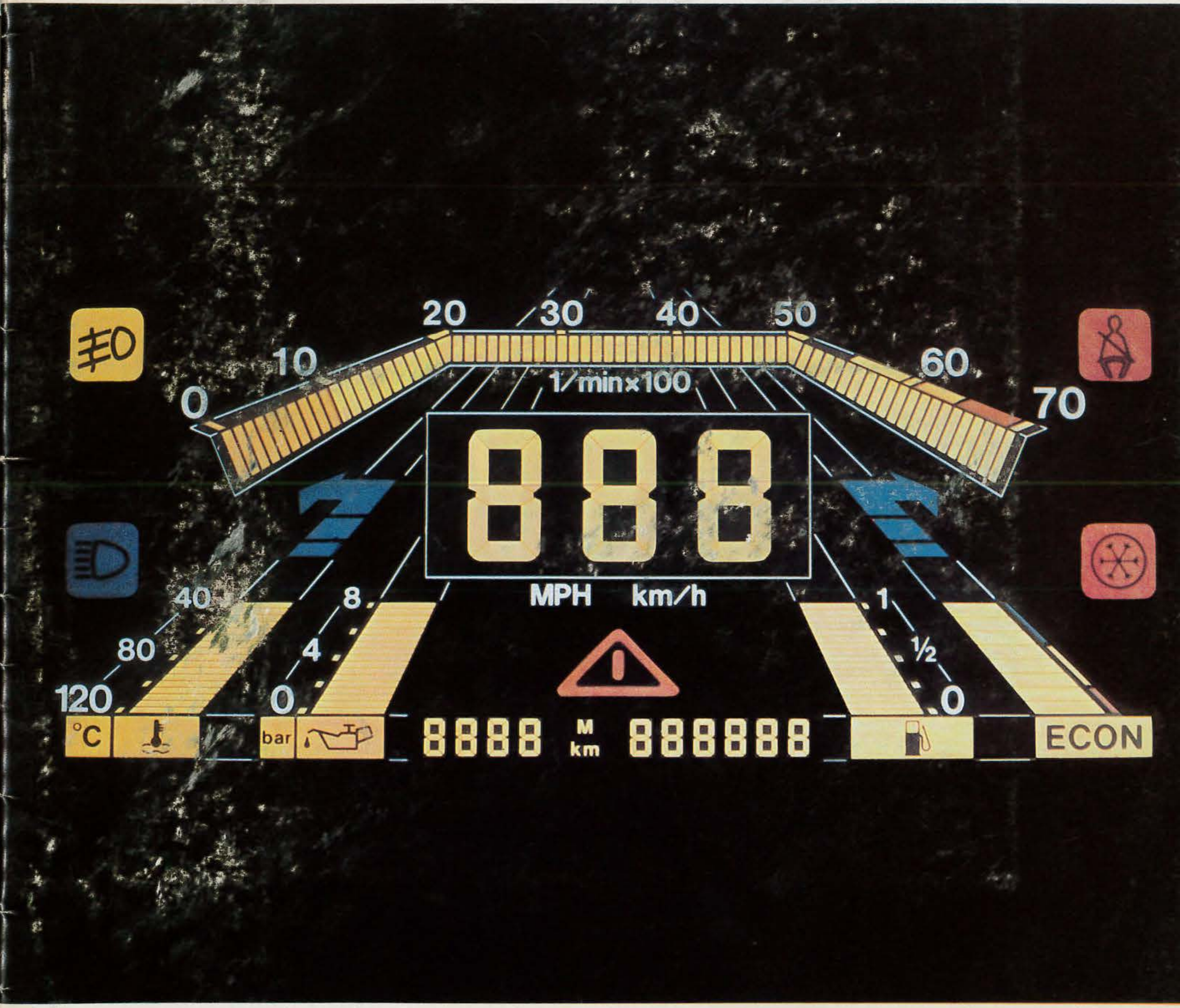
Official Monthly Publication of the Society for Information Display

INFORMATION DISPLAY

February 1988
Vol. 4, No. 2



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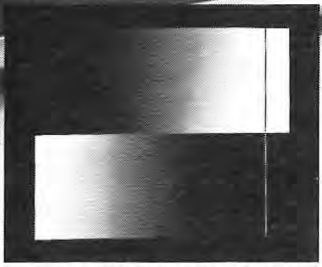

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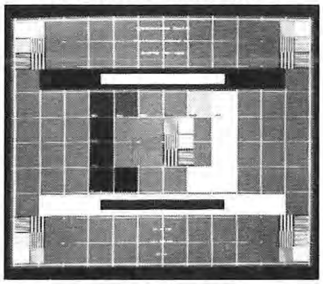

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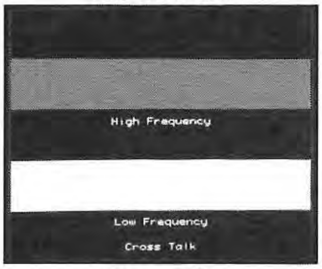

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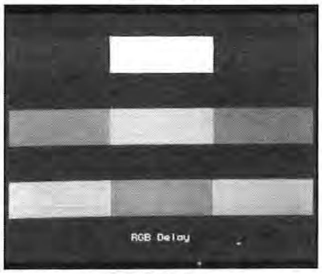

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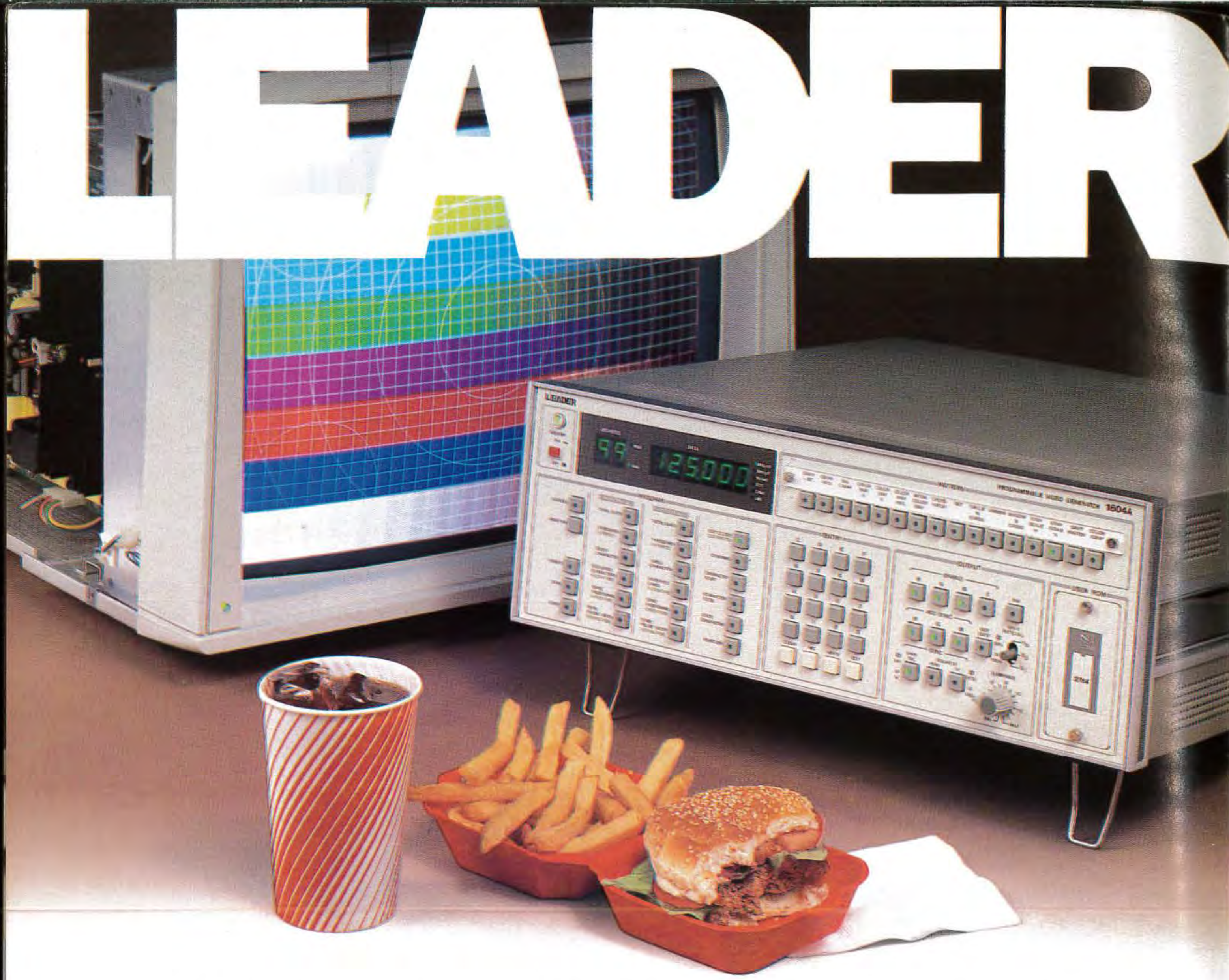

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Circle no. 3

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INFORMATION DISPLAY

FEBRUARY 1988
VOL. 4, NO. 2

Cover: LCD panels have become quite common in heavy-truck instrument clusters. This one was made by AEG Corp. for Borg Instruments. (page 12)

Photo: AEG Corp.

