SID 2011 PREVIEW/HONORS AND AWARDS ISSUE

# Information DISPLAY

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SOCIETY FOR INFORMATION DISPLAY

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April 2011
Vol. 27, No. 4

## SID Honors Its Best and Brightest


**Plus**

Going Wireless

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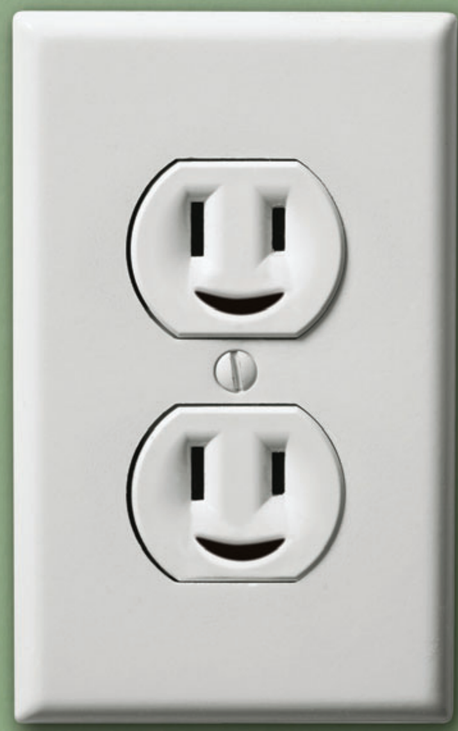
*Journal of the SID* April Contents



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APRIL 2011
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***ON THE COVER:*** *This year's winners, announced in the article beginning on page 6, will be honored during the annual Awards Banquet to be held on the Monday evening prior to the Symposium. Tickets for this event are available in advance only by registering at www.sid2011.org.*


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# editorial

## A Warning from Sendai for Displays

**Stephen Atwood**

The effects of the recent earthquake and tsunami in the northeast region of Japan continue to draw the world's attention as stories emerge about the full impact not only on the people but on the display, electronics, and technology industries as a whole. We have all seen the aftermath of earthquakes and some of you may even have experienced a major earthquake firsthand. Recently, there have been three earthquake events that formed permanent memories for me. The first two were in California (Loma Prieta, 1989, near San Francisco) and (Northridge 1994, near Los Angeles). Both those quakes caused major disruptions of infrastructure and commerce as well as loss of life. Many of us remember the 1989 San Francisco event because it happened during the baseball World Series game, but the memory that is more vivid for me was the footage of the collapse of sections of the double-deck Interstate 880 highway. To this day, I fear driving on the lower level of bridges.

Besides the immediate upheavals, both of these events in California caused major commercial disruptions for long periods of time and certainly affected supply chains for many businesses. Consequently, they brought about more frequent discussions of "disaster planning," in which suppliers provide their customers with plans for how they will recover from events like these and still provide the required components and services. Making such planning trickier, modern manufacturing plants use processes that are designed to require the smallest possible amount of extra inventory. This makes regular on-time delivery of components critical to the plant's operation. Even one missed day of deliveries due to an earthquake or other disruptive event can shut down the lines and cause a significant economic hardship up and down the chain, making the risk far too great to ignore.

The other earthquake that is unforgettable is the 1995 Great Hanshin Quake in southwestern Japan near Kobe. There as well we saw an extraordinary disruption of infrastructure and commerce, but in this case a much larger loss of life than in the two California events. The images from Japan were terrifying – people being rescued from under the rubble and the devastating collapse of highways and buildings. (Still further reason for my fear of driving on bridges.) At that time I had colleagues traveling in Japan who were missing for several hours but later were located unharmed. I had just made trips to Japan myself for business and had been in Kobe earlier that year. It was painful to see all the damage and destruction. And, my business was materially impacted because afterwards we could not get some critical electrical components and neither could many of our customers, so we experienced a double hit both in lost production days and in cancellation of orders. I'm sure other companies experienced much greater impacts than we did, but it galvanized my recognition of the fragility of the economic food chain.

However, none of these memories, nor my ability to understand the science of geology, nor even my appreciation of other recent events (such as the tsunami in the Pacific Ocean in 2009), prepared me to expect what happened in Japan on March 11, 2011. The remarkable combination of a 9.0-scale earthquake that lasted literally minutes, and a subsequent tsunami that swept the low-lying region around Sendai, has shown me that I did not appreciate the full scope of what could happen, in terms of both human and commercial catastrophe.

*(continued on page 42)*

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## Samsung Electronics Begins Mass Production of Transparent LCD Panel

Samsung Electronics Co., Ltd., began mass production of a 22-in. transparent LCD panel in March of this year, claiming it is the first company to do so. (Samsung showed a 46-in. transparent LCD prototype at Display Week in Seattle last year.) The panels do not have a mirror or other type of reflective material behind the LCD. Users can look right through them. For illumination, the panels use ambient light such as sunlight, which consequently reduces dependency on electricity for generating power. According to Samsung, the panels consume 90% less electricity compared to conventional LCD panels using backlight units. According to Bill Beaton, Senior Manager, TV/DID, Samsung LCD Business, "In most applications where sufficient ambient light is available, no backlight or additional lighting is required. When the ambient lighting is not sufficient, external lighting could be added to light the display."

Obviously, transparent LCDs are not for laptops or workstations. "What is special about them," says Jennifer Colegrove, a vice president with DisplaySearch, "is that they offer a new kind of functionality. They can be used for retail sales and advertising – in shop windows, for example. They are definitely "attention-getting" (Fig. 1). A watch or other object, for example, can be placed behind the display, and information about the watch overlaid on the display in front of the object. Samsung also suggests that corporations and schools could use the panels as interactive communication devices of some kind. Museum exhibits are another possibility.


*Fig. 1: Samsung's transparent LCD panel will allow retailers to place changing text and graphics in front of physical merchandise, such as these portable display devices.*

The new panels come in two varieties, black-and-white or color. They have a contrast ratio of 500:1 with a WSXGA+ resolution of 1680 × 1050). Compared with conventional LCD panels that use a backlight unit (BLU) and have 5% transparency, Samsung's transparent LCD panel have transparency rates of over 20% for the black-and-white model and over 15% for the color model. They also incorporate the High Definition Multimedia Interface (HDMI) and the Universal Serial Bus (USB) interface.

*– Jenny Donelan*


THE DISPLAYS GET REAL

# 2011 SID Honors and Awards

*This year's winners of the Society for Information Display's Honors and Awards include Dr. Rudolf Eidenschink, who will receive the Karl Ferdinand Braun Prize for his invention and development of low-birefringence, fast-responding, and highly stable phenyl-cyclohexane (PCH) and bi-cyclohexane (CCH) liquid-crystal families; Dr. Hideo Hosono, who will be awarded the Jan Rajchman Prize for his invention and development of high-performance transparent thin-film amorphous oxide semiconductors with large electron mobility; Scott Daly, who will receive the Otto Schade Prize for his many contributions to the enhancement of image quality and display performance; and Dr. Shin-Tson Wu, who will be awarded the Slottow-Owaki Prize in recognition of his exceptional contributions to the education and training of graduate students and professionals in the field of flat-panel displays.*

by Jenny Donelan

SERENDIPITY has played a part in the careers of many of the individuals honored by the Society for Information Display this year. One scientist whose research would eventually contribute to the commercial success of LCDs encountered liquid crystals by chance in one of his first jobs. At the time, LCs were considered non-essential and non-viable for business purposes. Another young researcher awoke to the possibilities of his future field on hearing an industry pioneer describe amorphous semiconductors. Yet another honoree was lucky enough to be born in a time when he could merge his interests in art and science into new discoveries about visual perception. And a lab researcher with no prior teaching experience discovered that he had a gift for inspiring students to do great work

So, it is true that all this year's winners were lucky in being at the right place at the right time, but it is also true that they made their own luck. They kept their eyes open and stayed receptive to new ways of doing things. As Jan Rajchtman prizewinner Dr. Hideo Honsono puts it, although it is valuable to contribute to the improvement of existing technology, "It is revolutionary materials that open new frontiers." We owe this year's honors and awards recipients a debt of gratitude for their farsightedness and their willingness to recognize the possibility in new, as-yet-untested technologies.

This year's winners will be honored by the Society for Information Display during Display Week 2011 at the annual awards banquet to be held on Monday evening, May 16, prior to the Symposium. Tickets for this event are available in advance only by registering at www.sid2011.org.

## Karl Ferdinand Braun Prize

This award is presented for an outstanding technical achievement in, or contribution to, display technology.

***Dr. Rudolf Eidenschink***, SID Fellow and Founder and President of Nematel, has received the Karl Ferdinand Braun Prize *"for his invention and development of low-birefringence, fast-responding, and highly stable phenyl-cyclohexane (PCH) and bi-cyclohexane (CCH) liquid-crystal families, enabling the advancement of thin-film-transistor liquid-crystal displays (TFT-LCDs)."*

Dr. Eidenschink spent many years at Merck Darmstadt, where he did most of his pioneering work as a key liquid-crystal research chemist in the synthesis of PCH and CCH liquid crystals.

"Dr. Rudolf Eidenschink is one of the most outstanding pioneers in the field of liquid-crystal material research and development," according to Dr. Haruyoshi Takatsu, company Fellow of DIC Corporation. "The phenyl cyclohexane liquid crystals (PCHs) Dr. Eidenschink invented in 1977 showed a new concept of liquid crystals linking directly between a benzene and a cyclohexane ring, and extended the applications of LCDs due to the high stability and excellent properties."

At the age of 16, Eidenschink was working as an apprentice in a large chemical factory when he began to notice the work that engineers were doing to make chemical reactions occur on a large scale. This kind of work

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*Dr. Rudolf Eidenschink*

impressed him, and he continued in the field of chemistry, working at AEG and earning a doctorate in organic chemistry at the University of Münster. He was also granted a postdoctoral fellowship at the University of Sussex in England. Upon his return to Germany, Eidenschink joined the liquid-crystal research department of the chemical company Merck KGaA.

"At the time," says Eidenschink, "knowledge of the liquid-crystal state was not very great in chemistry." In fact, liquid crystals – "fluessige Kristalle" in German – were often referred to as "ueberfluessige Kristalle" (superfluous crystals) because of their lack of relevance to profitable business models. However, notes Eidenschink, "having seen the first pocket calculator with a TN cell, it was clear to me that this was the beginning of a never-ending story. There was no technique to compete with it in terms of low energy consumption and use of space. [Liquid-crystal] TV screens, however, were dismissed as science fiction."

In his career at Merck and later on, Eidenschink was responsible for or involved in more than 60 journal articles and approximately 120 patents. In 1987, he founded his own research and development company, Nematel, Inc., in Mainz. He notes that the display industry represents an "exciting overlap" of different fields of knowledge. It is an industry that keeps you young, he says, "because you are steadily being reexamined in physics, engineering, and chemistry."

## Jan Rajchman Prize

This award is presented for an outstanding scientific or technical achievement in, or contribution to, research on flat-panel displays.

***Dr. Hideo Hosono***, a professor at the Tokyo Institute of Technology, has received the Jan Rajchman Prize *"for his invention and development of high-performance transparent thin-film amorphous oxide semiconductors with large electron mobility, especially InGaZnOx, for use in active-matrix-addressed displays."*

A backplane TFT array is the central building block of active displays. To date, amorphous hydrogenated Si (a-Si:H), which was invented by Spear and LeComber in 1975, has been widely used as the channel layer of TFTs for active-matrix LCDs. However, because the mobility in a-Si:H is low, this technology is not as suitable for active-matrix OLED displays as it is for AMLCDs. The next generation of LCDs, with larger dimensions and frame frequencies of 240 or 480 Hz for 3-D displays, also demands new backplane TFT technology with higher mobility. In addition, future flexible display technologies will demand TFTs that can be fabricated by a low-temperature process.

Dr. Hosono's research efforts have resulted in creating technology that may answer the above challenges. He has invented a new class of semiconductor, transparent amorphous oxide semiconductors (TAOS), which meet the above requirements of high mobility and easy formation at low temperature through conventional sputtering methods.

According to Hideya Kumomi, "Prof. Hosono's invention with the first demonstration of high-performance amorphous In-Ga-Zn-O TFTs in 2004 opened up a new field of transparent amorphous oxide semiconductor (TAOS) TFTs, based on a theoretical hypothesis he established in 1996. Today, TAOS TFTs occupy the majority of technical meeting and journal papers for TFTs and displays and are regarded as the most promising backplane technology for the next-generation of active-matrix flat-panel displays (FPDs). Such a revolution has come not only through Professor Hosono's pioneering work or the inherent excellent characteristics of TAOS, but from his continuous contributions to rapid progress in TAOS TFT technology." Such contributions include publishing many papers that clarify fundamental scientific issues with regard to the electrical and structural properties of TAOS and presenting information

*Dr. Hideo Hosono*

about these results in both academic and industrial settings. "We may expect commercialization of TAOS TFT-based FPDs soon," says Kumomi.

Hosono first became interested in his field as a graduate student when he heard a talk by Dr. Kazunobu Tanaka about amorphous semiconductors. Until that time, he says, he had not considered that amorphous material such as glass had anything to do with semiconductors, but Tanaka's original approach and enthusiasm impressed him. Ten years then passed before Hosono began to focus on ionic semiconductors. At the time, "almost no cultivation of iconic semiconductors such as oxides had been performed," he says. He developed a material design to realize a TAOS with high electron mobility and presented a paper on it at the 16th International Conference on Amorphous Semiconductors (ICAS) held in Kobe, Japan, in 1995. Interest in a-Si was so high at the time, he remarks, that his paper was the only one on amorphous oxide. Nine years later, interest in TAOS had grown to the point where a review paper Hosono had written on it was chosen as a plenary lecture at that year's ICAS. Hosano began that talk by saying, "This is a kind of revenge for ICAS 16."

He advises those entering the field of research to be alert for novel concepts in materials. Incremental improvements of existing technology are indispensable for industrial applications, he explains, but eventually reach their limit. "It is revolutionary materials that open new frontiers."

# SID's best and brightest

Dr. Hosono received his Ph.D. in applied chemistry from Tokyo Metropolitan University in 1982 and became a professor of Tokyo Institute of Technology in 1999.

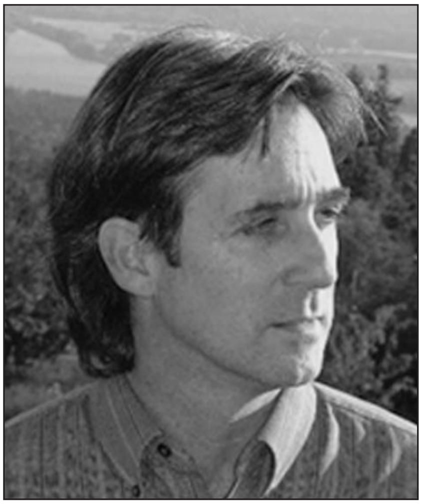
**Otto Schade Prize**

The Otto Schade Prize is awarded for an outstanding scientific or technical achievement in, or contribution to, the advancement of functional performance and/or image quality of information displays.

***Scott Daly*,** a Senior Member, Engineering and Color Science, with Dolby Laboratories, is receiving the Otto Schade Prize *"for his many contributions to the enhancement of image quality and display performance, including the development of image/video/display algorithms incorporating advanced models of the human visual system and methods for visualizing maps of visible image distortions."*

Daly's career over the past 25+ years represents a unique mix of science and art. In addition to degrees in electrical engineering and bioengineering, "I've been interacting with imagery ever since I could pick up a pencil," says Daly. Early experiences working in stage lighting were followed by work in photography, electronic art, and television displays – all of which fed a lifelong interest in visual perception.

Today, Daly is most often cited for his work on a model developed for determining the perceptibility of image distortions (what artifacts and distortions were likely to occur) as well as the visualization of those distortions in a map known as the VDP (Visible Differences Predictor). The VDP combined knowledge of spatial channels, transducer functions, and contrast masking to provide a practical model of the visibility of artifacts in images. An extension of this work, the HDR-VDP (High Dynamic Range Visible Differences Predictor), which was developed with Max Planck Institute researchers, has become a



*Scott Daly*

## 2011 SID Fellow Awards

The grade of fellow is conferred annually upon SID members of outstanding qualifications and experience as scientists or engineers whose significant contributions to the field of information display have been widely recognized.

***Julie J. Brown***, *"For her many contributions to the OLED display industry, including the pioneering development of high-efficiency phosphorescent OLEDs, and for technical leadership in commercializing the technology."* Dr. Brown is Senior Vice President and Chief Technical Officer at Universal Display Corp. (UDC). She received her Ph.D. in electrical engineering/electrophysics at the University of Southern California.

***In-Jae Chung***, *"for his contributions to advanced technology for the TFT-LCD flat-panel-display industry, including copper bus lines, low-mask-count TFT-array processes, and in-plane-switching (IPS) displays."* He is the Chief Innovation Officer at LG Display Co., Ltd.. He received his Ph.D. in electronic engineering from the University of South Australia.

***Yoichi Sato***, *"For his major contributions to the development of advanced PDP technologies, including T-shaped electrodes, waffle ribs, the CLEAR driving method, high-Xe-content gas, and cathode electroluminescence (CEL)."* Mr. Sato is the Director of the PDP Development Center at Panasonic Plasma Display Co., Ltd., and President of the Advanced PDP Development Center Corporation. He received his B.E. degree in electronic engineering from Tohoku University.

