TABLETS AND TOUCH ISSUE

Information DISPLAY

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The Evolving World of Tablets and Touch

A NEW CARBON NANO-MATERIAL ENHANCES TOUCH SENSORS

THE DISPLAY BUSINESS IN TAIWAN

NEW TRENDS IN TOUCH

CHARACTERIZING CURVED TV — OLED vs. LCD

BEST PERFORMING TABLET DISPLAYS

SELECTING THE RIGHT DIGITAL PEN

Plus

The Passing of Two Display Pioneers

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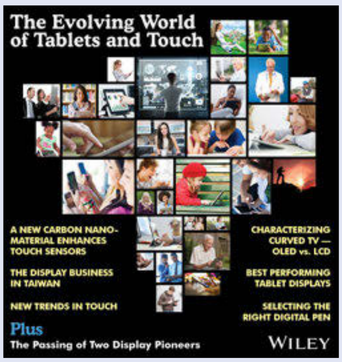
ON THE COVER: *As the markets for touch and tablets expand, so do the opportunities for new and innovative product designs and concepts.*



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contents

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In the Next Issue of *Information Display*

Display Week 2014 Review
- Technology Reviews
  - New Materials
  - OLEDs for Displays, Lighting, and Wearables
  - Touch and Interactivity
  - 3-D and TVs
  - Flex and e-Paper Trends
- Why Monitors Should Not Be Overlooked
- Best in Show and I-Zone Prototype Awards

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editorial

It's Not Just Science Fiction

by Stephen Atwood

I've been a fan of science fiction stories and movies for most of my life. I enjoy the idea of distant worlds and the way the limits of physics, chemistry, and biology are stretched far beyond what we know today. Whether the stories take place on distance space stations like Babylon 5, with beings such as Vorlons, Narns, and Centauri, or on starships traveling through the planetary systems of Vulcan, Klingon, or Aldebaran, they all incorporate certain exaggerations of known science, such as traveling faster than the speed of light or near-instantaneous transformations of living tissue into any genetic code or condition required to make the story work.

Of course, we know today that many things that seemed like fantasy a generation ago, such as gene splicing and genetic engineering, are now serious research topics that are evolving into practical science. It's not quite so yet for faster-than-light space travel or telepathic communications, which will probably take at least a few more generations before they are realized. However, in any of these aforementioned imaginary worlds, as well as the 2013 movie *Ender's Game* (based on the novel by Orson Scott Card), computers always play a critical and pivotal role in supporting humans or aliens through their complex missions. It's hard to imagine a science-fiction story that does not have a computer or network of computers as part of its central premise.

In the ongoing quintet of books starting with *Ender's Game*, computers provide vital communications, analysis, and control of practically all technology. New life forms emerge within the circuits and webs of digital interconnections, one of them so powerful it can intercept and monitor all communications between all computers in the novels' planetary system simultaneously and provide compassionate humanistic analysis of that information in real time. This entity, named simply "Jane," becomes a sentient person who battles alongside the main characters to save their world while at the same time solving the most complex mathematical problems ever considered in known history. This is something even Apple has not yet been able to put into an iPhone app.

In many of these stories, however, the authors struggle and usually fail to represent the practical realities of interaction between the users of these complex machines and the computers themselves. Where vast amounts of real-time information are available, the solution is usually to have the computer sort it all out and talk to the humans or aliens in their own spoken language. Star Trek characters used a combination of spoken interrogations and display screens to get the information they needed. These interactions were usually devoid of typical real-world clutter such as missing information, false conclusions, or mis-adjusted instruments. Later embodiments of the Star Trek world did embrace holographics and handheld devices, but overall they never truly addressed the problem of real information management and transfer between people and machines. In the *Ender's Game* universe, we see computers that communicate with their users through holographic displays and two-way audio/video devices – not unlike a Bluetooth earpiece and a pair of Google glasses. These methods appear feasible, but, in fact, computer networks today can access and analyze vast amounts of data far faster than human beings can interpret and process that data.

As we move away from keyboards and into all manner of so-called "wearable" devices, we are only now beginning to deal with the challenges of advanced interactivity. Having constant conversations with your devices and counting on them to interpret all the nuances of the problems to be solved is just not realistic at our present time. Our

(continued on page 38)

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Samsung Invests in Cambrios

Cambrios Technologies Corporation, the maker of silver-nanowire-based technology for transparent-conductor markets, recently announced a $10 million second round of strategic investment by Samsung Venture Investment Corporation (SVIC). (Cambrios received an investment of $5 million from SVIC in 2011.)

Cambrios' ClearOhm coating material is made from highly conductive silver nanowires that are designed to offer higher optical and electrical performance than previous-generation transparent conductive materials such as indium tin oxide (ITO). ClearOhm ink is currently being used to produce high-performance transparent conductive films that enable touch panels and displays, as well as OLED lighting tiles and solar cells.

Product News from Display Week

Here are just a few of the many new products and technologies announced at Display Week last June, as reported by *Information Display*'s staff and roving reporters. For more about these and other announcements from the show, visit http://idmagazine displayweek2014.blogspot.com. In-depth coverage from Display Week will appear in the September/October 2014 Show Review issue of *Information Display*.

E Ink Introduces Super-Sized e-Paper Module

On the first day of the show, E Ink Holdings announced a new e-Paper module that is substantially larger than any it has produced thus far. The new display measures 32 in. diagonally (almost 25 times the size of the display in a typical e-Reader). It is designed primarily for digital signage and information-kiosk markets and is available in both black and white and in color. The display has a resolution of 2560 × 1440 at 94 ppi and was developed in cooperation with Global Display Solutions (GDS), which created enclosure technology so that the display can be used outdoors. GDS will jointly market the product with E Ink.

– Jenny Donelan

The Femtosecond Solution for Cutting Glass

The folks at Raydiance believe that femtosecond lasers will transform glass-cutting display applications much as they have made significant contributions to micromachining solutions in the medical and automotive industries. The company's "R-Cut" solution can perform free-form cuts in Gorilla Glass and other materials, as well as drilling micro-holes and other precise features, and can produce cover-glass parts at half the cost of mechanical singulation methods. The cost savings are due in large part to the fact that femtosecond-laser cuts have an excellent finish and require no further polishing or smoothing steps. The company formally introduced the system at Display Week.

– Ken Werner

Notebook Display Uses QDEF for Stunning Imagery

At Display Week, 3M and Nanosys showed ASUS notebook PCs with 15.6-in. 4K quantum-dot-enhanced screens with a wide color gamut. This is the first high-volume product using 3M's QDEF (based on quantum dots from Nanosys), and 3M sees the product's introduction as a milestone. The resulting imagery was so striking it was difficult to look away from. This is a display that could easily sell the product of which it is a part, and it's an example of the remarkable ability of quantum dots to provide dramatic increases in a display's impact.

–Ken Werner

Merging Fiber Optics with Displays

INCOM showed some interesting demonstrations of its fused fiber-optic technology at Display Week, including changeable keyboard keys. This technology uses a simple, low-cost LCD panel mounted inside the control panel. INCOM's fused fiber-optics blocks channel the light from the panel to the key cap. By changing the image displayed by the panel, you can change the image under the key cap. This provides an instantly changeable control panel without the cost and complexity of creating separate displays for each key. INCOM has used this technology to create controls and display panels for everything from flight simulators to slot machines. The company originally made the materials out of glass, but has since added polymer products that reduce weight and cost.

– Alfred Poor

INCOM's fiber-optic technology enables keypad keys whose displays are changeable through programming just one LCD panel. Photo courtesy INCOM.

Self-Healing Material Protects Mobile Devices

By their very nature, mobile devices are more exposed to physical damage than desktop devices that spend their time sitting safely

(continued on page 39)

guest editorial

The Next Frontiers for Touch Technology

by Bob Senior

As the market for touch, touch-related applications, and materials continues to explode, so do the opportunities for new and innovative product designs and concepts. Where all this will propel the display industry is just about anyone's guess, but for sure it will bring about better interfaces and methods for consumers to interact with and control their world in simpler and more efficient ways than ever before.

Perhaps the most hyped touch applications at the moment are automotive and wearable. The sheer breadth and depth of new wearable companies that launched at CES earlier this year was staggering, but in some ways also a little disappointing. I didn't see anything that had any real "wow" appeal. In general, what I witnessed were a multitude of companies jumping on the bandwagon with underwhelming, relatively conservative, and even what some might call boring designs.

I have to admit that all the necessary components for fashionable wearables are not readily available. I'm talking about small, flexible OLEDs. When these do finally arrive in volume, what's left of the startups and, of course, the big companies should be able to design truly awesome devices that will be differentiated and fashionable. They will also offer a real use case that will compel people to wear them. (I read recently that one out of six Americans owns a piece of wearable tech, but that one third of them stopped wearing it after 6 months!)

The trend for flexibility will continue to drive the market toward truly flexible touch materials. It's a given that ITO will not work, but will the ITO replacement materials currently touted work? Just about everyone claims flexibility, but just how will these things stand up in the real market, after many hundreds of thousands of bends, twists, rolls, and even folds? The stunning answer is that right now no one really knows. The testing thus far has been cursory; customers can only rely on the marketing promises of the ITO replacement vendors.

Flexibility is one thing, but readability in varying lighting conditions is another. I have been amazed to see smart watches brandishing ITO-based touch technology that are rendered next to unreadable by reflections as soon as you go outdoors with them.

Automotive applications will also throw interesting challenges at the touch industry. All of a sudden, car makers want to make just about every surface in the car touch interactive – ok, maybe this is a slight exaggeration! Clearly, however, a desire for conformable 3-D touch surfaces will set more goals and challenges for the touch industry. Molding surfaces through tight radii can introduce significant material stretching, anything up to 100%, I'm reliably informed. This means the touch interface is stretched as well. Only now are companies beginning to test out base materials and beginning to understand how to solve these real issues, but the general knowledge base remains bereft.

Don't get me wrong – the consumer market has a knack of driving solutions to these issues. We are in the exciting phase of discovery, and I'm sure that real, worthwhile, functioning, and fashionable technology is on the way very soon.

The touch-technology articles I assigned for this issue of *Information Display* reflect the topics outlined above. For example, I asked Jenny Colegrove, Ph.D., President of Touch Display Research, Inc., to provide a short overview of the market, highlighting what she sees along with some of the key challenges and opportunities facing the

(continued on page 43)

Technologies and Requirements for Digital Pens

N-trig, a maker of digital pens and an innovator of touch technology, describes what to look for and what to expect when selecting a digital pen for mobile devices such as smartphones, tablets, and subnotebooks.

by On Haran

MANY digital-pen-equipped devices have been introduced recently.[1–4] This is, in part, because users are demanding a more capable tablet than one solely designed for media consumption. While the technologies behind these pens vary significantly, they all are subject to varying levels of jitter, linearity, and accuracy, and they all have requirements such as pressure sensitivity and palm rejection that must be addressed in order to provide a feel to the user that is similar to that of pen and paper. In addition, the ideal digital pen should be cost effective and integrate easily into all kinds of mobile devices. Besides enabling content creation and manipulation, the digital pen should complement the man–machine interface by introducing mouse-like capabilities such as accurate on-screen pointing, left and right button clicks, and "hover over" detection not possible through touch alone. Figure 1 shows various examples of content creation with digital pens.

Fig. 1: Digital pens enable content creation such as note taking, document annotating, drawing, and signing.

Digital-Pen Technologies

Digital-pen technologies can be classified as shown in Fig. 2. Device-integrated pens enable interaction with and writing on device screens, whereas offline pens capture inking on paper or dedicated substrates and subsequently transfer the collected data to the devices. (Inking is the industry keyword for the act of transferring user pen gestures into digital representations.) Offline pens require increased cognitive activity on the part of the user and tend to reduce the overall experience to some degree. Touch-sensor-integrated pens interact with the grid of capacitive-touch electrodes that exist on most laptops, tablets, and smartphones, providing simultaneous pen and touch as well as palm rejection and therefore providing a better user interface with the device. Other pen technologies – including optical, ultrasonic, and electromagnetic – require the addition of dedicated sensing components within the device, increasing the device cost, thickness, and power, and thereby compromising the touch integration.

Touch-sensor-integrated digital pens can be further classified as a passive stylus or active pen, with physical operation principles shown in Fig. 3. The passive stylus operates by

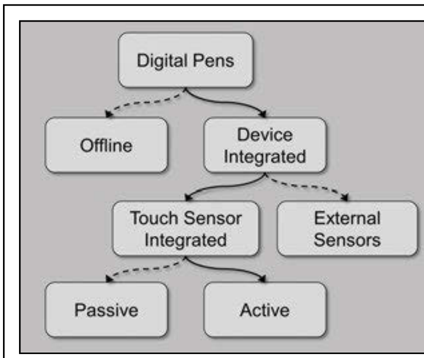

Fig. 2: Digital pens can be roughly classified by the above attributes.

