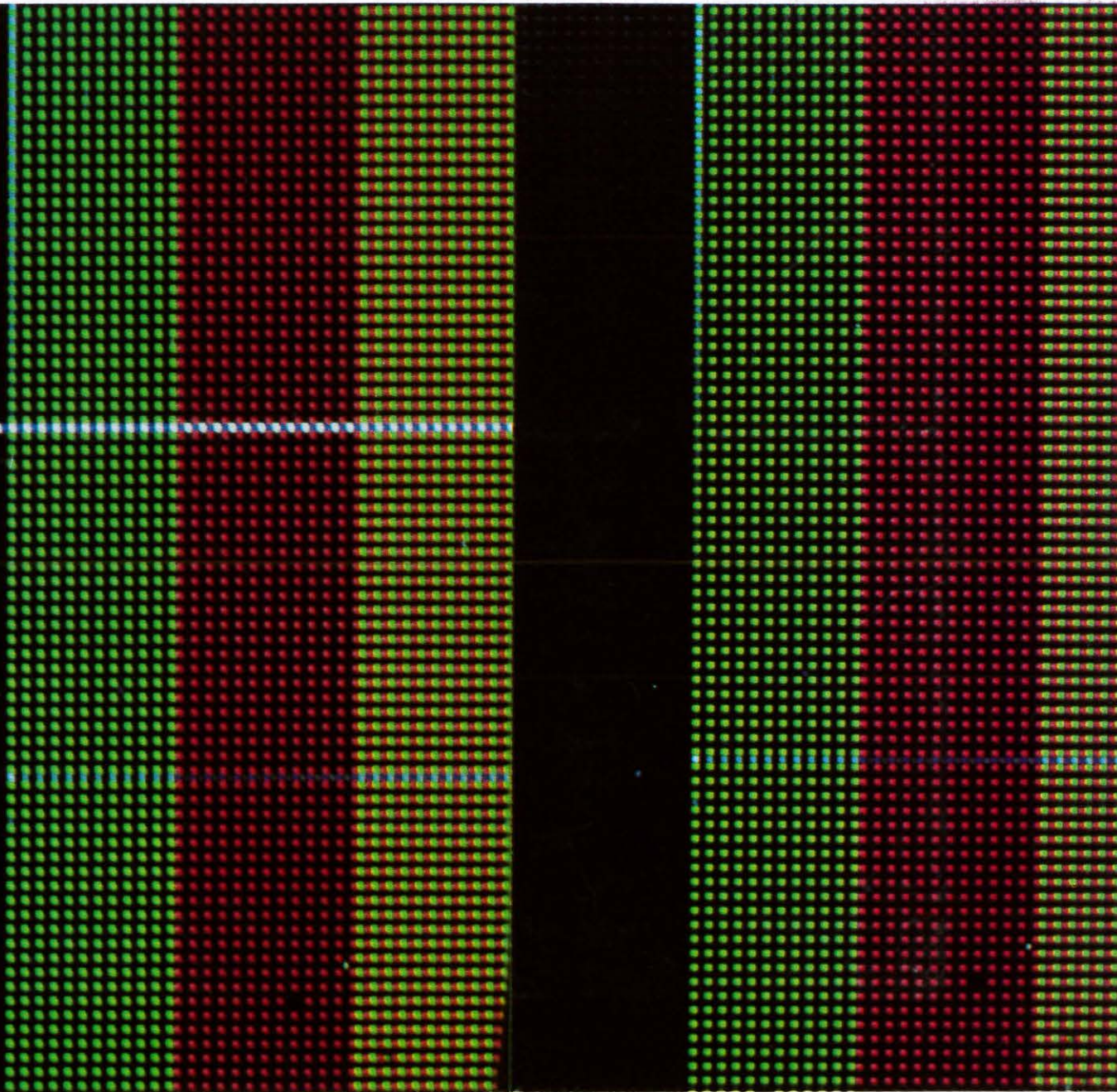


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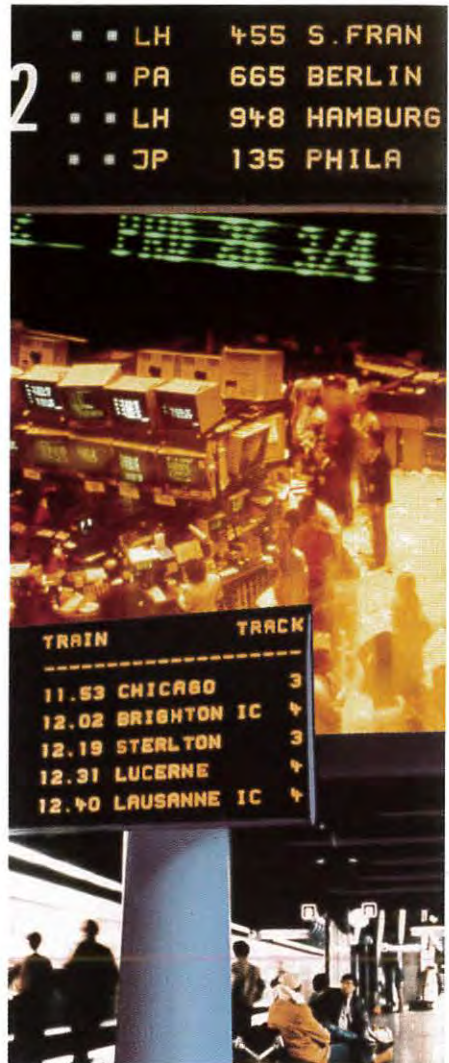
INFORMATION DISPLAY

September 1988
Vol. 4, No. 9



Industry directory
Laser repair of LCDs
Ruggedized color CRTs

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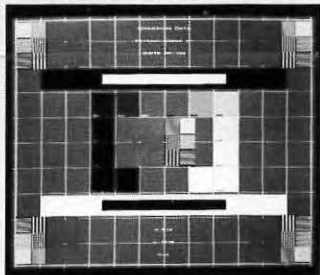
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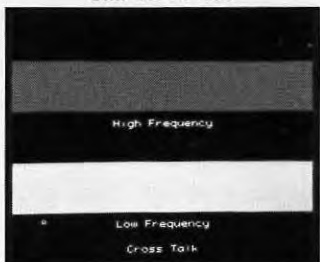
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INFORMATION DISPLAY

SEPTEMBER 1988
VOL. 4, NO. 9

*Cover: A 192 × 192 pixel
color liquid-crystal display
before and after repair
with a xenon laser.*

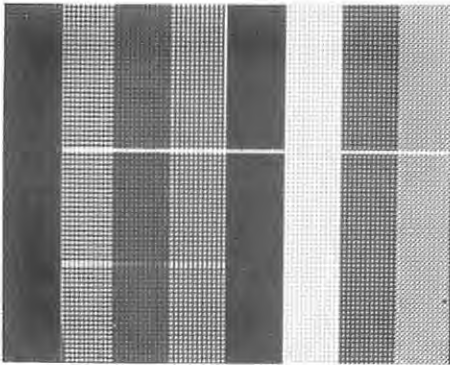


Photo: David Sarnoff Research Center

Next Month in Information Display

Color Hard Copy Issue

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can you get there from here?
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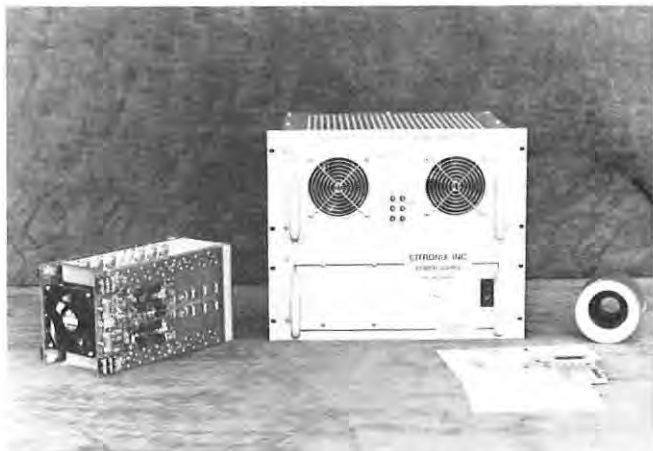
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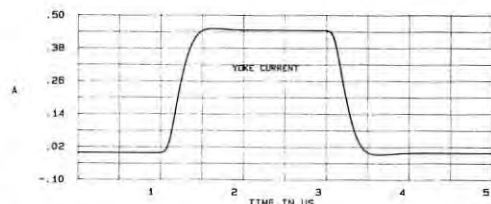
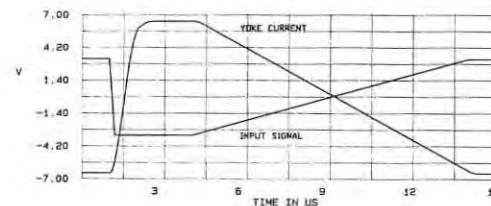
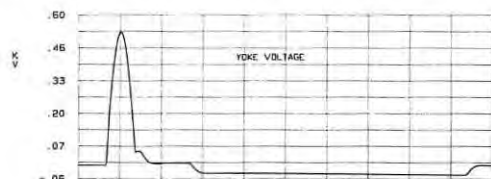


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editorial



Everything you ever wanted to know?

Herein you will find *Information Display's* bigger and better Second Annual Directory of the Display Industry. It's bigger because virtually everyone who was a part of last year's premier edition quickly submitted their information forms for this year's version, and many additional companies have joined them. It's better because we listened to you. We have eliminated categories you told us weren't helpful. We've added categories you told us

you wanted. We've changed many categories to make looking up the information you need quicker and more natural. And we've provided cross-references to ease your way to what you are looking for, even if you don't think in exactly the same way we do.

Our departments editor Lynne Henderson and our managing editor Hildegard Hammond have put in long hours and late nights, and have held open this issue of *ID* much later than is usual so late entries could be included, thus making the Directory as complete as possible.

Does all this mean that the Directory contains *everything* you ever wanted to know about the display industry? We doubt it. It contains a lot, and we think you will find it an invaluable resource over the next 12 months, but the works of man are not perfect. Even so, those works can be very good and they can be made even better. You can help us do that. Please tell us what you find particularly helpful and useful about the Directory. More important, please tell us what you'd like to see there that isn't, and how we can make it easier to use. All suggestions will be carefully considered, and implemented next year if at all possible.

While Lynne and Hildegard have been occupied (obsessed?) with the Directory, none of us has forgotten that technical content is one thing most of our readers expect from *ID*. Our cover story, by Lee Branst and Floyd Pothoven, is a selective look at the history and practice of repairing with lasers faults in complex liquid-crystal displays.