***Sung Tae Shin***, *"For his invention and development of high-transmittance vertical-alignment LCDs, invention of biaxial nematic LCDs, and development of blue-phase LCDs."* Dr. Shin is a Senior Vice President for the LCD Business unit of Samsung Electronics. He earned his Ph.D. in physics at Kent State University.

***Xiao Wei Sun***, *"For his many contributions to the science and technology of applying ZnO in flat-panel displays, organic light-emitting diodes, and liquid-crystal technologies."* He is a professor with the Division of Microelectronics in the School of Electrical and Electronic Engineering at Nanyang Technological University. He received his Ph.D. in photonics from Tianjin University and a second Ph.D. in electrical and electronic engineering from the Hong Kong University of Science and Technology.

commonly downloaded tool for quality analysis and image-quality benchmarking.

His main focus has been in developing algorithms based on human-vision models for applications within display and imaging system products. Some of these include display-adaptive tone-mapping, field-of-view expansion via display vibration compensation, skin-cognizant color processing, and many more. He holds more than 50 patents and has received a number of awards, including an Emmy in 1990 for helping develop the Kodak Video Transceiver used in the coverage of the Tiananmen Square protests.

Says SID Fellow Louis Silverstein, "Otto Schade made many fundamental contributions to optics, image science, and imaging technology. But perhaps his greatest contributions were the recognition of the nexus between image science and vision science and the remarkable work that modeled and included the human visual system as an integral component of the imaging chain. Clearly, throughout his career Scott Daly has followed closely in the footsteps of Otto Schade while refining and expanding the creative vision which Otto Schade brought to the sciences of imaging and optics."

Daly's technical career began at Photo Electronic Corporation. He then moved to Eastman Kodak, where he worked in the areas of image compression, image-fidelity models, and image watermarking; then to Sharp Laboratories of America, where he was a Research Fellow and a Group Leader for the Display Algorithms and Visual Optimization Group. He joined Dolby Laboratories in 2010, where he now focuses on overall fundamental perceptual issues and on applications whose aim is to preserve artistic intent throughout the entire video path.

## 2011 SID Special Recognition Awards

Presented to members of the technical, scientific, and business community (not necessarily SID members) for distinguished and valued contributions to the information-display field.

***Hyun Chul Choi***, *"For his significant contributions to the commercialization of large in-plane-switching (IPS) panels for TVs and monitors, including the development of a high-performance 9.7-in. XGA IPS panel."* Dr. Choi is a Vice President with LG Display Co., Ltd. He received his Ph.D. in chemistry from KAIST (Korea Advanced Institute of Science and Technology).

***Tieer Gu***, *"For his contributions to TFT-LCDs, particularly high-aperture-ratio panel design and processes, and for his successful start-up and management of an independent TFT-LCD company in China."* Dr. Gu is Chief Operating Officer of Tianma Micro-Electronics Co., Ltd. He received his Ph.D. in electrical engineering from Pennsylvania State University.

***Takahiro Ishinabe***, *"For his outstanding contributions to research on advanced LCD technologies, including single-polarizer reflective LCDs, in-plane-switching (IPS) LCDs, and fast-switching optically compensated-bend (OCB) LCDs for field-sequential displays."* He is a professor in the Department of Electronics, Graduate School of Engineering, at Tohoku University. He received his Ph.D. in electronic engineering from Tohoku University.

***Kyeong Hyeon Kim***, *"For his development and commercialization of patterned vertical-alignment (PVA) and super-PVA (SPVA) LCDs."* Dr. Kim is Vice President at Samsung Electronics. He has a Ph.D. in material engineering for liquid crystals from the Tokyo Institute of Technology.

***Oh-Kyong Kwon***, *"For his leading contributions to the research and development of driving methods and circuits for flat-panel displays, including charge-sharing circuits, shared-column line driving, and compensation circuits for active-matrix OLED panels."* Dr. Kwon is provost of the College of Engineering at Hanyang University. He earned his Ph.D. in electrical engineering from Stanford University.

***Ravilisetty Padmanabha Rao***, *"For his leading contributions to research on and development of phosphors, related materials, and deposition processes for flat-panel displays and solid-state lighting."* Dr. Rao is a senior member with Xicato. He received his Ph.D. in materials science from the Indian Institute of Technology.

***Jun Someya***, *"For his contributions to the development and promotion of moving-picture response time (MPRT) as a standard for the measurement of motion blur in TFT-LCDs."* Dr. Someya is Senior Manager of the Imaging I/O Technology Department, Advanced Technology R&D Center, at Mitsubishi Electric Corp. He received his Ph.D. in electrical engineering from Shizuoka University.

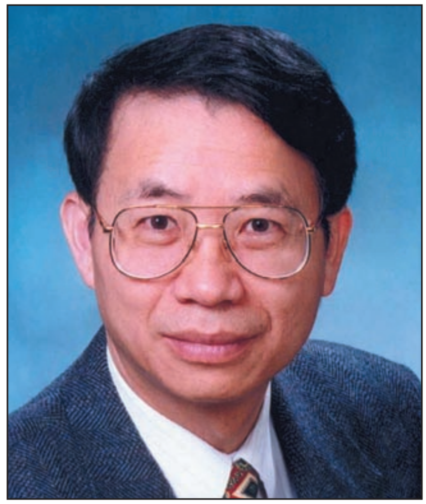
When asked about the challenges still facing today's display researchers, Daly first cited realism. "People are still not fooled by displays," he says. "They do not confuse them with reality." He also mentions the need for greater immersiveness (through haptics or touch) and convenience with regard to factors such as readability in both sunlight and dark environments. He is particularly excited about future-oriented vision-display interdisciplinary work incorporating displays in contact lenses as well as new developments in visual prostheses. Such technology could eventually lead to a retinal prosthesis that would enable the ultimate perceptual shift – allowing blind people to see.

### Slottow-Owaki Prize

The Slottow-Owaki Prize is awarded for outstanding contributions to the education and training of students and professionals in the field of information display.

***Dr. Shin-Tson Wu***, SID Fellow and professor for the College of Optics and Photonics at the University of Central Florida, is receiving the Slottow-Owaki Prize *"in recognition of his exceptional contributions to the education and training of graduate students and professionals in the field of flat-panel displays."*

If students' achievements are an indication of a professor's success, then Dr. Shin-Tson Wu has by all measures been extraordinarily successful. In the last 7 years, his students have won more than 20 major honors, including SID Distinguished Student Paper Awards, Otto Lehmann Awards, and numerous SPIE educational scholarships. Since coming to the University of Central Florida in 2001, Wu has supervised 21 Ph.D. students, two master's students, 17 post-docs, and hosted approximately 15 visiting students and scholars. Each of his Ph.D. students publishes an average of 15 journal papers before graduating in 4–5 years' time. In 2010, Wu received the University of Central Florida's most distinguished faculty award, the title of Pegasus Professor, which recognizes extraordinary contributions to the university community through teaching, research, and service.



*Dr. Shin-Tson Wu*

Citing the number of students who have received honors under Wu's mentorship, Linghui Rao, President of the University's SID Student Chapter, says, "The competition for these awards is fierce. Professor Wu seems to have the magic power to turn an ordinary student into extraordinary." But awards do not tell the whole story. "Professor Wu equips us to be future display leaders," continues Rao. "He motivates us by telling us about his life experiences in both industry and academia." Many past students wrote SID about the extra steps that Wu took on their behalf, including Yi-Hsin Lin, now an Assistant Professor at National Chiao Tung University. "I still remember him telling me: 'Finding a good problem makes the difference between a good scientist and a bad scientist.' He trained me to think like a scientist and identify challenging problems. When the experimental results were not as expected, he encouraged me not to give up but to try different approaches. And when I faced difficulties in my research, he was always there to help."

Wu actually had little pedagogical training when he came to UCF. He had worked for Hughes Research Labs for 18 years, where he had gained a great deal of knowledge of liquid crystals in addition to his background in infrared lasers (his Ph.D. from the University of Southern California was on non-linear optics). "Since I came from an industrial research lab," says Wu," I did not know how to be a professor in the beginning. But I loved my students as my own children because they were about the same age as my daughter and son. It is love which shortens our gaps." As time went on, he also learned how to motivate his students. "I always challenge them to become a 'better you,' " he says. "I often assign the most difficult problems to first-year graduate students because they are fearless and they have fresh ideas. I also set monetary awards ($100–$500) to motivate students to solve challenging problems."

For those in the business of working with students or teams of any kind, Wu has these words to offer: "A team approach consisting of faculty, post-docs, and young graduate students is powerful. White hairs are symbols of wisdom, but students are dynamic and energetic. There is a Chinese proverb that says: three ordinary persons can together perform better than one extraordinary guy." ■

**The Society for Information Display is indebted to the following companies, who each donated $2000 to sponsor a prize:**

**Braun Prize**
AU Optronics Corp.

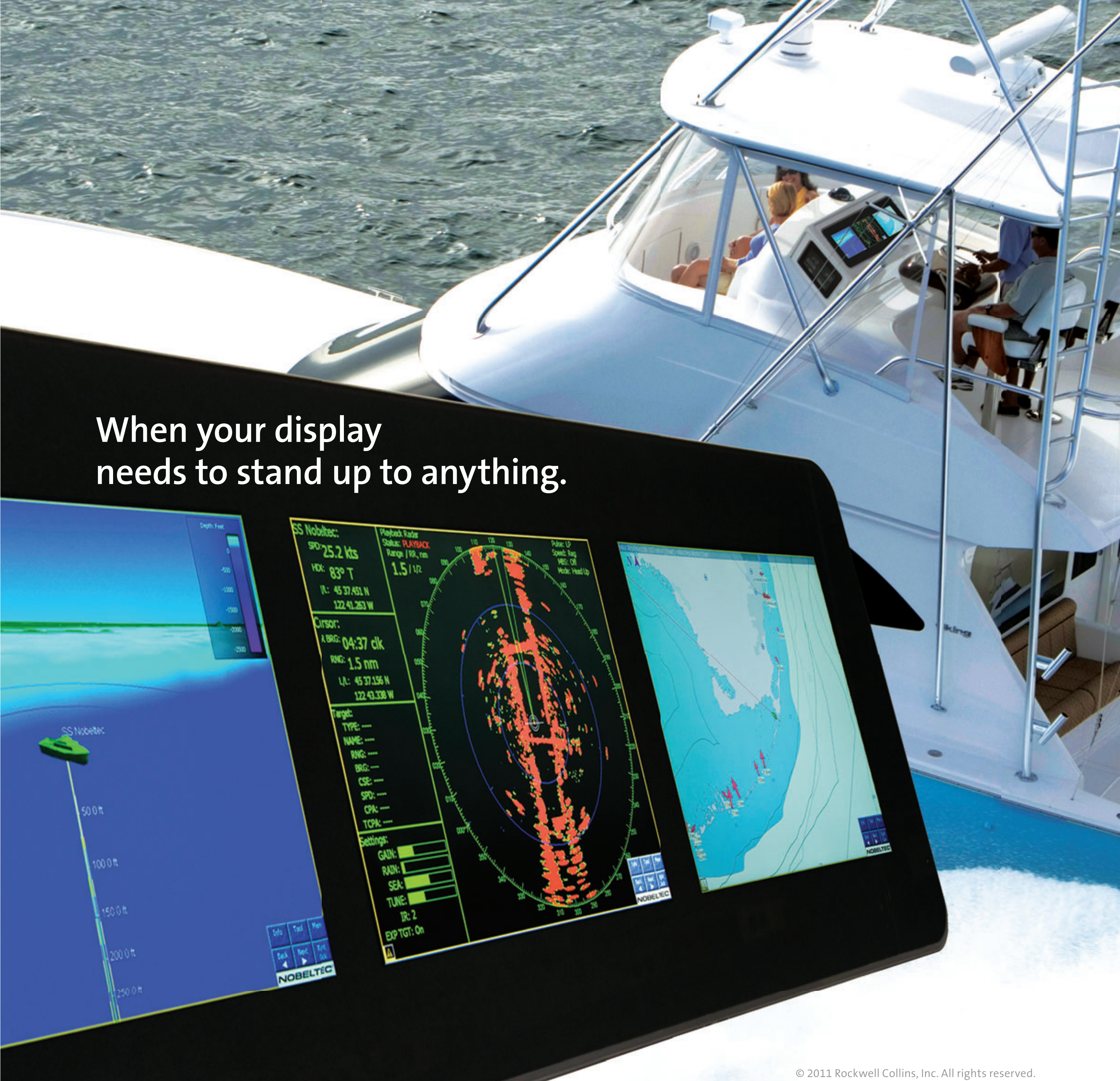
**Rajchman Prize**
Sharp Corp.

**Otto Schade Prize**
Samsung Mobile Display

**Slottow-Owaki Prize**
Fujitsu, Ltd., and Dr. Tsutae Shinoda

The 2011 award winners will be honored at the SID Honors & Awards Banquet, which will take place Monday evening, May 16, 2011, during Display Week at the JT Marriott. Tickets cost $50 and must be purchased in advance – tickets will not be available on-site.

Visit **www.sid2011.org** for more information.



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# Symposium Preview

*Plan your visit to Display Week 2011 with an advance look at some of the most exciting developments that will be revealed in this year's display-technology sessions.*

by Jenny Donelan

THE PAPERS that will be presented at the Society for Information Display's annual Symposium at Display Week 2011 in Los Angeles, California, May 17–20, represent cutting-edge research, ingenious manufacturing ideas, and brilliant solutions to ongoing design problems. The Symposium is an unparalleled opportunity to learn what researchers have just learned themselves and to share knowledge and information with the rest of the international electronic-display community.

"At this very moment, the display industry is experiencing a drastic technological transition, primarily driven by mobile-display requirements for superior image quality, ultra-high resolution, and a touch interface. Many SID 2011 technical symposium presentations will cover the exciting advancements in this space," says Display Week 2011 Program Chair John Zhong.

The following is a list of session highlights by subcommittee, which includes active-matrix devices, applications, applied vision, display electronics, display manufacturing, display measurement, display systems, emissive displays, flexible displays, liquid-crystal technology, OLEDs, projection, and touch and interactivity. In addition to these session topics, the Society for Information Display has also designated special topics of interest for Display Week 2011. These are green technology, 3-D, and solid-state lighting.

Whatever you do, be sure to catch some of these sessions at Display Week. The Technical Symposium is the heart of SID's annual event, where everyone gets to share and learn about the amazing discoveries and advances made in our industry during the past year. See you in Los Angeles!

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### Active-Matrix Devices: Oxide Conductors Keep Gaining Ground

Two years ago, the idea of oxide semiconductors replacing silicon semiconductors was a novel one. Last year, the idea had clearly gained traction, with several active-matrix papers dedicated to the subject. In 2011, two of the seven active-matrix sessions, Oxide TFTs I and Oxide TFTs II, consisting of a total of nine papers, are devoted solely to this technology. Among the highlights in oxide-TFT presentations is the distinguished paper, "Novel Self-Aligned Top-Gate Oxide TFT for AMOLED Display," by Narihiro Morosawa from Sony Corp., which describes how a 9.9-in.-diagonal qHD AMOLED display could serve as a large-sized and ultra-high-definition OLED for mass production. Other papers of interest in this area include "Metal-Oxide TFT with High Performance and Operation Stability," by Gang Yu of CBRITE, Inc., and "An Ambipolar Oxide TFT," by Hideo Hosono of the Tokyo Institute of Technology. (Note: Dr. Hosono is being honored with SID's 2011 Jan Rajchman Prize for outstanding achievements in flat-panel displays.)

Other active-matrix sessions include Mobile Display Technology, AMOLEDs and AMLCDs, AMOLED Driving, 3-D TV: OLED, and Low-Power Active-Matrix Alternatives. One paper of note in the mobile space is "Turning Points in Mobile-Display Development," by Hiroyuki Ohshima from Chimei Innlux Corp., which examines how recent shifts to larger sizes, higher resolutions (>300 ppi), wider viewing angles, higher contrast, and integration with touch functionality have all caused major changes in mobile-display architecture and technology.

### Applications: Near-to-Eye and Head-Worn Displays Evolve

The Applications area is a bit of a "grab bag," as subcommittee chair Jyrki Kimmel puts it, but this diversity is one reason why these presentations are so stimulating. The technologies range from holographic displays to head-worn displays to a zoomable LED spotlight. The other exciting aspect of applications, the common thread that pulls them all together, is that they represent a real-world use or a product-based manifestation of a technology that has usually spent many years at the research stage. One such example from these sessions is "Quantum-Dot LEDs for Near-to-Eye and Direct-View Display Applications," by Seth Coe-Sullivan from QD Vision, Inc. This paper reports on the development of actual working prototypes with QLEDs for near-to-eye and direct-view display applications. As the author remarks in his introduction of the invited paper, "…while most [quantum-dot] literature reports focus on the performance of individual test pixels, examples of working display prototypes have been sorely lacking."

Another invited paper from this year's Near-to-Eye and Head-Worn Display Applications session is "Image-Source



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Evaluation and Selection for Rugged Near-to-Eye Displays," by James Melzer of Rockwell-Collins Optronics, which discusses the special and more stringent requirements for near-to-eye or head-mounted displays worn by soldiers, firefighters, or other first responders who work in extreme conditions. Far-ranging papers of note from other sessions include "Creative Integration of Micro-Tiles in Tiled Display Applications," by Delia Zsivanov of Christie Digital, Inc., and "A 360° Panoramic Stereoscopic Projection System for Using a Single Projector and a Related 3D Panoramic Camera System," by David Montgomery from Sharp Laboratories of Europe.


