DISPLAY METROLOGY ISSUE

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SID

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Introducing the International Committee for Display Metrology (ICDM)

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- *Measuring Display Performance*
- *Simulating Performance & Visual Perception*
- *Diffuse Clarification*
- *SID Heads to Hollywood*
- Journal of the SID *February Preview*

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editorial

You Might Be a Display Metrologist If …

In the world of display technology, there are numerous niches, important but specialized areas that stitch together to form a quilt stretching across the continuum. Display metrology is just such a niche, practiced by a few, but properly understood by even fewer. In fact, to be a display metrologist, you need to know a lot more than just how to aim and operate a photometer. You need to understand why that instrument works, and when you can rely on the value it measures — and more importantly, when you cannot.

I would actually suggest that the true metrology portion of display measurement is a niche of a niche, populated by those who regularly say "luminance" instead of "brightness" and can discuss the merits and shortcomings of Fourier optics in the same way many of us would casually debate about CCFL *vs*. LED backlighting. True display metrologists are the ones who augment $100,000 spectroradiometers with pieces of hand-cut black cardboard because the "stray light" is affecting the measurements. They create innovative solutions to complex problems that properly fit the circumstances and sometimes look too simple to really work. In fact, using the humor brought to the field by our colleague Dr. Edward F. Kelley, it is tempting to develop an almost Jeff Foxworthy-like attitude to the things that metrologists spend their time on. For example, if you can utilize a styrofoam beer cooler as a suitable integrating sphere for reflectance measurements, you might be a display metrologist.

But this is not a fair characterization because it implies that the work is not rigorous or precise. In fact, just the opposite is true. Display metrologists spend their entire careers pursuing two goals: the most precise and accurate measurement of light from displays and finding the best correlation possible between what they measure and what users of the displays actually see. And make no mistake, the accurate measurement of light from displays is no simple task. There are an astounding number of commercial instruments on the market today that even when used as rigorously as possible are not better than ±10% in absolute accuracy. Whether that performance is good enough for the intended application is a real problem with which display metrologists regularly struggle.

As you can imagine, educating users on the right ways to perform measurements has been a challenge as well. People want easy answers to questions such as, "How do I measure that parameter?" and "What number is good enough?" Providing answers to the first question was the goal of a standards group that started working with the Video Electronics Standards Association (VESA) to develop what is now known as the VESA Flat Panel Display Measurement (FPDM) standard. The VESA FPDM is widely recognized as one of the best instruction manuals ever produced on the practical application of optical metrology to displays.

In 2007, this effort took another great step. The team that developed the FPDM has re-organized themselves with the support of the Society for Information Display into the International Committee for Display Metrology (ICDM). The new ICDM is made up of the same team as the FPDM effort, but the process is now totally open to the display community, and their outputs will be offered royalty-free to the entire world. In a smaller way, this new approach is analogous to the effort to develop Linux in the 1980s, where anyone could use any part of the project and add their innovations to it royalty-free for the entire world to use.

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As PDP Shipments Surge, DuPont Remains Bullish on the Future of PDPs with Release of Next Generation of Fodel Paste

To borrow a line from Mark Twain, the reports of the impending death of the plasma-display panel (PDP) have been greatly exaggerated. And that suits companies that supply materials for the manufacture of the panels, such as DuPont, just fine.

For the past several years, as liquid-crystal-display (LCD) panels gobbled up market share and grew ever larger in size, it seemed as if it were only a matter of time before plasma panels could be relegated to the dustbins of technology history.

But according to the latest data released in January by market-research firm **DisplaySearch**, plasma panel shipments enjoyed a tremendous rebound at the end of 2007. DisplaySearch reported that for the second consecutive quarter, PDP shipments set a new record in Q4 2007 with almost 4.4 million units, a 42% increase from the previous quarter and a 62% increase from the same quarter in 2006. This was driven by several factors, including:

- A greater availability of 1080p resolution plasma panels, which accounted for 11% of all PDP shipments, a 46% increase from Q3 2007 and a 1300% jump from Q4 2006.
- Pricing: 42-inch HD PDP panels cost 20% less than comparable LCDs, and PDP pricing is falling faster each quarter than comparable LCD panel sizes.
- 32-inch PDPs selling well in developing regions, helping that size to more than double its share of PDP shipment to nearly 11%.
- Generally better plasma panel availability than LCD going into the holiday season.

This is good news not just for the PDP makers themselves, but all the companies that supply materials for the manufacture of the plasma panels. One such company, **DuPont Microcircuit Materials**, announced in January that **Matsushita Electric Industrial Co. (MEI)**, the largest supplier of plasma panels according to DisplaySearch, adopted the newest DuPont™ Fodel® 8th Generation (8G) photoimageable thick-film pastes in its latest line of Panasonic VIERA® Plasma televisions.

These DuPont™ Fodel® 8G pastes are used in the metallization of the PDP front bus electrodes in order to improve image quality and achieve substantial cost savings through dramatically reduced precious metal content. Specifically, the 8G pastes have eliminated ruthenium, a metal garnered during the mining of platinum, by replacing the ruthenium pyrochlore-based black pigments used in previous generations of the Fodel® system with a novel and proprietary black pigment system based entirely on lower cost metals. This has been accomplished while simultaneously improving the overall system's performance including resistivity, blackness, processing margin and latitude, and cycle time.

According to **Marc Doyle**, business director for Dupont Microcircuit Materials for Asia, the market for ruthenium exploded about 18 months ago after the material began to be used in perpendicular magnetic recording hard disk drives, driving the price from about $80 per troy ounce to about $800 per troy ounce. The price has since come down to about $400 per troy ounce.

"Suddenly the cost of ruthenium became this huge issue for the PDP guys," Doyle explained. "The price of our paste went up 4X, and obviously price increases in PDP [manufacturing] is not a good thing, so we suffered a tremendous amount of pressure."

The elimination of the ruthenium cuts the cost of the black paste in half, to about $5 per panel for a 42-inch TV, which represents 2 percent of the total cost of the panel. This is

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Renesas, Sharp and Powerchip Semi Announce Joint Venture for Small- and Mid-Size LCD Components

TOKYO - **Renesas Technology Corp.**, **Sharp Corp.** and **Powerchip Semiconductor Corp. (PSC)** announced in February an agreement to establish a joint venture specializing in drivers and controllers for small- and mid-size LCDs. Consolidating the business operations of Renesas Technology and Sharp in this field, the new company will engage in the design, development, sales and marketing of LCD drivers and controllers, according to a press release. Business operations related to these products will be transferred to the new company starting April 2008 for Renesas Technology, and by the end of fiscal 2008 for Sharp. The new company will begin full operations on April 1, 2008.

The new company, called **Renesas SP Drivers Inc.**, is a fabless semiconductor manufacturer. Powerchip Semiconductor, one of the investors in the new company, will handle most of the actual production, using its ultrafine process technology and production cost competitiveness, according to the press release. It has capita of ¥5 billion and 170 employees. Renesas owns 55% of the company, Sharp owns 25% and PSC owns 20%.

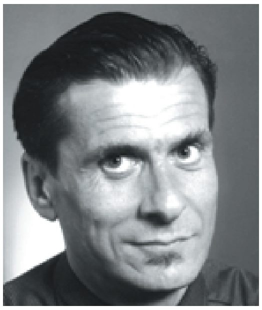
In recent years, the market for LCD panels has grown exponentially, due to the growing popularity of LCD TVs, mobile phones with higher quality displays, and the use of LCDs in products such as car navigation systems and game consoles. The market growth for small- and mid-size LCDs is expected to be especially strong because of the emergence of mobile phones. More mobile phones are required to support sophisticated multimedia capabilities such as built-in digital cameras and reception of TV programs to enable the mobile phones' advanced functionality and higher picture quality standard. In addition, the demand for mobile phones is also accelerating in emerging markets such as the BRICs economies, notably China and India. As these conditions generate heavy demand for integration of driver and controller functions for small- and mid-size LCDs, market competition is expected to become increasingly fierce due to intensifying price competition and the emergence of fabless manufacturers overseas.

To respond to such growing competition, the three companies have agreed to establish a joint venture in order to realize improved cost competitiveness, increased design capabilities, more attractive products, and expanded sales.

By maximizing its strengths as a fabless semiconductor manufacturer, the new company will strive to achieve stable growth in the field of drivers and controllers for small- and mid-size LCDs.

—Staff Reports

guest editorial



Display Metrology: What Is It (Good for)?

Michael E. Becker

Display Metrology, the measurement of the optical properties of electronic displays, is intended to support the supply of customers with display devices that satisfy visual performance requirements resulting from specific applications.

Display metrology is practiced in order to provide physical data as an objective basis for rating of the visual performance of electronic-display devices; *e.g., luminance* is measured in order to estimate the *brightness* perceived by a human observer. Display metrology thus contributes to bridging the gap between physical measurements and the human visual perception of electronic displays and thus their ergonomic performance. It is subject to a variety of boundary conditions (canonical rules) and the way it is exercised or the results are featured may severely affect commercial competition. For example, in a court case from 2003 (NEC Mitsubishi Display of America *vs*. ViewSonic Corp., Illinois Federal Court, Case No.: 02 C 08304), NEC Mitsubishi had charged that ViewSonic could have been misleading or confusing customers with the way they had specified the contrast of ViewSonic LCD monitors. While this was a case between competitors, similar cases involving consumer advocacy groups holding manufacturers to task for issues of exaggerated technical claims have been initiated many times over the years as well. Display metrology and the resulting data is of significant commercial interest and thus often subject to manipulations. Hence, the stakes for understanding and properly exercising the practice of display metrology are very high.

In the first step, physical measurements that are significant have to be carried out, providing characteristics that are meaningful with respect to *human visual perception*, such as measuring *light* instead of infrared or ultraviolet electromagnetic radiation. The object of measurement has to be in a state that corresponds to a *realistic application situation* (*e.g.*, not in a completely dark room), and its controls have to be set accordingly (*e.g.*, luminance and contrast settings).

It is taken for granted here that display metrology is *reproducible*, *i.e.*, providing the same results when the specifications of the measurement procedures are followed, simple, and robust (*i.e.*, insensitive to small variations of the instrumentation and its geometry).

The *measuring methods*, usually specified by international standards (no qualified competent monographs are available on this complex subject; the FPDM-2 provides the required solid basis), should be clearly described to be easily understood, and all details that are important for implementation and accomplishment of the method must be disclosed (see ISO/IEC Directives, Part 3: Drafting and Presentation of International Standards). A comprehensive compilation of compulsive *terms and definitions* is a prerequisite for unambiguous communication and understanding between any two parties.

In addition, the methods should be applicable to a wide range of different display effects and technologies. They should be honest (*i.e.*, not devised to hide deficiencies), allowing for a broad range of instruments (not restricted to unusual, highly specialized, or hardly accessible instrumentation). International metrology standards should not be misused as marketing instruments for metrology instrumentation manufacturers.

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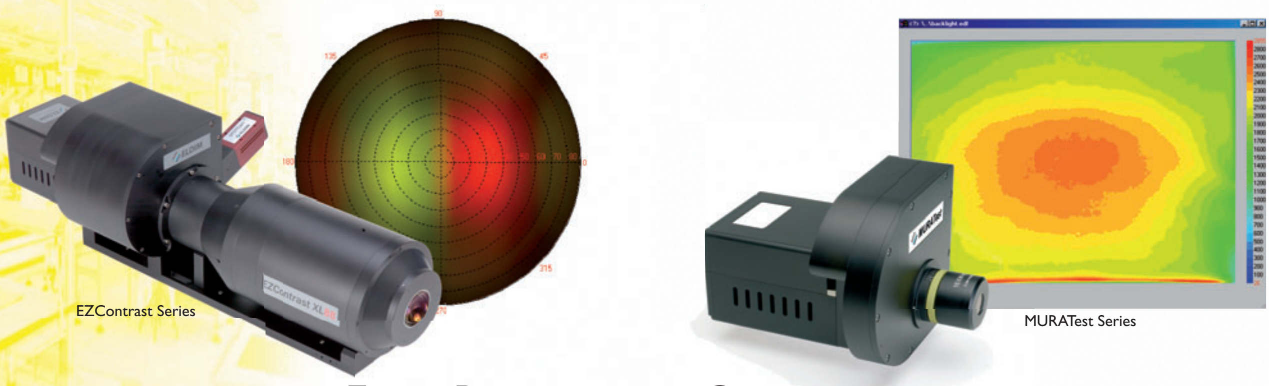

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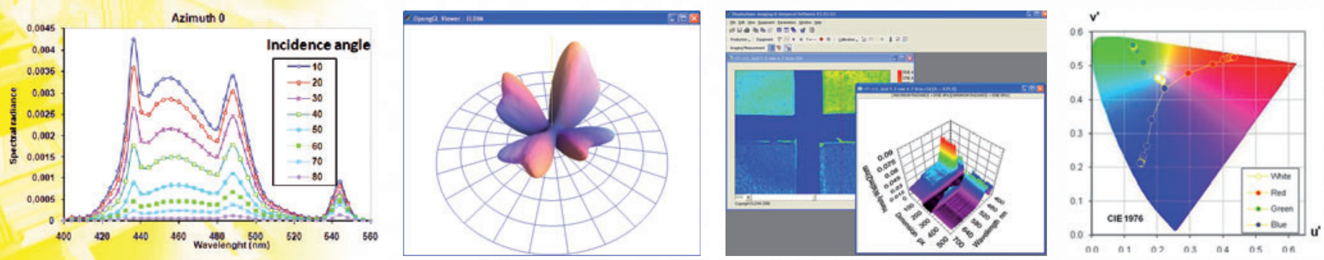

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Evolving the LCD Marketplace

Sang Soo Kim

Do you remember the movie "Jurassic Park"? In the climactic scene of Steven Spielberg's classic film, a huge *Tyrannosaurus rex* attacks a slew of raptors that have been hunting the park's visitors. After emerging the winner in its battle with the raptors, the *T. Rex* roars out in victory, while a park banner saying, "When dinosaurs ruled the earth," falls to the ground – cinematically underscoring the larger message that even the dominant will fall to the wayside if they are not prepared to evolve.

The scene reminds me of cathode-ray-tube (CRT) displays, which were the absolute dominant force in the display industry until the 1990s. At first, it seemed that they also would dominate the TV and monitor markets at the onset of the video era. However, the opposite occurred. CRTs are gradually disappearing – only a little more than a decade after the advent of liquid-crystal displays (LCDs).

The LCD is the *T. Rex* in today's display industry, accounting for 85% of the total display-market revenues (DisplaySearch, 2007), a tremendous expansion from the mid-1990s when they were primarily applied to notebook computers. In 2000, LCDs enjoyed a great deal of growth in the desktop-monitor segment. Today, the upward spiral is fueled not only by growth in PC usage and the use of small-screen LCDs for consumer-electronics devices, but also by the phenomenal ascent of the large flat-panel-TV market, in which LCD technology is now the leader.

But we must not become complacent. The IT market is maturing and the TV market is expected to approach saturation around 2010. Moreover, there is some concern that the LCD market could stagnate if we do not find a new growth engine and if LCD technology does not evolve more rapidly.

The LCD industry has heeded these warnings. We have learned from the demise of the CRT and have continued to seek out new industry growth engines that can work hand-in-hand with the development of new technologies.

I am happy to report that the industry is moving in the right direction. As more LCD production lines come on line and the size of glass substrates continues to expand, the "extra-large" display field, in particular, is expected to create new markets for LCD applications.

I see four major growth areas approaching:

- The next growth segment of the large-display market is digital signage. Until now, the use of digital signage, or digital information displays (DIDs), was seen as most promising in public areas such as airports, stock exchanges, hospitals, banks, and exhibition halls. Recently, however, that view has shifted somewhat to where digital outdoor commercial boards at bus stops and outer building posters are seen as having even larger growth potential. Yet, to truly add to the success of LCDs in the TV market, digital signage must overcome the limitations of current DID technology, including fully resolving the challenges of outdoor visibility, long-term reliability, and multi-screen design. The industry has been making significant strides to meet these challenges, but there is more to do.
- Beyond digital signage, another bright spot for LCD-market expansion is that of e-boards for use in offices. E-boards can replace the white boards and beam projectors currently in use with 100-in. or larger displays. To jumpstart the e-board market, the industry must secure technology for multi-touch screens and develop

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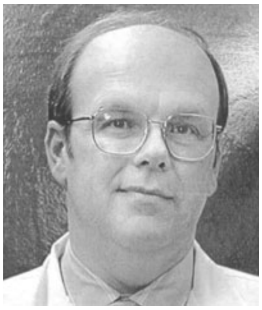

Diffusion Confusion

by Edward F. Kelley

There seems to be some confusion in the display industry regarding the use of the term "diffuse" as applied to reflection. Strictly speaking, diffuse reflection means to scatter out of the specular or regular geometrical direction, whereas the term specular or regular reflection refers to reflection as from a perfect mirror, without any diffusion or scattering (see definitions box). If a display has a specular component of reflection, then we will be able to see distinct virtual images of the sources in the room as we gaze at the surface reflections from the display. When other types of reflection properties are present, such as a background gray or a fuzzy smearing of the light sources, then we have diffuse reflection properties. Unfortunately, many people confuse the term "diffuse" with "Lambertian," which is not correct. Lambertian refers to a special type of diffusion, but diffusion is not limited to Lambertian surfaces.

Some refer to a Lambertian surface as a uniform diffuser. Such a surface obeys Lambert's law: $I = I_0\cos\theta$, where I is the luminous intensity, I_0 is the luminous intensity in the normal direction, and θ is the angle from the normal. This gives rise to the familiar Lambertian characteristic that the luminance L of a Lambertian surface does not change with the direction of observation and that the luminance does not depend upon the direction of the illumination; only the magnitude of the illuminance E is important: $L = \rho E/\pi$, where ρ is the diffuse reflectance of the material. For a diffuse reflectance of $\rho = 1$, we have a perfect reflecting diffuser. The white diffuse reflectance standards – white pucks – that are often used are close to being perfect reflecting diffusers, but they are not perfect; they are not perfectly Lambertian. There are many diffuse surfaces in our environment. Walls painted with matte (or flat), semi-gloss, satin, or eggshell paints are all examples of diffuse surfaces that are not Lambertian and for which the equation $L = \rho E/\pi$ is not strictly valid where ρ is assumed to be a constant. Matte wall paints appear Lambertian to the eye, but they are not perfectly Lambertian if we measure them carefully. Unfortunately, many people apply this Lambertian equation to our display surfaces with impunity, without regard to the true nature of the optical diffusion when present, and this can lead to serious errors in reproducibility when comparing the reflection properties of displays from laboratory to laboratory. This is not to say that the equation $L = \rho E/\pi$ cannot be used; we just need to realize that for most materials the ratio L/E is not very constant but depends strongly upon the geometry of the illumination and detector. We cannot use $\rho = 0.99$, or whatever, for those white pucks for just any source-detector geometry we choose.

In Fig. 1, we show a laser pointer hitting a flat-panel display (FPD). The FPD reflects the laser light onto a white card in a dark room. The display is assumed to have several reflection properties: specular, producing the bright spot at the center of the card; and haze, a non-Lambertian property that produces the fuzzy ball of light surrounding the bright specular dot. The specular component is represented by the bright line. The haze component is represented by the lobed structure indicative of the luminous-intensity distribution surrounding the specular ray. If the FPD also had a Lambertian component, then there would be a dull-red background covering the white card that would be much dimmer than the haze fuzzy ball. Such a Lambertian component is represented by a spherical distribution in the luminous intensity (the dashed line in Fig. 1).

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Introducing the International Committee for Display Metrology (ICDM)

The International Committee for Display Metrology (ICDM), the first standards-development committee within SID, is preparing a metrology standard for practical and relevant measurement methods for the complete evaluation of displays. This will provide display manufacturers, equipment makers, those who commercialize displays, and any level of user a common language to ensure that all display measurements are performed in the same manner, and correctly. This article details the efforts and goals of the ICDM.

by Joe Miseli

THE DISPLAY INDUSTRY has reached a tremendous state of technology development today. Products which are currently produced and will be forthcoming are often breathtaking. Displays of immense proportions have been built having excellent performance, and they keep getting bigger, better, and lower in cost. They have advanced much further than all but the most gifted visionaries might have imagined a scant 20 years ago, when the market was completely dominated by cathode-ray-tube (CRT) displays with sizes rarely exceeding 30 in. Just two decades later, wall-mountable flatpanel displays over 50 in. are quite common and low in cost, with sizes increasing so much that some are too big to be hung on the walls of many living rooms!

Along with great-looking displays and evolutionary technologies comes an increased need to analyze their characteristics so that those who use, build, specify, and qualify displays can understand their true performance quality. This can be complicated because some display-performance characteristics are stated with figures in a less than clear and precise manner or creatively expressed to favorably skew the perception of performance. We can avoid this "specsmanship" by use of solid metrology that uses well-defined terms and definitions, clear and pre-

Fig. 1: *Shown is the ICDM logo.*

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cise measurement and evaluation procedures, *etc*. By doing so, we will help reduce or eliminate the proliferation of these items. This is where evaluation by metrology standards comes into play.