Next Month in Information Display

- Image processing primer
- PS/2 graphics
- SID '88 preview

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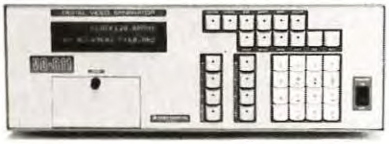

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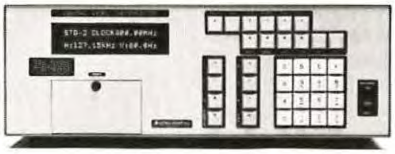

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INFORMATION DISPLAY (ISSN 0362-0972) is published monthly for the Society for Information Display by Palisades Institute for Research Services, Inc., 201 Varick Street, New York, NY 10014; David Slater, Chief Executive Officer; Leonard H. Klein, President; Harold R. Summer, Vice President; Hildegarde Hammond, Secretary; Laura Mangone, Treasurer.

EDITORIAL AND BUSINESS OFFICES: Palisades Institute for Research Services, Inc., 201 Varick Street, New York, NY 10014; telephone 212/620-3371. Send manuscripts to the attention of the Editor, ID.

WEST COAST SALES OFFICE: c/o Ted Lucas, P.O. Box 852, Cedar Glen, CA 92321; telephone 714/337-6627.

SID HEADQUARTERS, for correspondence on subscriptions and membership: Society for Information Display, 8055 West Manchester Avenue, Suite 615, Playa del Rey, CA 90293; telephone 213/305-1502.

SUBSCRIPTIONS: Information Display is distributed without charge to those qualified and to SID members as a benefit of membership (annual dues $35.00). Subscriptions to others: U.S. & Canada: $36.00 one year, $64.00 two years, $90.00 three years, $3.00 single copy; elsewhere: $72.00 one year, $128.00 two years, $180.00 three years, $6.00 single copy.

PRINTED by Sheridan Printing Company, 1425 Third Avenue, Alpha, NJ 08865. Third-class postage paid at Alpha, NJ.

POSTMASTER: Send address changes to Society for Information Display, 8055 West Manchester Avenue, Suite 615, Playa del Rey, CA 90293.

editorial

Liquid-crystal displays are this month's featured topic, and we lead off by surveying the state of the liquid-crystal art. Manufacturers and industry watchers have been promising exciting developments in this arena for some time now, but commercialization in many products has been slower than originally projected. In recent months, there has been a variety of scientific development and commercial advances. We try to bring you up to date on who's doing what.

Next, Dave Ross discusses the potential for LCDs in automobile instrument clusters and why, despite low market penetration, noncompetitive cost, and consumer resistance, virtually everybody agrees that automotive LCDs have a bright future. A sidebar takes a brief look at a growing niche market with fewer price pressures than those faced by passenger-car manufacturers.

Finally, Laurie Allard reports on the third Eurodisplay conference, which was held in London last September. Our appreciation to Derek Washington for recruiting Laurie and getting his fine report to *ID*'s editorial office precisely when due.

Now, a statement of editorial intent. We plan to announce the introduction of new and updated software packages of interest to our readers, and to publish occasional software reviews, much as we do now for books. If you have any favorite packages whose identity you would like to share, or if there is a package you'd be interested in reviewing, please let us know. Similarly, please don't keep it a secret if you are a software publisher or developer working on programs that would help *ID*'s readers. However, please limit yourselves to programs that will run on personal computers or the more popular engineering workstations.

—Kenneth I. Werner

The flowering of liquid-crystal technology

BY KENNETH WERNER

WHEN Mao Tse-tung decreed "May a thousand flowers bloom in the meadow," it is unlikely he was thinking of free enterprise in general or liquid-crystal displays in particular. But after a protracted evolution, liquid-crystal displays (LCDs) are blossoming both in the variety of technologies used and in the range of their application.

In 1986, 845 million LCD units were manufactured—59% were wristwatch displays; 15% calculator displays; and 26% were used in office equipment, thermometers, clocks, television sets, and other applications. The news was in the 26% of production not used in calculators and watches. LCDs have dominated the two latter segments for some time, and their success in those relatively undemanding applications has paradoxically served to underscore the technology's traditional limitations—narrow operating temperature range, poor overall ergonomics, small pixel array size, low brightness, and low contrast ratio. But new materials and enhanced electronics are extending LCDs into applications as diverse as high-performance numeric readouts for aircraft, hand-held color televisions, electro-optic CRT shutters for stereoscopic displays, and large-screen projection light valves. These successful applications are reversing the tendency of the display industry as a whole to underestimate the diversity of applications suitable for LC phenomena. In addition to benefitting from their expanding technical capabilities and a raised industry consciousness, LCDs remain the only solution when a combination of small profile, low power, low cost, and sunlight readability is required. Except for low cost, this is the general design profile for hand-held, outdoor, and portable display-based products.

It is only relatively recently that LC panels displaying full color have been fabricated for hand-held televisions. These panels give up the LC's traditional cost and power advantage, but are currently the only commercial technology for flat-panel color. The very large birefringence $(n > 0.15)$ of the LC materials available today, coupled with their faster response and wider temperature range and with active-matrix electronics, promises a further blossoming of new LC products.

Kenneth Werner is the editor of Information Display. *He would not have been able to write this article without the generous and extensive assistance of Larry Tannas, flat-panel display consultant and industry watcher and, incidentally, vice president of SID. Mr. Tannas supplied the data for the tables and many of the technical and historical insights on which the article is based.*

The origins of LCDs

When dynamic-scattering LCDs first emerged from the RCA Sarnoff Laboratories in 1968, there was guarded optimism that something would come of this technology. The 1969 discovery of a room-temperature eutectic mixture of MBBA and EBBA LC material made dynamic-scattering displays practical. In the early 1970s, Rockwell International and Sharp Corporation of Japan started manufacturing dynamic-scattering displays for calculators. But there was no significant product application or production volume until the 1972 discovery of the lower-power higher-contrast twisted-nematic (TN) LC mode. Despite the improvements offered by this technology, its impact was moderated by the continuing competition from light-emitting diodes (LEDs).

LCDs were introduced into quartz watches in 1977 when it was realized that LEDs consumed too much power for that application. This was pivotal and provided the emerging LCDs with the first market segment they could dominate, replacing the previously more successful LED. But in the late 1980s, the growth of the watch market is slowing as consumers rediscover their taste for analog watches.

In diversity, strength

While dominating the digital watch market and establishing a substantial share of the hand-held calculator market, LCDs were building a market base in a variety of applications. As the low cost, low-power requirement, thin profile, and sunlight readability of LCDs became more widely recognized, the devices found increasing industrial application in products such as gasoline pumps, fish finders, automobile instrument panels, small computers, multimeters, and medical instruments. LCDs have never been as ergonomically pleasing as, for example, gas-discharge or LED displays, but they had no competition in direct sunlight.

By the mid-1980s, multiplexability[1] reached 1:128 and LCs could be used in personal computers to display graphics or a full half-page of text. Unfortunately, the stretch to 1:128 was too much to give

Photo: Seiko-Epson

Fig. 1: A 14-in.-diagonal active-matrix color LCD made by Seiko Instruments, Inc., of Chiba, Japan. It incorporates 640 sets of red, green, and blue column lines and 1140 row lines. The liquid crystal operates in the TN mode and is driven by TFTs made of hydrogenated amorphous silicon. This development unit exhibits a few evident defects. Anticipated production is several years away.

the viewing angle, brightness, and contrast most consumers demanded. For portable applications, technologists are pursuing newer approaches like the supertwisted birefringent effect (SBE or "supertwist"), active matrices, backlighting, and experimental materials such as ferroelectrics.

In desktop personal computers, cathode-ray tubes (CRTs) dominate and are not even threatened by any of the flat-panel technologies. The more exciting contest is for the portable personal-computer market, which makers of gas-discharge, electroluminescent (EL), and LC displays are all pursuing vigorously.

Be fruitful and multiplex

Shadowing the evolution of primary LCDs has been the active-matrix LCD. While TN LCDs offer low power consumption, low cost, and sunlight readability, they suffer from low contrast and reduced viewing angle when matrix addressing is used. Combined with a general dimness, these factors result in an unappealing display that is barely functional, particularly when the multiplexing exceeds 1:64. An active matrix can eliminate the contrast and viewing-angle problems, and backlighting can eliminate the dimness, but at the sacrifice of liquid crystal's traditional power and cost advantages.

Active matrices using thin-film transistors (TFTs) were first proposed in the late 1960s at the RCA Sarnoff Laboratories and at Westinghouse Research Laboratories.[2] Shortly afterwards, Hughes Aircraft used metal-oxide-semiconductor (MOS) transistors on a silicon substrate. A variety of active-matrix LCDs has followed using different materials for the transistors, including cadmium selenide, silicon, polysilicon, and amorphous silicon. The greatest enthusiasm for this approach has been in Japan. The growing Japanese excitement began in 1983 and has centered on amorphous TFTs and the TN LCD mode. The addition of RGB color-filter dots for a full-color display has resulted in television products from Seiko-Epson, Panasonic, and Sharp that are extremely impressive. Sixteen Japanese companies are doing extensive R&D on color LC television displays, and at least three U.S. companies, and several from Europe, are following suit.

The peculiar LCD

LCDs have become so ubiquitous that it is easy to forget how different they are from the other common electronic display technologies. They are made of organic compounds that in themselves do not emit or absorb light. Polarizers or suspended dye molecules absorb light energy to create contrast in electronically selected areas defined by electrodes.

