Displays for Handheld Devices Issue

Information DISPLAY

October 2008
Vol. 24, No. 10

SID

Official Monthly Publication of the Society for Information Display • www.informationdisplay.org

- Large-Screen Mobile Touch Devices
- Video-Based Gaze Tracker for Near-to-Eye Displays
- Display Interfaces for Mobile Devices
- Commercializing HIC Flexible Displays
- *Journal of the SID* October Preview

COVER: Mobile displays have been transformed from simple alphanumeric and monochromatic passive-matrix LCDs to full-video-capable multi-media displays that boast some of the most advanced features found today in displays.

CREDIT: Cover design by Acapella Studios, Inc. Readius photo courtesy of Polymer Vision (top right). Electronic Reader photo courtesy of Plastic Logic (bottom left). iPhone 3G, iPod Touch, and MacBook Air photos courtesy of Apple (middle right, top left, bottom right).

Next Month in
Information Display

LCD Technology Issue

- Ultra-Thin LCD TVs
- High-Performance OCB-III LCDs
- Improving LCD Efficiency
- Procurement of Military Displays
- *JSID* November Preview

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, Editor-in-Chief, 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, 1475 S. Bascom Ave., Ste. 114, Campbell, CA 95008; telephone 408/879-3901, fax -3833. 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.

Information DISPLAY

OCTOBER 2008
VOL. 24, NO. 10

For Industry News, New Products, Current and Forthcoming Articles, see www.informationdisplay.org

editorial

Professional Development Programs Need Your Support

It's year-end planning time again at many companies, and there is a good chance either you or the department heads at your company are hard at work on 2009 budgets and revenue plans. Inevitably, the challenges of balancing headcount and employee-benefit expenses against projected income leads to the need to make difficult choices. I doubt any of us has ever said, "We could run this company much better if we just had fewer employees." Especially when it comes to research and development, we can almost never have too many players on the team, and, in most cases, we are desperately trying to succeed with way too few people who are being asked to work much longer hours than they should. Does working 14 hours a day really produce more creative thinking and productivity than 8 or 10 hours? I have my opinions, but they may be best left to another editorial.

Meanwhile, another important consideration often gets overlooked in the process: continuing professional training and education. According to the U.S. Department of Education, less than 30% of adults (26.9% actually) took part in career-related education in 2004 and 2005 (the latest period for which data has been released). Of those who did further their education, less than one-third of them took more than one course. I find this extremely disappointing. The single most valuable asset to any company is a team member who is up to date on the latest advances in their chosen field. If that field is a technical one, keeping up to date is a constant challenge made harder by the long hours demanded of all of us. Display technology is no different. That is why I am taking this opportunity to argue in favor of greater emphasis on continuing education for all employees.

Promoting professional development of employees requires a commitment to three important things:

(1) Accommodation for the time required for course work.
(2) Financial assistance in some form.
(3) Recognition of academic achievement and rewards for professional development.

All educational endeavors require a time commitment, and those with the most value usually require the most time in the form of preparation, participation, and implementation. However, even when well-meaning companies implement all of these things, employees often do not take enough advantage of them. The most frequent response I hear when I ask why people do not continue their education is that they do not have the time. That's an honest answer. Time for education usually has to be made, margined out of lifestyle and work-schedule adjustments. It usually requires tough decisions and rarely is easy to maintain. How many of us, myself included, have started down a degree path and have had to put it on pause because of work and family? A colleague of mine is working at a company near Boston while also completing his Doctorate at a downtown university. With a family and a suburban home, he was spending literally several hours commuting between work, classes, and home. His solution was to sell his house, move into a condominium within walking distance of his university, and reverse commute out of Boston every morning for work. Not only did he save countless hours every week, he now has time to eat dinner at home many evenings and still complete his coursework.

While selling one's house is a bit extreme, other similar adjustments are often necessary in order to achieve the level of career and professional growth most of us

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industry news

Plastic Logic Opens World's First Commercial Plastic Electronics Manufacturing Factory

DRESDEN, Germany - **Plastic Logic** officially opened what it is calling the world's first state-of-the-art commercial-scale plastic electronics manufacturing facility on September 17. The Dresden factory is a fully automated and integrated facility that will begin volume production of groundbreaking displays based on Plastic Logic's patented and proprietary plastic electronics technology, the company stated in a press release.

"Today marks an extraordinary achievement for our company and the plastic electronics industry," said Plastic Logic CEO **Richard Archuleta**. "It also marks a major milestone in preparation for the delivery of our first consumer electronics product early next year."

Plastic Logic's core technology solves the critical issue in manufacturing high-resolution transistor arrays on flexible plastic substrates using a low temperature, according to the company. The process is simpler than conventional glass silicon processes, and produces active-matrix displays that are thinner, lighter and more robust than glass.

The Dresden factory is set to begin volume production of the display that is the key feature of Plastic Logic's forthcoming electronic-reading product, scheduled to come to market in early 2009. Attendees at the ceremony received a sneak preview of the product in addition to a view of the specialized factory, which was completed and ready for production just 16 months after the building's cornerstone was laid in May 2007.

According to Plastic Logic, advanced new processes and tools were specified, designed and created to successfully transfer proof of concept technology and processes first developed in Plastic Logic's Cambridge, UK, research and development lab. The company utilized a unique mix of standard production equipment from display manufacturing and other industries that were tailored to produce displays delivered in high volumes at costs to give it significant competitive advantage. In addition, the factory was designed for flexibility and the capacity to produce hundreds of thousands of the displays annually.

— Staff Reports

Samsung Electronics America Launches SAMSUNG RECYCLING DIRECT

RIDGEFIELD PARK, N.J. - **Samsung Electronics America Inc.** announced September 3 its SAMSUNG RECYCLING DIRECT program, its commitment to the take-back and recycling (TB&R) of Samsung-branded consumer electronics across all of its product lines. Beginning October 1, 2008, people will be able to drop off their Samsung-branded consumer electronics sold in the United States at convenient collection sites, including permanent drop-off centers in all 50 states, and at a wide range of recycling events across the country. Samsung-branded consumer electronics will be accepted for no fee, and non-Samsung-branded consumer electronics will be accepted for a nominal fee paid directly to Samsung's contracted recycling partners upon delivery of the e-waste.

"Since the 1996 launch of our global Green Management Initiative, Samsung Electronics Co. has been a staunch advocate of preserving our environment and greening the consumer electronics industry," said **DJ Oh**, President and CEO, Samsung Electronics America. "As a global enterprise, we have worked diligently to put our environmental responsibility philosophy into practice across our worldwide operations, among our suppliers and partners, and within our local communities."

Samsung elected to contract directly with recycling companies, unlike other consumer electronics TB&R programs that rely on intermediaries. Samsung conducted extensive research into the qualifications, capabilities and integrity of these companies to ensure that they mirror Samsung's own environmental philosophy. As such, the SAMSUNG RECYCLING DIRECT program will only utilize recyclers that do not incinerate, landfill, or export toxic waste to developing countries, the company stated. The SAMSUNG RECYCLING DIRECT program also allows Samsung to track and monitor all of the collected consumer electronics for added assurance that it is recycled responsibly.

"We took the extra care to develop the SAMSUNG RECYCLING DIRECT program to achieve the highest integrity end-of-life standards," Oh added. "Samsung Electronics America has set scorecard standards with our contracted recyclers, and we will track and monitor their processes and results very closely." SAMSUNG RECYCLING DIRECT results will be posted on www.samsung.com/recyclingdirect throughout the year. This will provide an unprecedented level of transparency to the public.

The SAMSUNG RECYCLING DIRECT program joins the numerous TB&R initiatives that the company currently has in place. Samsung's commitment will now apply to all Samsung-branded consumer electronics ranging from televisions, DVD and VHS players, audio equipment and home theater systems, to cameras, camcorders, computer monitors, printers, and peripherals. In addition, a growing number of fixed drop-off locations will be made available for home appliances.

"We at Samsung listened carefully to our consumers' needs and want to build the con-

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guest editorial

As Mobile Displays Boom, Innovations Continue

by Jyrki Kimmel

Mobile displays have transformed from the early, simple alphanumeric and monochromatic passive-matrix LCDs to full-video-capable multimedia displays that boast some of the leading characteristics in displays found today. The increasing demand for space savings, robustness, reduced power consumption, and improved image quality in an environment of rapid cost erosion presents trade-offs that are difficult to solve for any display provider – yet the market is booming. This is due to the proliferation of mobile phones in all markets worldwide, including previously inaccessible third-world countries where a mobile infrastructure is rapidly being deployed.

In the developed countries, mobile multimedia delivery to cell phones has become a hit. Multimedia in this context includes music videos, TV broadcasts, movies, and navigation applications, all of which demand high image quality on the display under various ambient-lighting environments. The entry point for many of these services is the Internet, and to access Web pages comfortably, highly legible displays are required. The entire mobile user interface is therefore a major focus of development, as can be seen in products that are coming out from major manufacturers. These include devices with touch screens and other advanced interaction capabilities. One challenge remains in "pocketable" devices, since one cannot stretch the screen size beyond the limits of the phone frame with current commercially available displays. The main dilemma is how to present all the information required by the mobile user in a virtual screen size that is significantly larger than the dimensions of the device itself.

One solution to the dilemma is to use head-worn displays, such as "goggles," that show the image by enlarging the view from a microdisplay. The early attempts at making these devices were not successful due to the bulky optics, which resulted in cumbersome devices with uncomfortable, nose-heavy weight distribution. They also must be tethered to the main device that is responsible for the reception, storage, and display of the content. Current radio interfaces cannot reliably deliver full video to a VGA resolution display, and thus the user needs to be wired to the device.

Another problem is the interaction paradigm with which the user is expected to control the mobile device. Touch input on the main screen is one obvious solution that is finding use in many forms. With head-worn displays, however, new ways of interfacing the user with the control of the device are required.

With respect to integrating displays into mobile devices, significant developments have taken place to ensure data delivery to the display module by adopting high-speed serial interfaces. With advanced interaction capability being integrated in the display itself, the back channel also becomes a problem to be solved, which future interfaces will address.

The three feature articles in this issue of *Information Display* describe the mobile-display market, interaction mechanisms, and the electrical interface development. First, Jeff Brown from Portelligent describes the effect that mobile smart-phone development has had on the small-to-medium–sized display market, including trends in phone form factor and the integration of touch screens. Overall, it seems like a boom for the small-display makers, even though the cost pressure remains high.

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president's corner

SID Shows Its Flexibility

The 2009 Call for Papers has been online and in the mail for some time, and hundreds of scientists and engineers worldwide are considering their contributions to the 2009 SID International Symposium to be held May 31 – June 5, 2009, in San Antonio, Texas. This Call for Papers breaks new ground in showing SID's strong commitment to supporting flexible displays and printed electronics, two very hot areas in the display-development community. While these topics have always been welcome at SID, I want to explain how this new organization will make the SID Symposium a better and more receptive place for papers in these areas. SID's annual International Symposium has evolved into a major venue for competition and collaboration.

Last year, more than 800 papers were submitted for possible presentation at the meeting, but only about 550 were accepted by the Technical Program Committee for inclusion into the symposium. These demanding standards help ensure that the work presented at the symposium represents the forefront of technology.

One of SID's strengths is the participation of more than 150 volunteers who take the time each year to evaluate each paper and decide whether or not it should be included in the technical program. To keep the process manageable, the overall Program Committee is organized into 12 topical subcommittees, which are populated by experts in areas recognized as important in display development. While new members are usually rotated into each committee each year, the participation of volunteers for several consecutive years helps guarantee that the committee is well-positioned to follow trends in the industry, identify prominent invited speakers, and phase out topics that may have been important once, but perhaps are no longer on the cutting edge of development.

The program subcommittees have evolved through the years to provide coverage for the most important areas of display development. Twelve different subcommittees put the 2008 program together, organized around the following topics: Active-Matrix Devices, Applications, Applied Vision and Human Factors, Display Electronics, Display Manufacturing, Display Measurement, Display Systems, Emissive Displays, Field-Emission Displays, Liquid-Crystal Displays, OLED Displays, and Projection Displays.

A problem that arises every now and then, though, is what to do with a paper that doesn't fit neatly into the existing subcommittees. SID does not just reject papers that do not obviously fit into these categories, but rather works to find a home for that paper in an existing subcommittee. So, when electronic paper first arrived on the scene, the Liquid Crystal subcommittee was determined to have the best ability to judge papers on this topic, even though most of the displays had little to do with liquid crystals as a material.

While this process generally works, occasionally an unexpected (and undesirable) effect is that important emerging areas get distributed across a number of subcommittees. The purpose of the Symposium is to serve the needs of the attendees, and if a particular topic is spread around the technical program without obvious organization, it makes it difficult to cover the topic effectively. Additionally, it also means that the Symposium itself runs the risk of not making itself a welcome "home" for this new area. The most recent example of this problem has been in several topical areas related to flexible and printed displays and electronics. This is not to say that the Symposium has not had healthy

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Commercializing High-Information-Content Flexible Displays: A Global Initiative

by Greg Raupp

For years, the compelling advantages of flexible-display technology have driven display developers, manufacturers, and market analysts to make a wide range of predictions on their market entry point and time and their global market impact. Now that the release[1] of the first commercial product with a high-information-content flexible display, Polymer Vision's Readius, is visibly on the horizon, we have finally arrived at the dawn of the flexible-display revolution.

At some level, flexible displays have already entered the commercial marketplace through such products as Motorola's Motofone handset, wristwatches, and smart cards. However, these displays provide relatively low information content and, from a technology perspective, are direct-drive, segmented, or passive-matrix displays. The significance of the Readius product introduction and other exciting products soon to follow from other manufacturers is that the display is of the active-matrix high-information-content type that consumers have become accustomed to in their e-readers, PDAs, and feature-loaded mobile phones.

This significant commercial market entry and others soon to follow[2] have encouraged market analysts to adjust their market forecasts upwards. For example, in a recent report, iSuppli predicted a 35*x* total market increase from 2007 to 2013 for flexible displays to $2.8 billion.[3] Only slightly more than a year ago, the company was predicting a much smaller $340 million total market by 2013.

I am often asked at conferences and workshops, "What is the 'killer app' for flexible displays" that will dominate and drive technology acceptance and growth? As a not-for-profit technology developer (and not a commercial product developer), I am not well-qualified to answer this question and will be the first to admit I do not comprehend all that it takes to bring a new consumer product successfully to market. It is exciting to note that the new products soon to be released break free from existing "information scaling laws" that state that the amount of information visually presented (or size of display) must scale with product size. It is clear to me that in the highest level vision of the technology revolution, the new product opportunities are limitless since once a high-information-content display is fabricated on the proper flexible substrate, the display, in principle, could be placed on any surface, anywhere! This new-found design freedom should catalyze the creation of a whole new generation of user-friendly and highly desirable products that will change the way we access and share information and entertainment. In this context, I read with great interest the cover story of the July 2008 issue of *PC Magazine*[4]; it seems that many concept designers are already embracing this freedom in that all the "amazing gadgets that will change your life" detailed in the article incorporated a flexible display as a critical enabling feature.

So what is the killer app? When will it enter the market and how "killer" will it be? With apologies to Yogi Berra, predictions are always risky, especially when you are talking about the future. So rather than speculating on future products and markets, let's instead focus on the answer to a more straightforward question that merely requires 20/20 hindsight: "How did we get here, in 2008, to the brink of flexible-display commercialization?"

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We are always interested in hearing from our readers. If you have an idea that would make for an interesting Business of Displays column or if you would like to submit your own column, please contact Mike Morgenthal at 212/460-9700 or email: mmorgenthal@pcm411.com.

