MICRODISPLAY ISSUE AND SPECIAL EUROPEAN FOCUS

Information DISPLAY

March 2001
Vol. 17, No. 3

SID

Official Monthly Publication of the Society for Information Display

EID 2000 Opens London's ExCel Exhibition Centre

- *Microdisplay Measurement Standards*
- *Test for LCoS Manufacture*
- *Laser Glass Cutting*
- *European Monitor Survey*
- *EID 2000 Report*

MARCH 2001
VOL. 17, NO. 3

Information DISPLAY

EID 2000, held November 21–23, was the inaugural event at London's ExCel Exhibition Centre. Extensive coverage of EID, plus a survey of European flat-panel-monitor markets that shows surprising penetration in some countries, marks this issue's special European focus. Since this is also our Microdisplay issue, we also focus on microdisplay standards and testing for high-volume manufacturing.

ExCel Centre

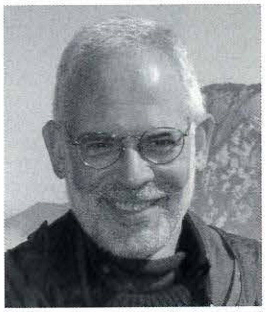
For more on what's coming in *Information Display,* and for other news on information-display technology, check the SID Web site on the World Wide Web: **http://www.sid.org.**

Next Month in *Information Display*

SID 2001 Preview Issue
- SID 2001 Preview
- FPD Technology in Korea
- Poly-Si TFTs for Plastic Substrates
- IDW 2000 Report

INFORMATION DISPLAY (ISSN 0362-0972) is published eleven times a year for the Society for Information Display by Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; Leonard H. Klein, President and CEO. EDITORIAL AND BUSINESS OFFICES: Jay Morreale, Managing Editor, Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; telephone 212/460-9700. Send manuscripts to the attention of the Editor, ID. Director of Sales: Michele Klein, Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; 212/460-9700. SID HEADQUARTERS, for correspondence on subscriptions and membership: Society for Information Display, 31 East Julian Street, San Jose, CA 95112; telephone 408/977-1013, fax -1531. SUBSCRIPTIONS: Information Display is distributed without charge to those qualified and to SID members as a benefit of membership (annual dues $75.00). Subscriptions to others: U.S. & Canada: $55.00 one year, $7.50 single copy; elsewhere: $85.00 one year, $7.50 single copy. PRINTED by Sheridan Printing Company, Alpha, NJ 08865. Third-class postage paid at Easton, PA.

editorial



Kahn International

Lafayette, We Are Here!

Information Display is an international publication with significant circulation in Europe as well as Asia and North America. Nonetheless, there is a perception in Europe that *ID* is a North American publication. This perception exists despite our routine coverage of European display issues and our publication of articles by European authors. So, in an effort to counteract this perception, the current issue of *ID* in addition to being our annual Microdisplay Issue, has a special European focus, with extensive coverage of EID 2000 in London (by Phillip Hill and George Isaacs) and a special analysis of the European LCD-monitor marketplace (by Bryan Norris).

Although enhanced coverage of specifically European issues is a worthy achievement, it is more worthy if more people read it. So, we are distributing *ID* to an additional 5000 members of the European display community.

We trust this initiative will give more Europeans an opportunity to appreciate *ID*'s truly international coverage of display technology, display manufacturing, display applications, display integration, and display markets, written and edited by experts in the field.

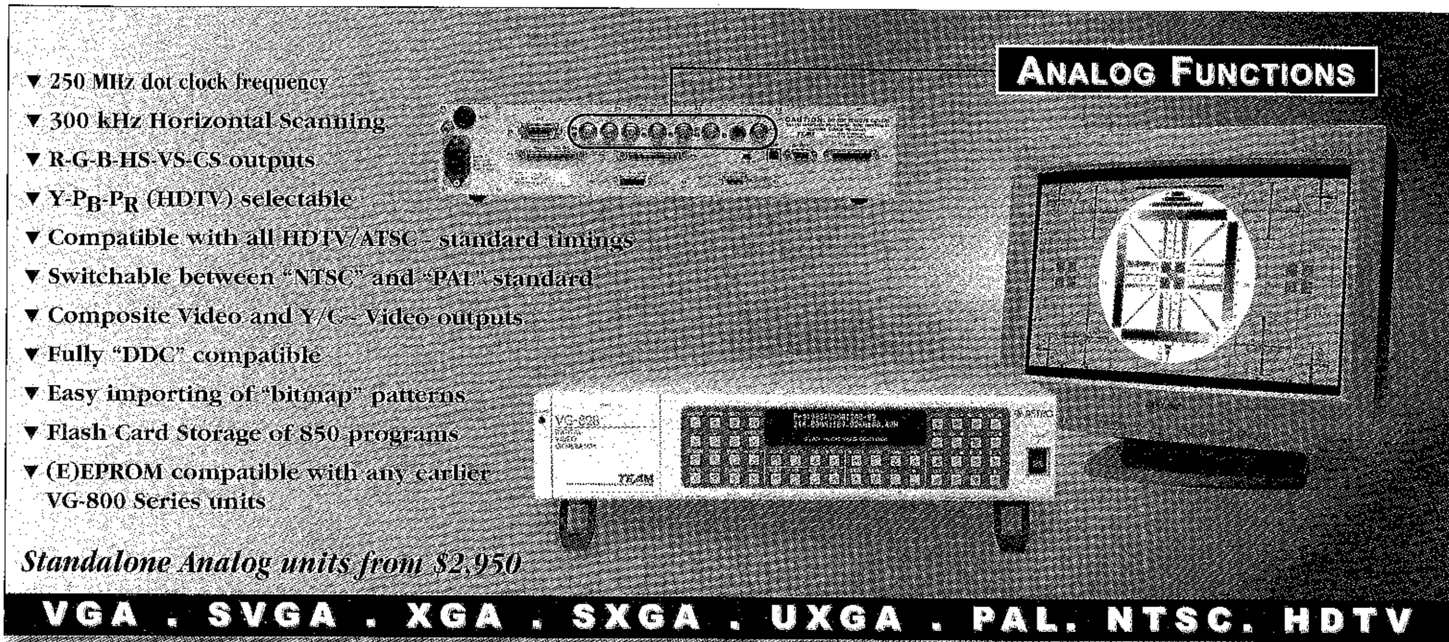
For our many thousands of readers who are not in Europe, we hope the European coverage in this issue will provide you with useful insights into new technologies and new opportunities.

– KIW

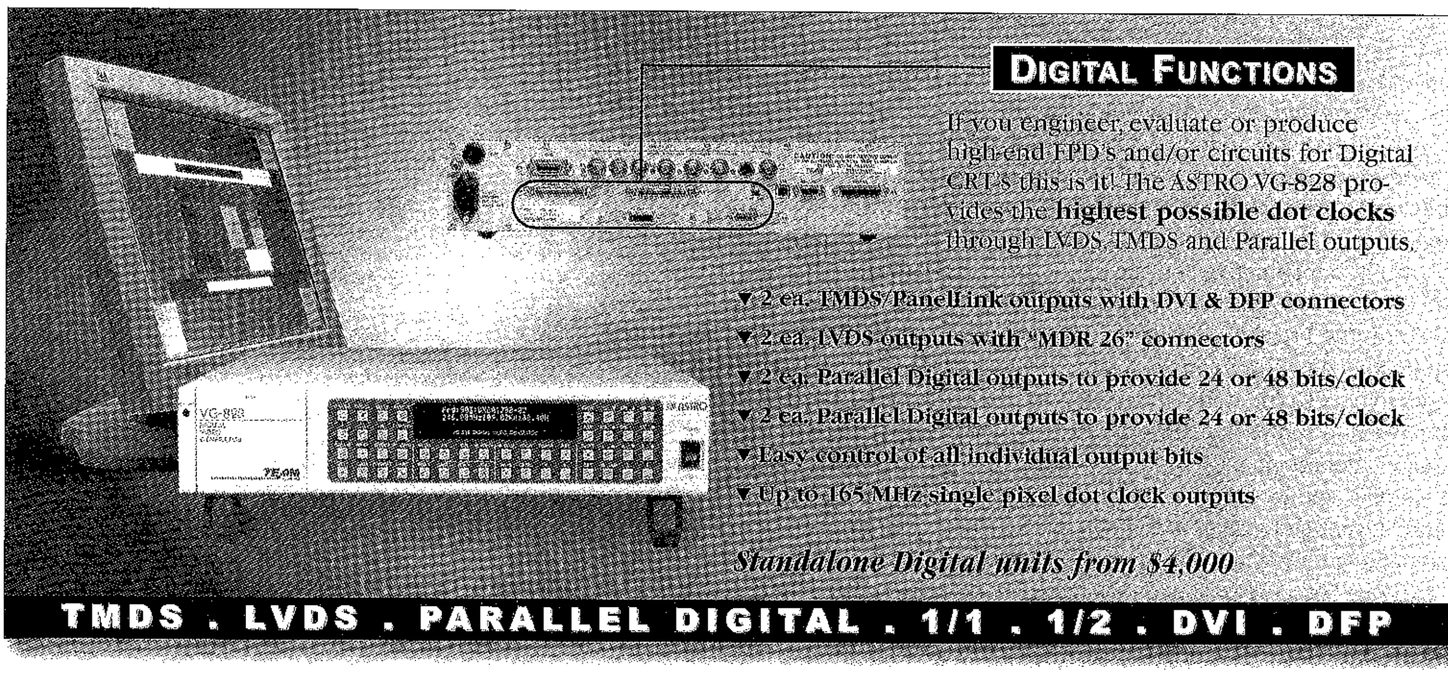
We welcome your comments and suggestions. You can reach me by e-mail at kwerner@nutmegconsultants.com, by fax at 203/855-9769, or by phone at 203/853-7069. The contents of upcoming issues of *ID* are available on the *ID* page at the SID Web site (http:// www.sid.org).

Information DISPLAY

What You Need Today in a Video Generator...
...The ASTRO VG-828 Has It!



A Single Video Generator with Double the Function!



Contact us today!
www.team-systems.com
1-800-338-1981
info@team-systems.com

Team Systems...The Smart Choice!

TEAM systems

Team Systems Inc. • 2934 Corvin Drive • Santa Clara, CA 95051 • Phone: (408) 720-8877 • Fax: (408) 720-9643

Circle no. 2

a view from the hilltop

And the Children Shall Lead Us ...

Quite some time ago, in the twelfth year of my life, I had the thrill of accompanying my parents on their annual Christmas shopping trip to Wichita, Kansas. I distinctly remember that the distance was 211 miles and that it took just over four hours to get there. This particular year turned out to be an extra special one because my objective was to come home with a Lionel electric train. I had saved every penny for most of the previous two years for this occasion and had worn out several Lionel catalogs – studying each page over and over again. With the additional contribution my parents had agreed to make as that year's present, I would have just enough to get the modest set I had selected.

The following morning, as we arrived at Innes's department store, I could hardly contain my excitement and concern – what if they didn't have the set I wanted? What if the price had changed and I didn't have enough money to get it? The price in the catalog was $39.95, and that is exactly how much I had – and in 1952 dollars that was a considerable amount. Whew! The price was still the same and they had the set. And of all my childhood Christmases, this one stands out as the most memorable.

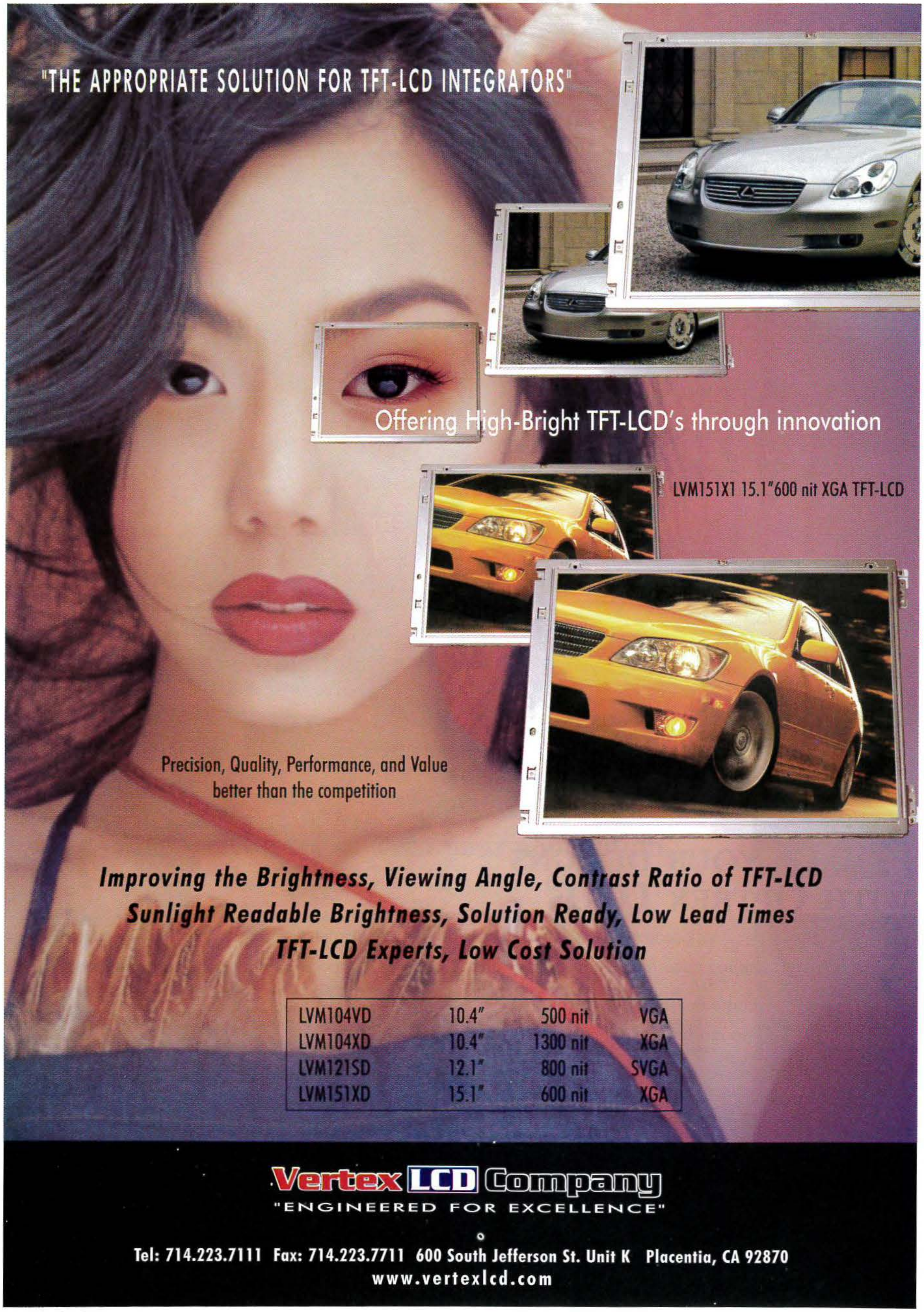
Further additions, such as the log car with the magnetic dumping relay and an oil derrick with a lighted bubbler, were made on subsequent birthdays and Christmases. However, some major wishes remained unfulfilled. A schoolmate, whose father was one of the wealthier businessmen in the small town where we lived – he owned the local drugstore – had a much more elaborate layout. He had several locomotives, including a blue diesel-electric model, as well as four remotely operated switches on his layout. Oh, how I wanted to add extra track and switches to my layout. But the switches were too expensive for my modest budget, as was the additional locomotive. The best I could do was to buy some extra track to add a few new curves and hills to my layout. Nevertheless, this train was my most prized possession for the rest of my growing-up years. The locomotive and several of the cars are today, almost fifty years later, on display in my office. It still seems like a neat toy.

