISPLAY

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Cover: Image of a NASA satellite fills the giant screen of FiberVision from Advance Display Technologies. (page 8)

Next Month in Information Display

- Maintaining the 3D illusion
- Display legibility guidelines
- Understanding and evaluating a computer graphics display

industry news

Color LCD production to begin in France

The first active-matrix color flat-panel LCD to be produced in Europe will go into production in early 1988. Thomson-CSF (France), VDO Luftfahrtgerate Werk Adolf Schindling GmbH (West Germany), and General Electric Co. (U.S.) have completed final plans to set up a common factory in France to produce color flat-panel LCDs. Production will be accomplished by a new French-based company, PRODIS, which will be owned by General Electric and Eurodisplay, and will benefit from technologies developed by General Electric in the U.S. Eurodisplay, a new subsidiary owned 80% by Thomson-CSF (Thomson Group), and 20% by VDO Luftfahrt, will be responsible for marketing its production in Europe and integrating the LCD panels into complete display systems. Production is expected to begin in early 1988. The panels are intended for professional systems operating in harsh environments, and for avionics and military equipment. The LCDs will employ a matrix driver with over 1 million transistors to provide a high-definition display and will have a screen size of approximately 7 × 7 in.

U.S.–Israeli HUD development

Effective December 1987, Bendix Flight Systems, a division of Allied-Signal, Inc., Teterboro, NJ, will co-develop and co-manufacture a head-up display (HUD) with Electrooptics Industries Ltd. (ELOP), an Israeli-based company. The displays will further enhance pilot effectiveness in the cockpit by presenting required flight and ballistic information on conventional and holographic glass combiners mounted in the pilot's forward field of view at eye level, eliminating the need for multi-indicator scanning, and enabling the pilot to fly head-up during all phases of the flight mission.

LCDs for U.S. Air Force

Ovonic Imaging Systems, Inc., Troy, MI, has been awarded a one-year contract by the U.S. Air Force Human Resources Laboratory to develop an advanced technology flat-panel LCD for evaluation and potential application in the Air Force's Integrated Maintenance System (IMIS). A key element of the IMIS is a

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editorial

For a change, this month's *ID* does *not* contain an article on CRTs—well, okay, the cover story may have a possible future application that would utilize a miniature CRT but . . . . The said cover story describes FiberVision, a novel laser-projection system that has been developed by Advance Display Technologies, Inc. Although the system was created for large-screen displays, smaller versions are feasible, and its fiber-optic screen may wind up in a variety of applications.

Our other two articles concentrate on LCDs. Those of you who are involved with the design of active-matrix thin-film transistors—or those of you who want to learn what's involved—will want to turn to Art Firester's definitive treatment of the subject. Of more general interest is Tom Credelle's review of the advances in LCD technology that have enabled it to be poised to challenge the CRT in avionic applications. After giving a general overview, he describes in detail a 1024×1024 6.25×6.25-in. color LCD recently shown at the Paris Air Show.

For personal reasons, this will be my last issue as Technical Editor of *ID*. I've learned a great deal about the display industry in the process, both technically and in trivial ways. Occasionally I go to Belmont racetrack with a friend. Though I rarely bet, he enjoys playing the odds on some, but not all, of the exotic betting combinations. In past years, for a given race we would stand patiently by one of the ubiquitous TV monitors waiting for a certain set of odds to appear, but this time they appeared together, color coded. He remarked on how nice it was that they had changed their system, and I refrained from explaining to him what is perhaps the most minor milestone in the display industry. It did make a Saturday afternoon excursion more enjoyable, though, both for those who bet and those who wait for others to bet. I suspect this interest in the myriad facets of information display will remain ongoing—I have a pile of clippings and ideas to be passed on to Ken Werner, who takes over next month.

compact, portable, battery-powered computer, similar to a lap-top computer, rugged enough for use on flightlines for aircraft maintenance. The IMIS computer's 6 × 8 in. display panel will contain a matrix of 640 × 480 pixels capable of displaying text and graphics. In text mode, it will present 30 lines of text at 80 characters per line. The active matrix display for the Air Force will have a 20:1 contrast ratio and a wide viewing angle (90° or greater) and will be readable in sunlight and in the dark with a built-in backlight.

New printer upgrades Navy computer system

Federal Technology Corp., Alexandria, VA, will soon complete installation of updated and advanced hardware to operate in a 3270-type system at eight U.S. naval shipyards. Included are more than 400 Genicom 4410 high-speed line printers from the Genicom Company of Waynesboro, VA, which will print reports, work orders, bills of lading, and other internal communications.

People

Automatic Connector, Inc., Commack, NY, announces the appointments of **Ed Josephs** to vice president, sales and marketing, and **Lou Maiolo** to vice president, lightwave products.

Howard L. Funk of **IBM Corp.,** Armonk, NY, has been elected vice-president of the American Federation of Information Processing Societies (AFIPS). The post of intersociety chairman on the SID board of directors passes from Mr. Funk to **Andras I. Lakatos** of **Xerox Corp.,** Webster, NY.

Librascope, Glendale, CA, a division of the Singer Company, has appointed **Grant Corcoran** manager, naval systems business development.

Micro Display Systems, Hastings, MN, has appointed Steven Weinstein director of marketing.

3M, St. Paul, MN, announces the following personnel changes: **Vincent J. Ruane,** vice president, electrical products, has been promoted to managing director and chief executive officer, 3M, Australia; **Russell J. McNaughton,** managing director, 3M, France, will return to corporate headquarters to head the electrical products division. ■

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president's message

The fascinating process to set "improved television" standards in the United States has been triggered recently by the FCC's issuance of a *Notice of Inquiry*. The resulting actions and debates are likely to have the same far-reaching consequences on the quality of television images seen by millions of viewers as did the earlier National Television Systems Committee (NTSC) standards adopted more than 30 years ago; the NTSC system represents one of the rare instances in which a committee designed a magnificent race horse rather than a camel. This system incorporates many tradeoffs and uses subtleties of the human visual system to squeeze a color TV signal—compatibly—into the bandwidth used for monochrome transmission.

Recently there has been much activity to develop a high-definition TV system (HDTV). The Japanese NHK system, though spectacular in performance, is non-compatible and requires more than 20 MHz of bandwidth to roughly double the horizontal and vertical resolutions in a wider (3 × 5) picture format. Demonstrations of HDTV and prototype cameras and recorders, however, have done much to whet the public's appetite for improved reception at home. The vast amounts of bandwidth required in the NHK system have also prompted new looks at alternate extended-definition TV (EDTV) systems that offer most of the image improvements at less bandwidth and, ideally, are reverse-compatible. It remains for the FCC to judge the proposed systems and, more importantly, to decide whether reverse compatibility is needed or whether the time has come to take a bold new step towards unprecedented performance.

This decision will not come easily and lobbying efforts can be expected to be strong since economic consequences will be huge. Several proposals have been advanced. The MUSE system represents an 8-MHz non-compatible approach to HDTV. North American Philips and William Glenn of the New York Institute of Technology both suggested two-channel approaches, one channel for transmission of standard signals and the other for the "enhancement signal." William Schreiber of MIT proposed a different two-channel system, one channel for standard signals and the other for the improved system; eventually the standard channel could be dropped when most viewers have upgraded to the new receivers. Richard Iredale of The Del Rey Group suggested a compatible system, with a 14 × 9 aspect ratio. The most recent proposal for advanced compatible television (ACTV), developed by the David Sarnoff Research Center on behalf of NBC and GE/RCA Consumer Electronics, offers NTSC-compatible EDTV performance in a single 6-MHz channel with 3 × 5 images and a 25–40% increase in resolution.

Whatever the final outcome, the FCC decision process merits close watching; the market opportunities for improved display devices, information systems, and other applications will be tremendous.

Fiber optics revolutionize the large-screen display

BY DOUGLAS GORDON

THE video display industry has had several revolutionary advancements since Thomas Alva Edison invented the light bulb. The latest is an ingenious application of fiber optics and lasers.

The next-generation large-screen display system, called FiberVision, was developed and is now being manufactured by Advance Display Technologies, Inc. (ADT), Golden, Colorado. FiberVision is based on a precisely configured matrix of fiber optics as pixels that transmit images produced by a variety of light sources, most notably a laser projector. The screens are composed of two elements—plastic optical fibers separated horizontally by nonreflective black spacers [Fig. 1]. The fiber-optic strands emanating from each 6 in. × 6 in. screen segment are grouped into a bundle a few feet behind the screen surface. The squared-off bundles are placed into a matrix onto which light sources are shone. Because of the spacing and sectional cuts of the fibers at the screen surface, images are enlarged approximately 36 times.

Seeing the light

FiberVision was invented by the founder and president of Advance Display Technologies, Steve Sedlmayr. Like his predecessors who have pondered ways of improving on the candle, Sedlmayr devoted several years to devising a new type of display technology. In addition to his experience in the display industry, he had a solid background in research and application. He was the youngest recipient, at age 17, of a National Science Foundation research grant (he received two). In his early twenties, he served as a configuration control manager at Martin Marietta Corporation. Through his experience running a company that operated the computerized scoring systems and display boards at McNichols Sports Arena in Denver, he was well aware of the requirements a new technology would have to satisfy. He also was a field engineer and consultant to the company that installed and ran the computerized display boards for the 1976 Olympic Games in Montreal. He wanted a display system that would eliminate the operating and maintenance costs associated with manually placing, tuning, and replacing thousands of light bulbs or cathode-ray tubes. He also realized that the technology would have to be efficiently manufactured.

But a key stimulus for Sedlmayr's invention was his fear of heights. He hated walking out into the arena's superstructure to maintain and tune the display boards, and he became consumed with trying to devise a passive system that did not rely on poorly performing conventional technology.

Ironically, it wasn't Sedlmayr's training and expertise that kindled the idea for FiberVision—it was a toy flashlight. He was watching an ice skating event at McNichols one night in 1982 and bought his niece a toy flashlight adorned with a thatch of fiber optics. As he watched his niece play with the flashlight, Sedlmayr realized that he was staring at the answer. He asked for the flashlight back, and he took it home and tore it apart.

Sedlmayr's experimentation quickly consumed many fiber-optic flashlights—and expensive, artsy lamps that use fiber optics—as he worked on ways of transmitting and enlarging images. Soon he was buying optical fibers from manufacturers and working with friends in his garage. Although the idea was simple, implementing it was not. Sedlmayr found that the key to his vision was an ordering system for the fibers. His research indicated that the idea for using fiber optics was not new at all, but it had not been developed because no one could quite figure out how to handle millions of extruded plastic strands that are slightly larger than human hairs. "Sometimes it looked liked four people with dozens of fishing lines crossed in a small row boat," he said, recalling the uncertain early days that lead to the formation of ADT. He faced the same problems that had prevented the idea from being developed earlier:

- *Material handling.* In addition to the tangling problems inherent in handling optical fibers, early applications of the idea were thwarted by the fragility of the fibers. Inner walls of the fibers are abrased easily from rough handling, and even the slightest abrasion ruins a fiber's ability to transmit light. Fiber optics also are extremely sensitive to the high temperatures encountered in manufacturing.
- *Gluing.* Commercially available glues typically could not stand up to envisioned manufacturing and operating requirements.
- *Sawing.* Once fibers are ordered, a problem remains—how to cut them precisely so that each one in a bundle of

Douglas Gordon is director of international affairs for Advance Display Technologies, Inc., Golden, Colorado.