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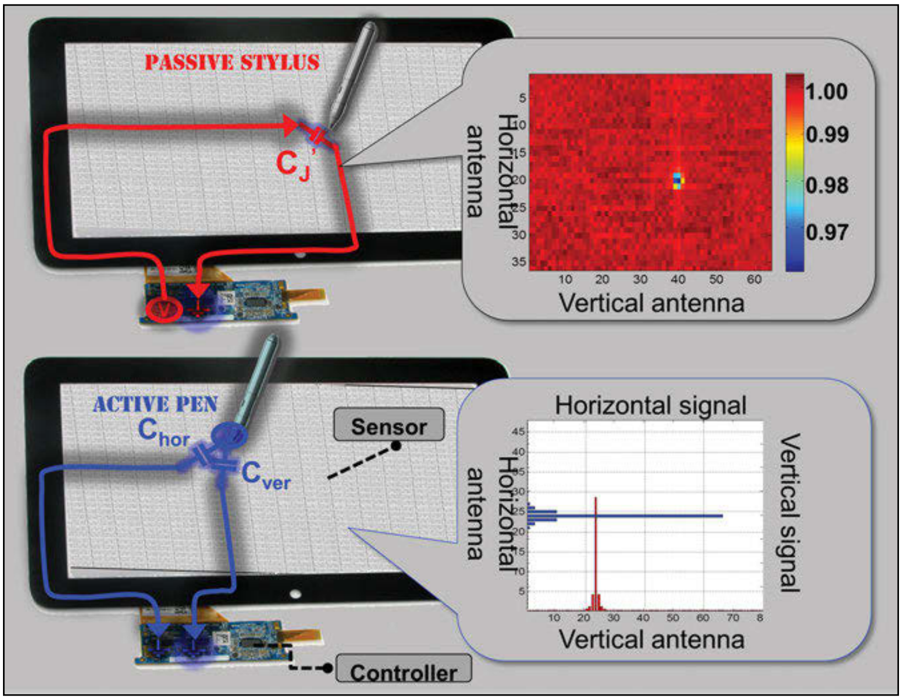

Fig. 3: Active pens and passive styli both interact with the touch sensor, but operate differently.

projected-capacitance (p-cap). In p-cap, electrical signals are driven on a set of conductive transparent electrodes deposited on one axis of the touch-screen sensor, while synchronized sensing of electrical signals takes place on a perpendicular electrodes set. The signal transfer between the axes depends on their "proximity," which is formally indicated by C_J, their junction capacitor. When an object, such as a human finger, is placed on the device screen in the vicinity of the junction area, C_J drops by 10–30%, depending on the touch-sensor design, leading to weaker sensed signals and, consequently, touch detection. While it works well for human-touch detection, p-cap poses challenges when it is utilized for passive styli because those employ fine tips (1–2 mm in diameter) to enable visibility of the underlying pen inking. As a result of the fine tip, the relative reduction in C_J is only around 1–3%. This weak effect challenges passive-stylus operation in the presence of user touch, electrically noisy environments, high and low temperatures, and other non-optimal working conditions. Furthermore, it is not easy to distinguish a passive stylus from fingernails and other fine user touches. The usage of passive styli is therefore restricted to less demanding applications. In some cases, powered electronics are used to enhance the weak passive-stylus signal by injecting a synchronized interfering signal to the touch screen to improve detection, but performance and feature shortcomings still exist compared to that of active-pen technology.

Powered active pens[13] drive unique modulated signals from the pen's tip to the horizontal and vertical grid of electrodes. In this operation mode, sensing takes place on both axes simultaneously, with the received signal magnitudes being proportional to the tip capacitance (= proximity) to the electrodes. Signal processing is employed to digest all received signals and extract accurate tip positioning. These modulated content-rich signals are orthogonal to the touch-sensing signals, and therefore active-pen sensing is not confused with touch sensing. Through their modulation, these signals provide additional information about the pen and its state (tip pressure, buttons pressed) and can be captured even when the pen is hovering above the device.

Figure 3 also shows the components of a digital-pen solution for both active pens and passive styli – the pen, the sensor, and the controller. The sensor, which is embedded within the device, senses the presence of the pen in its vicinity, and transfers analog signals to the controller. The controller applies analog and digital processing to the signals; extracts the pen information amidst the surrounding noises generated by the device display, power adaptor, and other peripherals; and forwards "pen reports" to the host device operating system, which acts upon the user instructions and operations embedded in these reports. This process enables pen reports that are more frequent in occurrence compared to touch events, improving the user experience.

Requirements

Despite the variety of technologies and options available for digital pens, a unified set of requirements can be defined to ensure that users will be satisfied with pen performance. Initial steps were taken by Microsoft, focusing on several mandatory performance metrics.[5] A more comprehensive set is discussed below, including automated (*jitter, accuracy, linearity, edge behavior, tilt-error*, and *pen lag*) and manual (*missing/extra strokes, inking in hover*) inking testing, as well as a description of pen requirements beyond inking.

It should be noted that pen performance does not only depend upon the pen but also on the sensor size, position, and design, and on the controller configuration, digital signal processing, and firmware; thus, pen verification should be conducted for the entire device, including pen, sensor, and configured controller.

Achieving high-quality inking is the cornerstone of a good digital pen. Various types of inking tests are discussed below. Automated testing highlights specific inking gaps. The testing is performed using a robot having X-Y-Z axes (see Fig. 4). Prior to performing the tests, the device should be properly aligned on the robot platform. Automated testing can also be applied to other digital pen features, as is shown in Fig. 4 on the right, where a pressure testing apparatus verifies active-pen pressure reports *vs.* the actual mechanic pressure applied by the tip to the device.

Jitter, linearity, and accuracy are major positioning metrics that are shown graphically in Fig. 5. Jitter refers to the maximal distance between pen reports obtained for a static pen. The robot thus positions a pen statically on the digitizer, and a related application measures the maximal distance between the resulting pen reports. Most pen controllers employ

Fig. 4: A robotic apparatus enables accurate verification of inking (left) and pressure (right).

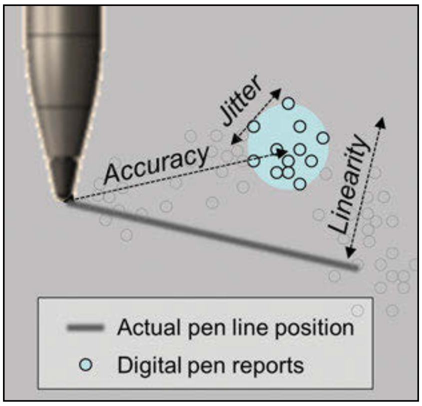

Fig. 5: Jitter, accuracy, and linearity are compared in terms of physical pen position vs. digital reports.

processing techniques to keep static pen reports uniform, hence this test should result with "0" jitter. Industry commonly acceptable non-processed pen jitter should not surpass 0.2 mm (being 2% in magnitude of 1-cm-sized characters).

Linearity is tested by slowly (<5 mm/sec) drawing diagonal lines across the screen in different orientations. The deviations of the reports from the best-fitted line are measured to yield the "linearity." A pen linearity up to 0.4 mm is commonly acceptable in the industry today. Typical linearity measurements for an active pen *vs*. a passive stylus are shown in Fig. 6.

For positioning accuracy, the test robot places the pen at different points across the device and ensures that the delta gap between the actual placement and the reported averaged position matches the specifications (typically <0.4 mm). In order to be accurate, the controller processing should account for the sensor design and positioning within the device.

The robot then tilts the pen to different angles, while maintaining the same tip-device physical touch position. Ideally, the device should report a steady position. In reality, though, the interaction between the pen and the device is not limited to their physical touch position, and therefore the reported position is biased to the direction of the tilt. Figure 7 shows this tilt-induced error, with the cursor reported at a shifted position due to the pen tilt. Industry acceptable tilt error is 0.75 mm at 30° tilt.

Edge inking is tested by drawing lines from within the interior of the sensor towards the boundary and in the inverse direction. Figure 8 shows an example of incorrect edge inking, where lines are not well terminated when reaching the device boundary.

Pen "lag" represents the gap between the actual and reported inking in terms of space and time. A cursor lagging behind when the pen is moved quickly illustrates this deficiency. Testing lag includes an optical beam or microphone to monitor the actual inking time, which can be compared to the reported one. Lag exists due to several mechanisms,

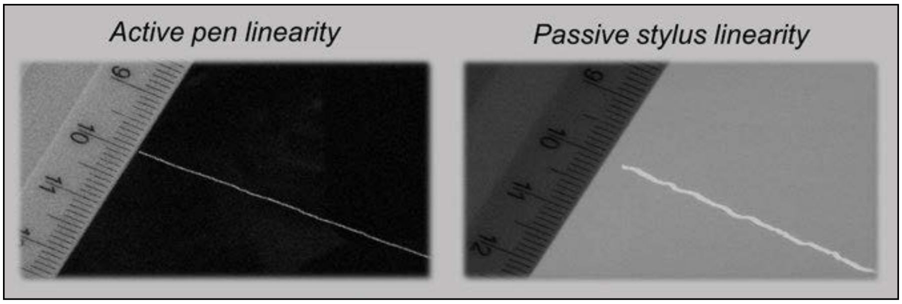

Fig. 6: Linearity testing demonstrates a performance gap between active pens and passive stylus.

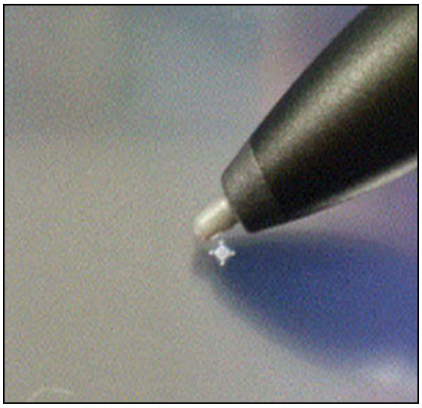

Fig. 7: The tilt accuracy of a digital pen is an important consideration in terms of accuracy and ergonomics.

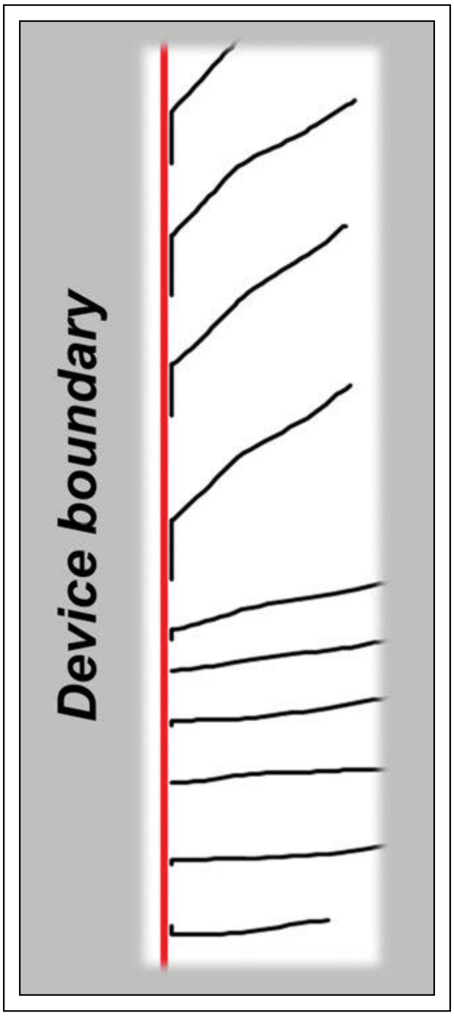

Fig. 8: Edge-inking imperfection is shown for lines drawn from the interior of the sensor toward the edges.

among which are the limited refresh rate of the controller (usually around 100 Hz), processing applied within the controller, and non-immediate interaction with the device OS and drivers.

Manual content-oriented inking testing addresses inking gaps that do not manifest themselves in robot testing. Figure 9 shows results from a manual inking test conducted by placing a paper and a sheet of carbon copy on the device. The digital pen writes both to the device and to the paper *via* the carbon-copy sheet. Overlaying the two sets of written elements highlights the inking gaps.

Major inking gaps relate to missing or extra strokes. Missing strokes are those that were conducted by the user, yet not reported at all by the pen controller. Missing a first stroke may occur when controllers do not react quickly enough to the pen presence, as may be the case when they have switched to idle modes to save power or to other non-optimized modes. Extra strokes may occur when the pen is not touching the device, yet is close enough that the sensor acquires significant signals. This problem is referred to as "ink in hover" and results in text elements being erroneously connected. High-quality pens and sensors contain dedicated mechanisms that enable clear identification of whether the pen is touching the device or not, avoiding these kinds of extra strokes. Other non-accurate inking effects may result from inaccurate sensor readings or from non-optimized controller processing.

Manual inking tests will lead to different results based on the user and writing type. The faster the writing, the larger the pen-inking gaps; handwriting inking problems will be manifested differently when a user is working in English, Chinese, or Arabic, and between small *vs*. large letters. It is thus advisable to conduct this test with different types of characters, written at different speeds, and in different sizes.