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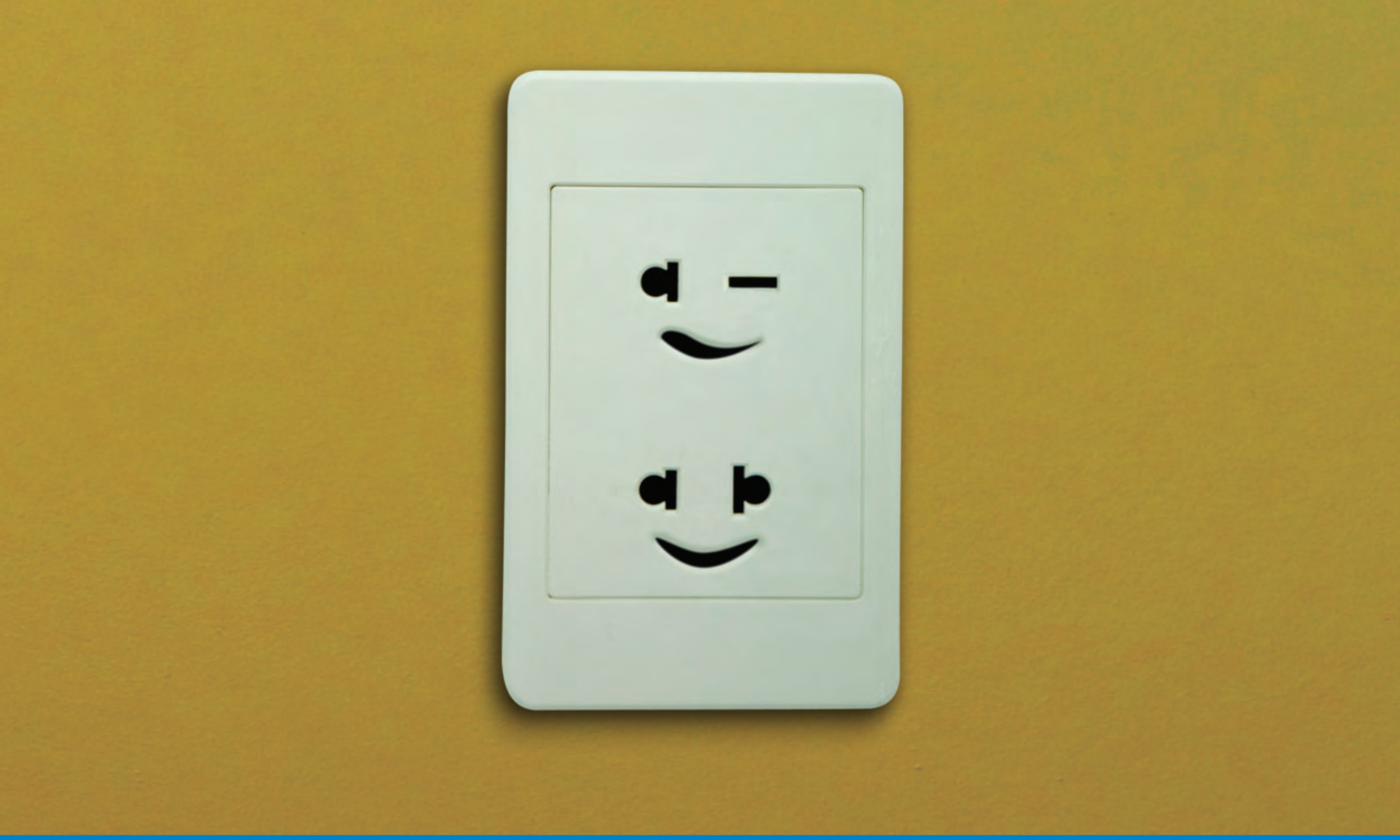

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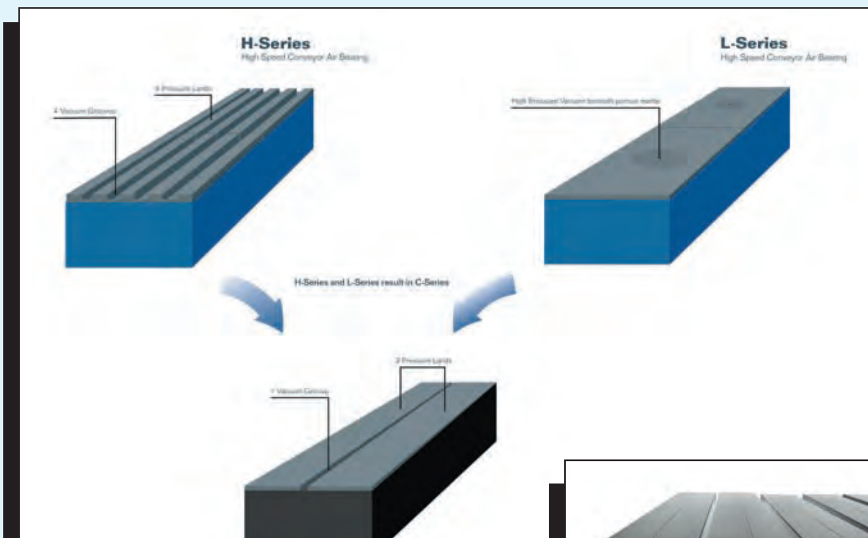

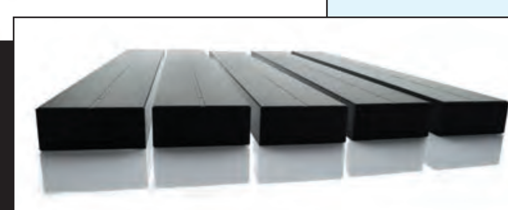

New Way's original line provided three different FPD products, the **H-Series** for high speed applications, the **L-Series** for applications where low airflow is a requirement, and a porous media **Precision Chuck** for processing or inspection zones and other areas of interest.

These products were so successful that New Way Air Bearings immediately set out to design the next generation. This new product, the **C-Series**, was launched in July 2008. It is a hybrid that combines the advantages of its two predecessors, providing high-speed capability with low air consumption requirements. Furthermore, New Way engineered this new product line for efficient manufacturability, also enabling the company to significantly reduce the cost-per-unit. And because of the performance advantages it provides, fewer C-Series conveyors are required for a typical system.

Each of New Way's modular air bearing components are robust and easy-to-use in scalable arrays. The arrays themselves are simple to align and adjust.

The elegant simplicity of this solution has made an impact on the FPD industry; and on New Way Air Bearings as well. The company, founded in 1994, had sales of $7.6 million in 2007. This year, New Way projects $9.2 million in sales, and appears to be ahead of schedule according to its management team. A significant portion of this growth can be attributed to the company's FPD market success.

New Way was named to both the 2007 and 2008 Inc. 5000 list of fastest-growing private companies in the USA. Further, the Philadelphia Chamber of Commerce selected the company as recipient of its prestigious Technological Excellence of the Year Award for 2008.

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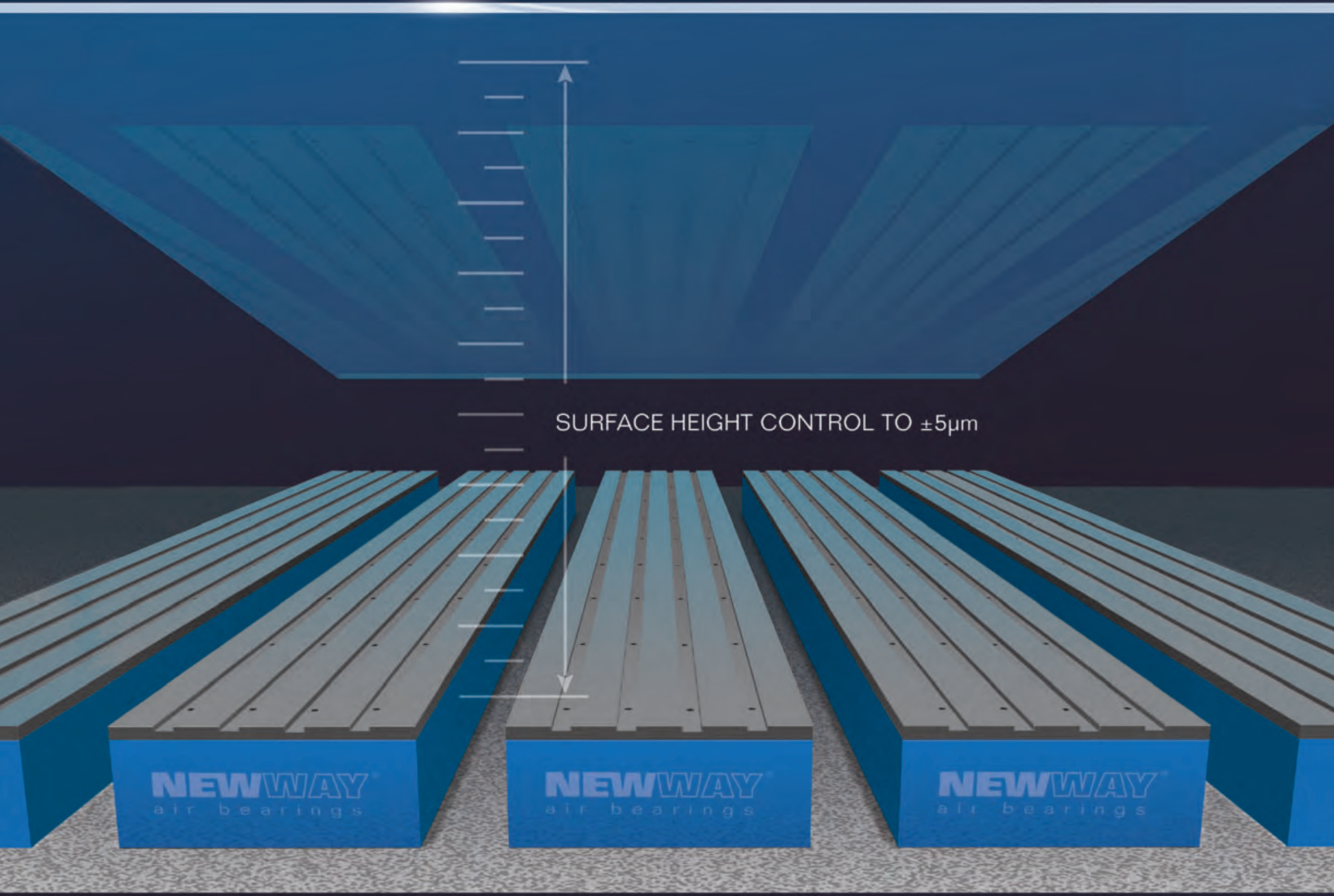

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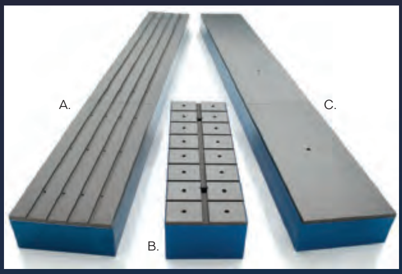

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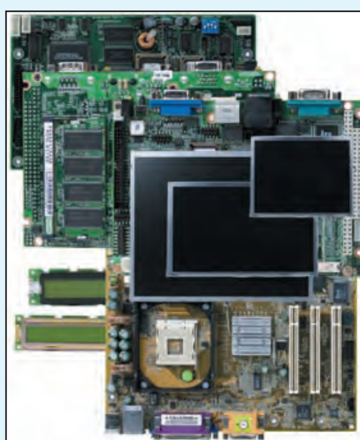
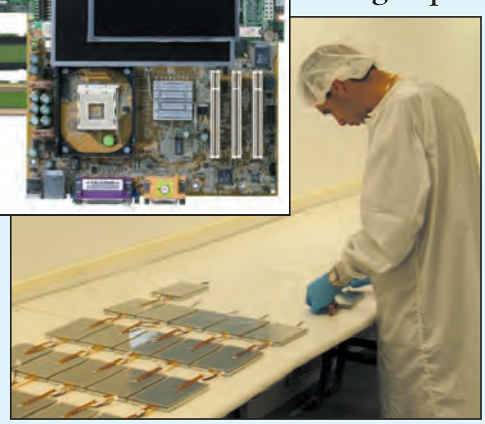
Jaco Electronics Inc. (Nasdaq: JACO) is a global distributor and integrator of electronic components, customized flat-panel-display solutions (FPD), and a provider of value-added logistics services including automated inventory management services and kitting. With distribution centers on either coast, a warehouse in Singapore, and 15 strategically located sales offices throughout the United States, Jaco is positioned to be where our customers need us.

Jaco Electronics Inc. operates a business unit dedicated to the design, development and integration of comprehensive display solutions for myriad markets and applications. This business unit, Jaco Display Solutions, includes manufacturing and design facilities available for integration, management, procurement and performance planning for our customers' programs. The Company operates an in-house FPD integration center housing its engineering, manufacturing staff and operations. The integration center enhances Jaco's ability to provide customers with unique value-added display and embedded solutions as a "one-stop" source for their FPD supply and integration requirements.





Jaco's 20,000 sq. ft. manufacturing facility was built to support the growing need for the integration and enhancement of displays. These include optical enhancements, assembly/box build and ruggedization of flat-panel displays. Integration to any level desired – from kitting of LCDs and associated products, through complete system assemblies – is available.

As a leader in FPD technology, Jaco Electronics Inc. brings its significant experience, along with continuous investment in new technologies, quality and personnel, when working hand in hand with our customers to create customized, fully integrated display solutions. With more than 45 years of experience, Jaco Electronics offers our FPD value-added business partners far more than just technological and manufacturing expertise. Our mission is to "be a major supplier of flat-panel displays and associated assemblies." Our goal is to provide our customers with real solutions to real needs.

Whatever your needs may be, chances are that Jaco has the solution for you. Among the continuously growing markets that Jaco Displays has already served are:

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Jaco Display Solutions' focus is on delivering unparalleled quality service and LCD solutions to its customers worldwide. We invite you to learn more about Jaco's products and services at www.jacodisplays.com. ♦

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Stars Align for LCD Suppliers to Enjoy Big Gains from Touch Phones

LCD suppliers were one of the largest beneficiaries of the launch of Apple's iPhone in 2007, which ushered in a new era for large-display touch phones. But this is hardly the first foray into large-screen mobile touch devices. This article will explore what makes this latest effort by Apple and the responses from Samsung, LG, and HTC different from past touch-phone efforts and what the future holds for this sector.

by Jeff Brown

THE LAUNCH of the iPhone in 2007 ushered in a new era for touch phones with large displays (larger than 2.8 in. on the diagonal) with LCD suppliers being some of the biggest beneficiaries. Rumored and confirmed iPhone display suppliers, including Epson, Sharp, and Toshiba, all stand to realize an increase in phone display sales as a result of Apple utilizing a 3.5-in.-diagonal display, one of the largest on the market (Fig. 1). Apple's goal of selling 10 million iPhones in the first year of production didn't hurt either.

Within 6 months following the release of the iPhone, LG, and Samsung had responded by introducing at least one competing large-display touch phone. The LCD divisions within LG and Samsung, while providing their respective phone divisions with displays, will also benefit from the hype surrounding the iPhone and the resulting consumer interest in phones with large displays. Second-tier cell-phone manufacturers such as HTC, which uses Samsung LCDs in its recently launched large-display touch phones, further expand the opportunity for Samsung beyond its complementary cell-phone division.

But what makes the launch of the iPhone a start of a new era? Did Apple pioneer the use of a large-display touch phone with the iPhone? If not, what makes this latest effort by Apple and the responses from HTC, LG, and Samsung different from past touch-phone forays?

Large Displays in Small Devices

The concept of utilizing a large touch display in a portable, handheld electronic device is nothing new. In fact, Apple led the way in the early 1990s with the introduction of the Newton (Fig. 2), which utilized a 4.5-in.-diagonal touch display in a handheld, battery-operated device. Shortly thereafter, several companies, including Casio, Compaq/Hewlett Packard, Dell, Palm, and Sony, followed Apple's lead by introducing their own, typically smaller, version of what came to be known as a personal digital assistant (or PDA). Despite the reduction in size, 12 PDA displays analyzed by Portelligent between 2000 and 2004 revealed an average screen size of 3.4 in. on the diagonal – consistent with today's iPhone display size.