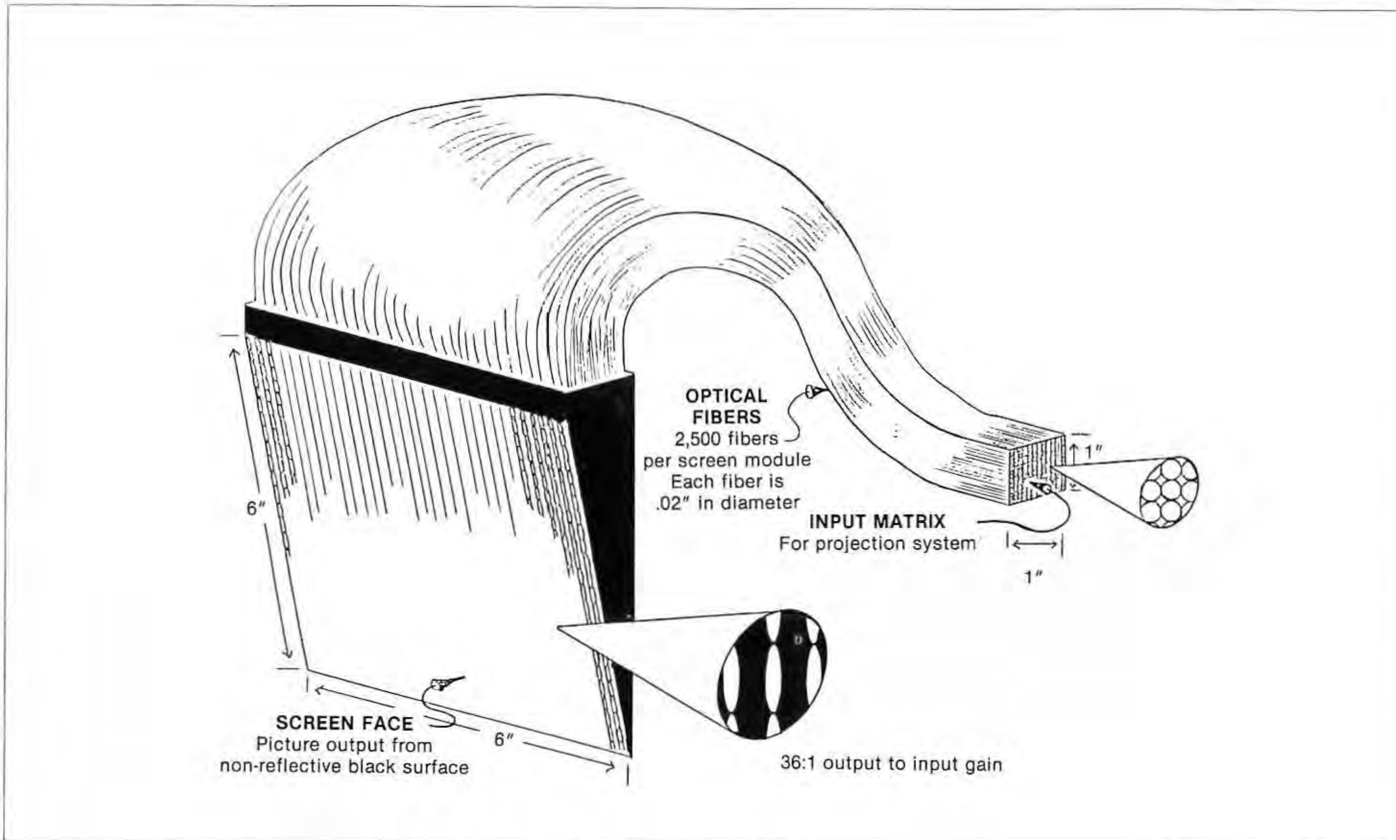

Fig. 1: FiberVision's screen module.

thousands is uniform.

Sedlmayr developed an ordering system based on a highly refined manufacturing or weaving system that untangled the problems. The company developed its own glue formula and invested in the best diamond saws available. The ensuing prototypes were enough to launch the company toward an initial public offering in early 1986.

That milestone was soon followed by ADT's first sale, which was part of a $5.1 million licensing agreement with Mitsubishi Rayon Company of Tokyo in January 1987. Under the agreement, ADT received fees of $2.5 million in exchange for Mitsubishi's receiving exclusive rights to manufacture and market the FiberVision display board in Japan for the next 11 years. Mitsubishi also retains nonexclusive manufacturing and marketing rights outside North America. ADT has also sold three screens to McCarran International Airport in Las Vegas for display advertising. The screens are expected to soon be in place.

The screen scene

FiberVision screens, which are manufactured with a unique, proprietary assembly line, offer a number of advantages compared with traditional display technology:

- *Superior resolution.* With 1800 apparent lumens, a contrast ratio of 100:1, and a pixel density of 107,000 pixels/m^2 (roughly 10,000 pixels/ft^2), FiberVision offers superior resolution with any light source.
- *Increased viewing angle.* FiberVision has a 170° viewing angle with no weakening of the image through the range, making it particularly suitable for displays in stadiums, arenas, and large public facilities. Display boards using conventional technology have viewing angles ranging from 100° to 120°, severely limiting a board's ability to convey information to widely spread or moving viewers.
- *Display flexibility.* FiberVision screens are manufactured in a variety of sizes and can be combined into large formats suitable for stadiums and arenas. Adding to the flexibility is FiberVision's light weight—1500 lbs for a 9-ft × 12-ft screen.
- *High brightness.* The fiber optics used in FiberVision are cut so that they point down and increase brightness, especially when a viewer is below the screen, making FiberVision ideal for displays above crowds.
- *Ruggedness.* The tough plastic screen is virtually unbreakable and is extremely weather resistant, making defense applications particularly attractive.
- *Decreased operating and maintenance costs.* Because it has no light bulbs that need to be manually maintained and no moving parts, FiberVision is far more economical for long-term maintenance. All it needs is an occasional dusting. And FiberVision puts out far less heat than conventional screens, eliminating costs for climate control.

Making good better

Once Sedlmayr figured out how to put together a fiber-optic display board, he had another problem. He could not find a projector good enough to take advantage of the screen's performance capabilities—at least not one having operating and maintenance advantages as good as the screen's. Although the FiberVision screen can show still and moving images from any type of light source—silhouette

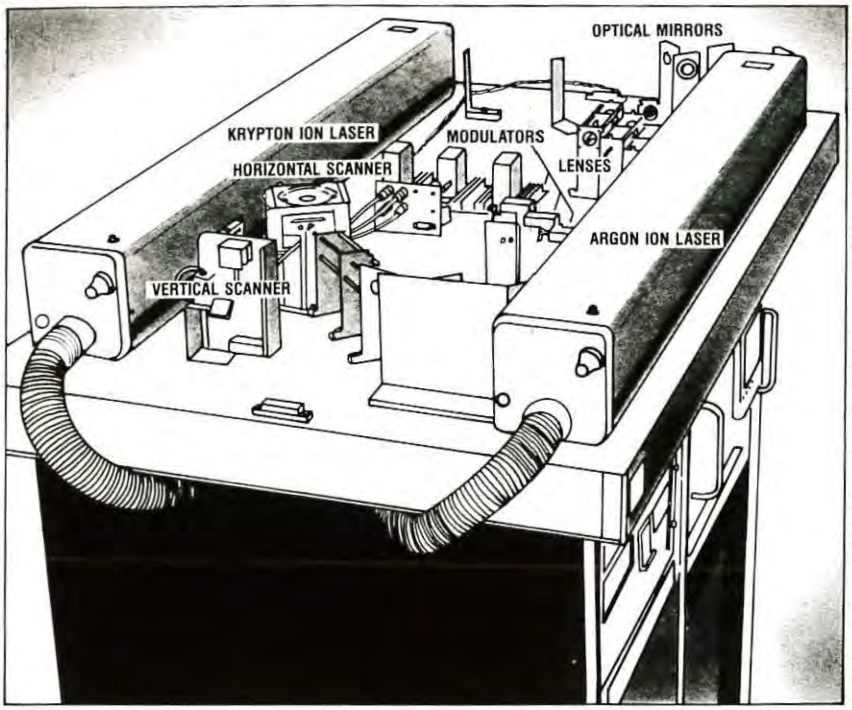

Fig. 2: *ADT's laser projector uses argon and krypton ion lasers rather than liquid dyes to produce colors.*

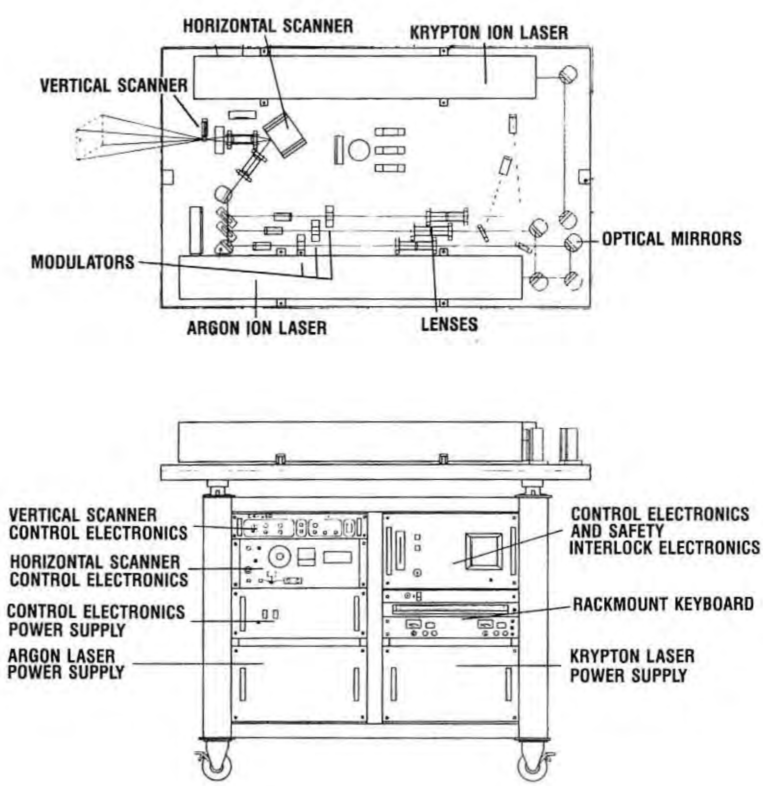

Fig. 3: *Plan and elevation of ADT's laser projection system.*

"hand puppets" can even be shown using ambient light falling on the input matrix—Sedlmayr just was not satisfied with marketing a screen alone. So he and his engineers decided to develop their own laser projector [Figs. 2 and 3].

The result is the first laser projector that does not depend on colors created by beams shone through liquid dyes. The laser has full-color capability (red, 647 nm; green, 514 nm; blue 746 nm) and horizontal resolution of up to 4 MHz and vertical resolution of 525 lines. The projection technique it uses is laser scan, and the display technology is raster scan. Geometric distortion is 1%, registration/convergence is 99%, vertical scan is 60 Hz field/30 Hz frame, and horizontal scan is 15.75 kHz. The laser power rating is 20 W (40 W is possible, but the power-supply system is the problem, because the intention is long-term operation). The laser projector produces images rated at 10,000 apparent lumens, and the brightness can be adjusted so that images are unaffected under varying ambient lightings. The projector can run for several thousand hours without major adjustments.

The entire FiberVision system, including laser projector and ventilation fans, weighs about 3900 lbs for each 9-ft × 12-ft configuration (smaller sizes are available) and has an operational life of about 20,000 hours except for the projector light sources, which should be replaced about every three years.

And next?

The implications of the FiberVision system's advantages are tremendous for the display industry. It provides a more vivid, striking medium at decreased operating and maintenance costs. It can operate from a variety of inputs—live TV, satellite feeds, taped programs, or computer-generated images.

But the potentials may be as revolutionary as the initial system. Future applications include home television, automotive and cockpit displays, and a variety of uses in the defense industry, both for the screen and for the laser projector. For example, ADT is in the early research and development phase of a television receiver, "HomeVision," that would combine a fiber-optic wall screen with a miniature CRT, sound system, and tuning components that could easily be replaced or upgraded as the need arose. ■

Active-matrix addressing for TFT-LCDs

BY ARTHUR H. FIRESTER

PRACTICAL active matrices composed of thin-film transistors (TFTs) are spurring the development of superb full-color liquid-crystal displays (LCDs) for data and TV applications. Active matrices[1] are needed because the number of addressable lines achievable by direct multiplexing of simple liquid-crystal (LC) cells is severely limited. Although considerable progress has been made in increasing the nonlinearity of the LC materials, it is still inadequate for the highest performance applications. Furthermore, increasing the nonlinearity to increase the number of addressable lines makes the attainment of gray-scale more difficult. For gray scale or TV applications, gentle brightness-voltage curves are most desirable.