In the "liquid crystal" states of the many compounds and mixtures used, the materials are highly birefringent, which leads to interesting electro-optic effects when the molecules are selectively rotated. The rotation is by electrostatic forces, and the molecules spring back to their initial wall-surface alignment when the electrostatic forces are removed.

That LCDs do not emit light is the fundamental reason they consume the least power, by far, of all commercial electronic display types. (Exceptions, like electrochromics, are far from commercial viability.) This nonemissiveness also ensures that the contrast ratio is unaffected by ambient illumination. But because they do not emit light, LCDs are always dim relative to their surroundings. The polarizers or suspended dye molecules in LCDs initially absorb more than 50% of the incident light and become darker in electronically selected areas. Despite high contrast ratios, the overall low brightness relative to room ambient makes the displays hard to read. The dimness is easily overcome by adding a backlight, but this diminishes the LCD's advantage in power consumption, and may sacrifice it completely. When color dyes (in guest-host displays) or color filters (in TN color displays) are used, the display is unreadably dim under reflected light—a backlight is essential.

Another basic LC characteristic involves the impact of temperature on the material's viscosity and speed of response. The position of the liquid crystal's molecules results from the balance of the rotating electrostatic forces and the restoring wall forces. The speed of response is proportional to these forces and inversely proportional to the material's viscosity. Viscosity is inversely proportional to an exponential power of temperature. As a result, when the LC material of a typical display cell is in the nematic temperature range, the material's response time can be several seconds at the low end of its operating temperature range and milliseconds at the high end. There is no expectation that LC materials will ever have as wide an operating temperature range as CRTs, EL, or LEDs. However, adding a heater to extend the low end of the operating temperature range and adjusting the material mixture to achieve the desired upper end is effective for most applications and does not cost much in power or complexity. Liquid-crystal materials engineering now permits an operating temperature range differential of 120°C for directly addressed displays and 50°C for highly multiplexed matrix-addressed displays, without heating.

Making personal computing portable

The old personal-computer display standard of 640×200 lines has been hard to achieve with liquid crystals in a way that consumers will accept. The conventional TN mode with 1:100 or 1:128 multiplexing has been unsatisfactory due, primarily, to poor viewing angle. (Two hundred rows are addressed through 1:100 multiplexing by addressing half the rows from the top and half from the bottom.) A much better viewing angle and greatly improved overall performance is provided by SBE, first reported by Scheffer and Nehring in 1984 when they were at the Brown Boveri Research Center in Baden, Switzerland. A chiral-doped nematic layer with boundaries tilted at 27° and a twist angle of up to 270° is used. (Conventional TN has a nominal tilt angle of 2° and a nominal twist angle of 90°). With SBE, high contrast inside a 45° viewing cone is achieved with fast response time. This technology is being developed by Tektronix.

Displays using related approaches, with various angles of twist, are now in production by several Japanese manufacturers. The overall luminance is still low relative to room ambient, and black-on-white images are not possible. As a result, most consumers are still not impressed when they see an SBE or super twisted nematic (STN) LCD next to a gas-discharge or EL display, despite SBE and

Photo: Yokogawa

Fig. 2: A 5.13-in.-diagonal active-matrix color LCD made by Seiko-Epson and packaged by Yokogawa of Tokyo, Japan, for avionic applications. It has a resolution of 127 lines/in. and self-contained lighting, which makes it suitable for nighttime as well as direct sunlight viewing. The LC is operated in the TN mode; the TFTs are ion-implanted polysilicon.

Table 1: Liquid-Crystal Display Applications

Application	Sample Companies	Mode	Multiplexing	Lighting Method	Temperature	Color	Special Features
Aircraft and high-performance numerics	EDS, Polytronics, General Electric	Guest-host (no polarizer)	1:1	Incandescent backlight, transmissive mode, most common	−30°C to 90°C without heater; −45°C to 90°C with heater	White on black background	16:1 contrast Wide viewing angle Wide temp. range Sunlight readable
Fixed font (for calculators, gas pumps, watches, office and medical equip.)	Hamlin (custom), Hitachi (custom), Sharp, Toshiba, Stanley, Sanyo	TN	1:1 to 1:16	Reflective mode most common	0°C to 70°C, usually not heated except in outdoor applications	White on black, black on white	Low profile Low cost Low power Sunlight readable
Automotive instrument clusters, numerics and icons, custom designs	Stanley, Hitachi Sanyo, Sharp	Guest-host with colored dyes; TN with colored polarizers	1:2 to 1:8	Incandescent backlight, transmissive mode, most common	−45°C to 90°C with heater	Red, yellow, green, white, etc., in fixed locations	Low cost Wide temp. range Sunlight readable
Laptop computers with matrix-addressed arrays	Sharp, Hitachi, Toshiba	TN	1:64 to 1:28	Reflective mode	0°C to 80°C without heater	White on black, black on white	Low cost Low power Sunlight readable
Personal computers	Sharp, Hitachi, Toshiba, Tektronix, Sanyo, Kyocera, Seiko-Epson	SBE, STN, OMI, D-STN	1:128	Reflective mode (SBE); Backlight (OMI, D-STN)	0°C to 55°C without heater	White on green, blue, or yellow-green	Low cost Low power
Portable monochrome TV	Citizen, Casio	TN guest-host with polarizer most common	1:64	Reflective mode	0°C to 55°C without heater	Black-and-white with gray shades	Low cost Low power Low profile Sunlight readable
Portable color TV	See Table 2	TN guest-host with polarizer most common	1:200 to 1:400 Active-matrix TFT using a-Si most common	Fluorescent backlight required, transmissive mode	0°C to 55°C	Red, green, and blue primaries selectively addressable, with gray scale	Low profile Low cost Low power Sunlight readable
Avionic primary displays	Yokogawa, Honeywell/Sperry, Bendix/King, Collins, Litton Canada, General Electric	TN most common	Up to 1:500 Active-matrix TFT using a-Si most common	Fluorescent backlight required	−40°C to 85°C with integral heater	Red, green, and blue primaries selectively addressable	Wide viewing angle Wide temp. range Sunlight viewable
Projection displays	Seiko-Epson Greyhawk Hughes Aircraft	TN active-matrix addressed poly-Si TFTs Smectic, laser-scanned Dynamic scattering, CRT projection addressed	N/A	Xenon lamp most common	0°C to 55°C typical	Red, green, and blue displays optically mixed for projection	High resolution
Shutter for sequential color from monochrome CRT; Shutter for CRT stereoscope	Tektronix, Stereographics	One-half wave retardation for sequential CRT images (tunable birefringence)	None	CRT image	0°C to 55°C	Broadband transmission	Electro-optic shutter up to 19-in. diag. 60-Hz rate
3D glasses	Tektronix, Hitachi, Sharp	Tunable birefringence	None	CRT image	0°C to 55°C	Broadband transmission	Eyeglasses 30-Hz rate
Electronic window shade and large alphanumerics	Taliq, Kent State Univ.	Nematic encapsulated LC	None	Modulates light from transparent scattering	−30°C to 70°C	Broadband transmission or color absorption with pleochroic suspended dye	

NOTE: TN = twisted nematic; SBE = supertwisted birefringent effect ("supertwist"); STN = super twisted nematic; D-STB = double super twisted nematic; OMI = optical mode interference; a-Si = amorphous silicon; poly-Si = polysilicon; TFT = thin-film transistor

STN being a clear improvement over traditional TN material. A backlight strikingly improves the luminance at the cost of the liquid crystal's normally low power consumption. In sunlight, of course, the ergonomic situation is reversed, with SBE and STN dramatically better than emissive displays.

Martin Schadt, one of the inventors of the TN mode, reported a new LC mode in the *Applied Physics Letter* of February 2, 1987, and presented his findings at the 1987 SID International Symposium in New Orleans, in his paper "Optical Mode Interference—OMI." OMI has a low tilt angle and less twist than SBE, which may make it more manufacturable. It has the additional advantage of having a transmissive mode and the ability to present a black-and-white image, which many users find more appealing than the unsaturated color contrasts available in the SBE and STN modes. An additional mode, double super twisted nematic (D-STN), has also evolved. D-STN, as developed by Sharp, Seiko-Epson, and other Japanese manufacturers, is much like STN except that there is a two-layer cell in which the layers have opposite rotation, with tilt angle of about 5° and nominal twist angles of from 180° to 240°. D-STN may be more manufacturable and have better overall ergonomics than SBE. SBE, STN, and OMI should all exhibit improved ergonomics and multiplexability over the original TN mode, but at higher manufacturing cost because of the increased tilt and twist angles.