Figure 9, right, shows typical inking results obtained using an active pen and a passive (stylus) pen, manifesting the gaps between their operations.

Special inking testing focuses on advanced features – including tip pressure, pen tilt, and tail eraser – available in some digital pens. Tip pressure measurement[11] enables users to draw thicker lines when the digital pen applies more pressure to the device. Pen-tilt measurement enables a user to draw thicker lines with a tilted pen, mimicking the action of a tilted pencil. Yet another inking feature is a tail eraser that mimics the pencil's counterpart. Every provided feature should be calibrated and verified to ensure its operation.

Inking testing in different real-life environments should be conducted. Some digital pens are challenged under moisture, some when the temperature changes significantly, some when noisy power adaptors are connected to the devices and others when a user touches the screen with his finger or palm during the pen operation. Inking-quality degradation under these disturbances is expected to be negligible for high-quality pens.

Touch-Sensing Integration

In a device supporting touch sensing and digital-pen sensing, integration between these user interfaces is a desirable attribute. The digital-pen solution should be aware of touch events, whereas the touch solution should be aware of digital-pen events. This awareness enables adaptive operation leading to a more robust and rich user experience. Specifically, this capability enables users to interface with a device using both touch and pen simultaneously. An expanded input vocabulary is afforded by supporting unimodal pen, unimodal touch, and multimodal pen + touch inputs. A recent study demonstrated[6] the richness of interactions available when compound gestures based on pen and touch primitive

Fig. 9: At left, an inking test uses carbon copy and paper placed over a display as a reference for digital writing. The center example shows good inking in pink, missing strokes in white, and extra strokes in red. At right, active and passive stylus inking is compared.

input operations (tap, drag, hold, and others) are supported.

Another integration challenge, described below, is known as palm rejection, relating to a natural human behavior that poses a challenge to the touch sensing system.[6–8] Especially for large devices (>10 in.), the user places his palm on the device as part of the natural writing process. Since this is a non-intentional touch, it is expected that touch systems will correctly identify the palm and avoid reporting it to the device OS. Yet, in reality, under certain conditions, touch controllers fail to classify the palm correctly, as can be tested using large conductive tokens (Fig. 10). High-quality digital pens and sensors, and, specifically, touch-sensor-integrated ones, are able to complement the touch-sensor analysis, ensuring that no false palm reports will be issued. For this integration, awareness of the pen presence should be available when the pen is hovering above the sensor while it is being held by the user.

General Pen Requirements

In terms of pen performance, durability, ergonomics, noise, surface friction, and cost are all important considerations.

Durability: The quality of the pen operation should remain consistent over years of operation. To avoid loss of the pen, it is ideal that it be able to be connected to the device, possibly using a dedicated storage cavity or "garage." Most pens require internal power sources. To avoid user frustration, the pen or controller should alert the user when the power source is depleted. Pens should be robust enough to avoid breakage following a drop from 1 m (representing the fall from an office desk).

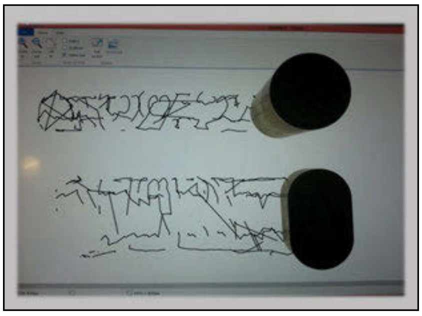

Fig. 10: Palm-like large tokens are placed and moved on the tested device, and if the device "draws" (as is the case in the figure), it indicates poor palm rejection.

Pen ergonomics: The pen should be lightweight and the weight should be well-balanced. Preferably, a device should work with pens of different diameters to optimize the grip for both children and adults. Hiroshi[9] found that thick (12 mm) pens reduce muscle load and mitigate fatigue as opposed to thin (8 mm) pens. This finding contradicts the drive to garage the pens in thin devices, which favors very thin (5.5 mm) pens. Ravindra[10] found that different pen diameters and shapes lead to different accuracies and speeds of writing; hence, the optimal pen should also depend on the planned usage.

Friction and noise: Some digital pens utilize metallic tips that generate loud noise when used to write on the cover glass of devices. Lieberman[7] commented that cultural differences, such as responding to the sound of a stylus used on a screen, will have a dramatic effect on utilization and acceptance of digital pens.

Furthermore, the metallic–glass interface is a low-friction one, with a kinetic coefficient of friction mK<0.2 (dependent upon the glass type and coating), and, as a result, the tip often glides over the device surface in a way the user had not intended. High-quality pens utilize alternative materials and tip designs to ensure that writing noises are kept to a minimum and increase mK above 0.2, providing better control over tip movement. Interchangeable tips are convenient for enabling users to optimize their personal writing experience. mK measurement is detailed in ASTM D1894.[12]

Writing the Future

As discussed earlier in this article, the functions of digital pens extend beyond writing because the pen represents an alternative man–machine interface (MMI) versus touch. Thus, functions such as "mouse over" can be accomplished by a "pen hover" feature and "mouse right click" may be enabled by introducing mechanical or capacitive buttons on the pen and ensuring that the pen controller will recognize and properly report when these buttons are pressed.

Since the digital-pen sensor and controller are embedded within the device, when a user purchases a device today, the user is restricted to a certain digital-pen technology. However, within this technology, some pen suppliers provide customers with different options for pens, ranging from basic models enabling touch, which is simply more accurate than a finger, up to high-end pens that enable reporting accurate 3-D positioning and orientation, tip pressure, support interaction with the device *via* additional buttons, and other added value.

This article has discussed some of the drivers for the introduction of device-integrated digital pens, classifying pen solutions and highlighting the benefits of on-device touch sensors integrated with active pens. Requirements related to touch integration and pen inking, enabling intuitive annotation, note taking, drawing and painting, collaboration, and other considerations, were also detailed.

Digital-pen technology has matured over the last decade to provide rich user interaction beyond pen-on-paper. Yet, as more and more people use digital pens for different applications and real-life environments, new needs and challenges occur, providing a basis for continuous research and development.

In addition to convenience and usability, digital pens offer environmental benefits. Worldwide consumption of paper has risen by 400% in the past 40 years, leading to an increase in deforestation, with 35% of harvested trees being used for paper manufacture.[14] Focusing on the users' needs and ensuring matching requirements will grow the desire for digital pens, driving towards a pen-on-paper-style user experience that will lead to a paper-less greener world.

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Tablets Are Trending Better, Bigger, and Brighter

The key element for a great tablet has always been a truly innovative and top-performing display, and the best leading-edge tablets have always had beautiful displays. But tablet displays are challenging to produce because of their large screens, which are 3–4 times the size of smartphone screens. DisplayMate's Ray Soneira discusses the major factors affecting tablet performance and popularity, as well as what improvements we are likely to see in the near future.

by Raymond M. Soneira

STARTING IN 2010, when Apple made the Retina display and display-quality central themes for its product marketing, displays have experienced an unprecedented renaissance in new technologies for smartphones, tablets, TVs, and even new classes of products such as wearable displays. Apple has recently given up the lead in displays – now Amazon, Google, LG, and Samsung are launching products with the best and most innovative displays, as documented in our recent Display Technology Shoot-Out article series.[1] The new iPad mini Retina display, for example, recently came in a distant third place finish.

This article looks at several of the most recent mobile-device display enhancements in terms of tablets, a product category not invented by Apple, but which gained large-scale commercial success only after the introduction of the iPad in 2010. Hopefully, Apple will join the leaders again with new and innovative displays in 2014. In the meantime, here is a roster of display advances that involve tablets.

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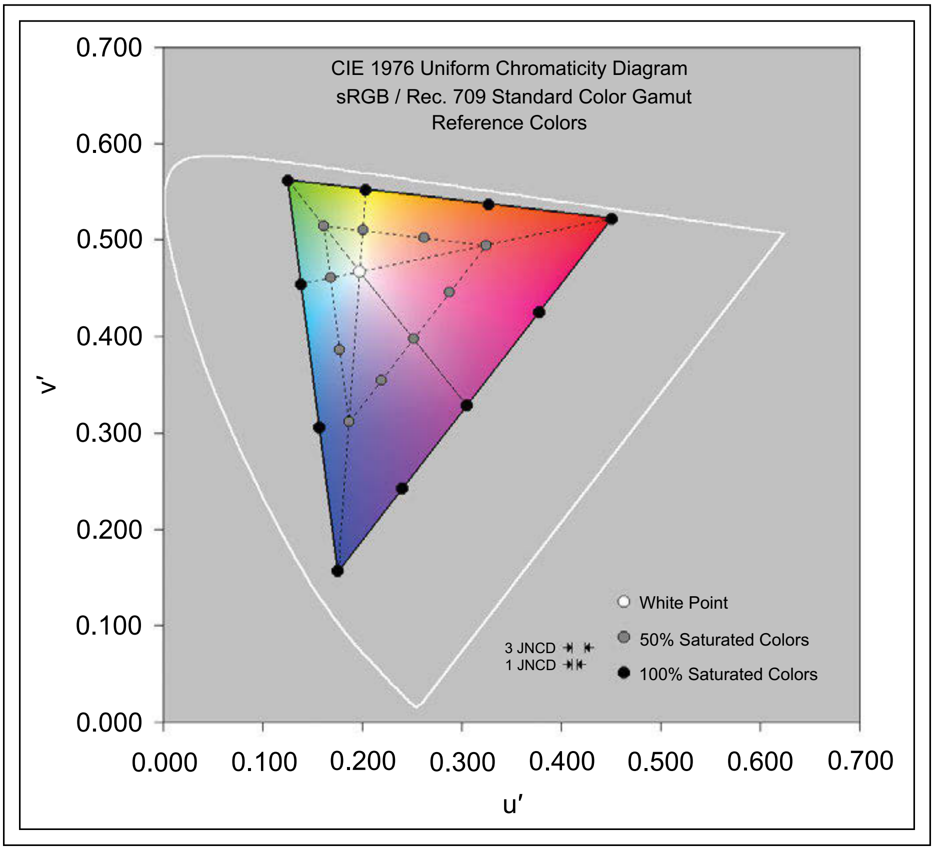

Fig. 1: Shown is the absolute color accuracy map for the sRGB/Rec.709 reference colors.

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Full Color Gamut

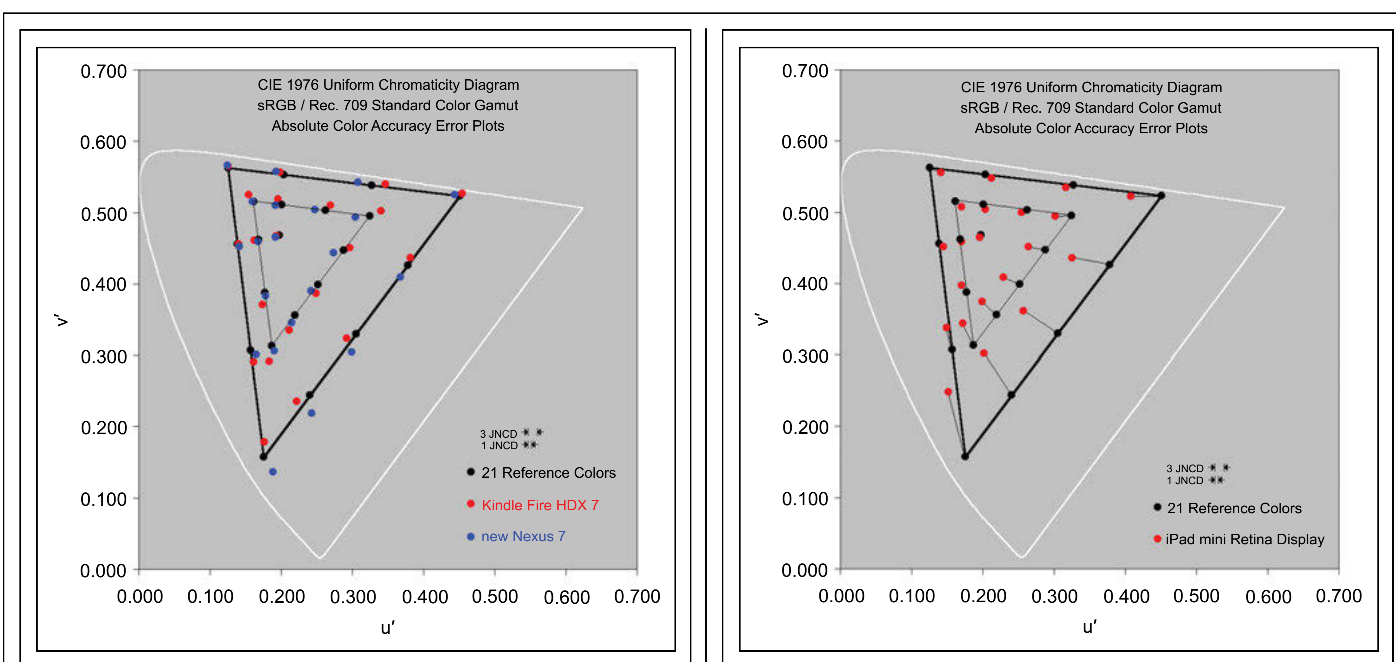
Up until recently, most LCDs had only 55–65% of the standard sRGB/Rec.709 color gamut that is used in producing virtually all current consumer content. This resulted in subdued colors in images, videos, and photos, a limitation that stems from the traditional reduction in brightness and power efficiency as the color gamut is increased for LCDs. This limitation can now be overcome using quantum-dot technology, which can efficiently enlarge the color gamut to greater than 100% for high ambient light and other applications. (For more about quantum dots, see the article, "The Virtues of Quantum Dots," in the May/June 2014 issue of *Information Display*.) Most leading LCDs now have color gamuts greater than 85%, with the best close to 100%. This has been accomplished with a number of innovative (and costlier) approaches including using low-temperature polysilicon (LTPS) backplanes, brighter and more efficient white LEDs in backlights, and better optics and optical films. Other methods include trading some peak brightness for a larger color gamut, and, lastly, just using heftier batteries to get the job done. The most notable laggards in 2013 were the iPad mini Retina display and the Microsoft Surface 2, both with just 63% of the standard gamut. In 2014, quantum dots will play a major role in continuing to improve the color gamut of LCDs.