For LCDs that respond only to the root-mean-square (RMS) value of the applied voltage, Alt and Pleshko[2] demonstrated that there is a relationship between the multiplex ratio (N) and the ratio of the RMS voltages applied to selected and nonselected pixels in a line-at-a-time scanned matrix. For $N = 200$, this ratio is only 1.08, and thus the brightness-voltage curve must be quite steep to achieve a useful contrast ratio [Fig. 1]. This problem becomes exacerbated still further with applications such as TV that require full color. Here the reduced contrast ratio constrains the attainable color saturation; saturated colors cannot be achieved.

Arthur H. Firester is director, advanced displays and microwave research laboratory, David Sarnoff Research Center, a subsidary of SRI International, Princeton, New Jersey.

The basic active matrix

The problem faced by the direct-multiplexed LCD is to achieve an adequate nonlinearity within the LC itself, in order to effectively isolate the cells by carefully controlling the select and deselect voltages. What the TFT active matrix does is separate the function of the nonlinearity from the LC material itself and use the transistor to provide the needed nonlinearity. Ideally, the TFT active matrix can be considered as an array of pixel switches [Fig. 2]. When a pixel is selected, we want to apply a given voltage to that pixel alone and not to any nonselected pixel. Those pixels that are nonselected should be completely isolated from the voltages circulating through the array for the selected pixels. The operation of this TFT matrix is as follows:

1. Appropriate select voltages are applied to the first row of TFT gates, while nonselect voltages are applied to all other rows of TFT gates.
2. Simultaneously, data voltages are applied at the same time to all of the column electrodes to charge each pixel in the selected row to the desired voltage.
3. The select voltage applied to the first row of control switches is changed to a nonselect voltage.
4. Steps 1–3 are repeated for each succeeding row until all of the rows have been selected and the pixels charged to their desired voltages.

All rows are selected in one scanning period. Thus, if there are 500 lines and the time to load data into each selected line is 50 μsec, then a single scanning period will be 25 msec, or equivalently, the field scanning rate will be 40 Hz. The average dc voltage across the LC material should be zero to avoid electrolytic effects. This is typically accomplished by repeating steps 1–4 with negative data voltages. Thus, after two complete scans of the array, the average voltage on each pixel is zero. For the 500-line display, this results in a full scanning period of 50 msec or a frame rate of 20 Hz.

TFT performance requirements

The requirements placed on the TFT matrix depend on the display application. Consider first a bilevel display. This is not necessarily a black-and-white display, but could just as well be an eight-color display. What characterizes a bilevel display is that each switchable LC element has only two states—ON and OFF.

First, consider what is required of the TFT matrix driving a bilevel LCD to turn a pixel ON. We assume that the ON condition occurs when voltage is applied to the LCD. The voltage waveforms appearing on an ON pixel are shown in Fig. 3. Our display has N rows and M columns of pixels. To turn a pixel ON requires a voltage, V_{on}, typically about 5 V. The pixel behaves as a capacitor with capacitance C, typically 5 pF for an LCD of thickness 10 μm and pixel area of about 300 × 300 μm. Thus, if we desire to charge the pixel to $+V_{on}$ from $-V_{on}$ during $1/N$ of the field time T, then the current to be supplied by the active matrix must average

$$I_{on} = 2 \cdot C \cdot V_{on} N/T.$$

Note that for a bilevel display the tolerance to which the pixel must be charged to a specific V_{on} is not particular-

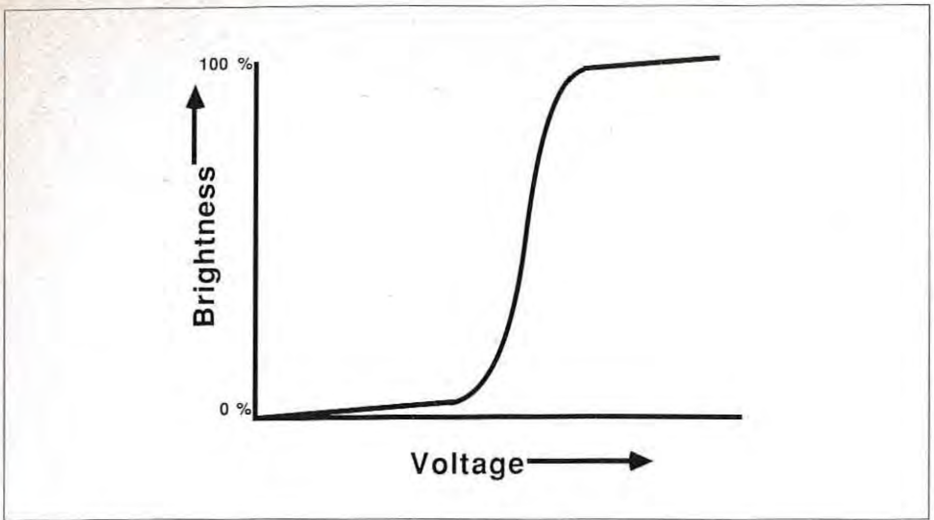

Fig. 1: Liquid-crystal brightness-voltage curve.

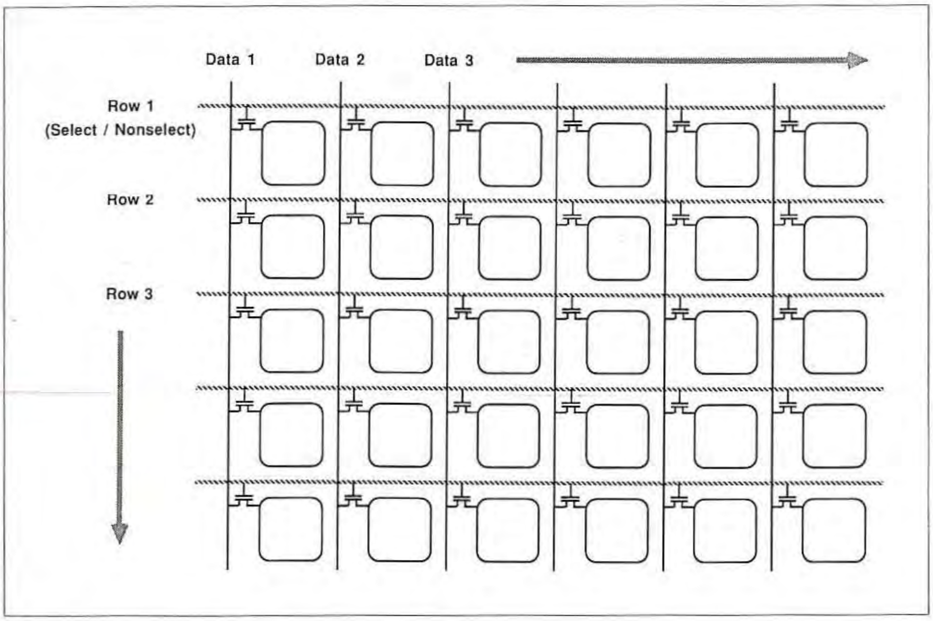

Fig. 2: Simplified TFT active-matrix array.

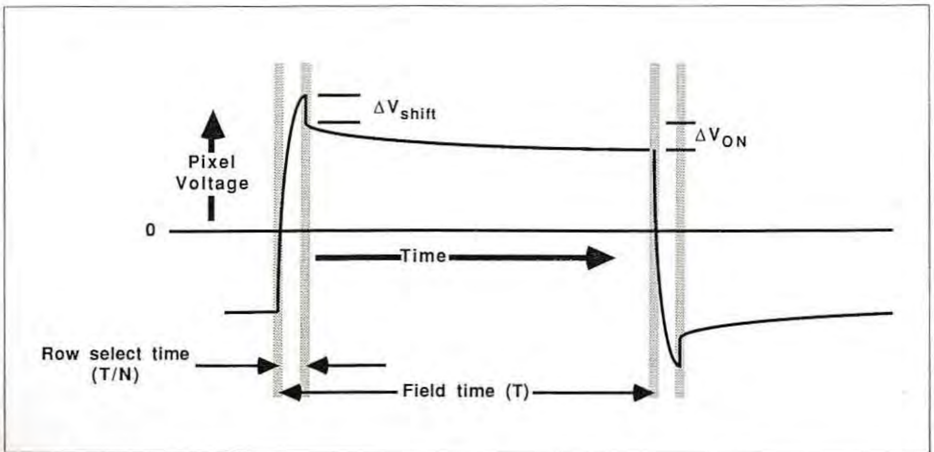

Fig. 3: ON pixel voltage waveform.

ly tight. Overshooting the maximum V_{on} by one or more volts is quite acceptable; as evidenced by Fig. 1, there will be no significant changes in the contrast of the display.

In actual practice, the ON characteristics of the TFT depend on the voltage on the pixel, and the charging current is not uniform during the entire charging cycle. Accordingly, we may have to apply an engineering factor F_{on}, typically of magnitude 1–10, to spec the device characteristics conservatively. Thus, our final drive current requirement for the switch is

$$I_{on} = 2 \cdot F_{on} \cdot C \cdot V_{on} \cdot N/T.$$

Now let us consider the requirements imposed on the active-matrix TFT to isolate the pixel during the remaining field time, $T(N-1)/N$. There are basically two different requirements: (1) leakage current through the TFT should not result in an ON pixel losing sufficient charge to appear partially or fully OFF and (2) voltages on the data lines intended for other pixels should not charge an OFF pixel to a partially or fully ON state.

For the bilevel LCD the first requirement is usually the more stringent, because the voltage required to bring a pixel to a partially ON state, such as $V_{10\%}$, is typically greater than ΔV_{on}. Let us assume that if the voltage drops during a field time T by only ΔV_{on}, then this will have no significant effect on the ON pixel brightness. To achieve this, the leakage current through the active matrix must be $[I_{leakage}]$ at operating temperature $\leq \Delta V_{on} \cdot C/T$.

Here also an engineering factor F_{leak} may be appropriate. For example, if the display is to operate over a wide temperature range, it is at the high temperatures that the device leakage increases and becomes a problem. One role for the engineering factor would be to account for this increase in leakage at higher temperature. From 20°C to 50°C, the leakage current of a silicon TFT increases by a factor of about five; that is, the leakage requirement at room temperature would have to be five times less than required to meet the leakage requirements at 50°C. It is sometimes easiest to modify the above equation to account for this temperature dependence. For the temperature range from 0°C to 50°C,

$F_{leak} = 5$:

$[I_{leakage}]$ at room temperature $\leq F_{leak} \cdot \Delta V_{on} \cdot C/T$.

The equations for I_{on} and I_{leak} define a required active-matrix ON-OFF ratio $R_{bilevel}$ as follows:

$$
\begin{aligned}
R_{bilevel} &= I_{on}/[I_{leakage}] \text{ at room temperature} \\
&= \{F_{on} \cdot C \cdot V_{on} \cdot N/T\}/\{F_{leak} \cdot \Delta V_{on} \cdot C/T\} \\
&= N \cdot (F_{on}/F_{leak}) \cdot (V_{on}/\Delta V_{on})
\end{aligned}
$$

This ratio is independent of the size of the pixels and the number of pixel columns. It depends only on the number of rows (i.e., the multiplex ratio), the choice of engineering factors, and the ratio of the pixel ON voltage V_{on} to the acceptable ON-voltage variations ΔV_{on}.

Now let us compare how these equations differ for a gray-scale (or full-color) application. First, we consider the ON-current requirements.