Table 2: Active-Matrix Color Liquid-Crystal Display Companies

COMPANY	MAJOR ACTIVITY	MARKET INTEREST
Sharp Nara, Japan	a-Si TFT, TN mode* 3-in.-diag. product 5-in.-diag. demonstrated	Consumer TV
Seiko Instruments Chiba, Japan	a-Si TFT, TN mode 14-in.-diag. in development	Consumer TV
Matsushita Osaka, Japan	a-Si TFT, TN mode 3-in.-diag. product 5-in.-diag. demonstrated	Consumer TV
Mitsubishi Osaka, Japan	a-Si TFT, TN mode 5-in.- and 10-in.-diag. demonstrated	Industrial
Seiko-Epson Suwa City, Japan	MIM switch, TN mode polysilicon TFT, TN mode 5.13-in. engineering sample available	Consumer TV
Toshiba Yokohama, Japan	a-Si TFT, TN mode 5-in.-diag. production startup	Consumer TV
Stanley Osaka, Japan	a-Si TFT, TN mode Approx. 5-in.-diag. demonstrated	Automotive and avionics
Hosiden Osaka, Japan	a-Si TFT, TN mode Custom 1-in.-diag. and high resolution	OEM component supplier
Sanyo Osaka, Japan	a-Si TFT, TN mode 5-in.-diag. demonstrated	Industrial
Hitachi Japan	a-Si TFT, TN mode 6-in.-diag. demonstrated	Consumer TV
General Electric Wilmington, MA	a-Si TFT, TN mode 8-in.-diag. demonstrated	Avionics
Ovonic Imaging Systems Troy, MI	a-Si diodes, TN mode in development	Avionics
Alphasil Fremont, CA	a-Si TFT, TN mode in development	Avionics and consumer products

*amorphous silicon thin-film transistor, twisted-nematic mode

"Look here, ump!"

We've already seen outraged baseball managers showing umpires a network instant replay on a portable television set. Now, a portable color TV can be kept in the manager's hip pocket. LC technology is staking out new ground with the color backlit active-matrix video display.

This concept is not new but the emphasis is, and the Japanese display industry is attacking the technology as if it could replace the CRT. The LC technology with the addition of backlighting, TFTs (or diodes or MIMs), and red, green, and blue color-dot filter triads (or quads, using two greens) working in concert is essentially that described in Albert G. Fischer's patent no. 3,840,695 issued October 8, 1974: "Liquid Crystal Image Display Panel with Integrated Addressing Circuitry." Unlike other LCD types, this one is not ergonomically marginal. It has the full television color range, with sufficient gray shades, viewing angle, contrast, and brightness, and is more resistant than are CRTs and other display types to washout in direct sunlight. There is a price to be paid—the cost and power consumption are now higher than for any other technology. But all other flat-panel color display technologies are still in the laboratory, and a CRT won't fit in Tommy LaSorda's pocket. LC color TV displays are truly flat and ideally suited for aircraft cockpits, primary flight instruments, and tight locations like behind-the-seat inflight entertainment systems for commercial airlines.

Through the looking glass

LC applications are not limited to displays in the traditional sense, and two new electro-optic shutters have reached commercial realization. One developed at Tektronix uses a unique homeotropic alignment that allows high-speed switching from open to closed in less than 3 msec. This is fast enough to switch at 120 Hz for sequential two-color or sequential left-right stereoscopic images with a flicker-free 60 Hz for each color or each stereo image.

A second shutter, developed independently at Taliq and Kent State University, uses an encapsulated nematic LC material. The nematic material is aligned in the capsule but the director is rotatable under a high electric field. The capsules are randomly oriented so that when at rest they collectively scatter the incident light in the forward direction like the old dynamic scattering mode. When the electric field is applied, the director aligns with the field and the shutter becomes transparent. Dyes can be added to the LC material to provide absorption, much like the guest-host mode. The best application seems to be electric shutters for architectural designs and automobile windows.

Notes

[1] Multiplexability describes the number of rows in a row-column matrix array of pixels that can be commutated for refresh during one refresh cycle. The columns are typically addressed in parallel and the rows in series for what is often called "line-at-a-time" or "row-at-a-time" addressing. The somewhat linear response of LC material restricts matrix addressability, which was once thought to be limited to 1:16. ("1:16" means that 16 rows can be addressed in one refresh cycle with specified contrast and viewing angle.) New LC materials have increased the multiplexability of the TN mode to as high as 1:128, but with marginal performance. Adding internal transistors at each pixel makes the display so nonlinear that factors other than LC material linearity (such as line resistance and speed of response) become the limits of display array size.

Matrix addressing itself reduces the number of external drivers to the sum of the number of rows plus the number of columns, as opposed to the product of the number of rows and columns, which is required in direct addressing.

[2] "Active matrix" refers to the addition of transistors or diodes at each pixel to electronically block the cross coupling that occurs when an array of pixels is matrix addressed by multiplexing the row lines. ■

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Automotive LCDs

BY DAVID A. ROSS

ELECTRONIC DISPLAYS have emerged in automobiles only within the past decade. Despite a temporary loss of momentum, their future is promising. The technical characteristics of liquid-crystal displays (LCDs), in particular, should enable them to command a steadily increasing share of the electronic portion of the automotive display market.

The driver's need to know

The need to convey information to an automobile's driver through instrumentation was apparent even in the early years of automotive development. In Chevrolet's first year of production, 1912, its Classic Six model featured no less than two gauges and two odometers. All of these were, of course, mechanical.

During the following decades the number of readouts increased, and they became segregated into what are now called primary and secondary displays. Primary displays are placed directly in front of the driver and present essential information: vehicle speed, engine parameters, and critical warnings. Secondary displays convey information of lesser importance, such as that relating to heating and air conditioning, the radio, and redundant or less important vehicle-parameter readouts. Secondary displays have typically been located in the dash near the car's midline between the driver and front-seat passenger.

As time went on, the increasing number of mechanical readouts were supplemented by electrical ones, such as resistive fuel-level gauges, but the first electronic display did not appear until the 1978 Cadillac Seville. This vehicle featured three digital displays for the fuel gauge, speedometer, and trip computer, using gas-plasma technology (which was changed to vacuum-fluorescent technology soon after the vehicle was introduced).

Liquid crystals were first utilized for a primary display in the 1984 Chevrolet Corvette. Three separate twisted-nematic LCDs were used for the speedometer, driver information center, and tachometer. Corvette designers based their selection on the LC's design flexibility and color capability as well as its consistency with the high-tech theme of the newly redesigned Corvette.

More recent milestones in the short history of electronic automotive displays are the red-green-blue CRT in the 1985 Toyota Soarer (optionally available in Japan) and the first production use of a monochromatic CRT in the 1986 Buick Riviera. The Toyota's CRT was placed directly in front of the driver. The Riviera's was, and is, a combined secondary display incorporating touch-screen controls. [See *ID*, January 1987.] Like the Corvette, the Riviera was a newly redesigned vehicle, and the unusual instrumentation helped create a unique image for it.

But despite these well-known innovations and the scattering of American and Japanese models that utilize electronic displays as either standard or optional equipment, purely mechanical instruments—those with pointer-and-dial readouts driven by flexible mechanical shafts—still make up 50% of the primary instrument clusters integrated into cars sold in the North American market. Electromechanical instruments—pointer-and-dial readouts driven by electronic signals generated by transducers—constitute a further 32%, leaving only 14% of the market to be divided among all the purely electronic technologies. Of these, a significant majority are vacuum fluorescent. Liquid crystal is next, followed by a small number of CRT and LED displays. Most of the electronic displays have been used as primary instrumentation—the readout has been placed directly in front of the driver.

Singing in the rain

The current status of automotive LCDs is dramatically punctuated by two facts: (1) consumers consistently express a preference for pointer-and-dial instruments over digital readouts; and (2) the current high value of the Japanese yen against the American dollar makes LCDs, most of which are manufactured in Japan, *more* expensive for North American automobile assemblers than the mechanical instruments now being used. Why, then, are automakers and display manufacturers both highly optimistic about the future of LCDs?

One reason is that North American automakers, including the makers of cars with Asian and European nameplates that

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Photo: David A. Ross

Fig. 1: The transition from discrete to integrated information display in automobiles, as in this prototype navigation display, is expected to accelerate the move to electronic displays.

are assembled on the North American continent, are striving to differentiate between models and to increase the feature content of vehicles. The stylists, who are primarily responsible for the differentiation task and who must create instrumentation that is coordinated with their automobile's image, want full-color capability, no size limitation, no limitation of display pattern, and the freedom of a reconfigurable display.

Another set of requirements is directed toward providing needed information to the driver in an easily understandable and cost-effective manner, while maintaining high reliability. These requirements shape the engineering side of the instrumentation. The engineer wants high quality, high reliability (a lifetime of 10 years or 100,000 miles), low cost, low generation of radio-frequency interference, high resistance to electromagnetic interference, flexible packaging, a straightforward electrical interface, and low-voltage and low-power requirements.

Above and beyond these two sets of requirements are the environmental constraints. To function fully in an automobile, instruments must operate from −40°C to +85°C, have high shock and vibration resistance, and survive high humidity and sunloads.

Aggressive research and development on the part of key display manufacturers had succeeded in meeting essential performance and quality targets and had attained parity in price with mechanical displays prior to the collapse of the dollar against the yen. Industry optimism is based in part on the success of LCDs in meeting these key demands and the conviction that the price penalty is temporary. Increased volume and improved technology should reduce prices considerably even at the current exchange rate. At the same time, Japanese manufacturers are moving production to lower-cost manufacturing sites elsewhere in Asia.

Position stacks the deck

Three additional factors convert the optimism about electronic displays to a conviction among most people in the industry that their ascendency is inevitable.

In the past, the information displayed in automobiles has been segmented: speed, fuel level, engine parameters, time. Increasingly in the future, information will consist of integrated and derived parameters presented in graphic form, as in navigation and fault diagnosis [Fig. 1].

The problem of limited dashboard "real estate" for displays and controls is already a problem in today's vehicles. With more information to be displayed, reconfigurable displays will become all but a necessity, except in the simplest vehicles.

Pointer-and-dial instruments work well for primary information. With their graphics capability and reconfigurability, electronic displays are particularly desirable for secondary displays. The trend, even in fairly basic automobiles, toward a growing ratio of secondary to primary display functions also favors the growth of electronics.