While display-size similarities exist between yesterday's PDA and today's iPhone, the time it took to ship 10 million units/year could not be more different. Ten years after the introduction of the first PDA, volume shipments barely exceeded 10 million units in a year, while Apple strives to accomplish that feat in its first year of production. But long before Apple realized the potential of bringing together the benefits of a large touch display with the volume opportunity in the cell-phone market, early pioneers such as Handspring, HP, and Palm paved the way by introducing their own large-display touch phones between 2000 and 2002. Yet, even with a cell-phone market size that exceeded 500 million units/year, these converged PDA and cell-phone devices never achieved sales of 10 million units in a single year. What kept these companies and their respective display suppliers from realizing the same success expected by the most recent lineup of Apple and other large-display touch-phone manufacturers and their LCD suppliers?

Form-Factor Evolution

As annual cell-phone shipments surpassed 500 million units by 2003 and demand for the

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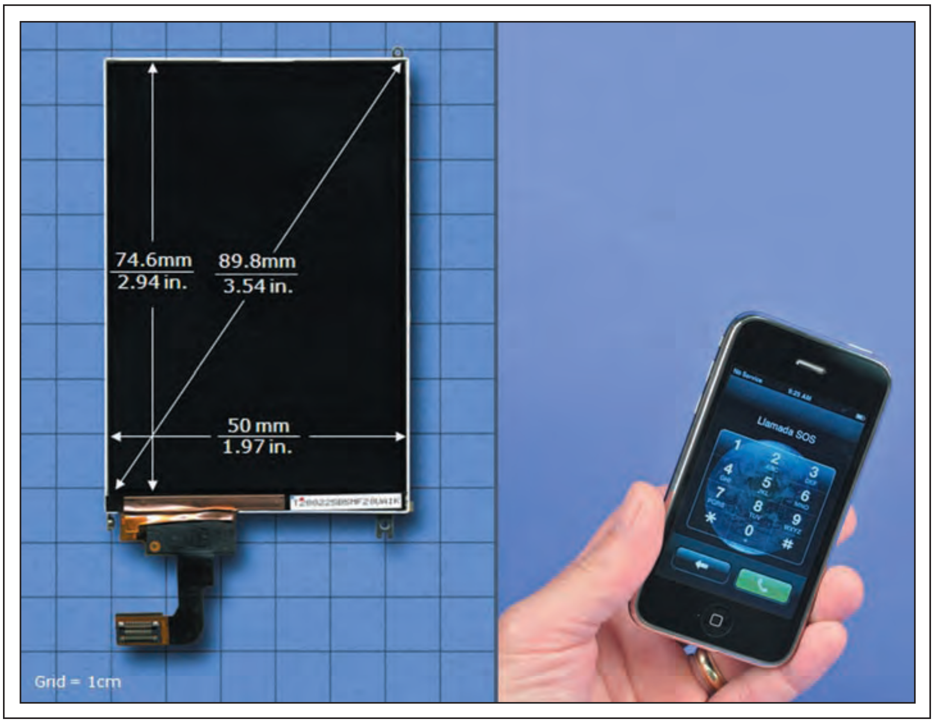

Fig. 1: ***This image shows the size of the display on Apple's iPhone 3G. At 3.66 in. on the diagonal, it represents one of the largest screen sizes of any mobile phone and helped usher in a new focus on large touch-screen phones. Photos courtesy of Portelligent.***

Fig. 2: ***The Apple Newton was the first handheld, battery-operated electronic device to utilize a large (4.5-in. diagonal) touch-enabled display when it was introduced in the early 1990s. Copyright Ralf Pfeifer, 2005.***

devices spanned all categories of age, race, income, and geographic location, the design of the phone, including the color, materials, size, and form factor, became at least as important as its functionality. Every year over the past 3-4 years, a single cell phone became the "must-have device," reflecting a certain fashion or style and with it a distinct form factor.

Launched at the end of 2004, the Motorola RAZR, with its ultra-thin form factor made of aluminum and magnesium, not only made a fashion statement but also cemented the flip form factor as the best design to combine style and functionality in a sleek device. As other cell-phone manufacturers copied the RAZR and sales of ultra-thin flip phones skyrocketed, the LCD industry benefited, as the average display size grew from the 1.8-in. diagonal found on block-style phones in 2004 to the 2.1-in. diagonal on the typical 2005 flip phone (Fig. 3). In addition to the growth in the primary display size found in the flip-phone form factor, LCD suppliers also benefited from cell-phone manufacturers often incorporating a secondary display housed on the outside of the device. By 2006, after Motorola had sold more than 50 million RAZRs, a new form factor was beginning to take center stage that would increase the display size, again further benefiting the LCD industry.

Although originally launched as a combination e-mail device and phone in 2002, the RIM BlackBerry went mainstream in 2006 with the release of the 8700 series of phones (Fig. 4) and the BlackBerry Pearl by including such features as Web browsing, multimedia playback capability, and image capture. Soon after the launch of the 8700, competitors including Motorola, Nokia, and Samsung followed with similar multimedia e-mail machines such as the Q, E61, and BlackJack. Once again, the LCD industry benefited from this latest form-factor transition as LCDs grew from the average 2.2-in.diagonal found on the RAZR and its competitors to an average 2.5-in. diagonal in the RIM BlackBerry 8700. By the end of 2006, as e-mail and texting became the killer app, RIM shipped more than 6 million BlackBerrys in a year with competitors likely adding another 1–3 million comparable e-mail machine devices. Not long after the launch of the BlackBerry 8700, cell-phone manufacturers were already set to launch the next evolution in cell-phone form factor to alleviate the display-size limitations imposed by the BlackBerry design.

By slicing the phone in half with the keyboard located in the base and the display nested in the top section, HTC and other major cell-phone manufacturers were able to further expand the display size beyond 2.8 in. on the diagonal while maintaining the same footprint as popular block-style phones. The HTC TyTN and TyTN II (Fig. 5), each incorporating a 2.8-in.-diagonal display and QWERTY keyboard in a slide message form factor, soon became the best-selling devices in Europe and Asia and helped push HTC's shipments to beyond 10 million units per year. Despite positive reviews for the combination of features, useable QWERTY keyboard, and large display, the slide message form factor required the thickness of the phone to grow from the benchmark 0.6 in. for the Motorola RAZR to almost 1 in. for the HTC TyTN and

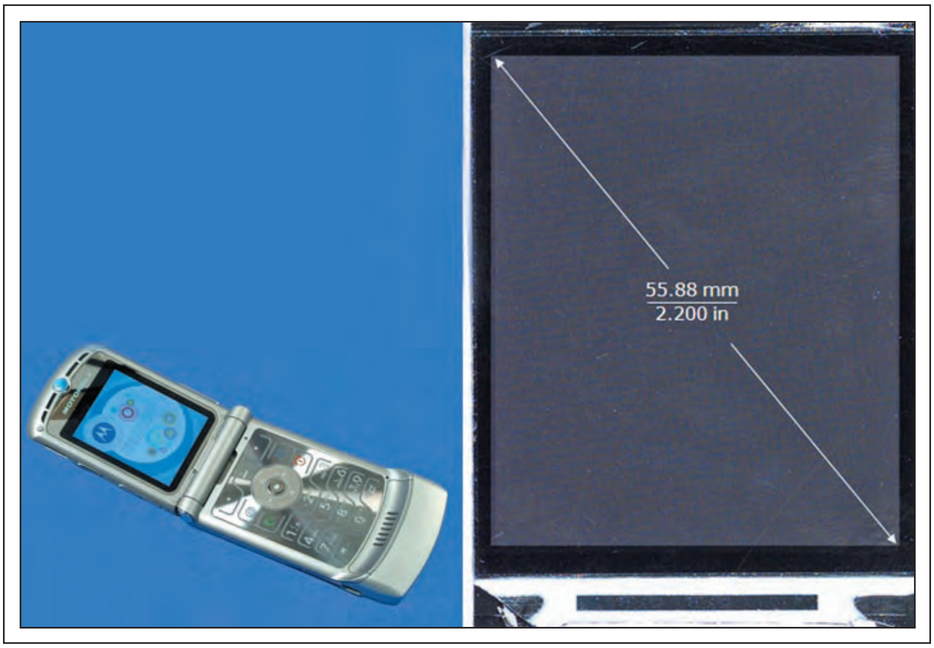

Fig. 3: After Motorola launched the RAZR phone with its 2.2-in.-diagonal LCD screen, other manufacturers followed suit, increasing the average screen size on flip phones. Photos courtesy of Portelligent.

0.8 in. for the HTC TyTN II. The next evolution in the phone form factor would solve the thickness problem while contributing to a further expansion in the display size.

With the launch of the Apple iPhone in 2007, the high end of the market turned to the most basic of form factors, eschewing all mechanical mechanisms such as hinges, pivots, and slides as well as the keyboard itself, while expanding the display size to a cellular-phone chart-topping 3.5-in. diagonal. Less than 0.2 in. wider than the iconic Motorola RAZR and 0.4 in. thinner than the RIM BlackBerry 8700, Apple managed to squeeze into the iPhone a display 40–60% larger than its famous predecessors by turning to a software-based keyboard and stretching the display to the corners of the phone leaving just enough frontal area for a speaker and a single Home button. Soon after the launch of the iPhone, Samsung, LG, and HTC followed with similar touch phones utilizing a display size greater than 2.8 in. Collectively, these large-display touch phones will ship close to 10 million units in their first year of production with an average display size over 3 in.

As Apple and the other major cell-phone manufacturers return to display sizes last seen on PDAs and converged PDA cell phones available more than 5 years ago, what is fueling the significant difference in demand and is it sustainable? Can the next evolution in cell-phone form factor further increase the average display size and are any disruptive technologies on the horizon that could turn the display-size trend upside down?

Operating Systems and Content

The original large-display touch phones launched between 2000 and 2002 made use of smart-phone operating systems from Microsoft, Palm, and Symbian, all of which evolved from the PDA market. By the beginning of 2003, Motorola launched a Linux-based touch phone with a 3.1-in. display. During the next 4 years, the smart-phone market saw explosive growth from less than 10 million units in 2003 to over 80 million units in 2006, according to IDC. But the majority of the volume and growth came from Nokia phones, which avoided the use of a touch display and had little impact on the average display size. The most common criticism of the large-display touch phones during this time period was the dependence of the operating system and its accompanying applications on the use of a stylus, relegating the phone to two-handed operation.

It wasn't until the launch of the iPhone utilizing the iPhone OS, derived from Mac OS X, where the operating system was designed from the ground up to take full advantage of

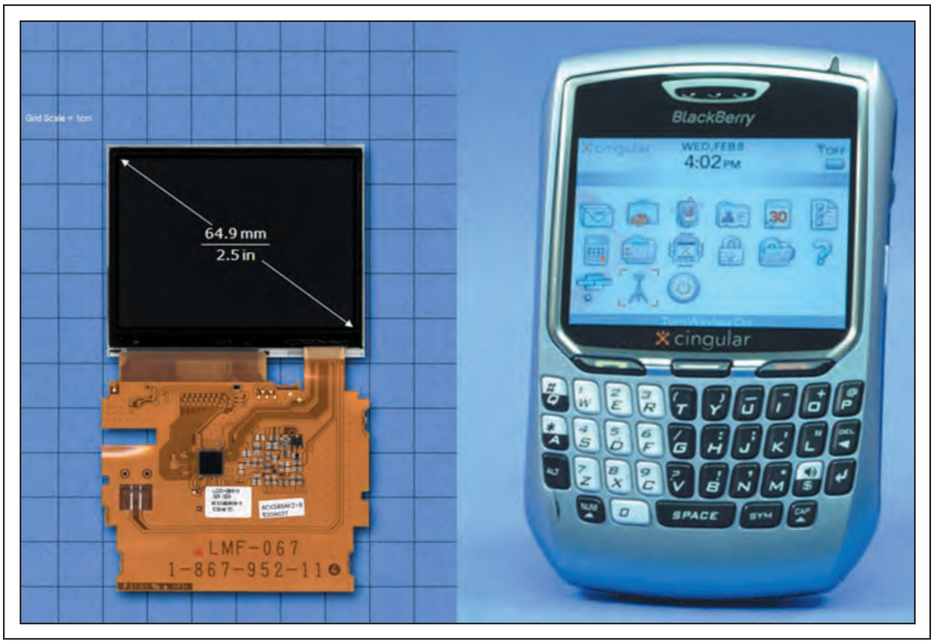

Fig. 4: The Blackberry 8700 series brought such devices into the mainstream in 2006, thanks in part to its 2.5-in.-diagonal screen. Photos courtesy of Portelligent.

the large, touch display without the use of a stylus, allowing for single-handed operation. Shortly after the release of the iPhone, HTC followed up with its own touch-interface overlay on top of Microsoft Windows Mobile, Microsoft released a new version of Windows Mobile that provided for enhanced touch-display browsing, Samsung launched the Samsung Instinct that utilized a proprietary touch-interface operating system, and Symbian demonstrated its own version of the S60 operating system, incorporating enhanced touch-interface capabilities. The responses from Apple's largest competitors in the phone and operating-systems markets indicate the seriousness of the threat the iPhone imposes on the entrenched players. Once again, the display manufacturers stand to benefit as large cell-phone displays are required to implement an effective touch-display interface. But it takes more than a slick user interface on a large-display touch phone to reach and sustain the volumes for which Apple and its competitors are hoping.

The rise of audio and video content that can be consumed on a portable electronic device has changed dramatically since the first large-display touch phones appeared in 2000. Back then, iTunes, YouTube, Rhapsody, and other online music and video services were not even in existence. In order to get music or video onto one of the early precursors to today's touch-display phones, a consumer had to purchase a software application for a personal computer, convert their analog content in the form of a CD or DVD into a reduced sampling of the original, and download the file to their phone. The time and cost to accomplish this feat usually meant the converged device was relegated to use as a phone and PDA while not performing either function as effectively as the stand-alone devices available at the time.

While MP3 players have continuously shrunk in size with audio playback having virtually no limits on form-factor miniaturization, video consumption on portable devices seems to be more correlated to form factor and display size. Although several portable media players providing video playback, including the iPod nano, have utilized displays as small 2 in. on the diagonal, a recent walk down the aisle of a flight from Austin to San Jose indicated the iPhone display at 3.5 in. on the diagonal was the minimum size to watch a full-length movie. With iTunes and other online media services allowing for easy downloading and consumption of high-resolution video content, the future once again looks promising for the display industry.

Fig. 5: Phones that featured a slide form factor, such as the HTC TyTN II, allowed phone makers to increase the screen size even more, to an average of 2.8 in. on the diagonal, while keeping the same footprint as other "block" phones. However, the overall thickness of the device increased. Photos courtesy of Portelligent.