For gray-scale displays one does not have the luxury of being able to overshoot the desired voltage. Indeed, the tolerance on the voltage accuracy determines the number of gray-scale steps. To make certain that the voltage has settled to the desired level during the row select time T/N and that small variations in the ON-characteristics of the TFTs are not translated into voltage variations on the pixel, we must increase the ON-current requirement so that the pixel charges to the desired voltage level in only a fraction of the row select time T/N. If we think of the active matrix as having an ON-resistance of R_{on}, then if we want the voltage to be within 3% of the desired voltage, the time constant $t = C \cdot R_{on}$ should be 30% of the row select time. For the bilevel display, since we had the option of overshooting the nominal ON voltage, we could require voltage tolerances of about 20%. Thus, our requirements for R_{on} could be much less stringent. Since the TFT does not behave as a constant resistance, this requirement must be calculated or simulated by actual TFT current-voltage curves over the entire charging period. Even without a rigorous simulation, we see from the above arguments that the ON-current equation must be modified by a factor $f_{gray\ scale}$ that is typically of order 1 to 10. Thus, the ON-current requirement for color is

$$I_{on} = f_{gray\ scale} \cdot F_{on} \cdot C \cdot V_{on} \cdot N/T.$$

The OFF-current requirements for the active matrix are also more stringent for a gray-scale display. Now we demand that the leakage of charge from an ON pixel be sufficiently small that during a field time T the change in the voltage ΔV_{gray} is less than a shift of one gray-scale level. As an example for a 5-bit gray-scale system, i.e., 32 equally spaced brightness levels, ΔV_{gray} might be about $(1/32) \cdot \Delta V_{on}$. In fact, this is more stringent than necessary. We can accept shifts in voltage larger than one gray level if all pixel devices leak comparably; it is the variation of these leakages that determine ΔV_{gray}. In any case the leakage current requirement for a gray-scale display is more stringent,

$$[I_{leakage}] \text{ at operating temperature} \leq \Delta V_{gray} \cdot C/T.$$

Relating these requirements to room-temperature device parameters,

$$[I_{leakage}] \text{ at room temperature} \leq F_{leak} \cdot \Delta V_{gray} \cdot C/T.$$

Similarly, the ON-OFF ratio requirement for a gray-scale display is:

$$
\begin{aligned}
R_{gray\ scale} &= I_{on}/[I_{leakage}] \text{ at room temperature} \\
&= \{f_{gray\ scale} \cdot F_{on} \cdot C \cdot V_{on} \cdot N/T\}/\{F_{leak} \cdot \Delta_{gray} \cdot C/T\} \\
&= N \cdot (f_{gray\ scale} \cdot F_{on}/F_{leak}) \cdot (V_{on}/\Delta V_{gray}) \\
&= R_{bilevel} \cdot f_{gray\ scale} \cdot (\Delta V_{on}/\Delta V_{gray}).
\end{aligned}
$$

So far our analysis of the performance requirements for the TFT active matrix has focused on the ON currents, the OFF currents, and their ratio $R = I_{on}/I_{off}$. Barring anomalous structural elements, these two currents are extrinsic parameters of one or more linear dimensions of the TFT. Thus, we generally find that the current ratio $R = I_{on}/I_{off}$ is independent of device size. Also, we have seen that for each application, the absolute magnitudes of these currents depend linearly on the capacitance load of the pixel. This might suggest that if any representative device has the requisite current ratio $R = I_{on}/I_{off}$, then it can be used in that application. This is not the case because of two further considerations: (1) the shunt capacitances and (2) the design rules that are economic for the particular application.

Figure 4 plots the active-matrix device parameters in terms of the ON current normalized to one device length I_{on}/W and the OFF current normalized to that same device dimension, I_{off}/W. For the TFT, the device dimension that we use is the channel width W. Thus, devices differing only in channel width W are plotted as a single point on this graph. Likewise, we can plot a line showing the ratio $R = I_{on}/I_{off}$ required for a particular display application. Then our first requirement is that the point representing the active-matrix device lies above this line.

To satisfy simultaneously the requirements on the absolute leakage current for a bilevel display application and our desire to not make devices with vanishingly small dimensions W, we impose the further constraint that $W \leq d$, where d is the minimum dimension allowed by the design rules of our process. Thus, we require that the normalized leakage current satisfy the relationship

$$I_{leakage}/W \leq \{F_{leak} \cdot \Delta V_{on} \cdot C/T\}/d.$$

This requires that the point P representing the active-matrix device lie to the left of the boundary AB. If the device has excessive intrinsic leakage current and lies to the right of AB, then it can still be used, but only with a pixel of larger capacitance. One way to fix this without changing the pixel size is to add a storage capacitor, $C_{storage}$, to each pixel. This effectively moves the boundary AB to $A'B'$, because now

$$I_{leakage}/W \leq \{F_{leak} \cdot \Delta V_{on} \cdot [C + C_{storage}]/T\}/d.$$

This increases the effective capacitance at the expense of increased process complexity and the likelihood of decreased process yields.

Are there any constraints on the drive current? Can we make the active-matrix device as large as required to satisfy the ON-current requirements? Not unexpectedly, the answer is no!

A trivial upper bound on the device dimensions is imposed by the available size of the pixel. If the device gets too large it will reduce the transmission of the pixel to unacceptably low levels. A more

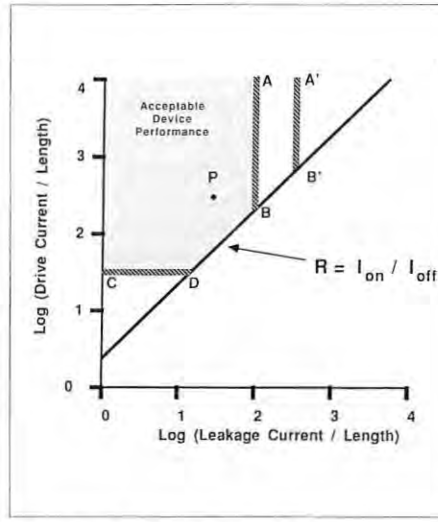

Fig. 4: TFT performance requirements.

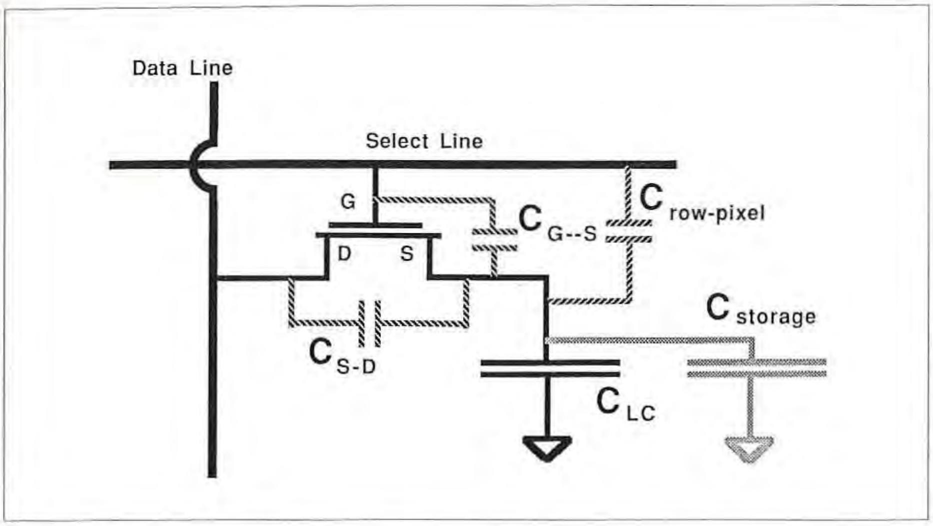

Fig. 5: TFT parasitic capacitances.

interesting and more severe upper bound is caused by parasitic capacitances intrinsic to the particular device. These typically scale with the geometry; that is, as the dimension W increases, the parasitic capacitances [Fig. 5] increase.

The source-drain capacitance couples the data voltages V_D on the column electrode to the deselected pixels, resulting in a shift in the pixel voltage ΔV_{noise} of magnitude

$$\Delta V_{\text{noise}} = V_D \cdot C_{S\text{-}D}/C_{\text{pixel}}$$

where

$$C_{\text{pixel}} = C_{LC} + C_{\text{storage}}.$$

Another noise source is caused by the gate-to-source capacitance coupling a voltage shift into the pixel as the gate voltage drops from the select voltage level, $V_{\text{G-sel}}$, to the deselect voltage level, $V_{\text{G-desel}}$. This change in the gate voltage $\Delta V_{\text{G}} = V_{\text{G-sel}} - V_{\text{G-desel}}$ is coupled to the pixel and causes a voltage shift ΔV_{shift} in the desired pixel voltage of magnitude

$$\Delta V_{\text{shift}} = \Delta V_{\text{G}} \cdot C_{\text{G-S}}/C_{\text{pixel}}.$$

Voltage shifts are not only due to the device's gate-to-source capacitance. Depending on the dimensions of the pixel layout, the gate row electrode running parallel to the pixel edge can also introduce a coupling capacitance $C_{\text{row-pixel}}$. For displays with many pixels per inch, this capacitance may be significant, and the last equation should be generally modified as

$$\Delta V_{\text{shift}} = \Delta V_{\text{G}} \cdot [C_{\text{G-S}} + C_{\text{row-pixel}}]/C_{\text{pixel}}.$$

This voltage shift is *not* necessarily a noise voltage. To the first order, ΔV_{shift} is a constant value determined by the display geometry. However, photolithographic and other process variables will result in fluctuations in $C_{\text{S-D}}$, $C_{\text{G-S}}$, $C_{\text{row-pixel}}$, C_{LC}, and C_{storage}. Furthermore, C_{LC} is not a simple capacitor and depends on the state of the pixel.

Returning to our focus on the role of the active matrix, we see that depending on the TFT itself and the tolerances of the fabrication process, there can be a noise contribution by the TFT, $[\Delta V_{\text{noise}}]_{\text{TFT}}$. We can represent this as

$$\begin{aligned}[\Delta V_{\text{noise}}]_{\text{TFT}} &= F_{\text{TFT}} \cdot F_{\text{process}} \cdot [\Delta V_{\text{shift}}]_{\text{TFT}} \\ &= F_{\text{TFT}} \cdot F_{\text{process}} \cdot \Delta V_{\text{G}} \cdot C_{\text{G-S}}/C_{\text{pixel}}\end{aligned}$$

where F_{TFT} is a multiplicative engineering factor that is intrinsic to the device and F_{process} is a multiplicative engineering factor that depends on the process.

For most TFTs, the gate-source capacitance $C_{\text{G-S}}$ is proportional to the channel width W. Thus, as we increase W to provide sufficient ON current to charge the pixel capacitance C_{pixel}, we also increase the gate-source capacitance $C_{\text{G-S}}$ and thus the TFT noise contribution $[\Delta V_{\text{noise}}]$TFT. These considerations put a lower bound on the acceptable normalized ON-current capability of the TFT. This bound is represented by boundary *CD* in Fig. 4.

It should be emphasized that the total amount of tolerable noise voltage depends on the specific display application.

Conclusions

We have emphasized the dc and dynamic requirements on TFTs for use in active matrices for LCDs. This is not the whole picture. It does not answer the question, Which technology is best? This question must be asked on an application-by-application basis. Key elements of the answer are *system* reliability, *system* yields, and *system* cost. For example, required TFT reliability for military systems are different from that required for consumer products: system yield requirements differ; acceptable defects differ.

System costs must also be taken into consideration. Yield is likely to be the major cost driver. Technologies that are simple or have tolerant design rules result in lower costs due to higher yields. The yield is also driven by the complexity of the process; one measure of complexity is the number of photomask steps.