Improved Absolute Color Accuracy and Picture Quality

Image and picture quality, as well as color accuracy, have been steadily advancing due to improved display technology, advanced signal processing, automated factory calibration, and the motivation of increased competition. DisplayMate's most recent lab tests and measurements show that the very best smartphones, tablets, and TVs are now comparable in accuracy to professional studio monitors. With good accuracy you will see high-fidelity presentations of your digital photos, which is especially important because you often know exactly what everything should actually look like. Another perhaps even more important advantage is that online merchandise will appear with accurate colors, so you will have a very good idea of exactly what you are buying and are less likely to return it. Potential downsides include on-screen food that will make you particularly hungry and shows, movies, and downloaded content that look so great you will find yourself watching more of it!

If you have ever wondered why some colors are way off on a display, there are many contributing factors and causes, including the color gamut, the calibrated white point, the intensity scale, and possibly poorly implemented dynamic picture processing and color management. It is possible to accurately measure and map the absolute color accuracy and color errors for any display by using a spectroradiometer and proprietary test patterns, which we do in our Shoot-Out series. We provide both the average and maximum color errors in terms of Just Noticeable Color Differences (JNCD) and include a full chromaticity color accuracy map, which is shown in Fig. 1. Color differences less than 1 JNCD are visually indistinguishable, while values greater than 1 JNCD are visually noticeable when the two colors are touching on-screen. When the colors are not touching and are farther apart, the visual threshold for just noticing a color difference on a display is higher. Here, we will use 3 JNCD for the threshold of a visually noticeable color difference on a display.

In 2013, the most accurate display we measured was the LG OLED TV, with an average absolute color error of just 1.3 JNCD, which is visually indistinguishable from perfect. Figure 2 shows absolute color accu-



Figs. 2 and 3: *Figure 2, on left, shows the Kindle Fire HDX and Nexus Absolute Color Accuracy Error Plots and Fig. 3, on right, shows the result for the iPad mini Retina display.*

racy plots for the Amazon Kindle Fire HDX 7 and Google Nexus 7, and Fig. 3 clearly shows the much larger color errors for the Apple iPad mini Retina Display.

In 2014, we expect to see major improvements in absolute color accuracy resulting from the use of quantum dots as well as from improved color-management processing.

LTPS and IGZO

All LCDs and OLED displays have an internal backplane layer that has the electronic circuitry needed to control the millions of subpixels. The backplane's performance is especially critical in high pixels per inch (ppi) displays. While most LCDs still use amorphous silicon (a-Si), many high-ppi LCDs use low-temperature polysilicon (LTPS), which has considerably higher electron mobility than a-Si, allowing the circuitry to be made much smaller. For LCDs, the electronic circuitry for every subpixel takes up precious screen area, which blocks the backlighting and decreases image brightness. LTPS results in significantly higher luminance and improved power efficiency, but also costs considerably more to manufacture.

Most high-performance smartphone displays now use LTPS, including the iPhone 5 and all mobile OLEDs (except flexibles). But most LCD tablets, monitors, and TVs still use a-Si because their larger screens would cost considerably more to manufacture using LTPS. An alternative backplane technology called IGZO (indium gallium zinc oxide), which has higher performance than a-Si but lower cost (and performance) than LTPS, was supposed to be available in 2012 for tablets, monitors, and TVs, but major production problems have significantly delayed and limited its availability even in 2013. This will continue through 2014, as Sharp is the only major manufacturer that is beginning to ship IGZO displays.

The two highest-performance tablet displays that we recently tested, the Amazon Kindle Fire HDX 8.9 and Google Nexus 7, were the early adopters of LTPS for tablets, while the latest iPads still rely on lower performance a-Si and IGZO, which limits their brightness, color gamut, and power efficiency. For 2014, the continued problems with IGZO will benefit both LTPS and the much higher-performance metal-oxide backplanes now under development by CBRITE, which should begin arriving by late 2014.

Tablet Outlook

While 2013 included a major shift to smaller 7–8-in. tablet displays from the first-generation full-size 9–10-in. displays, 2014 will see tablets growing again to include 12–13-in. tablet displays for the professional and education markets. Microsoft has the 12.0-in. Surface Pro 3, Samsung has the 12.2-in. Tab Pro, and Apple is rumored to be producing a 12.9-in. iPad. The screen resolution and ppi are also increasing, with high-end Android tablets moving up to 2560 × 1600 or Quad HD

An Advance Look at Samsung's New OLED Tablets

Up until now, tablets have been almost exclusively LCD based. There have not been any OLED tablets, with the exception of a single 7.7-in. model from Samsung launched in 2012.

Samsung is now producing the Galaxy Tab S series (see Fig. 4), with display performance widely expected to be comparable to that of the OLED Galaxy S5, which is the best smartphone display we have ever tested.

Samsung provided DisplayMate with pre-release production units of the Galaxy Tab S tablets in both 10.5- and 8.4-in. form factors. Here are a few highlights of the testing results:

Fig. 4: Samsung's new Galaxy Tab S tablets are OLED based, which provides excellent performance in terms of viewing angles. Image courtesy Samsung.

- Both Galaxy Tab S models offer Quad HD 2560 × 1600-pixel displays, currently the highest resolution for tablets, with 4.1 Mpixels – double the number on your HDTV. The 10.5-in. model has traditional RGB-stripe pixels with 287 pixels per inch (ppi), and the 8.4-in. model has Diamond pixels with a proprietary diagonal, symmetrical arrangement for the red and blue subpixels and subpixel rendering with 361 ppi. Both are higher than can be resolved with normal 20/20 vision at the typical viewing distances for tablets, so the displays appear perfectly sharp.
- Excellent absolute color accuracy in the Basic screen mode with an average error of just 2.1 JNCD, the best for any mobile display.
- Both of the Galaxy Tab S displays have very good to excellent screen brightness, but are not as bright as the brightest LCD tablets.
- While tablets are primarily single-viewer devices, the variation in display performance with viewing angle is still very important because single viewers frequently hold the tablet at a variety of viewing angles – often up to 30° or more when resting it on a table or desk. While LCDs typically experience a 55% or greater decrease in brightness at a 30° viewing angle, the OLED Galaxy Tab S displays show a much smaller 21% decrease in brightness at 30°.

In summary, the Galaxy Tab S tablets are the best-performing tablet displays that we have ever tested. More testing results can be found on DisplayMate's web site.[2]

(QHD) at 2560 × 1440 with 300–340 ppi based on screen size, and current Apple iPads at 2048 × 1536 with 264–326 ppi. However, a 12.9-in. iPad would only have 198 ppi, so to enable a Retina display another higher-resolution jump to perhaps 4K, at 4096 × 3072 with 398 ppi, seems likely. High-ambient-light performance will also continue improving, with the 2013 record holders Amazon Kindle Fire HDX 8.9 with a very low 5.0% screen reflectance, and the Nokia Lumia 2520 with a very bright 684-cd/m^2 display.

Also expected in 2014 are some high-resolution OLED tablets and many more LCD tablets with LTPS backplanes and quantum dots that will deliver very bright and wide-color-gamut images as mentioned above. At press time, DisplayMate had just completed a review of the OLED-based Galaxy Tab S tablets, the new OLED flagship units from Samsung.[2] (For more information about the Galaxy Tab S line, see the sidebar in this article.)

The most important developments for the upcoming generations of both OLED and LCD mobile displays will come from improvements in their image and picture quality in ambient light, which washes out screen images, resulting in reduced readability, image contrast, color saturation, and color accuracy. The key will be in enlarging the native color gamut and then dynamically changing the display's color management and intensity scales with the measured ambient light in order to automatically compensate for reflected glare and image washout from ambient light, as discussed in our 2014 Innovative Displays and Display Technology article online[3] and the "Tablet Display Technology Shoot-Out" article in the July/August 2013 issue of *Information Display*. The displays and technologies that succeed in implementing this new strategy will take the lead in the next generation of mobile displays.

In 2013, the Amazon Kindle Fire HDX tablets became the top-performing tablet displays in our Display Technology Shoot-Out series, leapfrogging the competition with cutting-edge displays using quantum dots and LTPS. But with the ever continuing and impressive improvements in display technology, the OLED Samsung Galaxy Tab S has now taken the lead for the best tablet display. With display technology advancing rapidly on many different fronts, things can change again in the next generation of displays for tablets and smartphones. A strong congratulations to Samsung, but please do not rest on your laurels – and best wishes to all the manufacturers in developing the next generation of even higher-performance displays!

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Printed Touch Sensors Using Carbon NanoBud Material

A new carbon nanomaterial is enabling touch sensors with high contrast for outdoor readability and flexibility that allows folding and sharp-angle 3-D formability.

by Anton S. Anisimov, David P. Brown, Bjørn F. Mikladal, Liam Ó Súilleabháin, Kunjal Parikh, Erkki Soininen, Martti Sonninen, Dewei Tian, Ilkka Varjos, and Risto Vuohelainen

THE user experience of current consumer electronics, and of touch displays in particular, is limited in large part by the properties of existing conductive materials used as transparent electrodes in capacitive touch sensors. In this article, we discuss recent progress in achieving advanced conductor material characteristics based on Canatu's Carbon NanoBud (CNB) technologies that allow improved optical and mechanical performance, novel flexible and three-dimensional form factors, and reduced cost. These advances are significant because they will enable flexible or 3-D-shaped touch sensors, high-optical-quality touch displays with almost no reflections and high outdoors contrast, and cost-effective manufacturing through dry roll-to-roll processing.

Specifically, we describe how we created a CNB-based GFF (two-layer Glass-Film-Film structure) demonstrator with only 2.2% reflection and 40% better contrast in bright ambient light compared to a comparable structure using ITO. We also show that CNB films can repeatedly be folded 140,000 times at a 2-mm radius. For 3-D-shaped rigid touch, we achieved formability with 1-mm-radius edges and 120% stretching.

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Limitations of ITO

Indium tin oxide (ITO) is the current industry-standard transparent conductor material. However, ITO is a brittle ceramic that has presented many challenges to developers of flexible electronics. In addition to its physical-property limitations, ITO poses optical-performance challenges due to a high index of refraction. Touch screens made with ITO layers tend to reflect relatively high amounts of incident light, and this may cause display images to become washed out in bright indoor

Table 1: A cost of ownership comparison of CNB laser ablation *vs*. ITO photolithography shows that CNB has the advantage. (Photolithography costs are based on a commercially available cost-of-ownership calculation tool for display manufacturing, and laser ablation costs are based on data available from 10 different laser-ablation machine vendors and Canatu's internal laser processing data.)