The best of the display-evaluation standards is considered to be the VESA FPDM2 (Flat Panel Display Measurement).[1] It is held as the definitive reference, and many other display standards leverage off it. However, it was last updated in 2001, and further work was halted when the FPDM activity at VESA was dissolved. Because display products are evolving at an amazing pace, the standards MUST keep pace.

The International Committee for Display Metrology (ICDM), part of the Definitions and Standards Committee of SID, has undertaken this task (Fig. 1). A new display-metrology standard (DMS) for the measurement and evaluation of displays is forthcoming from the ICDM, which includes the core group of individuals who wrote the FPDM with expanded participation of world experts from within the SID membership in the area of display evaluation. SID is the foremost display association in the world and consists of most of the display professionals in the industry, either as active members or associated with member companies. Experts of the Committee Working Group include display engineers, metrologists, color scientists, vision scientists, university researchers, human-factor specialists and ergonomists, as well as others with additional specialized display-related skills.

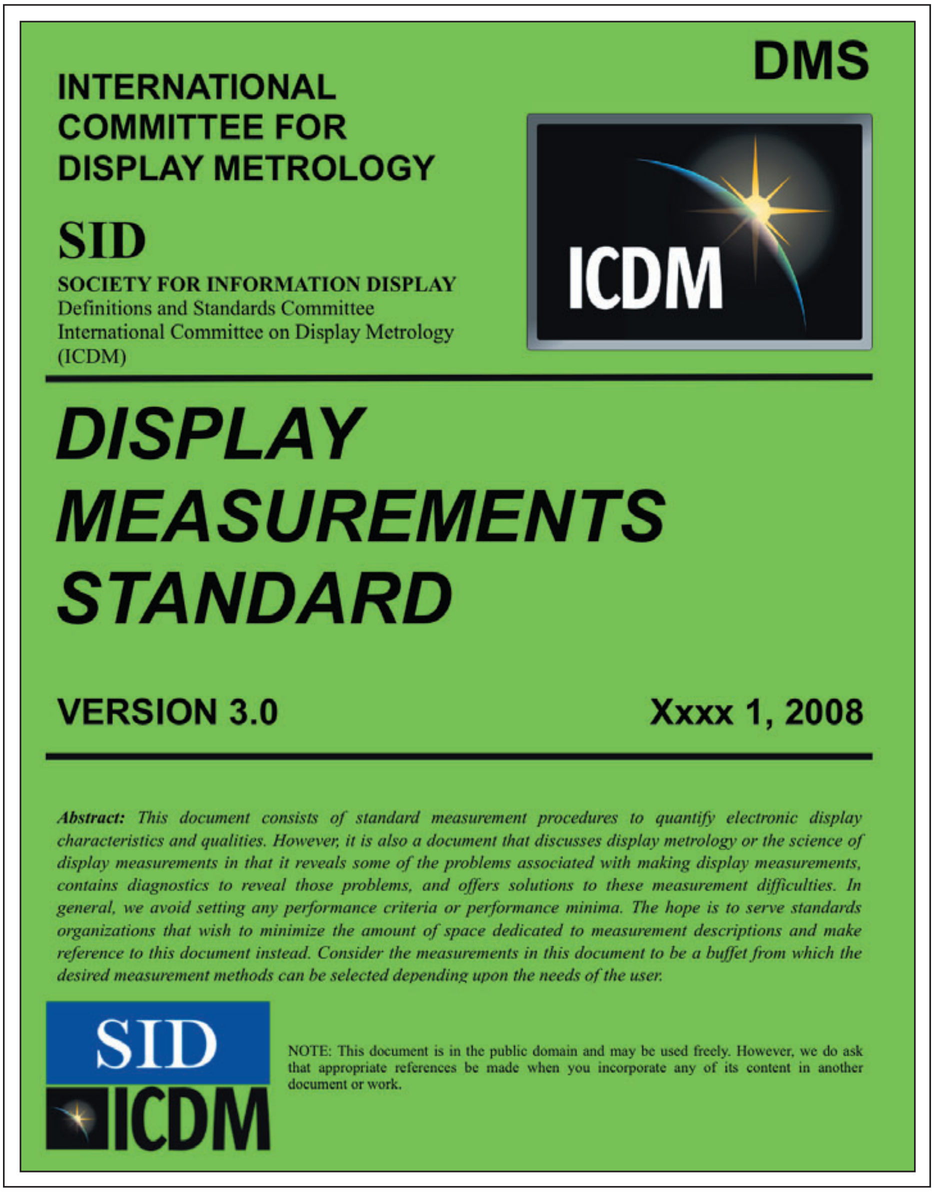
Philosophy and Goals

One of the goals of making the ICDM a universally accepted display-measurement standard is collaboration with other standards bodies, not competition with them. We want to take the burden of defining the full set of measurement methods off them so that they can reference the ICDM DMS and concentrate on other aspects, such as specifications, recommended practices, *etc*. As a result of these these efforts, the other standards bodies can produce standards to help rate the actual performance of a display for various parameters and to state what is good or bad based upon ergonomic considerations or other science. The ICDM standard provides the tools and methods to determine the performance numbers, while the other standards provide guidelines on what is good or bad, acceptable or not, or is expected.

The first version of the ICDM DMS will be available in 2008 (Fig.2). The ICDM plans for it to be available as a free download from the SID ICDM Web site (http://www.icdm-sid.org). We invite those who perform the measurements or actively use the standard in other ways to participate by way of feedback on the Web site. The ICDM also plans to make available a printed version for a nominal cost, with value-added content for the purchaser. This includes a bound copy of the standard along with a DVD-ROM containing many extras, such as test patterns for multiple resolutions, supplemental documents, and perhaps software templates. The ICDM will provide test patterns to make measurements when using the standard. These will be downloadable from the Web site and will also be included on the DVD-ROM.

ICDM DMS Style

The ICDM proposes a series of goals and


DMS

INTERNATIONAL COMMITTEE FOR DISPLAY METROLOGY

SID
SOCIETY FOR INFORMATION DISPLAY
Definitions and Standards Committee
International Committee on Display Metrology (ICDM)

ICDM

DISPLAY MEASUREMENTS STANDARD

VERSION 3.0 Xxxx 1, 2008

Abstract: This document consists of standard measurement procedures to quantify electronic display characteristics and qualities. However, it is also a document that discusses display metrology or the science of display measurements in that it reveals some of the problems associated with making display measurements, contains diagnostics to reveal those problems, and offers solutions to these measurement difficulties. In general, we avoid setting any performance criteria or performance minima. The hope is to serve standards organizations that wish to minimize the amount of space dedicated to measurement descriptions and make reference to this document instead. Consider the measurements in this document to be a buffet from which the desired measurement methods can be selected depending upon the needs of the user.

SID ICDM

NOTE: This document is in the public domain and may be used freely. However, we do ask that appropriate references be made when you incorporate any of its content in another document or work.

Fig. 2: *Illustrarted is the cover page of the ICDM Display Metrology Standard (DMS) to be released this year.*

parameters for writing the DMS. In the following sections, the italicized text details those goals which are followed by additional explanations for each of them where necessary.

- *The ICDM DMS is designed for all display configurations and technologies, from bare panels to finished monitors, TVs, and signage displays, and from liquid-crystal displays (LCDs) to plasma displays to organic light-emitting-diode (OLED) displays, as well as flexible, reflective, portable, and projection displays, 3-D, electronic paper, etc.*

The standard is display-technology independent wherever possible. Parameters such as luminance, uniformity, contrast, color saturation, and reflection tend to be common to all displays; their measurement methods should also be common. Other metrics such as viewing-angle characterization, luminance loading, geometric distortion, inter-image differential parameters (as is found in 3-D displays), and differential aging are more display-technology dependent. The ICDM DMS works to combine the similarities and account for the variabilities.

- *Keep the style, language, and methods simple and short, using plain English and abundant graphics. Cartoons are added to give the document a friendly manner.*

The ICDM DMS is written in plain English with no slang, jargon, idioms, technospeak, or colloquialisms. We maintain a style that is basic and consistent. Detailed terminology, definitions, and technical discussions are separated into other sections of the document to avoid complicating the measurements pages. In addition, many graphics and icons are used to help avoid misinterpretations by non-native English-speaking users.

- *To have a common terminology so that everyone can use the same terms and understand the same meanings regarding display metrics.*

It can be found today that different terms are sometimes used for the same measurement, and use of improper terms for display metrology is not uncommon. These can cause confusion and misinterpretation of measurement results as well as problems in communicating them. For example, the term residual image may also be known as image sticking, image retention, latent image, or burn-in, although some of these terms, such as burn-in, have entirely different meanings. The standard uses terms precisely.

- *A single measurement is presented on a single page wherever possible, keeping the number of words to a minimum, providing common structure, consistent style. There are icons that represent test conditions (especially for repetitive tasks). Extensive details, references, and technical discussions are included in separate sections of the document specifically dedicated for those purposes with hyperlinks to easily access them.*

Some display-metrology-measurement or related standards concentrate on one or only a few test items within a given document. There may be many pages written to describe a single measurement method. This can make the test unclear, confusing, and sometimes unmeasurable. The ICDM DMS document is comprised of many parts, and we strive to limit each test to one page in length, although there are a few tests that extend to two or more pages. We use icons to simplify repetitive tasks and reduce extra wording (Fig. 3).

Figure 3 illustrates some of the ICDM Measurement Section icons (from left to right: “Ambient Illumination Conditions,” “Controls Unchanged,” “Imaging Light Measurement Device (LMD) Field of View and Subtense Angle,” and “Electrical Conditions”).

Document Structure

- *No numbers that represent values or expected results are used in the standard – only methods and supported examples. The ICDM standard does not state how good a display is or what is expected, only how to measure it.*

We do not state what constitutes good image quality in terms of acceptability or preference – we state what is good metrology. Nor do we state or suggest how to rate a display. Rather, we describe the methods to measure them so that the results produce valid numbers that accurately state a display’s performance.

Supported examples describe how to make the measurements – these examples represent methods, not results or expectations of a display’s performance or capability.

- *The ICDM DMS describes how to make measurements on a display, or methods for Display Metrology. Display measurements are based on photometry and colorimetry, which by their nature are both vision/ergonomic measurements. Of the unlimited number of measurements that can be performed on displays, it may be advantageous to choose only those which are meaningful in terms of human vision.*

The participants of the ICDM include display-evaluation specialists with many areas of expertise including psychophysics, human vision, and ergonomics, all of whom can help determine relevance, usability, and presentation. They help complement proper metrology by validating the methods and assessing the relevance.

For example, let us examine the perception of motion. Motion does not exist on a display; rather, a ”moving” object changes its location or position on the display every refresh period; *i.e.*, it is a jump in position, not a continuous smooth motion. The eye performs a psychophysical transformation to convert that jump stimulus into a perception of motion by means of smooth-eye pursuit and intrinsic psychophysical filtering.

Some measurements might be qualified in terms of human-visual characteristics; *e.g.,* we can measure flicker beyond the human-vision perceptibility limits, and we may need some determination to help analyze what is meaningful. Relevancy of human-visual perceptions *vs.* instrumental capabilities has important interactions that must be weighed.

- *Many times, display-performance issues are easy to recognize but very difficult to measure.*

In such instances, these characteristics may be seen and their relative severity easily understood, but they might be very difficult to measure and determine their severity. Examples might be mura, residual image (also called image sticking), some motion artifacts, certain types of pixel defects, synchronization effects, improper colors, color matching, dynamic-range compression, and temporal distortions. The ICDM DMS addresses these types of items and provides information to help assess them, including setup conditions and some guidance for expectations.

- *Putting measurement results together in a coherent and meaningful manner can produce sets of composite metrics that can be used to define display-performance guidelines for predetermined environments or applications.*

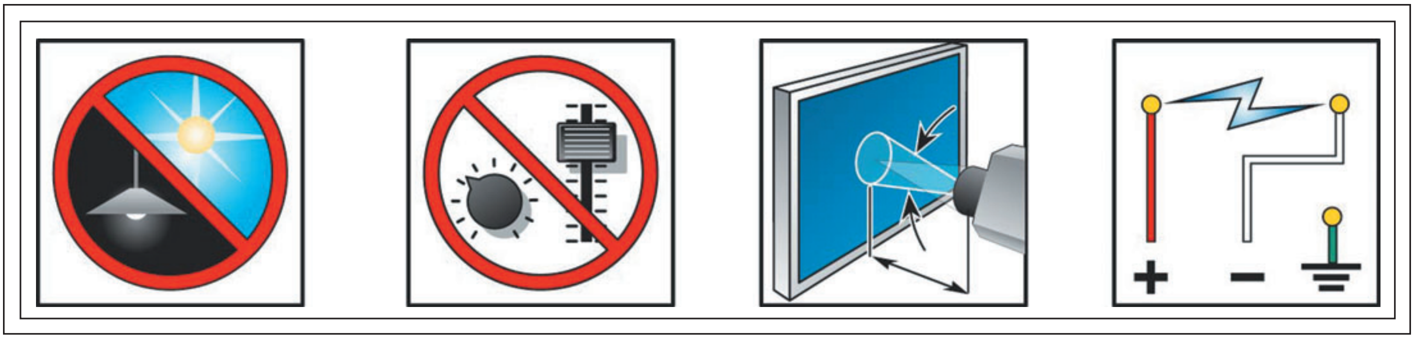


***Fig. 3:** Some of the ICDM Measurement Standard Section Icons: From left to right: "Ambient Illumination Conditions," Controls Unchanged," "Imaging LMD Field of View and Subtense Angle," and "Electrical Conditions."*

This can prove to be a valuable aspect of the ICDM standard, providing a method to perform assessment in a comprehensive manner. We put the pieces (or collections of metrics) together into sets in order to obtain extremely valuable and relevant composite metrics. Such measurements could be creatively combined to determine metrics for a display to be used for a monitor, a TV, a theater, a broadcast reference monitor, a living room, outdoors, an office, an operating room, or a radiology environment.

Committee Organization and Participation

The ICDM membership includes some of the world's foremost experts in a number of fields that help characterize display performance and quality. Examples of these fields include display metrology, color science, psychophysics, vision science, human factors, display engineering, display design, testing and test-equipment manufacturing, display manufacturing, and component manufacturing. In addition, ICDM development applies the skills of conventional science and engineering, such as physics, optics, electrical engineering, chemistry, and mechanical engineering.

The officers of the ICDM were elected on May 23, 2007 at the SID Display Week 2007 ICDM meeting in Long Beach, California, USA.

- Chair: ***Joe Miseli*** (Sun Microsystems)
- Editor-in-Chief: ***Ed Kelley*** (NIST)
- Vice Chair for Asia: ***Jongseo Lee*** (Samsung)
- Vice Chair for Europe: ***Michael Becker*** (Display-Metrology & Systems)
- Vice Chair for Human Factors and Vision Science: ***Andrew Watson*** (NASA).

ICDM Web Site

- *A place where members have access to ICDM display-standard- development-related documents and communication tools, and the world can have access to the ICDM.*

The ICDM Web site (http://www.icdm-sid.org) is designed for open access to the ICDM and its work, and for ICDM participants to have a members-only home reference location for document exchange and communications tools to help develop the ICDM display-measurement standard. This site is the home to ICDM activities (such as round-robin testing), links to other appropriate pages, and a depository for ICDM downloads.

One goal of the Web page is to include references to help users to better utilize the ICDM, including data of worked-out examples per the ICDM standard. One consideration is ICDM certification or validation when using the standard. Concepts are yet to be determined for this ambitious goal.

In addition, there are two Wiki sites for the ICDM. One is on the SID Wiki site and the other is on Wikipedia:

- ICDM SID Wiki page URL: http://wiki.sidmembers.org/ and search for ICDM.
- ICDM Wikipedia page URL: http://en.wikipedia.org/wiki/ICDM.

The Wikipedia site leverages the vast amounts of information posted on Wikipedia related to display performance and parameters. The SID Wiki site provides a format for links to complementary pages established and primarily authored by ICDM participants.

Characteristics, Activities, and Summary

There are many goals and plans for the ICDM beyond what can be referenced in one article. Here are just a few:

- *Address common measurements, and assure that they are standardized and well understood.*
- *Address difficult and future metrology needs which have not yet been standardized.*
- *Have separate sections for measurements, metrology, technical references, discussions, glossary, definitions, etc.*
- *Write the DMS in stages. The first version will have reduced content. Subsequent versions will address more advanced and/or difficult measurements, such as motion artifacts beyond motion blur.*
- *Establish standard setup and testing conditions to assure accuracy in testing and work to eliminate "wiggle room" so that all who test displays cannot manipulate setup conditions to give them preferential results of their measurements.*
- *Establish a palette or buffet of measurements so that the user can choose the desired test, thus providing different ways to make a measurement within the same category.*

Acknowledgments

The ICDM Committee Working Group members, from whose discussions, key points, ideas, and words helped formulate many parts of this article, are greatly acknowledged for their efforts. Special thanks to Ed Kelley for his invaluable contributions to the formation of the structure of this article.

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Simulating LCD Moving-Image Representation and Perception

In order to conquer the issue of motion blur, it is important that a model be developed that simulates and visualizes the performance of an LCD screen together with the perception of the viewer. In this article, such a model – based on an earlier model used to predict PDP performance – is proposed.

by Carsten Dolar

ALTHOUGH flat-panel displays have almost completely replaced cathode-ray-tube (CRT) displays in television and video applications, in some aspects they still need further improvement to meet the performance expectations set by CRTs. Nowhere is this more apparent than in the display of moving images on liquid-crystal displays (LCDs). In order to fully understand the problem and characterize the effects of different components in a typical display system such as a television, it is desirable to model the flat-panel-display system together with the perception of the human observer. Such a model would make it possible to predict the perceived image quality.

Some years ago, a model had been proposed[1] to demonstrate the perceived image quality of a plasma-display panel (PDP). This model has now been adapted to the representation of moving images on LCDs to produce the descriptive simulation results[2] presented in this article.

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Simulation Model

To simulate the perceived image, two models are actually required: a display model and a visual perception model, as shown in Fig. 1. Let us start with a model for the LCD that can be divided into two blocks: a model for the spatial behavior (the pixel intensity profile or spatial aperture) and a model for the temporal behavior (the impulse response or temporal aperture). This is in good agreement with other LCD models.[3] An LCD pixel is rectangular in most cases and subdivided into three subpixels for the primary colors. For comparison, the intensity profile of the pixel of a CRT-based display is almost Gaussian.

Modeling the temporal behavior of the LCD is based mainly on concatenated step responses from one frame to the next, taking into account the hold-type behavior of the active-matrix addressing and driving scheme and using a first- or second-order low-pass filter to model LC dynamics. However, the LC material's switching properties depend on the current state and the input signal. Therefore, the LCD in general is a non-linear system, but it can be linearized in some cases. Due to the addressing and driving scheme, some space-dependent delays also need to be modeled, *e.g.*, a certain delay per line since the lines are addressed sequentially, one after the other.

The perception model, as the second major part of the presented model, comprises basic reception mechanisms. The two important components in this model are smooth pursuit eye tracking and temporal integration of the eye. The first is simply modeled as a compensation of a linear movement; the latter is implemented as weighted temporal integration yielding a still image that represents a snapshot of the subjective impression of an observer watching an image sequence. The spatial filter in the perception model is used to simulate different viewing distances with a simple spatial low-pass filter.

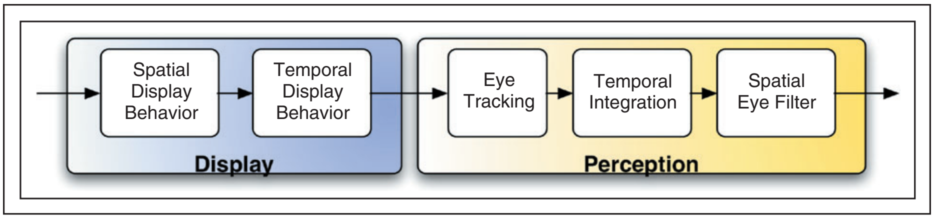

Fig. 1: *Model of LCD moving-image representation and perception.*

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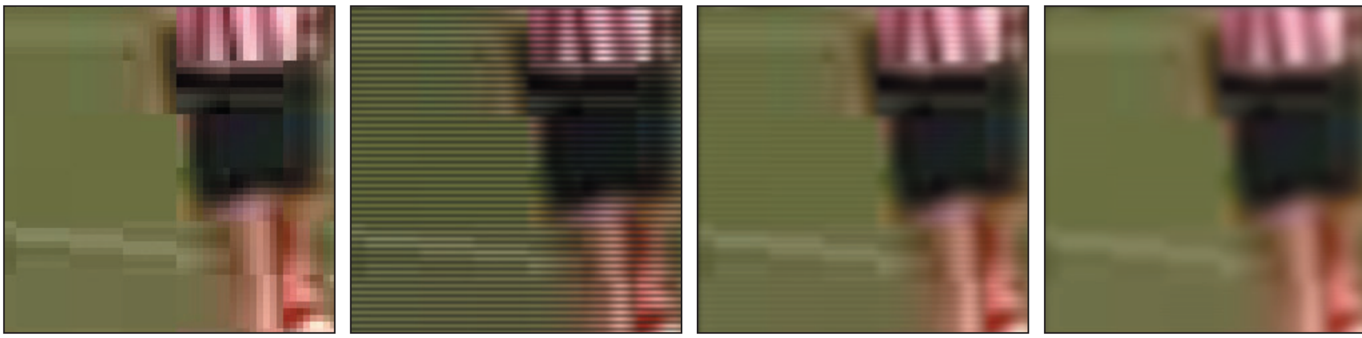


(a) (b) (c) (d)

Fig. 2: Error visibility on different displays: (a) LCD, (b)–(d) CRTs with different beam sizes (spot diameters 0.5, 1, and 2 lines).