Another cost consideration is whether the same TFTs that form the active matrix could also be used to fabricate matrix-drive electronics. Straightforward analyses of matrix displays pinpoint the interconnection of the matrix to external-drive electronics as a significant cost component as well as a potential failure point for the display system. Thus, if the drive circuitry could be fabricated as part of the active matrix, there would be a significant opportunity for cost reduction and reliability improvement. This possibility has not gone unnoticed by researchers[3] in all the TFT technologies.

Which technology is best is yet to be determined, but based on the active-matrix system requirements discussed above, undoubtedly many of the highest-performance LCD applications will use a TFT active matrix.

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Recent trends in color avionic LCDs

BY THOMAS L. CREDELLE

As THE amount of information to be processed in modern aircraft cockpits increases, so does the need for better and better display media. A slow but steady transition from analog electromechanical gauges to cathode ray tubes (CRTs) is being made. While CRTs, both monochrome and color, offer significant advances in the presentation of information, they do suffer from several drawbacks, including high power, weight, and volume; reduced visibility in high ambient conditions; and low reliability compared to their electromechanical counterparts. Active-matrix-addressed liquid crystal displays (LCDs), an emerging technology which is challenging the venerable CRT in many markets, are now ready to challenge the CRT in the demanding cockpit environment—both commercial and military. These flat displays offer the exciting potential of lower power, volume, and weight; sunlight readability; and high reliability.

Basic concepts

An active-matrix-addressed LCD can be defined as an LCD with a non-linear element at each picture element or pixel. Liquid crystal displays, developed fewer than 25 years ago,[1] are now pervasive in our society. They are used in watches, calculators, computer displays, commercial instruments, pocket TVs, and even aircraft cockpits. Almost all these applications use the twisted-nematic effect, whereby aligned, elongated organic molecules are oriented by an electric field to create a change in the electro-optic properties of the liquid crystal. Polarized light is either transmitted unchanged (field ON) or rotated 90° (field OFF) by the liquid crystal. If a second polarizer is added, then the equivalent of a light shutter can be formed. The switching speed of the liquid crystal molecules is in the tens of millisecond range, making them suitable for dynamic displays. An important point to remember is that the twisted-nematic field effect modulates light, either from the ambient or from a backlight, but does not generate light. In many applications, such as watch displays, a reflector is added so that ambient light can be used; in most avionic applications a backlight is required for either night viewing or high-ambient viewing.

To create an alphanumeric or graphic LCD, an array of row select electrodes is formed on one piece of glass and an array of column data electrodes is formed on a second piece of glass. By applying voltages to these electrodes, the liquid crystal can be switched. These simple matrix or directly multiplexed LCDs do, however, suffer from one major problem: as the number of rows increases, the contrast ratio and viewing angle decrease.[2] Although improvements in the switching characteristics of liquid crystals has improved over the years, the twisted-nematic effect is limited to approximately 100-line displays.

To make high-resolution color LCDs, the active-matrix approach was proposed and demonstrated in the early 1970s.[3] [Arthur Firester's article in this issue covers this subject in detail.]

Today's TFTs

Three types of TFTs are being developed today at laboratories around the world. By far the most prevalent TFT technology today is based on hydrogenated amorphous silicon (a-Si:H). First developed for solar cell applications, it was adapted for use in TFTs in 1979 by researchers at the University of Dundee.[4] Since that time there has been a steady growth in development, culminating in large high-resolution color TFT-LCDs. The most common configuration of the a-Si:H TFT is shown in Fig. 1a. It consists of a metal gate, a thin film of hydrogenated amorphous silicon nitride and amorphous silicon, and a metal source and drain. In a TFT array for an LCD, a transparent pixel electrode is added. The silicon nitride and silicon layers are plasma deposited at temperatures less than 350°C so that inexpensive glass can be used. The metals are typically sputtered, also at low temperature. The current-voltage characteristic of GE's a-Si:H TFT is shown in Fig. 2.[5]

A second technology, under development at a few laboratories, and the first to be commercially produced,[6] is based on polycrystalline silicon (poly-Si). It is made up of low-pressure deposited poly-Si, a thermal or deposited silicon dioxide layer, a metal or poly-Si gate, and ion-implanted source and drain regions [Fig. 1b]. Aluminum is usually used as the interconnection metal. One advantage of poly-Si over a-Si:H is its high mobility (10–50 $cm^2/V\text{-sec}$ vs. 0.5–1.0 $cm^2/V\text{-sec}$); this

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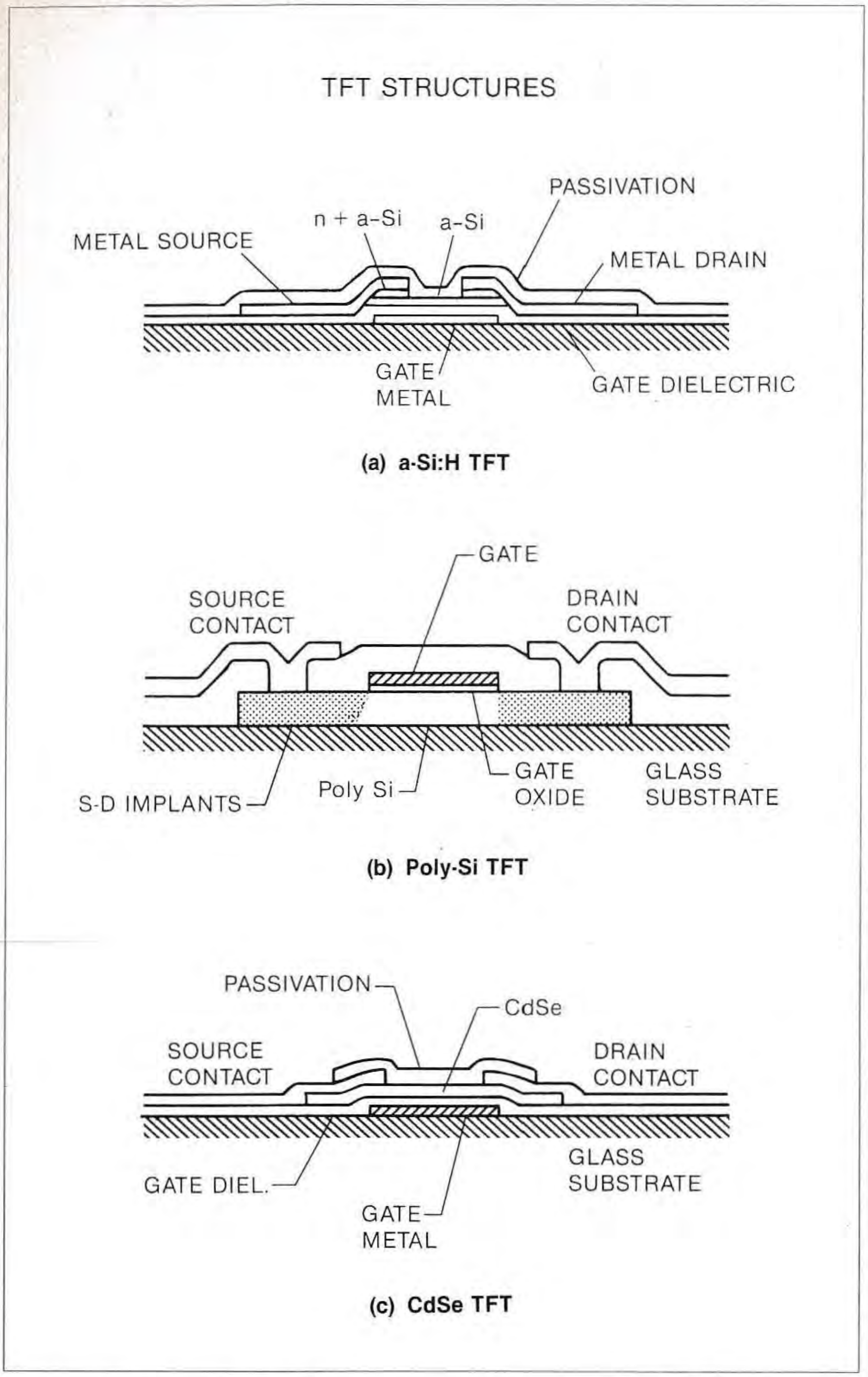

Fig. 1: The three types of TFTs currently under development are shown in cross section: (a) a-Si:H TFT; (b) poly-Si TFT; and (c) CdSe TFT.

can lead to integration of drive circuits on the display substrate. A disadvantage is the high temperature processes (greater than 600°C and as high as 1000°C) and the use of ion implantations, a slow and expensive process. The OFF currents are also typically too high for use in TFT-LCDs and developers have resorted to multiple-gate devices and storage capacitors at each pixel.

The third and final technology under development is CdSe; the first TFTs ever produced were in CdS and CdSe[7] and they do offer some desirable features. The TFT [Fig. 1c] consists of a metal gate, low-temperature evaporated insulator and evaporated CdSe layers, and metal source and drain electrodes. CdSe is also a high-mobility semiconductor and therefore shares the advantage of integrating drive circuits with poly-Si. Unfortunately, the OFF currents are rather high, and a storage capacitor is required at each pixel. There are also problems in maintaining good device stoichiometry, which affects TFT performance.

Over the past several years, progress in the development of TFT-LCDs has been enormous. High-resolution color displays in sizes up to 14-in. diagonal have been shown. A short list of TFT-LCDs that have been developed is presented in Table 1, in order of display size. Some companies have developed more than one size; only the largest reported is listed here. Two companies, Seiko-Epson and Matsushita, have pocket TVs using TFT-LCDs on the market today, and several others are delivering samples. As can also be seen from this list, a-Si:H is the choice of most of the companies working in this field.

Avionic considerations

The use of the TFT-LCD in the cockpit offers significant advantages over the CRT; it also presents significant challenges for the display designer. These are listed in Table 2 for a typical multifunction display (MFD) planned for a military cockpit. Among the most demanding requirements are high brightness, wide dimming range, and high contrast under high ambient illumination. To obtain high brightness and a 2000:1 dimming range, high-efficacy fluorescent lamps are typically used; brightnesses of over 5000 fL at the lamp surface can be obtained. For a color LCD, where the transmission efficiency is only 3–5%, this can result in a display peak brightness of over 200 fL. With proper dimming circuits, brightnesses as low as 0.1 fL can also be achieved.

A characteristic related to display brightness is display contrast and color rendition; contrast ratios over 7:1 are required for good readability in 10,000 fC ambients (bubble cockpit conditions). An important advantage of TFT-LCDs is, in fact, their sunlight readability. With proper anti-reflection coatings on the glass surfaces, contrast ratios of over 10:1 can be obtained in high ambient. There is also significantly less "washout" of colors in high ambient.

In some applications, wide viewing

Table 1: TFT-LCD Activity

Diagonal Size (in.)	Resolution (Vert. × Horiz.)	Active Material	Display Type	Company
14.0	440 × 1950	a-Si:H	Color TV	Seiko Instruments
12.5	480 × 640	a-Si:H	Color TV	Matsushita
10.0	408 × 640	a-Si:H	Color graphic	Mitsubishi
9.5	480 × 640	a-Si:H	Color graphic	Toshiba
9.5	400 × 640	CdSe	Mono graphic	Litton Panelvision
8.8	1024 × 1024	a-Si:H	Color graphic	GE
7.2	650 × 650	a-Si:H	Color graphic	Hosiden
6.0	250 × 320	a-Si:H	Mono graphic	CNET
6.0	600 × 640	a-Si:H	Color TV	Hitachi
5.7	210 × 960	a-Si:H	Color graphic	Fujitsu
5.1	440 × 480	poly-Si	Color graphic	Seiko-Epson
5.0	250 × 666	a-Si:H	Color TV	Sanyo
4.9	250 × 250	a-Si:H	Mono graphic	Asahi
4.3	378 × 480	a-Si:H	Color TV	NEC
3.2	240 × 255	a-Si:H	Color TV	Sharp

angles are required (for example, in two-seat cockpits). LCDs are known for a somewhat reduced viewing angle compared to other display technologies. With proper design of both the TFT and lighting system, however, a wide viewing angle can be obtained. Contrast ratios of 55:1 on axis and 15:1 at ±40° (horizontal) and ±30° (vertical) have been reported for a TFT-LCD used in a pocket TV.[8] These viewing angles are sufficient for most avionic applications.