*The Los Angeles Convention Center is the site of Display Week 2011.*

## Applied Vision: Adding the Human Factor to Displays

Of the five senses, vision obviously relates most closely to displays. Human perception of display imagery, including color, luminance, *etc.*, key to the success or failure of any display application, yet agreed-upon standards for such perceptions are still the subject of research. One paper that tackles this issue is the invited, "The Effect of Surround on Color and Image Appearance," by Ronnier Luo from the University of Leeds. Luo's research seeks to provide definitions for "surround" and examines how changes in surrounding conditions can affect perceptions of color and image appearance in displays. The distinguished paper, "Appropriate Luminance of LCD-TV Screens under Actual Viewing Conditions at Home," by Tatsuhiko Matsumoto from Sony Corp., looks at preferred luminance levels from televisions viewed in the setting in which they are actually used – ordinary households.

The Medical/Visual Performance session should be interesting, with two invited papers that discuss the role that displays can play in human health. "The Impact of Self-Luminous Electronic Devices on Melatonin Suppression," by Mariana Figueiro of Rensselaer Polytechnic Institute, examines whether exposure to lit computer screens can suppress human manufacture of melatonin to the extent that it interferes with sleep or creates other health issues. "Enhanced Minimally Invasive Surgery by Endoscopic 2D-to-3D Conversion," by Kai-Che Liu from IRCAD-AITS suggests how adding depth perception to endoscopic surgical procedures can improve results.

## Display Electronics: Behind the Screens

This year's sessions on Display Electronics – the parts of the display you do not see – include Panel Driving Technology, 3D TV: OLED (a joint sesson with 3D and active-matrix devices), Image and Video Processing, and Interface Technologies for Displays. The two invited papers from the Interface session are "Dynamic-Range Management for Displays for Reduced Power and Improved Ambient Contrast," by Viacheslav Chesnokov of Apical Limited, and "DisplayPort 1.2, Embedded DisplayPort, and Future Trends," by Craig Wiley of Parade Technologies. Chesnokov's paper explains how combining display power control with content dynamic-range control can achieve a "near-seamless user viewing experience" over a very wide range of ambient light. Wiley's presentation will describe a new, extensible video interface standard that utilizes a data-communications-like packet structure.

Another invited paper of note is "iDP Standard for an Internal Connection in a Large-Screen Display," by Alan Kobayashi from STMicroelectronics, which describes an open industry standard developed for transporting a video pixel stream from a TV/monitor controller SOC (system on chip) to a TV/monitor panel TCON within a TV/monitor chassis.

## Display Manufacturing: New Processes, Including Roll-to-Roll, Lead the Way

A session on processes starts off this year's Display Manufacturing presentations, with the invited papers, "Enabling High-Throughput OLED Manufacturing by Carrier-Gas-Enhanced Organic Vapor-Deposition" (OVPD), by Michael Long from Aixtron AG and "Fabrication of TFT Circuits Using Shadow Masking: A Low-Cost Alternative to Conventional Photolithography," by Thomas Ambrose of Advantech US. The OLED paper describes a deposition source that is characterized by reduced vaporization temperatures and very short thermal exposure times. The shadow-masking presentation presents a method for realizing transistor circuits without conventional lithography, thus creating components that should be useful in active-matrix backplanes for top-emitting OLED and e-paper displays.

Any discussion of cutting-edge display manufacturing techniques must include roll-to-roll, which many companies are seeking to master due to its cost-saving and other benefits. This year's Flexible Displays session includes the invited paper, "Electrical Testing of Roll-to-Roll SAIL-Manufactured Flexible-Display Backplanes," by Richard Elder of Hewlett-Packard Labs, which describes efforts to develop a fully roll-to roll fabricated display for a solar-powered wrist display. These included methods for electrical testing of the display backplanes on flexible substrates that were not bonded to a carrier, which enabled improvement of yield through rapid electrical test feedback. (For more about HP's SAIL process, see "Paper-Like Electronic Media: The Case for R2R-Processed Full-Color Reflective Displays" in the January 2011 issue of *Information Display*.)

### Display Measurement: New Technology Requires New Standards

Crosstalk in Stereoscopic Displays, Display Measurement Standards and Applications, and Achieving Accurate Color Reproduction are the titles of this year's Display Measurement sessions. The crosstalk presentations build on last year's trend of establishing measurements for critical aspects of 3-D displays. Crosstalk between right- and left-eye imagery, which degrades the stereoscopic effect, is chief among those aspects.

In the Display Measurement Standards category, subcommittee chair Thomas Fiske recommends the invited paper, "New Information-Display Measurements Standard: A Display-Metrology Document," by Edward Kelley of Keltek. Kelley, the editor of the Information Display Measurements Standard (IDMS), which Fiske describes as "a monumental document years in the making," addresses some of the most recent elements – motion artifacts, 3-D measurements, and more – of the standard. The IDMS, expected to be released this year, is a work in progress by The International Committee for Display Metrology under the auspices of the Society for Information Display.

Also recommended is a distinguished paper by Louis Silverstein of VCD Sciences, Inc., "Achieving High-Color-Reproduction Accuracy in LCDs for Color-Critical Applications." The paper describes a methodology and associated software modules for the calibration, characterization and profiling of color LCDs for color-critical applications such as medical imaging.

### Display Systems: No Shortage of Novel Display Technologies

Display Systems is a far-ranging category, with 11 sessions in total, six of which are combined with 3-D, Green, Applications, Display Measurements, and other technology areas. Backlighting is a major topic this year, with three sessions – Local Dimming, LED Backlights and Laser Backlights, and Integrated Optics for Backlights – devoted to the topic. Papers to look for include the invited paper, "Recent Trends of LED Backlights with Local Dimming and Its Application for Multi-Primary-Color Displays," by Yasuhiro Yoshida from Sharp Corp., and the distinguished paper, "Directional Backlight with Narrow Angular Luminance Distribution for Widening Viewing Angle of a LCD with a Front-Surface Light-Scattering Film," by K. Käläntär from Leiz Advanced Technology. In the Novel Displays session, there is also a presentation that involves backlighting, though it is employed in an unusual way. The invited paper, "Imaging via Backlights," from Adrian Travis from Microsoft, describes using a wedge-shaped light guide to capture images in front of an LCD as though they were from a point behind it.

Two other Novel Displays papers whose very titles are intriguing are "Color Displays Using Reconfigurable Liquid Droplets," by Su Xu of the University of Central Florida, which discusses a fast technology that might be suitable for mobile displays, and "Flat-Panel-Display System Based on Interference Modulation for Both Intensity and Color," by Yikai Su from Shanghai Jiao Tong University, a technology that may increase the optical efficiency of current TFT-LCD technology by a factor of six, enabling it as a promising display solution for handheld devices.

### Emissive Displays: Protective Layers for Plasma

Plasma continues to be the major focus in the emissive-displays area. Researchers are busy developing energy-efficient PDPs, and these are the subject of the High-Efficiency Plasma TVs session, as discussed in the Green Special Focus article below.

The protective layer is key to successful plasma applications, and plasma papers of note from the session Plasma-Display Protective Layer include the invited presentations, "Surface Electronic States of MgO Induced by Auger Neutralization Process," by Hiroshi Kajiyama from Hiroshima University, and "The Role of the Impurity Diffusion Barrier for the Cathode Material in ACPDPs," by Ki-Woong Whang from Seoul National University. Addressing the MgO-CaO protective layer for plasma displays is a paper titled, "High-Luminous-Efficacy PDP Using $Ca_xMg_{1-x}O$ Protecting Layer," by Qun Yan from Sichuan COC Display Devices Co., Ltd.

Although each year seems to find fewer field-emission-display papers at SID, promising research is still being done in this area, as evidenced by the invited paper, "Highly Efficient and Long-Life MIM Cathodes for FEDs," by Toshiaki Kusunoki of Hitachi Research Laboratory, which describes how the lifetime of MIM (metal-insulator-metal) cathodes was lengthened to more than 20,000 hours by using a thinner tunneling insulator. Another invited paper to check out is "Flexible Transparent Photoluminescent Display," by Kyung Cheol Choi from KAIST. Choi's paper suggests that the plasma platform is an ideal candidate for flexible transparent displays because it has a simple structure and does not require TFTs to drive it.

### Flexible Displays: Growing More Flexible

Two years ago, due to the ever-increasing number of flex submissions received by SID, flexible displays enjoyed their own dedicated sessions for the first time. This year, with seven sessions and a total of 27 papers, interest in flexible displays is clearly still high. Color continues to be a recurring theme – researchers are still seeking a technology that supports low-power flexible displays capable of rich and vivid color imagery. One of the color-related presentations of note is the invited paper, "A 5.7-in. Color mirasol XGA Display for High-Performance Portable Applications," by Brian Gally of Qualcomm MEMS Technologies, which describes a reflective display based on bistable Interference Modulation Devices (IMODs).

Creating flexible displays that are more flexible – even rollable – is another popular theme. The invited paper, "Stretchable and Foldable Displays Using Organic Transistors with High Mechanical Stability," by Tsuyoshi Sekitani from the University of Tokyo, looks at just how far such flexibility can go. The paper describes how organic transistors were integrated with elastic conductors to produce ultraflexible CMOS-based integrated circuits that can be bent to a radius of 100 μm and active-matrix displays that can be stretched by 50% without suffering any electrical or mechanical damage.

Highlighting the Flexible Backplane session is a distinguished paper from Chao-

Chien Chiu from AU Optronics Corp., "Rollable Electrophoretic Display with an Integrated a-Si Gate Driver Circuit." In this work, Chiu and co-authors explain how they designed a display that can withstand 10,000 rolling cycles of 20-mm radius without any line defect or optic performance degradation.

## Liquid-Crystal Technology: More Than a Phase

Liquid crystals have dominated the display field for a long time, but that does not mean the technology has grown stagnant. The big news in LCDs this year is the growth of blue phase, according to LCT subcommittee chair Xiao-Yang Huang, who points out that there are three sessions (a total of nine papers) devoted to blue phase. Among those papers, he recommends the invited paper, "The World's First Blue-Phase LCD," by Seungho Hong from Samsung Electronics Co., Ltd. "It covers the fundamentals of materials, process, characterization, modeling, and display driving [needed for a blue-phase LCD]," says Huang. Another notable blue-phase offering is the invited paper, "New Materials for Polymer-Stabilized Blue Phase," by Michael Wittek of Merck KGaA, which describes a promising way to broaden the narrow temperature range of blue phase through polymer-stabilization. Yet another blue-phase paper that discusses polymer-stabilization is "Polarization-Independent Adaptive Microlens Array Using a Polymer-Stabilized Blue-Phase Liquid Crystal," a distinguished student paper by Yan Li from the University of Central Florida.

There are also two sessions on liquid-crystal alignment this year, and a highlight of those is "Liquid-Crystal Devices Based on Photo-Alignment and Photo-Patterning Materials," by Vladimir Chigrinov of the Hong Kong University of Science & Technology, which features a discussion of devices including patterned retarders for 3-D applications, lenses with electrically tunable focal distance, LC-based sensors, switchable q-plates, and optically rewritable e-Paper.

## OLEDs: Still Lots of Promise

Not too long ago, the display industry was expecting to see OLEDs take their place alongside LCD and plasma as a core TV technology. This has not happened yet, but OLEDs are still very much among us. They are the platform for an increasing number of mobile devices and for cutting-edge lighting applications, and they continue to be the subject of a great deal of research. Some of that research has to do with those sought-after TV-sized panels, and some focuses on better performance in handheld devices. Specific OLED sessions number five this year (with 19 papers), but OLEDs are the subject of numerous other session papers, including lighting, applications, flexible, manufacturing, and more. The technology has had the ability to fascinate researchers over the long term, which says much about its potential.

Among the highlights from this year's OLED Displays session are the invited paper, "Full-Color Phosphorescent OLED Displays: Power Savings and Implementation," by Mike Hack of Universal Display Corp., and the distinguished paper, "High-Resolution AMOLED Panels for Mobile 3D Applications Using White OLEDs with Color Filters," by Changwoong Chu of Samsung Mobile Display Co., Ltd. Hack's paper looks to phosphorescent OLEDs (PHOLEDs) as the key enabling technology for OLED TVs and other larger-area displays. Chu's presentation will cover the development of an autostereoscopic OLED panel for hand-helds.

In the OLED Devices session, next-generation devices are discussed in the invited papers, "Emergent Oxide-TFT Technologies for Next-Generation AMOLED Displays," by Toshiaki Arai from Sony Corp., and "Transparent AMOLED with On-Cell Touch Function Driven by IGZO TFTs," by Hsing-Hung Hsieh from AU Optronics Corp.

## Projection: Enabling Movies in and out of Your Pocket

As in previous years, the subjects described in the projection papers at Display Week 2011 vary greatly in size, from digital-cinema applications to pico-projectors. This year, Projection has become beyond a doubt the most amusingly titled session of the Symposium: Despeckling Despicable Speckle and Rejecting Ambient Light. If your work involves finding a solution to this seriously vexing problem, you will want to catch the three papers in this session.

Recommended in the Digital Cinema category is invited paper, "Dual Paraboloid Reflector Illumination System for Digital Cinema," by George Ouyang from Wavien, Inc., which

*The Wednesday evening Special Event will be held at Dodger stadium, where the Los Angeles Dodgers are scheduled to play the 2010 World Champion and arch rivals San Francisco Giants.*

presents initial simulation results for a DPR reflector that outperforms compound elliptical reflectors in terms of efficiency.

In the smaller world of pico-projectors, look for the distinguished paper, "Laser + LCoS Technology Revolution," by Karl Guttag from Syndiant, Inc., which discusses how the advent of affordable direct diode lasers is changing all the rules for optical designs and the associated technologies that generate images from laser light. Guttag also examines these topics from the perspective of laser-light-illuminated LCOS microdisplays.

### Touch Technology: Expanding More than Growing

Touch is appearing in more and more consumer products, but the technology itself is an evolutionary phase now; this year's papers reflect "incremental" changes for the most part, according to subcommittee member Geoff Walker. The current diversity of approaches – projective-capacitive, optical, and more – are reflected in the sessions as well. Leading off the Capative Touch session is the invited paper, "Advances in Touch Sensing Materials," by Bob Mackey from Synaptics, which describes how rapid growth in capacitive touch sensing and the related need for transparent conductors are pushing improvements in materials performance as well as overall cost reductions.

Another invited paper of note is "Planar Scatter Detection: A New Method for Optical Touch Screens," by Ola Wassvik of FlatFrog Laboratories. This work points out that projected-capacitive technology is highly dependent upon the availability of indium, a rare and increasingly scarce element that forms a key component of indium tin oxide (ITO), and proposes a solution.

Also recommended is "Mutual Capacitive Touch Screen Integrated into Thin-Film-Encapsulated Active-Matrix OLED," by HongShik Shim of the Samsung Advanced Institute of Technology, which describes a thin and high-performance input/output device consisting of capacitive-touch sensors integrated on a thin-film encapsulated AMOLED.

The March 2011 issue of *Information Display* (guest edited by the aforementioned Geoff Walker), featured a provocative article, "The Breadth–Depth Dichotomy: Opportunities and Crises in Expanding Sensing Capabilities," by Daniel Wigdor from the University of Toronto, that suggested why meaningful touch development may currently be stymied. If you would like to catch the author deliver his paper by the same name, the Touch Systems session at Display Week is the place to do it.

### Special Focus Areas: Green Technology, Lighting, and 3-D

Last year, the Society for Information Display designated special sessions to explore the impact of green technology on the display industry and to examine the increasing synergies between the lighting and the display industries. This year, there are six green technology sessions, four lighting sessions, and 11 3-D sessions, each featuring presentations that offer invaluable insights as to where display technology is headed.

### Green Technology Focus

Energy-efficient products and processes have become increasingly key to display designs and manufacturing. If you are even peripherally involved in the development of display technology, you need to know about the latest green research and development. Many of this year's papers focus on cutting-edge low-power technologies and applications in areas ranging from cholesteric liquid crystals and electrophorectic displays to OLEDs, LCDs, plasma, and more. The 2011 Symposium Green Technology sessions are Flexible Displays, Green Display Applications, Panel-Driving Technology, Low-Power Active-Matrix Alternatives, Local Dimming, and High-Efficiency Plasma TVs.

With devices such as the Kindle and current mobile phones that offer a battery life in terms of days, consumers have begun to expect similar efficiency from other display products, no matter what their underlying technology. Consequently, panel-driving technologies and local dimming that help realize energy efficiency are the subject of eight of this year's papers. Known low-power technologies such as reflective and electrophoretic are also covered in several papers, but so are ways to make LC and plasma displays more energy efficient.

Roll-to-roll manufacturing techniques for flexible, low-power displays continue to generate a lot of interest. Two papers in the joint Green/Flexible Displays session that approach this topic are "High Resolution and Multi-Color R2R Flexible Papers," by Heng-Yin Chen, and the invited presentation, "Electrochromic Display: Full-Color-Technology, Flexible, Roll-to-Roll Processing, *etc*." from Yi-Wen Chung. Both authors are from ITRI in Taiwan.