Then, André Martin discusses the engineering of fully ruggedized color displays for industrial and military applications, and what can happen when system integrators try to cut corners. Finally, we present our second software review, this one of a package for symbolically solving algebraic equations. Our reviewer Richard Lee also comments on a book that does what the program's documentation doesn't.

—Kenneth I. Werner

Laser repair of liquid-crystal displays

BY LEE BRANST AND FLOYD POTHOVEN

HIGH-INFORMATION-CONTENT liquid-crystal displays (LCDs) for color television and avionic applications can contain as many as 1,000,000 pixels. Each of those pixels represents an opportunity for something to go wrong in the manufacturing process. When faults do occur with structures this complex and expensive, everything possible is done to save them. Currently, the use of lasers to repair active-matrix thin-film-transistor LCDs is attracting substantial interest.

Most faults that affect the actual display of an LCD are either pixel or row/column defects. In a large high-resolution display, isolated point (pixel) defects can be nearly invisible and are therefore often tolerable. On the other hand, row/column defects are rarely acceptable. An entire line that is nonfunctional is esthetically displeasing and may be downright dangerous if it causes the loss of critical information or delays quick reading of the display.

The defects themselves can generally be classified as either opens or shorts. Shorts between display lines, for example, are often caused when excess material is laid down during the deposition process. Such defects are most easily repaired with a pulse of laser light that vaporizes (or "zaps") the excess material, restoring the

Lee Branst is president of Caracal Communications, Redondo Beach, California. He was previously senior editor of Lasers and Optronics magazine. Floyd Pothoven is vice president of Florod Corporation, Gardena, California, which manufactures laser-based turnkey systems for microelectronics applications.

display line's operation.

The repair of opens is not as simple since lasers, by their very nature, are more useful for removing material than for depositing it. Laser-enhanced chemical-vapor-deposition (CVD) systems are being developed, but we do not know of any now being used in a commercial manufacturing setting.

The best available solution, then, has been redundancy. Many large high-resolution displays include redundant display lines in both the vertical and horizontal directions. Some even incorporate transistor redundancy for each pixel [Fig. 1].

T. Peter Brody of Active Matrix Associates, Pittsburgh, Pennsylvania, has been a pioneer in the development of thin-film transistors (TFTs) for active-matrix addressing systems. He estimates that there are upwards of 70 firms involved in the development and manufacturing of active-

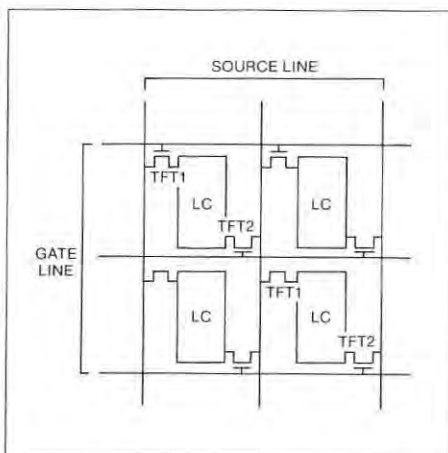


Fig. 1: A typical LCD pixel with redundant TFTs.

matrix LCDs, over half of them in Japan.

Some of these companies make relatively simple LCDs that are more sensibly scrapped than repaired when defects appear. For makers of more complex devices, however, laser repair is the only way to obtain acceptable manufacturing yields.

That laser-repair and redundancy techniques are widely used was demonstrated at the Society for Information Display's 1988 International Symposium (SID '88) held last May in Anaheim, California. In the three different sessions on active-matrix LCDs, at least half a dozen speakers referred to the topic of laser repair. This is significant because laser-repair techniques for LCDs, like other processing methods, are often not patentable. Most manufacturers would therefore be reluctant to discuss the matter in public unless the technology were already widespread.

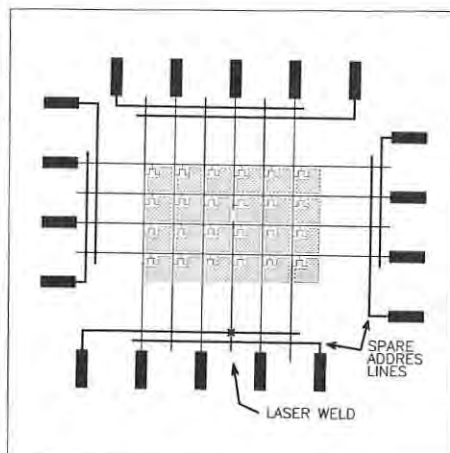


Fig. 2: Schematic of open line repair with spare address lines and laser welds.

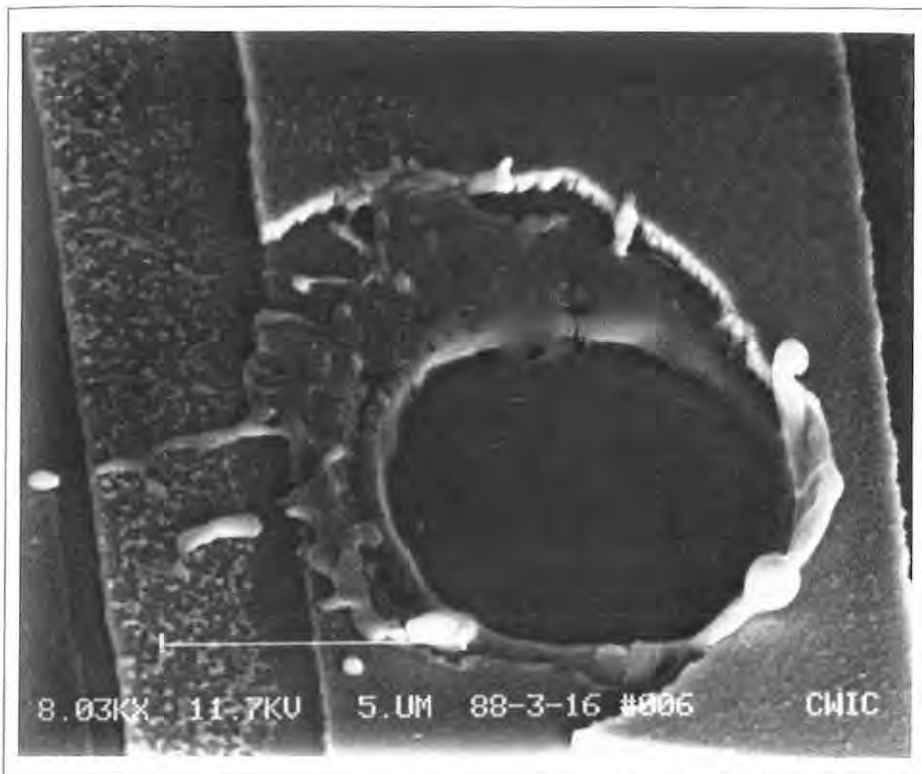


Photo: General Electric Corp., Schenectady, New York

Fig. 3: SEM photograph of a laser weld connecting a spare address line to an array address line.

Laser repair—a selective history

So where did the idea of laser repair originate? While most of those contacted for this article claim to have come upon the laser-repair process independently, there are a few whose work clearly predates the rest.

Since Brody's group was the first to pursue research and development of active matrices utilizing TFTs on an ongoing basis, it is not surprising that it was also the first to employ laser repair.¹

In commenting on this work, Brody told the authors, "In our work at Westinghouse, we demonstrated both active-matrix LCDs and active-matrix electroluminescent (EL) displays in the early 1970s. In both cases we used YAG lasers principally to repair shorted crossovers of buses and to remove debris between adjoining contact fingers. Since we used stencil masks in those days to define busbars, we did not have any problem with shorts between adjoining buses. To the best of my recollections, we introduced the laser-repair technique around 1977, when we obtained a major government manufacturing methods contract on active-matrix EL displays."

Brody said that Westinghouse got the idea to repair shorts with a laser from the then familiar work of repairing opaque defects on masks. In both cases the repair process involved zapping a deposition error on glass.

After Westinghouse gave up on active-matrix displays in 1979, Brody started Panelvision (now Litton Panelvision) in 1980. He said that in late 1981 or early 1982, the company purchased a Florod YAG laser-repair station, which incorporated a motorized X-Y stage.

"A computer-controlled test rig was used to interrogate the active-matrix circuit," said Brody. "This test gave the X and Y coordinates of a crossover short. If the number of such shorts fell below a cutoff number, the circuit was transferred to the repair station. The coordinates of each short were dialed up by the operator, who could visually see the defect through the microscope and more accurately locate it in the laser beam focus. The operator then triggered a laser burst of controlled energy that was sufficient to remove the short without damaging the rest of the metal busbars.

"This repair procedure was done even before the circuit was fully completed,

thus culling rejects at the earliest possible stage. After repair the circuit was completed, tested for TFT performance and, if accepted, passed on for LC processing. We did make some experiments on laser repair of completed displays (i.e., after LC filling and sealing) but, because of our concern about what the vaporized debris would do to LC resistivity and consequent leakage, this process was not installed into our production line at Panelvision during my time there from 1980 to 1985."

As far as the authors of this article are aware, Brody's group was the first to use lasers to repair LCDs. A similar story is told by Don Castleberry of General Electric in Schenectady, New York. "We were in the photomask repair business. This is probably where the idea of removing shorts came from. We were certainly aware of the use of lasers in that field. It was an obvious way to remove excess material. The first time I tried this was in 1982 or 1983."

General Electric's repair procedure for LCDs includes a novel way of handling opens, as Castleberry described it at SID '88:

"Open lines that are due to processing defects or deliberate cutting in the shorts repair process are repairable using spare address lines. These are extra lines along each edge of the display that cross over the ends of array address lines and are connected to their own connector pads. The array address lines are normally only connected to connector pads on alternating sides of the display. If a line is open, the open end segment can be connected to a spare address line by welding through the repair line crossover with the laser [Fig. 2]. The repair line is driven either by (1) connecting the spare lines to their own set of drivers or (2) connecting the driven end of a repaired line to a spare line and connecting the spare lines on opposite sides of the display together.

"The welding process consists of simply zapping a small spot in the repair line crossover. This removes both metal layers and the SiN_x/a-Si [silicon nitride and amorphous silicon layers] from the center of the spot and redeposits the gate metal on the walls of the hole [Fig. 3]. This technique produces very reliable and low-resistance connections.

"A gate-drain short in a TFT which affects both address lines can be changed to a one-pixel defect by disconnecting the gate of the TFT from the gate bus line with the laser. Shorts at the crossover can



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be repaired by cutting either address line at both sides of the crossover. This results in an open, which is repaired as described above.^{1,2}

These are not the only two methods of laser repair. On the contrary, there are probably as many different laser repair schemes as there are different LCDs.