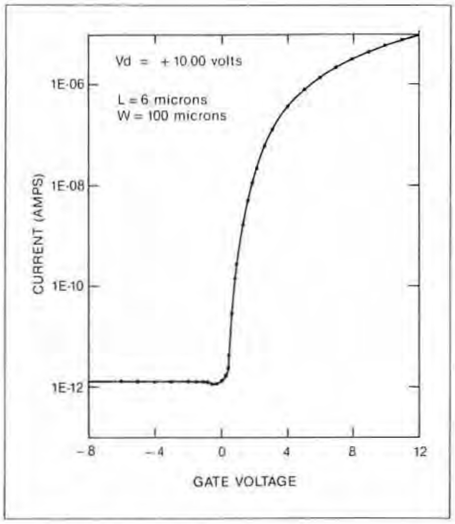

Fig. 2: The current-voltage characteristic of GE's a-Si:H TFT.

Temperature and humidity are important concerns for military displays. These displays must operate over a temperature range of −55°C to +90°C, and they must also survive several days in high humidity (60°C, 95% RH). Special attention must be paid to the materials used in display fabrication, as any contamination will reduce the display contrast. Also, wide-temperature-range liquid crystals must be developed for this application; conventional materials in use today do not operate at 90°C. To operate at low temperatures with reasonable response times, a transparent heater is usually incorporated. It must be capable of heating the cell and lamps in 1–2 minutes and sometimes faster.

Finally, reliability of the LCD system is a key concern of avionic display designers. Special care must be made in the assembly of not only the cell but also the display module. In a high-resolution display there are over 2000 connections between the LCD and the drive circuits. For highest reliability, soldered interconnects have been developed and have been shown to be reliable under military en-

Table 2: Avionic Display Requirements

Active area	14–80 in.^{2}
Resolution	100–200 pixel/in.
Viewing angle	
Horiz.	±60°
Vert.	+45, −10°
Contrast ratio	
Dark	40:1
10,000 fC	7:1
Brightness	0.1–200 fL
Gray shades	1–8
Color	Full color
Pixel defects	<1/in.^{2}
Response time	<30 msec
Temperature range	−55°C to +90°C
Environment	MIL-E-5400
MTBF	2000–10,000 h

vironmental conditions. Power supplies, which are all low voltage (28 V max.), are very reliable compared to CRT supplies. It is estimated that 10,000 hours MTBF can be achieved in this technology, which will be a significant cost savings over current technology.

GE's avionic color LCD

An example of the state of color LCD technology for avionic applications is GE's high-resolution color avionic LCD. GE has been an active participant in the development of a-Si:H TFT-LCDs since the early 1980s. The main focus of this development program is avionic displays for both commercial and military use. Several display sizes have been developed by GE, but the largest to date is the 1024×1024 6.25-in.×6.25-in. color LCD recently shown at the Paris Air Show. It contains the largest number of pixels demonstrated in the world. A summary of the display characteristics is shown in Table 3 and a photo of the display is shown in Fig. 3. The LCD is configured as a 512×512 color resolution display and uses the quad color pattern. This pattern has certain advantages in display resolution for white (or green) images and can also be used to reduce aliasing artifacts. The display characteristics represent performance measured on actual LCDs; they do not represent a limit to the technology by any means. Research and development in this field is still underway and improvements are expected. If progress continues at the present pace—and it is fully expected that it will—then these displays will be available for integration into the next-generation aircraft scheduled for the 1990s.

Table 3: GE Color TFT-LCD

Resolution	
(Quad color design)	
Green	1024×512
Red	512×512
Blue	512×512
Pixel size	155×155 μm
Pixel arrangement	RG (Quad) GB
Display size	
Active area	159×159 mm
Overall	170×170 mm
Brightness	0.1–150 fL
Contrast Ratio	>30:1
Viewing Angle	
(>4:1 contrast ratio)	
Horiz.	±60°
Vert.	±30°

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Acknowledgments

The development of the high-resolution TFT-LCDs at GE is a result of the combined efforts of many dedicated workers at both the Corporate Research and Development Center and Aircraft Instruments Department of GE Aerospace Business Group.

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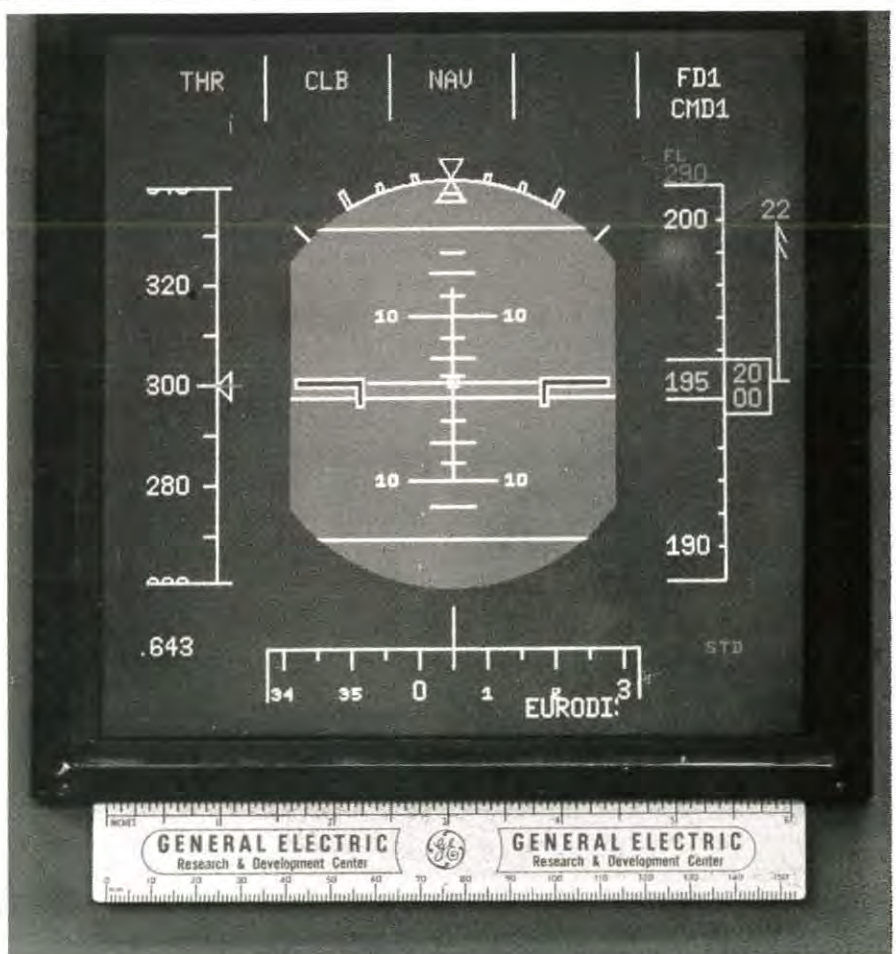

Fig. 3: GE's 1024×1024 6.25-in.×6.25-in. color LCD.

have you read . . . ?

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"Application of Expert Systems in Air Traffic Control," G. D. Gosling, *Journal of Transportation Engineering*, Vol. 113, No. 2 (March 1987), pp. 139–154. ■

Vacuum display converters

Endicott Research Group, Inc., has now made available the Quad Output E900VF² Series DC-DC/AC converters for vacuum fluorescent displays. These converters provide two dc anode and two ac filament voltages to power one two-color VFD, or two dissimilar VFDs, requiring up to 12 W total output power. The units are $2.00 \times 2.50 \times 0.98$ in., are encapsulated in aluminum cases, and are PC board mountable. Price in quantities of 250 is $29.72 ea.

For further information contact Michael Foldes or Dan Ward, Endicott Research Group, Inc., P.O. Box 269, 2601 Wayne St., Endicott, NY 13760. 607/754-9187.
Circle no. 7

Gas-discharge display subsystems

The DM-0416-02 is the first of a new series of gas-discharge subsystems from Babcock Display Products, Inc. The neon-orange 0.33-in.-high characters, arranged in 4 lines of 16 characters each,

are visible up to 10 ft. An on-board microprocessor-controller allows easy interface to a user's 8-bit bus and provides flexible editing intelligence. All necessary voltages are generated with a DC-DC converter so that the unit operates on +5 V only. The subsystem accepts parallel data, and also serial data at selectable baud rates up to 4800. The 96-character ASCII font is displayed, as well as many scientific and international characters. Availability is stock to 12 weeks. Price is $225 in production quantities.

For further information contact Carl Cox, Babcock Display Products, Inc., 1051 S. East St., Anaheim, CA 92805-5799. 714/491-5122.
Circle no. 8

Touch-panel terminal

Emerald Computers, Inc., introduces the FPS570, a totally integrated flat-panel touch switch terminal built with an electroluminescent panel and either infrared or resistive touch switch devices. The FPS570 offers a complete text and bit-mapped graphics terminal in a compact ruggedized package that can be mounted in most locations. The touch switch allows the use of "soft keys" that can transform the FPS570 into a control panel

with limitless function, control, and input switches. The FPS570 is controlled by the Emerald FPC500 text and graphics controller, and can produce 80-character × 25-line, and 40-character × 12-line text and complete bit-mapped graphics. The graphics function includes pixel, continuous pixel, line, continuous line, circle, rectangle, and fill-and-shade polygon. The FPS570 also comes with 64K of video RAM (4 video pages), 32K of scratch pad RAM, and capacity for up to 64K bytes of ROM.

The resistive FPS570-R weighs 6.5 lbs. and is only 2.7 in. deep. The infrared FPS570-I weighs 7.7 lbs. and is 4.0 in. deep. Each accepts standard 120 VAC at 60 Hz and meets FCC Class-A. The FPS570 can be ordered with either a bench stand, studs for wall mounting, or an optional swing arm attachment. Either unit sells for $2855 in single quantities, and $2395 in 100s.

For further information contact David Blass, Emerald Computers, Inc., Display Products Group, 7324 S.W. Durham Rd., Portland, OR 97224. 503/620-6094.
Circle no. 9

Added touch capability

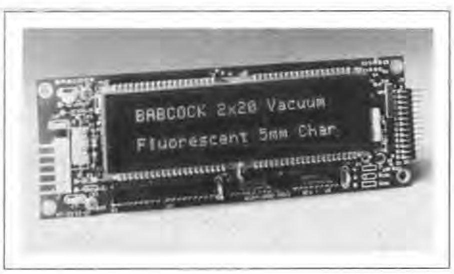
Interaction Systems, Inc., has added capacitive touch input capability to the Princeton Graphic Systems HX-9E 9-in. monitor. By attaching a standard ISI 9-in. solid glass touch screen to the CRT, and connecting the screen via a single cable to an ISI touch controller, the user is immediately able to input and access data via touch. The ISI touch controller boards are available for applications requiring a serial, parallel, IBM PC plug-in, or stand-alone touch controller interface. ISI touch controller boards feature skew compensation for accurate registration of touch screen and raster image; write default for storage of touch system parameters in non-volatile RAM; specification of touch response rates from 50 to 500 msec; optional display of first touch, repeat touch, last touch, or any combination of these; and electrostatic discharge protection. Prices for the ISI touch screen and con-

troller for the HX-9E in OEM quantities range from \$295 to \$395.