The Future

History has shown that the cell-phone industry has consistently responded to consumer's desire for a larger display through the evolution of the form factor. But with displays now stretched to the four corners of a device without room to grow in either width or length, the future evolution of the cell phone will rely on a display that is not bounded by the limited dimensions of the device. Wireless USB and other short-range high-speed wireless technologies will allow cell phones to send a high-definition video stream to a nearby display on the back of a plane seat or a hotel-room television, while microdisplays built into personal media viewers connected to a cell phone will provide the equivalent of a 27-in. high-definition television emanating from what looks like a pair of sunglasses. It remains to be seen whether these advances will yield the same benefits for the LCD manufacturers that they enjoyed from the development of previous generations of cell phones. ■

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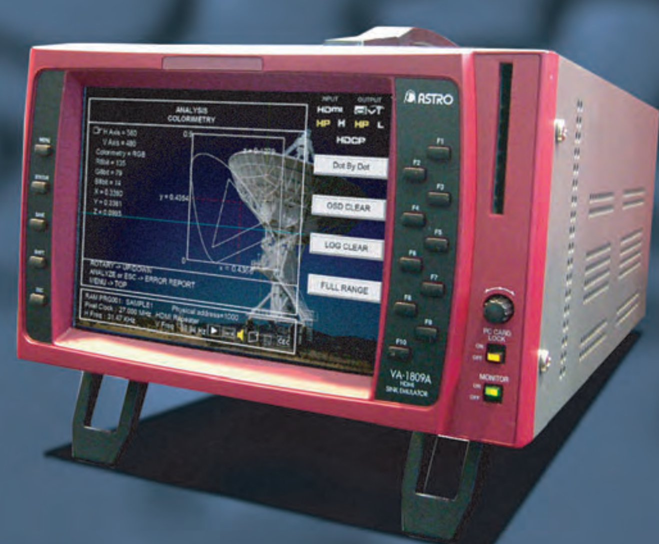

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Developing Gaze Tracker for Diffractive-Optics-Enabled Near-to-Eye Displays

A near-to-eye display (NED) is one display solution where an image can be perceived to be larger than the actual physical device on which it is displayed. A thin, light user friendly and high-performing see-through NED has been prototyped using very thin plastic light guides with diffractive structures on the surfaces. To be able to efficiently interact with the displayed user interface, we have also integrated a video-based gaze tracker into the NED, using similar diffractive optics.

by Toni Järvenpää

DESKTOP COMPUTERS are slowly but surely converging with handheld devices. More and more is required from battery-driven, handheld (and preferably pocket-sized) mobile devices. However, this creates a problem in terms of interaction. Large displays, keyboards, and mice are not easily fitted into the mobile domain. Many alternatives can partly replace these well-proven elements, but none has proven to be a universal fix. We have chosen to study two concepts that can be seamlessly integrated into mobile applications and together enable versatile usage experiences, some of which may not yet be applicable with any conventional consumer devices.

Near-to-Eye Displays

In order to fully take advantage of the rich visual content that is becoming increasingly available on mobile devices, a high-resolution large display is a must-have. However, the days of placing a higher-and-higher-resolution direct-view display into a physically small device seems to be coming to an end. In theory, rollable and projection-based displays for mobile applications may satisfy this need, but these technologies have not yet reached a mature enough state. Near-to-eye displays (NEDs), however, may offer a feasible solution to this dilemma by producing a virtual image that is perceived to be larger than the physical display itself.

The first head-mounted displays (HMDs) were introduced during late 1960s, and since then many concepts and NED designs have been presented, especially during the past 2 decades. In a typical system, the image from a microdisplay is enlarged by imaging optics located close to the eye(s). The user perceives a virtual image of a certain size and at a certain distance. Although the main principle is fairly simple, the optics design is challenging and can lead to large and heavy systems that have poor ergonomics and are uncomfortable to wear.[1] For example, in two-eye biocular systems, the alignment of the two

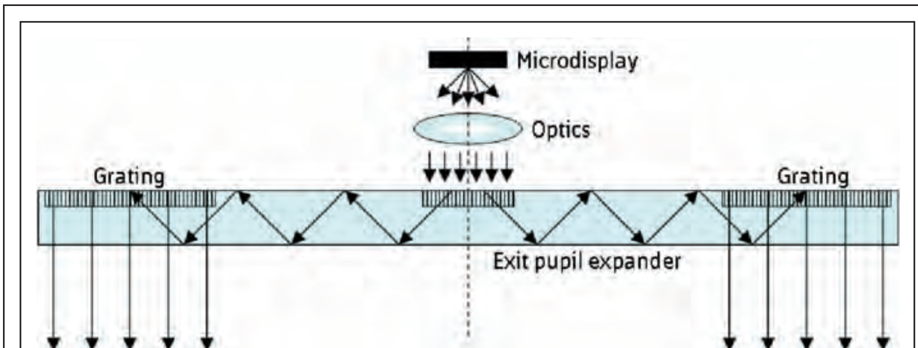

Fig. 1: The Exit-Pupil-Expander (EPE) plate is based on engraved diffractive optical elements and total internal reflection. Arrows represent part of the light rays from one single display pixel.

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separate optical arrangements can vary, causing symptoms such as eye strain and dizziness. To solve these ergonomic problems, diffractive optical elements on planar wave guides have been proposed to be used as miniaturized, good quality, and ergonomically acceptable NED optics.[2,3]

Exit-Pupil-Expander Plate

NED miniaturization can be realized by using a conventional microdisplay along with small-sized optics with a small exit pupil, which would be inadequate to be used as such. This set is attached to a stack of Exit-Pupil-Expander (EPE) plates, which enlarge the exit pupil and also transfer the image to a new position. Therefore, only a thin transparent plastic plate needs to be placed in front of the user's eyes while the image source can be placed elsewhere, thus enabling see-through functionality. Because EPE plates have problems delivering uniform light distribution due to the different path lengths for the light propagating inside the EPE plate, two plates have been stacked – one designed for the red wavelength and the other for green and blue wavelengths. An example of the structure of a system with an EPE plate is illustrated in Fig. 1. The plate has one in-coupling area, two vertical expansion areas, and finally two out-coupling areas, which enlarge the exit pupil horizontally. Vertical expansion gratings are not illustrated. The two-eye system from one source is achieved inherently as the gratings in the in-coupling produce light beams in two first-order diffraction modes that propagate in the plate in opposite directions to each other.[3]

The user sees large, distortion-free identical virtual images at an infinite distance with both eyes. The EPE plate with the described diffractive optical elements is geometrically accurate and achromatic. We have successfully demonstrated an NED consisting of these stacked EPE plates.

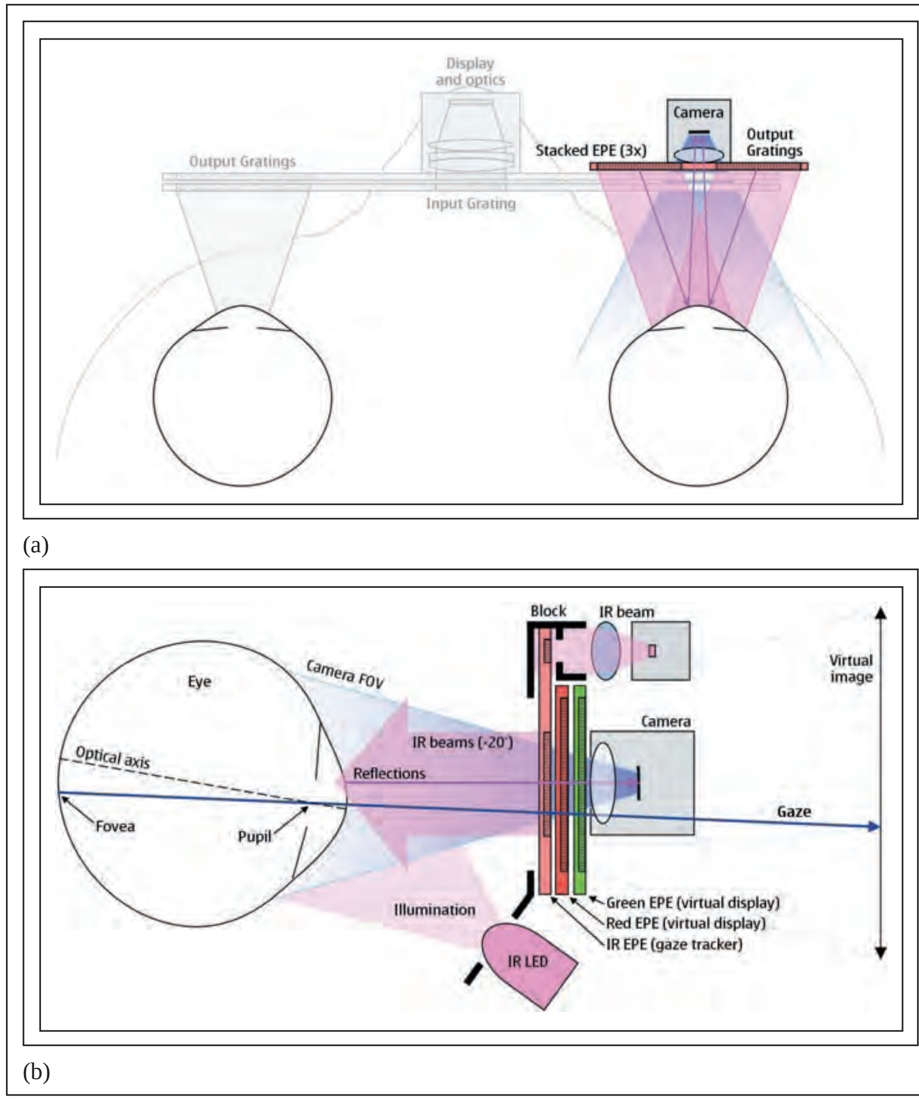


Fig. 2: Basic component setup of the gaze tracker and NED integration. The additional IR EPE plate is placed in front of the right eye in a stack with the NED EPE plates: (a) Top view, (b) side view. IR light is used both for the reflection illumination and to generate more pupil contrast.

Gaze Trackers

Despite the high level of audio-visual user experience in a NED system, some interaction deficiencies arise from the immersive nature and the hands-free operation of the NED. One solution is to integrate a gaze tracker into the NED.

Tracking the gaze direction of a viewer has historically been a specialized tool for research purposes because the gaze direction also reveals the focus of attention. Gaze-controlled systems have been deployed in a few applications, mainly used by the military or by people with disabilities. For consumer products, the cost of such systems is prohibitively high (but is expected to decrease); however, they may not have the required quality to suit the consumer market. To date, there have been some interesting experiments, such as commercially available consumer cameras with gaze-controlled lens focusing.

Conventional gaze-tracking techniques were intrusive by nature, but easily available IR-sensitive camera sensors have changed the situation. Modern video-based gaze trackers rely on camera(s) and special IR illumination invisible to the human eye. Although their accuracy of about 0.5–2.0° of visual angle is typically lower, they are more appealing for various applications. Two types of video-based gaze trackers can be distinguished: More common remote-eye gaze trackers (REGT) are typically integrated into a flat-panel display, whereas near-to-eye gaze trackers (NEGT) are fixed to the head. Usually, both are based on corneal reflections of an IR light source(s) and a camera(s) capturing glints of these lights from the cornea with respect to the pupil or the limbus (the part of the eye that borders the cornea and the sclera). Depending on the camera quality and the detecting algorithms, the calibration of the gaze tracker can be a very demanding process, which in most cases must be repeated at certain intervals after calibration has drifted, for example, when the head has moved from the chin rest.[4]

Gaze Tracker and NED Integration

A NEGT system might be a usable tool as such, if the gaze direction can be mapped to something such as a world coordinate system. This setup would enable diagnostic applications and even some level of interaction. The ability to integrate the NEGT with an NED makes the overall system more appealing because the visual feedback can be easily utilized.

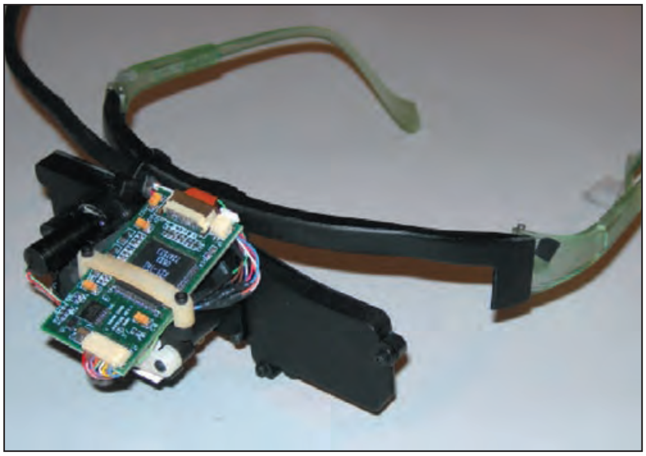
We have created a prototype system where the NED with a diffractive EPE stack is equipped with one more EPE plate, which serves as an illumination expander for a collimated narrow IR light beam (850 nm). The beam size and the output angles are matched with the exit pupil of the display. After processing the eye-camera image, the gaze point in the displayed virtual image of the NED is detected. The system is illustrated in Fig. 2. (More specific information on the system can be found in Ref. 5.) It should be noted that in the human eye, there is an individual offset angle between the visual axis (gaze) and the optical axis, typically around 4° of visual angle.

The main innovation in our approach is the IR illumination diffracted out from the EPE wave guide. In conventional video-based trackers, the eye is approximated as a planar surface, whereas in our setup the actual camera-eye geometry is modeled. Our illumination arrangement resembles more that of the REGT system[6] where the light beam is collimated and the camera is a considerable distance from the eye. In our NEGT system shown in Fig. 3(a), however, the camera is near-focused and two IR beams are required. The angular separation must be high enough in order to reduce the noise in the tracking. Output angles of ±20° have been chosen. The center of curvature of the presumably close to spherical cornea can be calculated by detecting the two glints in Fig. 3(b). The gaze vector is then fitted to go through this point and the detected pupil center. To correct for the fovea not being on the optical axis of the eye and the pupil being at a certain distance from the cornea inside the eye, calibration is required.

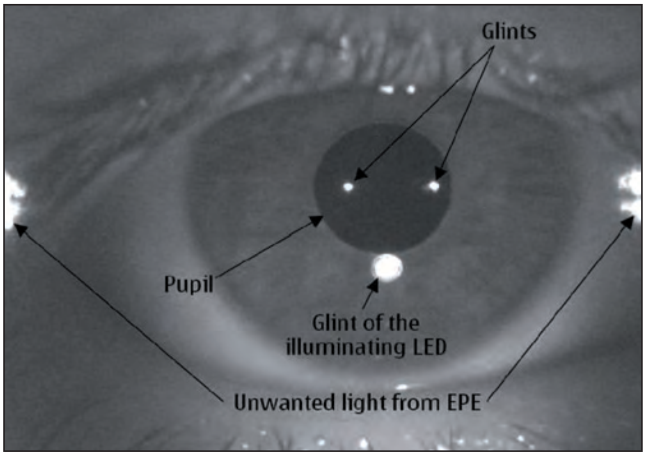
Related information on the mathematics or the pattern-recognition algorithms of the actual implementation can be found in Ref. 7. In short, the image-detection algorithms are loosely based on the well-known Starburst algorithm.[8] An ellipse is fitted to the pupil contour. The glints are detected in the neighborhood of the pupil as a high intensity pair of small spots. The C++ implementation runs on a miniature laptop equipped with an analog frame grabber to capture the eye camera image and a VGA output to supply the image to the NED.

Robust Calibration

Some of the problems of other video-based corneal trackers also affect the performance of our system. For example, eyeglasses can be a problem because the extra reflections can affect the measurements. But what makes our system dramatically different from the others is the robustness of the calibration. In typical systems, the illumination-camera-eye geometry is rather intolerable to changes. Overall, the calibration seems to be a major challenge for the gaze trackers.[9,10] The purpose of the IR EPE is not just to expand the IR beam but to fix the output angle(s) of the IR light, resulting in an invariant camera location. When the output angles in respect to the camera are known, the gaze angle can be accurately calculated with only a slight effect on the lateral movements of the eye. By recording three fixations on the virtual image, the needed variables can be calculated and the gaze point deduced. The calibration lasts through the future sessions. By using our novel approach, the problem of drifting calibration is surpassed, releasing the gaze-tracking applications to fulfill their full potential.



(a)



(b)

Fig. 3: (a) The prototype NEGT. (b) Camera image of the tracked eye.

We are currently working on simplifying the structure of the prototype. Because the EPE plates are almost fully transparent, the possibility of seeing the real world through a virtual image is of interest to many applications. The current IR EPE plate is designed so that the eye camera must be placed in front of the eye. The new prototype will include a redesigned EPE plate with gratings fully integrated with the NED EPE plates, thus reducing the amount of stacked EPEs from three to two. The camera is placed at the edge of the visual field to enable a real see-through mode.