All zaps are not equal

One of the major differences in the repair processes described by Brody and Castleberry is the kind of laser they used for the repair process. Brody used a solid-state Nd:YAG laser for his early work at Westinghouse and Panelvision. Castleberry at GE and the researchers at The David Sar-

noff Research Center who made the display illustrated on the cover used a gas-discharge xenon laser.

Technological evolution was a major determinant of these choices. The YAG laser is a well-known laser made by many manufacturers (including Florod) and has been used for many years in industrial applications. The xenon laser also is well established, but is made by just a handful of companies. Of these, only Florod has fully developed the xenon laser's attributes for microelectronic applications.

In an informal survey of LCD makers at SID '88, most who used YAG lasers were switching to xenon units when they needed new repair systems. Their reasons related both to the properties of the laser itself and the abilities of the enabling laser systems.

The xenon laser emits a combination of wavelengths ranging from 480 to 540 nm—in the center of the visible spectrum. The standard YAG emits at 1064 nm—well into the infrared region. Thus, the corresponding spot size is about twice as large unless additional frequency-doubling or beam-narrowing optics are included.

Another important reason for choosing the xenon laser relates to repair after assembly. As Brody reported above, most manufacturers would rather test and repair the structure after the active-matrix circuit is constructed but before the LCD "sandwich" is completed. The great majority of repairs can be accomplished at this time.

However, there are occasions when a fault does not show up until after the LCD is produced. In this case a repair may be effected by shooting the laser directly through the glass, the transparent conductors on the glass, and the LC material. This process often creates a bubble in the LC from the heat of the laser. However, the bubble created by the xenon laser nearly always dissipates, leaving a fully functioning LCD.

Most manufacturers report that using a YAG laser in this situation is a more uncertain proposition. Often the YAG leaves a permanent bubble in the LC material, a condition that may show up as a visible defect.

Xenon lasers are also generally capable of removing thinner layers of material than YAG lasers. For example, Florod's MEL-30 xenon laser, supplied with a programmable square aperture, can remove material from a roughly cubic volume measuring as little as $2 \times 2 \mu\text{m}$ on the surface and less than $1.5 \mu\text{m}$ deep. Be-

cause of their higher peak power, longer wavelength, and beam-shaping optics, YAG lasers generally produce a crater-like central pit that penetrates much deeper into substrates, possibly creating sub-level damage. The square aperture also produces a rectangular laser spot that is compatible with the rectangular pixel geometry common to LCD arrays and, therefore, allows material removal adjacent to straight edges. It is difficult to get a clean beam profile through an aperture with the YAG because of the complex optics required.

Besides the actual hole generated by the laser pulse, there is also a surrounding heat-affected zone, or "blast area," that is caused by the laser pulse. For a pulse in a square spot of $2 \times 2 \mu\text{m}$, the xenon laser generates a heat-affected zone only $10 \mu\text{m}$ across. The YAG laser generates a heat-affected zone some two to three times larger in diameter. Because the debris from the blast area contains metallic particles, larger blast areas are more likely to cause unintended shorts in the circuit.

YAG and xenon laser systems are not the only contenders. A European laser systems manufacturer is trying to apply its argon laser system to LCD repair. While the argon laser can ablate metal, it is of the continuous variety—not pulsed like xenon and YAG. The LCD manufacturers we surveyed felt this would make the system difficult to use in real-world situations.

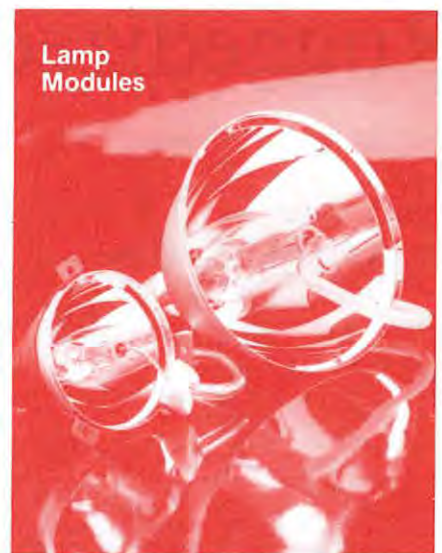
The future of laser repair

Most manufacturers would naturally prefer to avoid the necessity for laser repair of LCDs. Some Japanese manufacturers of simple LCDs for consumer products claim their tightly controlled manufacturing processes do, in fact, achieve yield rates in excess of 90% without resorting to repair.

Nevertheless, color capability and higher pixel counts are adding ever increasing layers of complexity to modern LCDs. For these advanced displays, the attempt to manufacture perfect devices is increasingly difficult.

Attempts are under way to produce more fault-tolerant displays. At SID '88, both NTT of Japan and GEC of the U.K. described redundancy schemes that automatically activate the spare circuit line when there is an open on the primary line. However, even with these systems, shorts remain a problem that require repair by laser or some other means.

Despite these advances in manufacturing methods and fault tolerance, it will



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be some time before we outgrow the need for laser repair of LCDs.

Notes

¹Peter Brody's fascinating personal account of the beginnings of thin-film transistor development at Westinghouse and

elsewhere appears as "The Thin-Film Transistor—A Late Flowering Bloom," *IEEE Transactions on Electron Devices*, Vol. ED-31, No. 11 (Nov. 1984).

²D. E. Castleberry and G. E. Possin, "A 1 Mega-Pixel Color a-Si TFT Liquid-Crystal Display," *SID Digest*, Vol. 19 (1988), pp. 232-234. ■

Ruggedized color CRT assemblies

BY ANDRÉ MARTIN

JUST AS COLOR cathode-ray tube (CRT) displays are in increasing demand for commercial applications, so are they sought for industrial and military (I&M) applications where high resolution, color stability with time, tolerance of temperature extremes, and resistance to shock and vibration are essential. But progress in ruggedizing an evacuated glass bulb containing precisely located suspended elements has not been easy, and has come only with extensive research and development.

The monochrome model

Monochrome CRTs have been used in ruggedized industrial and military displays for many years. The best ruggedization is obtained by fully encapsulating the CRT within a magnetic shield, with its deflection coil, focus coil, and other drive elements potted in silicon resins [Fig. 1]. Encapsulated tubes of this type, which are called assemblies, have passed qualification at shock levels of over 120 g and at vibration levels of 12 g rms from 10 to 2,000 Hz. Such assemblies routinely survive temperature cycling from -65°C to $+95^{\circ}\text{C}$ and altitude tests up to 55,000 ft.

Pursuing rugged color

The first attempts to design rugged color displays were based on the color penetration tube. Such tubes vary the depth to which the electron beam penetrates a suc-

cession of phosphor layers deposited on the inside of the CRT's face by changing the accelerating voltage. Because each phosphor layer produces a different color, different accelerating voltages produce different colors. The mechanical structure of beam-penetration color CRTs is identical to that of monochrome CRTs, and assemblies made from these tubes have the same basic construction and ruggedness as monochrome CRT assemblies.

The penetration CRT requires a sequential presentation of color images and a high-voltage switch. It is not compatible with television standards, so it has been limited to vector-scanning displays or to displays using sequential raster modes. Within these limitations, the penetration tube has been widely employed to present high-resolution images in four to six colors.

Expanding the limits

When a larger number of colors and a raster display are required, the penetration color tube cannot be used and other approaches are needed. One of these is the beam-index tube. This tube uses a striped RGB color screen and a single electron beam. Additional "indexing phosphor stripes" produce light that is scattered back into the tube. Detecting this light permits the electron beam's position on the phosphor screen to be located precisely, and the single beam can be used to excite all three color phosphors sequentially. The beam-index tube inherently possesses the same sturdy structure as the monochrome CRT and can be mounted in comparable assemblies. However, the necessarily fast video switching between color stripes and the fast stripe-

position detection require high electronic bandwidth, and this generally limits the beam-index approach to tubes not exceeding a few inches on the diagonal. But these tubes are experiencing continuing development, and we are likely to see more application of beam-index tube assemblies in larger sizes.

The price of size

For the time being, the only CRT over 10-in. in diagonal capable of displaying raster images and resolving over 1,000 TV lines with a full range of color is the shadow-mask tube, well known for its commercial television applications.

The typical commercial shadow-mask color tube [Fig. 2] comprises within its envelope:

- *A thin perforated mask* of mild steel, which is generally suspended from the envelope at three points.
- *A precision in-line electron gun* that produces three independent electron beams in the same plane.
- *A phosphor screen* composed of RGB stripes or trios of RGB dots.
- *An internal magnetic shield* for isolating the electron trajectories from the earth's magnetic field while the electrons are in the driftspace between the deflection coil and the shadow mask.
- *A deflection coil*, precisely aligned on the tube neck and glued to the tube's flared section.
- *Convergence magnets* placed on the tube neck behind the deflection coil.
- *An antenna getter* that maintains the vacuum in the tube at the desired level.

The tube and deflection coil are made so each of the three electron beams corre-

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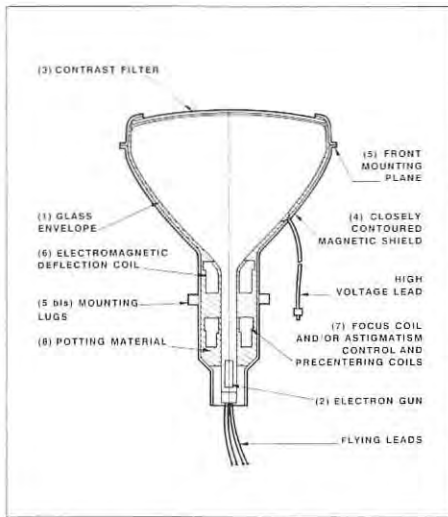


Fig. 1: A typical ruggedized mono-chrome CRT assembly consists of a CRT with its glass envelope (1) and electron gun (2). A contrast filter, usually with coatings to reduce reflections and suppress electromagnetic interference, is laminated to the CRT faceplate (3). A closely contoured magnetic shield (4) provides a front plane (5) and lugs (5 bis) for securely mounting the assembly. An electromagnetic deflection coil (6), focus coils, astigmatism control, and precentering coils (7) are between the tube neck and the magnetic shield. A potting material (8), usually consisting of a silicon resin, fills all voids between the various elements of the assembly. This material has enough elasticity and resiliency to protect against thermal stresses, vibration, and shock.

sponds to only one color—either red, green, or blue. But each beam is broad enough by the time it reaches the screen to illuminate several trios of phosphor dots or stripes, so the desired color is obtained by shadowing the unwanted phosphors from the beam by a mask—the shadow mask. With this method of color selection, the shadow mask, electron gun, deflection coil, and convergence magnets must be mounted with extreme accuracy in the high-precision glass envelope. Any relative movement of these components beyond specified tolerances, whether due to mechanical stresses or thermal expansion, will cause a loss of color purity. For a 19-in.-diagonal high-resolution color tube having a screen pitch of 0.31 mm, these tolerances are on the order of a few thousandths of an inch.