For further information contact Joanne Dawson, Interaction Systems, Inc., 130 Lincoln St., Brighton, MA 02135. 617/789-5900.
Circle no. 10

Compact 40-character VFD

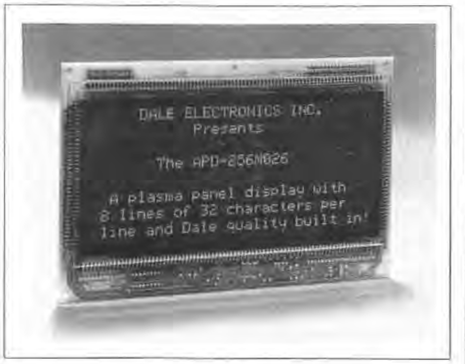
Babcock Display Products, Inc., announces their Vf-0220-01, a 2-line by 20-character vacuum fluorescent display subsystem. The 0.20-in. (5-mm) dot matrix arranges 40 characters in a tight footprint, and the blue-green display can be filtered to blue, green, aqua, or yellow to complement front-panel design. The module contains all display drive, refresh, and control electronics. In addition, an on-board DC-DC converter allows operation from +5 V only, and a microprocessor-controller provides many powerful editing functions, such as blinking characters and horizontal scrolling. Availability is stock to 12 weeks and price is \$148 at 100 piece quantities.



For further information contact Carl Cox, Babcock Display Products, Inc., 1051 S. East St., Anaheim, CA 92805-5799. 714/491-5100.
Circle no. 11

Complete character display

Dale Electronics' APD-256M026-1 plasma panel display is programmable to operate in a serial or parallel mode, and provides 8 lines of 32 characters, each 0.18 in. (W) $\times$ 0.26 in. (H) in a 5×7 dot-matrix format. Each character has a 5-dot underbar which can be used as a visible cursor and/or lower-case descender. The compact APD-256M026-1 is 6.10 in. (H) $\times$ 11.00 in. (W) $\times$ 2.2 in. (D) for easy packaging. Its 3.3-in. (H) $\times$ 7.62 in. (W) viewing area provides high brightness (110 fL) and a 150° wide viewing angle. Its 4K $\times$ 8 bit EPROM character generator is capable of storing two 128 character sets including 128 US ASCII characters and an alternate set of 128 characters which can be user programmed.



Basic price of the APD-256M026-1 is \$730 ea. in lots of 100 with delivery in approximately two weeks. The new display can also be provided for interfacing with CRT controllers (Model APD-256M026) if desired.

For further information contact Margaret Nowicki, Dale Electronics, Inc., 2064 12 Ave., Columbus, NE 68601. 402/564-3131.
Circle no. 12

Vacuum fluorescent graphics module

Surface-mount technology, high brightness (200 fL), page buffering, and software-dimming capabilities are all features that have been combined in Futaba's 176×16 vacuum flourescent graphics module. This compact unit consists of the VFD, driver circuitry, microcontroller, and optional power supply. The module can be driven by connecting to the host system through a simple interface which allows each pixel to be addressed to create different size characters and reconfigurable graphics. The 176×16 operates off 5 VDC and typically consumes less than 200 mA.

For further information contact Electronic Components Div., Futaba Corp. of America, 711 E. State Pkwy., Schaumburg, IL 60173. 312/884-1444.
Circle no. 13

Miniaturized avionic CRTs

Thomson-CSF introduces three new compact CRTs for head-up and helmet-mounted displays. The TH X2633 is a short head-up CRT with a 65-mm optically flat circular screen and an overall length of just 112 mm. It employs electromagnetic deflection and a high-voltage electrostatic focusing gun to achieve an output brightness of up to 100,00 cd/m^2 (P53 phosphor) and a typical half-brightness linewidth of 0.19 mm. The TH 8449-1 P43 is an example of Thomson-CSF's micro-miniature CRT assemblies for helmet-mounted display. It has a 1-in. optically flat screen with a P43 narrow bandwidth phosphor. Overall size is 100 mm (L) and 27 mm (diam.), including built-in deflection coils and mu-metal shields. Typical brightness with night vision systems is 150 cd/m^2 with 600 TV lines resolution. In stroke writing, the TH 8449-1 P43 will deliver a peak line brightness of 3600 cd/m^2 with a half-brightness linewidth of 28 μm. The same tube can be supplied, as TH 8449-2, with a fiber-optics screen.

For further information contact Thomson Electron Tubes and Devices Corp., 550 Mount Pleasant Ave., P.O. Box 6500, Dover, NJ 07801. 201/328-1400.
Circle no. 14

Panel meter modules

D1 Products, Inc., introduces its DPMM10 Series of low-cost 3.5-digit battery-operated digital-panel-meter modules. The series' five modules are capable of reading dc voltages over a range of ± 199.9 mV, 1.999 V, 19.99 V, 199.9 V, or 1000 V, and feature an LCD display with 0.5-in. readouts, automatic zeroing, and autopolarity indication. The digital modules operate from a single 7 VDC to 15 VDC power supply; a "LO BAT" indication appears on the LCD display when battery voltage drops below 7 VDC. Approximate current requirement is 2.5 mA at 9 VDC, and 4.5 mA at 12 VDC. Accuracy is typically 0.2%. PCB size is 2 in. (H) × 3 in. (W). The decimal point is user selectable and, depending on converter or transducer input circuit configurations, the digital panel meter modules can be used as a readout for a variety of applications. Price in quantities of 1-49 pieces is $38.65, and includes bezel.

For further information contact P. Jason, D1 Products, Inc., 95 E. Main St., Huntington, NY 11743. 516/673-6866.
Circle no. 15

Digital panel meters

A range of digital panel meters in the 3-1/2, 4, and 4-1/2 digit categories has been introduced by the Triplett Corp. In addition to standard models, Triplett is

offering five digital indicator comparators, an LCD two-wire process meter, a selectable-range LCD digital panel meter, and a miniature and subminiature series. Triplett's digital instruments feature displays up to 0.56 in. high; LED, gas discharge, vacuum fluorescent, or LC displays; DIN, IEC or NEMA cases and adapters; dc voltage ranges from 20 mV to 1000 V; dc current ranges from 2 μA to 2 A; ac voltage ranges from 100 mV to 700 V; and ac current ranges from 100 μA to 5 A. Temperature ranges for thermocouple meters extend from $-50°C$ to 1200°C (K thermocouple). Basic accuracy is to $\pm 0.005\%$ on some models, and true RMS is available on some of the meters.

All models offer such standard features as open collectors and relay controls. Some models also feature BCD output and analog output. The user net prices range from $58 for the DT-51A to $495 for the comparators. Quantity discounts are available, and delivery is approximately two weeks ARO.

For further information contact Triplett Corp., One Triplett Dr., Bluffton, OH 45817. 419/358-5015.

Circle no. 16

Rugged color graphics

Chromatics, Inc., introduces the Baja™ Colorgraphic Display System, a ruggedized version of the company's high-performance Le Mans™ system. Baja can draw one million fully transformed two-dimensional vectors per second, and 250,000 fully transformed three-dimensional vectors per second. It can also generate 25,000 smooth-shaded polygons per second utilizing the Gouraud algorithm with hidden surface removal in 3D applications. Baja packaging and electronics are designed to exceed MIL-STD-810D specifications for shock and vibration.

The graphics engine is based on multiple processors arrayed in a 32-bit fully pipelined architecture, and can contain up to 32 Mbytes of display-list memory and up to 24 double-buffered bit-mapped memory panes, as well as support application development in industry-standard GKS software or CX 3D—Chromatics' implementation of PHIGS. The system is interconnected via Motorola's standard 32-bit VME bus, providing an "open" architecture based on industry standards.

Baja also provides a 1280 × 1024 non-interlaced display monitor. The system is software compatible with the Chromatics

CX Series and can be easily interfaced to host computers such as VAX, Sun, or Apollo systems. The basic Baja configuration is priced at under $34,000. Substantial discounts are available for volume purchases.

For further information contact Chromatics, Inc., 2558 Mountain Industrial Blvd., Tucker, GA 30084. 404/493-7000.

Circle no. 18

Self-contained compact display

A new 192-column × 88-row graphics display has been introduced by Dale Electronics, Inc. Model APD-192G088-1 has a full-field dot-matrix design with drive electronics and a microprocessor-based controller. Programmable to operate in a serial or parallel mode, the Model APD-192G088-1 contains all the necessary refresh memory, character generaton, and control logic to enable it to serve as direct readout. The display uses single- and two-byte commands to allow simplified code generation while accomplishing complex display tasking such as scrolling or inserting lines and characters. A 4K × 8 bit EPROM generates 256 characters consisting of 128 US ASCII characters and 128 block graphics characters. Alternate character sets can be factory or user programmed. Overall size of the APD-192G088-1 is 10.35 in. (W) × 6.00 in. (H) × 2.20 in. (D). Display viewing area is 7.66 in. (W) × 3.50 in. (H). Cost is $699 each in lots of 100. The display can also be provided for interfacing directly with CRT controllers (Model APD-192G088) if desired.

For further information contact Margaret Nowicki, Dale Electronics, Inc., 2064 12 Ave., Columbus, NE 68601. 402/564-3131. ■

Circle no. 19

calendar

November

Advances in Intelligent Robotics Systems and IECON '87 Joint Conference. SPIE, P.O. Box 10, Bellingham, WA 98227-0010. 206/676-3290.
Nov. 1-7 Cambridge, MA

Electronic Imaging '87. Richard Murray, Institute for Graphic Communication, 375 Commonwealth Ave., Boston, MA 02115. 617/267-9425.
Nov. 2-5 Boston, MA

COMDEX/Fall '87. The Interface Group, 300 First Ave., Needham, MA 02194. 617/449-6600.
Nov. 2-6 Las Vegas, NV

INFOTEX. The Interface Group, 300 First Ave., Needham, MA 02194. 617/449-6600
Nov. 3-5 Canberra, Australia

International Plastics and Rubber Exhibition. British Information Services, 845 Third Ave., New York, NY 10022. 212/752-8400
Nov. 3-7 Birmingham, England

Workshop on Workstation Operating Systems. Luis-Felipe Cabrera, 6572 Northridge Dr., San Jose, CA 95120. 408/927-1838.
Nov. 5-6 Cambridge, MA

Cambridge Symposium on Fiber Optics/Integrated Optoelectronics. SPIE, P.O. Box 10, Bellingham, WA 98227-0010. 206/676-3290.
Nov. 8-13 Cambridge, MA

Micro Robots and Teleoperators Workshop. MRT Workshop, 4B-623, AT&T Bell Labs, Holmdel, NJ 07733.
Nov. 9-11 Cape Cod, MA

NCGA's Mapping & Geographic Information Systems '87. Bob Cramblitt, National Computer Graphics Association, 2722 Merrilee Dr., Suite 200, Fairfax, VA 22031. 703/698-9600.
Nov. 9-12 San Diego, CA

Photometry and Colorimetry for Information Displays—Short Course. UCLA Extension, P.O. Box 24901, Los Angeles, CA 90024. 213/825-1047.
Nov. 9-13 Los Angeles, CA

Drives/Motors/Controls and Programmable Controllers and Systems Exhibitions. British Information Services, 845 Third Ave., New York, NY 10022. 212/752-8400.
Nov. 10-12 Birmingham, England

International Symposium on the Technologies for Optoelectronics. SPIE, P.O. Box 10, Bellingham, WA 98227-0010. 206/676-3290.
Nov. 16-27 Cannes, France

Computer Peripherals and Small Computer Systems Exhibitions. British Information Services, 845 Third Ave., New York, NY 10022. 212/752-8400.
Nov. 17-20 London, England

International Conference on Information Science and Engineering. R. Larry, Institute of Electronic and Radio Engineers, 99 Gower St., London, WC1E 6AZ, U.K.
Nov. 25-27 York, England

Workshop on Computer Vision. Prof. Kang G. Shin, Dept. of EE and Computer Science, Univ. of Michigan, Ann Arbor, MI 48109-1109. 313/763-0391.
Nov. 30-Dec. 2 Miami Beach, FL

December

OIS 1987: Seventh Annual Optical Information Systems Conference and Exhibition. OIS '87, Meckler Corporation, 11 Ferry La. W., Westport, CT 06880. 203/226-6967.
Dec. 1-3 New York, NY