Applications

A separation into diagnostic and interactive gaze-tracking applications can be made.[10] Diagnostic systems record the eye movements, and processing can be done off-line. Still, the requirements of the tracker are often very demanding. On the other hand, interactive applications should work during usage, but the requirements are highly application dependent. The tracking accuracy of our system has been currently measured to be around 1° of visual angle, which results in hundreds of separable parts on the 30° field-of-view virtual screen of the NED. In principle, all the required interactions starting from writing could be done by using the gaze. A simple concept of selecting and browsing photos is illustrated in Fig. 4.

One of our demonstrated applications is an image navigation demo, where a 360° panoramic photo is panned and zoomed purely according to the gaze direction. Fixated objects are shifted to the center of the displayed image and zoomed in. Looking off the center results in increased panning and zooming out. After a quick learning process, the experience is quite intuitive for most people and something that truly cannot be achieved with any other conventional input methods.

The future see-through capability of the system makes it possible to create augmented reality applications by mixing virtual and real objects. Because of the integrated gaze tracker, only the parts that are under the visual attention of the user could be enhanced with some mixed reality information. We will research this more after our next prototype version is finalized.

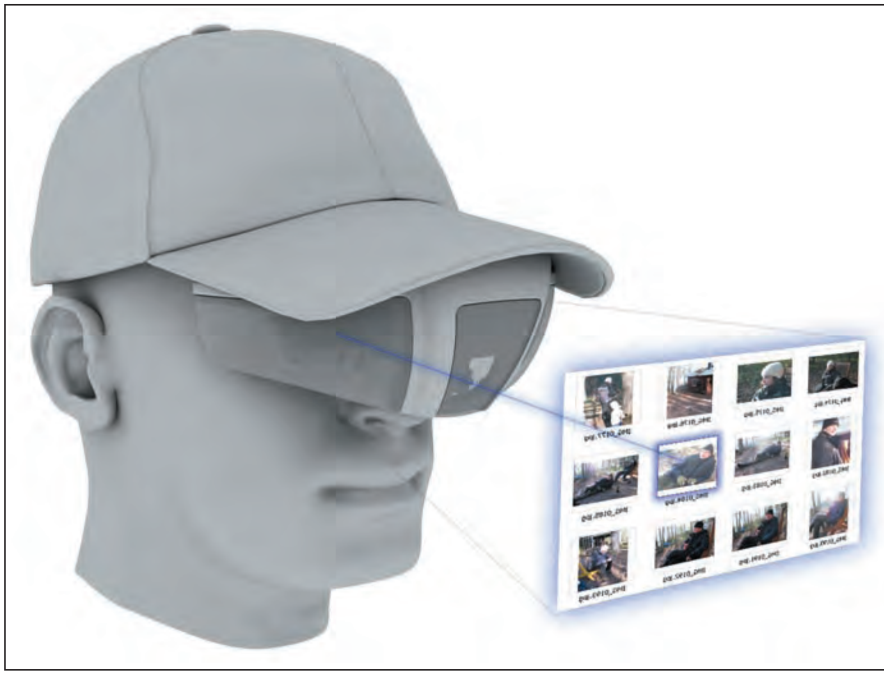


Fig. 4: *A simple illustration of an NED photo-browsing application.*

Conclusion

We have prototyped a compact NED having a novel gaze tracker. The algorithms for the gaze angle detection have been verified and tested for the prototype, and the clearly advantageous robustness of the calibration has been demonstrated. With further developments, the possibility of constructing an affordable and wearable mobile terminal with an immersive nature with full interaction capabilities can be a reality.

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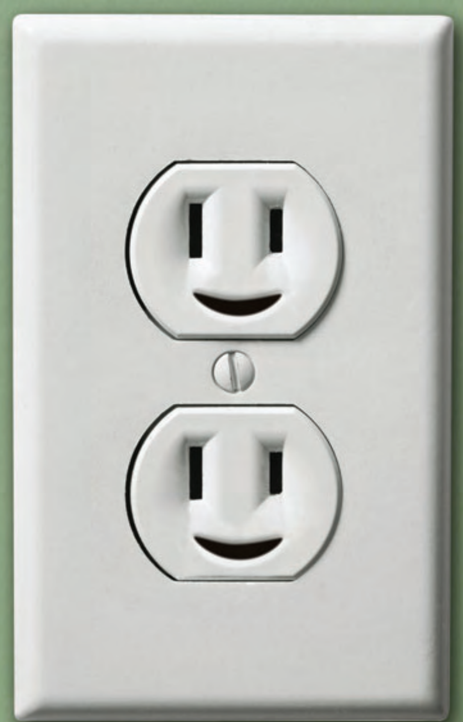

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Display Interfacing – Moving Beyond the Pixels

Displays for mobile devices keep getting larger and more complex. In order to obtain optimum performance from these devices, display interfaces that can transfer other data not related to the pixels are necessary. This article reviews the history and examines the latest developments in this area.

by James E. Schuessler

RECENT handheld electronic product introductions have made one thing clear: Displays are consuming an ever-increasing percentage of the product surface. It may be a stretch to state that the display makes the product, but a poor display can certainly limit its acceptance by end users who grow more critical by the day. End-user expectations are high because the display industry has delivered many front-of-screen performance improvements within the past year alone, including more color depth, higher contrast with more saturation, and a pixel density commonly exceeding 150 pixels per inch (ppi).

This rate of improvement shows no signs of stopping. Wide video graphics array (WVGA) formats at approximately 860 × 480 pixels are being introduced at over 300 ppi, approaching the limit of human perception at common viewing distances. Much has been written about the pressure that more pixels and higher color depth is placing on the display interface.[1] Way back in 2003 – maybe 8–10 product generations ago – these trends were anticipated by several companies, who began work on a new generation of higher-speed and more-serialized display interfaces. This marked a return to serial interfaces, since before the advent of color displays in mobile handsets, serial interfaces were used commonly for display interconnects. However, as displays grew in size and manufacturers adopted more color displays, this low-speed digital interface could not keep up (see sidebar: A Little Display Interface History).

Interfaces have a way of lasting "forever," so it is somewhat dangerous to place a timeline against these interfaces, but if one were to generalize and look for the most popular interface on the leading-edge products of the time, a trend that moved from low-speed serial, to CPU-style parallel, and then to RGB raster-scan-style parallel would be observed (see Fig. 1). In terms of bits per second per pin (just dividing the bandwidth by the number of signals to get a figure of merit), one can see some improvement over three eras of display interfaces, yet as we move into the era of high-speed serial interfaces (HSSI), we see a jump to almost a 10× improvement over RGB parallel and more than 20× improvement compared with CPU parallel interfaces. But this move was not made only for the efficiency improvement of squeezing more bits down a narrower pipe; it was also driven by the potential to reduce electromagnetic interference (EMI) and a longer-term vision to reduce power consumption.

The Move to High-Speed Serial Interfaces

Within the span of 6 months from 2003 to 2004, at least four different HSSI were introduced, and by the end of 2004 two more were announced. These included Mobile Pixel Link (MPL), Mobile Video Interface (MVI™), Mobile Shrink Data Link (MSDL™), Mobile Display Digital Interface (MDDI), Mobile CMADS (M-CMADS™), and Micro Serializer-Deserializer (μSerDes™). Several were based on ground referenced and lower current variations of EIA-644, or low-voltage differential signaling (LVDS), but at least one chose a single-ended approach to further reduce the interconnect size. Support and plans ranged from single company introductions to multi-company partnerships, to industry consortium, open alliances, and standards organizations.

So, if these needs were anticipated as early as 2003, why are HSSI not more common in today's handheld portable electronics? At the proverbial 30,000-ft. level, the reasons can be sorted into two categories: a critical need for high-speed serial that has only emerged recently, coupled with an explosion of proprietary, consortia, and standards-making bodies – all of whom looked to take the lead – slowing the emergence of clear winners. Engineers are a conservative lot; unless forced to change, we probably will not because change represents risk. Thus, we see HSSI used only where mechanical or space constraints forced that use.

The emergence of many swiveling, sliding, and flipping handsets often provided no other option other than serial for connecting the display, yet heroic efforts were made on the mechanical front to allow the 30, 50, or sometimes more than 60 signals to traverse this

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treacherous hinge without going serial. But now the need is truly critical. As more functions are being shoehorned into smaller case sizes, even those handhelds with no moving appendages are adopting serial interconnects for the improvement in volume. Those with moving modules want to distribute heat and relieve complex and costly mechanical hinges to make ever lighter and more attractive designs. Furthermore, a trend has emerged where multiple radio receivers with extreme sensitivity are being integrated, making HSSI's additional benefit of EMI reduction another critical factor driving adoption.

This breakpoint in interface development presented a clear need for industry-wide standards to reduce the supply-chain risk the end-system OEMs were experiencing and the added design time semiconductor companies were spending to address multiple interfaces. While it is typical that costs increase in the short run to address new technical challenges, mass adoption requires the multi-vendor availability and a path to lower costs that standards bring. So let us fast-forward to today and ask whether these needs have been addressed.

DSI and MDDI to Co-Exist

Two HSSI with open standards support are emerging with a critical mass of adoption, which is so necessary to long-term viability. These include the Video Electronic Standards Association's (VESA) MDDI and the Mobile Industry Processor Interface Alliance's (MIPI™) Display Serial Interface (DSI). While some may have wished for one standard to emerge by now, most acknowledge that a handset market that exceeds 1 billion units per year can successfully support two. Let us take a brief technical dive into these interfaces to see how they support the requirements of today's display subsystems.

At first glance, there are quite a few similarities. Although both do not define maximum data rates overtly, current or soon-to-be-introduced versions support approximately 800 Mb/s per lane, but particular implementations may be higher or lower. Both support scaling data rates by adding lanes to either increase total bandwidth or lower the maximum data rate per lane for EMI or cost reasons. Both use source-synchronous clocking that dedicate one differential pair to a clock or strobe signal and that obviates the need for PLL or DLL clock recovery circuitry, often a

A Little Display-Interface History

Early displays for mobile devices relied on common low-speed serial interfaces such as SPI and I2C, and many small secondary or sub-displays still do. As on-display buffer-memory sizes increased for graphic displays, the two common microprocessor bus interfaces were introduced, based on the Intel 8080 (i80) and Motorola 6800 (m68) microprocessors. Amazingly, these are still in use more than 25 years later, although engineers have taken some license with respect to bus widths. Examples are available at 8, 9, 16, and 18 bits. They are commonly used for fully buffered, memory mapped, or sometimes called CPU-type or "smart" displays.

As graphic displays still grew larger and became bufferless, the standard raster interface used in notebook computers was introduced, based on an RGB color data bus the width of a full pixel, and control signals for the pixel clock (PCLK), horizontal and vertical synchronization signals (HS, VS), and sometimes a data enable (DE). These bufferless displays are often called "dumb" displays, yet some contain partial frame buffers accessed via a slow serial bus and execute some low-level commands.

As displays reach beyond qVGA, several factors converge and multiply the deleterious effects of parallel data interfaces. Most obvious is the PCLK rate increase as the number of pixels track to the squared power with X and Y length increases. Color depths are moving beyond 18 bits as devices become more entertainment centric, and novel mechanical designs proliferate as manufacturers seek to engage ever more repeat customers in an upgrade cycle with better ease of use, more comfortable form factors and eye-catching fold outs.

Each of these serves to either increase the data bandwidth to the display or constrain the dimensions of the physical interconnect. Manufacturers have responded by packing more conductors into smaller spaces, increasing the number of layers in flex interconnects, moving to more-expensive micro-coax, and also moving to high-speed serial data transfer.

Excerpt from Chapter 9, Advances in Mobile Display Driver Electronics *by the author, contained in "Mobile Displays – Technology and Applications," edited by Achintya K. Bhowmik, Zili Li, and Philip J. Bos ©2008 John Wiley & Sons Ltd. Reproduced with permission. Note: Chapters 10 and 11 elaborate on VESA MDDI and MIPI DSI, respectively.*

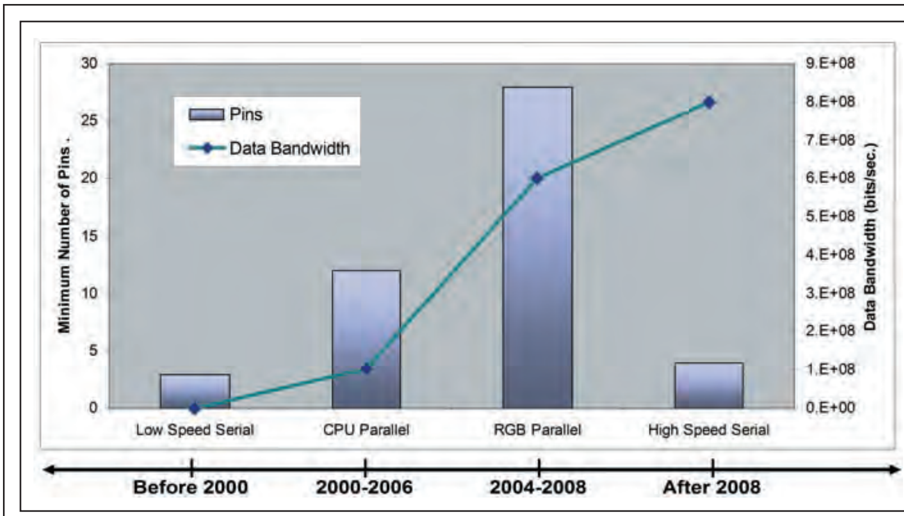

Fig. 1: *A representation of the most popular display interfaces on the leading-edge products of each era shows a trend that moved from low-speed serial, to CPU-style parallel, and then to RGB raster-scan-style parallel, and finally to high-speed serial.*

source of additional power consumption in embedded clock serial interfaces.

Power consumption is always of high interest, but often not put into the correct context of use case or relative importance compared with other elements of the display subsystem (especially the backlight, but increasingly the panel drive dynamic power with larger displays). Looking at a common metric such as picoJoules per bit (pJ/b), only theoretical analysis is possible at this point due to the early stages of rollout. Far more important will be how efficiently the features of MDDI and DSI are used. Both support a relatively fine-grained level of power management by bursting data at high speed and then shutting down during periods of inactivity to save power. When used with a remote (display side) frame buffer, only changes to the displayed image need be sent across the link, saving power over the alternative of refreshing the display from a local (host side) frame buffer. Finally, both support multiple displays over the same interface and color depths including 16, 18, and 24 bpp.

Are there any differences between MDDI and DSI? Most definitely – they are found by looking at the original design goals for each. Back in 2003, MDDI was intended to support external "mobile docking station"-type applications and, as such, boasted support for stereo displays (for near-to-eye 3-D glasses), plus data types for keyboard, mouse, and even stereo audio. To support these features, the protocol required a back channel that interleaved data with the forward direction and a method to avoid audio sample rate jitter. This made it difficult for the original protocol version to support displays without a frame buffer. As MDDI rolled out for internal displays, these features have been retained by the protocol.

MIPI DSI was defined later with a more-targeted set of features to support internal display interconnects only. Displays that contain a full frame buffer, no frame buffer, or a hybrid partial frame buffer are supported. Although the physical layer supports a relatively high-speed back channel, the DSI protocol utilizes the 10-Mb/s low-power Phy mode for its reverse communications. Responses to generic Read commands and trigger responses for tearing effect (a feedback mechanism that allows the host to avoid overwriting the refresh pointer on a display that contains a frame buffer), command acknowledge and user defined are supported. Furthermore, up to four logical channels are available to support multiple displays over the same high-speed link.

Taking a Subsystem Approach

Building architects and mechanical designers will say "form follows function," but in the world of interface development, the analog to this aphorism is "function follows application." In the same breath, one must acknowledge the relentless cost-reduction pressure that must also be satisfied. In truth, new display-subsystem applications driven by the need for better user interfaces at lower costs are driving the need for new functions in the interface. Let us look at some of those new applications being integrated with the display subsystem.