Recently, I read an article in the *USA Today* business section that the Lionel train company is enjoying a great revival, and that once again kids and parents are buying electric trains. This success is allowing the company to add new features and to further refine its products. However, the prices are a bit higher (in today's dollars) than when I went on my shopping trip to Wichita, with some of the upper-end locomotives now selling for well over $1000. This newspaper article went on to suggest that perhaps parents as well as kids are searching for something more than video games and computer screens for entertainment. The "real feel" of a toy train and the mechanical precision that it represents are meeting some fundamental need for us to connect with the world around us.

Whether this is true or not, I do believe that toys represent a "leading indicator" of what is in store for us in the future. Looking back, perhaps we can say that in the 1950s toy electric trains were symbolic of our growing fascination with mechanical devices of all kinds – cars, airplanes, and appliances. In the 1980s, video games presaged the arrival of the home computer and all the other microprocessor-inspired devices that followed.

continued on page 42

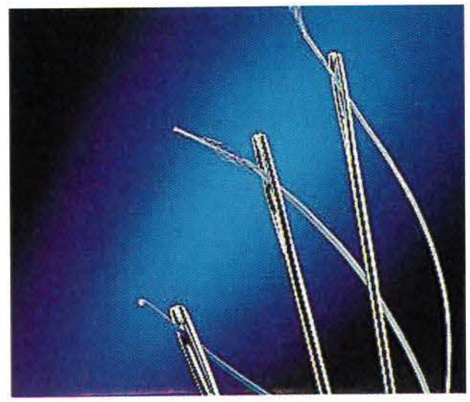
Society for Information Display
31 East Julian Street
San Jose, CA 95112
408/977-1013, fax -1531
e-mail: office@sid.org
http://www.sid.org


"THE APPROPRIATE SOLUTION FOR TFT-LCD INTEGRATORS"
Offering High-Bright TFT-LCD's through innovation
LVM151X1 15.1"600 nit XGA TFT-LCD
Precision, Quality, Performance, and Value better than the competition
Improving the Brightness, Viewing Angle, Contrast Ratio of TFT-LCD
Sunlight Readable Brightness, Solution Ready, Low Lead Times
TFT-LCD Experts, Low Cost Solution
LVM104VD 10.4" 500 nit VGA
LVM104XD 10.4" 1300 nit XGA
LVM121SD 12.1" 800 nit SVGA
LVM151XD 15.1" 600 nit XGA
Vertex LCD Company
"ENGINEERED FOR EXCELLENCE"
Tel: 714.223.7111 Fax: 714.223.7711 600 South Jefferson St. Unit K Placentia, CA 92870
www.vertexlcd.com

Circle no. 6

Miniature Coax Cable

Transmit a great number of signals over extremely small diameter cable, (as little as Ø 0.22mm). PICO-COAX®

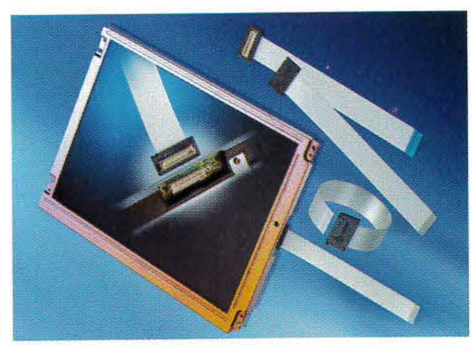


offers a complete range of choices for applications ranging from notebook computers, imaging systems, medical, test and measurement, and others. High clock speeds, flexibility, and small size are just a few advantages. Custom cable designs are a specialty. Phone: Axon' Cable 847-699-8822. E-mail: sales@axoncable.com

Circle no. 9

Flat Display Interconnect

Cable assemblies for board to panel connections consist of a 0.50mm flat flexible cable with 31 (VGA) or 41



(SVGA) conductors connected to a Hirose DF-9 interface at one end, and either another DF-9 connector or a ZIF termination at the other. AXOLINK® FDC cable is compatible with flat panels where VESA and FDPI-1 standards are met. Available in shielded versions. Standard samples readily available. Phone: Axon' Cable 847-699-8822 E-mail: sales@axoncable.com

Circle no. 10

SS200 SERIES DISPLAY ANALYSIS SYSTEMS

Microvision's SS200 series of display analysis systems allows you to precisely, automatically and quickly measure display performance. And with many test laboratories currently using the SS200 series as their standard test system, shouldn't you?

The SS200 series includes the SS210, SS220 and SS230 systems. Each system allows for modular field upgrades for increased functionality - Buy what you need, when you need it! Each system may be used on any display type from **CRT**, all **FPD's**, **Projection**, **HDTV**, and **Microdisplays**. The familiar *Windows*-based GUI makes the equipment easy to use and personalize. All versions come with the time tested Spotseeker five-axis positioning stage integrated into all test sequences. Each system is a complete turnkey system with a computer, 5-axis positioner, monitor, software, spectrometer, and camera system. For automatic testing to **ISO, VESA, NIDL & TCO** specifications, or comprehensive analysis for engineering and quality control requirements, the SS200 series has the system for you!

SS210 System:

The SS210 package has a CCD camera to provide spatial measurements such as Line Width and MTF. It includes an integrated spectrometer for spectral analysis and color measurements and also includes an optional response time measurement capability.

SS220 System:

The SS220 system is the perfect choice for flat panel testing. It features spectrometer-based, off-axis measurements, color analysis, contrast ratio and luminance testing.

SS230 System:

The SS230 (pictured above) is a combination of the SS210 & SS220 system, resulting in the most comprehensive test system available. All tests are performed at NIST traceable accuracy.

Used by Test Laboratories Worldwide

MICROVISION

Dedicated to the Needs of the Display Industry

550 High Street, Auburn, CA 95603 USA
Tel:(530) 888-8344 * Toll Free: (800) 931-3188
Fax: (530) 888-8349 * Email: info@microvsn.com
Web site: www.microvsn.com

International Representatives:
Japan - ARGO CORP., 06 339 3366
Taiwan - SUPERLINK TECH., 886 2 2698 3456
Korea - B & P INT'L, 02 546 1457
China - China National Electronics Imp. Exp. Corp. (010) 6829-6310

Circle no. 13

Testing for High-Volume LCoS Microdisplay Manufacturing

The success of LCoS manufacturers and their test-equipment suppliers depends on opening a dialogue that produces clear descriptions of test definitions and requirements.

by Pete Smith and Dan Hoffman

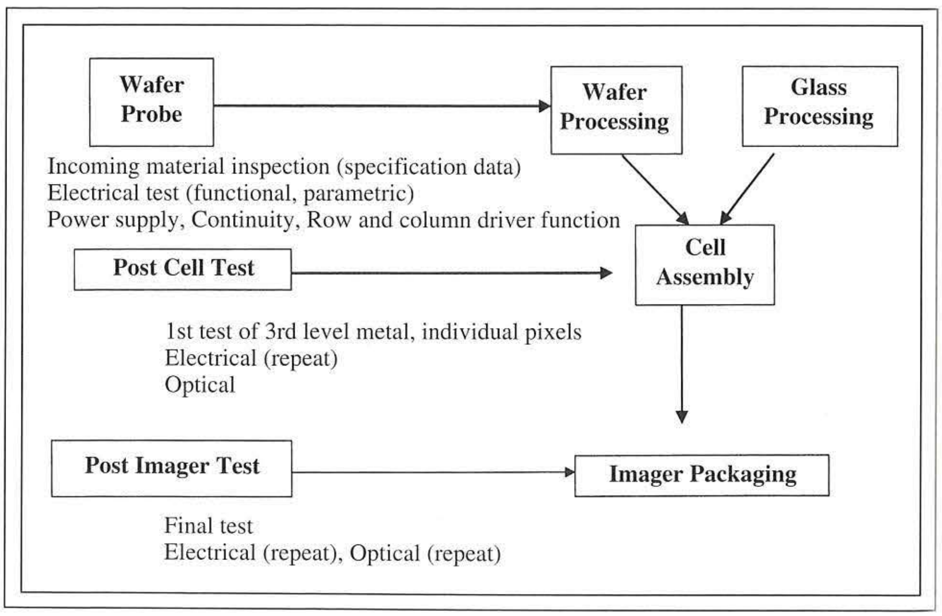
THE HIGH-VOLUME production of liquid-crystal–on–silicon (LCoS) microdisplays presents a series of unique manufacturing challenges. Certain tests for microdisplays are required, and must be developed taking into consideration the usual manufacturing concerns of repeatability, test time, and cost. Success during the preliminary phase of LCoS development hinges upon finding a successful manufacturing test that encompasses customer needs, product design, and operational requirements.

An LCoS product test should ensure that the manufacturing process achieves the specified product design (Fig. 1). Thus, LCoS manufacturing tests are a subset of the total LCoS product-design validation, and the parameters and bandwidth of the manufacturing test must be selected to implement that validation. Moreover, effective manufacturing tests and test equipment must facilitate a pass/fail test rather than a full suite of characterization tests. This means that both the hardware and software for the equipment designed to implement the manufacturing test must differ from that intended to characterize LCoS displays.

The manufacturing test must successfully test parameters that are inherent in LCoS manufacturing processes, including pixel-level defects, blemishes, electrical continuity, and, potentially, some representations of color or uniformity. These tests are dependent on the device type and the markets for it. Let's examine the manufacturing test requirements in some detail and compare them to the LCoS test equipment available today.

Manufacturing Test Flow

Not surprisingly, test flow must correspond to the LCoS process flow (Fig. 2). The wafer probe test shown in the figure determines the number of good dice per wafer. The advan-

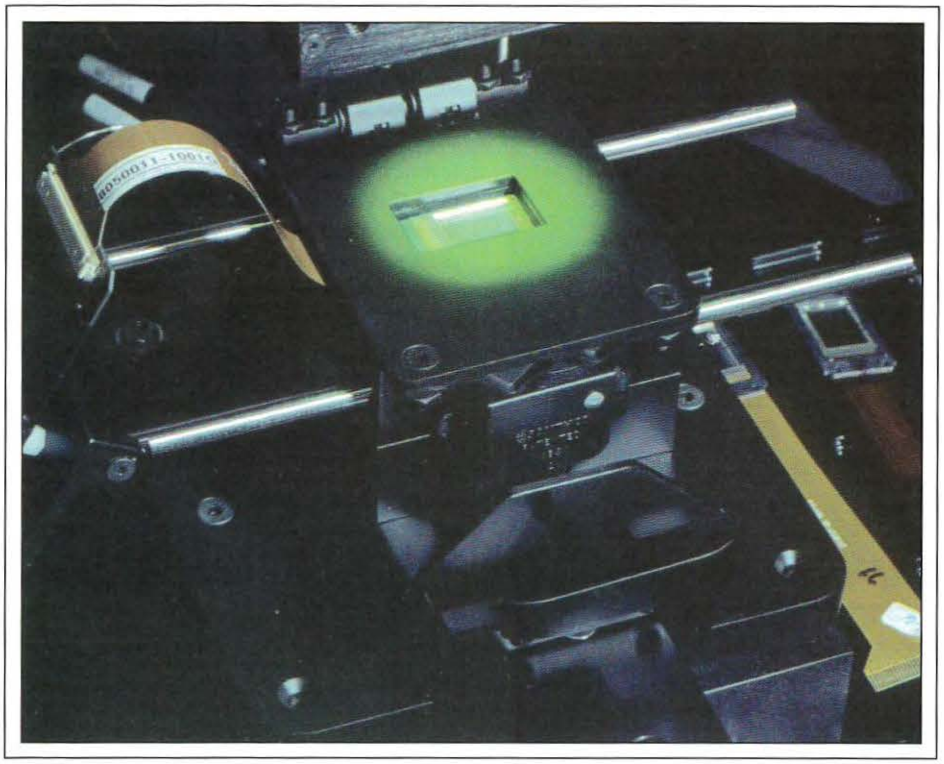


Three-Five Systems, Inc.

Fig. 1: The LCoS product test is designed to ensure that the manufacturing process achieves the specified product design.

*Pete Smith is Director of Advanced Manufacturing Engineering at Three-Five Systems, Inc., 1600 N. Desert Dr., Tempe, AZ 85281; telephone 602/389-8617, fax 602/389-8701, e-mail: psmith@mail.35sys.com. **Dan Hoffman** is Principal Engineer at Three-Five Systems.*

0362-0972/01/1703-014$1.00 + .00 © SID 2001



Three-Five Systems, Inc.

Fig. 2: Test flow must correspond to the LCoS process flow. The wafer probe test determines the number of good dice per wafer.

tages of in-house test capability at this stage are the opportunity for learning and wafer-scale process debugging. But the wafer probe is limited in its ability to test the top metal layer or pixels of the silicon backplane (for analog and/or mixed-signal designs).

This limitation can affect the next LCoS test, cell-level testing. The cell test provides the first opportunity to test the top layer of metal and obtain full feedback on the cell-fabrication process. Finally, the imager test serves as a final test to assess the packaging process (Fig. 2). The development of cell and imager tests is essential in LCoS manufacturing.

There are several tests that could be implemented at the cell and/or imager levels (Table 1), but the development of manufacturing tests has been mired in requirements related to product and technology development rather than directed towards manufacturing solutions. Requiring a tester to meet both production and quality needs results in a tester that is not adequate for either function.

To be appropriate and effective, the specific tests to be used in production must be clearly defined. Ultimately, the test vendor must deliver a robust solution for administering these manufacturing tests.

What Equipment Is Available Now?

We have sampled test equipment from various vendors and summarized the tests available (Table 2). All of these companies are capable of meeting any LCoS manufacturer's testing needs. As an industry, LCoS manufacturers must collectively specify the necessary tests for production. An open discussion of which high-volume tests are actually essential will raise questions about the need for tests such as image retention (which has a long time requirement) and tilt loops (which is a design rather than a production requirement).

In order for the supply base of LCoS tests to be adequate and appropriate, the LCoS industry must define the production tests and the qualification tests. Careful consideration of which tests are needed in production will enable the industry's infrastructure to mature at a faster rate.

What Should Be Tested in Production?

The LCoS manufacturer's choice of tests impacts both the tester cost and throughput. The LCoS design must achieve flicker, crosstalk, image retention, tilt loops, and color targets. The achievement of these targets is verified by quality-assurance testing and during design verification. The LCoS manufacturer must ensure that the correct processes are always followed. As a simplistic example, quality procedures in the manufacturing process would ensure that the correct liquid crystal is placed in the cell. As a result, color testing would not be needed.