National Database and Fourth Generation Language Symposium. Mary E. Lownie, Digital Consulting Assoc., Inc., 6 Windsor St., Andover, MA 01810. 617/470-3870.
Dec. 2-5 Boston, MA

IEDM: 1987 IEEE International Electron Devices Meeting. Melissa M. Widerkehr, Courtesy Associates, Inc., 655 15 St. N.W., Suite 300, Washington, DC 20005. 202/347-5900.
Dec. 6-9 Washington, DC

Lasers '87. Society for Optical and Quantum Electronics, P.O. Box 245, McLean, VA 22101. 703/642-5758.
Dec. 7-11 Lake Tahoe, NV

1987 Microcomputer Graphics Conference. Susan Werlinich, Expoconsul International, 3 Independent Way, Princeton, NJ 08540. 609/987-9400.
Dec. 16-18 New York, NY

1987 Architects and Engineers Conference. Carol S. Henderson, Expoconsul International, 3 Independence Way, Princeton, NJ 08540. 609/987-9400.
Dec. 16-18 New York, NY

January

1988 Simulation in Education Engineering. Simulation Councils, Inc., P.O. Box 17900, San Diego, CA 92117. 619/277-3888.
Jan. 7-8 San Diego, CA

O-E LASE/'88. SPIE, P.O. Box 10, Bellingham, WA 98227-0010. 206/676-3290.
Jan. 10-15 Los Angeles, CA

Conference and Exhibition on Electronic Imaging Devices and Systems '88. SPSE, 7003 Kilworth La., Springfield, VA 22151. 703/642-9090.
Jan. 15-20 Los Angeles, CA

Paper and Film for Copiers, Printers and Plotters. Diamond Research Corp., P.O. Box 128, Oak View, CA 93022. 805/649-2209.
Jan. 31-Feb. 2 Santa Barbara, CA

Second International Conference on Computer Workstations. Patrick Mantey, 335A Applied Science Bldg., Dept. of Computer Engineering, Univ. of Calif. at Santa Cruz, Santa Cruz, CA 95064.
Jan. 31-Feb. 3 Santa Clara, CA

Medical Imaging II. SPIE, P.O. Box 10, Bellingham, WA 98227-0010. 206/676-3290.
Jan. 31-Feb. 5 Newport Beach, CA

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EM Industries
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chapter notes

Japan Chapter

The SID Japan Chapter announces the election of the following officers: Chairman, **Cuji Suzuki**; Vice Chairman, **Takehiro Kojima**; Secretary, **Akito Iwamoto**; and Treasurer, **Kunihiko Arai**. The September 21 meeting of the SID Japan Chapter focused on "3D Imaging and 3D Television," and featured several speakers. The July 31 meeting highlighted SID '87 in New Orleans.

Mid-Atlantic Chapter

Arch Luther of **David Sarnoff Research Center** was the guest speaker at the September 8 meeting of the SID Mid-Atlantic Chapter. Mr. Luther's presentation highlighted "Digital Video Interactive Technology." **Peter Seats** of **Thomson-CSF** gave a presentation on "Current Trends in CRT Technology" at the October 13 meeting of the SID Mid-Atlantic Chapter. **Webster Howard** of **IBM Corp.** spoke about "Current Trends in LCD Technology" at the Chapter's November 10 meeting.

Peter Seats of Thomson-CSF addresses a recent SID-MAC meeting.

Upcoming meetings include:

Dec. 8. "Current Trends in EL Displays," Elliott Schlam, US Army LABCOM

Jan. 19. "Current Trends in Plasma Displays," Larry F. Weber, Univ. of Illinois

Feb. 9. "Dynamic 3D Displays," Joel Pollack, Tektronix

Mar. 8. To be announced

Apr. 12. To be announced

All meetings are held at IBM Corp., 590 Madison Ave., New York, NY, at 7:30 p.m., and are preceded by a 6:00 p.m. dinner at Wolf's Restaurant, 57 St. and Ave. of the Americas. ■

Circle no. 21

id classified

Classified ad rates: $55/column-inch (min.); $10/line (for fractions of an inch); $10/insertion for blind box no. at *ID* (replies forwarded). **Size:** 1 column-inch = 10 lines (ave. 6 words/line). Large-type all-caps heading (max. 17 characters) takes up 2 lines. Allow 1 line for blind box no. **Deadline:** One month before issue date. **Payment:** Send minimum $55 payment with order to: Information Display, c/o Palisades Institute, 201 Varick St., Suite 1140, New York, NY 10014. **Questions?** Call 212/620-3371.

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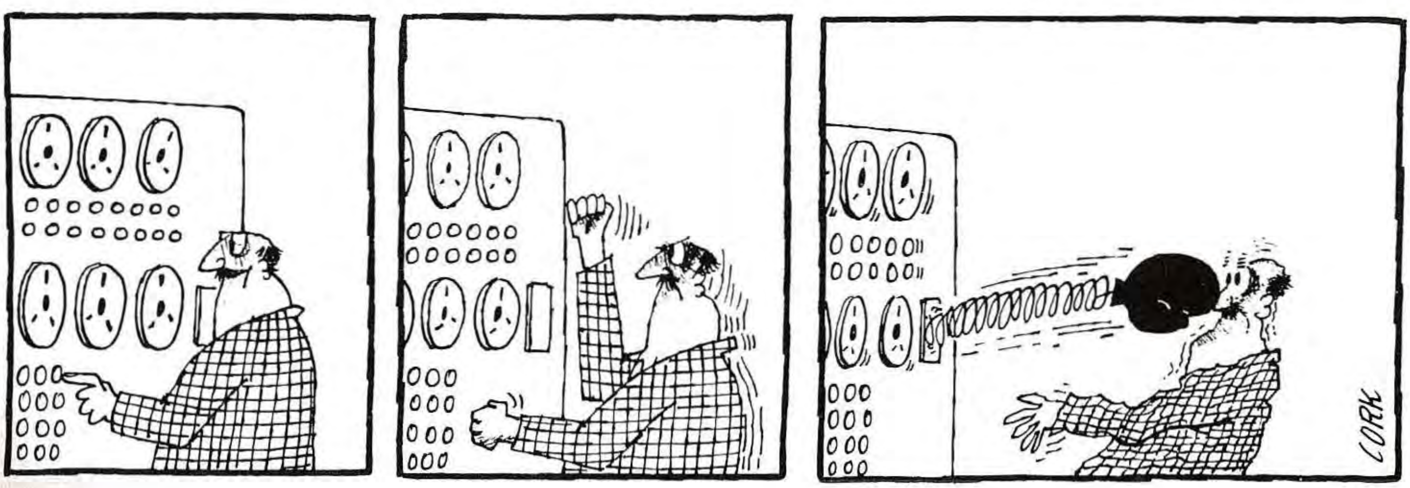

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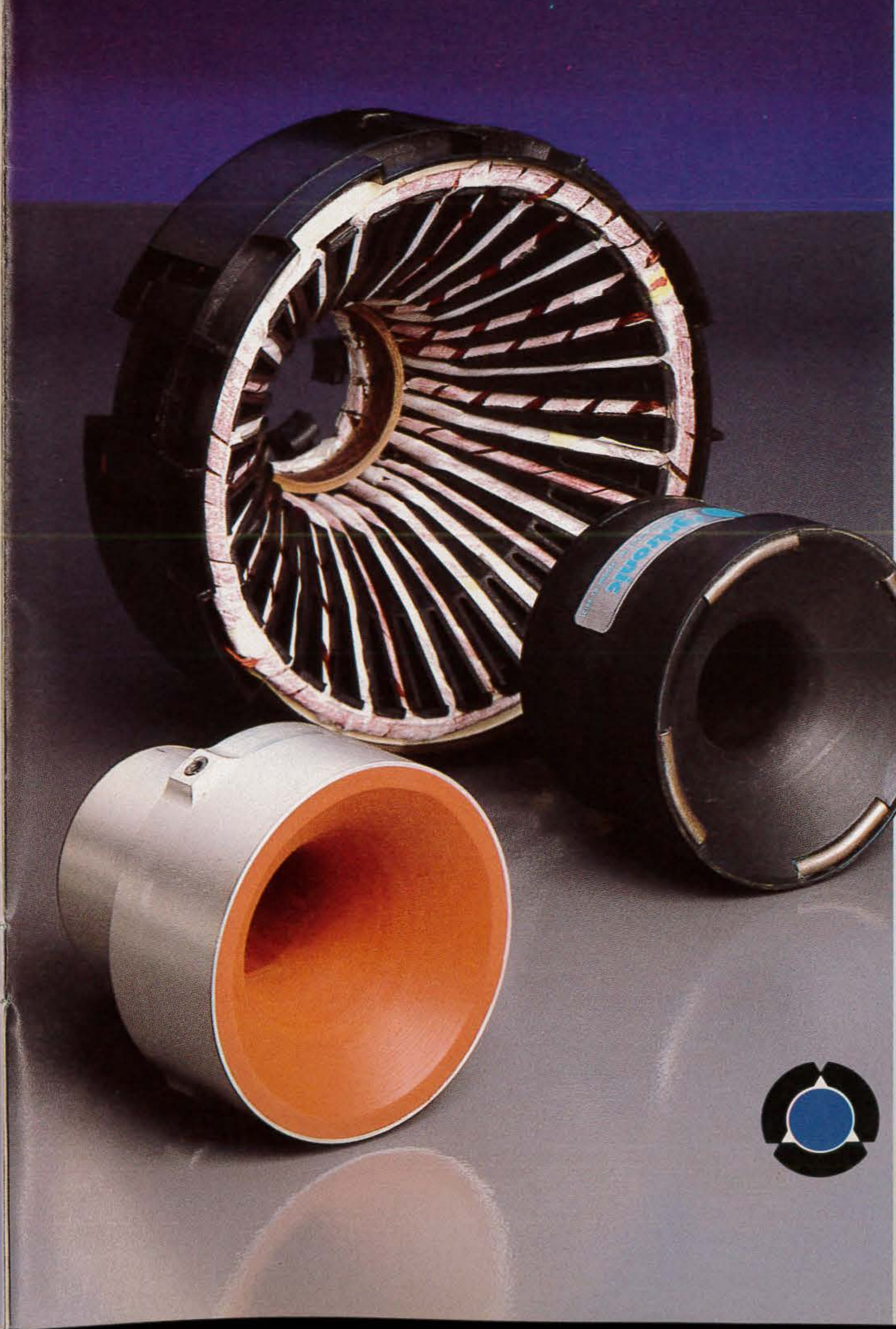

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Circle no. 22

Celco *Junior* Color Film Recorder

16mm, 35mm, 4" x 5"

CELCO *Junior* produces 16mm, 35mm or 4" x 5" imagery for volume producers of high quality animation and presentation business graphics.

- **Animation**
- **Business Graphics**
- **Bright, rich colors**
- **Low cost**
- **Compact size**
- **Fast film production**
- **Fast film recording speeds:**
  —15 seconds for 16mm image
  —Less than 1 minute for a complex 35mm slide
- **Precise addressability: 8192 x 8192**

APPLICATIONS

The CELCO *Junior* is designed to fill a specific need where high throughput and high quality 16mm, 35mm or 4" x 5" computer-generated imaging is required.

OTHER FEATURES

Low cost, compact size, ease of operation and CELCO reliability make this system ideal for animation and business graphics producers worldwide.

The CELCO *Junior* Color Film Recorder provides extremely accurate film registration for the most demanding animation sequences.

OPTIONAL CELCO CONTROL SOFTWARE

—Plotting control
—File handling
—Complete diagnostic and calibration routines
—Job Control Block (JCB) for animation files handling

Original photo was digitized by Eikonix in preparation for computer-controlled retouching by Magicmation, Seattle, WA. Digital image was then output to CELCO Film Recorder.

CELCO *Junior* saves time and makes money for animators: Data courtesy Pacific Data Images.

For further information call CELCO today.

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