Innovative locations for displays are under serious consideration at all major manufacturers. Head-up displays, displays in the steering-wheel hub, in the rear-view mirror, and in the headliner, as well as the now common placement in the dash and console, will frequently place a premium on thin packages, light weight, and low power.

Integration, reconfigurability, the increase in secondary display functions, and innovative instrument placement favor electronic displays generally and LCDs in particular. This is not to say that LCDs are likely to be the favored technology in all applications—many different display technologies will continue to grow and survive. But the capabilities of LCDs when compared to the automotive environment, engineer's goals, and stylist's goals indicate a good "fit."

New LCDs to come

The ongoing improvements in LC fluids, polarizers, and production processes have increased contrast ratio; reduced response time; and reduced the temperature dependence of optical parameters in existing automotive LCDs; and continued improvement is likely. But LCD technologies that are relatively new promise to make LCDs even more attractive in automotive instrument clusters.

Presently, automotive LCDs are of the passive (twisted-nematic) type. Active-matrix LCDs using thin-film transistors (TFTs) are a major advance in LCD technology that offers automotive stylists the possibility of full color and total reconfigurability, while offering engineers the contrast ratio and viewing angle of a statically driven LCD. This combination of characteristics is made possible by depositing a TFT at each pixel location with processes similar to those used in traditional semiconductor fabrication.[1]

The transistors are driven at a high multiplex rate, but each liquid-crystal pixel is driven by the TFT as a static element.[2,3]

Several Japanese manufacturers are developing "large" (more than 3-in.-diagonal) TFT displays for consumer applications. Hitachi, for example, is working on a 6.3-in. TFT module [see Table 1]. The major stumbling block in developing these displays for automotive application is the limited operating temperature range. Major efforts are being made to expand the range to the required −40°C to +85°C, as well as to offer larger-sized TFT displays.

Another interesting approach, which can be used with both active-matrix and passive twisted-nematic displays, is chip-on-glass technology. Here, the integrated-circuit die containing LC drivers is bonded directly to the glass display panel using flip-chip technology. A specialized metallic film circuit line is used on the glass to ensure both good reliability and repairability [Fig. 2]. Hot-gas heating reflows the solder without damaging the LC fluid or subjecting the glass to excessive thermal shock [Fig. 3]. This technology greatly reduces the number of connections between the LCD and the printed circuit board for greater system reliability. The additional glass required to mount the IC is minimal (13 mm maximum), producing a system package that can be much smaller.

Multicolor LCDs using internal color technology satisfy one of the stylists' major requirements. One approach is to construct the traditional seven-segment digit from alternating, finely spaced red, green, and blue lines. By activating the appropriate lines, the color of a segment can be changed. Previously, this was possible only in multilayer LCDs. Changing a segment's color can be used, for example, to warn the driver of high coolant temperature or low fuel level.

Finally, a technique that is already being used on a limited basis is analog simulation—an LCD patterned to mimic a pointer and dial [Fig. 4]. This may, at first, seem ridiculous, but the LCD can present more information than a true analog gauge in the same amount of space. Stylists can achieve the analog look while offering the driver a multigauge option in one display, scale expansion or reduction, flashing warning information, and color changes. It also takes care of the consumer preference for analog instruments.

Stalled in cars, LCDs keep on truckin'

Sales of LCD instruments in North American passenger cars have yet to take off, but at least one small mobile market is healthy and growing.

Kenworth and Peterbilt trucks offer an LCD instrument option at $1300 over the price of a bare-bones mechanical instrument cluster. The added expense is more than most buyers are willing to ante up. But, in 1987, more than 5000 Kenworths and Peterbilts were sold with the LCD cluster installed. Glenn Barone, product manager for LCDs at AEG Corporation in Somerville, New Jersey, expects that number to rise to well over 10,000 in 1989. AEG makes the LCD subassemblies that the U.S. Gauge Division of Amatek, Inc., integrates into the complete instrument clusters they sell to Kenworth and Peterbilt.

Kim Misenar, product manager for Kenworth, told *Information Display* that about 8% of Kenworth trucks were delivered with electronic instrument clusters in 1987, and that he anticipates that number to grow to between 10 and 15% by the end of 1988. As diesel engines with increased electronic controls enter the market—and they are being actively promoted by the three major engine manufacturers, Detroit Diesel, Cummins, and Caterpillar—Misenar expects the use of electronic instrumentation to increase even more.

Ron Harris, vice president for sales and marketing at U.S. Gauge, believes that only Kenworth and Peterbilt among North American heavy-truck manufacturers are currently offering electronic instrument clusters, but electronics are under consideration at most major manufacturers. Although the LCD clusters have proved their reliability in the Kenworth and Peterbilt applications, other manufacturers are considering a variety of electronic technologies, Harris said.

The display subassembly AEG makes for U.S. Gauge uses statically driven twisted-nematic liquid crystals backed with a *transflector*. A backlight added by U.S. Gauge is continually on when the vehicle is operating. In low ambient light the display works in a backlit transmissive mode, with the backlight shining through the semitransparent transflector. In a bright ambient, light passes through the activated segments, reflects off the transflector, and returns through the display to deliver a typical 18:1 contrast ratio.

AEG uses chip-on-glass mounting of its drivers for reliability and convenient interfacing, claiming a median expected lifetime of 100,000 h. Each driver operates 40 display segments and requires one 8-pin connection. Unlike Hitachi [see main article], which uses flip-chip technology for its chip-on-glass prototype displays, AEG uses tape-automated bonding. AEG's announced operating temperature range is from −40°C to 85°C. The minimum operating temperature can be extended to −54°C with an optional integrated heater.

The meaning of "operating" temperature requires some discussion. The panel survives these very low temperatures and functions after a fashion. But LC switching time at −35°C is approximately 2 sec, while AEG's LC cell-drive frequency is between 32 and 100 Hz. The incandescent backlight raises the panel temperature fairly quickly, though. And in any case, how many drivers would operate their vehicles for extended periods at subfreezing temperatures without turning on the cab heater?

—K. I. W.

Table 1: Hitachi 6.3-in. Color TFT Module

Pixels	200 × 3 (V) × 640 (H)
Effective display size	96 mm (V) × 128 mm (H)
Pixel pitch	160 μm (V) × 200 μm (H)
Module dimensions	175 mm (V) × 195 mm (H) × 16 mm (Thick)
Operating temperature range	0°C to 50°C

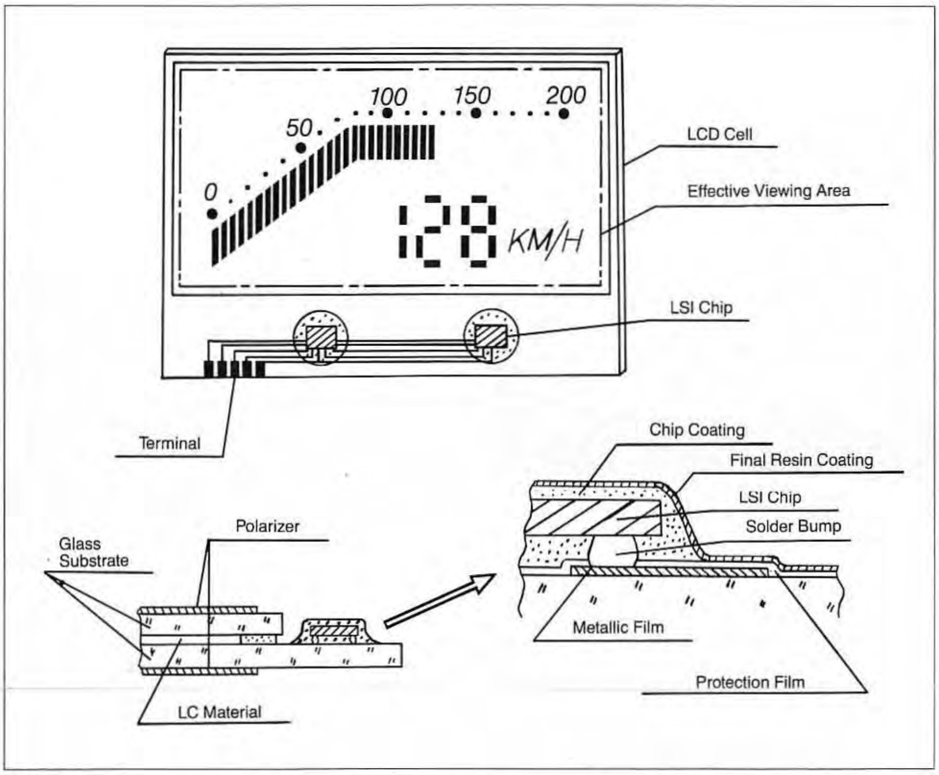


Fig. 2: The structure of Hitachi's prototype chip-on-glass LCD.

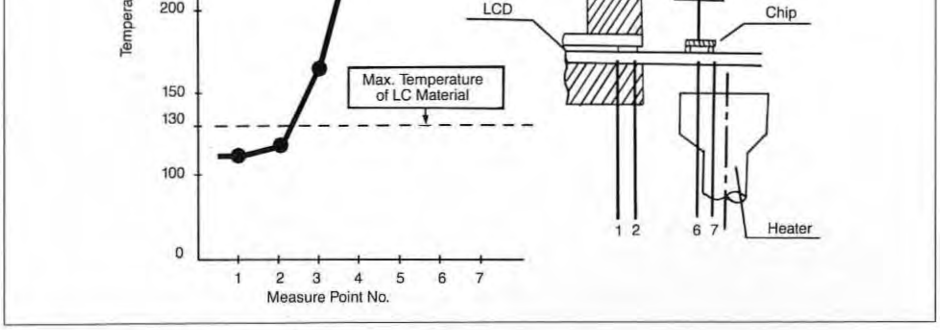


Fig. 3: Temperature distribution in hot-gas heating.