Magnetic protection

Shadow-mask tube and deflection-coil designs for providing proper electron-beam

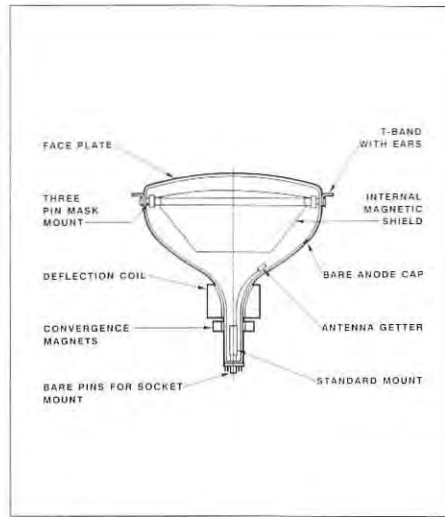


Fig. 2: Structure of a typical commercial shadow-mask color tube.

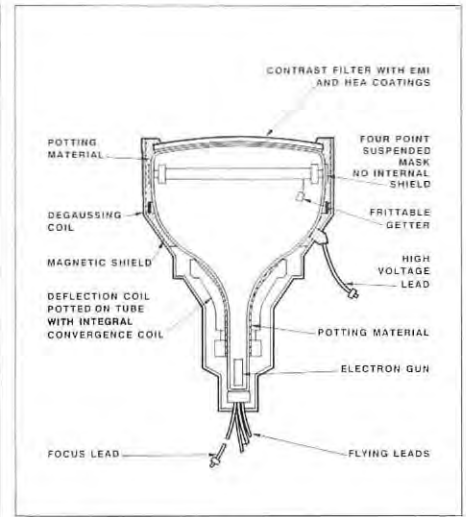


Fig. 3: Structure of a typical, fully shielded, ruggedized shadow-mask tube.



Fig. 4: A typical 19-in. ruggedized color shadow-mask tube assembly.

Photo: Michel Mathieu

trajectories normally incorporate the influence of the earth's magnetic field for tube operation in landscape mode—that is, when the tube face's largest dimension is horizontal. Any other orientation of the tube relative to the earth's magnetic field requires proper magnetic shielding.

In addition to this ever-present earth field, stray magnetic fields may exist near the display. A shield surrounding the whole tube provides good protection.

Ruggedizing shadow-mask tube assemblies

Fortunately, there are solutions to the technical difficulties of designing shadow-mask tube assemblies for the requirements

posed by demanding environments [Table 1].

To meet these specifications, the suspended weight of the mask and the internal magnetic shield must be reduced, and the attachment of the mask to its frame and of the frame to the envelope must be reinforced. Together, these modifications reduce the movement of the mask and shield during shock and vibration by increasing the mask's resonant frequency and reducing the transmissibility of the mask assembly. Usually, a four-point symmetrical suspension is adopted for the mask, and the internal magnetic shield is removed to reduce the suspended weight [Fig. 3].



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The antenna getter of a commercial tube moves during severe vibration and shock, which scratches the tube bulb's interior coatings. This produces particles that induce arcing and breakdown. The antenna getter also interferes with the deflection field for frequencies above 32 kHz, causing convergence errors. For I&M tubes, the antenna getter is therefore replaced with a frittable getter placed on the mask frame.

The electron gun can be ruggedized by using stiffer springs for locating the electron gun in the tube neck, and by repositioning the stem-to-gun connections so arcing between electrodes does not occur during vibration. Additional potting of the anode and stem leads helps prevent arcing during exposure to altitude or humidity.

Potting the package

Commercial tubes are attached to their monitors by means of "ears." For ruggedized applications, mounting points are provided on the external shield—the same technique successfully employed for years in monochrome assemblies.

The tube is encapsulated in the shield by means of a suitable potting material, usually a silicone resin or foam. The resin, disposition, and thickness of the potting material are adapted to each tube, deflection coil, and shield combination to obtain the dampening required for the shock and vibration levels specified. The dampening must be particularly effective at the shadow mask's self-resonant frequency, where loss of color purity appears at only a few g of acceleration.

When it's too darn hot

These potting techniques prevent glass breakage from temperature cycling over a 100°C range, but temperature is also of concern in relation to convergence errors—differences in the landing locations on the tube screen of the three electron beams.

All commercial tubes use convergence adjustment by means of permanent magnets, which produce magnetic fields that vary by about 20% over a temperature change of 100°C. Magnets with improved temperature stability have been developed for avionic color assemblies. They can maintain acceptable convergence over 100°C temperature cycles in small tubes but are not stable enough for large-screen CRTs with deflection angles of 90°.

Another approach is the use of convergence coils driven by temperature-compensated dc power supplies. This elegant

solution not only provides temperature-independent convergence, but also permits the use of other dynamic convergence signals to improve picture quality.

Adding mass and volume—but not too much

A shadow-mask tube assembly is generally used as a retrofit for a monochrome display, so it has to be installed in the same volume. Room must be provided within the monitor case for the heavier power supplies and additional printed-circuit boards required by a color display. Because of the high mechanical precision required, the thickness of a shadow-mask tube bulb is much greater than that of an equivalent monochrome bulb, which means additional weight, and even more weight results from the internally suspended mask. The internal magnetic shield of commercial tubes is usually removed to reduce the suspended weight and must be replaced by an external shield that covers the tube [Fig. 4].

Table 1: Typical Requirements for Industrial and Military Displays

Vibration	6-13 g rms from 10 to 2,000 Hz
Shock	30-120 g for 6 to 20 msec
Temperature	
Operating	-55°C to +75°C
Nonoperating	-65°C to +90°C

Closely contouring the shield to the tube and the deflection coil keeps the overall weight and volume down. But a closely contoured shield interferes with the deflection field generated by the standard toroidal or saddle-toroidal deflection coil employed on commercial television tubes, making it impossible to obtain good color purity and convergence. If such a coil were used, the shield would have to clear the deflection coil by approximately 2 in.

A better solution is the saddle-saddle shielded coil, which uses a long trumpet-like ferrite. This coil confines the deflection field to a small volume and permits the magnetic shield to be as close as 0.25 in. from the coil. Another benefit of the confined deflection field is improved coil deflection sensitivity.¹

A color shadow-mask CRT assembly using a saddle-saddle coil and a typical 0.040-in.-thick magnetic shield is fully protected against magnetic fields up to 1 Oe (80 amp-turns/m). Above that, additional protection is required.

A tense development

Flat tension shadow-mask (FTSM) tubes have been developed by Tektronix for military applications and by Zenith for the commercial sector.^{2,3} The mask is attached around its entire periphery to the tube faceplate or envelope, nearly eliminating suspended weight. Resistance of the tube to shock and vibration is comparable to that of a monochrome CRT, except for vibration near the taut mask's resonant frequency. Special mask damping can be provided for this frequency, or the potting in the shield can be designed to damp the vibration.

These FTSM tubes are now available in sizes ranging from 7 to 15 in. in diagonal. Their structure permits the design of very rugged assemblies, particularly when associated with saddle-saddle deflection coils.

You get what you pay for

There has been, in some segments of the market for industrial and military monitors, a lack of appreciation for how much specialized engineering and how many low-volume custom components go into a fully ruggedized I&M monitor. When the \$50,000 cost typical of such monitors is compared with the \$5,000 typical for enhanced commercial monitors, some managers have been tempted to use the apparently low-cost approach in mobile applications. The result can be a painful and costly development cycle culminating in a late switch to fully ruggedized monitors, or a failure of the system to pass qualification.

Notes

¹J. M. Perreaut, A. Dumesnil, R. Pieri, "Shielded Yoke for a High-Resolution Color CRT," *SID Digest*, Vol. 19 (1988), pp. 129-131.

²L. Dietch, K. Palac, W. Chiodi, "Performance of High Resolution Flat Tension Mask Colors CRTs," *SID Digest*, Vol. 17 (1986), pp. 322-323.

³R. Robinder, D. J. Bates, P. J. Green, G. D. Lewen, and D. R. Rath, "A High Brightness Shadow Mask Color CRT for Cockpit Displays," *SID Digest*, Vol. 14 (1983), pp. 72-73. ■

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ELECTROMECHANICAL DISPLAYS

□ Advanced Computer Sys. □ AMETEK Aerospace Prods. □ Astronautics □ Ca-

nadian Marconi □ Densitron □ El-Op Electro Optics □ GEC Avionics □ Honeywell Defense Avionics □ IEE □ Interface Prods. □ Lucas Duralith □ NEI Ferranti-Packard Elec. □ Regisbrook □ Rockwell Int.

ELECTROCHROMIC DISPLAYS

□ Astronautics □ Comfuture □ Mito Fine Glass

ELECTROLUMINESCENT DISPLAYS

□ Acculex □ Astronautics □ Bonar Kard-O-Lite □ Canadian Marconi □ Carroll Touch □ Cherry Display Prods. □ Cherry Elec. Prods. □ Comfuture □ Computing Devices □ Craft Data □ Data General □ Densitron □ Digital Elec. □ Eaton □ Emerald Computers □ Epson America □ Finlux □ GTE □ Hoffman Engineering □ Hycom □ IEC □ IEE □ Infodex □ Interface Prods. □ Interstate Elec. □ Korry Elec. □ Levy Hill Labs □ Lohja, Finlux Display Elec. □ Lucas Duralith □ Mito Fine Glass □ National Res. Resources □ NEC Elec. □ Norden Sys. □ Phosphor Prods. □ Photonics Sys. □ Planar Sys. □ SAI Tech. □ David Sarnoff Res. Ctr. □ Scriptel □ Sharp Elec. □ Sigmatron Nova □ Texas Instruments □ Thin Film Device □ Thomson-CSF/C-SD □ UCE Liquid Crystal Displays

ELECTRON GUNS

□ Burle Indus. □ Chunghwa Picture Tubes □ General Atronics □ Ginsbury Elec. □ Hitachi □ Richardson Elec. □ David Sarnoff Res. Ctr. □ Sony □ Device Group □ Southwest Vacuum Devices □ Video Display □ Zenith Components □ Zenith Elec.

EYE AND HEAD MOVEMENT TRACKERS

□ El-Op Electro Optics □ GEC Avionics □ ISCAN □ Personics

FACSIMILE ("FAX") MACHINES

□ Canon □ Citizen-CBM America □ Data Copy □ IBM □ Pacific Basin Distributing □ Relisys □ Unlimited Sys.