The simulation tool based on the described model can be parameterized by identifying the single-pixel shape (monochrome situation) or the shape of the subpixels as well as the positions of the differently colored subpixels, and by defining the display's step response with either a rise and fall time or gray-to-gray response times to adjust the LC low-pass behavior. Moreover, the backlight switching can be parameterized (*e.g.*, for a blinking backlight), as well as the addressing delays for each row of pixels (*e.g.*, line-to-line delay). Further parameters comprise bit-depth and electro-optical transfer function (*e.g.*, "gamma").

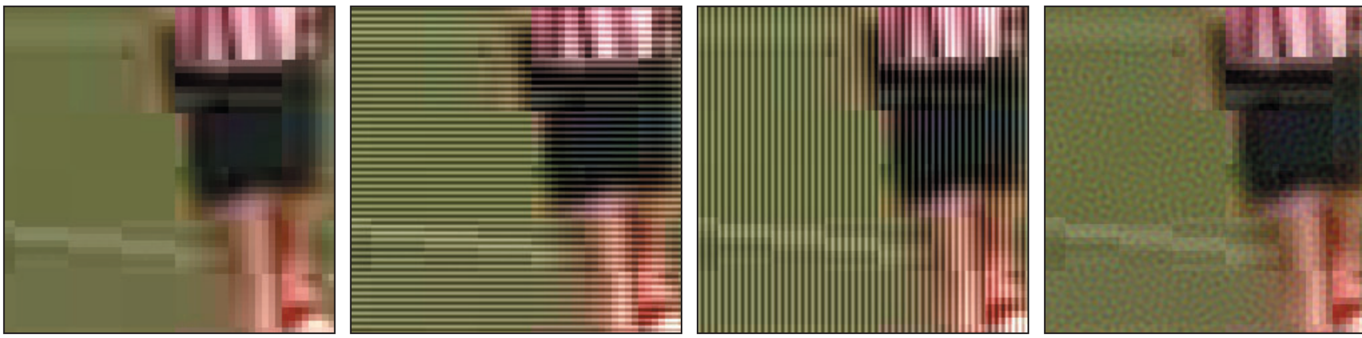
The current version of the simulation tool has been implemented in a MatLab environment; it has not been optimized for speedy performance and, thus, simulations are not carried out in real time.

In the following, we first describe static LCD behavior, *i.e.*, the still-image representation, before the simulation results for moving images are presented. One important aspect therein will be the comparison between the presentation on a CRT and on an LCD. Later, the dynamic behavior of the LCD, *i.e.*, the moving-image representation, is investigated and demonstrated. The most interesting point therein is the effect of motion blur in tracked objects in an image sequence.

Static LCD Behavior

The first interesting phenomenon to investigate with the model is the higher degree of error visibility on matrix displays.[2] Direct visual comparison of a CRT with an LCD shows that errors such as coding artifacts, block noise, *etc.*, are more visible and thus more disturbing on an LCD than on a CRT. To investigate further, we simulated the perceived image impression of a still image with the described model. In this case, the display and perception model will reduce to spatial filtering, yielding the display's static behavior. It is assumed that the spatial display aperture is Gaussian for the CRT and rectangular for the LCD.

Figure 2 shows the output of the display model for an LCD and three CRTs with different beam diameters. (Note that the simulation results demonstrate the basic effect rather than the exact appearance since the shadow mask and subpixels are neglected in the simulations presented here.) The input image for all display simulations has been the same, *i.e.*, having the same level of block artifacts. The output, however, looks very different. In the CRT representations, the blocking errors are concealed either by a lack of sharpness or by a visible line raster that masks the vertical block boundaries. In the LCD representation, however, these block boundaries are clearly visible. What are the reasons for the increased visibility of the errors? First of all, an LCD has a sharper image impression due to the fact that the pixels in a matrix display are separated from each other by a black-matrix structure. A step in intensity between two adjacent



(a) (b) (c) (d)

Fig. 3: Adding a masking signal to LCD simulation. (a) Vertical, (b) horizontal, (c) oscillation, and (d) masking noise.

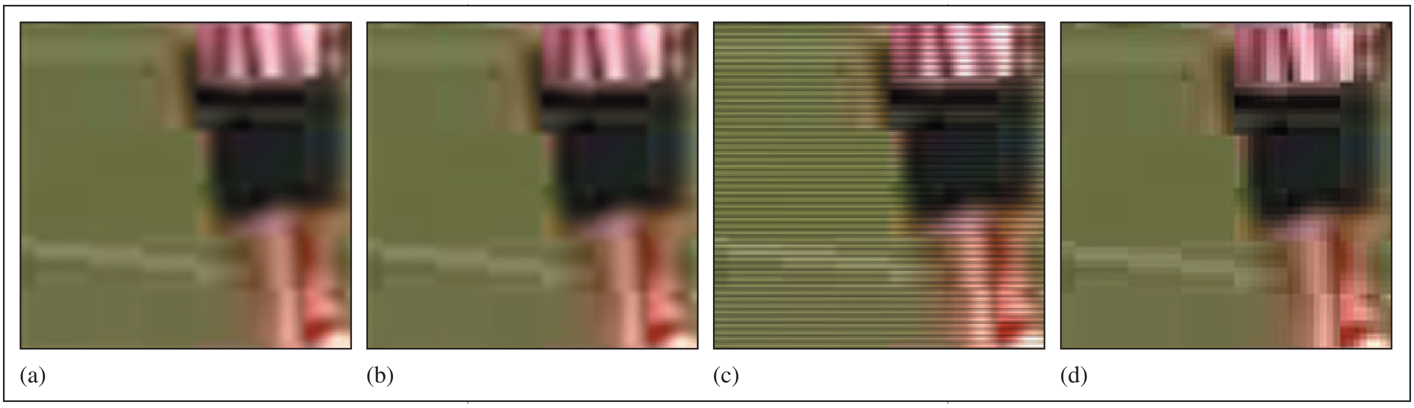


Fig. 4: Influence of the viewing distance: (a) CRT and (b) LCD representation at long viewing distances, and (c) CRT and (d) LCD representation at short viewing distances.

pixels can therefore be displayed ideally, contrary to CRT representation where the pixel profile leads to smooth transitions. Second, the LCD representation lacks a masking signal such as the line raster in CRT representation. A masking signal influences signal components that have the same direction and spatial frequency; in this scenario the line raster in the CRT representation affects the visibility of vertical block boundaries.

To demonstrate the effect of masking on the image impression, artificial masking signals (vertical and horizontal oscillation, noise) were applied to the LCD simulation (see Fig. 3). Depending on the spatial frequency and the direction of the masking signal, horizontal and/or vertical blocking errors are concealed (which does not mean that the presented masking signals improve the overall image quality). Simply put, an LCD is able to present an image with very high subjective sharpness without interference by a masking signal. Therefore, steep signal transitions are perfectly displayed, positive at the edges of the image and negative at errors because it enhances the visibility of those artifacts. Thus, the image quality needs to be controlled very carefully in the editing process, in the coding for transmission, and, finally, in the signal processing in the display

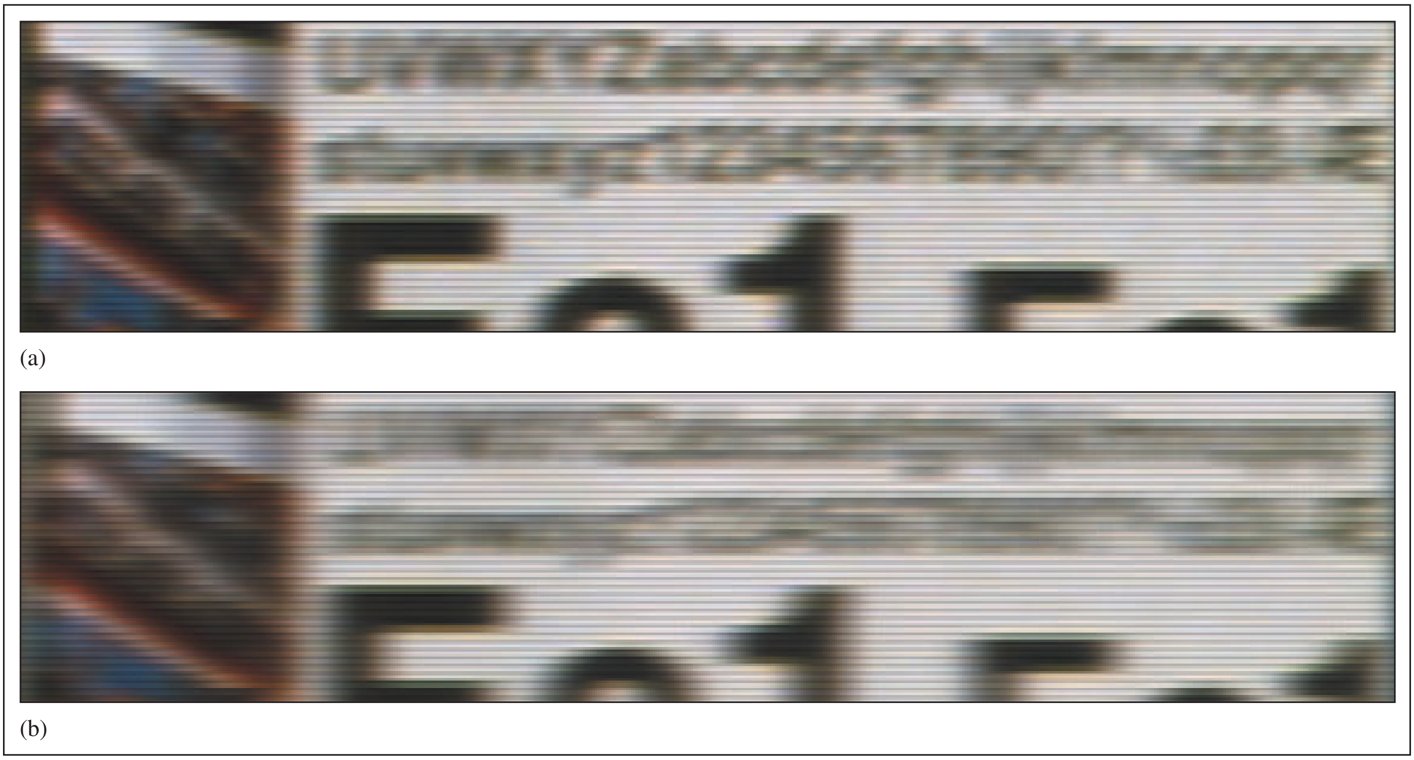
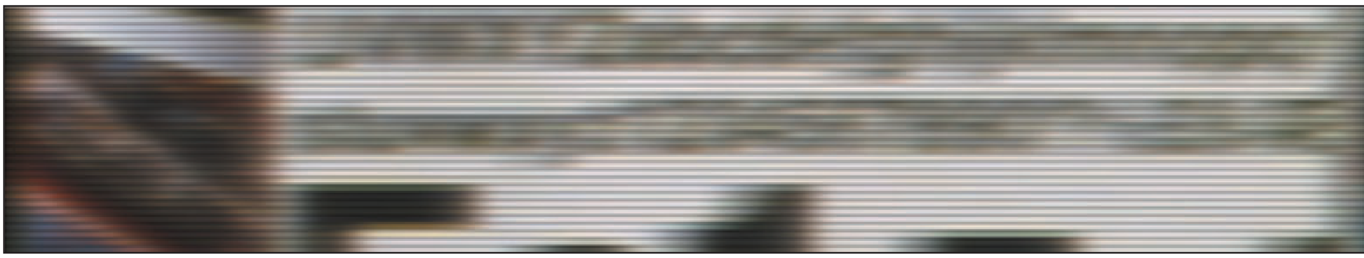


Fig. 5: Influence of velocity on motion blur: (a) 60-Hz Panel, vx = 3 pixels per frame; (b) 60-Hz panel, vx = 6 pixels per frame.



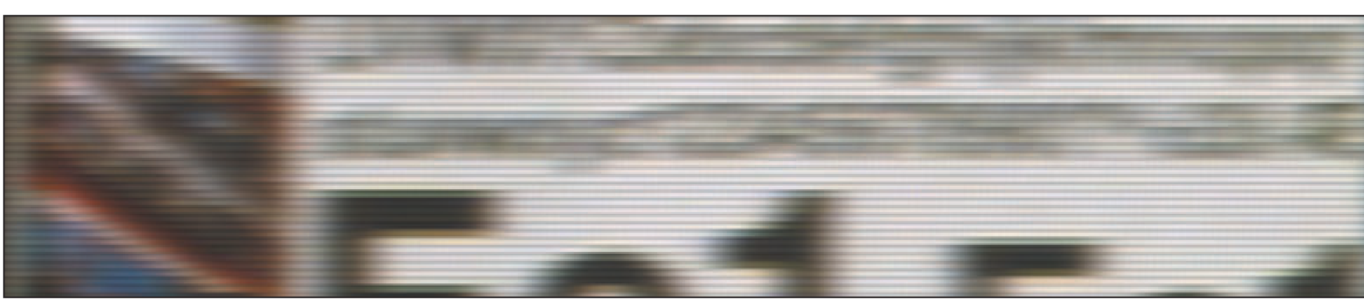
(a)

(b)

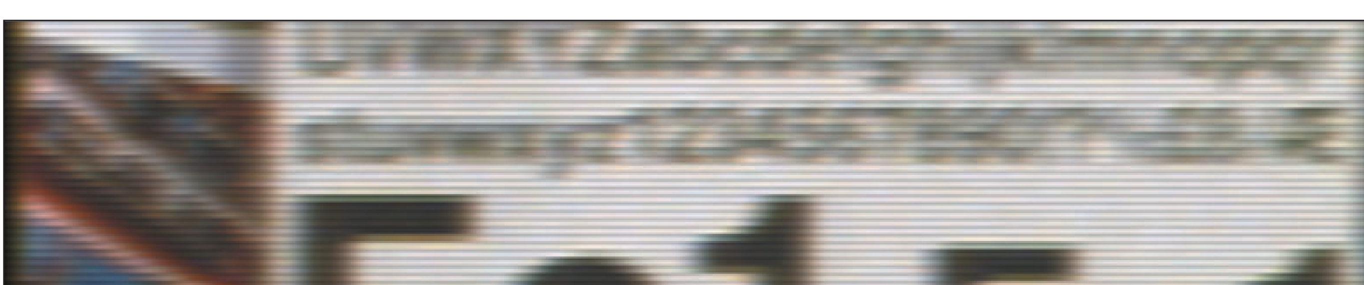
***Fig. 6:** Influence of LC response time (60-Hz panel, vx = 6 pixels per frame). (a) Long LC response times and (b) zero LC response time (ideal hold-type behavior).*

system (*e.g.*, computer monitors or television sets).

This raises a question: How much of the mentioned error enhancement is perceived? To answer this question, the viewing distance and the acuity of human vision has to be considered. Short viewing distances will lead to a high spatial cut-off frequency in the perception model, yielding a distinct visibility of details. Long viewing distances will lead to the opposite, and the ability to perceive details will decrease. Figure 4 shows that the longer



(a)



(b)

***Fig. 7:** Comparison of 60- and 120-Hz panels. (a) 60-Hz panel, vx = 6 pixels per frame and (b) 120-Hz panel with ideal motion compensation.*

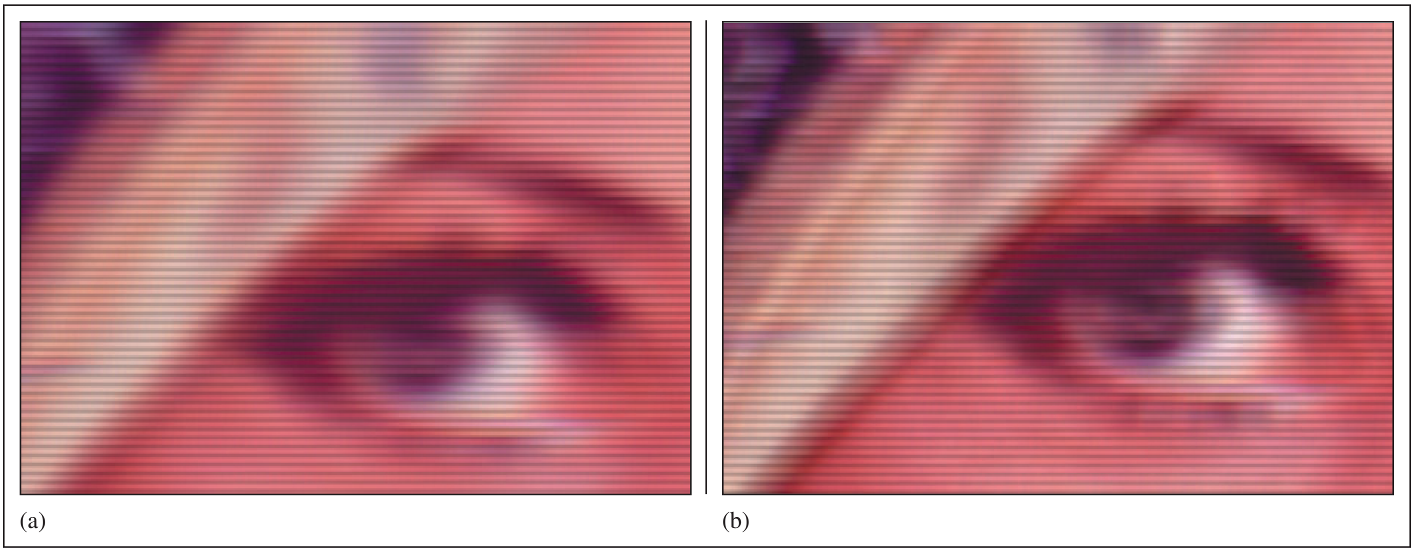


Fig. 8: Motion de-blurring with motion-compensated inverse filtering. (a) Unprocessed and (b) preprocessed.

the viewing distance, the less the differences between the CRT and LCD representation. As the preferred (relative) viewing distance decreases with increasing screen size, the mentioned error enhancement is more visible on large-sized LCD-TV sets compared to that of common medium-sized CRT sets. Again, this emphasizes the point that the image quality needs to be checked with great care in each processing step.

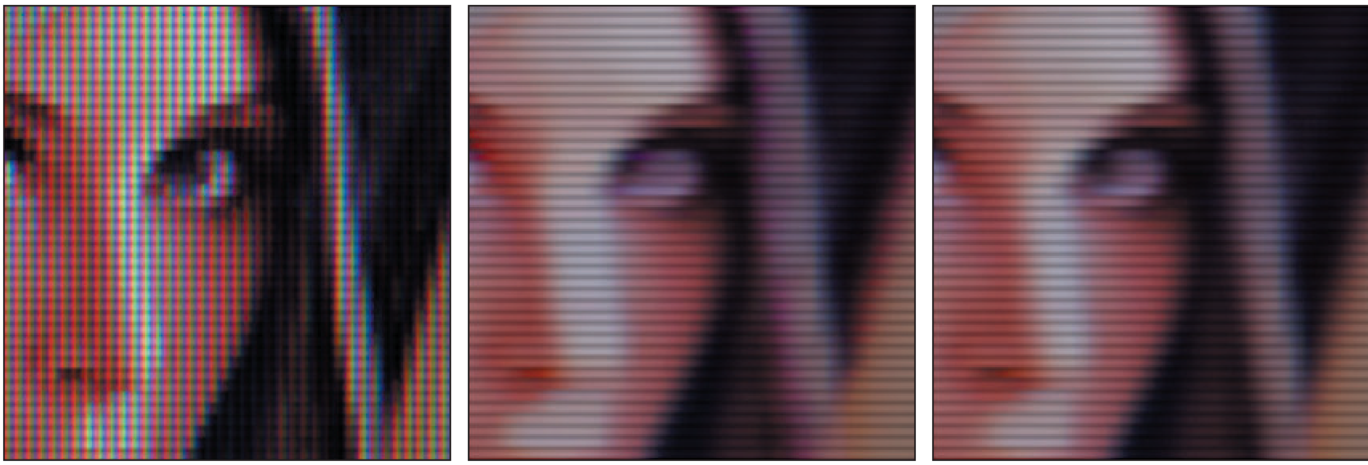
Dynamic LCD Behavior

Now let us examine the dynamic behavior of the LCD in presenting a moving-image sequence. A widely noticed attribute of LCD moving-image representation is the introduction of motion blur to a tracked moving object in an image scene. The cause of this display artifact is now known; it is, namely, the length and the shape of the temporal impulse response of the display. To explain motion blur, imagine one pixel changing from black to white from one frame to the other and back to black in the next frame. The intensity of the pixel will be held for the entire duration of a frame (*i.e.*, hold-type behavior). The gradual response of the LC material will introduce an additional low-pass behavior to the signal. Finally, the backlight modulates the light signal, which also affects the display's temporal impulse response. If the eye of the observer moves with a certain velocity relative to the screen, the position of the said pixel will move on the retina along the trajectory of the movement. Thus, the light intensity of the pixel will also be perceived along this trajectory. The temporal integration by the eye will transform the moving pixel to a spatial sensation along the motion trajectory, causing a blurring of the pixel or a point spread function that has the shape of the display's temporal impulse response. The higher the eye velocity and the longer the temporal impulse response, the more the pixel becomes blurred.