Cost per 500 nm x 500 nm sensor sheet	Photolithography	Laser ablation
Equipment (depreciation)	$0,76	$0,71
Consumables/Utilities (OH)	$0,26	$0,01
Maintenance	$0,07	$0,06
Labor	$0,15	$0,04
Support Personnel (OH)	$0,24	$0,23
Scrap	$0,39	$0,15
Finance cost (10% interest rate)	$0,22	$0,21
Total direct patterning costs/sheet	$2,09	$1,43

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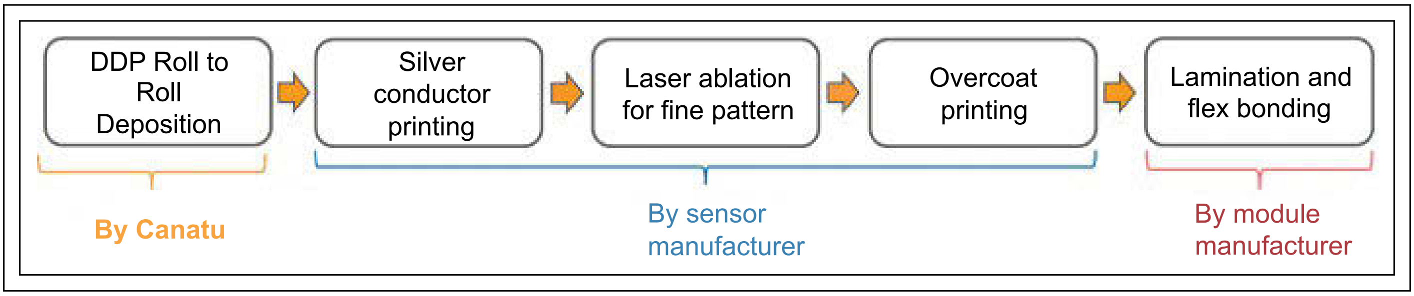

***Fig. 1:** Shown is a CNB touch-sensor manufacturing process and business model for high-volume touch-sensor sales.*

and normal outdoor conditions. The effect can be reduced by using index-matching layers in ITO sensors, but these add cost and complexity.

Recently, silver nanowires and different forms of metal-mesh alternatives have emerged as ITO replacement materials. These have benefits for large-area touch displays because they often provide higher conductivity values for comparable light-transmission performance compared to ITO. However, silver nanowires and metal meshes are metallic based and hence also have relatively high-ambient-light reflectance, which can result in a washout effect.

To address the shortcomings of the above existing solutions, we developed a new carbon nanomaterial, the Carbon NanoBud; a hybrid of carbon nanotubes and fullerenes.[1] Hybridization is achieved directly in the material synthesis process and the resulting material combines the high functionality of fullerenes with the high conductivity and robustness of nanotubes. The aerosol synthesis of carbon nanotubes has been demonstrated by Nasibulin *et al*.[2] This method has been modified and scaled to produce commercial quantities of clean, lightly bundled, high-crystallinity CNBs directly in the gas phase, thus eliminating the need for liquid processing.

We have also developed a new thin-film manufacturing method called Direct Dry Printing (DDP), based on the work described in Kaskela *et al*.[3] and the thermophoretic technique described in Gonzales *et al*.[4] that allows direct synthesis and patterned deposition of CNBs by aerosol deposition. The combination of aerosol synthesis and DDP allows homogeneous or patterned deposition on any substrate at room temperature and pressure, resulting in a simple, scalable, one-step, low-cost, and environmentally friendly thin-film manufacturing process that improves the quality and performance of final products. Unlike conventional methods, no material degrading or hazardous acid treatments and no sonication, surfactants, or functionalizations for dispersion, purification, and deposition are required. DDP is applicable to both sheet and roll-to-roll implementations and can be combined with conventional screen, gravure, and flexo printing to allow the production of continuous rolls of complex, multi-layered components.

CNB Film and Touch-Sensor Manufacturing

For this work, we have made homogeneous and patterned depositions of CNB films on A4- and A3-sized sheets by combining the aerosol synthesis method with room-temperature deposition based on a modification of the above described filter transfer technique. Consequently, high purity, low bundling, and low concentration of catalyst material have been achieved.[5]

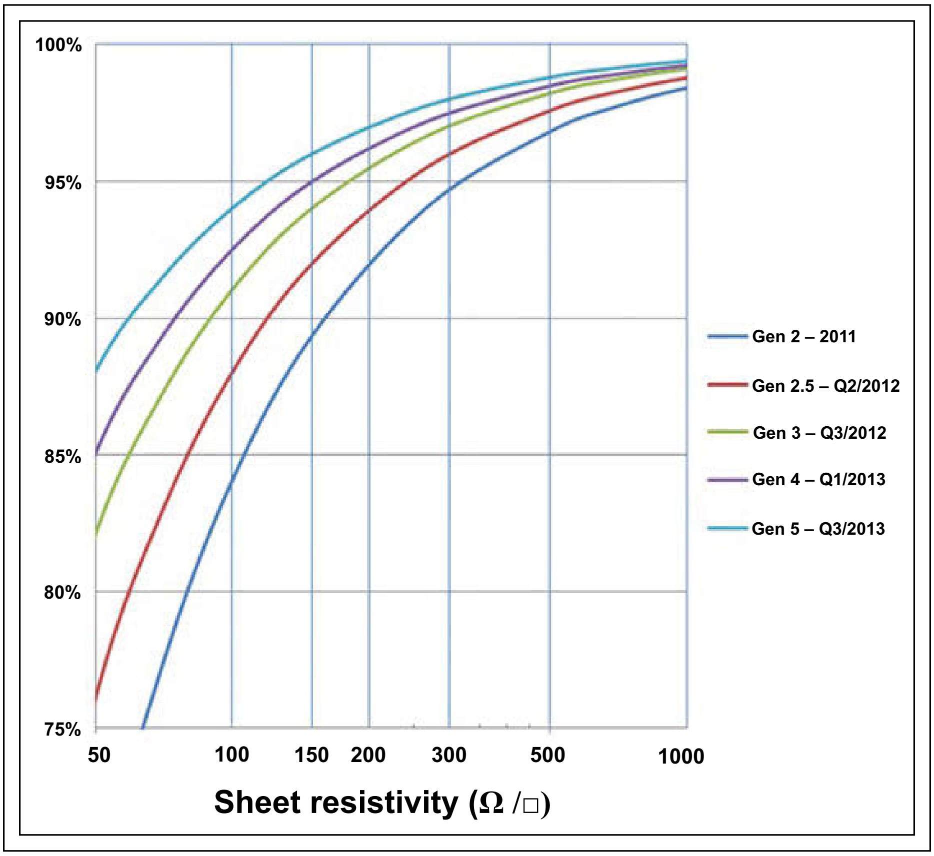

***Fig. 2:** CNB film transmission vs. sheet resistivity is compared for the current Gen 5 to previous results from 2011 to 2013. Transmission is substrate-normalized.*

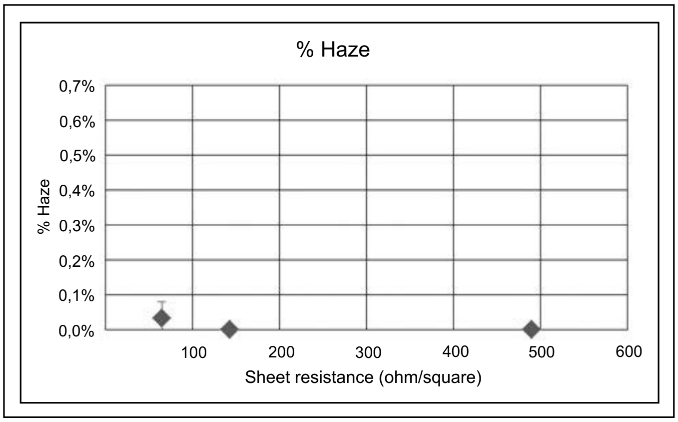

Fig. 3: The haze of substrate-normalized CNB films appears above as a function of sheet resistivity. Haze does not increase at low sheet resistivity as it does with AgNW and metal meshes.

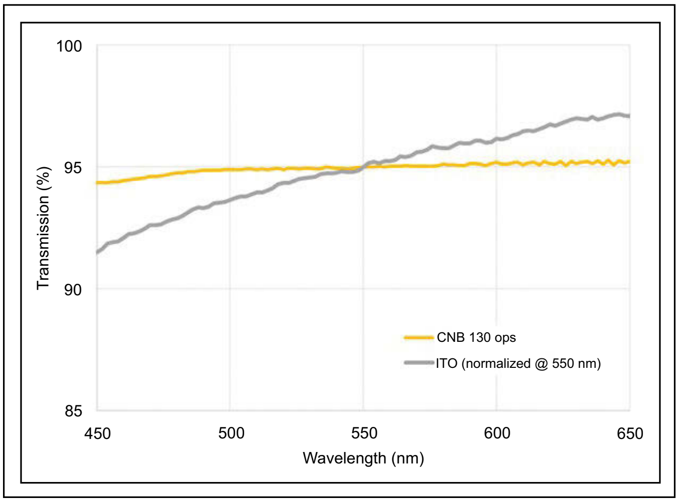

Fig. 4: The transmission spectrum of substrate-normalized CNB films is compared to ITO.

Fine patterning and conductive traces. Most projected-capacitive touch sensors require fine patterning with minimum feature sizes of 25–50 µm. We have achieved this via laser ablation, which maintains the dry manufacturing process with no liquid handling and hence a lower environmental footprint. Because no masks are required in laser ablation, the lead time for pattern changes is short. Only one process step is required, as opposed to eight steps in photolithography. Laser patterning is therefore more cost competitive than the more commonly used photolithography (see Table 1), and the low incremental capital expenditure for laser equipment as opposed to a photolithography line makes it more flexible for demand fluctuations and enables better line utilization.

Canatu uses CNB patterning with 30-µm gaps in its production, enabling fully invisible conducting patterns on touch screens.

To complete the touch sensor, a conductive silver (Ag) layer is printed using a Microtec MTP-1100 TVC screen-printing machine. Ag traces are fine patterned, either by laser ablation in the same process step as the CNB patterning or, for even better production efficiency, by direct screen printing. We can now produce silver patterns down to 30 µm/30 µm lines and gaps with both laser ablation and screen printing.

It is important to note that metal-mesh-based touch sensors require very high tolerance and early design know-how of display pixel geometry to reduce the moiré effect between the display and the sensor. Metal-mesh manufacture is also demanding, as the bonding equipment needs to be highly controlled. CNB sensors are display-design agnostic due to the pattern invisibility and random orientation of the CNB deposition.

Manufacturing process and line. In our factory in Helsinki, Finland, we are developing the production capacity for medium-volume manufacturing of CNB films and touch sensors (400 m^2 of CNB film/month or 20,000 mobile-phone touch sensors/month). Our business model for high-volume touch-sensor manufacturing is to deliver CNB films for touch module manufacturers (Fig. 1).

The company is currently building a 600-mm-wide roll-to-roll CNB deposition machine. The first unit was scheduled for production in June 2014. The capacity for the machine is 8000 m^2/month and the company is planning to have four lines installed by Q4 2014. The current facility allows capacity up to 500,000 m^2/month.

CNB Film Properties: Transparency, Reflectivity, and Haze

Since 2007, Canatu has been able to double

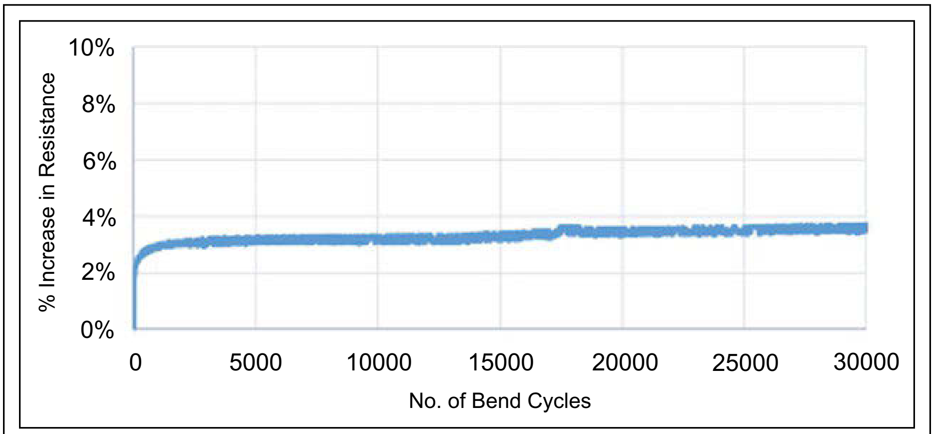

Fig. 5: The change in resistivity for a CNB film on a 130-µm PET substrate is shown for repeated bends. The bending radius was 2 mm.

CNB film conductivity at a given transparency approximately every 12 months. Figure 2 shows CNB film releases since 2011. We now manufacture Gen 5 films with the following properties without substrate: 100 Ω/□ at 94%, 150 Ω /□ at 96%, and 270 Ω /□ at 98%. In the lab, we can make 100 Ω /□ at >95%. CNB film transparencies are on par with ITO in touch devices with stacks such as GF1 or GFF. High transparency is needed for enabling bright display images and pattern invisibility.

The haze of CNB film is negligible, as measured by the HunterLab Ultra-Scan VIS spectrometer (similar to ASTM D1003-95 standard) (see Fig. 3).

Color neutrality. A transmission spectrum for a CNB film is shown in Fig. 4. The transmission spectrum was first measured by HunterLab from the film on a PET substrate (ASTM E1164 standard). Subsequently, the absorption of the PET was subtracted to obtain substrate normalized data. As can be seen, the optical absorption is uniform over the entire visible spectrum. The CIELAB color coordinates after normalization were measured as L*= 97.9 ± 0.1, a* = 0.0 ± 0.1, and b* = 0.6 ± 0.1, demonstrating that CNB films and sensors have very little color distortion.