So what does that leave for the LCoS producer to test in high-volume manufacturing? It leaves blemishes, luminance, contrast, Newton fringes, pixel functionality, and uniformity. Judicious review of these parameters shows some interdependencies. A measure-

Table 1: Tests That Can Be Made at the Cell and/or Imager Level

Test	Production Test	QA/QC Tests	Detector
Defect detection	x	x	CCD
Reflectance	Optional	x	Spectrometer
Reflectance uniformity	9-point/array	1,5,9 points	Spectrometer or CCD
Contrast and contrast uniformity	9-point	1,5,9 points	Spectrometer
Brightness *vs.* *f*/number		x	Spectrometer
Reflectance *vs.* wavelength		x	Spectrometer
Crosstalk		x	CCD
Contrast *vs.* *f*/number, wavelength		x	Spectrometer
Gray-scale linearity		x	Spectrometer
Mura		x	CCD

Table 2: Tests Available from a Sampling of Leading Test-Equipment Vendors

Vendor/Test	Anteon	Cimmetric Technologies	Integral Vision	Westar
Blemishes	x	x	x	x
Brightness or reflectance	x	x	x	x
Color	x	x		x
Contrast ratio	x	x		x
Crosstalk	x	x	x	
Flicker		x	x	
Image retention			x	
Newton fringes	x		x	
Pixel functionality	x	x	x	x
Tilt loops			x	
Uniformity	x	x	x	x

ment of contrast, for example, requires the "brightness" to be measured in both the black and white states, so a measurement of contrast carries brightness as a subset.

To optimize (reduce) test time with respect to overall test coverage, the minimum testing that must be performed includes a measurement of pixel functionality – which amounts to a test for pixel-size defects – and uniformity. This test approach has some inherent assumptions:

- Blemishes will be a subset of defects detected by the pixel-functionality algorithm. This implies that a clean, dust-free imager surface must be presented to the tester.
- The uniformity test will be more sensitive than a Newton fringe test.
- The manufacturing process will not compromise any of the parameters specified in the design. These parameters include color, crosstalk, flicker, image retention, and tilt loops.

If the previous assumptions and discussion are accurate, the only test that remains for consideration is contrast. The manufacturer must be convinced by design verification and process control that the contrast specification is met consistently. Alternatively, the manufacturer may ask, "Do the same process variations that cause an unacceptable contrast produce a 'fail' in any of the other tests being used?" If so, the contrast test can be removed.

Basically, the choice of LCoS high-volume tests must be continually refined based on product specifications, process improvements, and product maturity. Ultimately, the goal is to remove the need for a tester. In the nearer term, the goal is to continually reduce test time. As products and processes mature, the test for pixel functionality and defects becomes the most time-intensive test, and therefore governs the tester throughput.

To help assess the throughput of the tester in cases where the pixel-functionality test is rate limiting, we compiled data that compares the system components and capabilities of some leading testers (Table 3). These tester features define the performance envelope for the LCoS manufacturer. The camera size and the ratio of camera pixels to device pixels define the number of images that must be captured to measure a specific device, *i.e.*, a specific array of pixels. In addition, a higher ratio of camera pixels to device pixels implies a greater probability of defect detection. All else being equal, the higher confidence in defect detection comes at the cost of slower throughput.

The system contrast has a direct influence on the system's ability to resolve differences in gray scale. In testing LCoS devices, this resolution capability is evident in the pixel functionality and uniformity tests. Of the tester companies, Westar has given significant consideration to system contrast, which is reflected in the specification for system contrast over the range of required wavelengths.

Grading of Parts

The flexibility of the tester in grading parts as a function of device and market is another essential feature. A production tester must test different parts using different test electronics and product specifications. The soft-

Table 3: Comparison of the System Components and Capabilities of Some Leading Testers

Vendor/ Tester Feature	Anteon	Cimmetric Technologies	Integral Vision	Westar
Camera size	1024 × 1024 (2 cameras)	1.3k × 1k	1.3k × 1k thru 4k × 4k	1.3k × 1k
Camera pixels:device pixels	16:1	9:1	9:1 (proposes 6:1 for high-pixel-count devices)	16:1
Spectrometer	x	x		x
System contrast	1000:1	4000:1	1000:1	9000:1 @ 550 nm and >1000:1 from 475 to 750 nm
User-defined regions of interest	x	x	At factory	x
User-defined grading criteria	x	x	At factory	x
Cell testing	Maybe	Maybe	No	No

ware must have the capability to be easily changed by an on-site engineer. Having a spectrometer incorporated in the tester allows the LCoS manufacturer to test contrast and reflectance by different methods, which could prove useful in meeting certain customer specifications.

The ability to perform cell-based testing is warranted for low-yielding products and for products with high packaging costs. As the industry matures, this justification for cell testing will lose its validity. But if there is to be a sort yield for products of differing package configuration and image quality, it may be necessary to perform automated testing at the cell level.

We believe that each of the testers listed in Tables 2 and 3 has a distinctive benefit. The Integral Vision system is the lowest in cost. The Westar system has the best-conceived approach to measuring system contrast, and is also being modified for automated materials handling under a U.S. Display Consortium contract. This will certainly be a distinctive feature.

The Cimmetric Technologies tester is the most robust in mechanical design of any of the testers we have reviewed. The Anteon tester is currently employed by Three-Five Systems in the high-volume production of LCoS displays for three-panel systems. The Anteon tester has delivered a greater than 90% uptime in the most recent quarter. Ultimately, each of these testers will be judged by its capability and robustness in the manufacturing environment.

We hope that this article will initiate a dialogue regarding a sensible approach to LCoS high-volume manufacturing test. The success of both LCoS manufacturers and the suppliers of their test equipment will depend on reaching clear descriptions of test definitions and test requirements. ■

Please send new product releases or news items to Information Display, c/o Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003.

Measuring Microdisplays

Measurement procedures designed for direct-view displays do not adequately characterize the performance of microdisplay-based systems. To help guide the direction of microdisplay development, new procedures are needed.

by Haviland Wright and Mark Handschy

MANY CHALLENGES will be encountered in the transition of liquid-crystal microdisplays from a promising technology through proof-of-concept to volume production of commercial imaging devices. Among the toughest of those challenges will be the identification of appropriate characterization methods and metrics. In addition to providing the information necessary for microdisplay product design and manufacturing, the testing results will help manufacturers determine the direction that microdisplay development must take in order improve performance.

The first microdisplay applications area that will require high-volume production is consumer products. In fact, the production of viewfinders for digital cameras and camcorders and microdisplay-based rear-projection televisions has already begun. Although these applications leverage the performance and cost advantages that are unique to microdisplays, the evaluation of system performance often utilizes legacy test instrumentation that has been designed for direct-view displays. In order to develop instruments that are specifically designed to measure microdisplay characteristics relevant to end-product performance metrics, product designers must explore the similarities and differences between microdisplays and direct-view displays.

Haviland Wright is Chief Executive Officer at Displaytech, Inc., 2602 Clover Basin Dr., Longmont, CO 80503-7603; telephone 303/772-2191, fax 303/772-2193, e-mail: haviland@displaytech.com. Mark Handschy is President and Chief Scientist at Displaytech.

One difference is that there are currently few, if any, direct-view microdisplay applications. This has critical implications for the evaluation of microdisplays. In microdisplays – unlike direct-view display technologies – we must distinguish the performance of the microdisplay itself and that of the system delivering the viewable images to the user.

As microdisplay applications become commonplace, the reliance on display-evaluation systems geared to direct-view displays will have to give way to instruments, methods, and metrics that address microdisplays specifically. Such systems must be built with an understanding of microdisplay characteristics and capabilities, as well as the requirements of systems that produce images using microdisplays.

Although assessments of display-system performance are essentially qualitative, measurement is critical in display assessments. Display-system measurements can include estimations, observations, evaluations, appraisals, and judgments. In many cases, specialized instruments provide the means for reducing observations to numerical data. When the display system is observed in operation, however, the effects of a single variable or single system component may be difficult to identify because the user's perception of an image depends on the operation of the entire system, including its optical and electronic components.

The measurements, often made with sophisticated instruments, to characterize display performance are meaningful only if three essential assumptions are valid: (1) the measurement can be reproduced, (2) the dispersion and bias of repeated measurements is known and constant, allowing measurements to be aggregated into sets of repeated trials or time series, and (3) the measurements of display systems are assumed to be relevant. By "relevant," we mean that the measurements must predict some aspect of user experience, guide product improvement, or provide a basis for comparing one display product with competitive display products.

None of the above assumptions is generally true for microdisplays. Consider, for example, the measurement of contrast for a near-to-eye microdisplay. The light that enters the photometer must come from a complete microdisplay system comprised of a lamp, illumination optics, a microdisplay component, a polarizing beam splitter, and perhaps a viewing optic. Unless each of these elements is present, light can not enter the photometer but their presence introduces to many variables in the measurement.

These measurements are not valid as a means of comparing microdisplays unless each manufacturer conforms to a standard reference system, which must be recalibrated on a regular basis. Without such a standard, every measurement reported would be meaningless. Comparisons between systems – or even on the same system at various locations – could not be taken at face value.

Consider, for example, the reported contrast ratios of CRTs. The results of these measurements, made in almost completely dark rooms, are extremely high. But the measurements are not representative of user experi-

0362-0972/01/1703-018$1.00 + .00 © SID 2001

ence under normal viewing conditions. If "normal conditions" includes the use of room lighting, the contrast of a CRT can easily degrade to a value roughly equal to that of a first-generation GAME BOY®.

Other types of displays – such as rear-projection microdisplay systems – have much lower contrast ratios than CRTs in totally dark rooms but outperform them under normal conditions. So, how is contrast to be measured? In a totally dark room? The problem is that the ranking of displays in terms of contrast ratio, or some other characteristic, can change depending on the conditions under which the measurement is made.

The situation gets more complex when multiple measurements are considered. Here it is possible to create performance targets that appear reasonable taken one at a time, but are inconsistent when taken together as an overall program for system improvement. Consider, for example, the very sensible desires for uniformity in the dark state and for high contrast. Both characteristics are critical for high-quality images, but improvements in contrast make dark-state nonuniformity more evident and easier to detect.

With multiple conditioning factors and cross-dependencies, the responsibility for valid characterizing data must rest with microdisplay producers and their customers. Current display-measurement standards based on emissive and transmissive direct-view displays – the CRT and LCD, respectively – do not provide a complete conceptual base for methods and metrics intended for application to microdisplays. The increasing commercial significance of microdisplays will drive the evolution of new microdisplay-specific measurement standards. ■

Laser Glass Cutting

Sealed CO_2 lasers can reduce FPD-glass production time by improving cut quality and eliminating the post-processing steps necessary in mechanical scribe-and-break techniques.

by Stephen Lee

THE seemingly insatiable consumer appetite for electronic devices is presenting the flat-panel-display (FPD) industry with an explosive growth in demand for its products. Wireless telecommunications devices such as mobile phones, portable computing devices such as notebook computers, wide-screen televisions, and other consumer-electronics devices that incorporate FPDs are enjoying an unprecedented explosive demand in the marketplace (Figs. 1–3). This in turn has forced the FPD industry to increase production, and manufacturers are investigating many ways of achieving this goal. Among the possibilities are newer alternative manufacturing technologies – such as laser cutting of glass. This article will compare laser cutting with the more traditional methods of glass separation currently being used by the FPD industry.

Cutting FPD Glass

The traditional method of cutting glass, which involves mechanical scribing with a diamond blade or a hard metal wheel followed by breaking the glass, has remained essentially unchanged for decades. Two newer methods have been investigated since the early 1970s, and have been steadily improved and developed into practical manufacturing solutions for cutting glass. Both involve the use of carbon dioxide (CO_2) lasers. One method is a laser scribe-and-break process; the other is a direct laser-cutting technique.

The liquid-crystal displays (LCDs) used in mobile phones, PDAs, *etc.*, are typically made of borosilicate glass that is 0.7 mm thick (or less), while plasma-display panels (PDPs) used in flat-screen monitors and large-screen TVs use 2.8-mm soda-lime glass. Both types and thicknesses of glass can be separated by either laser-cutting method.

Mechanical Scribe-and-Break Method

The traditional method of cutting glass is a two-step process in which a line is mechanically scribed on the glass surface by either a diamond blade or a hard metal wheel. Following this, the glass is separated by mechanically stressing the glass panel until it snaps along the scribed line.

After the glass is separated in this way, it must pass through several post-processing steps. First, the glass must be cleaned because either the diamond blade or the hard metal wheel used in the scribing process creates residual glass-dust particles that settle onto the surface of the glass panel. After cleaning, the panel edges are beveled and polished, and finally the panels are cleaned one last time.

Direct Laser-Cutting Method

The idea of cutting glass with lasers was investigated in the early 1970s, but the process only became practical from a manufacturing standpoint in the mid-1990s following

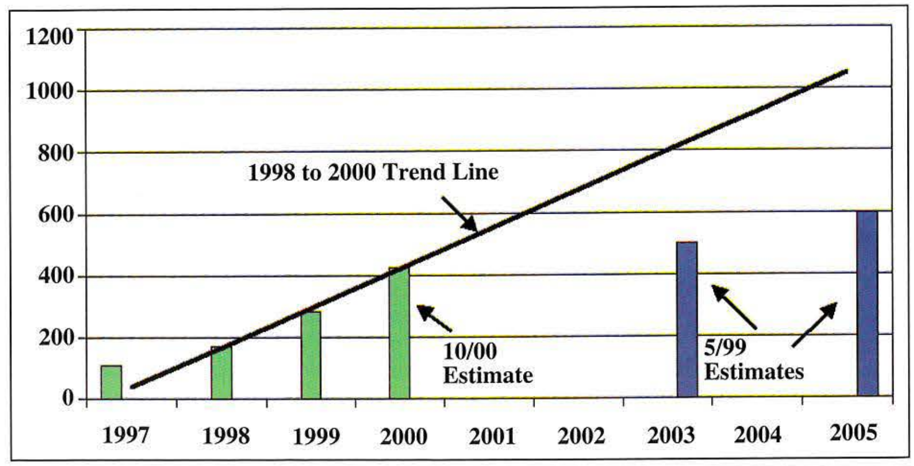


Fig. 1: *Worldwide sales of mobile phones that use small LCDs are a major force in driving increased demand for FPDs.* (Data and graphic courtesy of IPC TMRC 11/2000.)