FIBER-OPTIC FACEPLATES

□ Corning Glass Works □ Galileo Electro-Optics □ Incom □ Interface Prods. □ Scriptel □ Teltron □ Thomson-CSF/DTE

FILTERS

□ Babcock Display Prods. □ Bates Mfg. □ Brewer Science □ Robert Busch □ Canadian Marconi □ Chomerics □ Craft Data □ Dainippon Ink & Chemicals □ Dotech □ El-Op Electro Optics □ Ginsbury Elec. □ Hoya Elec. □ Hoya Optics □ Interface Prods. □ Int. Polarizer □ K&R Engineering Sales □ Kensington Microwave □ Kollmorgen □ ElectroMagnetics □ Liberty Mirror □ Lucas Duralith □ Metavac □ Mito Fine Glass □ Norden Sys. □ O&S Res. □ OCLI □ Optical & Conductive Coatings □ Optical Devices □ Panelgraphic □ Pulseview □ Raytheon □ Regisbrook □ Rockwell Int. □ David Sarnoff Res. Ctr. □ Southwall Tech. □ Sun-Flex □ Thin Film Device □ 3M Indus. Optics □ Viratec Thin Films

FLAT-PANEL DISPLAYS

See individual listings for backlights, electro-mechanical displays, electrochromic displays, electroluminescent displays, large-screen displays, liquid-crystal displays, plasma displays, projection displays, touch interactive displays, vacuum fluorescent displays

FLAT-PANEL MATERIALS

See individual listings for masks, filters, glass, liquid-crystal materials, magnetic shielding, optical coatings, polarizers

FOCUS COILS

□ CELCO □ DISCOM □ Penn-Tran □ Syntronic Instruments

GETTERS

□ Burle Indus. □ SAES Getters

GLASS FOR CRTS

□ Corning Glass Works □ Displays □ Hoya Elec. □ Mito Fine Glass □ OCLI □ OI-NEG TV Prods. □ Panelgraphic □ Precision Electronic Glass □ Schott America □ Viratec Thin Films

GLASS FOR FLAT-PANEL DISPLAYS

□ Alphasil □ Applied Films Lab □ Babcock Display Prods. □ Cherry Display Prods. □ Civ-Chem Engineering □ Corning Glass Works □ Hoya Elec. □ Hoya Optics □ Liberty Mirror □ Micro Fusion □ National Res. Resources □ Norden □ OI-NEG TV Prods. □ Panelgraphic □ Planar Sys. □ Plasmaco □ Schott America □ UCE Liquid Crystal Displays

GRAPHICS BOARDS AND PROCESSORS

□ Aydin Controls □ C&C Tech. □ CalComp □ Canadian Marconi □ Computer Peripherals □ Cornerstone Tech. □ Crystop Display □ Data Translation □ Datacube □ Densitron □ Digital Elec. □ EPIX □ Human Designed Sys. □ Interactive Machines □ Interface Prods. □ KMW Sys. □ KONE □ Kontron Elec. □ Mantron Displays □ Matrox Elec. Sys. □ Norden Sys. □ Nth Graphics □ Omnicomp Graphics □ Parallax Graphics □ Primagraphics □ Racal Micro. Sys. □ RasterOps □ Relisys □ David Sarnoff Res. Ctr. □ Sigma Designs □ Sigmex □ Sony of America □ Sony Graphic Display □ Star Tech. □ Verticom □ Yamaha □ Zenith Components

GRAPHICS WORKSTATIONS

□ Alliant Computer Sys. □ Aydin Controls □ Chromatics □ DataBeam □ Fairlight Instruments □ Hazeltine □ Hughes Aircraft □ Imapro □ Interactive Machines □ KONE □ Librascope □ Norden Sys. □ Primagraphics □ RasterOps □ SAI Tech. □ Sanders Assoc. □ David Sarnoff Res. Ctr. □ Sigma Designs □ Sigmex □ Sony □ Tektronix □ V.I. Corp.

HARD-COPY DEVICES

See individual listings for digital film recorders, facsimile machines, plotters, printers (impact, ink-jet, thermal-transfer, electrophotographic, color graphic), and printer supplies

IMAGE TUBES

□ Burle Indus. □ EEV □ Imaging and Sensing Tech. □ Litton Electron Devices □ Quantex □ David Sarnoff Res. Ctr. □ Sony □ Teltron □ Texas Instruments □ Thomson-CSF/DTE □ Thomson Electron Tubes & Devices

IMAGING BOARDS

□ Computer Peripherals □ Coreco □ Data Translation □ Datacube □ EPIX □ Imaging Tech. □ Imapro □ Mantron Displays □ Matrox Elec. Sys. □ Omnicomp Graphics □ Parallax Graphics □ Primagraphics □ Princeton Graphic Sys. □ PULNIX America □ RasterOps □ 3M Comtal □ Vutek Sys.

IMAGING WORKSTATIONS

□ Alliant Computer Sys. □ Datacube □ Ektron Applied Imaging □ Global Imaging □ Hazeltine □ Imapro □ Kontron Elec. □ Primagraphics □ Quantex □ RasterOps □ Recognition Concepts □ David Sarnoff Res. Ctr. □ Tektronix □ 3M/Comtal

JOYSTICKS

□ Aydin Controls □ Robert Busch □ Interactive Machines □ Kraft Sys. □ Penny and Giles □ Recognition Concepts □ Sigmex □ Varitronix □ VL Elec. □ WICO Distribution

KEYBOARDS

□ Aydin Controls □ Robert Busch □ CAM Graphics □ Canadian Marconi □ Cherry Display Prods. □ Cherry Elec. Prods. □ Futaba □ Ginsbury Elec. □ Hitech Intl. □ HMW Enterprises □ Human Designed Sys. □ IEC □ IEE □ Interactive Machines □ Interface Prods. □ Korry Elec. □ Lucas Duralith □ Norden Sys. □ Omnicomp Graphics □ Penny and Giles □ Regisbrook □ SAI Tech. □ Sigmex □ Transicoil

LARGE-SCREEN DISPLAYS, ALL TECHNOLOGIES

See also projection displays

□ Advanced Computer Sys. □ Comfuture □ Cornerstone Tech. □ Craft Data □ DataBeam □ Davis A/S □ EEV □ Electronic Image Sys. □ Emerald Computers □ FIMI Phillips □ Futaba □ Hughes Aircraft □ IEC □ Ikegami Elec. □ Image Amplification □ Interface Prods. □ ISE Elec. □ Librascope □ Lucas Duralith □ LXI □ Mantron Displays □ Magnavox Elec. Sys. □ Micro Display Sys. □ Mito Fine Glass □ Mitsubishi Elec. Sales America □ Norden Sys. □ Norsk LCD □ OI-NEG TV Prods. □ Omega □ Panasonic Indus. □ Phosphor Prods. □ Photonics Sys. □ Pulseview □ Quantum Elec. □ Racal Micro. Sys. □ RasterOps □ Redifusion Simulation □ Regisbrook □ SAI Tech. □ David Sarnoff Res. Ctr. □ S.E.O.S. Displays □ Sigma Designs □ Sony, Display Device Group □ Systems Res. Labs. □ Thomson Electron Tubes & Devices □ Viratec Thin Films □ Zenith Components

LIGHT EMITTING DIODE DISPLAYS

□ Advanced Computer Syst. □ Bowmar/ Ali □ Craft Data □ Display Tech □ Eaton □ El-Op Electro Optics □ Epson America □ GEC Avionics □ Hewlett Packard □ IEE □ Interface Prods. □ Korry Elec. □ NES □ Norden Sys. □ Optotek □ Pulseview □ Racal Micro. Sys. □ Regisbrook □ Rohm □ David Sarnoff Res. Ctr. □ Sharp Elec. □ Texas Instruments □ Toshiba America

LIGHT PENS/POINTING SYSTEMS

□ Aydin Controls □ Hazeltine □ HMW Enterprises □ Interactive Computer Prods. □ Iscan □ Photonics Sys.

LIQUID-CRYSTAL DISPLAYS, ACTIVE-MATRIX

□ Advanced Computer Sys. □ Alphasil □ Astronautics □ Robert Busch □ Crystaloid Elec. □ EEV □ Epson America □ GEC Avionics □ General Elec. □ Hitachi □ Honeywell Defense Avionics □ Hughes Aircraft □ Ikegami Elec. □ Interface Prods. □ Litton Data Images □ OI-NEG TV Prods. □ Ovonic Imaging Sys. □ Photonics Sys. □ Racal Micro. Sys. □ David Sarnoff Res. Ctr. □ Scriptel □ Sharp Elec. □ Thin Film Device □ Toshiba America □ UCE Liquid Crystal Displays □ Varitronix □ Villa Precision □ World Prods.

LIQUID-CRYSTAL DISPLAYS, FERROELECTRIC

□ Acculex □ Autodisplay □ Crystop Display □ Hornell Elektrooptik AB □ OI-NEG TV Prods. □ Polytronix □ Scriptel □ UCE Liquid Crystal Displays □ Villa Precision

LIQUID-CRYSTAL DISPLAYS, PASSIVE

□ Acculex □ AEG □ AMETEK Aerospace Prods. □ Autodisplay □ Robert Busch □ Clover Display □ Craft Data □ Crystaloid Elec. □ Crystop Display □ Davis A/S □ Densitron □ EEV □ Emerald Computers □ Hamlin □ Hercules Aerospace Display Sys. □ Hitachi □ Hornell Elektrooptik AB □ IEE □ Interface Prods. □ Kyocera America □ Litton Data Images □ LXI □ Mito Fine Glass □ National Res. Resources □ Norsk LCD □ OI-NEG TV Prods. □ Photonics Sys. □ Polytronix □ Pulseview □ Racal Micro. Sys. □ Regisbrook □ SAI Tech. □ David Sarnoff Res. Ctr. □ Scriptel □ Sharp Elec. □ Sony □ Toshiba America □ Transcoil □ UCE Liquid Crystal Displays □ Varitronix □ Villa Precision □ VL Elec.