Used separately or in combination, these four technologies make LCDs extremely attractive to automotive engineers and stylists.

Coexisting technologies

The next 5–10 years will see the phasing out of mechanical instruments and the coexistence of electromechanical and electronic instrumentation in automobiles. Beyond 10 years, automotive instrumentation will be principally electronic. LCDs in general, and TFT-LCDs in particular, will almost certainly be a dominant technology, but not the only one. Display approaches will be sufficiently broad, and the inclinations of engineers and stylists sufficiently varied, so that the strengths of the different display technologies are all likely to be attractive in particular cases. But TFT-LCDs especially seem capable of offering the features important to auto designers: low cost, the ability to provide product differentiation, and high reliability.

Cost will be a determining factor in the future of all display technologies. Costs will not fall as quickly as they should unless display suppliers and automakers cooperate. Suppliers need to bring down manufacturing costs, improve performance, and provide more features. Automakers need to take a total system view of automotive electronics to control cost and improve efficiency overall.

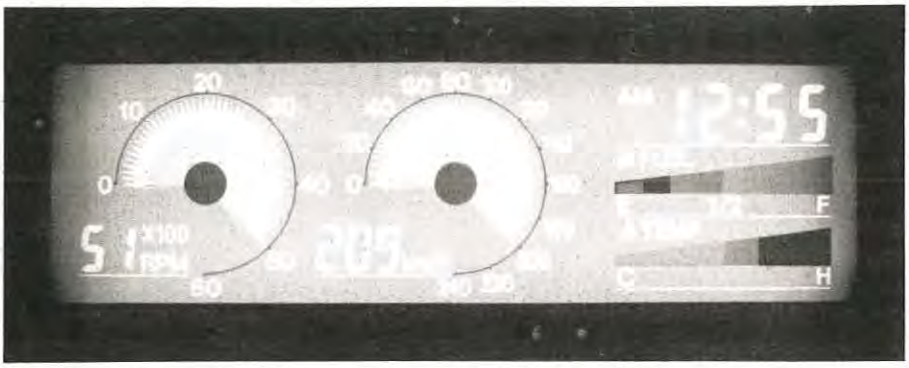


Fig. 4: *A simulated analog display combines many benefits of the liquid-crystal and pointer-and-dial technologies.*

Notes

[1] A good illustration with a caption giving a brief but clear description of the deposition process for TFTs made of amorphous silicon appears in "Amorphous Silicon: From Promise to Practice" by Arun Madan, *IEEE Spectrum*, September 1986—the illustration and caption are on page 43.

[2] For a survey of active-matrix LCDs, see Larry Tannas' article in this issue.

[3] Arthur Firester concisely described the operation of active matrices in LCDs and the performance requirements for TFTs in "Active-Matrix Addressing for TFT-LCDs," *ID*, November 1987. ■

Conference report: Eurodisplay '87

BY LAURIE S. ALLARD

THE THIRD Eurodisplay conference was held in London, September 15–17, 1987. It was the first to be held in the United Kingdom, the previous conferences having been in Germany (1976) and France (1981).[1] Of the 350 attendees, 80% came from 12 European countries including Poland, Hungary, and East Germany. The non-European contingent was divided equally between Japan and the United States. It was a surprise to some that the Americans came fourth in the list of presenters, with Japan second. Presenters from the United Kingdom were the most numerous.

A keynote triad

The keynote address was given by conference chairman Cyril Hilsum of GEC, who looked back over the addresses he had given to earlier display conferences. In 1976 the display industry was in the doldrums, but by 1981 the market had reached $1 billion. There was large production in the United States and Japan, and an obvious need for European cooperation in developing production capability. In 1987, Japan is increasing its command of the industry, but the marketplace is still not enthusiastic over LCD production in the United Kingdom. The remaining problems can be solved, given adequate time and money.

While the future for LCDs did not look promising at one point, the devices now seem to have a very good possible demand. By 1995 the display could well become the complete instrument—much as solid-state circuits evolved from individual circuits to VLSI in the 1960–1985 period. A flat display panel could have all the circuits mounted to it so that the panel would be the complete instrument.

Projecting an image

In opening the conference, W. M. van Alphen of Philips Research Laboratories, The Netherlands, spoke about the "Implications for HDTV Displays," a display application that is bound to be with us during the next 10 years, but whose problems are not yet well defined. At present, the short-to-medium-term prospect is to use a direct-view shadow-mask tube, succeeded by a projection CRT, which would be succeeded, in turn, by a projection set with a color LCD. Ironically, the paper given at the end of the conference by J-N. Perbet of Thomson-CSF entitled "Projection Displays: CRT versus LCD" discussed the use of an LCD when high brightness and high resolution are required. Both van Alphen and Perbet concluded that although projection CRTs will be used at first, projection LCDs will replace them.

The remaining part of the morning session on emissive displays dealt with electroluminescent (EL) devices. Christopher N. King and his colleagues at Planar Systems described the design and fabrication of a 320 × 320 full-color display using a patterned phosphor and improved electronics for full addressability. The authors commented that the 6-in.-diagonal picture size usually associated with EL devices is governed mainly by the size of the vacuum equipment designed for the requirements of conventional solid-state circuit manufacturers!

Other papers in this session, by Japanese and French authors, dealt with 640 × 400 green-light-emitting TFEL displays and with higher efficiency SrS:Ce blue-green ACTFEL displays incorporating rf sputtering and electron-beam evaporation techniques at lower substrate temperatures.

Liquid crystals flow

The afternoon sessions included some of the many papers on LCD devices. In fact, if one can draw any general conclusion about the state of display development from the conference, it is that work on LCD devices is flowing reliably at many research and production facilities throughout the world.

W. A. Crossland of STC Technology outlined the work of his team and other collaborators on the prospects and problems of ferroelectric LCDs. The main conclusions were that the devices are likely to be used mainly for information display rather than TV and that very high resolution can be obtained.

__Laurie Allard__ graduated from London University in 1943 and spent his working life on cathode-ray devices at GEC, first at the Research Laboratories and finally at Hammersmith. In 1980 he retired early and has spent the intervening time developing other interests, including scientific, educational, social, and church work—not forgetting family life and the garden. He has been a member of SID for many years and is a founding member of the SID U.K. & Ireland Chapter committee, on which he still serves.

Hearing a well-prepared and gracefully presented paper is one of the joys of attending conferences. Such a paper was B. M. Nicholas' description of work done at the GEC Hirst Research Centre at Wembly on thick bistable ferroelectric LCDs. The technique described results in very uniform alignment of the liquid crystal with none of the zig-zag defects that degrade the performance of conventional surface-stabilized devices.

During the talk no reference was made to the material used in the device, which caused the session chairman, Mino Green, to inquire for details of the material. Whether by accident or by design, much was said in the reply, but nothing that told the chairman what he wanted to know. This induced the chairman to comment that he wished he hadn't asked the question in the first place! It is a pity that Mino was not present at the last morning of the conference. He might have been encouraged to hear the several papers by different British authors treating the design of liquid-crystal materials having various properties particularly suited for display purposes.

A detailed overview of the worldwide progress in active-matrix-addressing LCDs—another well-presented paper—was given by P. Migliorato of the GEC Hirst Research Centre at Wembley. It would appear that displays up to 12 cm could be incorporated into specialized avionics and military equipment during the next five years, followed by large-scale production of active-matrix displays up to 25 cm.

7½ pounds (sterling)

In the same session on active-matrix displays, a paper entitled "Active-Matrix-Addressed LC Television Using a-Si Thin-Film Transistors" was presented on behalf of what almost appeared to be the entire staff of the Philips Research Laboratories! They found that a key issue in these displays is the photoconductivity of the transistor, which leads to non-uniformity and flicker of the display. Other sources of flicker can be eliminated completely by a line-inversion drive scheme in which the video signal is inverted every line as well as every field. The success of the work described was amply demonstrated during the subsequent author interview session with an operating TV display system. This paper was awarded the £100 (£7.70 per author!) prize presented by the SID U.K. & Ireland Chapter for the best oral paper at the conference.