Mechanical and environmental performance. CNB films on a 130-µm PET substrate were exposed to severe (180°) bending at a radius of 2mm, with results shown in Fig 5. Sheet resistance was shown to remain nearly constant over 30,000 bend cycles, after an initial change of a few percent. In another similar test with 140,000 bend cycles, the change in resistivity was less than 7%. This demonstrates the applicability of CNBs for flexible and foldable touch products.

We have applied film insert molding (FIM) (aka in-mold decoration or IMD) as a standard industrial process for rigid 3-D shaped touch devices. Figure 6 shows a demonstrator with 120% stretching and 87° bending at 1 mm radius in an FIM device, demonstrating the high stretchability of CNB films. In collaboration with Bayer MaterialScience, we have made both 1-CNB-layer and 2-CNB-layer test devices for PF1 (Plastic-Film) and PFF (Plastic-Film-Film) type touch stack constructions. CNB layers, applied on polycarbonate Makrofol DE film, were three dimensionally shaped by a high-pressure forming process.[6]

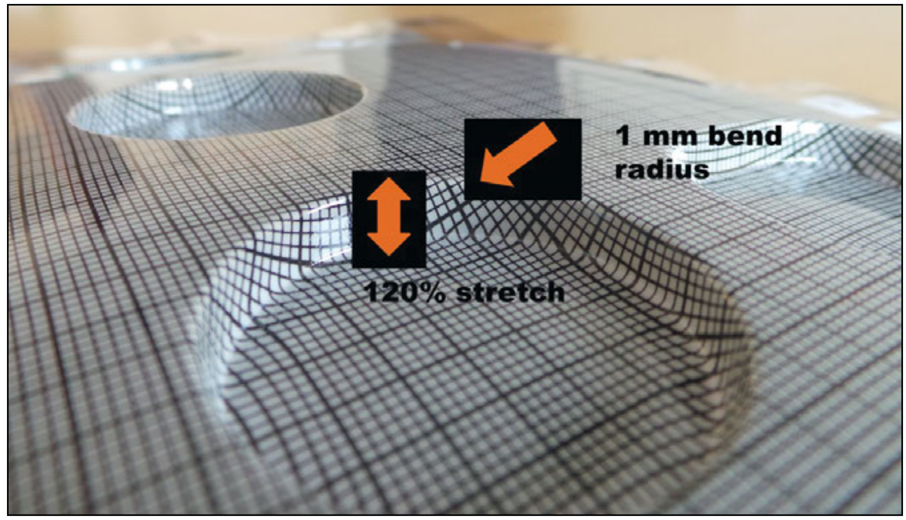

Fig. 6: This film-insert-molded demonstrator for CNB films shows the possibility of sharp angles and deep indentations.

Table 2: Tests of CNB films included both environmental and accelerated aging.

Test	Standard	Specification				
		ΔRs (Sheet resistivity change	Δ%T (Transmission change	ΔHaze	ΔE (Color change)	Adhesion (Cross cut and tape peel off, JIS K5600)
Room temperature storage	25°C/60% RH	Passed	Passed	Passed	Passed	Passed
Constant temperature/ Humidity storage	IEC 68-2-78 (IEC 68-2-3) 60°C/90% RH	Passed	Passed	Passed	Passed	Passed
Thermal cycle storage	IEC 68-2-2, IEC60068-2-14 Test N, IEC 60068-2-14 Na, –40°C/	Passed	Passed	Passed	Passed	Passed
High temperature storage	IEC 68-2-2, IEC 60068-2-2 Dry heat tests, 85°C	Passed	Passed	Passed	Passed	Passed
Low temperature storage	IEC 68-2-1 –40°C	Passed	Passed	Passed	Passed	Passed

The resulting inserts were injection back-molded with clear Makrolon polycarbonate resin. In all test devices, CNB layers maintained their conductivity with a linear response to stretching.

We exposed the CNB films to all typical consumer-electronics environmental tests, and these tests were passed, as shown in Table 2.

Touch Sensors

We made 13.3-in.-diagonal CNB projected-capacitive touch sensors with the manufacturing process as described. The touch stack was the Glass-Film-Film (GFF) type with sense and drive electrodes on separate PET sheets, laminated together and to the front glass with optically clear adhesive. The CNB film sheet resistivity was 220 Ω/□. The sensors were bonded with a flexible circuit board to the driving electronics, and the touch module assembly was "plug and play" retrofitted to an existing Intel Ultrabook reference design for comparison with the existing standard commercial ITO One-Glass Sensor (OGS). In this product, there is an air gap between the touch and the display. The assembly was made by SMK Corp. in Japan. An Atmel mXT224 chip was used as the touch controller. No modifications to the touch-sensor chip were required.

The CNB touch sensor passed Windows WHCK tests and is therefore fully certified for Windows 8. As characterized by Atmel, the touch performance was found to be equivalent to commercial ITO sensors. The reflectivity, as measured by HunterLab (ASTM E1164) from the CNB GFF touch display, was significantly lower than that from the comparison ITO OGS touch display. In a bright office on a sunny day (2000 lux, 1000-cd/m^2 specular light), the resulting 4.2:1 contrast is 30% better in the CNB-based laptop than in the ITO-based laptop.

To compare CNB to ITO and metal meshes, we performed optical characterization of various touch modules at the Intel laboratory in Santa Clara. Table 3 shows that CNB touch modules have the lowest haze in this test.

To demonstrate touch on 3-D surfaces, we made a 12-cm-diameter dome-shaped PFF touch sensor with a 15-cm radius of curvature (Fig. 7).

The drive and sensor sheets were made using a 500-Ω/□ CNB film. An Atmel mXT768E controller was used and the sensor pattern was "Flooded X" type with 10-finger multi-touch, 254-dpi resolution, and a 12-msec report interval. There is a high transmission of >97% through the active CNB layers, and the patterns are totally invisible.

In collaboration with TactoTek Oy, we also built a highly transparent 3-D shaped demonstrator with slider, wheel, and button touch, applying the FIM process with CNB on thin polycarbonate substrate and clear PMMA overmold (Fig. 8). The radius of curvature was 130 mm. TactoTek did the forming and injection molding with integrated LEDs.

Table 3: The optical characterization of touch modules in terms of haze is shown with a variety of transparent conductors.

Touch Module	Type	Sensor	Haze (%)
Carbon NanoBud	CNB	GFF	0.6
ITO OGS (no index matching)	ITO	OGS	3.3
Silver nanowires Metal Mesh	Mesh	GFF	1.4
Silver Metal Mesh #1	Mesh	GFF	2.0
Copper Metal Mesh #1	Mesh	GF2	1.6
Copper Metal Mesh #2	Mesh	GF2	2.0
Silver Metal Mesh #2	Mesh	GF2	1.3
IPAD 4 (Air)	ITO	GF2	1.0

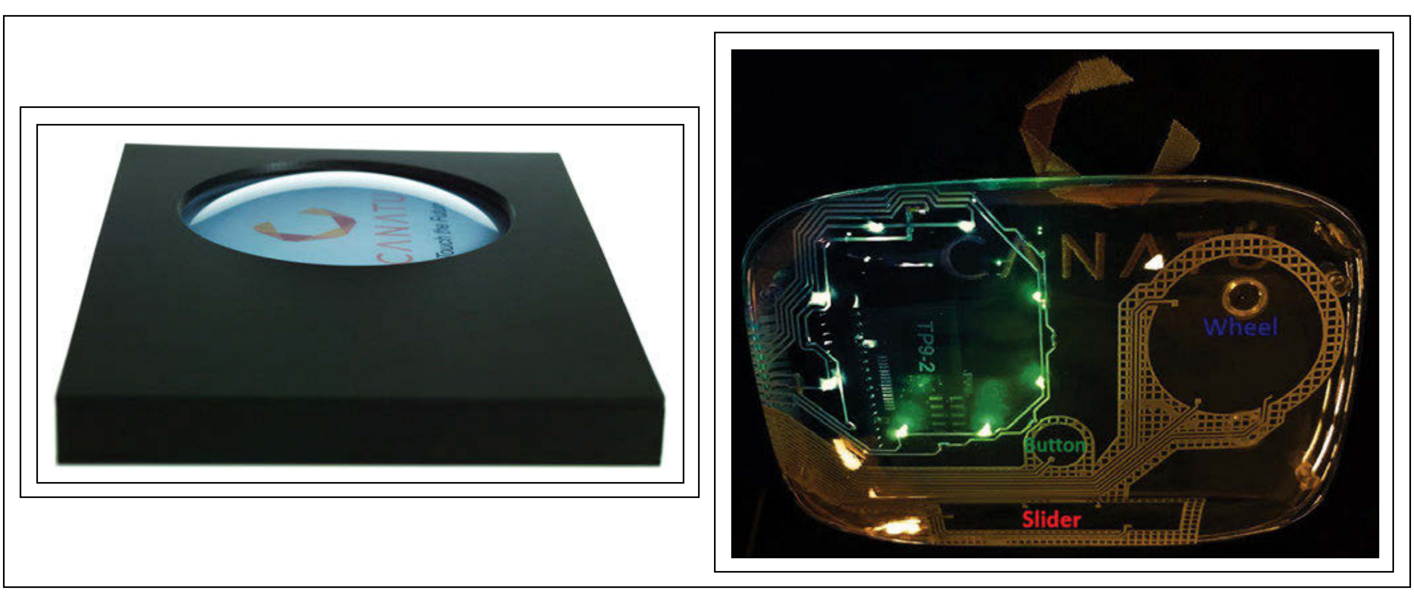

Fig. 7: At left is a 5-in. dome-shaped CNB projected-capacitive multi-touch sensor. At right is a 3-D shaped-CNB FIM demonstrator with touch (right).

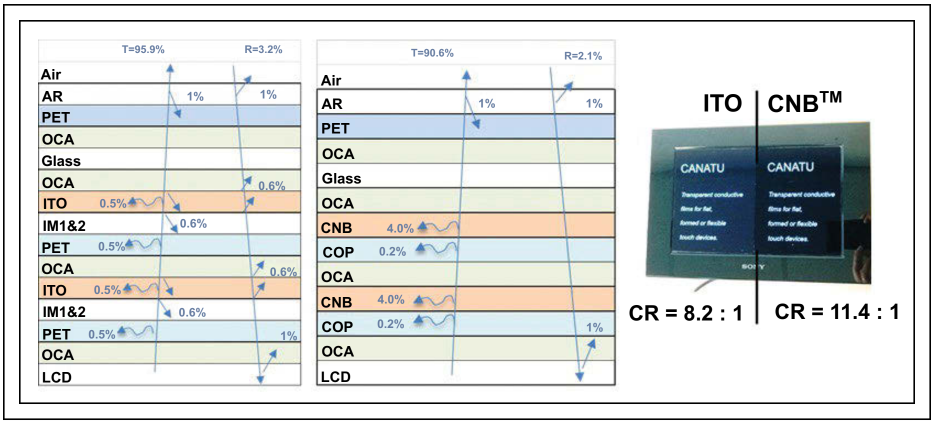

Fig. 8: A stack diagram of direct-bonded 150-Ω/□ ITO GFF (left) is compared to CNB GFF (right). A photo of the demonstrator is at far right.

Optical Demonstrators

To demonstrate touch-display contrast in a direct-bonded construction, we built a 10-in. optical demonstrator to compare a TFT-LCD touch panel with an ITO-based 150-Ω/□ GFF stack to one with a 150-Ω/□ CNB GFF stack. The ITO film chosen for this demonstrator was industry state of the art with complex index-matching layers and optically optimized ITO. There was no air gap between the touch and the display. In order to demonstrate the lowest possible reflectivity, we added an AR coating to the front window (glass/air interface). As seen in Table 4, the CNB GFF device has 2.2% total reflectance. The total reflectance from the ITO GFF device is 3.4%.

Table 4 shows the breakdown of the reflection values in the touch-display structure. The CNB sensor stack has no inherent reflections; hence, the 1.8% specular reflections in the GFF stack originate from the glass/AR/air interface and from the display (Fig. 8).

For the ITO sensor stack, despite complex index-matching layers, there are still 1% specular reflections from the ITO layers. By better optimizing the AR coating, using a less reflective display, and optimizing the direct bonding materials, <1% specular reflection is feasible with CNB GFF sensors.

Contrast ratios of the combined TFT-LCD used in this demonstrator (with ON Brightness of 220 cd/m^2 and OFF brightness of 0.3 cd/m^2) and the GFF touch stack were calculated using the measured reflections from the stacks presented in Fig. 8. The contrast ratio was calculated using the following formula:

$$CR_h = \frac{(I_0 + R_d * A_{mb} + R_s * Spec)}{(I_{dk} + R_d * A_{mb} + R_s * Spec)}$$

R_h – the contrast at high ambient
I_0 – white luminance of the display in dark room
I_{dk} – black luminance of the display in dark room
R_d – diffuse reflectivity
R_s – specular reflectivity
A_{mb} – diffused (daylight) ambient illumination
Spec – specular (glare) light source

Figure 9 shows the contrast ratio plotted as a function of ambient illumination for the direct-bonded GFF devices with AR coating. In this simulation, we considered both diffuse ambient illumination and a bright specular source (*i.e.*, a bright spot/area reflecting directly from the display). This combination is specified, for instance, in Vehicle Display standard J-1757. In a 2000-lux ambient/1000-cd/m^2 specular source, the contrast ratio of CNB-based devices is 12:1 (40% higher than the similar ITO device).