***Stephen Lee** is Product Manager for CO_2 lasers at Coherent Photonics Group, Laser Division, 5100 Patrick Henry Dr., Santa Clara, CA 95054; telephone 408/764-4663, fax 408/764-4800, e-mail: stephen_lee@cohr.com.*

0362-0972/01/1703-020$1.00 + .00 © SID 2001

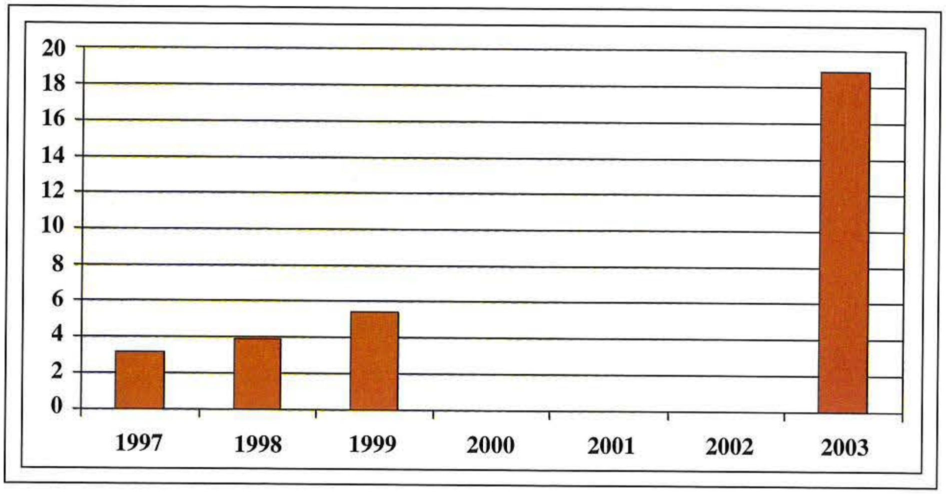


Fig. 2: *Worldwide sales of hand-held devices such as personal digital assistants (PDAs) are expected to increase fivefold by 2003.* (Data and graphic courtesy of IPC TMRC 6/2000.)

the development of the sealed CO_2 laser. Prior to the advent of sealed lasers, flowing-gas lasers with output power of more than 1 kW were used to cut glass, and developers found that they cut at viable rates. But, since laser cutting is essentially a thermal process, the high-power lasers would produce local melting of the glass. The result was an edge that was not clean or sharp; edge grinding was therefore needed for most applications, which offset the advantages of laser cutting.

Unlike the flowing-gas lasers of the past, sealed CO_2 lasers incorporate slab-discharge technology and diffusion cooling, which result in several important advantages for FPD-glass cutting. As the name implies, sealed lasers completely enclose the lasing gas mixture between two rectangular plate electrodes, which results in a robust yet simple construction. The gas mixture is permanently confined within this cavity and does not need to be replenished or replaced. For example, the lasing gas in the Coherent Photonics Group's Diamond series of sealed CO_2 lasers lasts for up to 25,000 hours of continuous operation.

The slab-discharge design also results in a very compact laser package that can be integrated into small dedicated industrial systems, such as software-controlled automated glass-cutting stations. A significant benefit of the sealed laser is the accuracy with which its output beam can be controlled. These lasers emit their light in pulses, which permits accurate control over how much and how fast energy is delivered for material processing. A single sealed laser can therefore be used to cut a variety of types and thicknesses of glass by switching between sets of preset parameters stored in software.

During direct laser cutting, the far-infrared (10.6 μm) beam from a medium-power (250–500 W) sealed CO_2 laser is focused onto a glass surface (Fig. 4). Both the soda-lime and borosilicate glasses that are used in FPDs strongly absorb this 10.6-μm laser light to a depth of a few microns. Typically, the laser's focal spot is elliptical, so the laser energy is absorbed in a narrow region on either side of the intended break line. The break line is defined by moving the focal spot along the surface of the glass panel either by moving the panel itself or the laser-focusing optics. The spot speed is chosen so that the glass is heated enough to experience local thermal tension without becoming hot enough to melt.

A jet of coolant closely follows the path of the laser's focal spot, and directs cooling liquid or gas – or a mixture of the two – at the glass surface. This rapid heating and cooling causes a crack to form along the line of maximum thermal tension defined by the path of the laser beam. The depth to which this crack can be created depends on the power of the laser and the speed at which the focal spot is translated. To initiate the crack, it is necessary to mechanically score the glass at the start of the break line.

Direct laser cutting is a single-step process. It also requires no post-processing because laser-cut edges are naturally smooth, although

The Case for Mechanical Scribing

The laser scribing of glass is an exciting technology. In their enthusiasm for it, several vendors have expressed the belief that laser scribing is faster, cleaner, better, and less expensive than the proven mechanical-scribing technology. Why, then, do the vast majority of FPD production lines still use mechanical scribing? The answer is a short one: Although laser separation offers real benefits, the technology is not yet ready to deliver those benefits cost-effectively in high-volume-manufacturing environments. Some of the claimed benefits are listed below.

Speed. The recently reported speeds of laser-scribing machines are certainly acceptable, but they are easily matched or exceeded by conventional mechanical scribing. Some mechanical-scriber manufacturers report scribing speeds as much as four times faster than laser scribing. (But please note that many factors play into the scribing process, and the quality of the end product can not be gauged by speed alone.)

Cleanliness. Companies worldwide are able to operate conventional mechanical scribers in cleanrooms without the need for after-scribe cleaning.

Superiority. Three major global contingents are working on improving the quality of laser glass scribing, and these companies have recently produced some striking results. If the scribe process is conducted properly, both the laser and mechanical technologies produce clean and smooth after-break edges, with minimal micro-cracks. I have been told that laser scribing, however smooth, in some cases requires edge grinding and polishing as well as the assistance of a small mechanical scribe to initiate crack propagation. It is hard to see how this process sequence can prove more economical than conventional mechanical scribing.

It is also hard to see how the after-process yields of laser separation can be higher when there are numerous compa-

(continued on next page)

(continued from previous page)

nies using conventional close-tolerance mechanical scribers that report yields in excess of 99%. Current laser technology requires a conventional scribe wheel or stylus to initiate the scribe crack, or vent, prior to laser operation. When a laser scribe vent crosses another laser scribe vent, it is sometimes necessary to use the stylus or cutting wheel at each intersection.

Cost. CO_2 laser tubes need not be replaced as often as a conventional scriber or cutting wheel. But as a laser tube weakens with use, scribe parameters must be changed – much as they do with a wearing scribe wheel. The cost associated with replacing a wheel – or a hundred wheels – does not approach the cost of replacing a laser tube.

It is worth noting that little high-accuracy scribing is done these days with a diamond stylus because it creates glass dust. Almost all conventional scribing is done with a tungsten carbide wheel in ranges from 0.3 to 3.00 mm. It is a simple matter for the operator to change the scribe wheel to meet the characteristics of the glass and, in many cases, of thin-film coatings.

Production costs are very important to manufacturers. This, I believe, is the main reason why most companies still choose a conventional mechanical scriber with 1–6 heads, ranging in price from $35,000 to $225,000, rather than a single-head standalone laser system incorporating mechanical scribing that may cost from $450,000 to $750,000 or more.

One day laser scribing will take a prominent place in the close-tolerance glass-scribing industry, side by side with conventional mechanical scribing. I do not believe that laser technology has quite reached that pinnacle yet.

– Ernest K. Linden

Ernest K. Linden *is the president of TLC International, Phoenix, AZ; e-mail: elinden@tlcinternational.com. His company sells and services mechanical-scribing equipment and CO_2-laser processing equipment, and also offers contract scribing services and process-development consulting.*

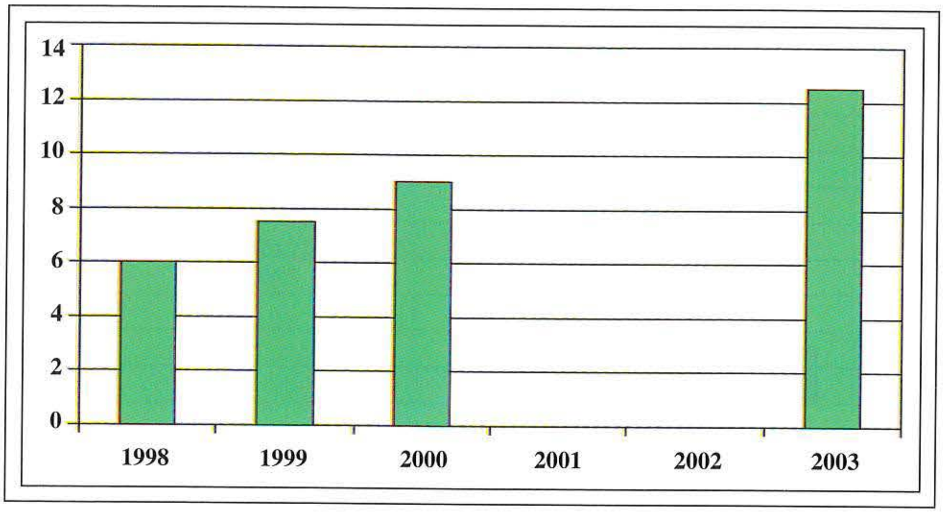


Fig. 3: *U.S. sales of notebook computers that use larger FPDs are also expected to increase.* (Data and graphic courtesy of Custer Consulting 8/2000.)

in some cases the edges are beveled after cutting. Laser cutting creates no micro-cracks or chipping, and the heating/cooling cycle of the cutting process creates a hardened edge with superior edge strength. Because no material is ablated or melted, the laser process also creates no debris or glass-dust particles that must be removed.

Laser Scribe-and-Break Method

The laser scribe-and-break technique is a two-step process in which the first step is virtually identical to that in laser cutting. A CO_2 laser is used to raise the temperature of the glass panel and to define the scribe line while a cooling jet creates the thermal gradient necessary to crack the glass to a shallow depth, thereby creating the scribe line. The final separation of the glass is achieved by breaking the material mechanically. The laser scribe-and-break method also creates a high-quality edge that needs no post-processing and creates no residual glass dust.

Pros and Cons

Each of the glass-separation methods described above have positive and negative characteristics (Table 1). A combination of several of these characteristics will strongly influence the manufacturing throughput, yield, and cost of the final FPD.

Cutting Speed. Three factors determine the maximum glass-cutting speed of lasers: the output power of the laser, the thickness of the glass, and the glass's thermal-expansion coefficient. A typical direct-laser-cutting speed is 200 mm/sec for LCD glass and 100 mm/sec for PDP glass. Laser-cutting speeds are lower than in mechanical scribe-and-break methods, but the superior edge quality, no post-processing, and lower operating and maintenance costs of laser-cutting equipment compensate for the cutting-speed disadvantage.

Edge Quality and Strength. Metal wheel cutters and diamond blades both produce micro-cracks, chips, and inhomogeneities, which result in rough edges that require grinding. These micro-cracks are potential failure sites because any of them can develop into a "macro-crack" during edge-beveling, edge-grinding, and cleaning, resulting in rejected parts.

Laser cutting, on the other hand, creates no micro-cracks, and the heating and cooling cycle of laser cutting toughens the glass edge, making future cracks and breaks even less likely.

Consistency and Reliability. The high edge quality of laser-cut glass is uniform throughout the length of a cut and from panel to panel because a laser beam is a non-contact tool that does not wear out or need replacing. In contrast, the edge quality of mechanically cut glass varies over time because tools degrade with age. The potential for rejected parts increases with tool wear, so worn tooling must be replaced regularly, which results in downtime and reduced throughput.

Post-Processing. As already mentioned, the rough edges produced by mechanical sep-

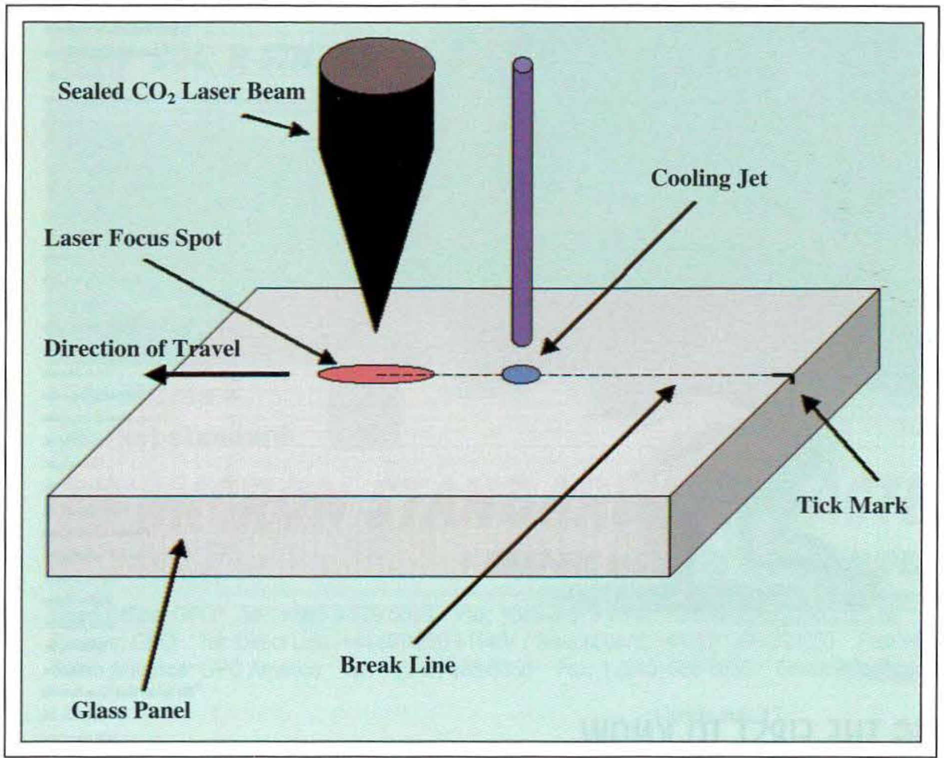


Fig. 4: In the direct laser-cutting process, a focused CO_2 laser beam that produces heat is followed closely by a cooling jet. The combination causes a crack along the line of maximum thermal tension. (Figure courtesy of PTG Precision Technology Group, Inc.)

aration require grinding and polishing, and the glass dust produced by these operations must be cleaned off. Laser separation requires no post-processing because the process leaves no debris and creates an inherently smooth edge. In some applications, the edges of the panels are beveled and cleaned, but beveling is not a risky process with laser-cut glass because there are no micro-cracks and the edges have been toughened in the cutting process.

Manufacturing Costs. Manufacturing costs per part are determined by the cost of materials, consumables, labor, scrapped parts, hard-tool replacement costs, facilities costs, *etc.*, and they obviously increase with each additional manufacturing step. Laser-cut parts require fewer manufacturing steps than mechanically cut parts; therefore, their manufacturing costs are lower. The smooth edge created by laser cutting eliminates edge grinding and polishing steps, which eliminates the consumable and labor costs associated with these steps. Furthermore, because a laser is a zero-wear tool, diamond-blade and metal-wheel replacement costs disappear, and because the sealed CO_2 lasers used in glass cutting are maintenance-free devices, no maintenance or downtime costs are associated with them. In addition, the absence of micro-cracks and the creation of toughened edges during laser cutting reduce rejection and, therefore, scrap rates.