Using this linear display and perception model, the perceived image can be calculated with the (solely spatial) convolution of the image with the spatially transformed impulse response, known as the "motion-blur filter." The parameters of this motion-blur filter are given by the shape of the temporal impulse response of the display and by the velocity of the eye relative to the screen. Figure 5 demonstrates the influence of the object's velocity on the blur in the perceived image. The higher the velocity, the more blurred the perceived image becomes. The length of the display's temporal impulse response is determined by the duration of the hold-period and by the LC response time(s).

Let us now examine the influence of the response time of the display on the perceived image first. Figure 6 shows the simulation results of a display with a long response time for all gray-level transitions (around 20 msec) and of a display with zero response time, yielding a perfect hold-type behavior. The display with the long LC response time obviously presents a strongly blurred image. However, the ideal hold-type display also suffers from motion blur. This occurs due to the fact that the hold-type behavior itself also has an impact on the motion blur that cannot be neglected. Therefore, the response-time compensation by using faster LC materials or by applying signal preprocessing, *e.g.*, overdrive, can only reduce the motion blur to a certain limit.[3,4] The shortening of the hold-time is thus an effective technique in motion deblurring when the LC response times are short enough. Several ways have been proposed to do this: blinking the backlight, inserting black or gray images between two frames, or doubling the frame rate with motion-compensated frame interpolation. The latter is the preferred method in recent LCDs for TV applications. Another approach is to enhance the high spatial frequencies (details) that will be reduced by the motion blur by applying a motion-dependent signal pre-processing.[3]

Let us look at the simulation results of some of the measures that reduce motion blur. Figure 7 shows (a) simulations of a display operated at 60 Hz compared to (b) a 120-Hz display. This measure effectively reduces the amount of motion blur, but this will only hold in regions where the motion-compensated intermediate frame can be calculated exactly. Thus, the removal of the motion blur depends on the quality of the motion-estimation algorithm. The pre-emphasis of details prior to displaying a frame on the display is simulated



(a) (b) (c)

Fig. 9: *Influence of non-linear behavior on the perceived image: (a) unmoved original, (b) moved object on an LCD with non-linear behavior, (c) moved object on an LCD demonstrating linear behavior.*

in Fig. 8. Compared to the unprocessed version, more image details are retained in the perceived image. Because the amount of detail enhancement depends on the motion estimation as well, the reduction of motion blur will depend on the quality of the motion estimator in a display as well.

One question, however, remains to be answered: Is there a visible effect on the image due to the non-linear temporal behavior of the LCD introduced by the unequal response times for different gray-level steps? The answer is yes, but it depends on several factors. As is known, the LC-material response time depends on the starting condition and on the addressing voltage, and therefore on the image input signal. Thus, the temporal display model becomes non-linear, and common system theory cannot be applied to analyze the temporal behavior. However, the model can be considered linear for small temporal step sizes, and the system behavior can then be evaluated numerically. The simulation results shown in Fig. 9 demonstrate the differences between a display with a constant response time and a display with input-signal-dependent response times yielding non-linear behavior. Note that the input data is a downscaled version of Lena's face in order to emulate a low-resolution mobile-display device. The effects on the perceived image due to the non-linear behavior are geometric deformations and false colors. The first can be observed in the area around the root of the nose, the latter in the edge of the mirror. Those display artifacts depend on the differences in the response times of the display and the velocity of the eye movement. The smaller the differences in the response times for different gray level and color steps, the smaller the error in the perceived image. Because the differences in response times for different gray-level steps might be small in recent displays due to response-time compensation with overdrive, the differences in motion blur for those different gray-level steps will also be small. Therefore, the geometric distortions and color error will be less noticeable on large-sized home television sets and will more likely be visible in small-sized handheld TV devices because such display devices have a lower resolution and will be observed with a smaller relative viewing distance, which leads to a higher visibility of the mentioned artifacts.

Conclusions

So, how can this model be used? There is a variety of applications for such a model. For example, it can be used to optimize display-processing algorithms. With the right parameterization, an algorithm can be optimized for a certain display by evaluating the simulation results for this particular display. The current version of the simulation model has been implemented to yield qualitative illustrative results. It has been tested and verified by 10 subjects and various images in order to confirm the validity of the "frozen" moving images for illustration of motion-blur effects. In a further step, the model could be expanded to include more detailed physical properties of the display and a calibration in comparison to controlled subjective evaluations and ratings.

The simulator based on the presented model can also be used to investigate the perceived quality of new algorithms for flat-panel-display data processing. It can as well be used to quantitatively evaluate a display's properties, *e.g.*, measuring the amount of motion-blur. Last, but not least, the presented model is good for demonstration of the display artifacts and the causes thereof. For instance, the simulator and its results were used several times in lectures regarding image processing and display techniques to demonstrate the LCD moving-image representations.

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Measuring and Rating Electro-Optical Display Performance

From the moment that LCDs were introduced in the 1970s, display metrologists have worked hard to develop systems to accurately measure their performance, a constantly evolving process. This article details the history of those efforts as well as the current state of the art.

by Jürgen Laur

LIQUID-CRYSTAL DISPLAYS (LCDs) have evolved and flourished since the 1970s. After their debut in pocket calculators and wristwatches, they first created a visual interface basis for portable computers and, later, computer monitors. LCDs helped mobile telephones to offer video and TV content in truly handheld devices, and the latest wave of success brings large-area LCDs into the living room for TV and home-theater purposes.

Display-metrology instrumentation has evolved along with the features of LCDs. This article summarizes that evolution during the last 25 years. A strong example of this is the development of twisted-nematic LCDs (TN-LCDs).

Almost as soon as the electro-optical effects of liquid crystals were studied in practical structures, it became apparent that TN-LCDs offered special features, including the variation of contrast with viewing direction and its dependence on a variety of cell and material parameters. For systematic experimental optimization of TN-LCD performance, it became indispensable to accurately characterize these properties of LCDs.

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Initially, ad hoc laboratory setups with movable light sources and/or detectors performed goniometric readings at various angles of view. Later, the polarization microscope in the *conoscopic mode of observation* became the most widespread instrument used for analysis of the variation of transmittance and contrast versus viewing direction.[1,2] This approach provided direct observation of the *directions image*, but quantitative measurements were cumbersome to carry out and required special modifications of the microscope.[1,2]

In 1977, Kurt Fahrenschon, at that time working for the company Braun,[3] suggested to the Institute for Electromagnetic Theory and Metrology of the University of Karlsruhe, then headed by Professor Dieter Mlynski, to get involved in the development of an apparatus that would perform the required characterization of TN-LCDs. Since most LCDs at the time were operated in reflective mode, it thus became necessary to implement an illumination device that also provided isotropic illumination during scanning of the viewing cone of the device under test.

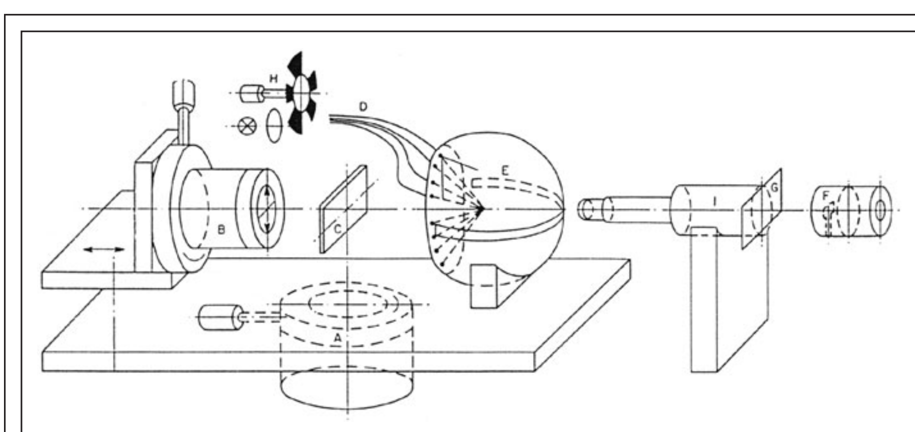

***Fig. 1:** Sketch of the first DMS developed at the University of Karlsruhe in 1979. (A, B) motorized rotary stages for adjustment of inclination and azimuth, respectively. (C) Object of measurement. (D) Light fiber bundles for illumination of the diffusing hemisphere. (E) Microscope for imaging of the field of measurement with aperture stop (G) and detector (F). The light source was mechanically chopped (H) and the detection was locked to the chopping frequency.*

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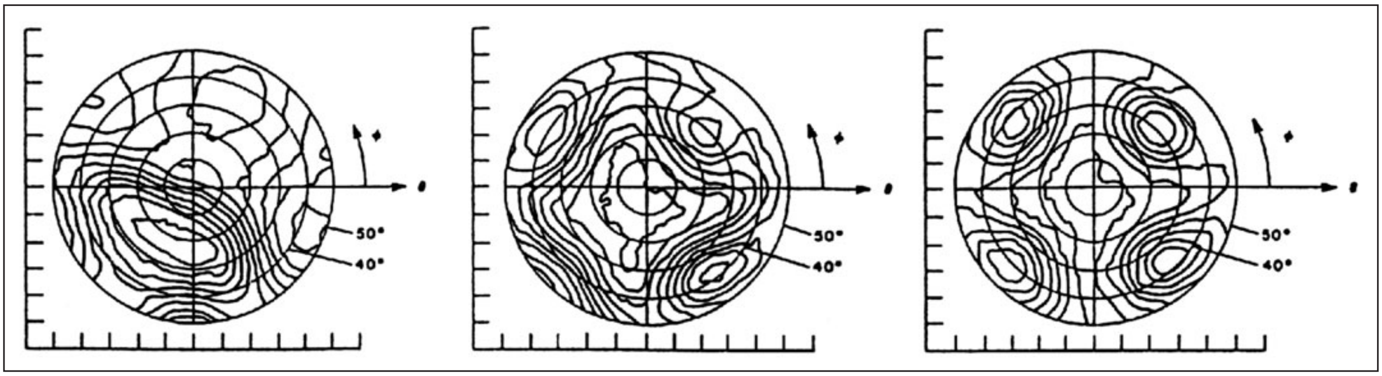

Fig. 2: *The first contrast contour plots (sometimes called iso-contrast diagrams because of the lines of constant contrast, i.e., the contrast contour lines) measured with the DMS prototype and published in 1979.[4] The measurements have been carried out for driving voltages 1.5, 4, and 8 times the threshold voltage* V_{th}.

The resulting apparatus was then used by Kurt Fahrenschon in his laboratory and the results of his evaluations were published as a paper in *Displays* in 1979[4] (Figs. 1 and 2). The instrument that was initially focused on measuring the directional contrast distribution, somewhat similar to that of Barna,[5] in the early 1980s was equipped with a range of extra features, making it the first computer-controlled apparatus for automated measurement of the complete set of electro-optical characteristics of LCDs. Since 1985, this instrument has been manufactured and marketed by autronic GmbH in Karlsruhe, Germany, and since 1993 by AUTRONIC–MELCHERS GmbH (Fig. 3).

The Need for Display Metrology

There are at least two good reasons for performing display metrology:

- The objective comparison of features before and after modification for device performance optimization in the laboratory.
- The objective comparison of the performance of products for purchasing

Fig. 3: *DMS-500 as manufactured by autronic-Melchers GmbH in 1990 with two motorized stages for inclination of the measuring microscope and for rotation of the sample LCD. The three axes were adjusted to intersect with a maximum deviation in the range of 50 µm to enable measurement of small segments and symbols. The apparatus features two illumination sources for diffuse reflective and transmissive mode of operation.*

and sourcing in the industry and in the private sector.

The second reason has gained increased attention of late because of the economical interests in securing a piece of the ever-increasing market for electronic-display devices. Even though the objective of a data sheet is "to define clear and unambiguous provisions in order to facilitate international trade and communication," (according to ISO/IEC Directives, Part 3: Drafting and Presentation of International Standards) and for that purpose should be "complete, consistent, clear, concise, and comprehensible," the customer is increasingly confronted with countless unexplained terms and skyrocketing or vanishing numbers for metrics such as contrast and response times.

This escalating hype of "dizzying performance specifications," also known as "specsmanship," has created a bazaar-like atmosphere where manufacturers' claims of contrast, response times, "brightness," "crispness of colors," *etc.*, place a higher value on attracting customers than on the accuracy of the data. This atmosphere unfortunately penalizes those companies that want to stay honest and reasonable, since they are running the risk of perishing in that cacophony of marketing blatancy.[6]

User of electronic-display devices want to have a reliable (*i.e.*, unbiased), understandable, and reasonable basis of data describing the performance of the product according to its intended application as a solid basis for a purchasing decision.

At the same time, however, the customer must realize that electronic visual displays have become so sophisticated and complex that their performance cannot be characterized simply and rated by one integral "figure of merit." Depending on the intended application (office work, display of video and movies, graphics and design, computer games, home cinema, nomadic ICT devices, *etc.*) emphasis must be placed on different individual aspects of performance, at least as long as the ideal display is not yet available at affordable prices. This simply means that the user has to continue the process of education and learning.[7]

Keeping Pace with LCD Performance

The first TN-LCDs were small and their electrodes were patterned in a seven-segmented layout for the display of numbers, sometimes with additional fixed symbols. In order to measure the contrast of such displays, the field of measurement had to be in the range of 0–1 mm and the mechanism had to ensure that the location of that spot does not change with direction of observation. The realization of a mechanism with a tolerance of the intersection of all axes in the range of 50 μm was quite a challenge for the mechanical workshop.

The optical appearance of the TN effect was usually *achromatic* (not involving colors) and thus photometric detectors (*luminance meters*) were sufficient for characterization of their visual performance. As noted above, since most of the TN-LCDs were operated in the reflective mode, a special illumination device had to assure the illumination to be isotropic for measurements as a function of viewing direction. The realization of this device with a section of an integrating sphere (*diffusing hemisphere*) also included a slit through the North Pole. This had two functions: (1) making observation of the device under measurement possible and (2) effectively suppressing specular surface reflections.[8,9]

Measurement and evaluation of the optical properties of reflective objects is not easy because the measured quantities always comprise the effect of object, illumination, and light-measuring device as well as the details of the geometry of the arrangement of all components.[8] Although it was (and still is) very difficult to make these measurements reproducible, no international standard has been created to provide assistance to those who have to carry out such measurements in their laboratories. It seems quite strange that after 30 years, there is no international standard for measurement and evaluation of reflective LCDs, but the WG2 of the IEC TC110 is currently working toward that objective. The lack of an international standard used to be compensated by the recommendation of a Japanese industry standard for reflective LCDs. This standard has been reflecting the features and limitations of a measuring apparatus developed and manufactured in Japan.[10]

In addition to contrast, the variation of the electro-optic transfer function and the dynamic response of the display under test (DUT) and its variation with viewing direction used to be of interest for optimization of the multiplexing conditions. This class of measurements also required a specific electrical driving (*e.g.*, waveforms for simulation of multiplex signals in select and non-select state, control of digital control signals for LCD modules, together with DC supply voltages, *etc.*). Coordination of electrical driving of the DUT, positioning of the detector, and data acquisition in order to keep the time required for the measurements at a minimum has required special software that also supports the definition of the series of measurements that can later be executed automatically without user interaction. This software makes a measurement system for electronic displays more than the sum of its components – its usability predominantly determines the value of a measuring system for the user and customer.

Advanced Display Metrology

With the invention of the supertwisted birefringence effect (STN) by Brown Boveri Electric in 1985, the need for *colorimetric analysis* increased because supertwisted LCDs (STN-LCDs) produce visual contrasts to a large extent by color differences between activated picture elements and the display background. As a consequence, monochromator systems and polychromators were adopted as light-measuring devices in display-measurement systems in order to support the development of better and achromatic STN-LCD screens as required for portable computers.

Although conoscopy was well known and widely used for LCD measurement and analysis since the very early days of LCDs, it was replaced by goniometric systems for three reasons: (1) quantitative analysis required focal-plane probing of very small spots that deteriorated the signal-to-noise ratio, (2) the range over which the angle of inclination could be varied used to be limited to ±30°, and (3) reflective TN-LCDs could be illuminated and measured more conveniently in goniometric arrangements.

In the early 1990s, however, when computer monitors combined a backlight unit with an LCD as a spatial light modulator, reflective displays lost market share, and LCD monitors moved into portable computers and onto the office desk. At Eurodisplay 1993, an advanced conoscopic lens with an acceptance angle of ±60° and a measuring spot diameter of 2 mm was introduced by T. Leroux from Eldim S.A.[11] This optimized lens design distinctly demonstrated the capabilities of advanced optical design and manufacturing, and triggered the development of a new generation of instruments for measurement and characterization of LCDs *vs*. viewing direction.

In the mid-1990s, some people claimed a paradigm change in LCD metrology and contended that within a short time only conoscopic instruments would remain. The commercialization of conoscopic measurement devices was severely hampered by the fact that a range of patents had been obtained on this well-known principle of measurement by a French government organization by carefully avoiding the term *conoscopy* and calling it *optical Fourier transformation* instead. After many years of legal disputes, the European patent EP 0 286 529 B1 based on the priority of the French patent FR 870 4944 was finally ruled invalid exemplarily for the Federal Republic of Germany on April 29, 2003.

More than a decade after the onset of the hype on conoscopic devices, this class of instruments has reached an amazing state of the art, but it did not succeed in eliminating and replacing gonioscopic LCD measuring equipment. Instead, it seems clear now that both approaches have advantages and limitations – choosing which one to use depends on the individual task of measurement.

Advanced conoscopic devices have been optimized for reflective measurements with collimated beam and isotropic illumination of the DUT; they can be used for measuring the LCD temporal response, and colorimetric evaluation is possible with color filters. Some features however, such as the masking of the isotropic sample illumination for suppression of specular surface reflections from the DUT, are adaptations from approaches originally developed for gonioscopic instruments.[7,8] Moreover, highly accurate colorimetry *via* spectral analysis still has not yet been adopted for conoscopic devices since its implementation is not an easy feat, except for the "brute force" solution of using 30 or more interference filters in the image path.

Looking at the current wave of TV screens that have to be measured and rated with respect to their visual performance, it becomes obvious that a *many-filter approach* is not the right way for accurate colorimetric characterization of these displays. As a solution for the conflict between measurement time and precision, we have recently implemented the concept of *multidirectional spectral analysis* (***PolyGonioscopic***), which for the first time combines fast, high-resolution spectral analysis with a minimum of time required for the full colorimetric characterization of LCD-TV screens, with extended viewing cones (Fig. 4).

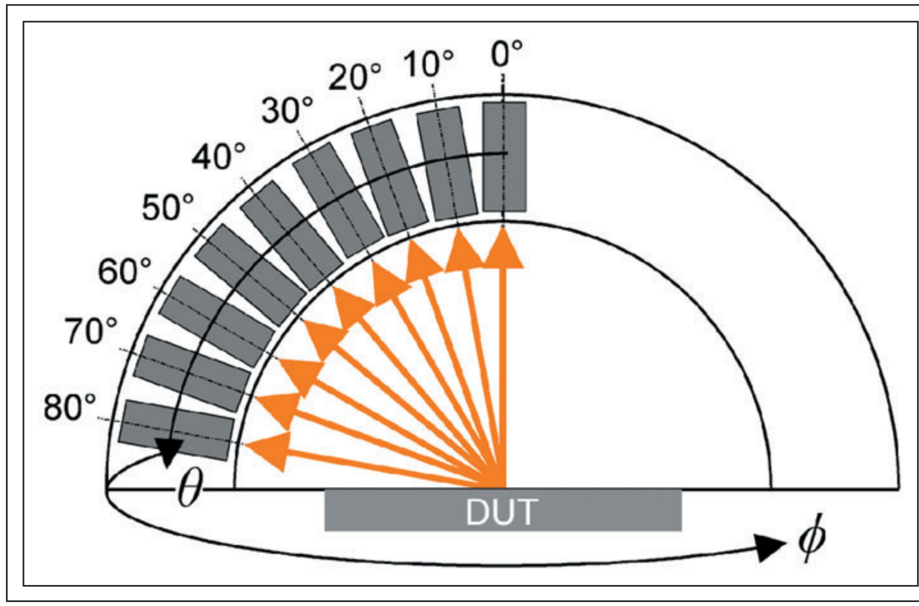

Fig. 4: *A PolyGonioscopic measuring head showing the optics of nine spectral channels. High-sensitivity spectral analysis is carried out for nine directions simultaneously. The diameter of the field of measurement is 10 mm. Motorized inclination of the assembly of the optics makes high-resolution directional scanning (inclination θ) possible.*

Conclusion

The continued development of increasingly complex LCD systems has posed great challenges to those charged with developing accurate display metrology systems. Because LCDs have become virtually ubiquitous in today's world, the ability to accurately measure their performance has never been more critical. New approaches, including poly-gonioscopic analysis, continue to be developed and improved.