In the Panel-Driving Technology session, two particularly interesting papers are the invited paper, "Driving mirasol® Displays: Addressing Methods and Control Electronics," by Russel Martin of Qualcomm MEMS Technologies, and "A 10-bit Compact Current DAC Architecture for Large-Sized AMOLED Displays," by Ki-Duk Kim from KAIST (Korea Advanced Institute of Science and Technology). Kim's paper proposes to overcome one of the biggest challenges for large AMOLED displays – an efficient voltage-driving scheme that ensures uniformity.

Among the low-power active-matrix alternatives discussed in the session of the same name are a bendable electrowetting display, a blockwise luminance control algorithm for AMOLEDs, a pixel design for TFT-LCDs with variable refresh rates, color-sequential LCDs, and electrophoretic displays. This last topic is discussed in an invited paper titled, "Active-Matrix Displays for e-Readers Using Microcup Electrophoretic Displays," by Bob Sprague from SiPix Imaging.

The presentations in this year's joint green/plasma session address the subject of more-efficient plasma displays. Although plasma has in fact steadily become more energy-efficient over the last several years, its name is not yet synonymous with low-power usage. Two invited papers address this issue. "High-Luminous-Efficacy and Low-Power-Consumption Plasma TV," by Sang-Koo Kwon of LG Electronics, discusses a new plasma TV designed to meet government energy regulations that also features higher reliability. "Improvement of Luminous Efficiency Using New Cell Structure in ACPDPs," by Panasonic's Shinichirou Hori, describes a new discharge cell structure that will raise the discharge efficiency of PDPs by 9% and lower displacement power by 10%.

### Lighting Focus

This year's four lighting sessions are Laser Light Projection, Solid-State Lighting Applications, and OLED Lighting I and II. Five of the OLED papers relate to panels, according to lighting session chair Mike Hack from Universal Display Corp., who notes that there has been a big move over the last few years to make efficient large OLED panels with performances that can be used by luminaire makers. While there are now OLED light fixtures that are commercially available, they are generally just in the form of high-end architectural lamps. So the push is to make OLED lighting more of a commodity. "I think this year's papers reflect this focus," says Hack.

A "large" OLED panel currently is about 4–6 in., or from $10 \times 10$ to $15 \times 15$ $cm^2$. This is the size that visitors are generally going to see discussed at the conference, notes Hack, and the size featured in two of the invited papers: "Performance of a Large-Sized White OLED for Lighting Applications," by Sehwan Son of LG Chemical, and "Challenges and Opportunities in Scaling-Up OLEDs for Lighting Applications," by Ruiqing Ma from Universal Display Corp.

Another invited paper that addresses efficiency issues is "High-Performance White OLEDs for Next-Generation Solid-State Lighting," by Takuya Komoda from Panasonic Electric Works Co., Ltd., which takes a look at just how competitive OLED lighting can potentially be with current lighting technologies such as fluorescent lamps. "Novel Approaches for OLED Lighting," by Karl Leo from the Technische Universitaet Dresden, looks at vacuum deposition on flexible substrates such as plastic and metal foils.

One LED paper of note is an overview of sorts: "Trends in LED Illumination and Display Backlighting," by Willem Sillevis-Smitt from Philips LumiLeds Lighting. In his invited paper, Sillevis-Smitt notes that requirements for illumination applications and backlighting for displays differ, and his presentation will highlight key similarities and differences between the markets and will suggest the likely implications for the LED industry.

Projection Lighting papers of note include the invited paper, "Progress in Green and Blue Laser Diodes and Their Application in Pico-Projection Systems," by James Raring from Soraa, Inc., and "Recent Progress in Direct Green Lasers for Mobile Image Projectors," by Adrian Avramescu from OSRAM Opto Semiconductors.

### 3-D Focus

Possibly the biggest commercial story in displays last year was the arrival of 3-D-ready TVs. Now that they have arrived, the story is far from over. Researchers continue to pursue the different approaches of active-shutter *vs.* passive-glasses technology, and glasses-free viewing is a major challenge that many experts believe must be met in order to make 3-D displays truly successful. This year's presentations cover these topics and more, including holographic displays, crosstalk reduction, measurements for 3-D performance, and numerous other issues related to both LCD and OLED 3-D displays. Also, do not miss the 3-D cinema event happening at Display Week on Tuesday, May 17.

The invited paper, "Advanced Technologies for 3D LCD Television," by Yuichiro Yamada from Sharp Corp., tackles the issue of 3-D TV quality with a look at ensuring that 3-D and 2-D image quality is comparable. "By applying advanced technologies such as UV2A (ultra-violet induced vertical alignment), four-primary-color technology, and sophisticated driving technology to LC-TV," writes Yamada, "crosstalk when displaying the 3D image can be removed."

Many researchers have proposed the AMOLED platform as a suitable one for 3-D TV, and the session 3D TV: OLED, conducted jointly with Display Electronics and Active-Matrix, includes four papers on the subject. In the AMOLED Driving 3-D session, the distinguished paper, "120-Hz 3D Driving for AMOLED with Interleaved Scan and Emission Operation," by Baek-Woon Lee from Samsung Mobile Display Co., Ltd., proposes a new driving method that enables higher resolution.

Autostereoscopic or glasses-free viewing continues to be a much sought-after but only partially realized display technology. Of interest in this area is the invited paper, "TRANSFORMERS: Autostereoscopic Displays Running in Different 3D Operating Modes," by Rene de La Barre from Franhofer HHI, which describes how to enable the use of content originally produced for glasses-type 3-D displays without the need of additional calculation of interpolating views. ■

# Multiprimary-Color Displays and Their Evaluation Methods

*A multiprimary-color display provides high fidelity and wide-gamut color reproduction, as well as power savings and other advantages. New methods will be required for evaluating multiprimary displays, particularly in terms of color gamut, color accuracy, and smooth tone reproduction.*

by Masahiro Yamaguchi

MULTIPRIMARY-color displays have begun to enter the consumer market. Their advantages include a wide color gamut, power savings, and suitability for high-fidelity color reproduction. How will these displays impact professional applications and what new aspects are needed for evaluating color displays so as to best incorporate the advantages of multiprimary devices?

### Multiprimary-color displays

Conventional displays reproduce colors based on the additive mixture of R (red), G (green), and B (blue) primary colors. The color gamut (range of colors reproducible by displays) is limited to the triangle spanned by the RGB primary colors. To realize wider-gamut displays, two different methodologies have been attempted: (1) more-saturated RGB primaries and (2) the use of more than three primary colors – the multiprimary approach. Wide-gamut displays such as LED-backlit liquid-crystal displays (LCDs)[1] and laser displays have been extensively commercialized based on the first approach. Multiprimary-color displays have more recently been investigated. Examples include multi-projection displays,[2,3] a projector with a multiprimary color-filter wheel,[4,5] a color pixel generated with a diffraction grating,[6] a time-sequential backlight using a multiprimary LED light source,[1,7] and an LCD with a multiprimary color-filter array.[8-10]

Figure 1 shows a comparison of color gamuts for a conventional standard RGB (sRGB) display, an LED-backlight wide-gamut display,[1] and a six-primary-color display.[3,11] The gamut of a six-primary-color display covers almost 100% of real-world object colors, while a conventional display gamut, such as sRGB or ITU-R BT.709, covers only 80%. This is one of the main reasons that the multiprimary approach is advantageous in high-fidelity color reproduction. The details of the evaluation of the size of the gamut will be explained further on.

### Advantages of Multiprimary-Color Displays

As shown in Fig. 1, the gamut of multiprimary-color displays efficiently covers real-world object colors. The design of the gamut shape becomes more flexible than that of wide-gamut RGB displays, in which the chromaticity coordinates of the G primary are often moved to shorter wavelengths so that the gamut covers the cyan region, but the yellow region is excised. In multiprimary displays, cyan and/or yellow can be added, and the yellow-green-cyan region can be broadly covered. In the three-primary case, narrow-band primary colors, especially R primaries of longer wavelengths and B primaries of shorter wavelengths, are used, but the sensitivity of human vision is lower at such wavelengths so that the overall efficiency is decreased.

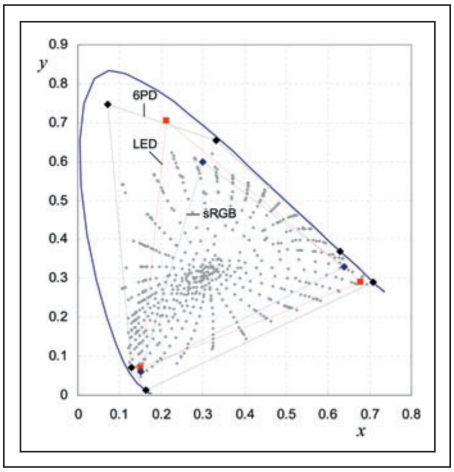


*Fig. 1: The graph represents the color gamuts of an ITU-R BT.709 (or sRGB) display, an LED-backlight wide-gamut display,[1] and a six-primary-color display.[3,11] The dot distribution represents the gamut of real-world object colors.*

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The advantage of multiprimary-color displays is not only wide-gamut color reproduction. A multiprimary-color display also enables the reproduction of color with spectral approximation,[12] in which the spectral difference between the original and reproduced colors is minimized in addition to the reproduction of colorimetric tristimulus values. Although conventional color reproduction is based on the color-matching function (CMF) of a standard observer defined in a CIE standard, such as CIE 1931 XYZ, the spectral sensitivities of real observers are slightly different from the standard CMF. This leads to a color mismatch between the real object and the image reproduced on a monitor, even though the color difference may be very small. Spectral approximation solves this problem. Unlike with a conventional colorimetric (metameric) match, the color matching can be achieved even if the observer variation of CMF is not ignored. Metamerism involves matching the apparent colors of objects with different spectral power distributions. "Spectral displays" are valuable in applications that require highly accurate color matching, such as soft-proofing (reviewing a print job on a computer monitor rather than on paper).

It has been recently publicized that power savings is an important feature of multi-primary displays.[10] Adding a yellow primary is effective for this purpose, and the design of color conversion is a key issue in reducing power consumption. A power savings of 20% has been achieved in a four-primary-color display[10] compared with a conventional RGB display. Even though some additional cost is required in color signal processing, the complexity of the color-processing engine is not significantly higher than that of a standard consumer television set.

Multiprimary-color conversion introduces a new flexibility in the design of color displays. The viewing-angle performance, which is a critical issue in LCDs, can be improved in a five-primary-color display by modifying the multiprimary-color conversion technique.[9] Also, multiprimary-color subpixels can be used to enhance the visual resolution by using subpixel rendering.

## Signal Processing in Multiprimary-Color Displays

The multiprimary-color signal is generated from imaging tristimulus values or multi-spectral data, called multiprimary-color conversion, as shown in Fig. 2, similar to the color decomposition for multicolor printers. For colorimetric color reproduction, three-dimensional tristimulus values (such as XYZ or YCbCr) are transformed to M-dimensional multiprimary-color values if the number of primary colors is M. This methodology involves a degree of freedom; plural combinations of multiprimary color values can reproduce a certain color. There have been various methods proposed for multiprimary-color conversion.

In the matrix-switching (MS) method,[13] the polyhedral color gamut spanned by M-primary colors is divided into pyramids, and a linear color conversion is performed in each pyramid. Another approach is based on linear programming.[14] Linear programming enables the incorporation of various criteria for selecting multiprimary-color-value combinations. For example, as the MS method sometimes induces contour-like artifacts at the boundary of pyramids, a constraint can be introduced to improve the smooth tone reproduction without such artifacts. In this case, multiprimary signal values are decomposed into visible and invisible [metameric black (MB)] components. The visible components are uniquely solved, where the MB components are determined such that the multiprimary signal values change smoothly if the change of tristimulus values is small.[14] Linear programming is also a powerful technique for incorporating extra features to a multiprimary-color display, such as power saving and the improvement of viewing-angle performance, as mentioned in the previous section.

For the spectral color reproduction explained previously, multiprimary device signal values are directly calculated from multispectral captured images. In the proposed conversion method for spectral displays, called the spectral approximation method,[12] the spectral error is minimized under the constraint in such a way that a colorimetric match is attained for the standard observer.

## Industrial and Medical Applications

High-fidelity color reproduction is required in industrial and medical applications such as printing, textiles, industrial design, digital archives of artworks, and true-color medical images. However, it is difficult to capture high-fidelity color with RGB-based color-

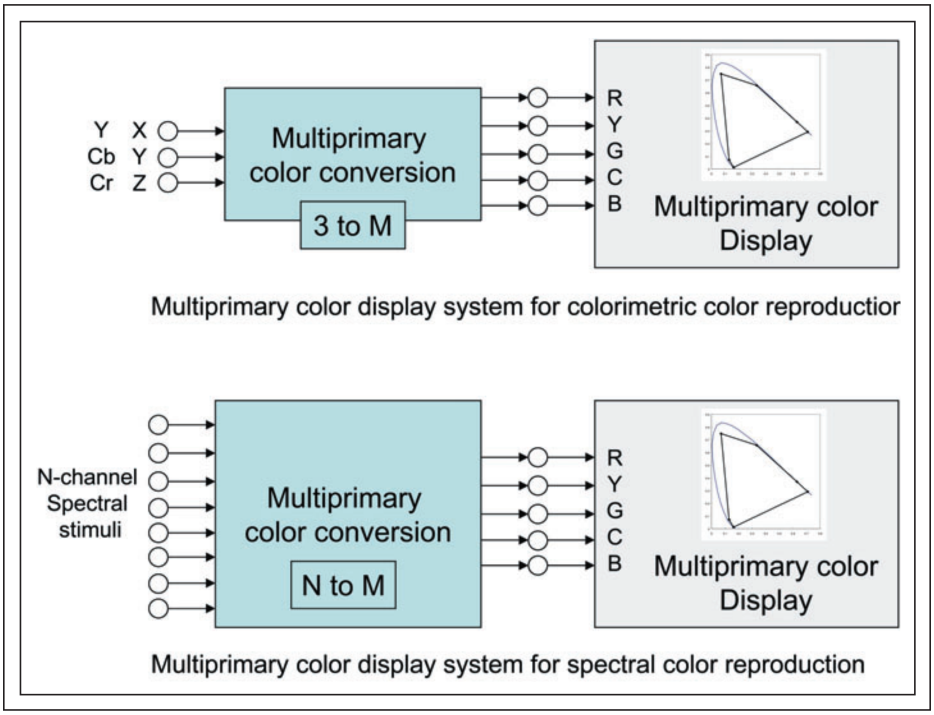


*Fig. 2: The system configuration of a multiprimary-color display for colorimetric color reproduction is shown above and for spectral color reproduction, below.*

imaging systems. An approach to overcoming such limitations is going beyond RGB – namely, adopting a spectrum-based system.[11,15] In the spectrum-based color reproduction system, the color signal captured by a multiband camera is used to derive the spectral image, and the output color is rendered using the spectral image and the spectrum of illuminant. A multiband camera with more than three-channels, *i.e.*, a multispectral camera, is useful for capturing spectral imagery with high accuracy. A multispectral imaging system enables both image capture with accurate color under various different illuminants and the reproduction of very natural and realistic images. The conventional sRGB gamut has been shown to be insufficient for printing, textiles, and artworks. Based on a color-gamut analysis of color-printer inks, textile samples, and oil paints, wide-gamut displays and wide-gamut image capture should be more appropriate for these applications.

High-fidelity color is important in medical color displays, especially for telemedicine applications such as teledermatology, telepediatrics, and home-care telemedicine. The effectiveness of multiprimary displays in medical applications has not yet been proven, but some experimental results show the potential of using wide-gamut and multiprimary displays in these scenarios.

For example, a telemedicine experiment was carried out in order to investigate whether dermatologists perceived the identical color from a reproduced image and the original skin, and how the color reproducibility influenced the skin lesion diagnosis.[17] For the preliminary test of the experiment, a conventional RGB CRT display with proper calibration was used, but the visual disagreement between the reproduced color and the original object was significant, despite the fact that the colorimetric accuracy was considerably high. The disagreement originated from the observer metamerism effect; the CMFs of real observers are slightly different from the standard CMF used in color measurement. This result does not necessarily mean that a three-primary-color display is inadequate for skin-color reproduction, but it does show the potential benefits of spectral displays. The experimental results showed that dermatologists perceived almost the same color in the case of the multispectral system, while perceived colors shifted to the red in the observation with an RGB system. In addition, there were oversights of erythema (skin redness) found in the RGB example, but no such oversights with the multispectral system. These results suggest the advantages of using the total multispectral system for accurate skin-color reproduction.

Another area of possible application is the video capture of surgery for case archives, conferences, education, and telesurgery with support from an expert surgeon at a remote site. The selection of the resection area is sometimes decided by faint color differences, which means natural-color reproduction is significantly important. An experiment was conducted[18] in which seven examples of hand operations were captured by a six-band video camera and visually evaluated by surgeons and dermatologists. Figure 3 shows the distribution of colors obtained from the six-band camera. The colors of tissues ranged from red to yellowish-white. The color of blood exceeded the sRGB gamut. It is probably advisable to employ a wide-gamut display, particularly in the deep red region, for reproducing blood color. In the experiment reported in Ref. 18, however, a flat-panel LCD with a normal color gamut was used, since another device suitable for this experiment was not available.