LIQUID-CRYSTAL MATERIALS

□ BDH □ Dainippon Ink & Chemicals

MAGNETIC SHIELDING

□ Ad-Vance Magnetics □ Amuneal Mfg. □ Daburn Elec. and Cable □ Eagle Magnetic □ El-Op Electro Optics □ Gerome Mfg. □ Ginsbury Elec. □ Hoya Elec. □ K&R Engineering Sales □ Magnetic Radiation Labs. □ Magnetic Shield □ David Sarnoff Res. Ctr. □ Southwall Tech. □ Sun-Flex

MANUFACTURING EQUIPMENT

□ ASET □ Brewer Science □ Southwall Tech. □ Tech Spray □ Tencor Instruments □ Villa Precision

MARKET RESEARCHERS/PUBLISHERS

□ Future Systems □ Int. Planning Information □ Int. Resource Development □ Microvitex □ David Sarnoff Res. Ctr. □ Stanford Resources

MASKS

□ Applied Image □ Hoya Elec. □ Microphase Labs □ Precision Photomask □ Thin Film Device □ Toshiba America

MICE

□ Asher Engineering □ Human Designed Sys. □ Kensington Microwave □ Kraft Sys. □ Numonics □ Omnicomp Graphics □ Penny and Giles □ Z-Nix

MICRO-CHANNEL PLATES

□ Galileo Electro-Optics

OPTICAL COATINGS

See also filters, polarizers

□ Andus □ Applied Films Lab □ Arconium Specialty Alloys □ Autodisplay □ Balzers □ Brewer Science □ Robert Busch □ Chomerics □ Civ-Chem Engineering □ Dantech □ El-Op Electro Optics □ Ginsbury Elec. □ Hoya Elec. □ Hoya Optics □ Interface Prods. □ Kollmorgen □ Liberty Mirror □ Litton Data Images □ Metavac □ Mito Fine Glass □ O&S Res. □ OCLI □ Optical & Conductive Coatings □ Optical Devices □ Panelgraphic □ Reynard Enterprises □ David Sarnoff Res. Ctr. □ Schott America □ Sierracin/Intrex □ Southwall Tech. □ Sun-Flex □ Thin Film Device

□ 3M Indus. Optics □ Viratec Thin Films

OPTICAL DISCS & SYSTEMS

□ Corning Glass Works □ Electronic Image Sys. □ Honeywell Defense Avionics □ IBM □ C. Itoh Elec. □ Mito Fine Glass □ Mitsubishi Kasei America □ Optigraphics □ Pentax Teknologies □ Primagraphics □ Reference Tech. □ David Sarnoff Res. Ctr. □ Sony, Display Device Group

PHOSPHORS

□ Ginsbury Elec. □ Hoya Elec. □ Levy Hill Labs □ Mitsubishi Kasei America □ Phosphor Prods. □ Quantex □ David Sarnoff Res. Ctr. □ Sony, Display Device Group □ Thin Film Device

PHOTOMASKS

See masks

PLASMA DISPLAYS, AC

□ Advanced Computer Sys. □ Craft Data □ Densitron □ Digital Elec. □ Electro Plasma □ Emerald Computers □ Interstate Elec. □ Librascope □ Magnavox Electronic Sys. □ Mito Fine Glass □ NEC Elec. □ Norden Sys. □ Photonics Sys. □ Photonics Tech. □ Plasmaco □ Plessey Naval Sys. □ SAI Tech. □ Scriptel □ Texas Instruments □ Thin Film Device □ Thomson-CSF/C-SD □ Thomson-CSF/DTE □ Thomson Electron Tubes & Devices □ Villa Precision □ World Prods.

PLASMA DISPLAYS, DC

□ Babcock Display Prods. □ Cherry Display Prods. □ Cherry Elec. Prods. □ Craft Data □ Dale Elec. □ Densitron

□ Displays □ DIXY □ Emerald Computers □ IEE □ Mito Fine Glass □ NEC Elec. □ Panasonic Indus. □ Photonics Sys. □ Scriptel □ Texas Instruments □ Villa Precision

PLOTTERS

□ CalComp □ Electrographics Int. □ John Fluke Mfg. □ Houston Instrument □ Insight Development □ IBM □ Numonics □ Pentax Teknologies

POLARIZERS

□ Robert Busch □ Chomerics □ Dana Enterprises Intl. □ El-Op Electro Optics □ Hoya Elec. □ Hoya Optics. □ Int. Polarizer □ Liberty Mirror □ Litton Data Images □ Norden Sys. □ Optical Devices □ Reynard Enterprises □ Homer Tilton Visonics

POWER SUPPLIES, HIGH-VOLTAGE

□ Canadian Marconi □ CELCO Pacific □ Data Translation □ Del Elec. □ Dynatech Computer Power □ DISCOM □ El-Op Electro Optics □ Endicott Res. Group □ Ginsbury Elec. □ Ikegami Elec. □ Int. High Voltage Elec. □ K&R Engineering Sales □ Keltron □ Kensington Microwave □ Librascope □ Murata-Erie North America □ Norden Sys. □ Optical Radiation □ Penn-Tran □ PTK/Rantec □ David Sarnoff Res. Ctr. □ Venus Scientific □ Wasatch High Voltage □ Zenith Components

PRINTER SUPPLIES

□ Bates Mfg. □ DeRex □ Eastman Kodak □ Imagen □ IBM □ C. Itoh Elec. □ Kensington Microwave □ Mitsubishi Kasei America □ QMS □ Syntest □ Zenith Components

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PRINTERS, COLOR GRAPHIC

Canon Circon DeRex HMW Enterprises Howtek C. Itoh Elec. KONE QMS Sigmex Tektronix Test & Measurement Sys. Toshiba America Versatec

PRINTERS, ELECTROPHOTOGRAPHIC (LASER AND LED)

Canon DeRex Ektron Applied Imaging Hewlett Packard Imagen IBM C. Itoh Elec. Mitek Sys. NBS Southern Optotek Pentax Technologies QMS Qume Raytheon Texas Instruments

PRINTERS, IMPACT

DeRex Epson America HMW Enterprises IBM C. Itoh Elec. NBS Southern Relisys Syntest

PRINTERS, INK-JET

Canon DeRex Hewlett-Packard Howtek IBM C. Itoh Elec. Sigmex Tektronix

PRINTERS, THERMAL-TRANSFER

Acculex CalComp Circon Craft Data DH Print Eastman Kodak Eaton Printer Prods. Epson America Honeywell Imapro IBM C. Itoh Elec. Lasergraphics Librascope Matrix Instruments Mitsubishi Elec. Sales America Mitsubishi Elec. America Norden Sys. QMS Raytheon Seiko Instruments USA Sigmex Syntest Tektronix Test & Measurement Sys. Versatec

PRINTHEADS

Rohm

PROJECTION DISPLAYS**Liquid-crystal light-valve projectors**

Alphasil Autodisplay Davis A/S Hitachi Hughes Aircraft National Res. Resources David Sarnoff Res. Ctr. Scriptel Telex Communications Thin Film Device UCE Liquid Crystal Displays Varitronix

Projection CRTs

DataBeam EEV El-Op Electro Optics Electrohome Electronic Image Sys. General Attronics Ginsbury Elec. Hitachi Ikegami Elec. Imaging and Sensing Tech. Mitsubishi Elec. Sales America Panasonic Indus. Rank Brimar Raytheon Rediffusion Simulation David Sarnoff Res. Ctr. Scriptel Sonic Tech. Sony Systems Res. Labs. Thomson-CSF/DTE Thomson Electron Tubes & Devices Toshiba America Varitronix Video Display Xytron

REPAIR AND MAINTENANCE**Of computer systems**

Computing Devices DeRex GEC Avionics Hughes Aircraft NEI Ferranti-Packard Elec. Recognition Concepts

Of display systems

Aydin Controls Chromatics Computing Devices El-Op Electro Optics Florod GEC Avionics Hazeltine Hughes Aircraft HMW Enterprises IEE Librascope Microvitec Phosphor Prods. Photonics Sys. Pixelink Relisys Tech Spray

Of high-voltage power supplies

Computing Devices El-Op Electro Optics Int. High Voltage Elec.

SCAN CONVERTER TUBES

Raytheon

SCANNERS, DOCUMENT AND FILM (GRAPHICS)

Computer Aided Tech. Data Copy DataBeam Eikonix Ektron Applied Imaging Houston Instrument Howtek Imapro Mekel Engineering Mitsubishi Elec. America Optographics Ovonic Imaging Sys. Pentax Teknologies Primagraphics Princeton Graphic Sys. David Sarnoff Res. Ctr.

SCANNERS, DOCUMENT (TEXT)

Canon Computer Aided Tech. Data Copy DataBeam Ektron Applied Imaging Ovonic Imaging Sys. Pentax Teknologies Princeton Graphic Sys. David Sarnoff Res. Ctr.

SCOREBOARDS

Omega

SEALANTS

Dainippon Ink & Chemicals

SIMULATOR DISPLAYS

Astronautics CalComp Canadian Marconi Computing Devices DataBeam Electronic Image Sys. GEC Avionics Ginsbury Elec. Honeywell Defense Avionics Hughes Aircraft Interactive Machines Interface Prods. Primagraphics Rank Brimar Rediffusion Simulation David Sarnoff Res. Ctr.

S.E.O.S. Displays Ship Analytics Systems Res. Labs. Xytron

SOFTWARE FOR DISPLAYS**Design and optimization software**

Astronautics Aydin Controls Robert Busch Computing Devices GEC Avionics Honeywell Defense Avionics Hughes Aircraft IBM ISC Cardion Elec. Librascope Matrox Elec. Sys. Racal Micro. Sys. David Sarnoff Res. Ctr. Sound Decisions

Graphics systems software

Alliant Computer Sys. Astronautics Autodisplay Aydin Controls Robert Busch CADKEY Canadian Marconi CELCO Pacific Chromatics Comfuture Computing Devices Data Copy Data Translation Digital Elec. GEC Avionics Hazeltine Honeywell Defense Avionics Hughes Aircraft Hughett Res. Human Designed Sys. Insight Development Interactive Machines IBM ISC Cardion Elec. Librascope Matrox Elec. Sys. Norden Sys. Parallax Graphics Personics Primagraphics RasterOps SAI Tech. Sanders Assoc. David Sarnoff Res. Ctr. Tektronix Z-Nix

Image processing software

Aydin Controls Robert Busch Canadian Marconi CELCO Pacific Computing Devices Coreco Data Copy Data Translation Eastman Kodak El-Op Electro Optics Eltime Vision Sys. EPIX GEC Avionics Global Imaging Honeywell Defense Avionics

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Hughes Aircraft Hughett Res.
 Image Amplification Imaging Tech.
 Insight Development IBM ISC
 Cardion Elec. Librascope Matrox
 Elec. Sys. Norden Sys. Recognition
 Concepts SAI Tech. David Sar-
 noff Res. Ctr. Ship Analytics 3M
 Comtal Videotex Sys. Z-Nix

Optical analysis software

Aydin Controls Robert Busch
 Computing Devices GEC Avionics
 IBM David Sarnoff Res. Ctr.
 Telic Optics

Signal processing software

Autodisplay Aydin Controls Ca-
 nadian Marconi Computing Devices
 Data Translation Dranetz Tech.
 Eastman Kodak El-Op Electro Op-
 tics EPIX GEC Avionics Honey-
 well Defense Avionics Hughes Air-
 craft Imaging Tech. IBM ISC
 Cardion Elec. Librascope Norden
 Sys. Primagraphics David Sarnoff
 Res. Ctr.