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13 MARCH 08

SID-ME Mid-Europe Chapter Spring Meeting 2008

MARCH 13–14, 2008
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Topical sessions include:

- Microdisplay Applications
- Light Sources
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- OLED Microdisplays

SID

23 SEPTEMBER 08

SID Mobile Displays 2008

SEPTEMBER 23–24, 2008
San Diego, California, USA

Topics include:

- Mobile-phone product design
- Other handheld mobile system designers
- Small display makers
- Driver chips for mobile displays
- Display component makers including backlights, optical enhancement films, polarizers, and drivers
- Wireless service providers
- Power management
- Graphics and display system architecture
- Materials and components for mobile displays

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SID Heads to Los Angeles for Display Week 2008

Without the display industry, there would be no Hollywood, so it makes perfect sense for Display Week 2008 to take place in the entertainment capital of the world. Here is a guide to what to do and see in Los Angeles when not at Display Week 2008.

by Jessica Quandt

REGARDLESS OF whether or not you actually have ever been there, chances are you have already seen your fair share of Los Angeles. For the better part of a century, the iconic imagery of Tinseltown (Fig. 1) has pervaded in both still and moving images: palm trees, beaches, abundant sunshine, swank shopping streets populated by the super-rich, and the super-beautiful celebrities roaming among mere mortals, surfing, theme parks, and ultra-luxurious homes.

So which of these myriad images represents the real "City of Angels"? You will find L.A. is all of these things when you come during Display Week 2008: The SID International Symposium, Seminar & Exhibition. Here's a quick snapshot of what to do when visiting Los Angeles.

Museums

Despite its popular image as the center of slackers and surfers, actors, and waiters who want to be actors, L.A. is actually quite the cultural and international mecca. The city boasts an impressive 300 museums.

Perhaps the most famous museum in the city is the ***J. Paul Getty Museum***, in part because of its vast collection of art and in part because of its stunning setting and design. The museum houses an enormous collection of European paintings, drawings, manuscripts, sculpture, and decorative arts, as well as European and American photography, all set in a gorgeous, sprawling $1.2 billion modernist hilltop complex designed by famed architect Richard Meier, affording views all the way to the Pacific Ocean. The museum, to which admission is free, is also home to the spectacular 134,000-square-foot Central Garden, which you can tour for free by making arrangements online prior to your visit.

Also under the Getty umbrella is ***The Getty Villa*** in the scenic L.A. community of Pacific Palisades, an educational center and museum dedicated entirely to the arts and cultures of ancient Greece, Rome, and Etruria. The museum's structure is an amalgamation of features from several well-known ancient Roman villas, complete with a giant reflective pool in the inner courtyard. Admission to the Villa is also free, but timed tickets must be purchased in advance online.

For something a little out of the ordinary, head over to the world-famous ***La Brea Tar Pits***. The central feature of this site is exactly what it sounds like: big, goopy tar pits from which scientists have salvaged the world's largest and most diverse collection of extinct

***Fig. 1:** The **Hollywood Sign** is one of the most iconic images in all of Los Angeles.*

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Nadine Markova

Fig. 2: ***Grauman's Chinese Theater*** *is the famous movie theater where stars have had their handprints and footprints cast in cement for more than 75 years.*

plant and animal remains. The site includes the ***Page Museum*** (adults $7), where you can get a glimpse of L.A. as it was 10,000–40,000 years ago. Sights in the museum include replicas and real skeletons of extinct animals such as mammoths and saber-tooth cats (most of which were actually found in the Tar Pits outside), and a window where you can watch bones recently excavated from the tar pits being cleaned. For another educational outing, check out the ***California Science Museum***, the West Coast's largest hands-on science museum, which is free to visit.

The *Natural History Museum of L.A.* (adults $9, children $2 has 33 million specimens and artifacts on display, including full skeletons of a *Tyrannosaurus rex* and a *Triceratops* in battle, dioramas of African mammals, rare dinosaur fossils, marine animals, and a gem and mineral hall boasting the largest collection of gold in the U.S.

The ***L.A. County Museum of Art (LACMA)*** exhibits works from its collection of more than 100,000 works of contemporary, Latin American, European, Islamic, and Korean art (among others); this museum on Wilshire Boulevard is a world-class institution that is also a great bargain: admission is $9, but it is free after 5:00 p.m. A new Modern Art wing designed by renowned architect Renzo Piano was scheduled to open in February.

If you are after something a little more glamorous (this is Los Angeles, after all), try the ***Hollywood Museum*** (adults $15). Located in the historic art-deco-style Max Factor Building, this museum is dedicated to entertaining and educating the public about the art, history, techniques, and technology of the entertainment industry, and its worldwide cultural effects. Items on exhibit include costumes and props from your favorite films, an extensive autograph collection, rare and vintage photos of Hollywood icons, and everything from Sylvester Stallone's Rocky gloves to Cary Grant's Rolls Royce.

Iconic Sights

Although L.A. offers a plethora of museums, there is so much to see and learn around the city that you may never have to set foot in one! One of the area's most popular tourist destinations is ***Grauman's Chinese Theater*** (Fig. 2). Opened on May 18, 1927, this Hollywood landmark receives more than

Fig. 3: *The* ***Hollywood Walk of Fame*** *extends 3.5 miles and features more than 2000 plaques commemorating legends of the entertainment industry, such as actress Sharon Stone.*

Kenna Love/LACVB

***Fig. 4: Venice Beach** stretches 3 miles along the Pacific Ocean, with an old-time boardwalk frequented by a vibrant mix of street performers, bodybuilders, and rollerbladers.*

4 million visitors each year, who come to ogle the pagoda-style architecture of the theater, marvel at the artifacts and art imported from China that decorate the inside of the building, and see the latest Hollywood releases on the big screen. But most of all, they come to see the theater's forecourt, where more than 200 stars have left their handprints and footprints embedded in the cement. Stars immortalized in the forecourt include everyone from Charlie Chaplin to Tom Cruise to Donald Duck.

Next door to Grauman's you'll find the famous ***Kodak Theatre***. Opened in 2001, this $94 million theater modeled after classic European opera houses is home to the annual Academy Awards ceremony. For $15, you can take a guided tour of the theater and find out who sat where at the entertainment world's biggest night of the year.

If that's not enough star power for you, head over to the ***Hollywood Walk of Fame*** (Fig. 3). Running East to West on Hollywood Boulevard from Gower Street to La Brea Avenue, and North to South on Vine Street between Yucca Street and Sunset Boulevard, this 3.5-mile stretch of pavement features tributes to more than 2000 celebrities. Familiar pink five-pointed stars bear the names of icons of film, TV, radio, live theater, and music – each celebrity's field is denoted by a bronze movie camera, television, radio microphone, set of tragedy and comedy masks, or phonograph, respectively.

For a different kind of stargazing, make arrangements to visit the ***Griffith Observatory***. Located in the park of the same name, this beautiful observatory was completed in 1935 and made famous in the classic James Dean movie *Rebel Without a Cause*. Admission to the observatory is free, although the shuttle up to the site costs $8 per person. Once you reach the observatory, purchase tickets in person for a show at the planetarium, or just enjoy the free public telescopes and astronomy exhibits.

Outdoor Activities and Architecture

Los Angeles is perhaps just as famous for its beaches as it is for the celebrities whose homes overlook them. ***Santa Monica Beach, Manhattan Beach, Paradise Cove,*** and ***Redondo Beach*** are all popular choices for a relaxing day in the surf and sun. For a somewhat wilder day at the beach, head for ***Venice Beach*** (Fig. 4), where 3 miles of coastline and palm trees provide the setting for colorful storefronts and an old-time boardwalk frequented by a vibrant mix of street performers, bodybuilders, and rollerbladers. The beachfront is located in the charming city of ***Venice***, which, as the name suggests, was originally constructed using 16 miles of man-made canals as streets. Today, less than 2 miles of canals remain (the bulk were eventually filled in with cement to make navigation easier by car and on foot), but there are still some beautiful canal-front houses to be seen.

The ***Santa Monica Pier*** (Fig. 5) is another great choice for a beach experience with some extra flavor. Constructed in 1909, this beach boardwalk is home to an arcade, a historic carousel, an amusement park (featuring the world's only solar-powered Ferris wheel, which provides views of the Pacific Ocean, and a roller coaster circling the majority of the

Getting to and around Los Angeles

Los Angeles International Airport (LAX) is the world's fifth-busiest passenger airport. Most major airlines offer service into and out of LAX, with non-stop flights to/from most major U.S. and Asian cities. Taxi service between LAX and downtown Los Angeles costs $42. For more information about the airport, including additional ground transportation options, visit the LAX Web site at www.lawa.org/lax.

Other nearby airports include Orange County/John Wayne Airport (SNA) www.ocair.com; Long Beach Airport (LGB) www.lgb.org; LA/Ontario International Airport (ONT) www.lawa.org/ont; and Bob Hope Airport in Burbank (BUR) www.burbankairport.com

While Los Angeles is the capital of U.S. car culture, the city actually has the second largest public transportation agency in the U.S., operating more than 1500 buses and a subway with four lines, three of which run through downtown, where Display Week 2008 will take place. The subway, called the Metro, can take you from Downtown Los Angeles to Hollywood in about 12 minutes. For more information, visit www.mta.net.

park), and an aquarium, not to mention various shops, restaurants, and vendor carts.

Ironically enough, some of the most appealing outdoor sights in Los Angeles are not easily viewed while standing out in the fresh air. If you have rented a car for the week, be sure to take a drive through some of the area's ritziest neighborhoods, where you will see spectacular homes with unbelievable views.

Start with ***Mulholland Drive***, which follows the ridgeline of the Santa Monica Mountains and the Hollywood Hills. Try to keep your eyes on the road as views of the L.A. Basin, San Fernando Valley, the famous Hollywood Sign, and downtown Los Angeles pass by your window. As the views might suggest, Mulholland is also home to some of the area's most beautiful and expensive homes. The roster of famous residents of this storied street reads like a Who's Who of Hollywood, including Jack Nicholson, Marlon Brando, and Tom Hanks.

Only one neighborhood, though, can claim the honor having the most expensive housing market in the country: ***Beverly Hills***. With a median home price of $2.2 million, Beverly Hills has quite an offering of gawk-worthy homes. And no trip to Beverly Hills is complete without a shopping excursion (or at least window shopping) on world-famous Rodeo Drive.

Seeing Stars

Everyone knows the stars live in Los Angeles. But the metropolitan area is a big place to say the least, covering 469 square miles and accommodating nearly 4 million residents, according to a 2006 census. So with so much ground to cover, how do you find out where your favorite stars live? Easy, pay someone to show you. A handful of companies offer guided bus tours that will spend several hours taking you down some of the area's most exclusive streets and pointing out the homes of major celebrities along the way. Star Line Tours offers 2-hour tours for about $36 per person, with pick-ups available in L.A., Hollywood, and West Hollywood.

For a better shot at seeing the stars in the flesh, your best bet is to follow them to work! Many major movie and TV studios offer guided tours of their lots (prices vary by studio), and tours frequently include stops on sets where movies and television shows are currently being filmed. Many studios are now located outside of Los Angeles and Hollywood, so be sure to check the location before buying your tickets if you're not renting a car for the week. Studios that offer tours include ***Universal Studios, Warner Brothers.***, ***Paramount***, and ***Sony***.

For a sure-fire way to get in a celebrity sighting, reserve tickets in advance to be in the audience at the taping of a TV show. Many shows offer free audience tickets that can be reserved online through a number of free services, including Audiences Unlimited.

Theme Parks

Southern California is a theme-park junkie's dream come true, with a cornucopia of parks to fit anyone's taste. The most famous is, of course, ***Disneyland*** (adults $66), located about 20 minutes from L.A. in Anaheim. With its staff of roaming life-sized cartoon characters, fantasy-themed rides, and trademark air of magic, Disneyland is sure to bring out the kid in anyone.

In the nearby city of Buena Park, you will find a theme park built around another animated empire: ***Knott's Berry Farm*** (adults $49.95; ticket discounts available online), populated by Snoopy, Charlie Brown, Lucy, and the rest of the gang from the Peanuts comic strips. The rides here are bigger than

Web Sites for Los Angeles

General Information

- ***Los Angeles Convention & Visitor's Bureau***: www.greaterlosangeles.com
- ***Los Angeles Public Transportation***: www.mta.net
- ***Los Angeles International Airport (LAX)***: www.lawa.org/lax
- ***City of Beverly Hills***: www.beverlyhills. org
- ***Venice Beach***: www.westland.net/venice

Museums

- ***California Science Museum***: www.californiasciencecenter.org
- ***Getty Center***: www.getty.edu/
- ***Hollywood Museum***: www.thehollywoodmuseum.com
- ***La Brea Tar Pits*** and the ***Page Museum***: www.tarpits.org/
- ***L.A. County Museum of Art***: www. lacma.org
- ***Natural History Museum of Los Angeles***: www.nhm.org

Tourist Attractions

- ***Grauman's Chinese Theater***: www. manntheaters.com/chinese/ index.php
- ***Griffith Observatory***: www.griffith observatory.org
- ***Hollywood Sign***: www.hollywoodsign. org
- ***Hollywood Walk of Fame***: http://www.hollywoodchamber.net/icons/walk_directory.asp
- ***Kodak Theatre***: www.kodaktheatre.com
- ***Santa Monica Pier***: www.santamonicapier.org
- ***Star Line Tours***: www.starlinetours.com
- ***TV Show Tapings***: www.audiencesunlimited.com

Studio Tours

- ***Paramount***: http://www.paramount. com/paramount.php
- ***Sony***: www.sonypicturesstudios.com/
- ***Universal Studios Hollywood***: www.|universalstudioshollywood.com
- ***Warner Bros.***: http://www.warnerbros.com/vipstudiotour/

Theme Parks

- ***Disneyland***: http://disneyland. disney.go.com
- ***Knott's Berry Farm***: www.knotts.com
- ***Six Flags Magic Mountain***: www.sixflags.com/parks/magicmountain

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Fig. 5: The ***Santa Monica Pier*** *was built in 1909 and is home to an arcade, a historic carousel, and the world's only solar-powered Ferris wheel.*

Disney's, making it a better bet for anyone seeking more thrills than theatrics.

Another popular choice is ***Universal Studios Hollywood*** (adults $64). This park has it all: thrill rides based on hit movies such as *The Mummy, Shrek*, and *Jurassic Park*; junk food; and even a guided tour of Universal's TV and film studios.

Between all the exhibits, seminars, and keynote addresses at this year's Display Week, you're sure to have more than enough to do during your time in Los Angeles. But try to make the time to go out and explore this surreal, unique, and, above all, iconic city. After all, no matter how many times you have seen it on TV or in the movies, there's nothing quite like experiencing L.A. and everything it has to offer in real life. ■


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Edited by Aris Silzars

PIN OLEDs – Improved structures and materials to enhance device lifetime

Jan Birnstock
Tobias Canzler
Michael Hofmann
Andrea Lux
Sven Murano
Philipp Wellmann
Ansgar Werner

Novaled AG

Abstract — Currently, three issues are identified that decide upon the commercial success of organic light-emitting diodes (OLEDs), both in display and lighting applications: power efficiency, lifetime, and price competitiveness. PIN OLEDs are widely seen as the preferred way to maximize power efficiency. Here, it is reported that this concept also delivers the world's longest lifetimes. For a highly efficient deep-red PIN OLED, a half-lifetime of 25,000 hours for a starting brightness of 10,000 cd/m^2 and a minimal voltage increase over lifetime is reported. This value corresponds to more than 1×10^6 hours at 1000 cd/m^2 using an exponent of n = 1.7, which was measured by driving the OLEDs at different starting luminances. Because there is no initial luminance drop, these PIN OLEDs also exhibit a very high 80% lifetime (>300,000 hours at 1000 cd/m^2). New record lifetime values for blue and green will be reported as well. Additionally, further topics that have impact on the production yield and cost such as the newly developed air-stable organic n-doping material NDN-26 and top-emitting structures will be discussed.

The origins of redox-doped OLEDs, so-called PIN OLEDs, date back to the nineties. At that time, it was believed that devices with low driving voltage and therefore high power efficiency could be achieved with this approach. However, it took about one decade until this promise could be accomplished – in 2004, a power efficiency of 64 lm/W for a green-phosphorescent PIN OLED was published. The next breakthrough in the development of PIN OLEDs was certainly the increase of the half-lifetime above 100,000 hours at an initial brightness of 500 cd/m^2.

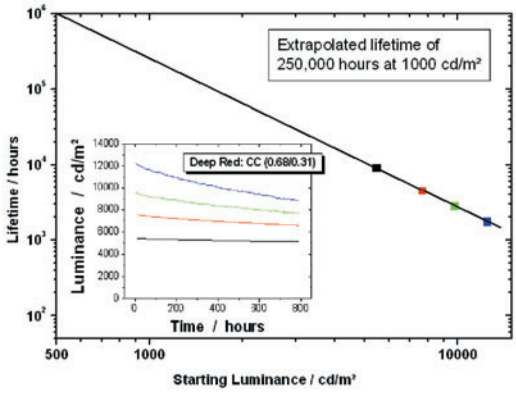


FIGURE 13 — Lifetime measurement of a deep-red-phosphorescent PIN OLED (top emitting) comprising the *n*-dopant NDN-26 and the emitter system TMM-004:TER-004. The OLED features a current efficiency of 31 cd/A and a driving voltage of 2.7 V at 1000 cd/m^2.

Development of a phosphorescent white OLED with extremely high power efficiency and long lifetime

Tomoyuki Nakayama
Kunimasa Hiyama
Keiichi Furukawa
Hirofumi Ohtani

Konica Minolta Technology Center, Inc.

Abstract — A white OLED device with extremely high power efficiency and long lifetime was developed, in which blue, yellow-green, and red phosphorescent emitters were used. The performances achieved were 64 lm/W and 10,000 hours of lifetime at an initial luminance of 1000 cd/m^2 by using a light outcoupling technique. The device also exhibited the good durability important for practical usage. New technologies, such as blue phosphorescent materials and a sophisticated organic layer structure, were applied to the device. Hopefully, these technologies will open the door to the practical use of OLEDs as light sources.

As shown in Fig. 11, the performance of our OLED device surpassed that of electric bulbs and reached the domain of fluorescent lamps. Although further study will be needed in the future, encouraging durability characteristics, such as the storage stability essential to practical usage, were obtained.

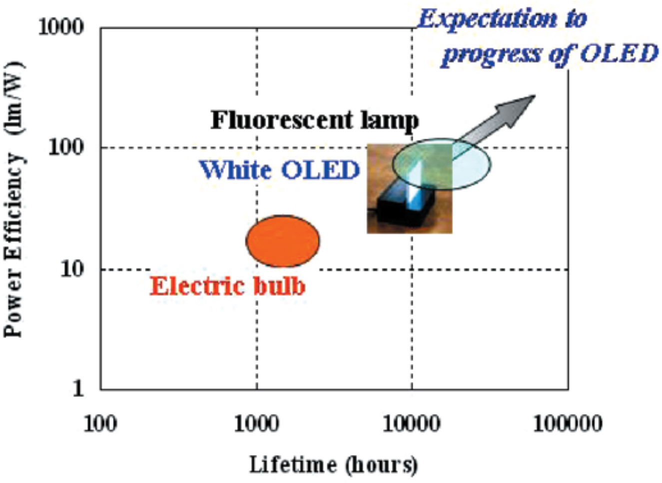


FIGURE 11 — Light-source trends; combined power efficiency and lifetime.

Novel highly reflective and bistable electrowetting displays

Karlheinz Blankenbach
Andreas Schmoll
Andriy Bitman
Frank Bartels
Dieter Jerosch

Pforzheim University

Abstract — Novel displays have been developed using the effect of moving a droplet by electrowetting. This approach enables bistable and reflective monochrome and color displays which could also be made on plastic substrates. Prototypes show promising performance in terms of contrast ratio, gray scale, and color.