## Evaluation of Multiprimary Displays

Evaluation methods for multiprimary-color displays are in some instances different from those standardized for conventional RGB displays. The color gamut of a non-standard display is often indicated with the NTSC (National Television Systems Committee) ratio, while the 1953 NTSC standard is not used in the current television systems. In fact, 3-D color space is advisable in order for a user to see the details of gamut size. Uniform chromaticity space, such as CIELAB color space, is suitable, and the volume of gamut in CIELAB color space can be an indicator of gamut size. Figure 4 shows the comparison of gamut shape in CIELAB space. It is visualized with the gamut expanded especially in bright orange, cyan, dark red, and dark purple regions in the six-primary-color display[19,20] (see also "The NTSC Color Triangle Is Obsolete, But No One Seems to Know" in the May 2006 issue of *Information Display*.)

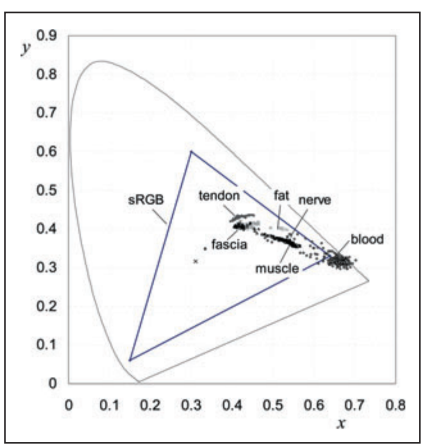


*Fig. 3: Color distribution of tissues involved in medical operations on hands was captured by a six-band camera (CIE xy-chromaticity coordinates).*

In addition, it is expected that a display gamut will cover the colors of real-world objects. The surface color data published by Pointer[21] have been sometimes used to evaluate wide-gamut displays. (Pointer measured real-object colors, including not only natural objects such as butterflies and flowers, but man-made ones such as paint samples and fabrics.[22]) However, the Pointer gamut is not necessarily sufficient for representing real-world natural colors. The colors calculated from the data in the Standard Object Color Spectra (SOCS) database in the ISO TR 16066:2003 standard can be compared with the Pointer gamut, and about 3800 among 50,000 samples are from the Pointer gamut. Thus, the SOCS database was integrated with the Pointer gamut for more representative reference. Figure 4 shows a plot of the merged Pointer + SOCS gamut boundary at different luminance on xy-chromaticity coordinates (fluorescent colors are excluded). It can be seen that the six-primary-color display covers the Pointer + SOCS gamut. Moreover, the outer boundary of the merged Pointer + SOCS is also designated in 3-D color space in Fig. 4. The coverage of object color is also a reasonable indicator of the gamut size. Table 1 shows an example of evaluation. The gamut volume of a six-primary-color display is about 1.8 times larger than a conventional RGB display and natural color coverage is larger than 99%.

## Color Accuracy

The accuracy of reproduced color can be evaluated by the difference between the target color and the reproduced color obtained by colorimetric measurement, as in the case of a

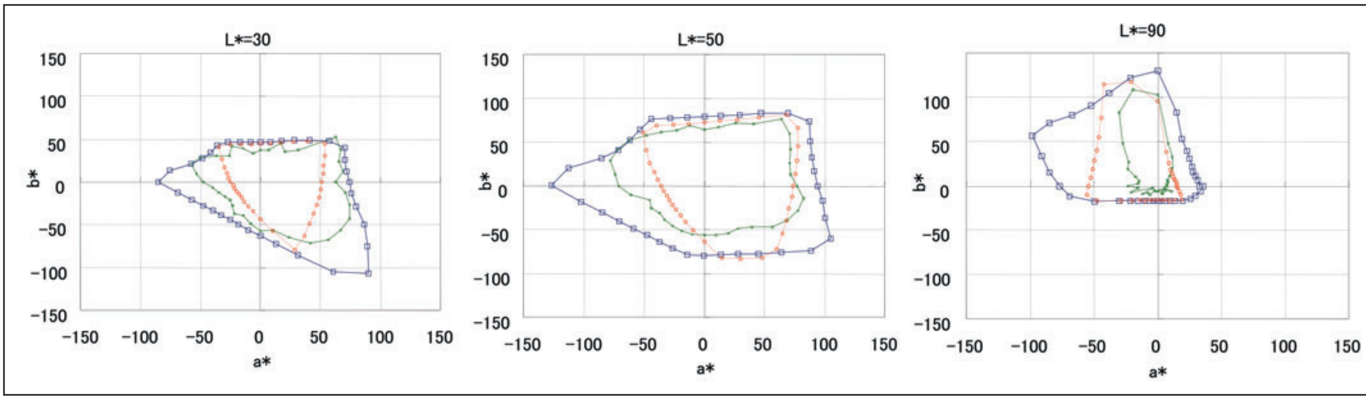


*Fig. 4: The color gamut of conventional RGB, six-primary colors, and Pointer + SOCS on constant lightness planes are shown at L* = 30, 50, and 90.*

conventional RGB display. However, it should be considered that color-reproduction errors originate from three sources: (1) the display color gamut, (2) the device characterization error, and (3) the color-conversion method. As for source (1), how is it possible to compare the color-reproduction accuracy of displays with different gamut shapes? How to select test colors? A possible way is to define the test colors within the Pointer + SOCS gamut and to derive the accuracy for the test colors inside the display gamut as well as for all the colors. Regarding the source of the color-reproduction error, [3] it is usually insignificant in conventional RGB displays, but cannot be ignored in multiprimary displays because the multiprimary-color conversion involves a somewhat more complicated process than the RGB system. For example, a certain color can be reproduced by a different

**Table 1:** The volume of color gamut and the coverage ratio of object colors (Pointer + SOCS) are shown in CIELAB color space.

| | Pointer + SOCS | Three-primary DLP | Six-primary DLP |
|---|---|---|---|
| Volume ($\times 10^6$) | 0.890 | 0.908 | 1.647 |
| Relative volume | 1.00 | 1.02 | 1.85 |
| Coverage ratio | 100.00 | 78.81 | 99.22 |

combination of multiprimary device signals. Thus, the reproducibility of a specific color depends on the multiprimary-color conversion method. While the device characterization can be performed by measuring the chromaticity points of primary colors, the tone-reproduction curve, and the background color, the accuracy of multiprimary-color conversion should be also evaluated.

Multiprimary-color conversion is sometimes an internal process in the commercial product, as in Fig. 2, and the input signal is in XYZ or YCC color space. In this case, it is impossible to control the primary-color signal independently. From the user's perspective, the conventional device used to make an ICC profile (a set of color-management data for a particular device, as established by the International Color Consortium) is not suitable for multiprimary-color displays. Accurate and efficient ways of characterizing multiprimary displays on the user side is an important issue.

## Smoothness of Tone Reproduction

Since the 3-to-M multiprimary-color conversion involves a degree of freedom, the device signal may vary largely even for a slight change of target color. Ideally, an observer cannot perceive such variation. However, when a smooth tonal gradation is reproduced on a multiprimary-color display, contour-like artifacts sometimes appear.[23] These result from characterization errors of the display and the variation in the color-matching functions of observers. For example, even if the artifact is not obvious when observed from the front of the display, it appears quite clearly at large observation angles because of the change in the spectral composition of reproduced light. The appearance of the contour-like artifacts depends on the multiprimary-color conversion. To reduce the artifact, the conversion method should ensure the continuity of device signal values for the continuous change of tristimulus values. The reproduction of smooth tonal gradation is one of the important issues in the image quality of a multiprimary display.

The number of reproducible colors in a multiprimary display is 2MB in principle, where M and B are the number of primary colors and bit depth of each channel, respectively. For example, in the case of a six-primary-color display with 8 bits/channel, the number becomes $2.8 \times 10^{15}$ colors. However, the quantized points are not uniform in 3-D color space. In addition, if a specific method for multiprimary-color conversion is adopted, the number of colors used for reproduction is much smaller; for example, $3.4 \times 10^{9}$ colors in the case of an MS color-conversion method. A method for dealing with the unused signal values has yet to be developed.

## Summary

A multiprimary-color display is beneficial for high-fidelity and wide-gamut-color reproduction, but also provides other advantages, such as power savings, spectral display, *etc*. The integrated design of the device with the multiprimary-color conversion is key to realizing the above advantages. Some modified methods are required for evaluating multiprimary-color displays, particularly with regard to color gamut, color accuracy, and smooth tone reproduction. The standardization of evaluation methods suitable for multiprimary-color displays will be an important contribution to this field.

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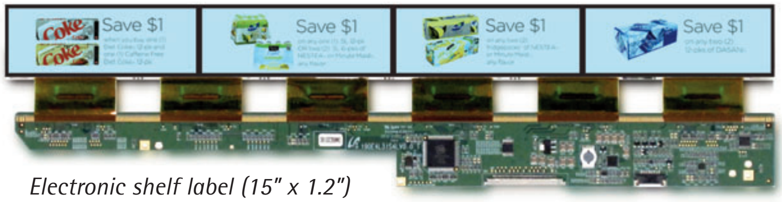


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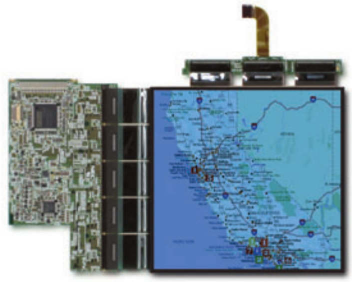

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# Part 1: Emerging Topics in Medical Displays

*New display applications for the interpretation of medical images include mobile image viewers, true-color modalities, and 3-D technologies for improved diagnostic performance.*

by Aldo Badano and Wei-Chung Cheng

As imaging technology evolves, so do the display devices used for image viewing. For instance, two-dimensional image acquisition techniques are being replaced with information-rich, three- or higher-dimensional schemes. This increased dimensionality for image sets is already occurring in breast imaging and needs to be considered when the performance of two- and three-dimensional display devices is being evaluated. In addition, modalities that were traditionally analog, such as optical microscopy and medical photography, are now migrating to the digital domain, following a path similar to that of radiology in the early 1990s. Finally, mobile-device technologies are prompting practitioners to consider using them to improve their workflow and availability. Most notably, mobile-display systems based on portable consumer-grade devices are now increasingly considered as complements to stationary desktop displays for review when there is no access to a dedicated workstation. The implications for pre-clinical regulatory evaluation of these emerging applications are considered and discussed in Part 2 of this article, "Pre-Clinical Assessment of Medical Displays for Regulatory Evaluation."

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## Displays for Mobile Devices

The introduction of a large variety of technologies and the improvements in the image quality of mobile display devices have led to the consideration of such devices as medical image viewers. From an evaluation perspective, the applicable methodology has to incorporate elements associated with the handling, orientation, and movement of the device with the possible interactions of software components with the operating system (*e.g.*, power manager, network connectivity, and other mobile-device functions), and, most importantly, with the variability in ambient-illumination conditions in which the device can be used (see Fig. 1).

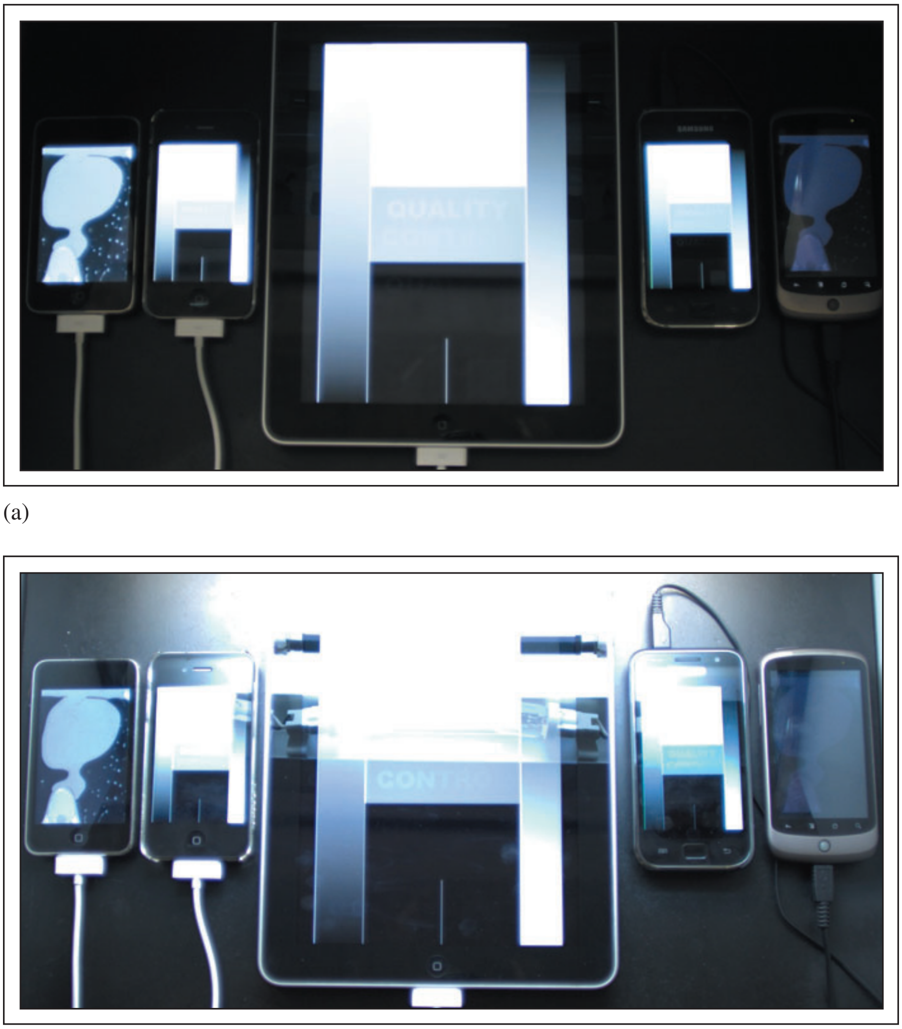
In addition, the viewing of images in hand-held devices has raised concerns about the need to quantify the display characteristics not only under typical static laboratory conditions, but also in the presence of movement. In this case, resolution properties measured by the modulation transfer function (MTF) might have to be extended to include a component from movement while noise metrics might need to consider the presence of fingerprint marks in touch-sensitive screens. For mobile displays, physical size and pixel-array size are not the only technological changes (newer versions of mobile displays might soon overcome the 1k × 1k barrier). Instead, key differences in terms of image quality might be more associated with variable ambient illumination conditions, variable device-user interaction, and the impact of smudges and fingerprints in touch-screen devices.

## Displays for True-Color Modalities

The emergence of medical-imaging modalities that rely on color scales in conjunction with gray-scale images has determined that display devices have to be capable of accurate color mapping with limited quantization or cropping of the color scales. This is typically achieved by tuning the subpixel look-up tables that map image values into pixel intensities. However, when these look-up tables are designed to map color, the gray-scale performance of the device can be compromised. Therefore, for modalities where color and gray-scale fidelity is relevant, additional testing needs to provide evidence that both scales are within appropriate tolerances. Several techniques have been reported for achieving proper gray scale and color calibration (criteria to guide these techniques have not yet been established). In addition, other aspects of technical performance might have analogous elements for color (*e.g.*, angular color shifts at 30° and 45° in the diagonal, horizontal, and vertical directions at center and edge spots and uniformity.

Another aspect to consider is the migration from optical or light microscopy to digital that has raised issues related to the display of the massive amount of information that can be captured for a single tissue slide. In addition to colorimetric issues, it is also important to note that the pixel-array sizes of tiled digital microscopy slides might raise additional needs for cataloging issues related to large displays (XQVGA or even wall-sized). Also worthy of consideration are the perceptual elements of characterizing image quality when the screen size is several times the distance from the reader to the screen (see Fig 2).

In this scenario, the temporal characterization might require more detailed methodology that incorporates not only transition times but also



(a)

(b)

***Fig. 1:** The visibility of image features in five mobile display devices shown in (a) degrades under ambient illumination effects as shown in (b). Note the degradation introduced by specular reflections in the visualization of gray-scale steps in the test pattern and the significant contrast reduction in the CT image due to diffuse reflections.*

moving-target techniques such as those that are part of the SID-sponsored ICDM document.[1]

### Displays for 3-D Modalities

Several three-dimensional modalities are being considered and utilized for detecting breast cancer as adjuncts to or replacements for full-field digital mammography examinations. Among them, breast tomosynthesis,[2] a limited-angle tomographic modality, has demonstrated that the additional volumetric information acquired using multiple projections holds promise for improvements in the detection of masses, in part by removing the masking effect of normal anatomical structures that can hide or mimic lesions. Other technologies being currently developed include dedicated breast computed tomography[3] and stereo-mammography.[4]

Display devices for these emerging three-dimensional breast-imaging modalities are partially characterized by the lists provided in Part 2 of this article in terms of their spatial and gray-scale performance. However, since the radiologist is now faced with a new reading paradigm that requires browsing over many high-resolution (several million pixel) images (slices from the reconstructed volume), the temporal response of the display becomes a relevant characterization topic. Detailed temporal characterization of the display devices is useful in understanding the potential limitations of different display technologies and products in their ability to accurately represent the images for the readers. For instance, a more complete set of gray-scale transitions and a more descriptive metric that characterizes limitations of proposed solutions (*i.e.*, overshoots in overdrive) can prove useful in demonstrating new product capabilities.