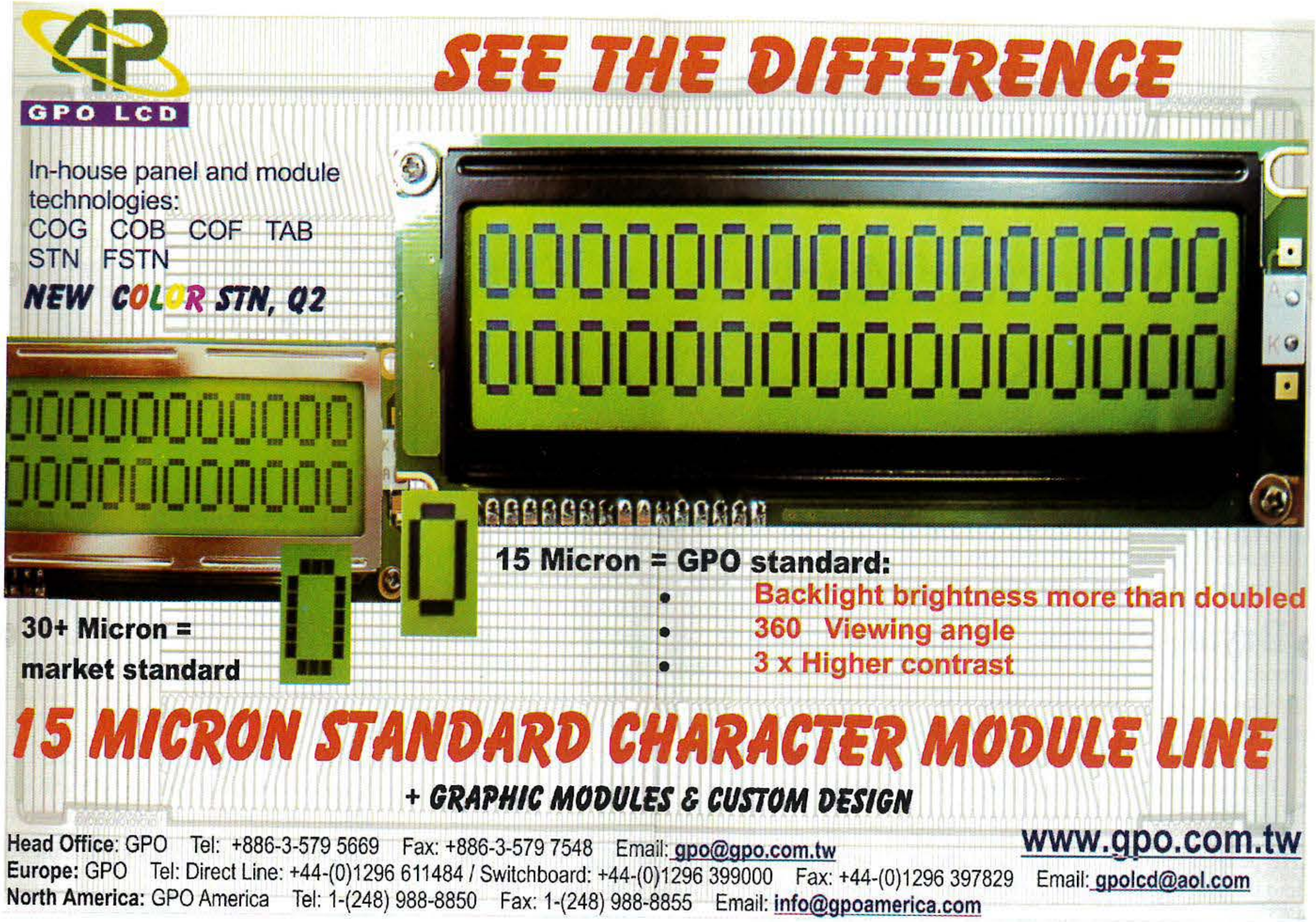
Capital Costs. Scribe-and-break systems are less expensive in terms of up-front capital costs. One manufacturer's single-head wheel scriber costs $70,000. Single-head sealed CO_2 laser models range from about $450,000 to $750,000. However, the up-front capital costs of mechanical scribe-and-break methods must include the cost of grinding, polishing, and cleaning equipment. Once these are included, the capital costs of laser-separation systems and mechanical systems are comparable.

Throughput. The overall throughput of laser-separated FPD glass is higher than mechanically cut glass. Although mechanical cut-and-scribe is a faster separation method, it does not yield a faster overall production time because the poorer edge quality of mechanically cut glass necessitates several post-processing steps, and mechanical tool wear results in downtime to replace worn-out tools.

What Is Industry Using?

The most common method of glass separation in the FPD industry, by far, is the mechanical scribe-and-break method. Mechanical separation has been around for many years and is familiar to manufacturers. Laser separation, on the other hand, is a relatively new and unfamiliar technology. Consequently, direct-laser-cutting and laser-scribe-and-break machines have only been installed in small numbers.

Given the need for increased manufacturing capacity in the FPD industry and the throughput-limiting problems of mechanical scribe-and-break methods, manufacturers need a better glass-separation solution that is both viable and profitable. Modern laser-induced separation can offer the benefits of higher throughput, lower manufacturing cost, and a more robust finished product. For these reasons, it is widely believed that, in the future, laser systems will replace mechanical scribe-and-break methods as the dominant glass-separating technology used by the FPD industry. ■



Circle no. 17

Circle no. 18

LCD-Monitor Markets in Europe and the U.K.

The penetration of LCD monitors is appreciable in Europe and will grow substantially over the next few years.

by Bryan Norris

THE penetration of LCD standalone monitors into the markets for visual display units (VDUs) in Western Europe and the U.K. is growing. In this article, we shall look at the current and forecasted markets, the players, the products, and some of the trends. And we shall also look at the picture across Europe country by country because we are not yet dealing with a United States of Europe. There are significant differences among the various countries.

Market Penetration of LCD Monitors

How far have LCD monitors penetrated the total VDU markets of all Western Europe and the U.K.? Before answering that question, let us define terms. The term VDU represents all monitors, including CRTs, LCDs, and, now coming into the picture, plasma displays. "Total VDU markets" includes both branded and OEM monitors. Branded units are those sold by companies – such as LG, Philips, and Samsung – that are in the business of selling monitors. OEM units are those sold by PC houses with their own label. Everybody has heard of the international PC houses such as Compaq, Dell, HP, and IBM, but we must also take into account the own-label monitors sold by local PC assemblers, such as Time and Tiny in the U.K. Increasingly, these local PC houses are trying to sell significant volumes of LCDs.

Sales of standalone LCD monitors began in Europe in about 1995 when the first 5000 10.4-in. units went mainly to the Swedish

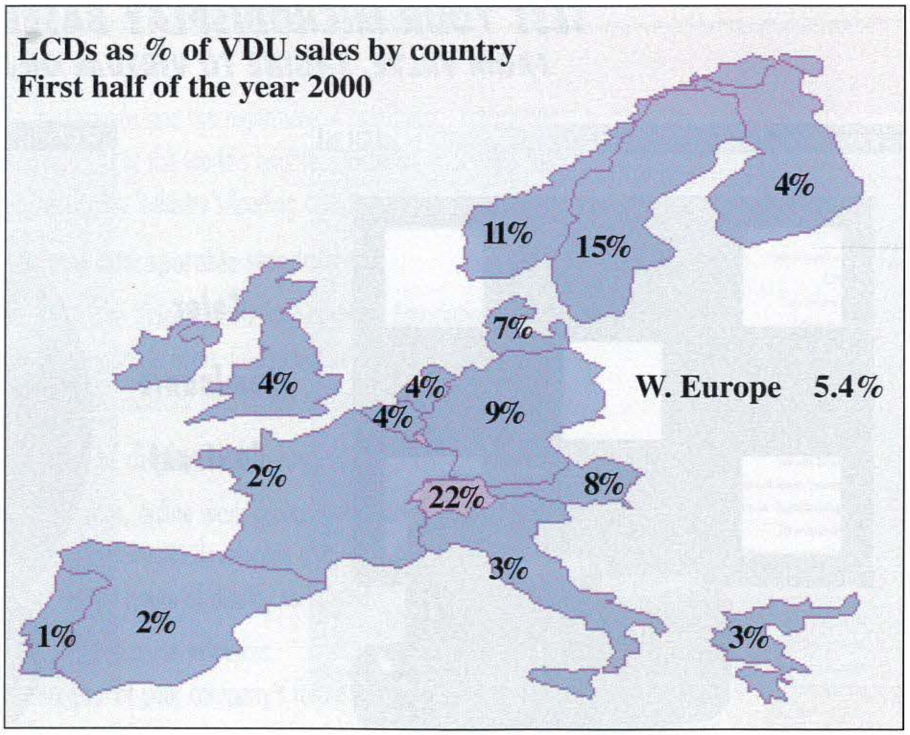


Fig. 1: Market penetration of LCD monitors as a percentage of all monitors sold varies widely from country to country within Europe. (Data and graphic courtesy of Bryan Norris Associates.)

Bryan Norris is Senior Partner at Bryan Norris Associates, 7 Biddenham Turn, Biddenham, Bedford MK40 4AT U.K.; telephone +44-(0)-1234-26-7988, fax +44-(0)-1234-26-2345, e-mail: bnorris@kbnet.co.uk. He is a contributing editor to Information Display. *This article is based on his invited presentation at EID 2000 in late November 2000.*

0362-0972/01/1703-026$1.00 + .00 © SID 2001

W. Europe	U.K.
Philips	NEC
Samsung	Samsung
NEC	Compaq
Fujitsu Siemens	Philips
Eizo	Eizo
Compaq	Dell
VideoSeven	Taxan
LG	IBM
Dell	Sony
Nokia	LG

Fig. 2: Top 10 monitor suppliers by volume for the first half of 2000 are somewhat different in Western Europe and the U.K. (Data courtesy of Bryan Norris Associates.)

market. By 1997, LCD-monitor sales represented 0.3% of the total Western European market. By 1998, this figure was 1.1%, and by 1999 it had jumped to 4.1%. People had expected the jump to be even higher than this, but the expected oversupply of panels did not materialize. (The Taiwanese panel makers did not get on-stream as fast as had been predicted, so prices remained fairly stable.) Despite this, we are predicting that LCD monitors will represent 5.4% of all VDU sales for the year 2000, which will total around 30 million units.

In the U.K., penetration by LCD monitors is somewhat lower, but the volumes are appreciable when considering the size of the U.K. market. This market is especially buoyant because of the flourishing financial sector (dealer rooms are now a sea of LCD screens).

By looking at LCD-monitor shipments as a percentage of the total VDU sales in the first half of 2000 in the other countries of Western Europe, it can be seen that Switzerland is way ahead, with LCDs accounting for 22% of all monitors sold (Fig. 1). In the branded sector in Switzerland, one in three of all monitors sold is now an LCD! The explanation for this singular statistic is that the typical Swiss end user has plenty of money and likes to have the latest technology. In fact, Switzerland is the only market where PC sales exceed monitor sales. Although PCs are usually replaced every 2 years, monitors are expected to last 4 years, so Swiss buyers are prepared to pay a bit more for a high-spec display.

At the other end of the scale are the Mediterranean countries, which are only now starting to accept LCDs. Price is a key factor.

Fifteen Is King

If we break down the market by screen size in the first half of 2000, the 15-in. LCD monitor – which has about the same display area as a 17-in. CRT monitor – is the most successful product by far. Of the 774,000 LCD monitors sold in Western Europe, 78% were 15-in. models. The "professional" 18-in. screen size took the second-largest share (12%), and this was far ahead of the 17-in. units (3%). The 17-in. LCD is considered a "high-end-consumer" product, with roughly the same display area as a 19-in. CRT. One of the reasons for the success of the 18-in. models over the 17-in. is that they have been on the market much longer. However, because the 17-in. units are cheaper to make, we predict that shipments of 17-in. units will overtake 18-in. units in a year or so.

In the U.K., the screen-size profile for the first half of 2000 is somewhat different. Of the 116,000 VDUs sold, 17% were 18-in. units and 6% were 17-in. units. As mentioned earlier, this is because the financial houses, banks, and dealer rooms are lapping up the larger sizes.

Who's Selling What?

The top LCD-monitor suppliers by volume in the first half of 2000 for Western Europe include big international names at the top of the list, such as Philips, Samsung, and NEC (Fig. 2). This is not surprising since they are also in the top world rankings. (NEC and Samsung are currently vying for the position of the leading LCD-monitor supplier in the world.)

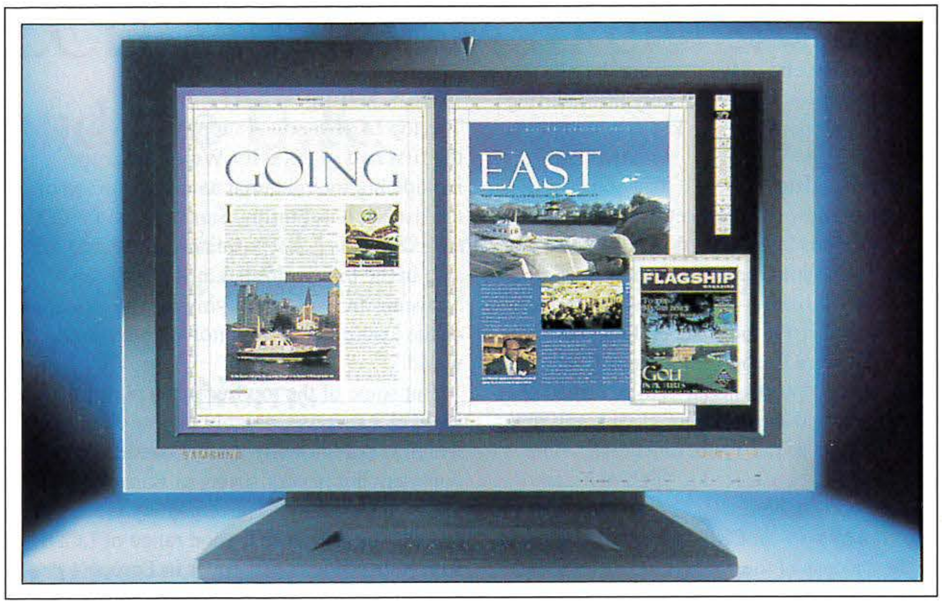
But some of the top European players are more of a surprise, notably Fujitsu Siemens, which is not normally known outside our little continent but is very strong in Europe, particularly in Germany. This company is a high-end PC supplier with a good range of LCDs, so it is an obvious contender in Europe's LCD-monitor battle. Eizo's position as an LCD-monitor supplier in Western Europe is also strong; it was followed by Compaq.

VideoSeven is another brand not seen in worldwide rankings. It is the brand of distributor Ingram Macrotron, based in Germany, and does particularly well in that market. VideoSeven is now trying to expand into the rest of Europe. LG, Dell, and Nokia took 8th, 9th, and 10th places, respectively. Nokia

First half of the year 2000

		<14	14	15	17	18	19	20	21	24
1	NEC			★		★		★	★	
2	Samsung			★	★	★			★	★
3	Compaq			★	★	★				
4	Philips		★	★	★	★				
5	Eizo			★		★	★			
6	Dell			★	★					
7	Taxan	★		★	★	★				
8	IBM			★	★	★				
9	Sony	★		★		★				
10	LG			★		★				
11	iiyama		★	★		★				

Fig. 3: The top 10 U.K. suppliers of LCD monitors seem to have agreed on a common core of products, but when they reach out from that core, they don't all reach in the same direction. (Data courtesy of Bryan Norris Associates.)