Without a doubt, the touch-input panel in the display subsystem poses the most interesting challenge to the interface. Yet, there are other non-display features that increase interconnect mass and that may benefit from integration into a display-subsystem interface. These include ambient light and proximity-sensing feedback, various haptic (force feedback) methods, and more feature-rich backlight control. How are these to be accommodated in a comprehensive way?

Touch-input controllers have been proposed within display drivers for some years, yet have not really taken off because touch features have always been implemented with overlays that are fully separate from the display. This resulted in air gaps and resulting reflections, thickness that increased parallax between the surface and the image, and generally degraded brightness to a large degree. Display makers were loath to build them together because such a small percentage of display systems required touch input; it was much more cost effective to offer the display alone and add the touch panel later if needed. The advantages of early system integration of touch and display functions now change this dynamic, and produce conditions whereby an integrated interface offers further advantages in cost, space, and EMI reduction.

Considering the other functions that may be useful in a display subsystem, the data bandwidth requirements of the touch interface exceed them all. This is especially true at point A in Fig. 2, where raw samples would be conveyed. The interesting thing is that this abstract model of the touch system is independent of technology (*e.g.*, resistive, capacitive, force, electromagnetic, *etc.*), yet a thorough job of gathering requirements for an exposed interface at this point should look at the band-

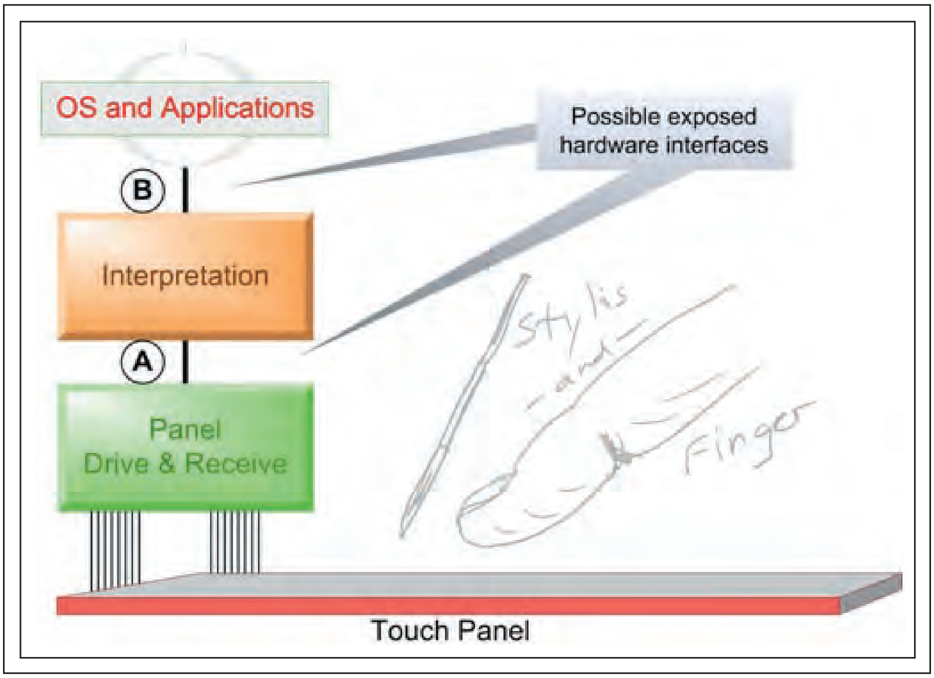

Fig. 2: A rendering of a touch panel and the requirements for its interfaces.

width requirements of each. Another often-neglected requirement of touch interfaces is the measurement time jitter and delivery latency of the samples. Handwriting recognition, shape interpolation, and gesture recognition all require that accurate time stamps (<10% of the sampling interval) be maintained with the data, either explicitly with "wall clock time" or intrinsically by the data path.

Interpretation of the raw samples into these higher-information-content data types (*e.g.*, characters, gestures, and filtered touch points) drastically reduces the data bandwidth (point B in Fig. 2.). However, an interface standard should never dictate functional partition; to do so would impose unacceptable physical restrictions on some systems and limit the adoption of the resulting standard. Fortunately, both MDDI and MIPI DSI have relatively speedy back channels (≧10 Mb/s) that can accommodate touch interfaces at the raw level. That is the good news. The bad news is that the back channel uses the same wires (half-duplex) and requires time interleaving of the reverse data path. For displays that contain their own full frame buffer, this restriction may be acceptable from a bandwidth perspective. For displays that do not contain a full-frame buffer, the forward direction display data has time restrictions due to the display refresh rate that both limit the bandwidth and superimpose asynchronous time boundaries on the reverse channel. Clearly, this will not work for raw ("A" Level) touch interfaces.

Conclusion

Today's MDDI and MIPI DSI have a long run ahead of them as they replace parallel CPU and RGB display interfaces. Their bandwidth capabilities match and exceed even the largest displays planned for use within handheld electronics, and their protocols support a variety of display types that allow cost, mass, and EMI-reduced systems to come to market. Yet, taking a look down the road at more integrated display subsystems with touch, advanced dynamic backlight controls, haptic feedback, ambient light, accelerometer, and proximity sensors require a fresh look at bandwidth and latency requirements. Full duplex interfaces – implemented as dual simplex data paths – completely remove these time restrictions and may be necessary for tomorrow's display subsystems.

[1]J. E. Schuessler, "Standardizing Display Interfaces for High-Performance Mobile Telephones, *Information Display Magazine* **20**, 16-21 (July 2004). ■

Tyco Electronics Introduces the Elo TouchSystems 1900L and 2200L Touchmonitors

The new touchscreen monitors are practical, durable, and stylish.

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A preview of some of the most interesting papers appearing in the October 2008 issue of the *Journal of the SID.*
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Edited by Aris Silzars

Comparisons of motion-blur assessment strategies for newly emergent LCD and backlight driving technologies

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Hao Pan (SID Member)
Scott Daly (SID Member)

Sharp Labs of America

Abstract — Compared to the conventional cathode-ray-tube TV, the conventional liquid-crystal TV has the shortcoming of motion blur. Motion blur can be characterized by the motion-picture response-time metric (MPRT). The MPRT of a display can be measured directly using a commercial MPRT instrument, but it is expensive in comparison with a photodiode that is used in temporal-response (temporal luminance transition) measurements. An alternative approach is to determine the motion blur indirectly via the temporal point-spread function (PSF), which does not need an accurate tracking mechanism as required for the direct "spatial" measurement techniques. In this paper, the measured motion blur is compared by using both the spatial-tracking-camera approach and the temporal-response approach at various backlight flashing widths. In comparison to other motion-blur studies, this work has two unique advantages: (1) both spatial and temporal information was measured simultaneously and (2) several temporal apertures of the display were used to represent different temporal PSFs. This study shows that the temporal method is an attractive alternative for the MPRT instrument to characterize the LCD's temporal performance.

Figure 2 shows a typical captured sequence of a moving edge that crosses the middle of a 37-in. LCD screen. The simulated retinal image is the superposition of the shifted version of the captured frames due to smooth pursuit eye tracking. When the frame period of the capture camera is much smaller than that of the LCD, the integration of the captured sequence in the motion trajectory is equivalent to the measured edge of the MPRT tracking camera system.

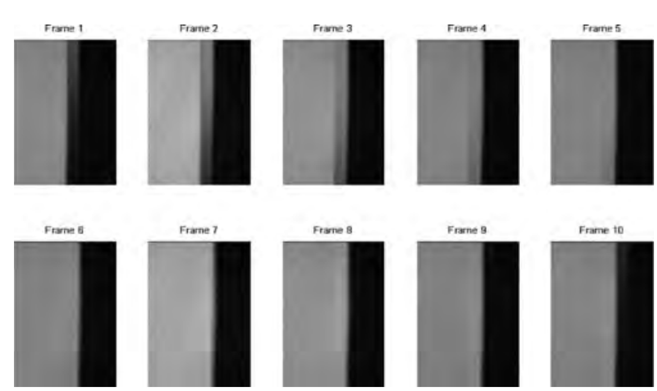

FIGURE 2 — Captured sequence of a moving edge (10 camera captures per one LCD frame).

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Motion-blur evaluation: A comparison of approaches

Michael E. Becker (SID Member)

Display-Metrology & Systems

Abstract — In this paper, the results obtained from two independent evaluations of motion-blur effects with respect to the agreement between the two different approaches used, imaging and non-imaging, are analyzed. The measurements have been carried out in different laboratories by different operators without the prior intention of a subsequent analysis as presented here. The resulting data is analyzed to quantify the repeatability of each instrument and, in a second step, the comparability of results from the two approaches is investigated. The imaging approach used in these experiments is based on a stationary high-speed camera with temporal oversampling and numerical image-data processing to obtain the intensity distribution on the retina of an observer under the condition of smooth pursuit eye tracking. Results from that approach are compared to results obtained from the evaluation of step responses acquired with optical transient recorders by frame-period convolution. Measurements are carried out with a first LCD monitor with test patterns of both contrast polarities, with three velocities of translation and four levels of gray. A second object of measurement is used for investigation of the effect of operator intervention in the process of evaluation of the imaging approach, especially on the determination of the reference levels that are needed for evaluation of the normalized blurred edge (NBE). Possible sources of uncertainties are identified for all approaches and instruments. Based on the analysis of that data, the practicability of step-response-based evaluations of the "blurred edge width/time" compared to the results obtained using the high-speed imaging approach, as long as there is no motion-dependent image processing, are confirmed.

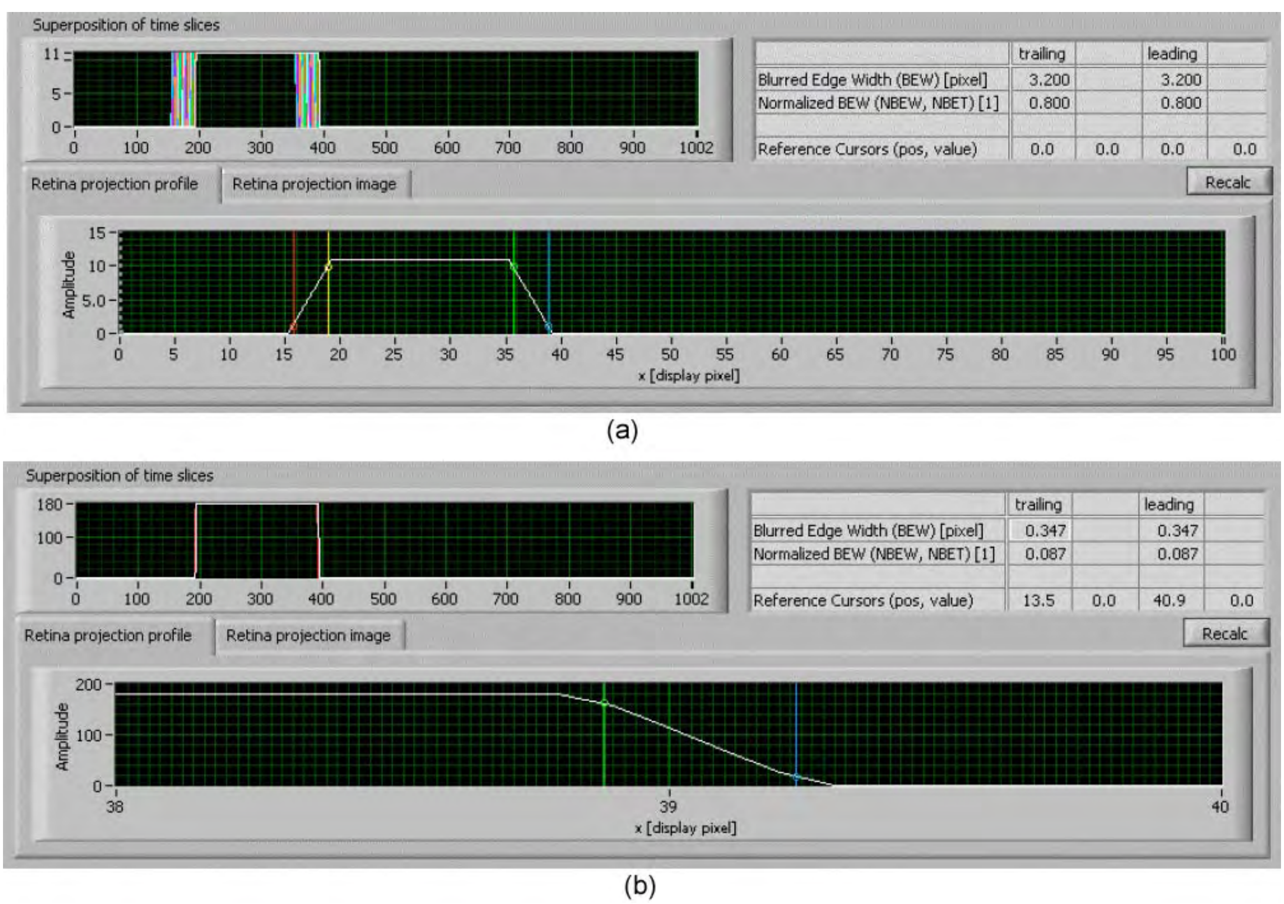

FIGURE 12 — (a) Evaluation of edge blur of a synthetic block target moving on an ideal hold-type display (*i.e.,* zero transition time) yielding a NBE of 0.800. (b) Evaluation of edge blur of a synthetic block target on an ideal hold-type display with blanking (10% ON duty ratio, pulse of 2-msec width at 50-Hz frame frequency) yielding an NBE of 0.087. The leading edge is magnified for illustration purposes.

LCD models to analyze and simulate motion artifacts

Carsten Dolar

Dortmund University of Technology

Abstract — In this paper, two models to evaluate the temporal behavior of liquid-crystal displays are described: a model assuming a linear display behavior and a model that incorporates non-linear effects. For the linear temporal model, it can be predicted that the response time starts to contribute to motion blur when it is longer than one-sixth of the hold time and becomes dominant when it is longer than eight times the hold time. The non-linear model can be used to visualize the appearance of effects that cannot be determined via linear system theory. Also, some means to reduce display artifacts are described and its impact is illustrated. Although the main focus in this article is on the temporal behavior of liquid-crystal displays, the spatial properties defined by the pixel structure can be simulated as well. A formula for the spatio-temporal display behavior is given, which can be evaluated numerically to simulate the perceived image for arbitrary image-sequence input material.

There are two types of models for the LCD behavior described in the literature: A model with linear temporal behavior [Fig. 1(a)] and with non-linear temporal behavior [Fig. 1(b)]. Both models will be used to describe and analyze LCD behavior, but the implemented simulation tool uses the more-general LCD model with non-linear temporal behavior because the linear behavior is also covered by it when choosing the same response time for every gray-level step.

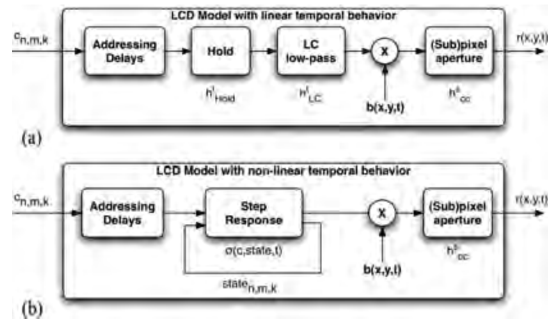

FIGURE 1 — Models for the simulation of the LCD behavior: (a) Model with linear temporal behavior, (b) model with non-linear temporal behavior.