SONIC DIGITIZERS

Science Accessories

SPEECH INPUT/OUTPUT DEVICES

Autodisplay Robert Busch Ca-
 nadian Marconi Norden Sys. Pa-
 cific Basin Distributing Voice
 Connection

TEST AND MEASUREMENT EQUIP- MENT

Automatic convergence systems

Argo EG&G Gamma Scientific
 Electronic Image Sys. Ginsbury

Elec. Hoffman Engineering Honey-
 well Defense Avionics Ikegami Elec.
 McMahan Electro-Optics Microvi-
 sion Photo Research David Sarnoff
 Res. Ctr. Spectron Engineering

Automated test equipment

Argo Astronautics Control Sys-
 tem Tech. CR Tech. Crystop Dis-
 play Data Translation Dranetz
 Tech. EG&G Gamma Scientific El-
 Op Electro Optics Eltime Vision Sys.
 John Fluke Mfg. GEC Avionics
 McMahan Electro-Optics Meylan
 Microvision Optical Radiation
 Photo Research Photon Rock-
 well Int. David Sarnoff Res. Ctr.
 Spectron Engineering Tektronix
 Tencor Instruments United Detec-
 tor Tech. VII

Gonioreflectometers

EG&G Gamma Scientific Hoffman
 Engineering McMahan Electro-Optics
 Photo Research

Photometers

EG&G Gamma Scientific Hoffman
 Engineering Labsphere LMT
 McMahan Electro-Optics Microvi-
 sion Minolta Photo Research
 David Sarnoff Res. Ctr. Spectron
 Engineering Tektronix United De-
 tector Tech.

Radiometers

EG&G Gamma Scientific Hoffman
 Engineering Labsphere Levy Hill
 Labs McMahan Electro-Optics
 Photo Research David Sarnoff Res.
 Ctr. Spectron Engineering Tektro-
 nix United Detector Tech.

Video generators

CELCO Pacific Leader Instruments
 Quantum Data David Sarnoff Res.
 Ctr. Test & Measurement Sys. VII

Video oscilloscopes

John Fluke Mfg. Leader Instru-
 ments Tektronix

3D DISPLAY SYSTEMS

CADKEY Electronic Image Sys.
 Hughes Aircraft Interactive Ma-
 chines Matrox Elec. Sys. Norden
 Sys. Omnicomp Graphics Optical
 Elec. Primagraphics David Sarnoff
 Res. Ctr. Seiko Instruments USA
 Tektronix Homer Tilton Visonics

TOUCH-INTERACTIVE DISPLAYS

Advanced Computer Sys. Audodis-
 play Canadian Marconi Carroll
 Touch Computing Devices Craft
 Data Dale Elec. Digital Elec.
 Electro Mechanical Sys. Electro
 Plasma Futaba GEC Avionics
 IEE Interface Prods. Korry Elec.
 Norden Sys. Omnicomp Graphics
 Phosphor Prods. Photonics Sys.
 SAI Tech. Sanders Assoc. David
 Sarnoff Res. Ctr. Tallq Thin Film
 Device UCE Liquid Crystal Displays
 Zenith Components

TOUCH SCREENS

Aydin Controls Babcock Display
 Prods. Robert Busch CAM Graph-
 ics Canadian Marconi Carroll
 Touch Craft Data Dale Elec.
 Densitron Digital Elec. Dranetz
 Tech. Electro Mechanical Sys.

Electro Plasma Emerald Comput-
 ers John Fluke Mfg. GEC Avionics
 HMW Enterprises Interface Prods.
 Korry Elec. Librascope Lucas
 Duralith Micro Touch Sys. Microvi-
 tec Norden Sys. Phosphor Prods.
 Photonics Sys. SAI Tech. Sierra-
 cin Transflex Southwall Tech. Sun-
 Flex Tektronix Thin Film Device
 TSD Display Prods. Varitronix
 VL Elec. Zenith Components

TOUCH TABLETS

Robert Busch Electro Plasma
 Lucas Duralith Sun-Flex Thin
 Film Device

TRACKBALLS

Asher Engineering Aydin Controls
 Interface Prods. Korry Elec. Li-
 brascope Penny and Giles Recog-
 nition Systems

VACUUM EQUIPMENT

Balzers Leybold NEC Elec.
 David Sarnoff Res. Ctr.

VACUUM FLUORESCENT DISPLAYS

Babcock Display Prods. Craft Data
 Digital Elec. EEV Futaba IEE
 NEC Elec. Pulseview Regis-
 brook Texas Instruments Villa Pre-
 cision

VIDEO AMPLIFIERS

CELCO Pacific Circon El-Op
 Electro Optics Electronic Image Sys.
 Ginsbury Elec. Norden Sys. Op-
 tical Elec. David Sarnoff Res. Ctr.

X-RAY IMAGE STORAGE SCREENS

Levy Hill Labs

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To Backlight?**

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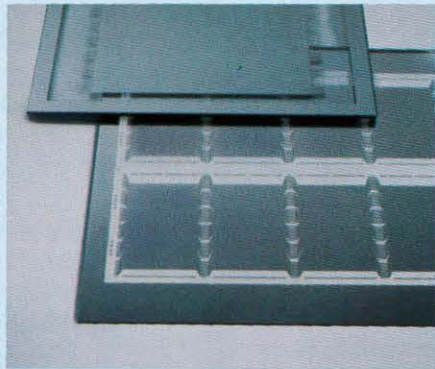
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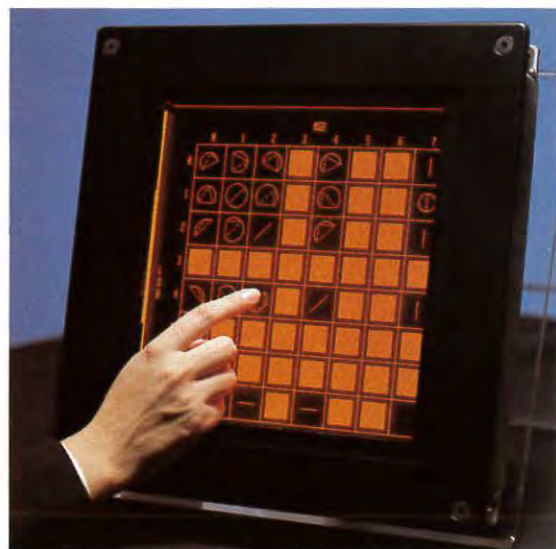