Another approach to visualizing the three-dimensional image sets is the use of three-dimensional display devices that are becoming available with increased performance due in part to advancements geared toward the consmer markets. In that sense, existing work regarding the use of two-dimensional display devices in medical imaging has to be revisited wherever appropriate. This extension of the physical measurements to a third dimension raises challenges, not so much in the development of the measurement methodology, but in bridging the experimental physical quantities (*e.g.*, stereo crosstalk and stereo acuity) to the task performance in diagnostic imaging. Figure 3 shows a stereoscopic display used to view digital microscopy. Such reconciliation is complicated by the widely different technologies that are now being considered for three-dimensional displays, including stereoscopic, autostereoscopic, volumetric, and time-sequential implementations, among others. A tentative list of pre-clinical tests of relevance for 3-D medical display products is presented in Table 1 of Part 2 in this issue. The list of tests that would be relevant for a particular 3-D medical-display product will depend on the visual task performed with the device and the associated claims made by the manufacturer.

Innovations in display technology are making possible new ways of reviewing medical images. How soon these devices become available to physicians will depend on the availability of validated methodologies that can be used to demonstrate their advantages and in what ways these devices contribute to the early detection of diseases and ultimately to improved patient outcomes.

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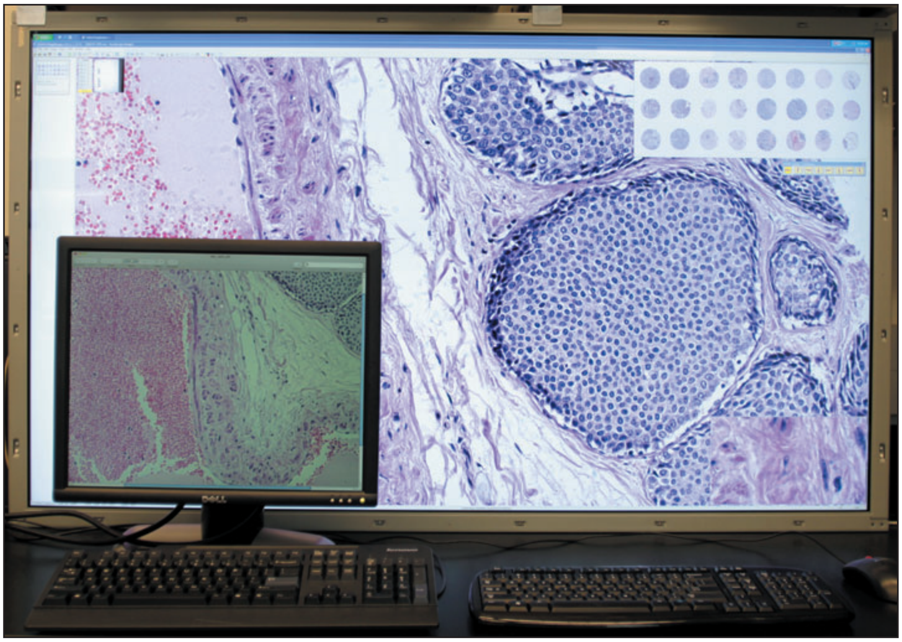

*Fig. 2: As displays for viewing digital microscopy images grow larger (background), issues of scale, accuracy, and time for pan/zoom operations in the computer hardware and software come to the fore.*

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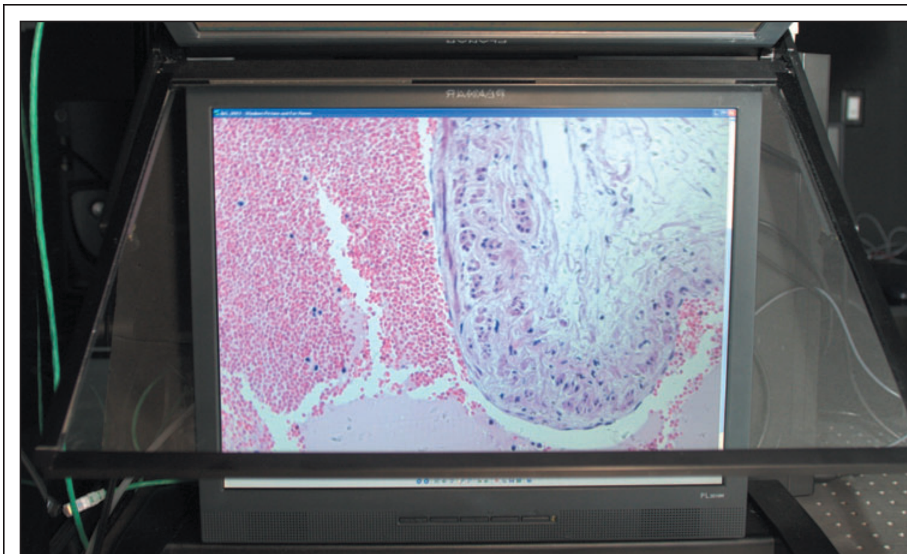

*Fig. 3: Stereoscopic viewing of digital microscopy and other imaging modalities is a means of improving the visualization of 3D datasets.*

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# Part 2: Pre-Clinical Assessment of Medical Displays for Regulatory Evaluation

*Challenges are emerging with regard to the pre-clinical, regulatory assessment of display systems used for viewing and interpreting medical images. This article discusses those, and also the types of evidence that might be relevant to the evaluation of mobile image-viewing devices, true-color devices with applications in digital microscopy, and 3-D medical displays as discussed in Part 1.*

by Aldo Badano, Wei-Chung Cheng, Brendan J. O'Leary, and Kyle J. Myers

DISPLAY SYSTEMS are important elements of imaging systems. They represent the last component in the chain that readers (radiologists, physicians, or technicians) use to make a determination regarding a patient's condition based on imaging data. In this context, a display system consists of all the hardware and software that determine the quality of the luminance output in the screen for a given image, including pre-processing operations on the data, the environment in which the device is operated, and device-user interactions.

### Regulatory Primer

Since the introduction of digital technologies for the image capture, processing, archiving, and transmission of medical images, display systems have been evolving technologically from bulky cathode-ray tubes with monochrome screens and poor spatial resolution to the current generation of liquid-crystal displays (LCDs) with increased image contrast and sharpness. This technological revolution has required the medical imaging community, including regulators, to adopt new assessment methodologies.

First, there is a need to characterize display image-quality issues that emerging technologies bring to the fore. In addition, it is occasionally useful to remove particular testing procedures because they have become obsolete due to technological advances. Today, we are seeing the transition from analog to digital in many areas of medicine, including tissue microscopy, pathology, and visible light-imaging modalities such as colposcopy (a gynecological diagnostic procedure). Medical displays need to be capable of providing stable and reproducible image quality that is appropriate for the application. For a display device to be marketed in the U.S. as part of a medical device, the manufacturer (or sponsor) needs to secure the FDA's approval or clearance. The regulatory pathways for medical display systems, briefly summarized in the following section, aim to promote public health and innovation by providing practical approaches for demonstrating safety and effectiveness.

Regulatory efforts are concentrated in two areas: pre-market and post-market. Pre-market refers to new products and technologies that have not yet been commercialized, for which evidence is gathered in support of a sponsor submission. The post-market area refers to issues that arise from the usage of the device after introduction into the market. In this article, we focus our analysis on pre-market topics since they relate to the introduction of new technologies.

The safety and effectiveness criteria for medical display systems are based on the clinical performance of the device and the potential for misdiagnosis due to pitfalls in the device design. Generally speaking, a device can be defined as safe if its use does not cause illness or injury. In terms of display performance, an effectiveness concern could be the use of a device that does not convey the image data to the user in a proper way due to, for instance, additional spatial noise resulting from variations in pixel gains or unwanted reflections of ambient light that mask lesions and significantly affect the outcome of the diagnostic test.

The FDA uses a three-tier classification system to categorize medical devices based on risk. Devices are classified as Class I, II, or III, from lowest to highest risk, with the class level determining the degree of regulatory oversight required. Currently, stand-alone display systems (referred to as "accessories" to complete imaging systems) fall under Class II based on moderate risk. For these systems, established testing methods provide adequate

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evidence of risk mitigation. These devices typically require 510(k) pre-market notification prior to marketing based on device-specific requirements described in Refs. 1 and 2.

This article describes the current challenges faced by both industry and regulators in the pre-clinical assessment of medical imaging display devices. In this context, it may be useful to provide a technical framework for future guidelines or guidance documents. From the perspective of the regulatory evaluation of displays, there is sometimes a trade-off between the need for sufficient evidence that allows performance comparisons with previously cleared devices already in the marketplace and the need of to establish additional benchmarks for next-generation devices designed to improve performance in areas where current devices are weak.

Efforts to document pre-clinical performance serve two purposes. First, comprehensive and appropriate pre-clinical testing of devices can minimize the need for more burdensome clinical evidence in support of the sponsor's claim. Second, the pre-clinical evidence sets quantifiable and reproducible performance levels that are benchmarks for new technology. A discussion of the least-burdensome requirements for regulatory review has to be framed by an analysis of the relevance of each test with respect to the clinical tasks to be performed with the device.

## Evidence Supporting a Submission

It is useful to define three types of pre-clinical evidence to be considered while evaluating medical display devices: (a) description of the hardware components of the display system, (b) pre-clinical performance tests that relate to the quality of the image display, and (c) supplemental characterization tests. Supplemental information on physical characteristics can be used to provide additional evidence in support of a particular display feature or to minimize the need for more comprehensive clinical evidence.

***Technological Characteristics of the Display System.*** The list provided in this section might serve as a template for the description of the software and hardware components of the display system. Some technological descriptors of the display device (*e.g.*, an LCD panel with a TFT active-matrix array with fluorescent backlight) are also included to facilitate comparisons with previously cleared devices. Some of these components might not be present in all medical display products.

The most relevant characteristics to describe include:

- ***Technology:*** Description of the technological characteristics of the display device (*e.g.*, LCD panel with TFT active-matrix array with fluorescent backlight).
- ***Screen size:*** Physical size of the viewable area in diagonal and aspect ratio.
- ***Emissive phosphor type (CRT only):*** Description of the type of cathodoluminescent phosphor material used in the cathode-ray tube (CRT) and its principal characteristics if not a known phosphor.
- ***Backlight type (transmissive displays only):*** Detailed description of the backlight type and, if substantially different from predicate devices, main properties including temporal and spectral characterization.
- ***Pixel array, pitch, subpixel pattern:*** Description of the pixel array including pixel size, pixel pitch, and subpixel pattern (*e.g.*, chevron, RGBW).
- ***Subpixel driving (spatial and temporal dithering):*** Are the subpixels used to improve gray-scale or temporal resolution?
- ***Video bandwidth:*** Capabilities of the information transfer pipeline between the image source and the digital driving levels in all associated components including the CPU, the GPU, and the connectors.
- ***On-screen user controls:*** Control knobs available for end users that relate to the display image quality (brightness and contrast controls, power saving options, *etc*.).
- ***Ambient light sensing:*** Method, instrumentation, and software tool description.
- ***Touch-screen technology:*** Method and functionality. Does it require calibration and periodic re-tuning?
- ***Luminance calibration tools:*** Description of the sensor hardware and associated software for performing luminance calibration. This also includes, if applicable, details about the user-level procedures, service-action tolerances, and centralized automatic calibration tools.
- ***Quality-control procedures:*** Frequency and nature of quality-control tests to be performed by the user and/or the hospital physicist with associated action limits. A detailed QC manual should be included for regulatory review.

***Pre-Clinical Tests:*** This section presents a list of pre-clinical, or physical, measurements useful for defining the performance characteristics of a medical display product. For all of these tests, there exist several methodologies that have been described in the literature, in professional guidelines[3] and recommendations,[4] or in standards.[5] The most relevant pre-clinical tests include:

- ***Maximum and minimum luminance (achievable and recommended):*** Measurements of the maximum and minimum luminance that the device outputs as used in the application under recommended conditions and the achievable values if the device is set to expand the range to the limit.
- ***Gray-scale resolution:*** Technique to convert image values to digital driving levels for achieving some degree of control over the transformation and measurements of the obtained 256 gray-scale resolution.
- ***Conformance to a gray-scale function (e.g., DICOM GSDF):*** Measurements of the intrinsic and calibrated mapping between image values and the luminance output following a target model response.
- ***Luminance at 30° and 45° in diagonal, horizontal, and vertical directions at center and edge spots:*** Measurements of the luminance response at off-normal viewing related to the target model for the luminance response.
- ***Geometrical distortion:*** Measurements of the geometrical distortion introduced by the display device.
- ***Luminance uniformity or Mura test:*** Measurements of the uniformity of the luminance across the display screen.
- ***Bidirectional reflection distribution function:*** Measurements of the reflection coefficients of the display device. Specular and diffuse coefficients can be used as surrogates for the full bidirectional reflection distribution function.
- ***Pixel fill factor:*** Measurements of the active pixel area typically referred to as the pixel fill factor. Since fill factor might vary with luminance, data at several points in the luminance range are indicated. Small fill factors add an unwanted, deterministic pattern to the image.

**Table 1:** Display descriptions, pre-clinical tests, and physical characterization tests for the regulatory review of medical imaging display products are shown here in chart form.

| Modality displays | Displays for FFDM [2] | Mobile displays (modality) | True-color modalities | 3D displays |
|---|---|---|---|---|
| **Display system description: hardware components of the display system** | | | | |
| Technology | **Same as modality plus:** | **Same as modality plus:** | **Same as modality plus:** | **Same as modality plus:** |
| Screen size | Backlight modulation | Brightness adjustment range | Pixel driving for color | 3D technology |
| Backlight type | | Pixel dithering techniques | Color calibration tools | Eye wear |
| Pixel array, pitch and pattern | | Client-server architecture | Method of color management | |
| Sub-pixel driving techniques | | Hardware requirements | | |
| Video bandwidth | | | | |
| On-screen controls | | | | |
| Ambient light sensing | | | | |
| Touch screen technology | | | | |
| Luminance calibration tools | | | | |
| QC procedures | | | | |
| **Pre-clinical characterization metrics related to image quality** | | | | |
| Luminance range | **Same as modality plus:** | **Same as modality plus:** | **Same as modality plus:** | **Same as modality plus:** |
| Grayscale conformance | Grayscale resolution | Angular color response | Color coordinates of primaries | 3D luminance response |
| | Angular luminance | Bidirectional reflectivity | White point and white balance | 3D luminance uniformity |
| | Luminance uniformity | Resistance to fingerprints | Luminance of primaries | Angular and tilt response |
| | Bidirectional reflectivity | Communication latency | Additivity of primaries | 3D luminance crosstalk |
| | Pixel fill factor | Performance and other apps | | Viewing freedom |
| | Pixel defects (count and map) | | | Optimal viewing distance |
| | Spatial resolution | | | |
| | Spatial noise | | | |
| | Veiling glare (small-spot contrast) | | | |
| | Chromaticity | | | |
| | Rise and fall time constants | | | |
| **Supplemental physical characterization tests** | | | | |
| Bidirectional reflection | Gray-to-gray time constants | **Same as modality plus:** | **Same as modality plus:** | **Same as modality plus:** |
| Pixel fill factor | Luminance stability | Interactions with network | Angular color response | 3D angular crosstalk |
| Pixel defects (count and map) | | Power manager interactions | | 3D color uniformity |
| Veiling glare (small-spot) | | Interactions with other apps | | |
| Chromaticity | | Exemption handling | | |
| Spatial resolution | | Fingerprints and image quality | | |
| Spatial noise | | Latency of image delivery | | |
| Backlight modulation | | | | |
| Rise and fall time constants | | | | |
| Luminance stability | | | | |

- ***Pixel defects (count and map):*** Measurements (counts) and location of pixel defects. This is typically provided as a tolerance limit. Pixel defects can interfere with the visibility of small details in medical images.
- ***Veiling glare or small-spot contrast:*** Measurements of the contrast obtained for small targets.
- ***Chromaticity at 5, 50, and 95% of maximum luminance and its variation across the screen or within screens for 205 multi-head displays:*** Measurements of the color at different luminance levels as indicated (at minimum) by the color coordinates in an appropriate units system (*u'v'*, CIELAB) and its variability across points in the screen.
- ***Spatial resolution:*** Measurements of the transfer of information from the image data to the luminance fields at different spatial frequencies of interest or by reporting the modulation transfer function. Non-isotropic resolution properties need to be characterized properly by providing two-dimensional measurements or measurements along two axes.
- ***Spatial noise:*** Measurements of the spatial noise level as represented by the noise power spectrum using an appropriate ratio of camera and display pixels. Spatial noise and resolution (see previous item) affect the way images are presented to the viewer and can alter features that are relevant to the interpretation process of the physician or radiologist.
- ***Frame rate and temporal/spatial backlight modulation techniques:*** Measurements of the temporal and spatial modulation of the backlight component.
- ***Rise and fall time constants for 5–95% and 40–60% luminance transitions:*** Measurements of the temporal behavior of the display in responding to changes in image values from frame to frame. Since these transitions are typically not symmetric, rise and fall time constants are needed to characterize the system. Slow displays can alter details and contrast of the image when large image stacks are browsed or in video mode.
- ***Stability of luminance response with temperature and lifetime:*** Measurements of the change in luminance response with temperature and use time for a subset of the measured data in previous items.

Table 1 presents a general summary of how these tests might apply to products under different categories.