Characterizing displays by their temporal aperture: A theoretical framework

F. H. van Heesch (SID Member)
M. A. Klompenhouwer (SID Member)
G. de Haan

Abstract — The spatio-temporal aperture and sample rate of a video display determines both the static and dynamic resolution of the video signal that is rendered. The dynamic display characteristics like the visibility of large-area flicker, motion judder, and motion blur can be derived from the frame rate and the temporal extent of the pixel aperture (*i.e.*, the temporal aperture). For example, liquid-crystal displays (LCDs) have an aperture that is relatively small in the spatial dimension and wide in the temporal domain. Consequently, moving objects displayed on an LCD suffer from motion blur. Especially in TV applications, the temporal dimension has a large impact on the overall picture quality. The temporal aperture, together with the frame rate, is shown to predict the amount of perceived large-area flicker, motion judder, and motion blur and also the performance of motion-blur reduction algorithms for LCDs. From this analysis it is further determined how to obtain the optimal temporal aperture of a television display, for which not only properties of the human visual system (HVS), but also the properties of the video signal have to be taken into account.

The temporal aperture is the response of the HVS to spatio-temporal frequencies, *i.e.*, the modulation transfer function (MTF) of the HVS. Although, in practice, this is a non-linear function that among others depends on the intensity, it is sufficient for our analysis to approximate it by a spatio-temporal perception window by only considering its approximate limits.

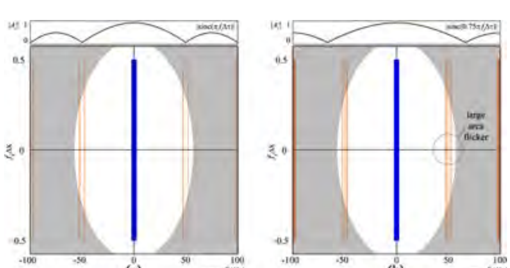

FIGURE 3 — The spatio-temporal frequency plots of the perceived video signal (without motion) (a) on a hold-type display and (b) on a stroboscopic display. Spatial frequencies are plotted vertically, temporal frequencies are plotted horizontally. The sampling of the video signal results in repeat spectra at multiples of the sample rate (50 Hz). The gray-area depicts the spatio-temporal frequency bound of the HVS. The plot shows the influence of the temporal display aperture on the suppression of the signal repeats; (a) full suppression on a hold-type display, (b) large-area flicker at 50 Hz on a stroboscopic display with $\alpha = 0.75$.

A geometrical approach for inverting display color-characterization models

Jean-Baptiste Thomas
Philippe Colantoni
Jon Y. Hardeberg
Irène Foucherot
Pierre Gouton

Gjøvik University College

Abstract — Some display color-characterization models are not easily inverted. This work proposes ways to build geometrical inverse models given any forward color-characterization model. The main contribution is to propose and analyze several methods to optimize the 3-D geometrical structure of an inverse color-characterization model directly based on the forward model. Both the amount of data and their distribution in color space is especially focused on. Several optimization criteria, related either to an evaluation data set or to the geometrical structure itself, are considered. A practical case with several display devices, combining the different methods proposed in the article, are considered and analyzed.

The main idea of the method and the notation we used are the following: One can define a regular 3-D grid in the destination color space (RGB). This grid defines cubic voxels. Each one can be split into five tetrahedra. This tetrahedral shape is preserved within the transform to the source space (either CIEXYZ or CIELAB). Thus, the model can be generalized to the entire space, using tetrahedral interpolation. The generalized way to define such a grid is to take directly a linear distribution of points on each digital R, G, and B axis as seeds and to fill up the rest of the destination space (Fig. 1).

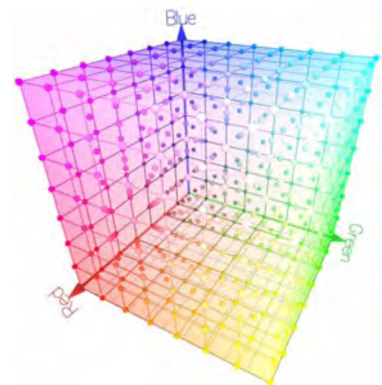

FIGURE 1 — Design of a regular grid N_{rgb} = 24 in RGB.

3-D crosstalk and luminance uniformity from angular luminance profiles of multiview autostereoscopic 3-D displays

Marja Salmimaa (SID Member)
Toni Järvenpää (SID Member)

Nokia Research Center

Abstract — Autostereoscopic 3-D display technologies enable a more immersive media experience by adding real depth to the visual content. However, the method used for the creation of a sensation of depth or stereo illusion contains several display design and content-related issues that need to be carefully considered to maintain sufficient image quality. Conventionally, methods used for 3-D image-quality evaluations have been based on subjective testing. Optical measurements, in addition to subjective testing, can be used as an efficient tool for 3-D display characterization. Objective characterization methods for autostereoscopic displays have been developed. How parameters affecting stereo image quality can be defined and measured and how their effect on the stereo image quality can be evaluated have been investigated. Developed characterization methods are based on empirically gathered data. In this paper, previously presented methodology for two-view displays is extended to cover autostereoscopic multiview displays. A distinction between displays where the change in content occurs in clear steps when the user moves in front of the display, and displays where the apparent movement of the objects is more continuous as a function of the head movement is made. Definitions for 3-D luminance and luminance uniformity, which are equally important, as well as 3-D crosstalk, which is the dominant factor in the evaluations of the perceived 3-D image quality, is focused upon.

One of the main drivers for multiview displays is that they may enlarge the effective viewing freedom of 3-D displays and provide a "look around" objects effect compared to two-view displays. In principle, this can be realized with both barrier- and lenticular-type displays, the latter better maintaining the 2-D luminance level of the display. To be able to utilize larger viewing freedom or "look around," the user typically needs to move in front of the display, or to rotate the display in the case of a hand-held device.

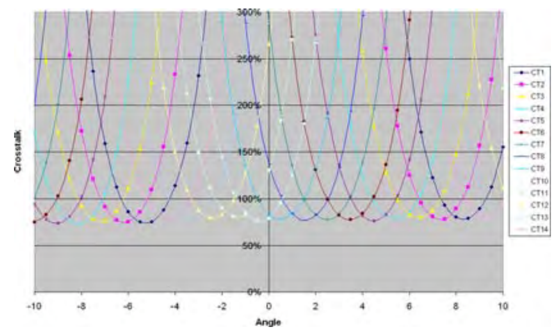

FIGURE 6 — Calculated 3-D crosstalk in multiview 3-D display mimicking continuous motion parallax.

The effects of glossy screens on the acceptance of flat-panel displays

Kjell Brunnström (SID Member)
Katarina Josefsson
Börje Andrén (SID Member)

Abstract — The TCO requirements provide well-known and recognized quality labels for displays. For these requirements to remain useful, they must continuously be reviewed and updated when necessary. The study described here was performed in response to the market trend of designing flat-panel displays and notebooks with glare panels. The purpose of this study was to investigate subjective responses to display screens of different gloss levels for office workers working on different tasks under normal office-lighting conditions. The study consisted of three parts, one where the users should set an acceptable reflex level, one where the user should rate their disturbance on a category scale, and one where the visual acuity of the users were investigated whether they were affected by glare or not. The results show that increasing gloss and increasing luminance levels had negative effects on the acceptance and the disturbance of reflexes. There were statistically significant differences in the acceptance and the disturbance levels between screens with low gloss and screens with high gloss, which suggests that screens with the highest gloss levels should be avoided. The study did not show an effect on the performance based on acuity testing.

A light-emitting-diode (LED) lamp with 36 white diodes was used to create the reflex on the screen. The luminance of the lamp was measured to 85,000 cd/m^2 at 240 V. To obtain a structure in the reflex on the screen, a lens was placed in front of the lamp to collimate the light rays. This made each diode visible on the screen. Also, a crossbar made of black tape was put on the lamp to make the visible reflex more structured (like a reflection from a window with window bars).

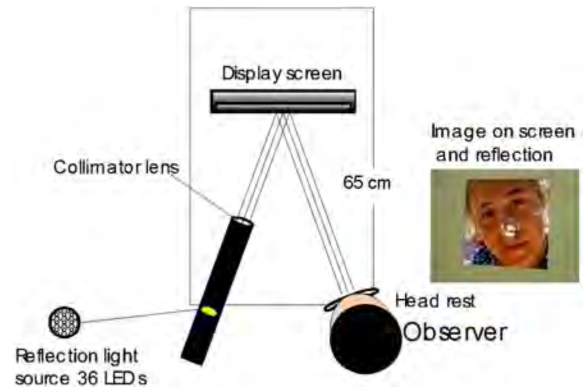

FIGURE 2 — The test set up. The angle in which the light falls on the screen is 20°, as well as the angle in which the observer is looking.

Surface treatment, reflectance, and age effects on electronic-paper reading performance

Yu-Ting Lin (SID Student Member)
Po-Hung Lin
Sheue-Ling Hwang
Shie-Chang Jeng

Abstract — This study is intended to explore the legibility and visual fatigue of different age users under various surface treatments and reflectance of electronic paper. Through the method of character-search task, the results indicated that compared with single types of treatment [anti-reflection (AR) 0.8%, anti-glare, 43% haze], the compound treatment of anti-reflection and anti-glare (ARC) exhibited the same legibility, and it showed superior properties to effectively reduce visual fatigue. Hence, it is suggested that electronic-paper manufacturers should choose the compound surface treatment for better visual performance. On the other hand, the findings also validated that enhancing the reflectance of electronic paper to the same level as regular paper (about 80%) is worthy to be practically implemented. Based on the results of this study, electronic-paper manufacturers can take useful information to fulfill ergonomic requirements on product design.

Visual-fatigue measurements can be classified into psychological and physiological indexes. Employing subjective questionnaire to assess psychological visual fatigue is easy to administer and more sensitive than physiological measures. In addition, the change of critical fusion frequency (CFF) and the change of accommodation power are considered as two important physiological indexes to evaluate visual fatigue.

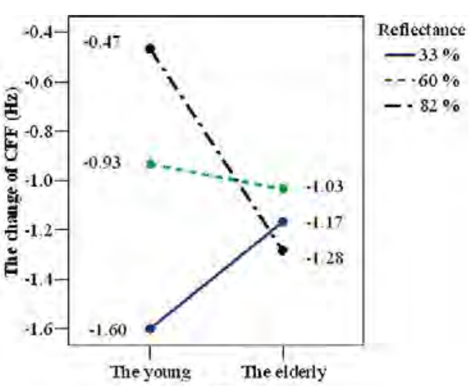

FIGURE 8 — Reflectance – age interaction for the change of CFF.

Analysis of the dependence of optical response time of liquid-crystal displays on the viewing direction

Hyung Ki Hong
JaeKyeong Yoon
Moojong Lim

LG Display

Abstract — The optical response time of liquid-crystal displays (LCDs) has recently been observed to be dependent on the viewing direction. For the vertically aligned LC mode, response time increased as the viewing angle increased when the final state is the zero gray level of the minimum luminance. This change in response time is analyzed to relate to the deformation of the normalized luminance curve of LCDs for different viewing directions. The dependency trends of the optical response time for the oblique direction can be estimated from the temporal luminance measurement data along the normal direction and the normalized luminance curve for oblique viewing directions.

In Fig. 3, the temporal luminance curve is observed to take longer time to reach the minimum luminance for the oblique viewing direction compared with that of the normal viewing direction. From this measurement, optical RT is calculated to be 4 msec for the normal direction and 9 msec for the viewing direction of 60°, showing a difference of more than two times. Users generally watch an LCD TV from various positions in the room. Moreover, a section of a large-area LCD is viewed from different angles even by a user in the same position. This implies that the current definition of optical RT derived from the luminance only along the normal direction may not be good enough to characterize the dynamic performance of LCDs.

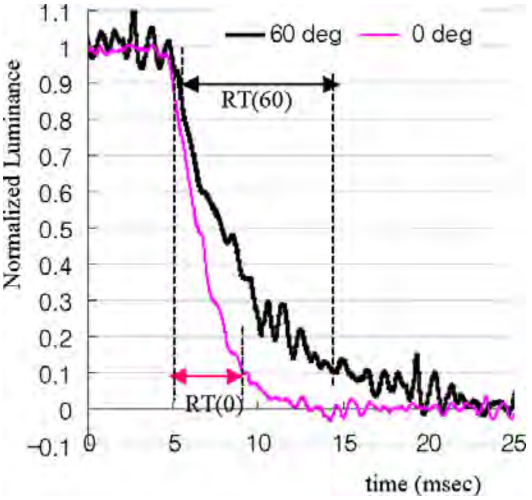

FIGURE 3 — Measurement of the temporal luminance at the viewing directions of 0 and 60° for multi-domain VA-mode LCDs. The horizontal axis represents the time in milliseconds and the vertical axis represents the normalized luminance. An optical RT at 60° is measured to be larger than that at 0°.

Fast-response liquid-crystal displays using crossed fringe fields

Yan Li (SID Student Member)
Zhibing Ge (SID Member)
Ruibo Lu (SID Member)
Meizi Jiao (SID Student Member)
Shin-Tson Wu (SID Fellow)

Abstract — A fast-response and wide-view liquid-crystal display (LCD) using the crossed fringe-field-switching (CFFS) mode is proposed, where the fringe-field electrodes exist on both the top and bottom substrates. The bottom fringe field is used to turn on the LC directors and the top fringe field is used to assist in the LC decay process. The decay time is reduced by ~2× compared to that of the conventional FFS mode between the full bright and dark states, and more than a 2× improvement is obtained for other gray-scale transitions. This CFFS mode also preserves the wide-view characteristics as the conventional FFS mode. Its applications to LCD TVs and monitors for reducing image blur are addressed.

Figure 1(a) illustrates a cross-sectional view of the CFFS device structure. On both top and bottom substrates, strip pixel electrodes and planar ITO (indium tin oxide) common electrodes are formed with a SiO_2 passivation layer (200 nm thick) in between. The bottom strip electrodes are perpendicular, while the top strip electrodes are at an angle α to the x axis. The LC cell has an initial homogeneous alignment and the employed LC has a negative dielectric anisotropy ($\Delta\varepsilon < 0$). The bottom FFS electrodes are used to drive the LC cell to different gray levels and the top electrodes are used to accelerate the LC decay process.

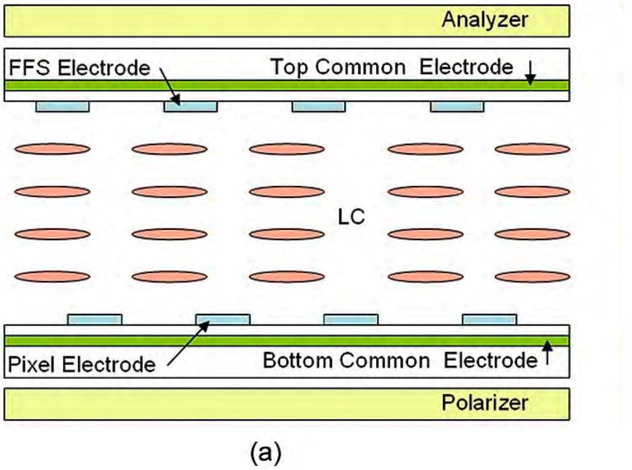

FIGURE 1 — (a) Cross-sectional view of the CFFS cell.

Plasma-beam alignment technique for ferroelectric liquid crystals

Gurumurthy Hegde
Oleg Yaroshchuk (SID Member)
Ruslan Kravchuk
Anatoli Murauski
Vladimir Chigrinov (SID Fellow)
Hoi Sing Kwok (SID Fellow)

Hong Kong University of Science and Technology

Abstract — The plasma-beam alignment procedure earlier developed for the alignment of nematic liquid crystals is successfully extended to ferroelectric liquid crystals (FLC). The highly uniform alignment of the "chevron" structure (before electrical treatment of FLC cells) and "quasi bookshelf" structure (after the electrical treatment) are realized. The contrast of bistable switching larger than 350:1 is achieved. This makes the non-contact plasma-beam alignment procedure especially attractive for high-contrast bistable LCDs on an LCOS base, particularly used in PDA and e-books. Fast switching and realization of gray scale in the plasma-beam-aligned FLC cells makes this technique also promising for full-color displays including color LCD TV.