Samsung

Fig. 4: The international monitor houses can throw a lot of research and product-development weight at the European LCD market, as well as all other LCD markets. This remarkable wide-screen 1920 × 1200 24-in. SyncMaster 240T was introduced at SMAU 2000 last October.

has now become part of ViewSonic; consequently, the Nokia brand will probably not make it into the top 10 for the full year, but we could well see ViewSonic there instead.

In the U.K., the rankings are slightly different. NEC, Samsung, and Compaq were the top three brands in the first half of 2000. Compaq sells a lot of its PCs in the U.K., where it maintains a high attachment rate, *i.e.*, its PCs are usually sold with Compaq monitors. Philips, Eizo, and Dell had good volume sales in the U.K. Then, in 7th position, came Taxan, followed by IBM, Sony, and LG. Taxan is a strong European player in the LCD markets – it was Taxan that sold those first few thousand units into Sweden back in 1995.

Looking at what products each of the top ten U.K. suppliers were offering in the first half of 2000 is interesting (Fig. 3). NEC has a variety of 15-in. models as well as an 18- and a 20–in. model which it has had for a long time – and recently introduced a 21-in. unit. This company is, and will remain, a good supplier of LCD monitors.

Samsung's big advantage is its fantastic panel-production capacity, available not only for its own brand but for lots of other brands as well. Until fairly recently, Samsung was the only supplier of 17-in. panels and, therefore, branded monitors. But now there are 43 17-in. models being promoted in Europe. Suppliers like Acer, which originally used Samsung's panels, now use their own panels made in Taiwan. As more Taiwanese panel makers come on-stream, we can expect to see the 17-in. size proliferating. Samsung also recently introduced its 24-in. monitor, quite an amazing product, which has a RRP of approximately £4200(U.S.$6000) and a street price that could be as low as £3500(U.S.$5000) (Fig. 4).

Compaq and Philips offer 15-, 17-, and 18-in. product. Philips's 17-in. is new, and the company has recently re-introduced a 14-in. unit. Eizo has introduced its first 19.6-in. unit; Dell has a 15- and a 17-in. model. Taxan is selling out its 10.4-in. models, but its 12.1-in. models are still doing particularly well. IBM has 15-, 17-, and 18-in. models. Sony has now removed its 13.3-in. model from its catalog but has a number of stylish slim 15-in. units.

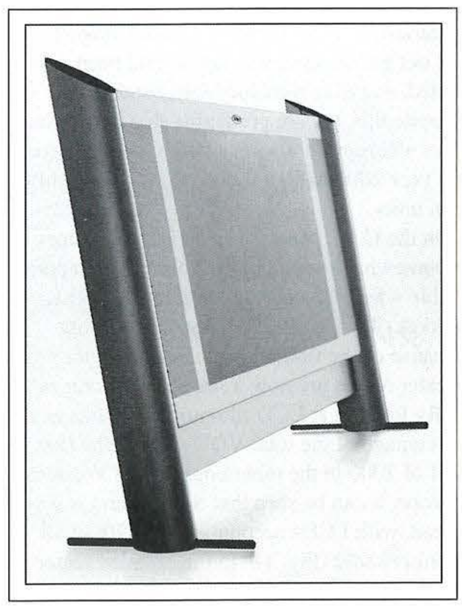
LG, which has been making a 22-in. unit as Apple's Cinema Display, will soon have its own brand on the market, which will probably be a TV monitor. (Monitor–TVs seem to be in vogue now, especially for executives who want to watch the cricket match but switch to their work if anyone comes in!)

There is also a 28-in. video monitor from Sharp, which is already in some local stores. Although accepting video inputs, this unit does not yet have a tuner. The disadvantage of installing a tuner for suppliers importing into the E.U. is the 14.5% tax incurred on TVs, but more and more companies are entering the LCD monitor–TV market. One of the most successful to date is the Italian company Seleco, which has been selling its 15-in. TV–monitor for a year now (Fig. 5).

Another strong Japanese company that is doing well, particularly in the U.K. and Germany, is iiyama.

Competing with CRTs

LCD monitors are, of course, still meeting fierce competition from CRTs, and, now, particularly from flat-screen CRTs. Flat-screen tubes were first introduced around 18 months ago, and there is now a variety of these tubes for CRT-monitor suppliers to choose from: Mitsubishi's NF Diamondtron™, Sony's FD Trinitron™, LG's Flatron™, Samsung's Dynaflat™, and Hitachi's e-flat™. In an analysis of Q1 '00 VDU sales, flat-screen-CRT-monitor sales in the U.K. amounted to 62,000 – 1000 of which were 15-in., 38,000 17-in., 13,000 19-in., and 9000 21/22-in. Interest-



Seleco

Fig. 5: Monitor–TVs are in vogue in Europe now. The success of Seleco's "Ego 15 LCD monitor–TV" inspired the company to show this "SuperEgo 21" LCD monitor–TV at SMAU 2000. It's scheduled to go on sale in Europe early this year.

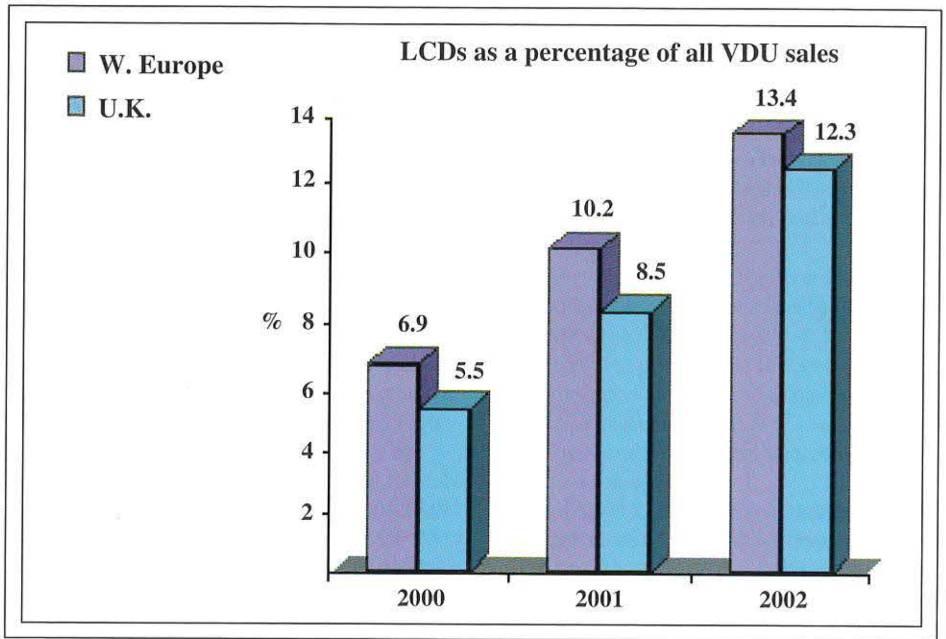


Fig. 6: Market penetration of LCD monitors is expected to nearly double in Western Europe over the next 2 years and more than double in the U.K. (Data and graphic courtesy of Bryan Norris Associates.)

ingly, there were very similar numbers for the 57,000 LCD monitors sold in Q1 '00 – 5000 14-in. and under, 37,000 15-in., and 13,000 17-in. and over).

So we can conclude that flat-screen-CRT sales are already closely tracking LCD-monitor sales. Of course, a major reason for the market strength of flat CRTs is price.

If we want to buy a monitor with a display diagonal of at least 15 in., we are looking at spending only around \$200 for a 17-in. flat-screen-CRT model. For a 15-in. LCD, we would need to find about \$1000 as of the time I am writing this article – although prices are predicted to drop dramatically during 2001. So, we are still talking about a 5:1 price ratio. But price is not the only reason for the continuing strength of CRTs. The CRT is still superior to the LCD in terms of brightness, particularly for CAD/CAM or DTP users. And it will be quite a while before the color gamut of LCDs will match that of CRTs. But in terms of size/footprint, weight, and power consumption, the LCD monitor has the clear advantage. And many people dream of having a svelte LCD monitor on their desk.

A Look into the Crystal Ball

LCD-monitor markets are far from easy to forecast, but that doesn't stop us from doing our best (Fig. 6). We think that for the year 2000, LCDs will command 6.9% of all VDU sales in Western Europe and about 5.5% in the U.K. In 2001, it will be up to 10.2% in Europe and 8.5% in the U.K. And by 2002, it will be up to 13.4 and 12.3%, respectively. LCD monitors are a growing business – and there's still some margin in it. ■

EID 2000 Opens London's ExCel Centre

EID was the first conference and exhibition to appear at London's spanking new ExCel Centre.

by Phillip Hill and George Isaacs

ELECTRONIC Information Displays (EID) – the Society for Information Display's three-day European event – moved to a new venue: the ExCel Centre, a brand-new exhibition and conference center extremely close to the now notorious Millennium Dome in London's former docklands (Fig. 1). It was an opportunity for the many visitors from abroad to see for the first and probably last time the ill-fated theme park built for last year's turn-of-the-millennium celebrations and now likely to be demolished. The Dome was an imposing sight, however, as participants came and went from the ExCel Centre.

SID was in fact ExCel's first client, with the EID exhibition that attracted more than 80 companies and the technical conference that opened on ExCel's first day. Conference Chair Chris Williams warned delegates that they were guinea pigs to some extent. The teething troubles included sweltering conditions during the conference and Arctic temperatures on the exhibition floor, but climatic extremes did not prevent the vast majority of participants from agreeing that the event was a success.

Are Displays Delaying Progress?

The main opening presentation was given by SID President Aris Silzars. In his talk, "The Information Age – Are Displays Keeping Up?", Silzars pointed out that if computer power was doubling every 18 months to 2 years (Moore's Law), then the display equivalent was only doubling every 10 years.

"Today, the best CRTs and LCD panels are still a reasonable match for desktop computers and perhaps barely adequate for portable laptop computers, cellular phones, and first-generation PDAs," he said. "But, what happens next? Although it is difficult to quantify all display parameters into a 'goodness' factor, the reasonable estimate is that display capability is doubling no faster than about every 10 years. If this is correct, then there is a serious rate-of-development mismatch that will require resolution. At our present rate of progress, in another 10 years we will have become the highly visible bottleneck of the Internet society."

The much-hyped convergence espoused by Bill Gates between television, computers, and the Internet would not happen, Silzars asserted, but instead there would be a proliferation of Internet devices. Turning to specific technologies, Silzars said that plasma-display

ExCel Centre

Fig. 1: EID 2000 was the inaugural event at London's new ExCel Centre.

***Phillip Hill** is Deputy Editor of Opto & Laser Europe magazine at IOP Publishing Limited, Dirac House, Temple Back, Bristol, BS1 6BE, U.K.; telephone +44-117-930-1014; fax +44-117-925-1942; phillip.hill@ioppublishing.co.uk. **George Isaacs** is Information Display's European Advertising Executive; telephone +44-(0)-1480-218400; george@gandg.demon.co.uk.*

0362-0972/01/1703-030$1.00 + .00 © SID 2001

panels were at a critical stage: "If their cost does not come down significantly, they will not become a consumer product." On the other hand, he was very optimistic about the future of OLEDs. "If I had to pick one technology right now, it would be OLEDs. There will be rapid development over the next 10 years."

Silzars was scathing about leapfrog technologies: "Real breakthroughs only occur at the materials level," he said.

This view was echoed in a keynote speech given by Professor Jack Silver, Head of the Centre for Phosphor and Display Materials at the University of Greenwich, London. Light-emitting phosphors are a vital element of many future-generation displays. But the subject is under-researched and under-resourced, he said.

"Phosphors are probably the most used and least studied component of electronic displays. The complexity of phosphor preparation is often referred to as a 'black art.'"

Silver believes that manufacturers of the next-generation television receivers and desktop monitors are neglecting fundamental research into the materials on which the entire displays industry is based.

Silver questioned much of the received wisdom current in phosphor development for display devices. The usual practice for CRT manufacturers is to purchase industrially available phosphors and assume that the phosphor can be used for new or extended applications. Many companies assume that phosphor optimization can be left to the later stages of development of new-technology displays that incorporate these materials. Silver was adamant, however: "History shows that, in nearly all cases, the reverse has been the case and major industrial exploitation has had to wait for the development of suitable phosphors."

More importantly now, the choice of light emitter, and its quality and reproducibility, are crucial to two emerging technologies – organic light-emitting diodes (OLEDs) and field-emission displays (FEDs) – which have the potential to replace established LCDs. Silver said that manufacturers of these devices neglect at their peril the all-important light emitters themselves.

In FEDs, it was previously thought that the addition of conducting powders to standard phosphors merely made the deposited screen more conductive. This is now being questioned, Silver said. He pointed out that there is little agreement on which phosphors can be used for FEDs. Some manufacturers claim that even minute traces of alkali metals cause instabilities, while others state that sulphides contaminate the microtip emitters. Others actually use sulphide phosphors in microtip devices and report improved performance of low-voltage phosphors.

However, Silver said, the improvements reported so far have not yielded a practical low-voltage FED. Zinc oxide still remains the most efficient phosphor at low voltage, but little quantitative data is available on the actual maintenance characteristics of low-voltage phosphors under long-term operating conditions in a real display.

Turning to LEDs, Silver stressed that, although there has been much hype about using blue, green, and red gallium nitride LEDs together to make cheap, efficient white light, it has now been recognized that there are serious problems. These include the fact that the three different LEDs may age at different rates, so, although the light begins as white, it may deteriorate quickly. Silver suggested that a combination of LEDs and phosphors may be a better long-term solution.

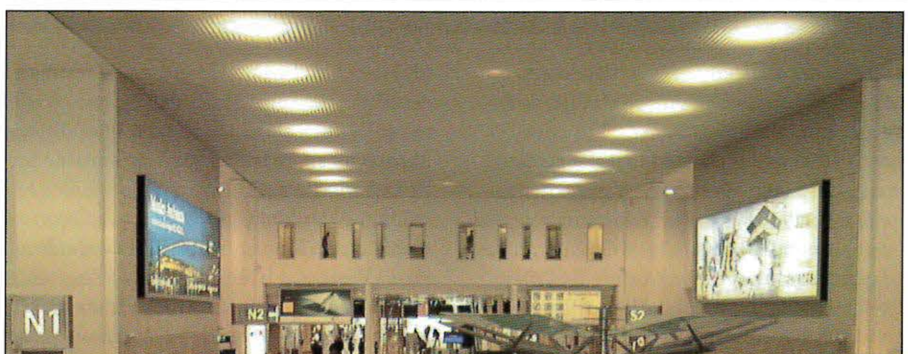
Silver believes that perhaps the most urgent need is for more fundamental research. "The demands for stable, saturated RGB high-resolution phosphors operating over a range of excitation is still far from being satisfied."

Mike Weaver of Universal Display Corp. (UDC) told the conference of his company's latest developments in flexible OLEDs. UDC will publish papers over the next few months announcing efficiencies of 100% and lifetimes of more than 10,000 hours with new structures, he said.