The table also includes a tentative list of pre-clinical tests that might be used in support of novel application areas such as three-dimensional breast imaging, true-color modalities, and mobile displays, which are reviewed in the companion article in this issue of *Information Display*.

Displays are integral parts of medical imaging systems. Their assessment and characterization need to balance the impact on public health with practical and meaningful approaches to demonstrate their safety and effectiveness. Creating an assessment framework upfront is especially important as displays continue to evolve extremely rapidly.

## Note

The mention of commercial products herein is not to be construed as either an actual or implied endorsement of such products by the Department of Health and Human Services. This is a contribution of the Food and Drug Administration and is not subject to copyright.

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# Display Interfaces Go Wireless

*The question is not whether display interfaces will become wireless but how. The sheer number of standards makes that difficult to determine.*

## by Matthew Brennesholtz

THERE ARE LITERALLY DOZENS of ways to connect an image source to a display. All of the most familiar connections involve running a cable from the one to the other. Now, after years of promise, a number of wireless solutions are maturing that can actually meet the needs of users. As "display people," we may not be paying much attention to what is going on with these wireless interfaces – which is precisely why an article on this topic seemed like a good idea. I think readers will find there is a lot more going on and providing a higher level of performance than might be imagined.

In the computer world, the classic VGA cable or the somewhat newer but still venerable DVI cable are perhaps the most familiar connections. In the video world, there are older composite and component connections and HDMI, the new kid on the block who is rapidly becoming the elephant in the room. HDMI is expanding its reach beyond television applications into computer displays as well.

Looking at my desk while I write this article, I see my computer monitor and keyboard and … wires: a VGA cable, at least seven USB cables, a phone cable, and power cords. At least I use Wi-Fi so I am not burdened by a network cable at home. Is there some way to get rid of this clutter and do it wirelessly?

The answer is yes, especially for video and data. Sometimes wireless connectivity can even include power, as is familiar to anyone who has a wireless-handset charging station.

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Fujitsu demonstrated a complete wireless desktop at CeBIT 2011, which used UWB for video and data. The power was inductively coupled into the monitor inductively using SUPA™ technology, as shown in Fig. 1.

The solutions are not simple, however. Part of the problem is not that there are no wireless display connectivity solutions but that there are too many of them. The four standards with the most industry support are two in the 5-GHz band: Wi-Fi, including Intel's WiDi variation on it and WHDI; plus two more in the 60-GHz band, WirelessHD and WiGig. These standards are discussed briefly in the following sections.

### Wi-Fi

Wi-Fi is a trademark of the Wi-Fi Alliance (http://wi-fi.org/) for products based on the


*Fig. 1: Fujitsu demonstrated a complete wireless desktop, including monitor power, at CeBIT 2011 using UWB/Wireless USB for video and data. Photo Credit: Robert Hollingsworth, SVP of SMSC.*



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IEEE 802.11 standard that the Wi-Fi Alliance has certified as interoperable, allowing equipment from different suppliers to reliably talk to each other. Other products based on IEEE 802.11 may be interoperable with Wi-Fi devices, but the Wi-Fi Alliance does not certify them or allow them to use the "Wi-Fi" word or logo. Wi-Fi operates in the 5-GHz RF band and is nearly universal in mobile computers.

Intel has developed a way to use Wi-Fi to connect laptop and desktop computers to displays, calling its approach WiDi (Wireless-Display). This proprietary system uses the normal Wi-Fi interface with video compression, employing Intel chips to fit the HD signal into the Wi-Fi bandwidth.

## WHDI

Wireless Home Digital Interface (WHDI) is a wireless protocol specifically designed to stream uncompressed video, including HD video. It is championed by the WHDI Consortium (http://www.whdi.org/WHDISIG/) and has wide support among HDTV manufacturers, including Haier, Hitachi, LG, Mitsubishi, Samsung, Sharp, Sony, and Toshiba. It also has strong support among component suppliers, including Amimon, Maxim, Motorola, and, presumably, the chip-making divisions of the standard's HDTV supporters.

**Table 1:** 60-GHz bandwidth allocations for indoor use vary somewhat from region to region. All regions, at a minimum, cover the 59–64-GHz range.

| Country/Region | Allocated Bandwidth (GHz) |
|---|---|
| North America | 57–64 |
| South Korea | 57–64 |
| Japan | 59–66 |
| EU | 57–66 |
| Australia | 57–66 |
| New Zealand | 59–64 |
| Brazil | 57–64 |
| China | 59–64 |
| South Africa | 59–64 |

*Source:* Insight Media

WHDI technology is said to enable wireless delivery of uncompressed HDTV throughout the home with video rates of up to 3 Gbps, sufficient for uncompressed 1080p, in the 5-GHz unlicensed band, with the same quality as a wired connection and no latency. WHDI is specifically designed to wirelessly connect multiple devices throughout the home. Because of the need to penetrate walls, ceilings, *etc.*, to meet this design goal, WHDI works in the same 5-GHz frequency band as Wi-Fi or WiDi.

Because WHDI and Wi-Fi use very similar technology in the 5-GHz frequency range, it is possible to build a single chip that integrates both WHDI and Wi-Fi, although to my knowledge, this has not been done yet. The WHDI consortium says that a combined WHDI/Wi-Fi chip would not cost much more than a Wi-Fi-only chip. In addition, software solutions are available that allow the WHDI protocol to be used over ordinary Wi-Fi connections.

WHDI 2.0 is scheduled for release in Q4 '11. This upgrade is expected to have three key improvements:

- Support for ultra-high-resolution video (4K × 2K pixels).
- WHDI/Wi-Fi integration and same channel co-existence.
- Mobile device integration.

## 60 GHz

60-GHz wireless technology has been adopted by two different consortia interested in wireless video connections, the WirelessHD Consortium (www.wirelesshd.org) and the Wireless Gigabit Alliance (WiGig) (www.wirelessgigabitalliance.org). Both consortia's technology is discussed further below. 60-GHz technology is in the early stages of adoption and, when fully implemented, is expected to be available worldwide.

The 60-GHz spectrum is unlicensed and is used for other things besides wireless video connectivity, just as the 5-GHz spectrum is unlicensed and used for more than Wi-Fi. Some of the applications that can benefit from use of the 60-GHz spectrum include wireless HDTV; wireless laptop docking stations; extremely fast downloading of files via wireless gigabit Ethernet, wireless USB 2.0, 3.0, or other non-video connectivity protocols; wireless telecommunications backhauls; *etc.*

Bandwidth in the 60-GHz spectrum in multiple countries/regions has been allocated

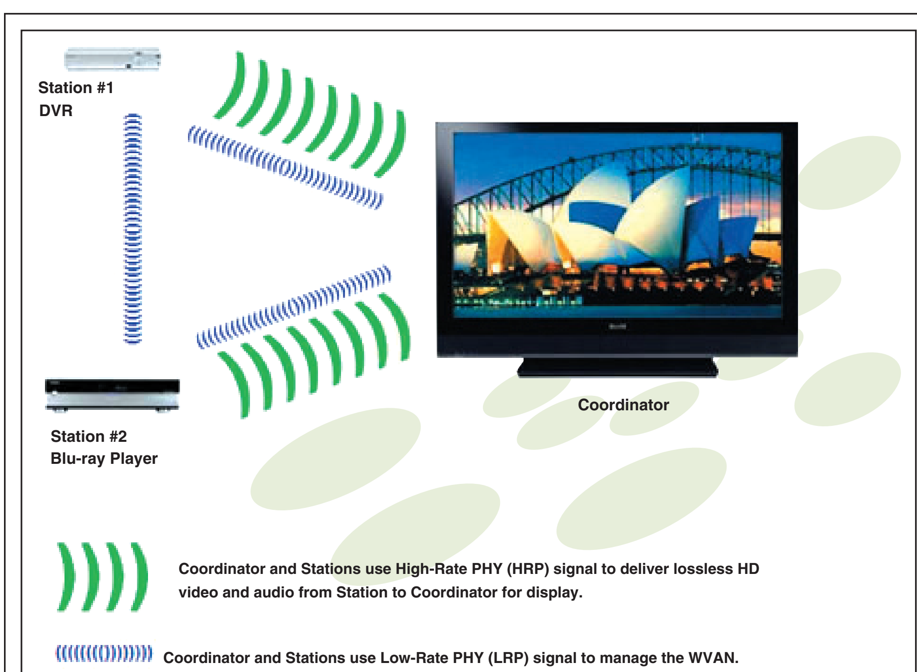


***Fig. 2:*** *This WirelessHD configuration is a Wireless Video Area Network (WVAN) that is using the HDTV as the coordinating component. Source: Wireless HD Consortium.*

for use by mobile computing systems. The allocated bandwidths do not completely overlap, as shown in Table 1, although the 59–64-GHz band is common to all nations and regions. Note that these specifications are for indoor use and some countries have a narrower spectrum allocated for outdoor use.

60-GHz technology is fundamentally shorter range than the 5-GHz technology used by Wi-Fi and WHDI. It also does not penetrate walls. These two properties make 60-GHz technology a suitable approach to point-to-point connection; for example, the connection of a video source such as a handset to a local display such as a pico-projector or micro-projector.

***WirelessHD*** is a 60-GHz technology based on the IEEE 802.15.3c specification. Version 1.0 of the WirelessHD specification was launched on January 3, 2008, and the companion WirelessHD Compliance Test Specification version 1.0 was launched on January 7, 2009. WirelessHD has a long list of sponsors, supporters, and adopters, including Intel, which also supports (and likely prefers) WiDi. Multiple companies that support WirelessHD also support WHDI. These include LG, Samsung, Sharp, Sony, Toshiba, and others. The specification includes provisions for universal remote control of all WirelessHD compliant devices. While the specification is primarily for the transmission of video and audio, including content protection, it can also support data transfer.

An example of a WirelessHD network is shown in Fig. 2. Note that in any WirelessHD network, there is one component, in this case the HDTV that acts as coordinator for the network. All members of the network have low-bandwidth bidirectional contact with all other members of the network. Some members of the network also have high-bandwidth unidirectional links. In this example, both the DVR and the Blu-ray player can deliver high-bandwidth content (*i.e.*, HD video, audio, and copy protection) to the HDTV display. Currently, WirelessHD-equipped HDTV systems are available from LG, Panasonic, and Sony.

***WiGig*** is a different application of 60-GHz technology that is based on the same IEEE 802.11 protocol as Wi-Fi. Therefore, WiGig can be thought of Wi-Fi with a higher bandwidth in a different RF frequency band. This compatibility allowed the WiGig Alliance and Wi-Fi Alliance to establish a cooperation agreement in May 2010 to share technology specifications for the development of the next-generation Wi-Fi Alliance certification program. This agreement further encourages the development of products supporting

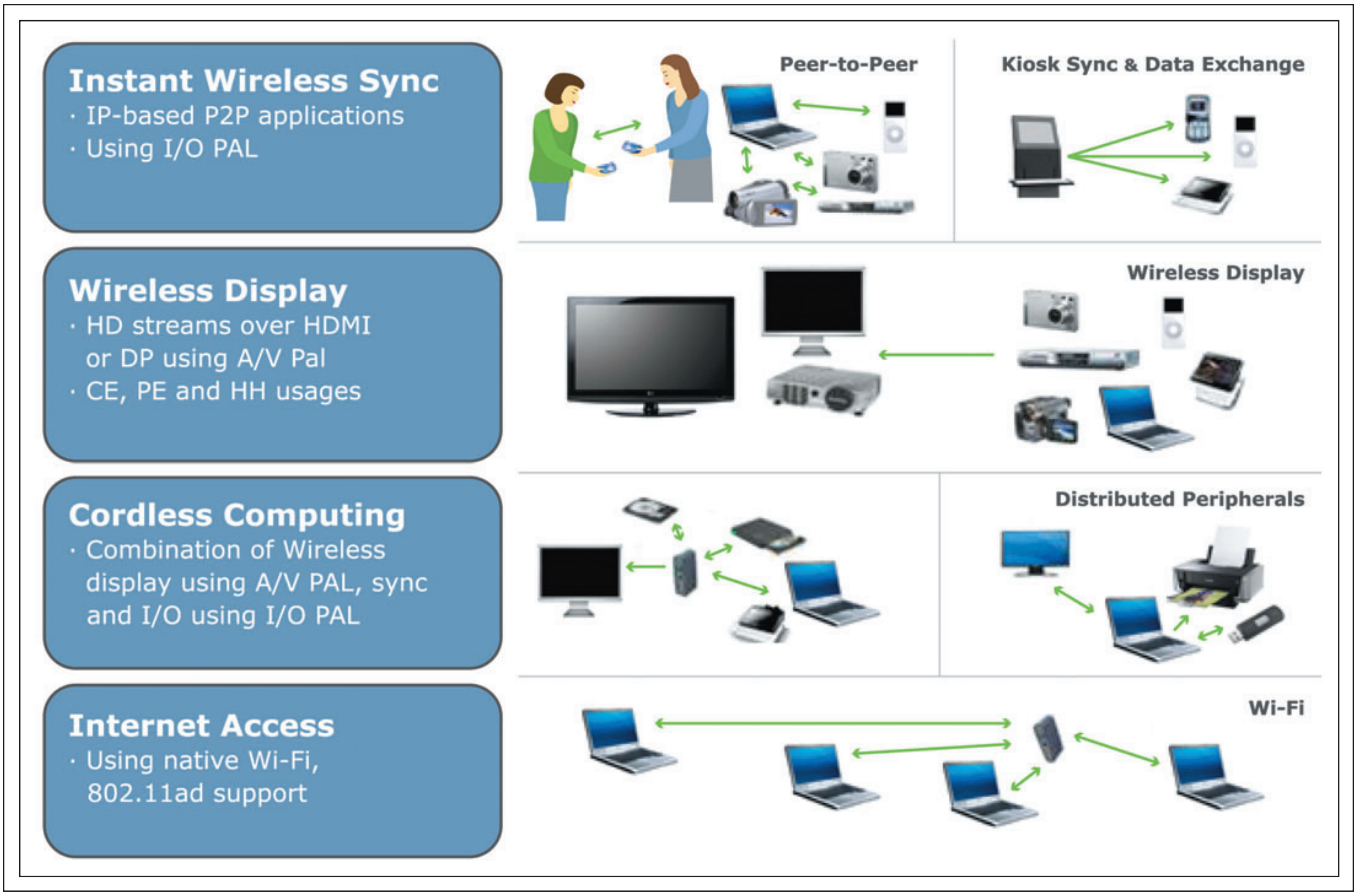


*Fig. 3: The WiGig Alliance has proposed usage models for wireless displays and other connectivity configurations. Image courtesy WiGig Alliance.*

**Table 2:** The various wireless formats have their advantages and disadvantages.

| Technology | Advantages | Disadvantages |
|---|---|---|
| **Suited for Video Rate Applications** | | |
| WHDI format. | • WHDI is the most common wireless video streaming problems in busy Wi-Fi areas such as trade shows.<br>• Will stream HD video without compression or latency.<br>• Low-power modes for mobile, battery-powered devices.<br>• Includes HDCP support. | • Long range (hundreds of feet) may cause interference<br>• Limited to 23 channels. |
| 60GHz | • Limited range and line-of-sight appropriate for mobile host/display connectivity.<br>• Higher bandwidth than Wi-Fi and WHDI, which are based on 5-GHz RF.<br>• Wider bandwidth will allow more end-users to share a channel. | • Antennas are highly directional.<br>• At least two incompatible implementations, WirelessHD and WiGig.<br>• Slightly different regions of the 60-GHz RF spectrum are allocated in different countries |
| Proprietary Standards | • Simplifies product planning by removing uncertainties on the format definition. | • Company pursuing this path would need to have considerable market power.<br>• Consumer would (probably) be limited to a single brand of handset.<br>• Only Apple and Intel may have the marketing power to use a proprietary standard. |
| **Possibly Suited for Video Rate Connections** | | |
| Bluetooth 2.1+ EDR, Bluetooth 3.0 | • Expected to be the default Bluetooth standard for future handset products | • An emerging format and not yet universally adopted<br>• Not all 2.1 products include EDR<br>• Potentially suited to connect portable sources such as handsets to portable displays such as pico projectors |
| Wi-Fi | • Used by most laptop and tablet computers and many smartphone handsets<br>• Implemented as WiDi by Intel | • Wi-Fi cannot accommodate HD video without compression<br>• Relatively long range causes interference problems in busy Wi-Fi areas such as trade shows |
| UWB/Wireless USB | • Compatible with USB 2.0 | • No major companies behind this technology and pushing it<br>• May have interference between multiple UWB users<br>• May cause interference with non-UWB equipment |
| **Unsuited for Video Rate Connections** | | |
| WiMAX | • TBD | • Effectively dead<br>• Long-range communication protocol not suited for connecting nearby host and display. |
| Bluetooth 1.2 | • Near-universal use in smart phone handsets<br>• Designed for mobile environments | • Insufficient bit rate for video |
| Bluetooth 2.0 | • Based on and backward-compatible with Bluetooth 1.2 | • While nearly 3x the data rate of Bluetooth 1.2, still marginal for video |
| Near Field Communication | • Short range and secure | • Low data rates do not allow current versions to be used with video. |
| ZigBee | • Low power | • Intended for control applications and has insufficient bandwidth for video. |

*Source:* Insight Media

60-GHz technology to expand existing Wi-Fi capabilities (Fig. 3).