Table 4: Reflection results from CNB and ITO GFF optical demonstrators with AR coating include specular and diffuse.

Direct Bonded Touch Module	Specular Reflection	Diffuse Reflection	Total Reflection
CNB AR/GFF	1.85%	0.36%	2.21%
ITO AR/GFF	2.91%	0.47%	3.38%

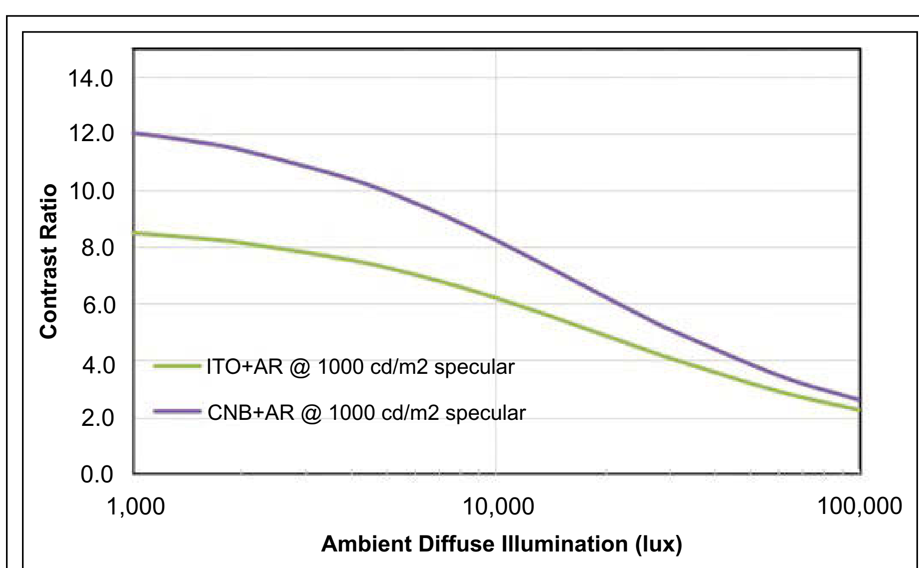

Fig. 9: The chart shows the contrast ratio for direct-bonded AR-coated GFF devices with ITO and CNB.

Potential Impact

We have ramped up the production of CNB films and built several products and demonstrators showing the applicability of the CNB material for high-optical-quality, flexible, and 3-D formable touch sensors. A Windows-8-certified 13.3-in. Ultrabook touch module, a 5-in. multi-touch dome-shaped demonstrator, and a 3-D shaped film insert molded touch device have been successfully produced as demonstrators.

CNB films are now a commercially viable option for high-volume applications and for high-quality flat, flexible, and 3-D formed touch sensors. Canatu is now in the prototyping phase, with more than 30 customers worldwide for mobile phones, tablets, phablets, laptops, smart watches, digital cameras, automotive consoles, and white goods.

Acknowledgments

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New Trends in Touch

With touch panels becoming ubiquitous, the touch industry is undergoing rapid change. Touch Display Research, Inc., reports on its most recent survey of the leading manufacturers in the touch-screen, ITO-replacement, and touchless-control industries.

by Jennifer Colegrove

THE touch-panel market has grown explosively since 2006. As the first industry analyst to write a comprehensive touch-screen industry report in that year, I feel very fortunate to have witnessed touch-screen engineers, technicians, and managers grow the industry through hard work and constant innovation. Despite a global economic recession over the last couple of years, the market has continued to expand at a handsome rate.

As shown in Fig. 1, Touch Display Research forecasts[1] that touch-module revenue will reach $36 billion by 2020, up from just $2 billion in 2006.

Touch-screen suppliers, especially projected-capacitive-touch suppliers, were mostly profitable during 2007 and 2009. But fast forwarding to 2014, the competition is fierce, with many touch-screen suppliers now encountering net losses. New business strategies are needed for companies to become leaders or maintain leadership positions in today's touch industry.

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ITO Replacement: Non-ITO Transparent Conductors

ITO is still the mainstream transparent conductor used for touch panels; however, due to ITO's high cost, fragility, and long process steps, ITO replacements have become one of the hottest trends. There are currently more than 10 types of ITO replacement technologies. I have placed them into six categories: metal mesh, silver nanowire, carbon nanotube, conductive polymer, graphene, and other transparent conductor technologies. In addition, there are over 200 companies or research institutes that are currently working on ITO replacements.[2]

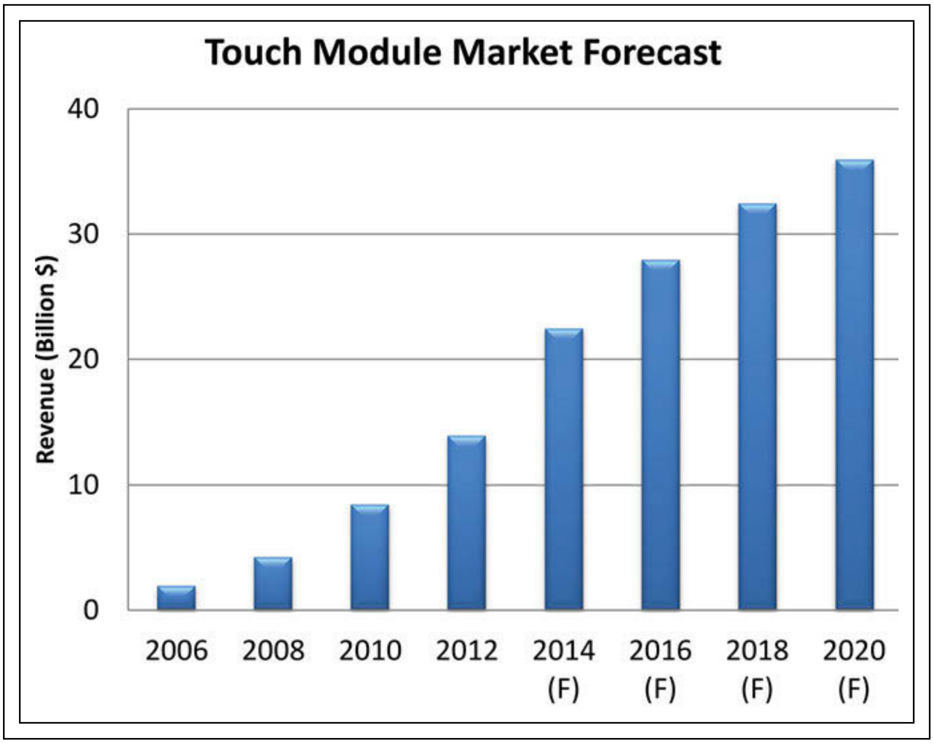

Fig. 1: *The touch-module market forecast calls for rapid advances through at least 2020. Source: Touch Display Research, Inc., 2014.*

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Each technology has its pros and cons. There are many characteristics to compare when choosing a transparent conductive material – sheet resistance, transmissivity, conductivity, haze, optical appearance, and cost are just several examples. Figure 2 compares cost and conductivity.

In late 2012 and early 2013, the shortage of touch screens for notebooks, ultrabooks, and all-in-one PCs – due to the high demand of touch from Windows 8 devices, coupled with a low yield of 10–29-in. ITO touch sensors – drove the adoption of ITO replacements.

After many touch-panel suppliers ramped-up capacity in mid-2013, the shortage turned into an oversupply by the end of that year, which resulted in substantial touch-screen-module price erosion. Touch Display Research expects the average selling price (ASP) of touch modules to continue to fall below $40 for notebook PC sizes, which, in turn, will expand the opportunities for low-cost ITO replacement. As a result, the non-ITO transparent-conductor market revenue is forecasted to increase from $798 million in 2014 to $8.1 billion in 2021 (Fig. 3). (Note: Not all ITO replacements are low-cost alternatives; some, such as graphene, are still more expensive than ITO.)

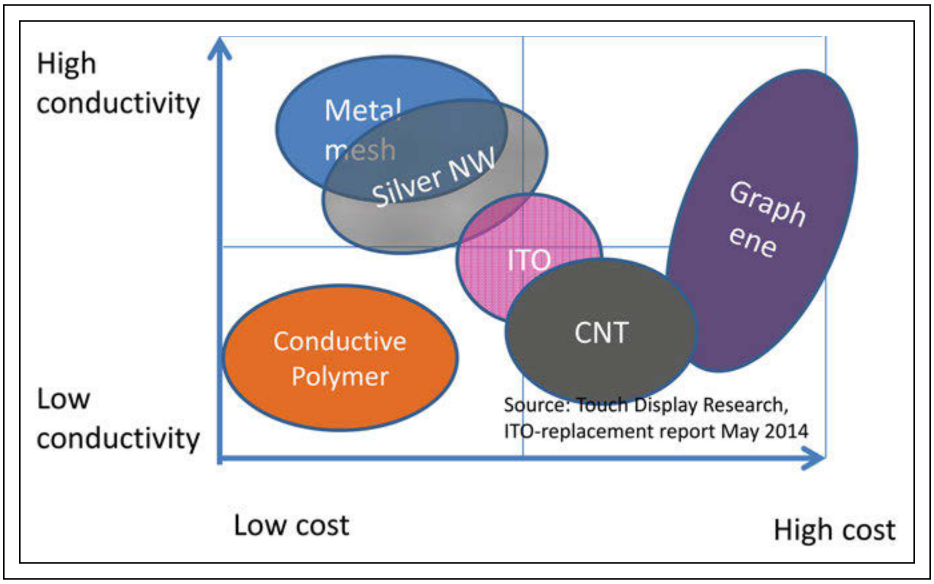

Fig. 2: ITO replacements are compared in terms of cost vs. conductivity. Source: Touch Display Research, ITO replacement: non-ITO transparent conductor technologies, supply chain and market forecast report, 2013 and 2014.

Active-Pen Technologies

While finger touch is intuitive, active-pen writing is accurate, easier, and can add a personal touch. Pen input is very useful in education and in certain types of language input, as well as in medical, financial, industrial, and content creation or markup applications. Touch Display Research defines an active pen as one with an electronic circuit. Some active pens have an integrated battery in them, some not. A passive pen has neither an electronic circuit nor a battery. According to our research, there are nine types of active-pen technologies and six passive-pen technologies, as summarized in Fig. 4.

In 2007, when Apple released the first iPhone with a projected-capacitive touch screen, it had the benefit of multi-touch, zero-force touch, good durability, *etc*. Referring to the first iPhone at the Macworld Expo in 2007, Steve Jobs told his audience, “Nobody wants a stylus. So let’s not use a stylus. We’re going to use the best pointing device in the world. We’re going to use a pointing device that we’re all born with – born with 10 of them. We’re going to use our fingers.” [3] Job’s point of reference for this statement was the old resistive touch pen. Since 2011, Apple has been investing heavily in active pens, and it’s my strong belief that Apple will release an active pen soon.

Samsung’s Galaxy Note series has successfully adopted active pens since 2010. The company’s active pen is an electromagnetic

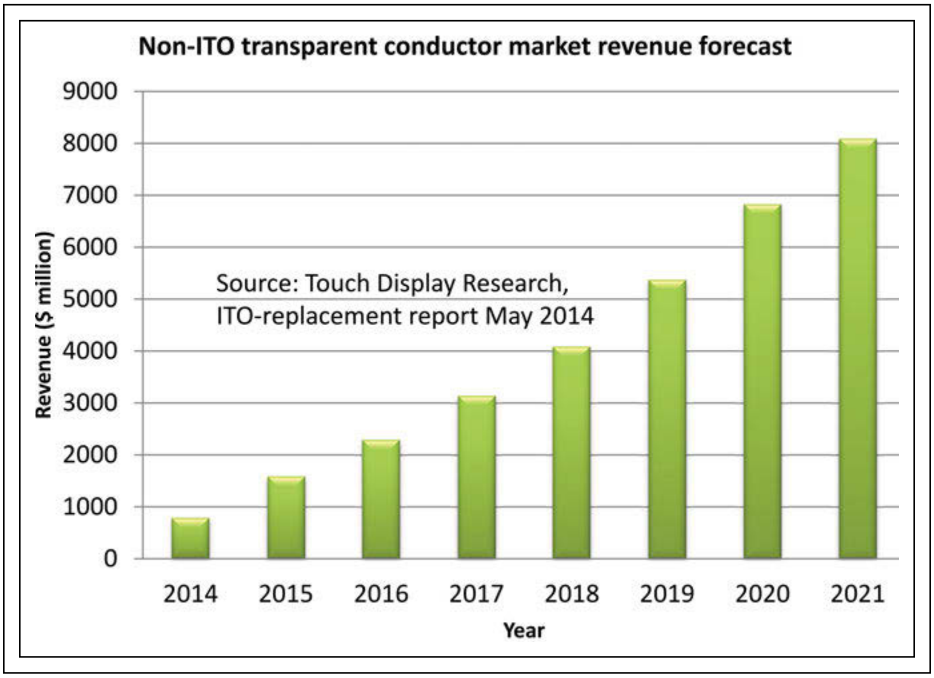

Fig. 3: The non-ITO transparent-conductor market is forecasted to reach $8.1 billion in 2021. Source: Touch Display Research, ITO-replacement: non-ITO transparent conductor technologies, supply chain and market forecast report, May 2014.