Lifetimes are a problem, he admitted, because water goes through the plastic polymers used in flexible and conformable structures. UDC is working on multi-layered barrier coatings consisting of layers of polymer films and high-density dielectric layers. Over 1000 hours has been achieved so far, he said.

Making Money

The first day of the conference was devoted to making money from displays and market trends. Jack Pringle of Pringle Brandon, Ltd.,



Phil Dakin, SID U.K./Ireland Chapter

Fig. 2: EID participants enter the brand-new ExCel Centre.

Society for Information Display

Fig. 3: *The exhibition at EID included 60 exhibitors.*

presented a case study of how flat-screen technology has revolutionized dealing-room practices in investment banks. The company's 1996 report showed that flat screens brought about smaller desks, higher occupational density, lower power consumption, and lower air-conditioning bills. Within a year, the company brought the world's first major flat-screen dealing room on-line. Flat screens are now set to fully colonize the office environment, said Pringle.

Myrddin Jones of Hitachi Europe gave a presentation on FPDs for monitors. He estimated that more than 1.5 million monitors based on TFT-LCD technology will be sold in Europe in the year 2000. Although impressive, he said, this number still represents only 5% of the total number of monitor sales, and there remains enormous potential for FPD-monitor growth. (For more information, see the accompanying article by Bryan Norris, "LCD-Monitor Markets in Europe and the U.K.")

On the second day, devoted to emissive and 3-D displays, Sergei Bukesov of Saratov State University, Russia, explored the characteristics of the phosphors used in low-voltage displays such as FEDs. He presented results of detailed experimentation and analysis leading to projections about the reliability of different phosphors and whether they are suitable for FED devices.

On the third day, given over to microdisplays and human factors, the conference heard Professor Bill Crossland of Cambridge University's Engineering Department describe recent innovations in deep submicron silicon technology that have greatly expanded the potential of next-generation microdisplays. New 0.25- and 0.18-μm processes have opened up the possibility of designing complex circuitry at each individual pixel, and the development of planarization-based metal mirror processes means that the circuitry can be set beneath an optical-quality pixel.

Microdisplays can now be used to project tiles onto an optically addressed display with memory, generating display resolutions in excess of 5000 × 5000 pixels. Subpixel circuitry can also be used to create intelligent pixel devices with complex image processing such as wavelet compression at the individual pixel level.

The Exhibition

The new ExCel Centre is an impressive facility. It occupies 90,000 square meters and, when complete, will have six on-site hotels with 1200 rooms and 150 apartments; several cafes, bars, and restaurants; and a crèche, nightclub, and business and media production centre. It will be served by three railway stations and a mooring suitable for large vessels. The Centre makes extensive use of smart-card technology to ease registration and expedite access to accommodations, services, and facilities. All this, regrettably, was not available when EID opened. The set-up day saw more builders with hardhats than exhibitors, and an air of gloom prevailed. But come the opening, the section of the ExCel Centre occupied by EID was in good shape and ready for business (Fig. 2).

EID shared a hall with an "Instrumentation" exhibition, with the idea of increasing the number of potential visitors to both shows (Fig. 3). Unfortunately, the event conflicted with Electronica in Munich – Europe's biggest electronic show, which has a large display section. This probably cost EID some exhibitors and visitors. Some exhibitors felt obliged to attend both events, but with a strain on resources that was, in some cases, obvious.

Nonetheless, there were 60 exhibitors at EID. Although some of the regulars from previous years were absent, new exhibitors compensated. The presence of several of the big Japanese display companies – Fujitsu, Mitsubishi, NEC, and Sanyo – was encouraging. The ***Fujitsu*** booth featured a driving simulator that utilized its impressive high-definition plasma screens (Fig. 4). This was a very popular attraction – for exhibitors as well as show visitors!

NEC also featured its range of plasma screens – as well as projectors – in its booth. The emphasis was on public-information displays and multimedia in all environments, from retail through leisure. NEC was happily pointing out that just outside the ExCel Centre at London's Millennium Dome there are over 350 of the company's PlasmaSync™ monitors in use.

The ***Mitsubishi*** booth emphasized projectors to good effect with a 2 × 2 video display wall. Each 50-in. screen was showing back-projected XGA images, with a gap between images of only 1 mm. Also on display was Mitsubishi's new X400 model, which showed its XGA images with a light output of 3000 ANSI lumens.

Sanyo displayed LCD monitors from 12 to 18 in., many fitted with touch screens, in desktop configuration and in chassis-mounted form for kiosk applications. Sanyo is not well known for its own brand of desktop monitors. When asked about this, the booth representative said the company's intention was to become more prominent in the future.

Noritake's U.K. subsidiary Itron (U.K.) Ltd., which specializes in the field of vacuum fluorescent displays (VFDs), had an impressive number of more than 200 standard products on view. VFD remains an extremely popular choice in many retail applications, not least for its demonstrated brightness of 3500 cd/m^2. One new version on display was a low-power low-profile transformerless model.

Arrow, ***Axon***, ***Fujitsu***, ***Ginsbury Electronics***, ***Impact***, ***NEC***, and ***Review Display Systems*** put particular effort into their booth designs. The results stood out – and pulled in extra visitors. Ginsbury, a specialist supplier of display solutions and a regular EID exhibitor, had one of the more eye-catching booths at the show. The company featured rugged and sunlight-readable LCDs, and reported exceptional interest in its sunlight-readable backlights from Landmark (Fig. 5).

A new feature of the show was a "Projector Shoot-Out" organized by Reflex, the U.K.'s leading presentation specialist and a newcomer to EID (Fig. 6). In the Shoot-Out's neutral environment, the difference between the different manufacturers' offerings was quite marked. A total of 20 projectors in a range of weights, sizes, resolutions, and luminous outputs from ***Sharp***, ***InFocus***, ***Sanyo***, ***Epson***, ***Mitsubishi***, ***ASK***, ***Plus***, and ***JVC*** were on display. There were no published "winners," but audience reaction showed the Sanyo XP30 to be well appreciated for fixed installations and rear projection.

Also on display from ***Reflex*** was the DNP Holographic Screen, a transparent, remarkably bright rear-projection screen that is designed specifically for point-of-sale applications or showroom windows. This screen probably attracted more attention than the projectors. Also of interest was ***Paradigm***'s split-screen rig that very effectively demonstrated the difference between front- and rear-screen projection. The Shoot-Out was very popular with show visitors, and Reflex was positive about exhibiting at next year's show.

Society for Information Display

Fig. 4: *In Fujitsu's booth, an automotive simulator that used one of the company's impressive high-definition plasma screens was a popular attraction.*

Another holographic screen was in the booth of late-entry U.K. exhibitor ***Digital Display Corp.*** Their screen was causing considerable interest, and appeared brighter than the DNP model. But extra brightness can conspire against a desirable feature of holographic screens: their transparency. The exhibitor was reluctant to reveal the screen's manufacturer, but reliable sources indicate the screen is of German origin.

EID traditionally has a strong showing of resellers, integrators, distributors, and specialist manufacturers: companies such as ***Craft Data, Anders Electronics, Danielson, Display Solutions, Impact Memec, Manhattan Skyline*** (a U.K. company despite its name), ***Review Display Systems***, and ***Sabre Vision***. Another of the regulars is ***Sascal Displays***, which manufactures special monitors for industrial and military applications. Sascal's booth was dominated by a fine range of CRT monitors targeted at specific applications.

There were a number of start-ups at the show, such as ***ZBD Displays*** (DERA's first spin-off), with its Zenithal Bistable Device; ***Cam3D***, with its "Wedge" concept that provides edge projection and image magnification; ***Elam-T***, with its organic phosphors (ELAMATES) for photoluminescent and electroluminescent applications; and ***EPI Centre***, a University of Abertay spin-off that provides measurement and evaluation facilities for the display industry. At the show, ***EPIC*** ran a series of test and measurement clinics with the cooperation of Trident Displays, which supplied the display equipment.

There were a number of European measurement companies exhibiting, including ***ELDIM SA*** from France, a manufacturer of systems for evaluating the electro-optical characteristics of all types of displays. Also from France was ***Light Tec***, with its videophotometer; and from the U.K. came ***Micron Techniques***, a specialist distributor of electro-optical prod-

Ginsbury Electronics

Fig. 5: *Ginsbury Electronics featured rugged and sunlight-readable LCDs on its well-turned-out stand.*

ucts and of instruments for calibration and for the measurement of light and temperature.

A few U.S. companies had their own booths, rather than just being represented by U.K. distributors or partners. Among these were ***Colorado Microdisplay***, showing a number of head-mounted applications of their chip sets; ***DuPont Displays***, with its holographic films, which could be seen in action on the DNP screen in the Reflex booth; ***Integral Vision***, with its "SharpEye" FPD Inspection System; ***Synaptics***, which had bought out the U.K. company ***Absolute Sensors*** in the interval since the last EID and were showing touch and pointing devices for hand-held and mobile applications.

At the show, Synaptics issued a press release announcing a partnership with the U.K. company Densitron Plc. Under the terms of the deal, Synaptics and Densitron will jointly develop and market the ClearPad and Spiral technologies that will be integrated into Densitron's own range of LCD modules.

Several companies of the ***Video Display Corporation*** group were present, including ***Lexel Imaging Systems*** with its extensive range of miniature CRTs, and ***Aydin Displays***, with its special-purpose and rugged LCDs. One Aydin product is an LCD with immunity to magnetic fields up to 4000 gauss for use as an MRI in-room monitor.

Several European component and subassembly manufacturers were present, and reported quality enquiries at their booth. Among them were ***Axon***, a French company established in 1965 that was featuring its extensive range of cable solutions, such as AXOLINK, a new flat-cable line, which the company claims is less than half the price of the opposition's. ***Anglia***, which distributes the STMicroelectronics range and was voted the Number 1 European Microcontrol Design Partner for 1999 by STM, was present at EID for the first time. ***Access Keyboards***, which specializes in the financial sector, showed their namesake keyboards, as well as a range of multimedia and broadcast distribution equipment.

Arrow is a major force in display-module distribution. With its brightly lit yellow booth and an enormous number of products on display, the company was hard to ignore. U.K. manufacturer ***Blue Chip Technology*** was present, with its integrated single-board computers for LCD and touch-screen applications. ***IVC Technologies*** is one of the better-known U.K. manufacturers of shielding solutions. From its factory in mid-England, it offers a wide range of coating technologies for EMI/ESD protection. Among the offerings is Elamet®, a process they license from Gfo in Germany and XY Shield. The result is an intriguing "form-in- place" EMI gasket material.

Touch screens were a big thing at EID 2000, and several companies were demonstrating touch solutions. As the 3M acquisition of MicroTouch was still hot news, touch technology was a common topic of conversation. Because touch technology is a central concern only for three of the companies that were present at EID: Synaptics, WASP, and Zytronics. ***WASP*** is a U.K. touch-screen manufacturer whose full name is Wessex Advanced Switching Products, Ltd. A long-established company that started with membrane switches and moved on to become a touch-screen specialist, WASP was displaying a range of standard touch screens from 5.7 to 15 in.

Another U.K. touch-screen manufacturer was ***Zytronic Displays, Ltd.***, which was known as Romag until a recent name change. The company is a specialist manufacturer of optical filters for displays. ***Zytronic*** had a new technology on display: Zytouch, a projected capacitive touch screen that differs from other capacitive types in that it allows a touch screen to be sensed through another screen – one added for protection, for instance. Zytouch can sense inputs from up to 25 mm away from the touch surface.

EID regular ***Brimar*** was present, with its speciality CRTs and a new Managing Director, John Heaton, on show. Brimar is a veteran supplier of CRTs, including miniatures for HMD, and typically serves the industrial and military sectors. Recently, it has gently repositioned itself to provide not only their CRTs but also the electronics that allows customers to package the CRT. In some cases – military applications, for example – the company is providing a complete display solution.

Calibre, a smaller, innovative U.K. company, had a lively booth and Meatloaf vocals summoning visitors to see their latest offerings. Featured were their PremierView LCD driver card and the very recently released

Society for Information Display

Fig. 6: A new feature at EID was a "Projector Shoot-Out" organized by Reflex, the U.K.'s leading presentation specialist and a newcomer to EID.

CityView version aimed at larger OEM markets. The card's design reflects Calibre's long experience in the monitor business. Said Managing Director Tim Broksbank, "We started at the picture and worked our way back to the digitals."

The only Scandinavian company that found its way to EID was Sweden's ***LC-TEC***, which manufactures and markets cholesteric LCD modules. This technology is characterized by zero energy consumption between updates, high contrast, and wide viewing angle.

Kent Modular Electronics, Ltd. (KME), a U.K. specialist display manufacturer, had an impressive array of primarily industrial display products. KME demonstrated its ability to address the replacement market with both CRT and LCD solutions down to a line rate of 15 kHz. Among the company's most recent LCD offerings was the closely packaged VISTA 3 Screen with mullions (the gap between screens) of as little as 17 mm.

The EID show can be an absorbing show to visit. It has been described as a "serious" show, which may imply that it attracts people on a buying mission. Less than 1500 of those people turned up at this year's show, but still some exhibitors said they had "good leads."

Some people in the industry have felt that EID has been getting stale, and this year's running at a new location was seen as a relaunch. But following the show the organizers apparently decided that the competition from Electronica in Munich and the weather problems that have crippled British Rail were not enough to explain away the relatively low attendance. For 2001, EID will return to Birmingham, where the show has pulled good audiences in the past. The dates will be October 30 to November 1. ■

Circle no. 28

Circle no. 29

Circle no. 30

a view from the hilltop

continued from page 4

Today, we are in the midst of another major toy revolution, with robotics, voice recognition, and interactivity. We are approaching the age of intelligent machines through the creative application of technology to products currently intended only for play and entertainment. And what better platform could we have for such experimentation? After all, a toy does not have to do anything "practical." Whatever it does is fine as long as it can sustain some reasonable level of interest and amusement. The criteria for what is "good enough" can be quite arbitrary compared to devices that must fill specified operating needs for business or home applications.

Through toys we can begin to glimpse the interests of future generations. After all, children are less set in their ways and are continually exploring and testing their boundaries and their environments anyway. For example, the strong market response to robotic animals as "pets" may be an indicator of the future acceptance of ever-more-capable robotic products with computer-generated personalities. It is also a positive indicator that voice interaction with our computers will become comfortable for most of us in the next decade.

As a result of the ongoing doubling of computing power approximately every two years, we are fast approaching the time when computers will be limited by the insufficient speed of our fingers to "tell" the machines what we want them to do. We will likewise not be able to absorb the results of these computations with our single-page-at-a-time displays. The limitations of sensors and keyboards on the input side, and displays, printers, and robotic mechanisms on the output side will become serious obstacles to information processing and the implementation of artificial intelligence.