In addition to working with the Wi-Fi alliance, WiGig is working with the Video Electronics Standards Association (VESA). In November 2010, VESA and WiGig announced that "VESA and the WiGig Alliance will share technology expertise and specifications to develop multi-gigabit wireless DisplayPort capabilities. A certification program for wireless DisplayPort products will be developed in parallel."

WiGig is intended to cover all devices that need a wireless link. According to the WiGig FAQ, "The WiGig specification was designed from inception to address the rigorous requirements of various platforms, including low-power handhelds and battery-operated CE devices. To be more specific, the WiGig specification will include a high-efficiency physical-layer mode for mobile devices, with error-control schemes and MAC-layer features that are optimized for energy efficiency."

### Proprietary Interfaces

One possible scenario for mobile video connectivity is for a company with a strong position in the mobile handset market and a desire to establish a foot-hold in the mobile projector market to establish a proprietary wireless standard. Apple did this in the wired video market with the video output on the iPhone and iPod. This has been a profitable path for Apple and there are many companies building products with iPod docks and paying Apple a royalty on each one. Apple does not license the connector for output: if you want to use the iPod dock on your projector, external speakers, or other system, you must own an Apple iPod or other Apple product, not a similar device from an Apple competitor. Another possible scenario is for a chip maker to provide a complete range of support chips for a proprietary interface. Intel is trying to do this with its WiDi system, as discussed.

The technology to pursue this proprietary strategy exists. Probably the strategy would take the form of a minor variation on one of the non-proprietary standards, just as the iPod connector, from a video point of view, is a minor variation on composite video.

The proprietary strategy would overcome the video-format compatibility issues inherent in the use of a non-proprietary wireless data transfer protocol. If Apple or some other company chose to pursue this strategy, there likely would be no advance notice: Apple (at a major media event) would simply announce its products, which would include at least one wireless-equipped iPhone or iPad and a compatible wireless equipped projector or other external display system (iProjector?). LG, Samsung, and a (small) handful of major handset manufacturers possibly could also pursue this proprietary path. LG and Samsung's announced support of standard protocols makes it unlikely they will introduce proprietary systems, however.

### Wireless Connectivity Summary

Table 2 shows a summary of the various wireless standards. For completeness, this table includes wireless standards that are clearly not suited for video-rate connection between a video source and a display. In the future, it is likely that mobile devices will have more than one wireless protocol, intended for different purposes. For example, it is not difficult to imagine a next-generation tablet computer having Wi-Fi, 3G, or 4G connectivity for Internet access; 60 GHz for display connectivity; Bluetooth for headset, keyboard, or mouse connectivity; and near-field communications (NFC) to make the handset a virtual debit card.

What can be concluded from all this? First, wireless connectivity between video sources and video displays is coming. In fact, it is not only coming, but has already arrived in some cases. Second, there are at least four standards with major corporate support that allow wireless video connectivity at HD data rates. These include WiDi and WirelessHD in the 5-GHz band and WHDI and WiGig in the 60-GHz band. WHDI and WiDi are both longer range. Unfortunately, they are in the already crowded 5-GHz band with Wi-Fi. WirelessHD and WiGig are both in the newer 60-GHz band and are intended for short-range connections.

I suspect in the long run there will be one 60-GHz and one 5-GHz video communications protocol. At this point, I refuse to guess as to which of the two standards in each RF band will be winners and which will be losers, but it would behoove display makers to follow the market carefully in order to ensure compatibility down the line. ■

## Get the Bigger Picture at Display Week 2011

*Parallel conferences provide overview of display industry finance, marketing, and business trends*

The Technical Symposium is the heart of Display Week. The products and prototypes on the exhibit floor are the excitement. And the parallel conferences help put it all into context. Display Week's Market Focus Conferences, Business Conference, and Investors Conference provide attendees with unique opportunities to learn more about the overall display landscape, including its marketing and financial trends. Each conference is run by experts in the field – analysts and investment specialists – who co-host their respective events with the Society for Information Display. Although it can be hard to fit in everything one wants to see and hear during Display Week, attending a market, business, or investors conference is essential in order to emerge from Display Week with a competitive edge. This information simply is not available anywhere else.

**Market Focus Conferences**

The Market Focus Conferences successfully debuted last year and will once again be held in conjunction with Display Week and in collaboration with IMS Research. The three conferences will focus on critical market-development issues in each of three technology areas: touch, green displays, and e-Books/tablets.

The "Innovations in the Touch" conference provides an international forum for senior executives, technical managers, and marketing personnel from leading companies involved in touch technology to meet with other industry players and examine the market potential, technical barriers, and new opportunities of next-generation touch and interactivity.

With increasing legislation and environmental awareness, the need for low-power displays has become greater than ever. The "Green Displays" Conference will look at issues such as green-display legislation and its impact on display manufacturers, the transition to LED-backlit displays to reduce power consumption, semiconductor initiatives that reduce power consumption, innovations in fully recyclable displays with non-toxic components, and new technologies for reducing power consumption.

The "eBook/Tablet Market Evolution" conference will address the ramifications of the rapid growth of the Amazon Kindle and the Apple iPad, which represent two of the fastest growing markets in displays. Will these markets remain distinct or will they collide? This conference will examine the outlook for each of these markets and how their displays are likely to evolve, in terms of size, form factor, and much more. For more information, http://65.38.182.180/Programs/MarketFocusConferences.aspx

**Business Conference**

DisplaySearch will once again organize the Business Conference to be held during Display Week. This year's conference will feature presentations from top executives of leading companies throughout the display supply chain. The sessions will be anchored by DisplaySearch analysts who will also present in-depth market and technology analysis, with their latest forecasts.

Sessions include:

- *Economic Issues and Consumer Trends*: What is the outlook for the global economy, and which are the fast- and slow-growing regions?
- *Equipment and Manufacturing:* What is the state of the art in flat-panel manufacturing equipment, materials, and manufacturing processes?
- *Panel Production and Technology, including Regional Trends:* How rapidly will panel production grow in China? Which regions will lose market share as China gains?
- *Set-Making and Applications:* How are the value chains for TVs, monitors, and notebook PCs, mobile devices, and other display systems shifting? How are devices such as e-book readers and tablet PCs changing demand?
- *Emerging Technologies and Applications:* What are the most promising new display

technologies? How is TFT-LCD technology improving to meet the challenge of other technologies such as OLED and reflective technologies?

For further updates visit http://65.38.182.180/Programs/BusinessConference.aspx

**Investors Conference**

The Investors Conference is co-sponsored by Cowen & Co., LLC, a securities and investment banking firm. The conference will feature company presentations from leading public and private display companies and is intended to appeal primarily to securities analysts, portfolio managers, investors, M&A specialists, and display company executives. For further updates visit www.cowen.com

For information about fees and registration for the conferences, and about the rest of Display Week 2011, visit www.sid2011.org. ■

*continued from page 2*

There are many philosophical issues to contemplate here, but I will address the commercial side; in particular, the business of displays. Despite the severity of what has taken place in Japan, it appears that the display industry may escape this one with only minor economic impact. Most of the major LCD manufacturing facilities in the country are located more to the south, and their factories were not apparently damaged, though we do know that Sony as well as others have suspended some production temporarily because of component shortages. There was some touch-screen manufacturing in the area around Fukushima that is likely shut down permanently. Other reports say that certain chemicals used in coatings came from that area and will be in limited supply indefinitely, and there is some OLED-material production as well that has been disrupted. Fortunately, there are other sources for these materials.

In many cases, we will likely see short-term disruptions due to infrastructure and power outages rather than directly due to factory damage. There has been some hoarding, with shortages of LCD panels, in the U.S. distribution channels that may or may not have resulted from anything more than speculation, but all in all I think the display industry dodged the big bullet – this time. That should not, however, reduce our sense of urgency for better disaster planning. If this event had happened in a different region of Japan, or in certain parts of other countries like Taiwan, Korea, or China, the economic impact to displays might have been crippling.

Thinking about all this has helped me to realize that our display industry worldwide is very vulnerable to large-scale natural and man-made events, and therefore so is the rest of the electronics industry. There are so many consumer and industrial products today that rely on displays that any disruption in the supply of display modules could have a very large economic ripple effect. Roughly half of all large-area TFT-LCD panels are produced on the Korean peninsula, with the other half coming from Taiwan, China, Japan, and neighboring countries. The entire Pacific rim is a region rich in plate tectonic activity and volcanic instability that has earned the name "Ring of Fire." Multiple sources confirm that the majority of the world's largest magnitude earthquakes occur along this ring, which forms a horseshoe extending roughly from New Zealand up past Japan, across the Aleutian Islands in Alaska, down along the U.S. west coast, and all the way to the bottom tip of South America. The world's electronics, and in particular displays, from raw materials and chemicals up to finished monitors, TVs, notebooks, handheld devices, and countless other display-enabled products, are manufactured in factories near this ring. It seems self-evident that any future large-scale natural event along this line could have a dreadful impact on the world's electronics economy.

This is why the industry must come together to develop real long-term comprehensive disaster prevention plans. Many companies have internal disaster recovery plans, but they generally do not address situations where entire geographic regions or complete supply chains are wiped out. The display industry needs a broad-based redundant capacity recovery plan that spans multiple continents and addresses recovery of the entire supply chain. It will not be easy because some of the most obvious things such as redundant manufacturing in multiple locations, and larger inventory reserves, are very expensive to implement. It would require that normally highly competitive and secretive companies must work together in ways to which they are not accustomed. Government is not the answer this time because no one country or even one political system controls the industry. Neither can major consuming customers such as cell-phone makers or notebook manufacturers drive this on their own, though they can make second sourcing and disaster planning a key part of their supply-chain acquisition strategy.

For this to really happen, it will require all the major players (and you know who you are) to take a very high-level view together of the entire landscape and decide for yourselves that you will never allow a large-scale natural disaster to cripple the rest of the industry. An extraordinary number of people rely on displays and electronics for their very economic survival. I think we are obligated as stewards of the display industry we have built to heed the warnings delivered to us by the Sendai earthquake, if not for ourselves, for the generations to come after us.

Returning to the "issue" at hand, let me welcome you to the 2011 SID Preview and Honors & Awards issue of *Information Display*. I have said this many times before, but it bears repeating, that while the discoveries and achievements being recognized through this years honorees may seem like overnight successes, they are the culmination of each person's lifetime of hard work and experience. As managing editor Jenny Donelan explains in her cover story, while there may have been some serendipity involved in their individual circumstances, it was their skills, insight, and a lifetime of hard work that closed the deal. I hope you will join us in celebrating this year's SID Honors & Awards recipients.

This was a busy month for Jenny because not only did she chronicle the Honors and Awards, she also contributed this month's annual Symposium Preview of the key papers to be presented at Display Week 2011 in Los Angeles this May. The annual Symposium is the heart and soul of SID and the place where the very latest cutting-edge developments get revealed. Reading the preview, I'm sure you will see that the variety and depth of innovation in all the different aspects of display technology is as strong as it has ever been. For me this is one of the best leading indicators of a healthy economic recovery!

Our Guest Editor for this month is Dr. Aldo Badano from the Center for Devices and Radiological Health, FDA, in Silver Spring, Maryland. Aldo not only took up the mantle of updating us on the field of medical displays, he also co-authored two of the three technology features we have this month, and we are very grateful for his tireless efforts on the behalf of ID. In the first feature, authors Aldo Badano and Wei-Chung Cheng discuss several very interesting "Emerging Topics in Medical Displays," including the potential and challenges of using mobile displays for some types of diagnostics, and the growing interest in 3-D displays and images to aid better breast-cancer detection. In the second feature, the same authors provide us with an overview of the challenges associated with pre-clinical, regulatory assessment of display systems used for viewing and interpreting medical images. As you will read, it is no small feat to gain the necessary data for eventual regulatory approval of a new display system for medical diagnostic use and the authors give us comprehensive insight into those issues.

Multiple-primary displays, those having more than just the traditional red-green-blue color components, have long been a topic of discussion and in some cases have resulted in innovative commercial offerings such as flat-panel TVs and projection systems. In this feature, "Multiprimary-Color Displays and Their Evaluation Methods," author Professor Masahiro Yamaguchi (Global Scientific Information and Computing Center at Tokyo Institute of Technology), using an example six-primary display, describes the complex technology of multiprimary systems, their advantages for medical applications, and the methodology of evaluating their performance.

Turning to the marketplace, we welcome again author Matthew Brennesholtz, who incidentally published a two-part article in *ID* in September and October of 2006 on the science of color gamuts. These articles provide some good background understanding of the color-space discussions in Professor Yamaguchi's feature. This month in his article titled "Display Interfaces Go Wireless," Matt takes up the challenge of summarizing the growing competitive space for wireless display interface standards and how they compare to each other in performance and future potential. This is a comprehensive survey that contains a lot of valuable information. I hope you will be able to use it as a reference in the next few years. You may even be able to make some smart feature or product platform decisions based on this data. I'm sure we'll be able to persuade Matt to keep us updated from time to time, but don't forget where you save this article when you are done with it! You'll need it again for reference, no doubt.

Remember, you can always find this issue and every other recent past issue of *ID* online at www.informationdisplay.org. And with that, I wish you well and look forward to seeing everyone in Los Angeles in May. ■

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The following papers appear in the April 2011 (Vol. 19/4) issue of *JSID*.
For a preview of the papers go to sid.org/jsid.html.

## Letters

### Projection Displays and Systems



## Special Issue on Advances in OLED Displays

### Organic Light-Emitting Diodes and Displays (OLEDs)

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Los Angeles, California May 15 - 20, 2011

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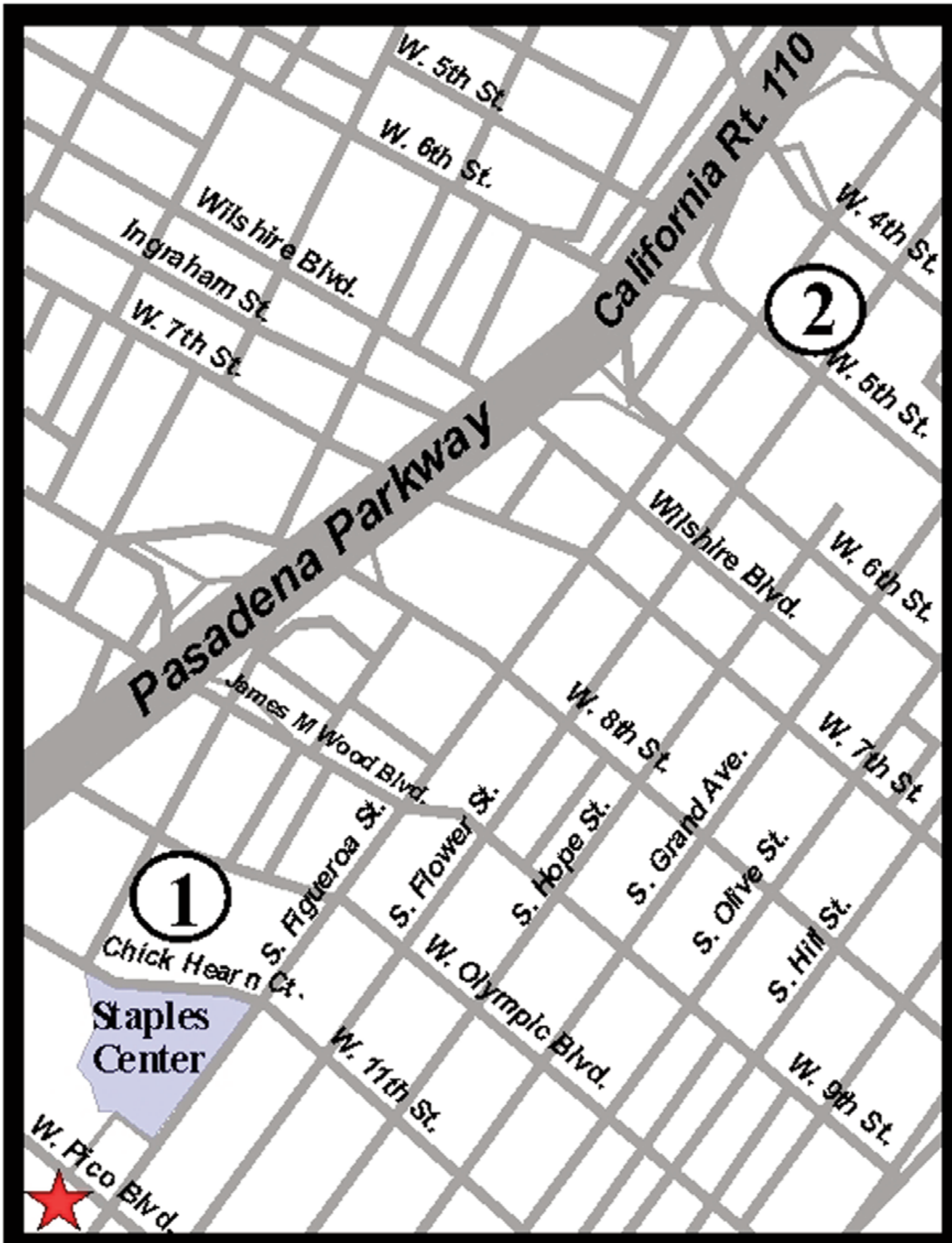


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