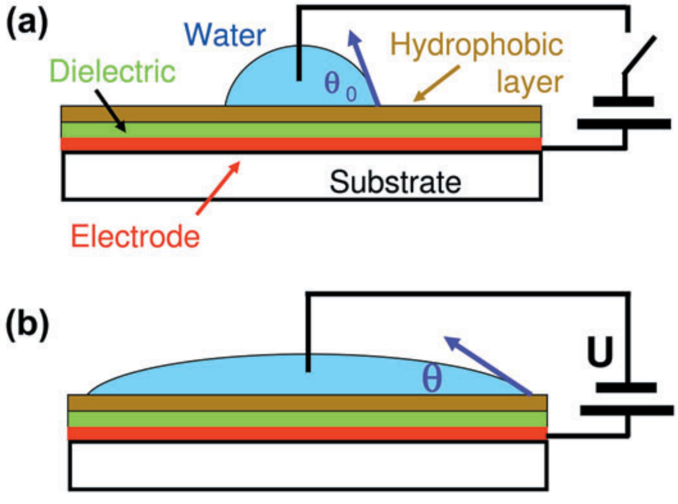


FIGURE 1 — Electrowetting principle: A water droplet on a hydrophobic layer is contracted without voltage (a) and relaxed by applying an appropriate voltage (b).

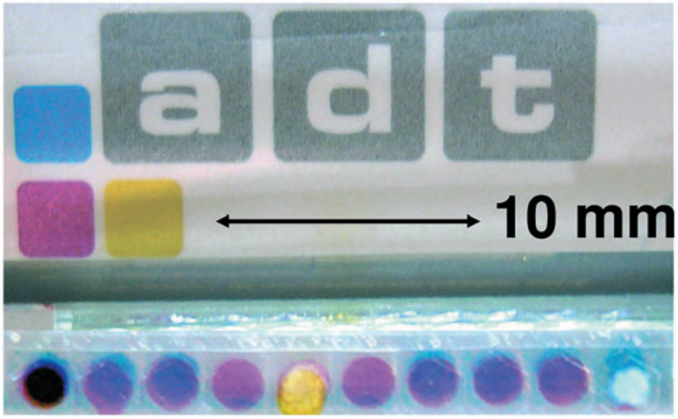


FIGURE 14 — CMY stacked EW droplet-driven color prototype displaying several primaries by 2-mm droplets in pure reflective mode.

Recent progress in flexible color reflective cholesteric displays

Asad Khan, Tod Schneider
Erica Montbach, Donald J. Davis
Nick Miller, Duane Marhefka
Todd Ernst, J. William Doane

Kent Displays, Inc.

Abstract — Highly flexible layered full-color cholesteric displays fabricated using ultra-thin substrates with encapsulation through the phase-separation approach is reported. Recent progress of the state of the art of cholesteric display technology will be discussed as well.

The display photographs are shown in Fig. 7. The display is only about 70 µm in total thickness (including the back absorbing layer) and a high degree of flexibility is clearly seen. There is no observable parallax because the display layers are very close to each other. In addition, the contrast, color saturation and reflectivity are high as well. The conducting-polymer coatings have a sheet resistance of about 1 kΩ/□ and a transmission greater than 90%. The absorption in the conducting-polymer layers adds quickly to reduce reflections from the lower layers of the display. However, as evidenced from the photographs, all display layers and colors appear bright and saturated.

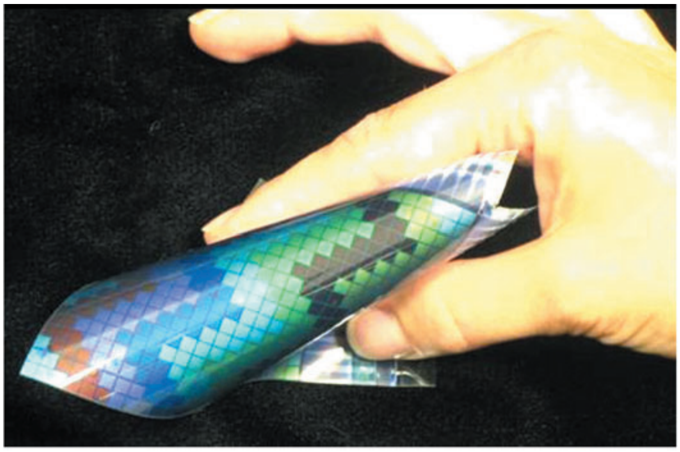


FIGURE 7 — Photographs of the full-color stacked ChLCDs using ultra-thin substrates and the phase-separation approach. The display format is 20 × 24 pixels.

High-performance OCB-mode field-sequential-color LCD

Takahiro Ishinabe
Kazuhiro Wako
Kazuo Sekiya
Tadashi Kishimoto
Tetsuya Miyashita
Tatsuo Uchida

Tokoku University

Abstract — Optically compensated bend (OCB) mode is a promising technology for future high-quality display devices due to its wide viewing angle without gray-scale inversion and color shift, fast response time, high contrast ratio, and wide temperature range. This paper summarizes the developments of the OCB mode and the optical performance of OCB-mode field-sequential-color LCDs.

A 15-in.-diagonal OCB-mode FSC TFT-LCD by using a scanning-LED backlight was developed. This scanning-LED backlight is used to realize RGB color fields with high brightness and good uniformity and has 10 blocks with partitioned walls to suppress light penetration from the neighboring blocks and undesirable inter-field color mixture. This is the world's first OCB-mode LCD that operates at 360 fields/sec, and it was confirmed that wide-viewing-angle, high-contrast-ratio, wide-color-gamut, high-quality moving images without color breakup can be obtained.

FIGURE 14 — Prototype 15-in. field-sequential-color OCB-mode LCD.

Viewing-angle compensation of TN- and ECB-LCD modes by using a rod-like liquid-crystalline polymer film

Tetsuya Uesaka
Satoru Ikeda
Suzushi Nishimura
Hitoshi Mazaki

Nippon Oil Corp.

Abstract — A liquid-crystalline retardation-film technology by using a rod-like liquid-crystalline polymer (LCP) for various LCD modes have been developed. In particular, considerable improvements in viewing-angle performance have been achieved for the twisted-nematic (TN) and the transmissive/transflective electrically controlled birefringence (ECB) modes by using hybrid aligned nematic film (NH Film).

As shown in Fig. 9, it was confirmed that the transmissive ECB-LCD with new NH film can display vivid color and clear images in both the horizontal and vertical directions. Although the viewing-angle range (CR > 10) of the ECB-LCD (I) exceeds 160° in the diagonal directions, it reaches only 120° in the horizontal and vertical directions due to the light leakage from the crossed polarizer in the off-axis. This problem can be solved by inserting the uniaxial film 2 into the ECB-LCD (I).

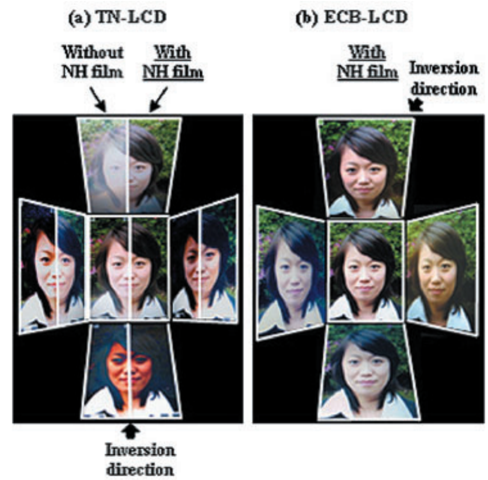


FIGURE 9 — Comparison of image qualities of a TN- and ECB-LCD (I) with NH film at oblique angles.

Oxide TFT with multilayer gate insulator for backplane of AMOLED device

Ho-Nyun Lee
Jaewoo Kyung
Myeon-Chang Sung
Do Youl Kim
Sun Kil Kang
Seong-Joong Kim
Chang Nam Kim
Hong-Gyu Kim
Sung-Tae Kim

LG Electronics

Abstract — An indium gallium zinc oxide (IGZO) film with an amorphous phase was deposited and had a very flat morphology with a RMS value of 0.35 nm. IGZO TFTs were fabricated on a glass substrate by conventional photolithography and wet-etching processes. IGZO TFTs demonstrated a high mobility of 124 cm^2/V-sec, a high on/off ratio of over 10^8, a desirable threshold voltage of 0.7 V, and a sub-threshold swing of 0.43 V/decade. High mobility partially resulted from the fringing-electric-field effect that leads to an additional current flow beyond the device edges. Therefore, considering our device geometry, the actual mobility was about 100 cm^2/V-sec and had a very low dependence on the variation of *W/L* (channel width and length) and thickness of the active layer. IGZO TFTs were also fabricated on a flexible metal substrate for a conformable display application. TFT devices showed an actual mobility of 72 cm^2/V-sec, a high on/off ratio of ~10^7, and a sub-threshold swing of 0.36 V/decade. There was no significant difference before, during, or after bending. Moreover, an IGZO TFT array was fabricated and a top-emitting OLED device was successfully driven by it. Therefore, the oxide TFT could be a promising candidate as a backplane for OLED devices.

Figure 7 shows as-fabricated IGZO TFTs on a stainless-steel foil. 100-μm-thick stainless foils have sufficient flexibility to be bent into a curve with the radius *(R)* of 40 mm. IGZO TFTs were fabricated with a 50-μm channel width *(W)* and 20-μm channel length *(L)*. Figure 8(a) is the transfer characteristic curve of the IGZO TFT. The IGZO TFT showed a high drain current (I_{DS}) of 120 μA for the conditions of V_{GS} = 10 V and V_{DS} = 10 V. Moreover, the TFT showed a low off-current of about 2 pA, which resulted in a high on/off ratio of over 10^7.

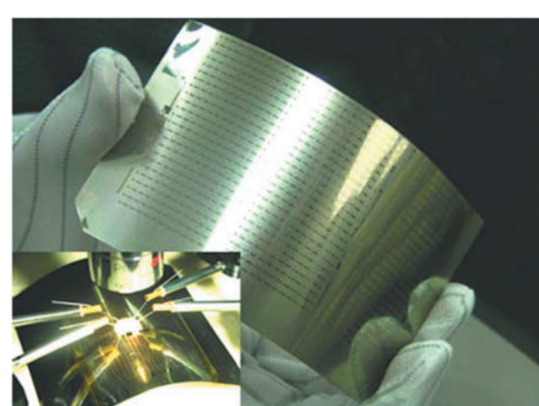


FIGURE 7 — IGZO TFTs fabricated on stainless-steel foil.

Practical CNT-FED structure for high-luminance character displays

Junko Yotani
Sashiro Uemura
Takeshi Nagasako
Hiroyuki Kurachi
Tomotaka Ezaki
Tsuyoshi Maesoba
Takehiro Nakao
Masaaki Ito
Akira Sakurai
Hideo Shimoda
Hiromu Yamada
Yahachi Saito

Noritake Co., Ltd.

Abstract — A high-luminance CNT-FED character display using a simple line-rib structure was constructed. The display panel had 48 × 480 dots and the subpixel pitch was 1 mm. The greatest benefit of a display using CNT technology is high luminance performance with low-power consumption. The luminance of the green-color dot was ca. 10,000 cd/m^2 under 1/16 duty-cycle driving at a 6-kV anode voltage. The high luminance of the display panel can provide good visibility when installed even in outdoor locations, and the power consumption was ca. 4 W at the character displaying module. Thus, a CNT-FED for character displays also has potential multifunctionality, which could be battery driven. It should be useful for public displays even under emergency no-power conditions. In this work, a practical structure and process technologies for making ribs with reasonable cost were developed. The newly introduced 2-mm-tall line ribs as spacers were formed by using innovative production processes; *i.e.*, the rib paste was pushed out of a multi-slit nozzle, and the rib shape was formed by UV-light irradiation. The developed panel structure and manufacturing processes also had the advantages of size flexibility and high production yield.

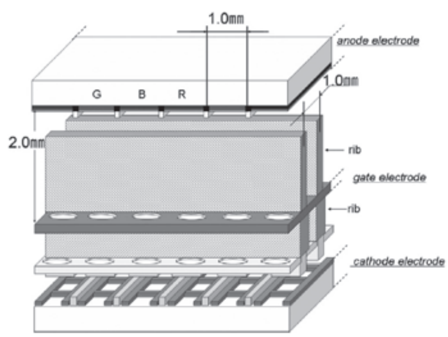
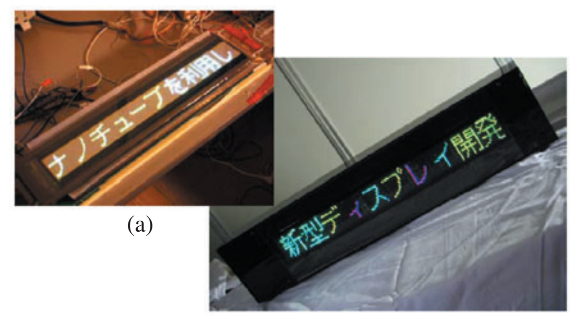


FIGURE 4 — Schematic of the structure of a practical new panel using line rib spacers.



(a)

(b)

FIGURE 11 — Photographs of a displayed color character pattern. The display area is 480 mm × 48 mm. (a) A prototype device. (b) A photograph of a battery-driven demo display.

Progress of LED backlights for LCDs

Munisamy Anandan

Organic Lighting Technologies LLC

Abstract — Cold-cathode fluorescent lamps (CCFLs) are being used for LCD backlighting and is currently the dominant technology for LCD backlighting. However, recent attention has been given to LEDs as light sources for LCD backlighting because of their (i) long life, (ii) low-voltage operation, (iii) fast response time, and (iv) wide color gamut. This review article commences with the basics of LEDs as light sources and their limitations, followed by various backlight structures employing LEDs in cell phones, notebook computers, and LCD TVs. The description of the improvement in image quality on an LCD screen, stemming from the characteristics of LEDs, is also given. In conclusion, the possible rapid growth of LED backlights is outlined, thus gradually ending the domination of CCFL backlights.

The performance level of LED backlights has exceeded that of CCFL backlights and is providing a boost to LCDs in enhancing its image quality and decreasing its power consumption. The barrier for penetration is their cost. For white LED backlights, the cost is not as large a barrier as the RGB-based white-LED backlight. With the substantial advantages consumers are getting with white LED backlights *vs.* CCFL backlights for laptop computers and the low-power (20 mA) white LED selling at low prices, white LED-backlight market for NBCs will significantly increase. A 15% market penetration can happen in 3 years with the unit requirement by the year 2010 reaching nearly 120 million units.

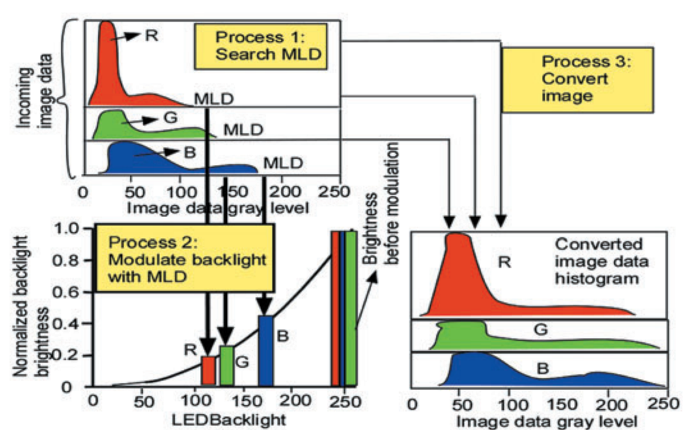


FIGURE 41 — RGB color control system employing LED backlights.

Power savings and enhancement of gray-scale capability of LCD TVs with an adaptive dimming technique

Tomokazu Shiga
Sho Shimizukawa
Shigeo Mikoshiba

University of Electro-Communications

Abstract — The luminance of a backlight unit for an LCD TV is adaptively and locally dimmed along with the input video signal in order to reduce the power consumption and also to improve the picture quality. By adopting the zero-dimensional (0D), 1D, and 2D adaptive dimming techniques, a sample movie having 8.0% post-gamma average picture levels (APL) could be displayed using 83%, 71%, and 50% of the original backlight power, respectively. For an adoption of the 2D dimming, an LED backlight is preferable. The adaptive-dimming technique also allows the differential aging characteristics between the LED components and temperature dependence of color and luminance to be overcome. From simulations of a reduction in power consumption, it was found that 40×40 pixels is a unit of the local dimming, 30 frames for the sampling period, 24 dimming steps, and an equal-signal-step method for determining the dimming factor have been found to be appropriate. The gray-scale capability of low-luminance images can also be improved by dimming the backlight luminance and expanding the input signal. By using an LCD TV having an 8-bit capability, an 11-bit-equivalent gray-scale expression was experimentally proven.

Figure 5 shows a structure of an experimental LED backlight unit used for the 2D-dimming investigation. The unit is divided into 3×4 blocks by using 0.2-mm-thick white optical isolators. A 19-in.-diagonal IPS-mode SXGA LCD module having a pixel pitch of 0.294 mm is mounted on top of the backlight unit. Each block corresponds to 102×102 LCD pixels. Due to the small size of the experimental backlight unit, only a portion of the LCD module is employed. The dimming experiments were performed using two 10-sec sample movies, consisting of 306 pixels vertically and 408 pixels horizontally.

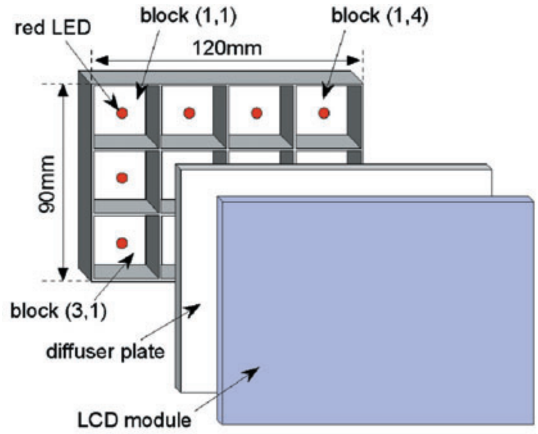


FIGURE 5 — LED backlight unit for 2D adaptive dimming.

Design and fabrication of a micropatterned polydimethylsiloxane (PDMS) light-guide plate for sheet-less LCD backlight unit

Joo-Hyung Lee
Hong-Seok Lee
Byung-Kee Lee
Won-Seok Choi
Hwan-Young Choi
Jun-Bo Yoon

Abstract — A polydimethylsiloxane (PDMS) light-guide plate (LGP) having micropatterns with an inverse-trapezoidal cross section was developed for a sheet-less LCD backlight unit (BLU). The micropatterned PDMS LGP was fabricated by back-side 3-D diffuser lithography followed by two consecutive PDMS replication processes: photoresist-to-PDMS and PDMS-to-PDMS replications. The fabricated LGP showed an average luminance of 2878 nits and a uniformity of 73.3% in a 2-in. backlight module with four side-view 0.85-cd LEDs. It also could feasibly be applied to a light source for flexible displays owing to the flexible characteristic of the PDMS itself.

Compared with a conventional LCD BLU, which has three optical sheets and one reflector film, the proposed BLU is comprised of only a PDMS LGP having micropatterns with an inverse-trapezoidal cross section on the front surface to emit light upward from the side-view LEDs as shown in Fig. 1. In this work, the optical properties of the fabricated LGP such as luminance profile and angular distribution when mounted in a 2-in. backlight module are described.

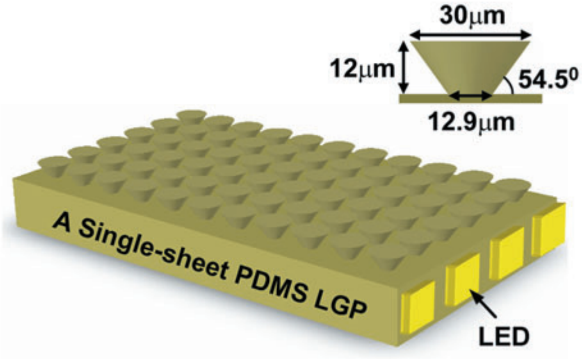


FIGURE 1 — A schematic view of the proposed micropatterned PDMS LGP for sheet-less LCD BLU.

A novel diffractive backlight concept for mobile displays

Jyrki Kimmel
Tapani Levola
Pasi Saarikko
Johan Bergquist

Nokia Research Center

Abstract — Power-efficiency demands on mobile communications device displays have become severe with the emergence of full-video-capable cellular phones and mobile telephony services such as third-generation (3G) networks. The display is the main culprit for power consumption in the mobile-phone user interface and the backlight unit (BLU) of commonly used active-matrix liquid-crystal displays (AMLCDs) is the main power drain in the display. One way of reducing the power dissipation of a mobile liquid-crystal display is to efficiently distribute and outcouple the light available in the backlight unit to direct the primary wavelength bands in a spectrum-specific fashion through the respective color subpixels. This paper describes a diffractive-optics approach for a novel backlight unit to realize this goal. A model grating structure was fabricated and the distribution of outcoupled light was studied. The results verify that the new BLU concept based on an array of spectrum-specific gratings is feasible.