Will it take our children to tell us how to solve these problems? Time and again I read about the coming "age of intelligent machines" and how computers will soon be able to out-think us. With what inputs and outputs? How will they help us if they can't interact with the "real" world? For this reason, I think it is great that mechanical toys are once again becoming more popular and that toys combining computing power and mechanical functions are coming on the scene. We need these toys to help us understand how to apply computer power and we need them to train our new generation in the importance of input and output devices to make artificial intelligence useful.

The opportunities for new displays will abound in this environment. We will need them to show us much more than one page at a time. We will need visual cues to great stacks of information. We will need virtual libraries and virtual desktops. We will need voice interaction with our displays – "Computer, please show me ... ". Our children are figuring this out right now. It won't be long before they will begin to show the rest of us how to do these things. I can hardly wait.

Whatever your age, please let me know what you think. I look forward to hearing from you by e-mail at silzars@attglobal.net or president@sid.org, by fax at 425/557-8983, by phone at 425/557-8850, or by the most senior medium, the U.S. Postal Service, at 22513 S.E. 47th Place, Sammamish, WA 98075. ■

Aris Silzars is President of SID and lives on a hilltop overlooking Issaquah, WA.

Singapore/Malaysia Chapter Inaugurated

Saturday, November 25, 2000, marked the formal inauguration of the Society for Information Display's (SID's) Singapore/ Malaysia Chapter. That's the date on which the chapter held its first general meeting at the Singapore Productivity and Standards Board with 16 members present. Officers and advisory committee members were elected, representing a broad cross section of industrial enterprises, government statutory boards, and academic institutions. Dr. Baharuddin Abdul Ghani (Crystal Clear Technology, Malaysia) was elected Chapter Director and Prof. X. W. Sun (Nanyang Technological University, Singapore) was elected Chapter Chair.

Following the general meeting, the chapter registered with Singapore Immigration and Registration as a society, which is a Singapore government requirement for any society with more than ten members.

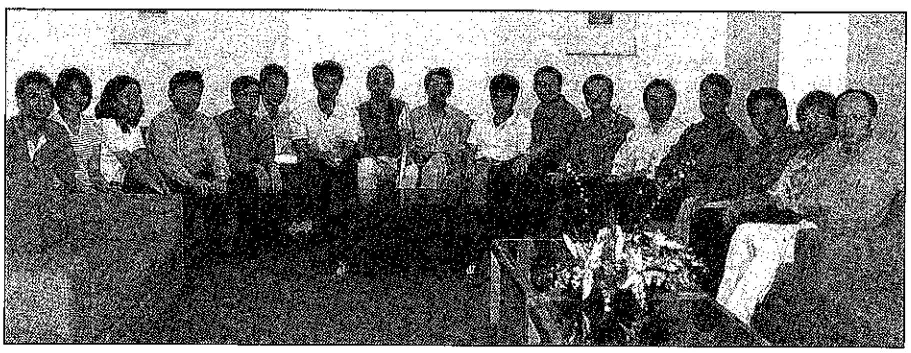
It is timely for a Singapore/Malaysia chapter to be formed. The regional display industry may be comparatively small, but it has quite a long history. The first LCD factories in the region were built more than 15 years ago, and the region now boasts several factories producing LCD products for world markets. The region also has several large CRT manufacturers servicing both local downstream industries and export markets.

This region is expecting more high-end display-industry investments. A major multinational company is building an OLED manufacturing facility in the region that will come on-line soon, and there are strong indications that major international players will be setting up TFT plants in the not-too-distant future.

Both the Singapore and Malaysian governments have recognized the strategic importance of the display industry. This is reflected in the strong encouragement by various government agencies of both countries for attracting investment in the display industry.

As one of the key societies contributing to the development of the display industry in the region, the Singapore/Malaysia Chapter of SID intends to play a major catalytic role in fostering closer relationships among the region's major players in this industry and, in the process, further promoting the industry in this region.

– B. A. Ghani
– X. W. Sun
– L. C. Wong



All of the members present at the first general meeting of SID's Singapore and Malaysia Chapter

calendar

Stage de Formation Generale: Les Techniques d'Affichage et de Visualisation. Sponsored by SID. Contact: Janine Verdez, tele/fax +33-(0)-2-96-23-31-64, e-mail: jverdez.clubvisu@wanadoo.fr.
March 20–23, 2001 Grenoble, France

U.S. FPD Conference and Exhibition 2001. Contact: Kevin Brown, 512/459-3126, fax -3127, e-mail: kevin@displaysearch.com.
March 21–22, 2001 Austin, TX

2001 SID International Symposium, Seminar & Exhibition. Sponsored by SID. Contact: SID Headquarters, 408/977-1013, fax -1531, e-mail: office@sid.org.
June 3–8, 2001 San Jose, CA

INFOCOMM 2001. Contact: ICIA, 703/273-7200, fax -5924.
June 13–15, 2001 Las Vegas, NV

FPD Expo Taiwan 2001. Contact: Cher Wu, SEMI Taiwan, +886-3-573-3399, fax -3355.
June 20–22, 2001 Hsinchu, Taiwan

PC Expo 2001. Contact: CMP Media, 1-800-829-3976, e-mail: kfripp@cmp.com.
June 25–28, 2001 New York, NY

10th Symposium on Advanced Display Technologies. Contact: Dr. A. Smirnov, +375-17-2398858, fax +375-17-2398486, e-mail: smirnov@gw.bsuir.
unibel.by.
Sept. 18–21, 2001 Minsk, Republic of Belarus

Asia Display/IDW '01. Contact: AD/IDW '01 Secretariat, c/o The Convention, Annecy Aoyama 2F, 2-6-12 Minami-Aoyama, Minato-ku, Tokyo 107-0062 Japan; +81-3-3423, fax -4108, http://www.sid.org.
Oct. 16–19, 2001 Nagoya, Japan

Electronic Information Displays (EID 2001). Sponsored by SID. Contact: Chris Williams; +44-(0)-1635-298395, fax +44-(0)-1635-299214, e-mail: chris@logystyx.co.uk, URL: http://www.sid.org.uk.
Oct. 30–Nov. 1, 2001 Birmingham, UK

Color Imaging Conference 2001. Sponsored by IS&T and SID. Contact: SID HQ, 408/977-1013, fax -1531, e-mail: office@sid.org.
Nov. 5–9, 2001 Scottsdale, AZ ■

sustaining members

Acer Display Technology
Ad-Vance Magnetics, Inc.
Advance Reproduction Corp.
Agilent Technologies
AMJ Industries, L.L.C.
Anteon-Engineering Technologies Group
Applied Concepts, Inc.
Applied Films Corp.
Aurora Systems
autronic – Melchers GmbH

Babcock, Inc.
BOC Coating Technology
Brimar Ltd.

Candescent Technologies
Canon, Inc.
CELCO
The Cherry Corporation
Chunghwa Picture Tubes, Ltd.
Clinton Electronics Corp.
Colorado Microdisplay, Inc.
Compaq Computer Corp.
Corning Incorporated
Corning Japan K.K.
CYRO Industries

DigiLens, Inc.
Digital View, Inc.
DisplaySearch
Dontech, Inc.

E-Ink Corp.
ELDEC Corp.
Electro-Plasma, Inc.
eMagin Corp.
Emco Electronics Ltd.
Endicott Research Group, Inc.
ERSO/ITRI

F-P Electronics
Fresnel Optics
Futaba Corp. R&D Center

Gerome Manufacturing Co., Inc.
Graphico Edgelit Panels

Hannstar
Hitachi, Ltd.
Honeywell
Hoya Corporation USA
Hunet, Inc.

iFire Technologies
Imaging Systems Technology
IMT Masken und Teilungen AG
Incom, Inc.
Industrial Electronic Engineers, Inc.
Infinite Graphics, Inc.
Innova Electronics, Inc.
Instrument Systems
Integrated Technology Express, Inc.
Interface Display & Controls, Inc.
Interserv Corp.
Intevac, Inc.
InViso
Ion Systems
Ise Electronics Corp.

Kent Displays

LC-Tec, Inc.
Lexel Imaging Systems, Inc.
LG. Philips LCD
Lite Array, Inc.
Lumin-Oz, LLC

Micronic Laser Systems AB
Microsemi Corp.
Microvision Corp.
Minolta Corp.
Mitsubishi Electric Corp.
Mitsubishi Electronics America
Molex, Inc.
Motorola Telematics Computer Group

NEC Corp.
Nippon Seiki Co., Ltd.

OCLI — A JDS Uniphase Company
OES/ITRI
Optoma Corp.
Optrex America, Inc.

Philips Flat Display Systems
Phosphor Technology Ltd.
Photon Dynamics
Photo Research
Pioneer New Media Technologies
Planar Systems
Plasmaco, Inc.
Polar Vision, Inc.
Polytronix, Inc.
Premium Allied Tool

Quanta Display, Inc.
Quantum Data Inc.

Radiant Technology Corp.
Rexam Image Products
ROLIC Research Ltd.

Sarnoff Corp.
Schott Corp.
Sharp Corp.
Sheldahl, Inc.
SI Diamond Technology
Silver Cloud Manufacturing
SmartASIC
Sony Chemicals Corp. of America
Sony Corp. Research Center
Stanford Resources, Inc.
Symbol Technologies, Inc.
Syntronic Instruments, Inc.

Tamarack Scientific
TCO Development
TDK Corp.
TEAM Systems
Techneglas, Inc.
Terapixel, Inc.
Thin Film Devices, Inc.
Thomas Electronics, Inc.
Thomson Components & Tubes
Three-Five Systems, Inc.
Toshiba America Electronic Components, Inc.

Unaxis
Unipac Optoelectronics Corp.
Universal Display Corp.
Ushio America, Inc.

Video Electronics Standards Association
Viratec Thin Films Inc.
Vishay–Dale Electronics, Inc.

Westar Corp.
White Electronic Designs, Inc.
WINTEK Corp.

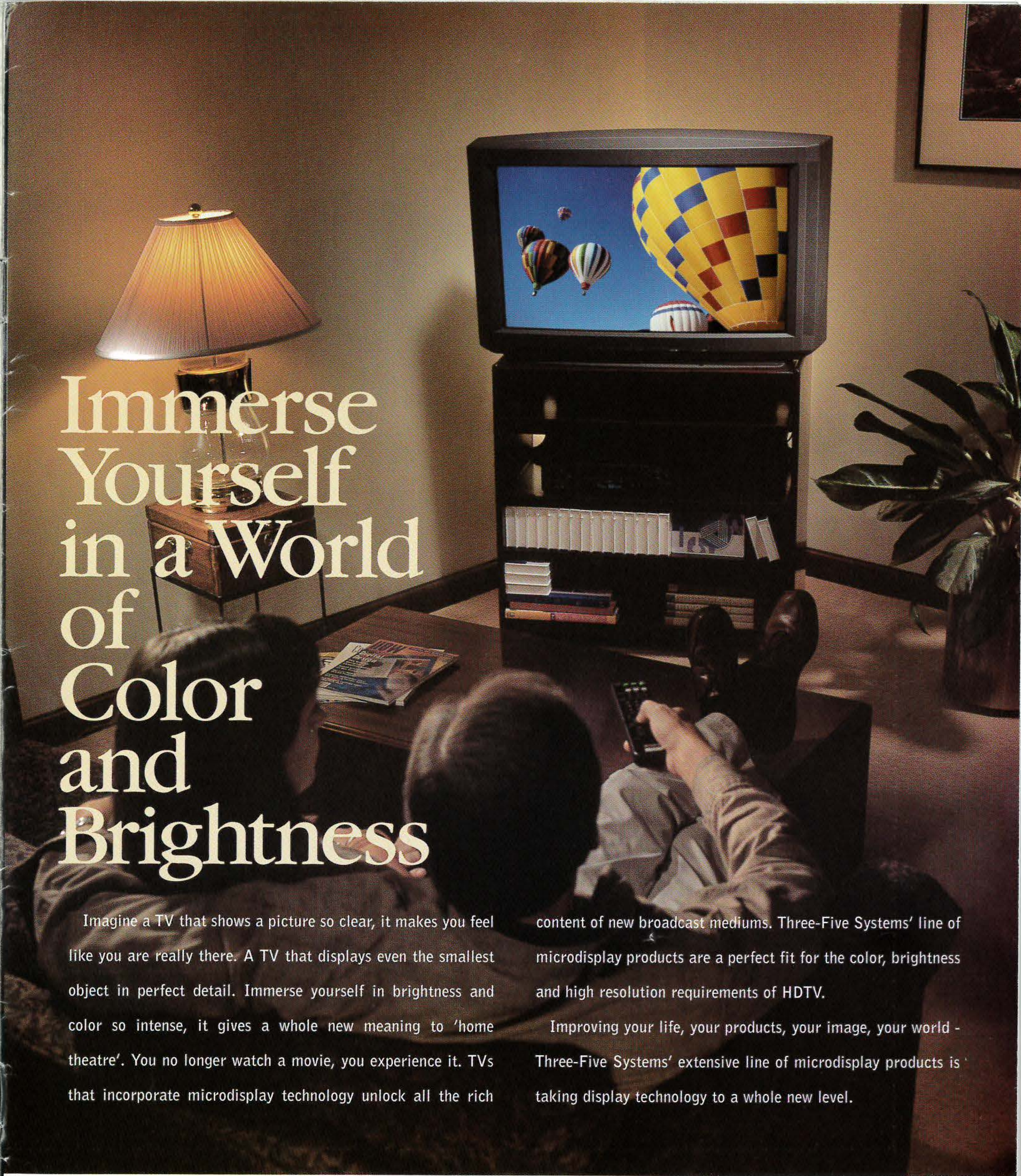
index to advertisers

Business and Editorial Offices
Palisades Convention Management
411 Lafayette Street, 2nd Floor
New York, NY 10003
Jay Morreale, Managing Editor
212/460-8090 x212 Fax: 212/460-5460
jmorreal@newyork.palisades.org

European Sales Office
George Isaacs
12 Park View Court
The Paddock, Eaton Ford
St. Neots, Cambridgeshire
PE19 7SD U.K.
Phone/Fax: +44-(0)-1480-218400
george@gandg.demon.co.uk

Sales Office
Palisades Convention Management
411 Lafayette Street, 2nd Floor
New York, NY 10003
Joanne Morgenthal, Sales Manager
212/460-8090 x211 Fax: 212/460-5460
jmorgenthal@pcm411.com

Korean Sales Office
Jung-Won Suh
Sinsegi Media, Inc.
Masters Tower, Room 2410
553, Dowha-dong
Mapo-ku, Seoul 121-040 Korea
+82-2-313-1951/2 Fax: +82-2-312-7335
sinsegie@chollian.net


Immerse Yourself in a World of Color and Brightness
Imagine a TV that shows a picture so clear, it makes you feel like you are really there. A TV that displays even the smallest object in perfect detail. Immerse yourself in brightness and color so intense, it gives a whole new meaning to 'home theatre'. You no longer watch a movie, you experience it. TVs that incorporate microdisplay technology unlock all the rich content of new broadcast mediums. Three-Five Systems' line of microdisplay products are a perfect fit for the color, brightness and high resolution requirements of HDTV.
Improving your life, your products, your image, your world - Three-Five Systems' extensive line of microdisplay products is taking display technology to a whole new level.