For irradiation,we used an anode layer source (ALS) with a racetrack-shaped glow-discharge area. In the beam mode, this source generates two "sheets" of accelerated plasma with a width of 25 cm [Fig. 1(a)]. The device operated in the regime of low energies (E = 500–800 eV) and currents (j = 5–20 μA/cm^2). The source was set for oblique irradiation [Fig. 1(b)]. The incidence angle of the plasma beam was about 70°.

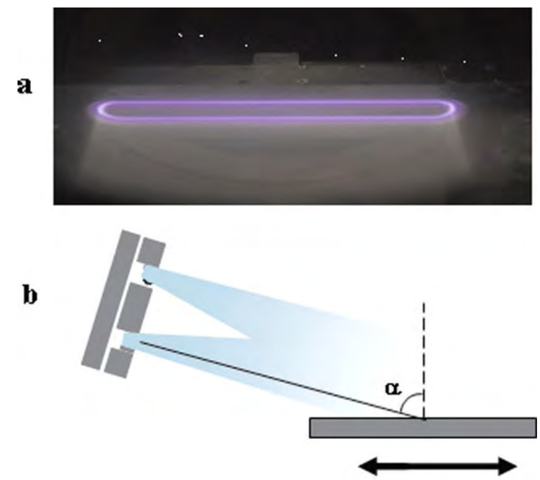

FIGURE 1 —(a) Photograph of anode layer source and generated plasma "sheets" and (b) geometry of plasma-beam irradiation of alignment substrates.

guest editorial

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In the second article, Toni Järvenpää from the Nokia Research Center illuminates a facet of research that has taken place in the past few years to develop a solution for the head-worn-display interaction problem. Gaze tracking is integrated in a diffractive optics module that provides the image from a microdisplay to the user. The result is a compact gaze tracker that is registered with the image path automatically, demanding only a single calibration for each user.

Lastly, Jim Schuessler from National Semiconductor describes the developments in the electrical display interfaces for mobile devices. The demands on the display interface have resulted in extensive standardization of these interfaces, and the industry needs to collaborate to develop the standards to reflect the future needs of mobile-device users.

The Society for Information Display (SID) is well abreast of the trends in mobile displays. The 2008 SID Symposium had quite a few papers on mobile displays, and the Display Week Exhibition presented vendor offerings from the main players in the field. In addition, the *Journal of the SID* publishes papers on mobile-display research. In fact, in the November 2008 issue of *JSID* there will be a special section on mobile-display research papers. In September, SID organized the third Mobile Displays Conference held in San Diego, a further indication that there is a demand in the industry for sharing information on mobile displays. Finally, in May, the SID/Wiley book series published a textbook on mobile displays. All this activity in SID on mobile-display aspects, starting from basic research and ending up in industry offerings to the device integrators, shows that not only is there a business demand outside the large-area glass industry, but that major breakthroughs are appearing in the mobile space as well. ■

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president's corner

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coverage of flexible-display technology – in fact, it has hosted a number of groundbreaking papers in these area. In the past, though, these papers have been finding homes in committees such as Liquid-Crystal Displays, OLED Displays, Display Manufacturing, and Active-Matrix Devices. Unfortunately, Symposium attendees have to work harder to find all of these papers. Additionally, the various committees were not set up to look at this field in an integrated way, making sure that all relevant topics were covered and the most innovative researchers invited.

Fortunately, SID is structured to take action when it becomes apparent that reorganization is needed. So, in 2009, we will see the first year of a brand new subcommittee structured around flexible displays. The Flexible Displays subcommittee will cover a number of emerging display and electronics technologies grouped around the common themes of flexible, printed, low power, paper-like, and the use of non-traditional materials (such as organic transistors). We anticipate that having a subcommittee focused on these topics will strengthen SID's coverage of these areas, and further ensure that the Symposium is considered "home" for these emerging technologies.

The Flexible Displays subcommittee is drawing its membership from across SID, including SID volunteers currently serving on other program subcommittees. For example, I am saying a fond farewell to my colleagues on the Liquid Crystal subcommittee so I can join the Flexible Displays subcommittee. The formation of this subcommittee has the strong support of the 2009 Symposium General Chair, Professor Jin Jang, and the Technical Program Chair, Dr. Fujio Okumura. The first Chair of the subcommittee is Dr. David Morton of the Army Research Laboratory in the U.S., and the committee is already populated with a diverse set of scientists and engineers from around the world, with tremendous experience in flexible and printed displays and electronics. There is a great deal of excitement within the group as we begin our planning for our inaugural sessions in 2009.

So, please take a look at the 2009 SID Technical Symposium Call for Papers, and in particular consider a contribution to subcommittee 10: Flexible Displays. I look forward to reviewing your papers!

Paul Drzaic
President
Society for Information Display

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Samsung Launches SAMSUNG RECYCLING DIRECT

(continued from page 3)

sumer-centric SAMSUNG RECYCLING DIRECT program which delivers on their highest priorities," stated **Steven Cook**, senior vice president and chief strategic marketing officer, Samsung Electronics America. "This resulted in a convenient way to responsibly recycle their consumer electronics products so that our consumers can enjoy a digital lifestyle in good conscience."

"As with any program of this magnitude and consumer-centric focus, considerations that include convenience, respect for environment and people, responsible program management, and the highest integrity are absolutely critical for a sustainable success," Oh concluded. "We at Samsung recognize our colleagues in the consumer electronics industry who have introduced take-back and recycling initiatives in recent months, and we sincerely invite those companies seeking a path to environmental responsibility for them to join us in our commitment to tackle this important issue."

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editorial

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desire. Like most things, you need to want them bad enough to make sacrifices.

It's hard to overemphasize the value of advanced education to both the employee and the employer. Complex problems can be solved faster, up-to-date business and technology know-how can be implemented, and unknown problems often are avoided at inception because of the higher level of knowledge being applied to the business. Employees who make the commitment to pursue an advanced-degree program, or even those who just want to stay current, are making a serious commitment usually well above their company's expectations. It is crucial that we, as managers, recognize this and provide all three necessary accommodations to the fullest extent we can. Everyone benefits including the industry we all love. So, as you pour over those budgets and have those challenging conversations in preparation for 2009, please do not forget the bigger picture and allocate some resources to employee professional development. If you are one of the lucky ones whose company already has a comprehensive professional-development program, USE IT! Take advantage of it in every way you can and invest in your future for the benefit of all of us.

I am really excited this month to welcome our Guest Editor Jyrki Kimmel from the Nokia Research Center in Finland. Jyrki has been a long time supporter of SID, having contributed numerous articles and papers, as well as working on the Symposium Program Committee and serving as past European Region Vice President. Jyrki has an amazing depth of knowledge and experience in the mobile-devices marketplace and his perspective goes way beyond just the displays. This month, he has brought to us three articles that each look at separate but important aspects of mobile-device development. You can read their introductions as well as his thoughts on the next technology challenges facing mobile devices in his guest editorial (see page 4).

One issue that he highlights is the same one I am particularly interested in – head-worn displays (*i.e.*, glasses or goggles). Like Jyrki, I am convinced we are reaching a critical limit in terms of the amount of information we want to put on handheld screens versus the workable size of the screens. If we make the screens any larger, the devices will not fit in our pockets and hands. If we make the pixels and hence the content smaller, people like me cannot read them comfortably. Yet the rush to implement Web browsing, videos, advanced gaming, word processing, and even HD television is irreversible, but unless we find a new paradigm these new high-bandwidth innovations could stall because of the limitations of the displays. I am sure a new generation of lightweight and ergonomically attractive head-worn displays is coming – I just do not know yet what form they will take. This is a segment that has seen many ideas but very limited market penetration in the past decade. The difference today appears to be that content is now in enough hands that the displays are now more necessary then ever for a completely rewarding user experience.

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Stephen P. Atwood

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A Global Initiative

A host of organizations across the globe and countless individuals within those organizations have contributed to this signal moment in display-technology history. Although there are major regional distinctions between the organizations as highlighted below, there is also a crucial commonality. Within any given region – Asia, Europe, or the United States – the spearheading organizations have leveraged their historical place, resources, and cultural heritage to drive the technology development in a way for which they were best positioned to achieve success.

Regional Differentiation

In Asia, historically, the home to flat-panel-display (FPD) manufacturing and with a culture willing to risk large manufacturing infrastructure investment, Tier 1 manufacturers LG Display and Samsung Electronics in Korea and Sony and others in Japan, as well as niche/custom display-manufacturer Prime View International (PVI) in Taiwan, are leading the way. These companies are funding their efforts internally through aggressive re-investment of a portion of the large revenue streams generated by their conventional glass-based FPD manufacturing fabs. They are heavily leveraging their years of accumulated experience with amorphous-silicon (a-Si:H) thin-film transistor (TFT) technology and working to transition that powerful know-how to flexible-display manufacturing.

In Europe, home to storied hundred-year-old-plus technology corporations and venerable academic institutions, Philips spin-out Polymer Vision and Cambridge University start-up Plastic Logic are the primary innovators. With the dominant position of Asia in a-Si:H technology, these relatively young European companies are pursuing a different path by pioneering the integration of organic thin-film-transistor (OTFT) materials and devices in displays. Funding comes from venture-capital firms and government sources eager to see the associated new manufacturing approaches and potentially disruptive technology succeed.

In the U.S., the historical home to new technology invention and major FPD materials and manufacturing supply-chain companies, but without a domestic display-manufacturing base, the Flexible Display Center (FDC) at Arizona State University, a not-for-profit government/industry/university consortium, is the tip of the spear. Following a long tradition of substantial military investment in the creation of new display technology, the U.S. Army Research Laboratory established the FDC in 2004 through a 10-year cooperative agreement with Arizona State University to accelerate the commercialization of flexible displays.[5] To achieve this objective, a world-class partnership framework was designed, and a network of more than 20 actively collaborating and financially contributing industrial members has been implemented. A dedicated state-of-the-art facility and manufacturing pilot-line infrastructure have been established to create a unique venue and national asset for the partnership to co-develop advanced technology and associated manufacturing processes. As a not-for-profit organization, the FDC can afford the luxury of being somewhat more technology-agnostic than commercial technology-development organizations. In the short term, efforts focused on developing the associated flex-compatible materials, tools, processes, and protocols to rapidly and cost-effectively transition a-Si:H TFT glass-based manufacturing infrastructure to fabrication on flexible substrates. However, with a look to the future and potential enabling or even disruptive technologies, parallel longer-term work on such topics as alternative break-out TFT technologies and roll-to-roll compatible processing is being actively pursued.

Global Interconnectivity

Which of the ground-breaking efforts described above will enjoy enduring success is impossible to judge at this moment in time. From the perspective of a customer – be it military, a display technology integrator, or the individual consumer – the best short-term outcome will be that all will be successful. In that context, there is a tremendous level of interconnectivity and interdependence between the efforts in the different geographic regions. For example, Philips in Europe has licensed an enabling display fabrication on thin-film spin-castable plastic protocol it calls EPLaR™ to PVI in Taiwan. EVG, an Austrian company with North American headquarters in the FDC facility and an FDC-member company, has recently sold production-level large-area organic coating tools that were developed in collaboration with the FDC to Plastic Logic for its new fab to open this fall in Dresden, Germany. Professionals at DuPont-Teijin Films in Japan and the U.K. have been working with the FDC to develop a "display-quality" engineered high-temperature polyester film that is now available as a commercial product, Planarised PEN™, for any flexible-display technology developer or manufacturer. LG Display has recently become an FDC member, and we are already collaborating actively on improvement of flexible metal-foil substrate systems. These are just a few of the many examples of the complex interconnectivity and interdependence of the global effort that will no doubt grow in number and impact as commercialization is fully realized.

Postscript: Back to the Future

Despite the tremendous advances and successes realized in the past few years, there is still much work to do. For the first generation of ultra-low-power daylight-readable e-paper reflective displays soon to be mass-produced, manufacturers will need to work through throughput and yield issues. Cost-effective flex-compatible processes and materials for color filters will need to be developed because many applications will require, or the consumer will demand, full-color displays.

An entirely new set of problems will arise as the different organizations focus more attention on the more-challenging emissive OLED displays still under development. Anticipating that neither a-Si:H TFTs or OTFTs will meet the demanding performance requirements of OLEDs, alternative flex-compatible TFT technology will need to be developed. Robust flexible barrier and encapsulation films and associated cost-effective low-tact-time processes will likewise need to be developed.

As for the technology development and commercialization efforts to date, it is likely that we will see differentiation by region as different organizations construct individualized roadmaps and pursue competing paths that leverage their unique historical place and core competencies. This healthy competition, coupled with strategic cooperation and interconnectivity, should drive the community to collectively arrive at effective solutions.

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[1]Scheduled for market release in Europe in Fall 2008 and in the U.S. in early 2009. Source: "Electronic Papyrus: The Digital Book, Unfurled," *The New York Times* (July 6, 2008).

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[4]"Future Tech: Seven Technologies that will Touch Your Life," *PC Magazine* 58-66 (July 2008).
[5]D. Morton and E. Forsythe, "Flexible Display Development for Army Applications," *Information Display* 18-23 (October 2007). ■

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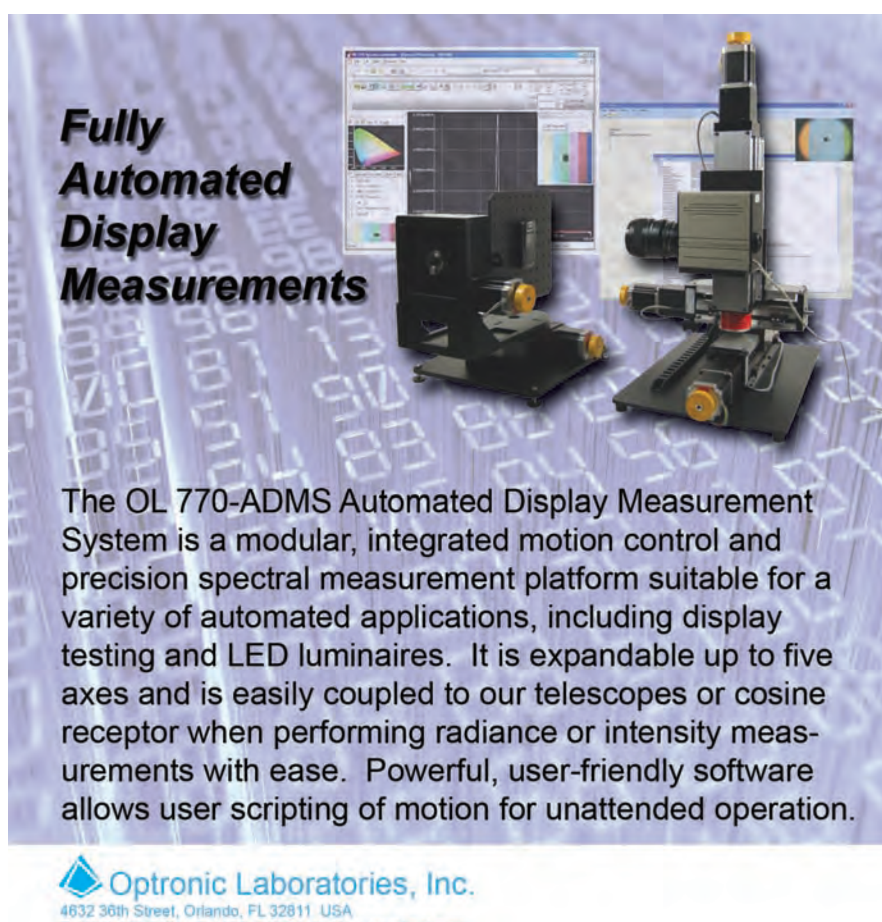

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