Figure 1 shows a schematic outline of the new pixelated diffractive backlight concept. Incoming light is fanned out by a grating that is selective for each primary color, and respective red, green, and blue LEDs are used for the color primaries. The light is then distributed throughout the active area of the display by total internal reflection (TIR). In the active area, an array of gratings couples out the light into the active aperture of the display pixel matrix. The separation of color primaries at the pixel level is achieved by color-specific gratings, and by orienting the green-primary light propagation inside the TIR light guide perpendicularly to the red and blue primaries.

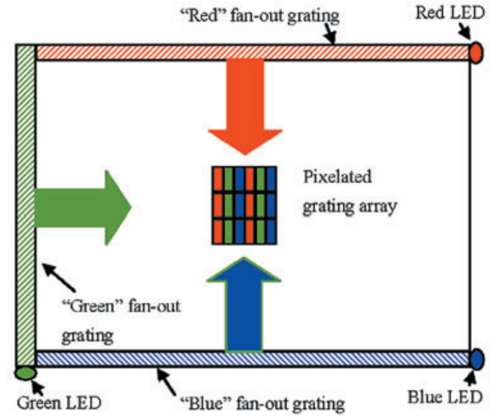


FIGURE 1 — Pixelated backlight concept (not to scale).

A YC-separation-type projector: High dynamic range with double modulation

Yuichi Kusakabe
Masaru Kanazawa
Yuji Nojiri
Masato Furuya
Makato Yoshimura

NHK Science & Technical Research Laboratories

Abstract — An experimental projector that features double modulation to obtain high-resolution (4096 × 2160 pixels) and high-dynamic-range images has been developed. Although a conventional projector contains three modulators for red, green, and blue and output light after combining the modulated light from these three sources, our projector has an additional modulator for luminance that modulates the combined RGB modulated light. It can display high-resolution color images by combining three low-resolution panels for chrominance modulation and one high-resolution panel for luminance modulation. In addition, the dynamic range is dramatically improved because the double-modulation scheme minimizes black levels in projected images. The projector demonstrates an extremely high dynamic range of 1.1 million to 1- and 10-bit tone reproduction.

Figure 9 shows examples of parts of projected images on each stage; the image modulated only by RGB signals, the image modulated only by a Y signal, and the total image with double modulation. The image modulated only by RGB signals appears blurred because of the low resolution of the RGB signals and relay lens. However, the resolution of the output image with double modulation is high. These photographs prove that a high-resolution color image is obtained only if the resolution of the Y signal is high.

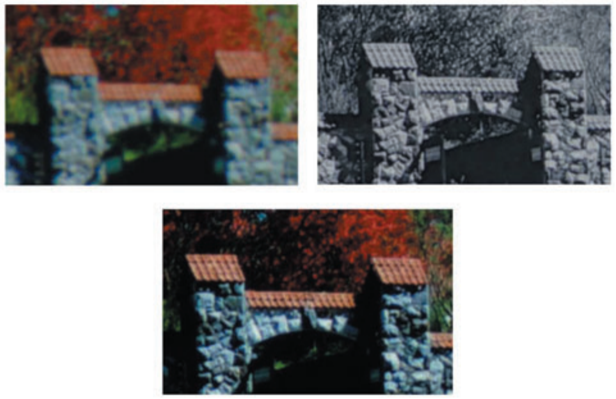


FIGURE 9 — Examples of parts of projected images. Upper left – image modulated only by RGB signals (low resolution). Upper right – image modulated only by a Y signal (high resolution). Lower – output image with double modulation.

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LatinDisplay 2007 Proves a Success

by Daniel den Engelsen

Nearly 200 people from around the world attended "LatinDisplay 2007," an international conference on displays and display technology held at the Nacional Inn Hotel in Campinas, Brazil, from November 12–14, 2007. This conference represented the merging of various information-display meetings and display seminars that have been organized during the past 14 years in Latin America.

The conference featured 19 oral presentations, 50 poster presentations, and 16 exhibitors. Attendees came mostly from Latin America, but there were also representatives from the U.S., Europe, Taiwan, China, and India. The driving force behind the previous conferences as well as LatinDisplay 2007 is Professor Alaide Mammana, President of the Latin American Chapter of the SID and also President of the Associação Brasileira de Informática (ABINFO), a cooperative association for R&D on displays and other fields of expertise.

Many may ask, why organize an international conference on display technology in Brazil, far away from the display industry's center of gravity in Asia? One reason is the growing deficit in the trade balance of Latin America in the field of electronic devices. Brazil has had a display-manufacturing activity for quite a long time, notably on cathode-ray-tube (CRT) displays. This manufacturing activity has recently been halted because of the declining sales of CRTs. The growth of flat-panel displays based on liquid-crystal and plasma technologies is irreversible and has already wiped out the CRT industry in the Far East, Europe, and North America. The price of LCD TVs and PDP TVs has dropped in recent years at a rate of about 25% per year, to the point where they are now also affordable for many people in Latin America. This trend will substantially contribute to the unfavorable trade balance between Latin America and the Far East on high-tech devices.

Fig. 1: SID President Larry Weber tests a student desk prototype with an innovative touch screen based on a thin film of tin oxide in the City of Serrana booth at LatinDisplay 2007.

One of the objectives of Latin Display 2007 was to address this trend and identify the initiatives needed in Latin America, notably Brazil, to deal with this economic reality.

In addition to discussing the economic aspects, the conference offered ideal opportunities to the participants to extend their network, exchange information and hardware, consider cooperation, *etc.* These latter aspects were reinforced by a small exhibition parallel to the conference. Among the exhibitors were the Campinas-based Centro de Pesquisas Renato Archer (CenPRA) and the ABINFO, Brazilian and foreign companies.

Various lectures given during the conference dealt with the dominance of LCD technology, as well as organic-light-emitting-diode (OLED) displays which have already being applied in cellular phones. Sony has just rolled out 11-in. OLED TVs. The picture quality of OLED TV is surprisingly good and many experts expect that OLEDs will be cheaper than LCDs in the future. However, that will depend largely on the economy of scale because it requires that the complete OLED production chain be in place.

Display experts from all over the world gave lectures, which provided a unique survey on the broad spectrum of display technologies. For a survey of the program, please visit the conference Web site at http://abinfo.ath.cx:8888/latindisplay2007/index.php?section=2).

The keynote address was presented by Dr. Margarida Batista of the Banco Nacional de Desenvolvimento Econômico e Social (BNDES) of Brazil, who gave an intriguing lecture on investing in Brazil: "Brazil: A Promising Place to Invest".

LatinDisplay 2007 offered ample time for brainstorming on and discussing initiatives for creating industrial display activities in Latin America, mainly Brazil. On November 12, there was a lively roundtable discussion between economists and technical experts. This was preceded by two excellent lectures, the first by Dr. Samuel Chung, until recently CTO of Kodak, on the critical success factors of the display industry, and the second by Dr. Baptista (BNDES), who explained the financial tools and the support of BNDES for starting new activities and companies. Due to an emergency, Dr. Chung could not attend the conference, but he was "on-line" via Skype, including Webcams, and the audience could interact with him directly. This was an interesting demonstration of modern communications technology.

According to Dr. Chung, one of the main characteristics of the display industry is long-term vision, which requires a long-term investment plan – this is opposite to the current impatient behavior of investors. Other factors crucial to the success of the display industry include critical mass and cooperation along the production chain. Since Brazil and other countries outside the Far East have neither a large "display mass" nor a sufficiently well-developed production chain for LCDs, PDPs, or OLEDs, the inevitable conclusion is that Brazil and these other countries need international cooperation in order to start display-manufacturing activities. On the other hand, there are plenty of opportunities for creative entrepreneurs in Latin America for special display applications, which do not depend on massive investments in LCD fabs.

An example of such an opportunity was highlighted in the lecture given by Dr. Victor Mammana, head of the display group of CenPRA, who presented a tablet used as a versatile input device for computers. This particular tablet, based on a thin layer of tin oxide on a glass plate, is a good example of a Brazilian innovation that is ready to be introduced into the market. We are used to the traditional keyboard and mouse as input devices; however, a tablet presents a more natural way for inputting drawings, graphs, and other data. Besides individual use, a tablet offers new opportunities in schools teaching basic disciplines such as arithmetic, writing, and language, as well as assisting children to develop their creativity.

At the exhibition, a new student desk prototype to support working with large-sized tablets of about $50 \times 40 cm^2$ was shown. This desk will be used by 4000 students in Serrana, a city of 40,000 in the state of São Paulo. The prototypes were built by CIATEC (Companhia de Alta Tecnologia de Campinas) of Municipal Government of Campinas, where ABINFO is located.

LatinDisplay 2007 received significant attention from the media in Brazil because of the high-tech content of the displays. Eight Brazilian TV channels broadcast pictures and interviews with organizers and participants of the conference in prime time, and various Brazilian newspapers reported on this conference.

Because of the broad scope of LatinDisplay 2007, various new business contacts were established and new opportunities for R&D were discussed and could lead to follow-up activities. This is a feather in the cap of the organizers of an interesting and stimulating conference.

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DuPont Remains Bullish on PDPs

(continued from page 3)

one of a number of cost-reduction efforts taking place throughout the PDP industry; others include the total elimination of indium tin oxide (ITO)—which has already been done in one 32-inch model from LG Electronics—and the adoption of offset printing of the bus and address rather than screen printing, a step which Samsung has taken with its P4 line. These are among the reasons that DuPont remains bullish on PDPs.

"We believe that the PDP TV market will continue to grow, at least for the next few years," Doyle added. "We think we'll get to a market of at least 30 million to 35 million panels a year because the price points will continue to come down and more consumers will opt for large panel-size TVs."

"Once [PDP manufacturers] build these plants, they don't have a lot of incentive to stop running them, particularly in a big market like this—that is why there is so much focus on cycle time," Doyle added. "They are driving down materials cost as viciously as possible so they can operate the plants at very low cost. When they are in a position in a few years to churn out plasma panels for $100 each, they will be very competitive with LCD even as LCD continues to invest and expand."

— Michael Morgenthal

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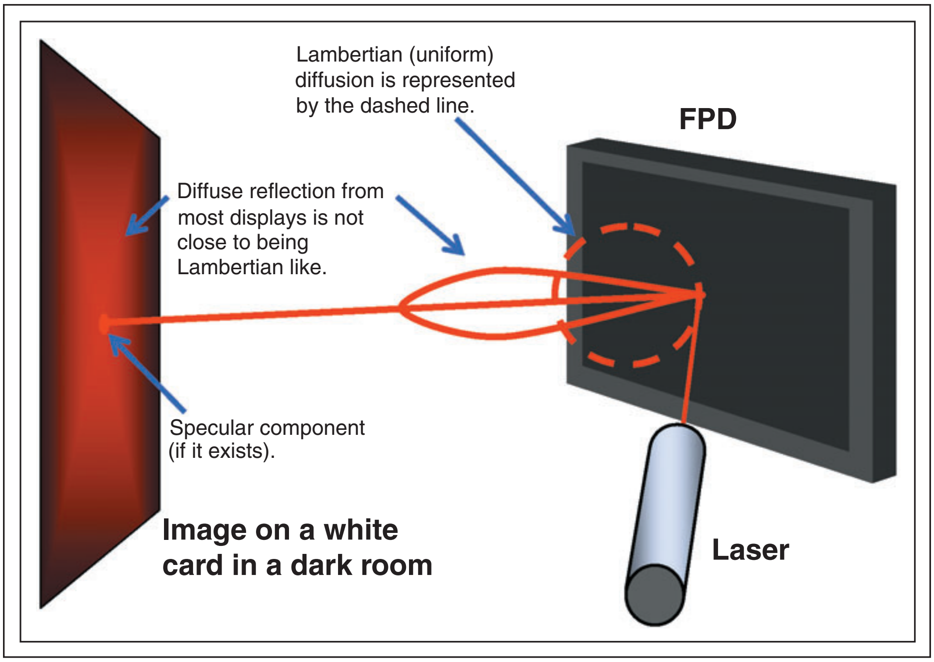

***Fig. 1:** Visualizing the planar projection of the BRDF.*

Anti-glare surfaces arise from a microstructure on the surface that scatters light away from the specular direction and produces the haze property. These anti-glare surface treatments are often made strong enough that no readily observable specular ray exists; i.e., for such a display there would be no distinct virtual image of the source visible in the display reflections – no bright dot from the laser, just a bright fuzzy ball. This is often very desirable for computer monitors so that lighting in the office does not objectionably interfere with the use of the display. However, the presence of haze makes the measurement of the reflection very difficult, and the measurement result becomes very sensitive to the geometry of the apparatus – both the detector and especially the source geometrical configuration.

How bad can it get? How far off the Lambertian assumption leads us depends upon how accurate we want to be and the geometry of the source and detector. If we want 1% results, a Lambertian assumption is not valid for almost any material under directional lighting (even the white pucks!). If we want 5%, things relax a little, but not by much. Even the white pucks deviate 5% or more from Lambertian, depending upon the direction of the illumination. What about anti-glare treatments? We should never use the Lambertian assumption! That is, when we make a Lambertian assumption, what we generally mean is that we measure a reflectance factor $R = \pi L/E$ in some source/detector geometry and then use that reflectance factor R for other different geometries. Nope, in general, we cannot do such a thing with accuracy, especially whenever haze is present and non-trivial.

How far off we will be on any of these materials depends upon the nature of the bi-directional reflectance distribution function (BRDF) of the material. The BRDF in its simplest expression is the ratio of luminance to illuminance: $B = L/E$ (kids, don't use this at home; the BRDF is usually taken with very well-defined sources and not just a light source placed at an angle). We can use these BRDFs to estimate what might happen to our measurement results if we looked at the display from the normal direction and moved a small light source off to the right as a function of angle. For Lambertian materials, the BRDF is flat. That would mean that the ratio of the luminance to illuminance is constant, independent of the angle of the source from the normal. In Fig. 2, we show a BRDF of a plasma-display panel (PDP) in blue and a liquid-crystal display (LCD) in red on a linear scale; here, the background gray of the PDP will look like dark-gray matte wall paint to

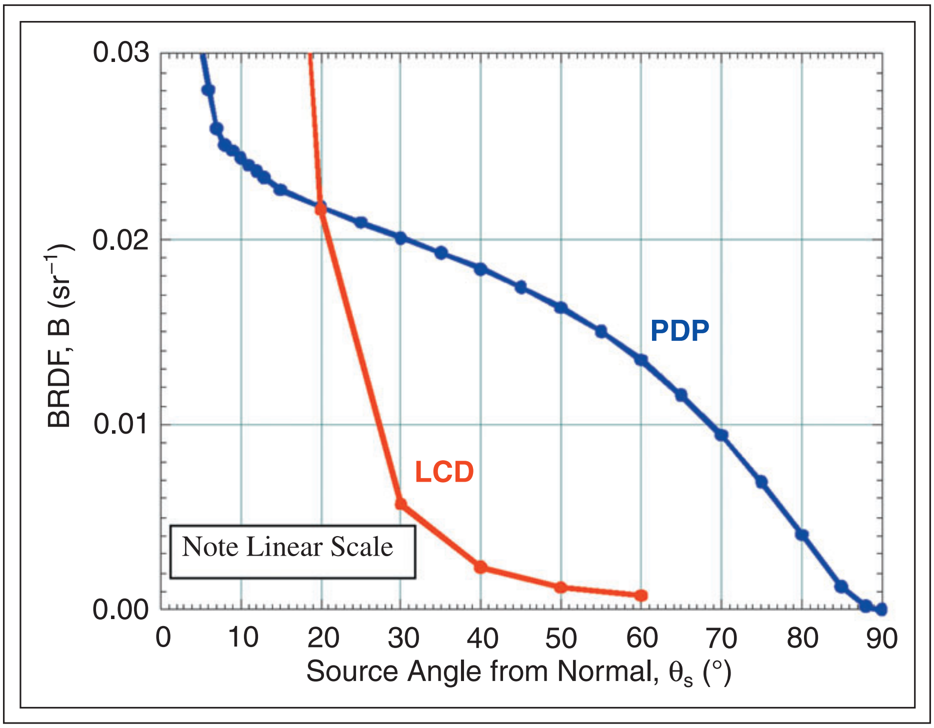

***Fig. 2:** Comparison of PDP and LCD BRDFs on a linear scale.*

our eyes. Rather than having a flat BRDF as a Lambertian material would, the PDP BRDF fall-off is approximately 2% per degree from a source angle of 20–80° and approximately 1% per degree at a source angle of 30°. To the eye, such a BRDF would appear to be flat and Lambertian, but not to our instruments.

Figure 3 shows the BRDFs of both displays on a log scale. The LCD has an anti-glare front surface with no specular component. The PDP has glass front surfaces with an anti-reflection coating (not an anti-glare microstructure) to reduce reflections. The glass produces a specular component (resembling a delta function) at a 0° source angle – the specular or mirror direction. This rendering on a log scale is approximately how the eye sees things, and the PDP appears to be very Lambertian away from the specular, but only to the eye. For the LCD, the BRDF is changing about 10% per degree or more around 30°.

How sensitive the measurement results are depends upon the geometrical configuration of the source and detector. If we apply a uniform diffuse illumination and measure the reflected luminance from off the normal by 6–10°, we will obtain a result that is very reproducible – a diffuse-reflectance measurement. The material is not Lambertian by any means, but the apparatus yields very reproducible results. The measurement result, the reflectance factor $R = \pi L/E$ (or diffuse reflectance ρ), cannot be used for other geometries of source and detector except for this uniform-diffuse-illumination source with the detector off normal from about 5–12°.

If we arrange a light source at some angle away from the normal and measure the luminance of the surface from the normal, the resulting luminance will vary considerably, depending upon the angle of the source as shown by the BRDFs above. For a PDP, if we have a source at, for example 30°, then we will obtain almost the same ratio L/E if we were to increase the diameter of the source quite a bit. Within 5% or so, the same may be true for an LCD. But if we change the angle of the source 2° toward the normal, the luminance of the PDP may measure almost the same, within 5%, but the luminance of the LCD will measure quite differently, an increase of 20% or more.

We can always write $L = \pi E/R$ for any geometry of source and detector, but that geometry must be carefully specified. However, the reflectance factor *R* (or diffuse reflectance ρ, or luminance factor ß) is only a constant for Lambertian materials, of which there are none. The reflectance factor *R* is sensitive to the geometry of the apparatus. The smaller the source, the more sensitive *R* can be to geometry in general. Because of this confusion of diffusion and Lambertian properties, some say we have "diffuse illumination" when we place a discrete source at some angle away from the normal and view the screen from the normal, and then they apply the Lambertian assumption. If the

(continued on page 50)

Reference: CIE Publication No. 17.4, International Lighting Vocabulary, Commission Internationale de l'Eclairage (International Commission on Illumination), 1987. A joint publication with the International Electrotechical Commission: IEC Publication 50(845), International Electrotechnical Vocabulary, Chapter 845: Lighting, 1987.

CIE 17.4: 845-04-45 "regular reflection; specular reflection.
Reflection in accordance with the laws of geometrical optics, without diffusion."

CIE 17.4: 845-04-44 "diffusion; scattering.
Process by which the spatial distribution of a beam of radiation is changed when it is deviated in many directions by a surface or by a medium, without change of frequency of its monochromatic components."
'Note — A distinction is made between selective diffusion and non-selective diffusion according to whether or not the diffusing properties vary with the wavelength of the incident radiation.'

CIE 17.4: 845-04-54 "perfect reflecting diffuser.
Ideal isotropic diffuser with a reflectance equal to 1."

CIE 17.4: 845-04-58 "reflectance (for incident radiation of given spectral composition, polarization and geometrical distribution) (r) unit: 1.
Ratio of the reflected radiant or luminous flux to the incident flux in the given conditions."