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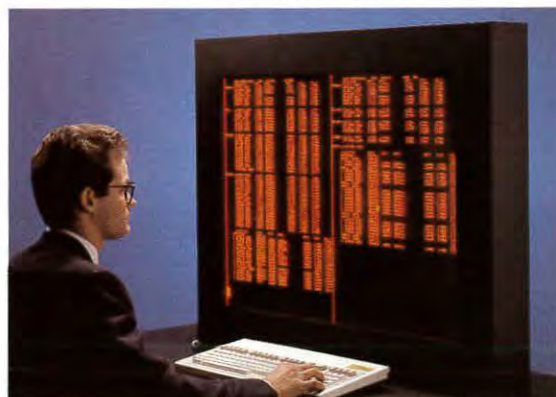
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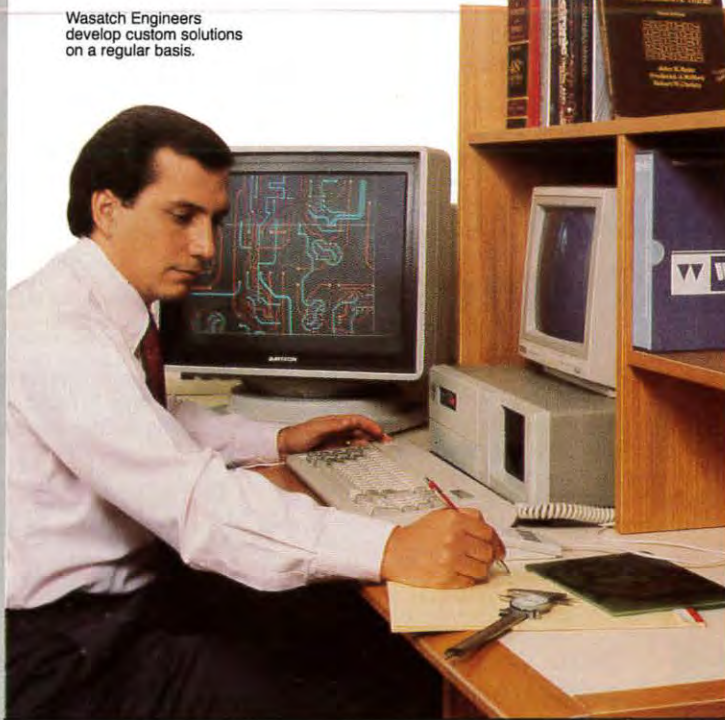
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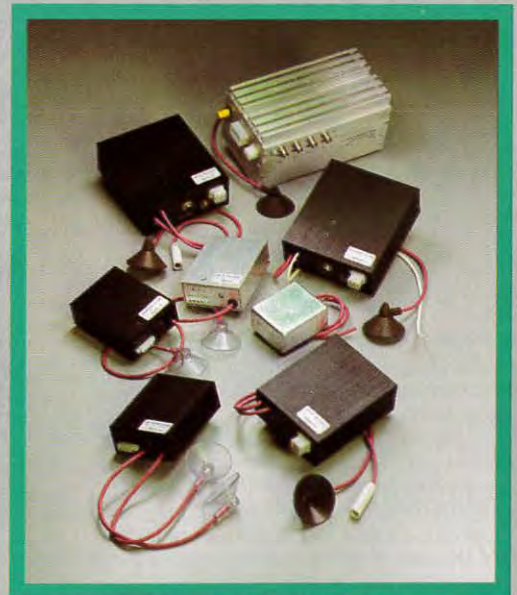
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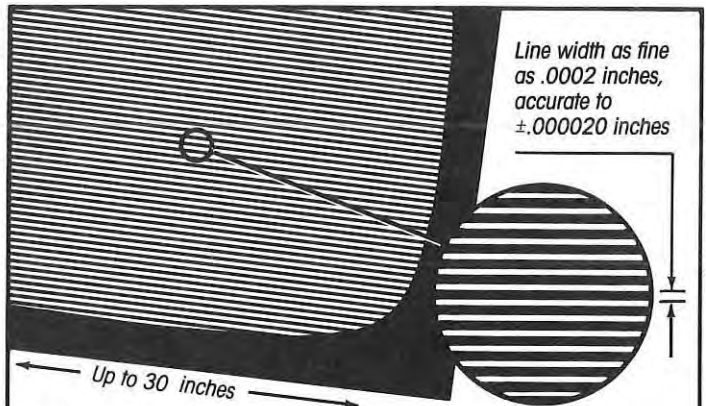
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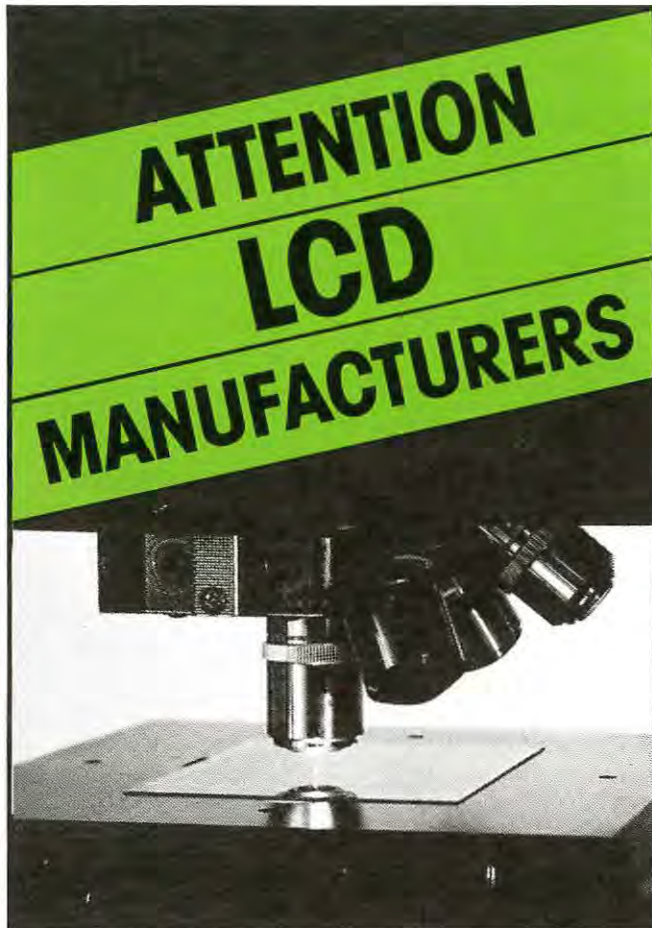
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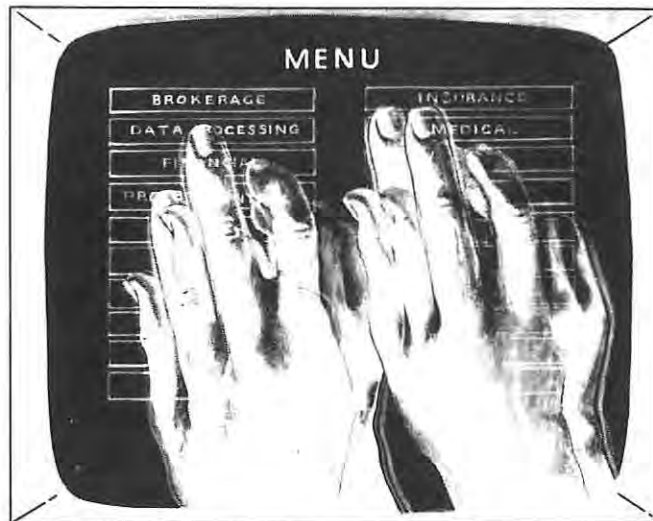
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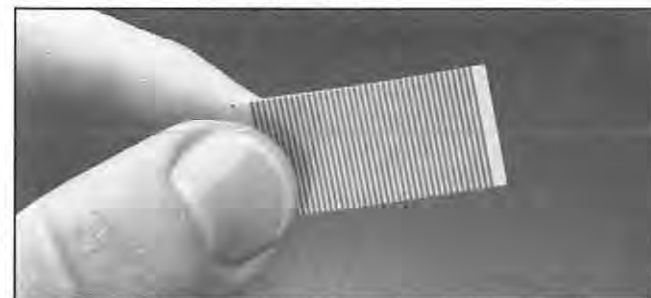
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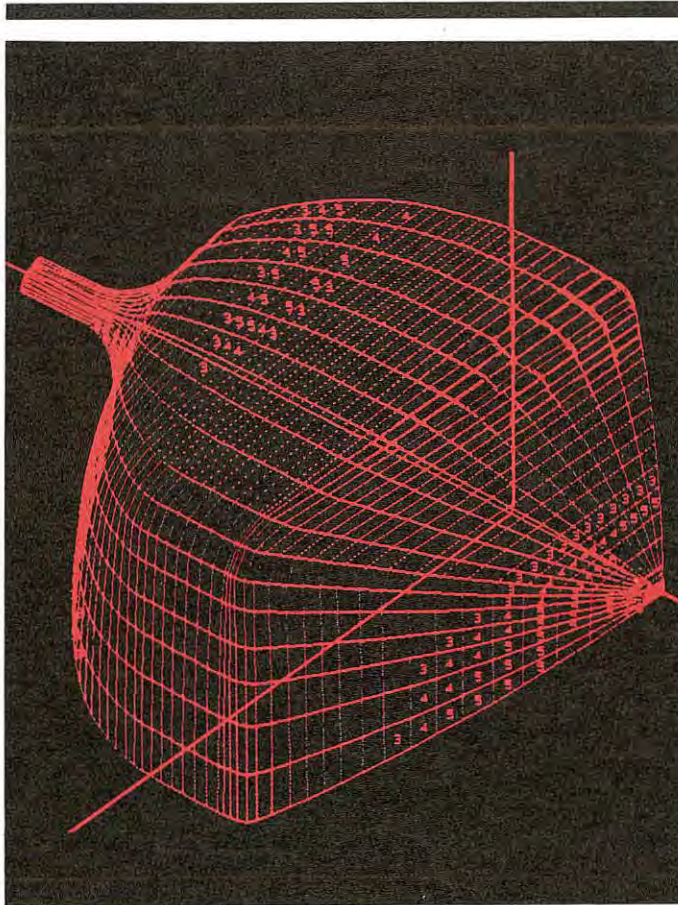
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muMATH-83

by Soft Warehouse, 3615 Harding Avenue, Suite 505, Honolulu, Hawaii 96816. \$300.

muMATH: A Microcomputer Algebra System

by C. Woof and D. Hodgkinson
176 pp. Academic Press, 1250 Sixth Avenue, San Diego, California 92101-9665. \$22.50 paper.

Reviewed by RICHARD LEE

The software

A by-product of the evolution of artificial intelligence is computer algebra—the symbolic, rather than numerical, solving of algebraic equations. Currently, several software packages for performing computer algebra are available, including FORMAC and REDUCE for the IBM 360; and REDUCE, MAPLE, and MACSYMA for DEC computers. These packages require anywhere from 150 kbytes to 2 Mbytes of memory.

MuMATH-83 comes on two 5¼-in. or 3½-in. floppy discs for IBM PCs, PS/2s, and compatibles having a graphics card and a monochrome or color monitor. It requires 128 kbytes of memory and MS-DOS 2.0 or higher. The program is written in the language muSIMP, which was developed specifically for it. I tested muMATH on an IBM PC/XT having 640 kbytes of memory.

The first of the two floppy discs contains three unprintable system image files; the second disc contains 22 printable source files. There is an automatic tutorial demo for each file which can be disabled if desired.

It took me several hours of use to become comfortable with the software. MuMATH is formatted in an interactive programming style, which requires the user to anticipate the program's logical flow. MuMATH readily handles algebra, matrix algebra, derivatives, integrals, or-

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dinary differential equations (ODEs), and fractions. It has problems with factoring, symbolic fraction simplification, and "complex" differential equation problems. Another shortcoming: after each SYS file, the user must load each source file in order of priority to avoid syntax errors during use.

Documentation consists of a 248-page manual separated into one section on muMATH and a second on the language muSIMP. The manual tends to be disorganized and poorly written, and not all commands and techniques are indexed. For these reasons, it is necessary to read the entire manual before attempting any serious problems. There is no coverage whatsoever of error troubleshooting.

Despite these significant limitations, muMATH is tremendously useful in scientific and engineering analysis of problems. The software obtains analytical solutions to ODEs quickly, so a number of different conditions can be considered without spending an unreasonable amount of costly professional time. However, the program can not solve partial differential equations such as heat conduction in solids, or complex ODEs such as the solution for atomic energy levels—significant sets of problems in science and industry.

In its areas of effectiveness, the program is not user friendly but is enormously useful once mastered. To solve the



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software notes

equation $d^2y/dx^2 + 4 dy/dx + 13y = 0$, for example, the user instructs the computer:

```
SOLN: SOLVE (DIF (Y,X,2) + DIF (Y,X) + 13Y,Y).
```

To this the machine replies:

```
@:{y= = ARB(1) SIN (3X)/  
#E^ (2X)+ ARB(2) COS (3X)/#E^ (2X)}
```

The software is mature. The current version is already five years old, with no more updates planned. When I called Soft Warehouse the staff was patient and helpful, and they had the answers to all my questions. For those solving the kinds of equations muMATH can handle, the package is well worth the price.

The book

There is a wonder drug for one of muMATH's more serious maladies, its poor documentation. The drug is Woof and Hodgkinson's book, which takes the reader on a structured and interesting journey through muMATH and covers all the major topics. The authors present sample problems exhibiting all the features of muMATH with a commentary on the program's strengths and weaknesses. Warning: the otherwise detailed examples do not include simple load commands, so the reader must remember to supply them. Since this information is also missing from the muMATH-83 documentation, the omission could pose a problem for inexperienced computer users.

The book, consisting of 11 chapters and five appendices, elaborates on the syntax used in muMATH and explains much that is missing from the manual. It is endorsed by Soft Warehouse, and the material it contains is well presented and well indexed.

The book is not bundled with the software, but it should be. I regard Woof and Hodgkinson's book as an essential adjunct to the program, and an inexpensive preview for those who are considering a muMATH purchase. It is also a good introduction to computer algebra in general. ■

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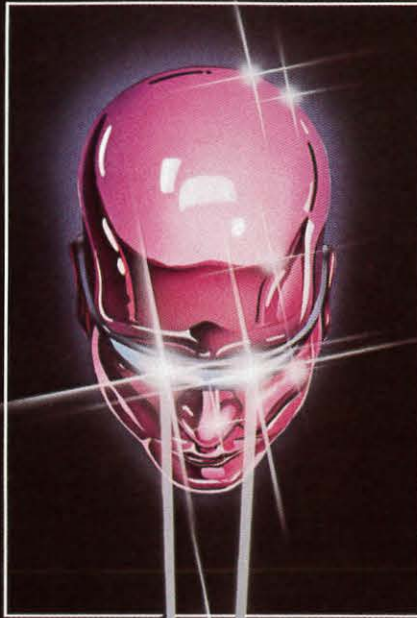
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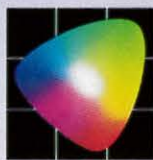


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