Cold cathodes warmed over

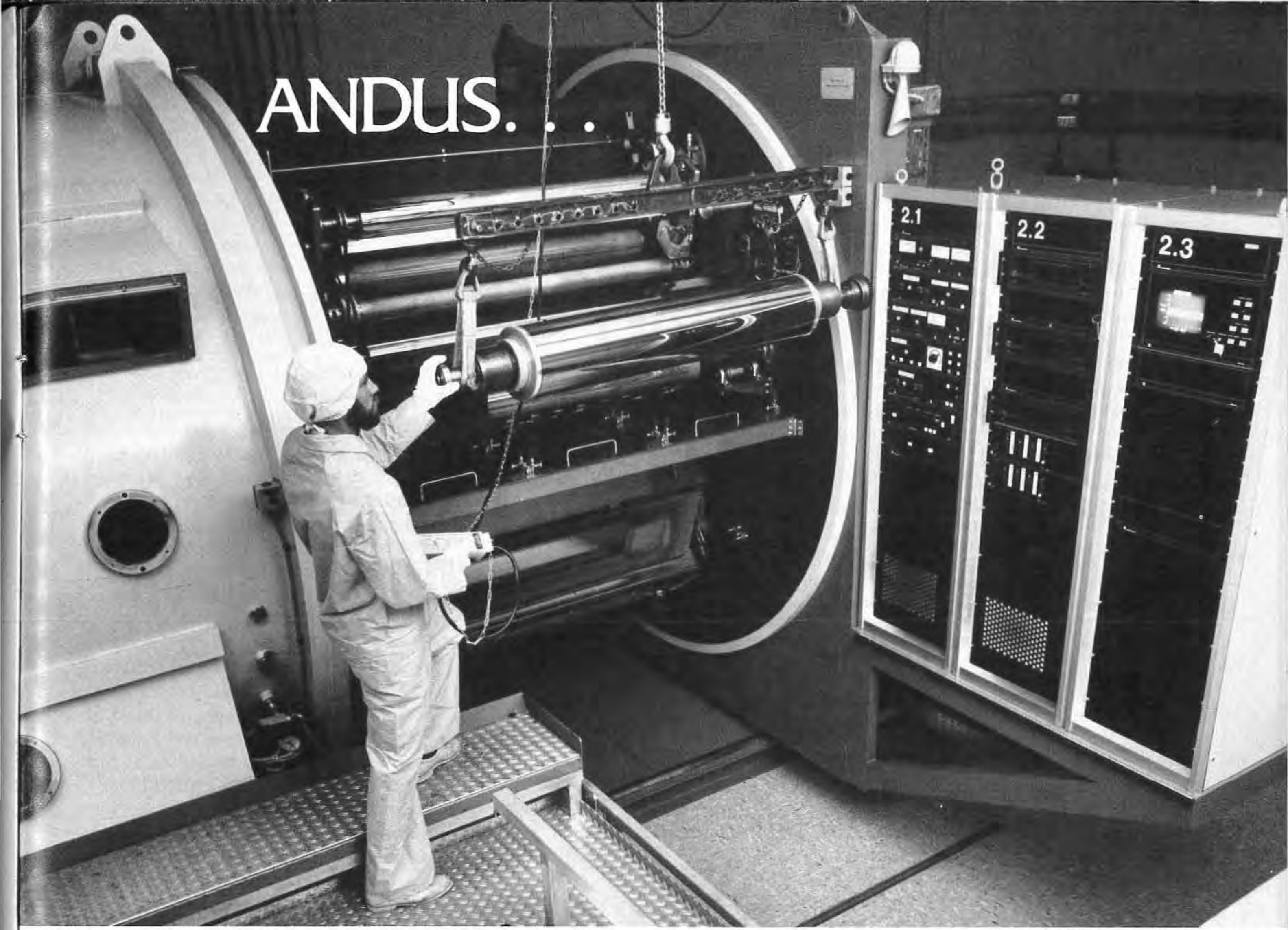
The lead paper in the first session on display devices provided an example of old ideas arising in fresh forms that can have an impact on the marketplace. The particular item for discussion is the cold-cathode vacuum-fluorescent display described by a team from SRI International. The team was led by Ivor Brodie, a British expatriate who had undertaken field-emission work originally at the GEC Hirst Research Centre at Wembley under R. O. Jenkins in the late 1950s. The current work succeeds where earlier efforts failed because C. A. Spindt, one of the current authors, has developed microfabrication techniques similar to those used in the manufacture of integrated circuits and has applied them to the fabrication of arrays of extremely small field-emission devices. These devices are well suited for matrix-addressed cathodoluminescent displays because they can operate with signals in the 50–150 V range, thereby ensuring that any ions formed in the device will have insufficient energy to sputter-erode the tip. This is the key to a long-life device, and color displays using color-stripe technology can easily be fabricated. Much work is still needed, but microfabrication may resurrect field emission as a viable device technology.

Bright, flat, and colorful

One of the four invited speakers was M. Watanabe of the Matsushita Research Laboratories, who spoke on thin CRTs. He presented an overview of the work on all such displays, including the Matsushita matrix drive and deflection system (MDS) that was described at the 1985 SID Symposium and has since been life tested for 10,000 h. The author stated that full-color thin CRTs of high resolution, high brightness, and good color quality were ready to leave the development laboratory and become practical devices. He predicted early availability, though initially, screen sizes will be small.

Color displays using 300-mm channel multipliers were described by J. R. Mansell and his colleagues from Philips Research Laboratories. These are the result of considerable work over the years on flat-faced channel multiplier CRTs.

A 4-in. flat CRT was described by S. I. Kishimoto et al. from the Sanyo Electric



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Co. This tube, unlike the one from Philips, has the electron gun at the side of the screen rather than behind. The authors stated that the beam-index system used solves registration problems, and the absence of a shadow mask results in high beam efficiency.

More liquid crystals

The last three papers on liquid-crystal materials, which were presented in a second session on the conference's final day, thoroughly reviewed the materials research and development being carried out in the United Kingdom. It was apparent that this work has progressed satisfactorily as a result of considerable cooperation between physicists and chemists.

The final paper of the active-matrix session, expertly presented by F. Morin, described an active-matrix-display image projector developed at the Centre National d'Etudes des Telecommunications. Mr. Morin was so confident of this work's success that he used the apparatus to display the pictorial information his lecture required. The entire paper was so well received that the conference sponsors named it one of the best-presented papers—and awarded the authors with an extra £50 prize that was warmly acclaimed by those present.

The last session of the conference treated various aspects of display systems. The invited paper was given by G. M. Murch of Tektronix and dealt with the important aspects of human factors in displays. Much work has been done, and continues to be done, on such aspects as resolution, luminance and illuminance, contrast, flicker, glare, and polarity. The success of this work can only lead to better display systems in the future.

J-N. Perbet of Thomson-CSF gave the conference's final paper, "Projection Displays: CRT versus LCD." This reviewed the overall requirements for various projection systems, together with the possibilities and limitations of the two competing techniques. The CRT projection system is available now and can be used for medium-performance TV displays and for graphic displays. However, when high definition and high brightness are required, LCD light valves are better because these two parameters are independent in the LCD technology. LCD light-valve projection should be suitable for a large range of applications in the not-too-distant future.

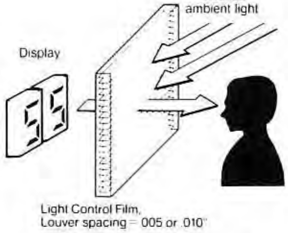
Post it

The organizers arranged poster and author sessions during the course of the conference, which enabled more papers to be presented and gave attendees the opportunity to discuss various points of detail with the authors. A wide range of display activities was covered in these poster-session papers, and the organizers had established a prize of £100 for the best of them. After extensive deliberation, the prize was presented to Messrs. McArdle, Clark, and Haws from the GEC Hirst Research Centre at Wembley for their paper "Information Storage and Erasure Processes in Liquid-Crystal Polymer Films." The authors believe that LCPs have a future in the erasable analog storage and display market.

One's concluding thoughts on a most successful conference are that the delegates attending the event should handle with great care their copies of the conference proceedings—there was a serious shortage. Perhaps they will become collector's items, like the American postage stamps with inverted centers so favored by the CIA.

Notes

[1] The third Eurodisplay was also the seventh International Display Research Conference, part of a series of annual conferences sponsored by SID that rotates among the United States, Japan, and Europe. The U.S. conferences are cosponsored by the IEEE. The next one will take place October 4–6, 1988, at the Hyatt Islandia in San Diego, California.■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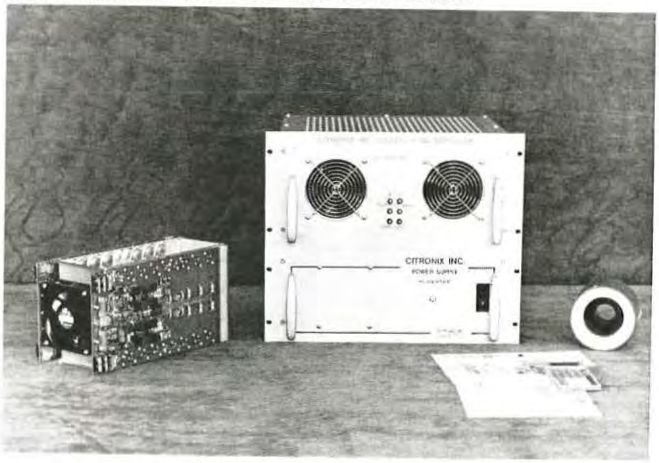
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patents

Compiled by Howard L. Funk
IBM Corp.

U.S. Pat. No. 4,688,899; Issued 8/25/87
Dual-Frequency Dielectric-Anisotropy Liquid-Crystal Display
Inventors: KENZO ENDO, KOH FUJIMURA
Assigned to: CASIO COMPUTER CO., LTD.

A liquid-crystal apparatus having first and second liquid-crystal substrates opposing each other is described. Segment electrodes are formed on the inner surface of the first substrate. Common electrodes are formed on the inner surface of the second substrate. Seal members seal a liquid-crystal composition in a predetermined region between the segment and common electrodes. Light shutters are formed by these electrodes-and the liquid-crystal composition is sealed in between. In order to reduce the influence of a hysteresis effect in the liquid-crystal composition when a high-frequency electric field is applied, the liquid-crystal composition has a dielectric scattering phenomenon in which its dielectric anisotropy in response to a low-frequency electric field is larger than the absolute value of its dielectric anisotropy in response to a high-frequency electric field.