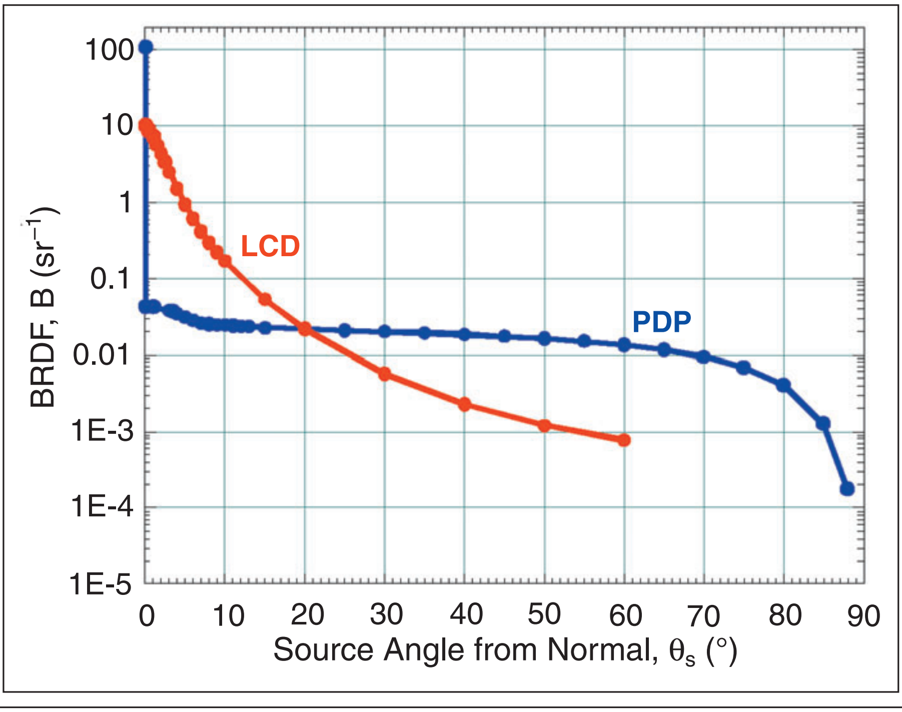

***Fig. 3**: Comparison of LCD and PDP BRDFs on a log scale.*

the business of displays

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an image sensor that can be built into these displays, to allow users to write on the displays in a way that is easy to read. We think this market holds great promise as a virtual "cash cow" if we can provide e-boards with an interactive communications function that allows meetings and conferences to be more widely shared in real time.

- A third growth engine for extra-large displays is likely to be intelligent TV. As mentioned earlier, the TV market is expected to approach saturation around 2010, but a major push for intelligent TVs will refresh the market and usher in a new LCD growth period beyond 2010. As envisioned, intelligent TV displays with large screens, high resolution, and highly stylized designs have tremendous potential to serve as the center of information flow into the home. In order for the large-TV market to experience strong continual growth, we need to have next-generation intelligent TVs with extra-large screens and ultra-crisp definition, by which I mean an extremely clear integration of 8 million pixels – this would quadruple the resolution of today's full-high-definition screens.
- The fourth market opportunity for LCD technology is what we refer to as the "art wall" display. In commercializing the concept of art walls, we will be encouraging the use of LCD-TV sets to display paintings or pictures when the sets are not being used to watch TV shows or movies. For this vision to become reality, we will need to significantly lower display power-consumption levels, while at the same time assuring that the picture presented is one of super-fine quality.

Our technology is advancing at a rate faster than at any other time in the history of displays. The progress of the most recent 5-year period may be equivalent to that of the 10 years preceding it, but it also may be equal to the pace of innovation for just a single year in the future.

There are number of theories about why the dinosaurs disappeared, yet one thing is for sure: They were ill-prepared for an enormous amount of change to their world, which simply occurred faster than they could evolve. The LCD industry is working hard to evolve faster than the market. We are committed to advancing LCD technology and LCD products from a world of predictable maturing to one of unlimited potential.

Mr. Spielberg had it right in conveying that the greatness of a past era cannot be resurrected without the structure to not only meet demand, but to allow evolution in even more wondrous ways. We must look beyond the near-term limits of the conventional and work together to ensure the potential for an astounding future for all of us. ■

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short subjects

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material were Lambertian, then the reflectance factor measured this way would be the same as the diffuse reflectance measured in an integrating sphere. A better term to describe the illumination from such an isolated source is "directed-source illumination." Such a term clearly distinguishes the illumination from a more uniform diffuse illumination. This may help avoid the historical temptation to apply Lambertian models to all light-diffusing materials.

Whenever complicated reflection properties such as haze exist with our displays, we no longer should employ the simplified equation that is used for Lambertian materials. Whereas haze is a form of diffuse reflection, it is not Lambertian. It is fine to think in terms of diffusion when considering reflection, but diffusion does not automatically mean Lambertian. ■

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editorial

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A major component of the ICDM education effort is the newly launched Wiki page located at http://wiki.sidmembers.org. This project will be similar to other Wiki efforts where anyone in the community is free to contribute and the pages will become the encyclopedia of everyone's collective knowledge, experience, and new innovations. The best innovations will undoubtedly become part of future versions of ICDM standards. In this case, the ICDM will serve as the moderators of the process, ensuring that everything added to the standard is of the highest quality and suitability for use on displays. By fostering a truly open process where everyone will benefit without regard to commercial interest, the ICDM is making a real positive impact on the display community.

Of course, this is only possible due to the dedicated efforts of the ICDM leadership including Joe Miseli, Ed Kelley, Jongseo Lee, Michael Becker, Andrew Watson, and Paul Boynton. These gentlemen deserve real encouragement and support from all of us to make the ICDM process everything that it can be. You can read much more about the ICDM in Joe Miseli's feature article in this issue of *Information Display*.

To be fair, I want to mention that the efforts of the ICDM are just a small part of the overall standards activities ongoing in the field of display measurement. Numerous standards organizations, including CIE, IEC, SMPTE, ISO, VESA, EIAJ, and others, also are making great contributions to the body of knowledge to better understand and characterize the performance of displays. There are nowhere near enough pages in 6 month's worth of *Information Display* to properly catalog all the contributions being made and all the efforts under way. That is not bad for a niche of a niche group within the displays industry.

I also want to introduce to you and personally thank Dr. Michael E. Becker for serving as our Guest Editor for this month. Michael has been a leading contributor to the field of display metrology for countless years and it has been an honor to serve with him on SID committees and learn from him in a variety of circumstances. Be sure to read Michael's guest editorial for his perspective as well as his introductions of this month's feature articles.

Stephen P. Atwood

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The above requirements for measurement methods and procedures imply that there should be as many of them available as required for carrying out the daily work in the metrology laboratory, but these days, unfortunately, there are too many applicable but unsynchronized standards providing confusion of *terms and definitions* and *measurement approaches* rather than the required clarity and assistance. This confusion is often exploited by marketeers by selecting such measurements that are yielding the "best numbers" for the product data sheet. In line with that mentality of *specsmanship* (*i.e.*, abuse of technical data to establish putative superiority of one device over another) is the measurement of contrast in a dark room, yielding (very) high numbers, especially for emissive displays, but under conditions that do not represent the actual application situation (about 99% of all display-application cases are under ambient illumination). The extension of *image formation* times according to ISO 13406-2 to transitions between different levels of gray was eagerly adopted by certain LCD and monitor manufacturers because an "improvement" by a factor of 2 was granted by the fact that ISO was using the sum of both transition periods between ON and OFF while the alternative *gray-to-gray response times* (not standardized before the introduction of ISO 9241-300) only specified one of the transition periods (usually the faster one).

The international standard ISO 13406-2 proves that a standard can actually help to advance technology and the quality of products to which most of us are exposed to for many hours every day. ISO 13406-2 for the first time introduced methods for the measurement and rating of directional variations and reflections from LCDs, and with the enclosed ergonomic rating of the physical data into performance classes it has been pushing the improvement of these features, thus making better displays available on the market.

We can now simply trace back the justification for solid display metrology also from an economical starting point: Every customer (private and corporate) deserves an unbiased, honest set of data for specification of the visual performance of an electronic-display device for a specific application (office work, video and television, home-theater, medical diagnostics, *etc.*) as a basis for purchasing decisions. The visual performance of the display is being evaluated from a set of physical data that must be obtained by significant, well-defined measurements and specified by standardized technical terms and performance characteristics.

So, if you are interested in purchasing electronic-display devices that are fulfilling your performance expectations without regrets, disappointment, or hangover, you should be interested in display metrology and the international standards that define them. You then should also be interested in knowing what the specifications mean and how relevant they are for your intended application.

In response to the question posed in the title, display metrology can be helpful in acquiring electronic displays with the visual performance adequate for a specific task at an affordable price. The articles in this issue were written with this in mind.

In his contribution "Diffuse Clarification," Edward F. Kelley, the *spiritus rector* of the FPDM2, provides a clarification of display-related terms that are often confused. This appetizer is intended to illustrate that unambiguous terminology is the basis for factual understanding and thus for the communication of technical specifications.

Carsten Dolar from the Technische Universität Dortmund (Germany) describes his numerical model for simulation of the perception of moving images displayed on LCD screens. This model is based on generalized measurement results (rules and laws expressed in mathematical formalism), and it offers the advantage of accurate control of all involved parameter values. The presented model comprises the electro-optical display together with human visual perception, and it has been developed for systematic optimization of the chain of signal transmission and processing.

Joe Miseli from Sun Microsystems introduces the International Committee for Display Metrology (ICDM)), which is currently producing a Display Measurement Standard (DMS), the updated successor to the most comprehensive reference on the "art of measuring electronic displays," the FPDM2, issued by VESA in 2001. In the Spring of 2007, the FPDM working group migrated to become the ICDM, under the auspices of SID.

The field of display metrology and its evolution during the past 30 years is described by Jurgen Laur from autronic-Melchers GmbH in his article, "Measuring and Rating Electro-Optical Display Performance," from the perspective of a long-term manufacturer of display-metrology instruments.

As guest editor of this Special Issue on Display Metrology, I sincerely hope that the contributions on display metrology stimulate your interest in the subject and provide you with useful information and some helpful clues. ■

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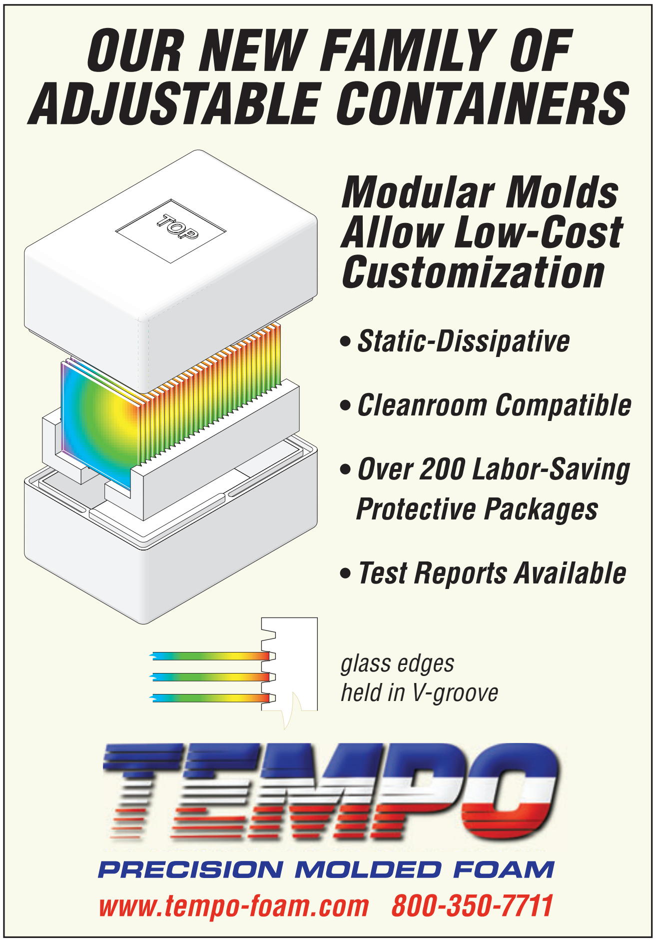
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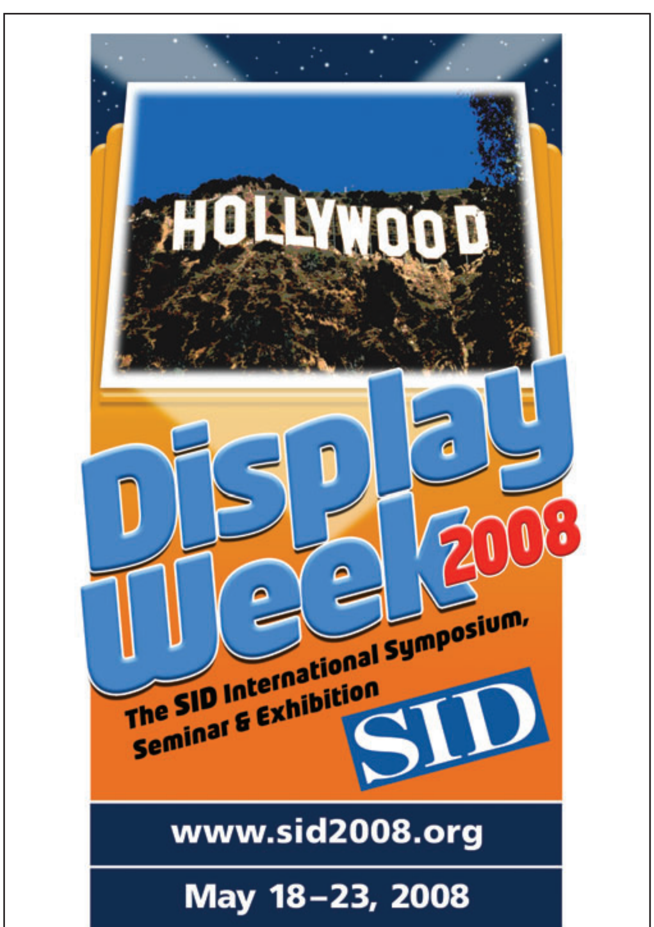
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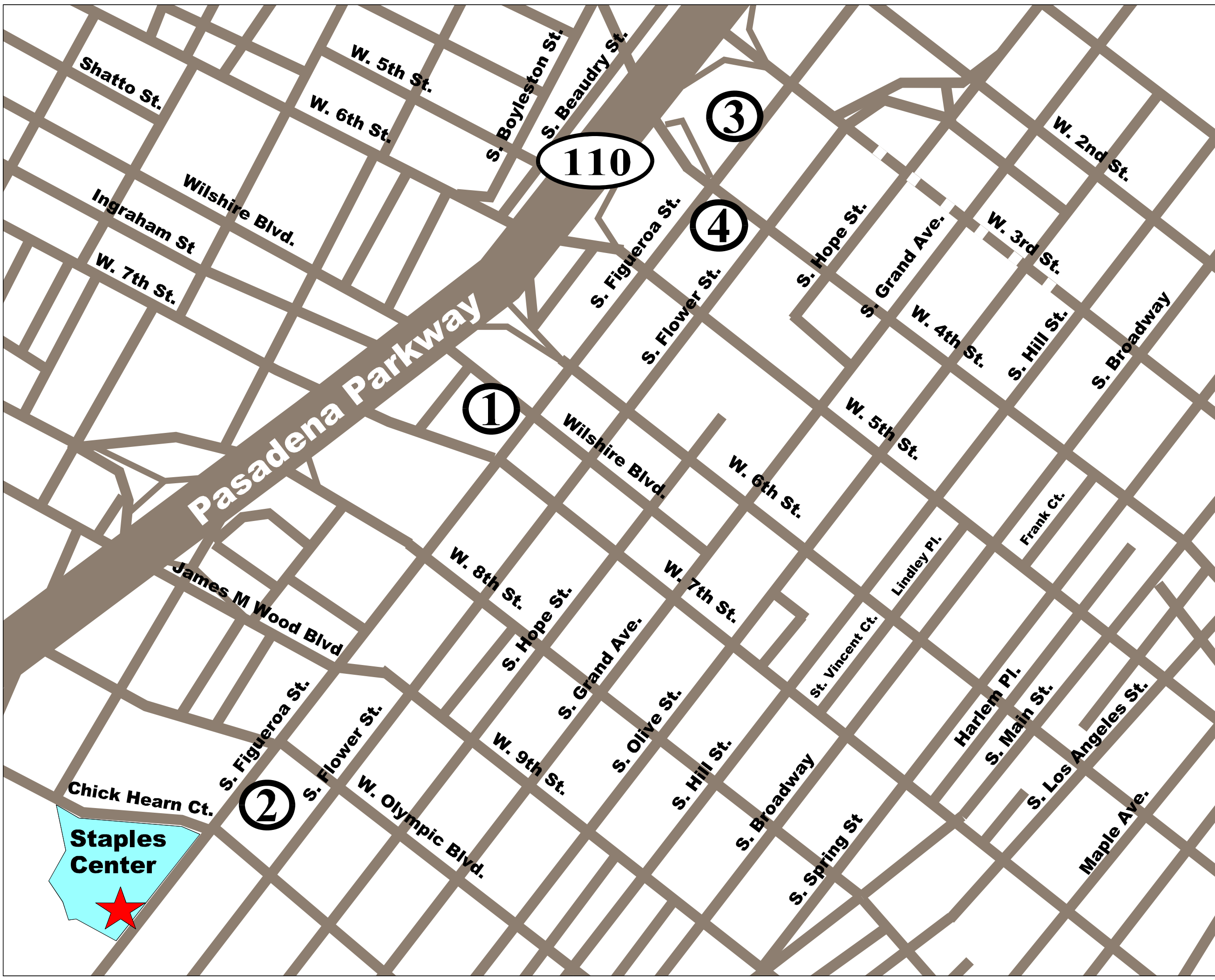

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Is spectral sensitivity a must? The PR-705 is one of the most sensitive spectroradiometers in it's class, features up to six apertures and can measure spot sizes as small as 0.02 mm.

All of our spectroradiometers can be supplied with the industry leading SpectraWin® software. SpectraWin furnishes capabilities that include luminance, chromaticity, L*a*b*, L*u*v*, CIE chromaticity, CRI, timed measurement, extensive math functions and macro programming. It can be supplied with RGB white point calibration and User Calibration functionality.

Need a fast, highly portable and inexpensive color solution? The PR-521 provides color, illuminance and luminance in near real-time (>1 second) and can easily fit in your brief case.

Want extremely high sensitivity and the ability to measure the luminance of a spot as small as 0.12 mm without special lenses? The PR-880 provides ultra low sensitivity and high dynamic range (10,000,000:1 for any aperture) and is equipped with 5 standard field apertures. The new PhotoWin® software package provides control of the PR-880 and measurement data analysis from your PC.

Is measurement automation an important criteria? Our instruments are designed to easily fit into an ATE environment by utilizing interface protocols ranging from RS232 to Bluetooth® wireless technologies.

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PROFESSIONAL INFORMATION

1. Are you professionally involved with information displays, display manufacturing equipment/materials, or display applications?

110 ☐ Yes 111 ☐ No

2. What is your principal job function? (check one)

210 ☐ General /Corporate /Financial
211 ☐ Design, Development Engineering
212 ☐ Engineering Systems (Evaluation, OC, Stds.)
213 ☐ Basic Research
214 ☐ Manufacturing /Production
215 ☐ Purchasing /Procurement
216 ☐ Marketing /Sales
217 ☐ Advertising /Public Relations
218 ☐ Consulting
219 ☐ College or University Education
220 ☐ Other *(please be specific)*

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3. What is the organization's primary end product or service? (check one)

310 ☐ Cathode-ray Tubes
311 ☐ Electroluminescent Displays
312 ☐ Field-emission Displays
313 ☐ Liquid-crystal Displays & Modules
314 ☐ Plasma Display Panels
315 ☐ Displays (Other)
316 ☐ Display Components, Hardware, Subassemblies
317 ☐ Display Manufacturing Equipment, Materials, Services
318 ☐ Printing/Reproduction/Facsimile Equipment
319 ☐ Color Services/Systems
320 ☐ Communications Systems/Equipment
321 ☐ Computer Monitors/Peripherals
322 ☐ Computers
323 ☐ Consulting Services, Technical
324 ☐ Consulting Services, Management/Marketing
325 ☐ Education
326 ☐ Industrial Controls, Systems, Equipment, Robotics
327 ☐ Medical Imaging/Electronic Equipment
328 ☐ Military/Air, Space, Ground Support/Avionics
329 ☐ Navigation & Guidance Equipment/Systems
330 ☐ Oceanography & Support Equipment
331 ☐ Office & Business Machines
332 ☐ Television Systems/Broadcast Equipment
333 ☐ Television Receivers, Consumer Electronics, Appliances
334 ☐ Test, Measurement, & Instrumentation Equipment
335 ☐ Transportation, Commercial Signage
336 ☐ Other *(please be specific)*

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4. What is your purchasing influence?

410 ☐ I make the final decision.
411 ☐ I strongly influence the final decision.
412 ☐ I specify products/services that we need.
413 ☐ I do not make purchasing decisions.

5. What is your highest degree?

510 ☐ A.A., A.S., or equivalent
511 ☐ B.A., B.S., or equivalent
512 ☐ M.A., M.S., or equivalent
513 ☐ Ph.D. or equivalent

6. What is the subject area of your highest degree?

610 ☐ Electrical/Electronics Engineering
611 ☐ Engineering, other
612 ☐ Computer/Information Science
613 ☐ Chemistry
614 ☐ Materials Science
615 ☐ Physics
616 ☐ Management/Marketing
617 ☐ Other *(please be specific)*

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7. Please check the publications that you receive personally addressed to you by mail (check all that apply):

710 ☐ *EE Times*
711 ☐ *Electronic Design News*
712 ☐ *Solid State Technology*
713 ☐ *Laser Focus World*
714 ☐ *IEEE Spectrum*

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