U.S. Pat. No. 4,694,348; Issued 9/15/87
Method of Driving Liquid-Crystal Display Panel of TV Receiver
Inventors: KIYOSHI KAMIYA, ATSUSHI SHIRAISHI, FUMINORI SUZUKI
Assigned to: CITIZEN WATCH CO., LTD.

A method of driving an LCD panel of a TV receiver is described whereby of each set of six scanning lines consisting of three successive lines of one field and three corresponding lines of the succeeding field, three lines are displayed by display elements driven by one scanning electrode and the remaining three lines by display elements driven by an immediately adjacent scanning electrode. One of the three lines to be displayed by the action of each electrode may be omitted. An increase in display resolution of approximately 4/3 is attained, by comparison with a simple prior art drive method.

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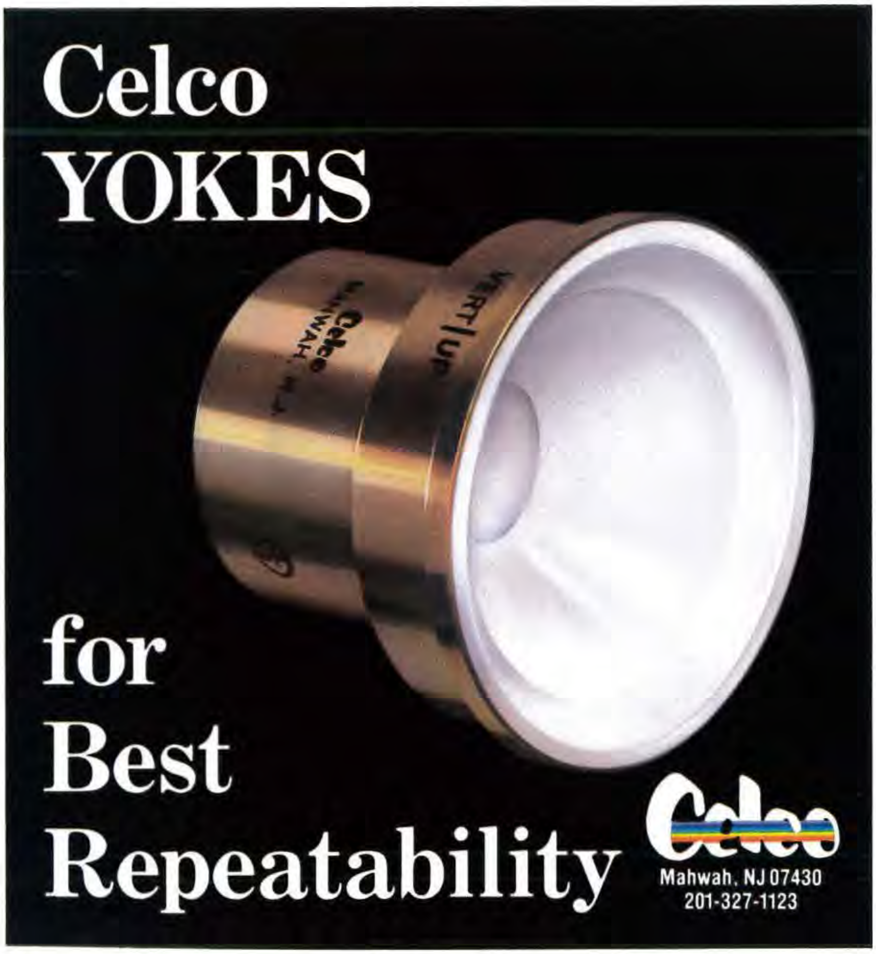
U.S. Pat. No. 4,694,356; Issued 9/15/87
Modification of Color Component Video Signals to Compensate for Decreasing White Sensitivity of Photographic Element
Inventor: DOUGLAS W. CONSTABLE
Assigned to: EASTMAN KODAK CO.

A color video printer for producing a color photographic copy from a color video signal is described. A self-processing color photographic element is exposed to a sequence of six color field images constituting a full frame of a color video image. The printer includes a monochrome CRT and a rotatable color filter having red (R), green (G) and blue (B) filters which are sequentially moved into an optical path between the CRT and the photographic element positioned at an exposure station. A video signal circuit provides a color video signal including concurrent R, G, and B component signals which are modified with additional gain in the near-white region to compensate for the drop-off in white sensitivity of the photographic element in this region. A gate is selectively actuated to apply one of the white-compensated color component signals to the CRT to effect exposure of the photographic element. Adjustable controls are provided to adjust the relative amount of R, G, and B signal contributing to the photographic exposure.

U.S. Pat. No. 4,694,347; Issued 9/15/87
Television Receiver Having a Liquid-Crystal Display Device
Inventor: KATSU ITO
Assigned to: CITIZEN WATCH CO., LTD.

A television receiver is described having a receiving circuit for producing audio and video signals, an LCD panel, and a driving circuit responsive to the video signals for driving the LCD panel. The receiving and driving circuits include elements provided on a SOS substrate. ■



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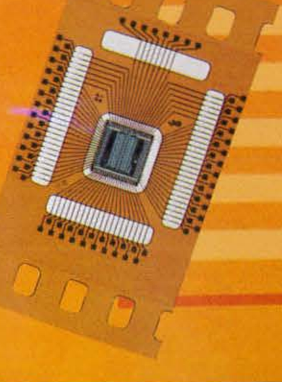

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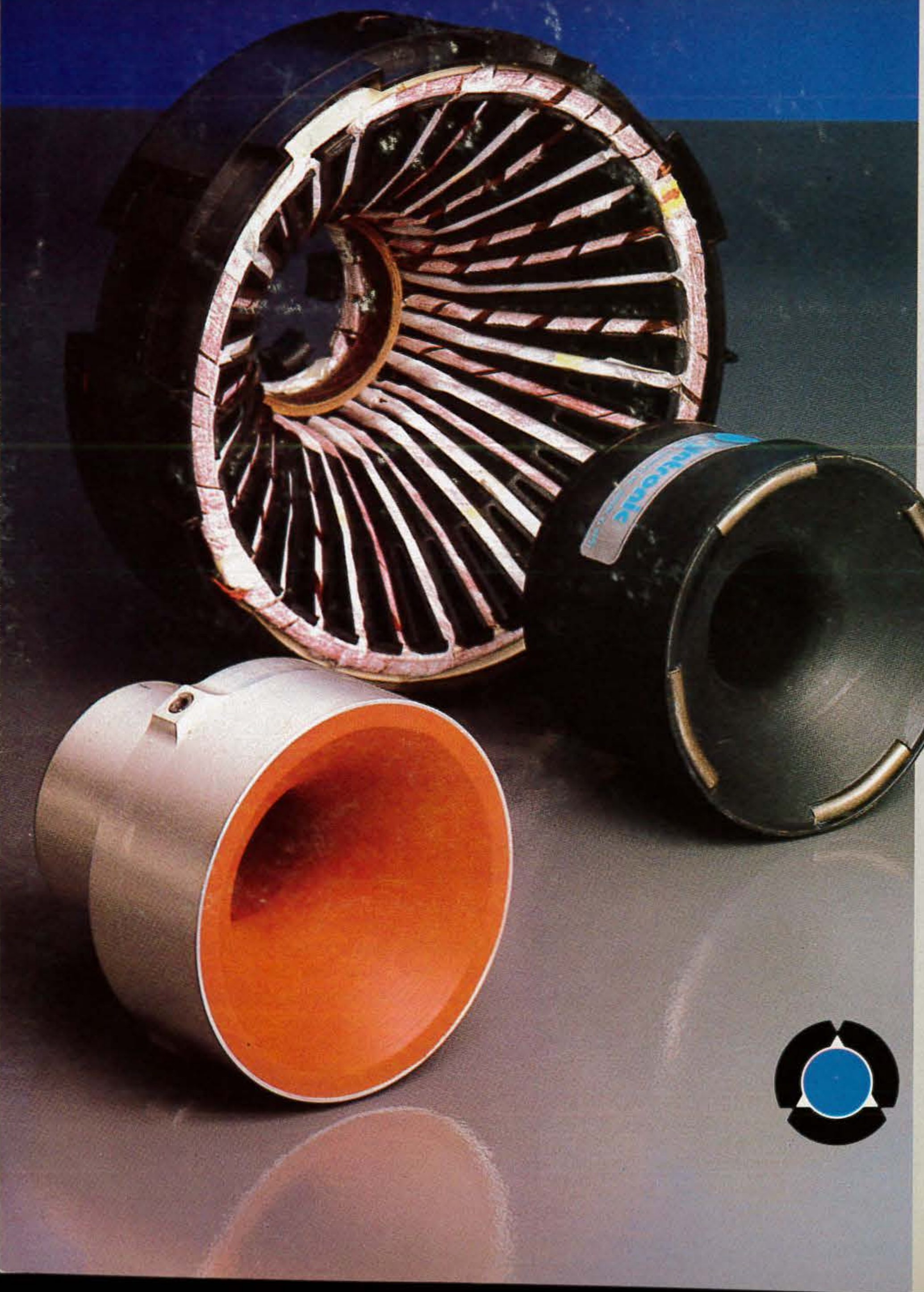

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