Pen	Technologies	Pen tip	Battery	Sense pen/finger
Active pen (electronic pen)	Electromagnetic	1.9mm fine tip	No battery	Pen only
		1.9mm fine tip	With battery	Pen only
		1.9mm fine tip	With battery	Pen and finger separately
	Projected capacitive	1.9mm~4.5mm tip	With battery	Both pen finger
	Ultrasound	disc tip	With battery	Both pen finger
		4mm soft tip	With battery	Pen only
	Receiver with wireless pen	real pen, 1mm fine tip	With battery	Pen only
	Camera with microdot surface	real pen, 1mm fine tip	With battery	Pen only
	Photo sensing	~4mm	With battery	Pen only
Passive pen (no electronic in the pen)	Projected capacitive	metal pen with 4mm~6mm rubber style tip	No battery	Both pen finger
		metal pen with disc tip		Both pen finger
		metal pen with driving-wheel-shape disc tip		Both pen finger
		conductive brush tip		Both pen finger
	Camera optic	IR reflector tip		Both pen finger, can have object identification software
	magnet ring	normal ball pen		Pen only

Fig. 4: Active pens and passive pens are compared in terms of technologies, pen tips, batteries, and sensing interfaces. Source: Touch Display Research, Active pen technologies, supply chain and market forecast 2014 report.

type made by Wacom.[4] N-trig's active-pen and sensor technology has been adopted by over 10 touch-screen device models.[5] In addition, many active-pen companies have raised funds on Kickstarter. Over 10,000 individuals have backed those pen projects.[6]

Active-pen technology is superior to passive-pen technology in terms of accuracy, pressure sensing, and ability to draw fine lines. Active-pen usage should therefore experience rapid growth in the next several years. Touch Display Research forecasts that the market for active-pen writing modules (including pen sensor, one pen, and the controller IC) will increase from $931 million in 2014 to $4.17 billion in 2020 (Fig. 5).

Touchless Control

While touch screens are ubiquitous, touchless control is also expanding. Touchless control has the benefit of being clean (no fingerprints) and hygienic (no germs). It also has the potential to be easier and more fun, depending on the application. Touchless control does have its downside, as shown in Fig. 6.

Here are some of the types of touchless control, along with their benefits and drawbacks.

Camera-based gesture control: The most popular example is Microsoft's Kinect, which uses PrimeSense's camera-based optical sensing technology. Gesturetek also provides camera-based sensing technologies.

Eye control: Eye control, also known as eye tracking, has increased in popularity in recent years. In fact, the technology has been around since the 1900s (using film cameras). Since the 1970s, video cameras replaced film cameras for eye control. At that time, most applications were medical (helping disabled individuals), or research driven, and, as a result, prices were very high. Since 2000, driven by consumer demand, camera (image sensor) prices have declined significantly. As a result, eye control has become more affordable.

Voice control: Voice control is now used in automobiles and mobile phones. Microsoft released voice-control software for mobile phones in 2003, but it was not popularized until Apple adopted Siri on the iPhone in 2011. In 2013, Intel mandated that voice control be facilitated on all Intel-based ultrabooks.

Ultrasound control: This technology can sense not only in front of devices but around them, and in both dark and light ambient situations. Some industry experts have indicated that ultrasound might in some way adversely affect animals.

Proximity sense: This is short-distance sensing, typically up to 15 cm from a touch-screen surface. Proximity sensing is typically combined with projected-capacitive touch screens, camera-based optical imaging, or infrared touch screens. Compared to camera-based gesture control, proximity sensing exhibits lower power consumption, roughly 10% that of camera-based systems.

Business-Strategy Recommendations

With the touch-screen-module market forecasted to grow to $36 billion by 2020 from just $2 billion in 2006, there will be many new opportunities in the fast-changing touch industry. In addition, the shortage and subsequent oversupply of ITO touch sensors created opportunities for ITO replacements, of which there are many, as described earlier in this article. The global non-ITO transparent conductor market is forecasted to grow to $8.1 billion by 2021, from $798 million in 2014.

Touch Display Research recommends metal mesh for simple designs with large volumes; silver nanowire for display and OLED lighting applications; conductive polymer for EMI and anti-static applications (due to low conductivity and prices); and carbon nanotube or Canatu's Carbon NanoBuds for mobile/wearable devices because of this technology's flexibility, low reflection, and near-zero haze. These last two qualities are essential for sunlight readability, and mobile/wearable devices are likely to be used in sunlight rather frequently.

In addition, companies that take strategic advantage of any of the other touch-related trends mentioned above have a better chance of succeeding over the long run. Pen and finger simultaneous touch are the ideal human–machine user interface for education, industry, and certain language usage. Active pens are obviously a growth area. And touchless control is expanding; it will have good penetration in TV, medical, public signage, and gaming applications.

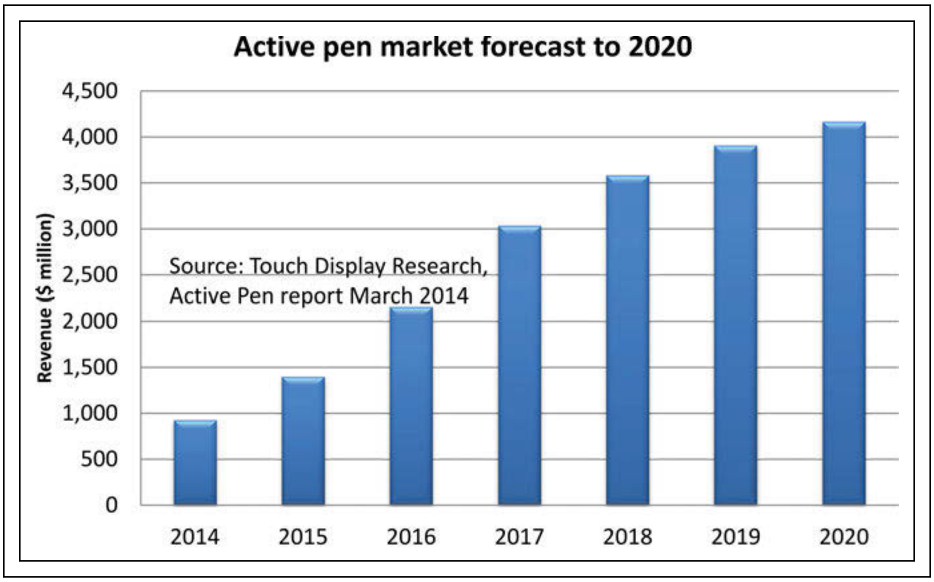

Fig. 5: *The active-pen writing-module market will increase significantly over the next 7 years. Source: Touch Display Research, Active pen technologies, supply chain and market forecast 2014 report.*

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	Camera-based gesture control	Voice control	Eye control	Ultrasound control	Proximity sense
Pros	some can sense 1 to 8 meters, can sense several person simultaneously. Some tech can sense 2 feet around	sense voice, therefore works in dark or light; small size; low cost	no gesture needed, only need eyes	can sense around the device, sense in dark and light, lower power consumption; low cost	Low power, combined with a touch screen
Cons	need 2 or 3 camera sensors, expensive	accuracy is issue, doesn't work in noisy environment	can only sense 1 person at a time; need good light condition to sense the eyes	sense within 2 feet distance; might affect animals	Only sense short distance within 15 cm

Fig. 6: *Touchless control technologies include camera-based gestures, voice, eye, ultrasound, and proximity. Some of the pros and cons of each interface are compared above. Source: Touch Display Research, Touch and Emerging Display Monthly Report, 2014.*

Rendering of Detail in Televisions

One of the creators of the IDMS (Information Display Measurements Standard) takes the measure of the very latest curved OLED TVs compared to LCD TVs. In this third article in a series, he looks at how well these displays render detail and at their resolution performance.

by Edward F. Kelley

IN the previous two articles in this series, we limited ourselves to comparing the two curved AMOLED televisions that had recently been released: the LG 55EA9800 and the Samsung KN55S9CAFXZA. For the sake of comparison, we are now adding two LCD TVs with LED backlighting to the mix: the Samsung UN55F7100AF and the LG 55LB7200. All are 55-in displays.

As in the previous articles, only one display from each manufacturer was measured, so a statistical sampling is not provided.[1,2] Please keep in mind that manufacturing details can change as newer displays are released with different properties. Additionally, using the Internet to download new operating software may also produce different characteristics depending upon the software modifications. Last, just as in the previous articles, we continue to make parenthetical references to the IDMS document where more information can be found.[3]

To test how these displays render detail (in 2-D only for this article), we needed certain setup conditions. Figure 1 shows a test pattern that we employed for some of our testing. (This may eventually be available on the www.icdm-sid.org site.) This pattern provides red-green-blue-white (RGBW) detail at a small average pixel level (APL) centered on a 3 × 3 matrix with complementary colors included. The tested displays needed to be set up with a 1:1 correspondence between the input-signal pixels and the displayed pixels, otherwise the rendering of this type of pattern would be compromised. Additionally, any sensitivity to ambient lighting had to be turned off, and any dimming features were likewise turned off as much as possible. Other than these special settings, our measurements used factory default settings for each display except where noted for the control of sharpening. We considered the standard modes and the theater modes (Movie and THX Cinema) for these displays.

Photography of Displayed Detail

The photography of display screens can be tricky. Even when close to the TV or com-

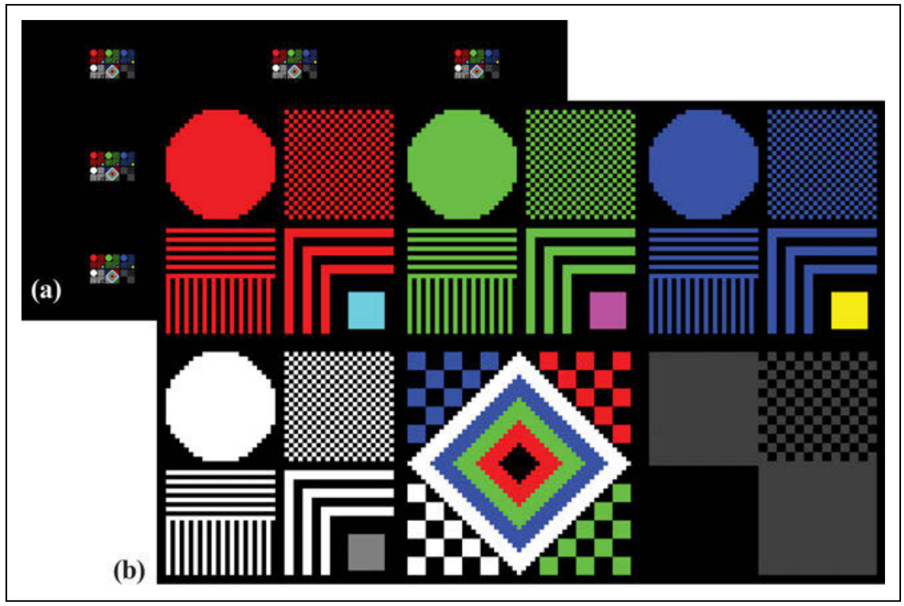

Fig. 1: Shown is a test pattern with nine elements. The RGB pattern element (b) is 160 px × 106 px to keep the APL low. The disks and 1 × 1 checkerboards are 24 px wide or high. The large white diamond is 49 px high and provides single-stairstep pixel regions; its RGBW bands are 5 px wide and high, and it is surrounded by a 4 × 4 pixel checkerboard. The bottom right cluster has a dark-gray background (63/255) for observing sharpening artifacts on a 2 × 2 checkerboard.

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puter monitor, the eye will generally not resolve the subpixel detail but will see the pixels as complete patches of light, and it was necessary to capture such a rendering in our photography as much as possible. The separation between the pixels will be visible because usually there is not a 100% fill factor for the pixels (see IDMS §7.4). To avoid moiré and render the photograph approximately as the eye sees it usually requires a large *f*-number (small effective aperture) and a reasonable distance from the screen.[4]

One of the problems with the photography of film-patterned-retarder (FPR) displays such as the LG displays used here is that some cameras will render a slightly larger gap between every two rows of pixels because of their sensitivity to circularly polarized light, presumably because of the autofocusing mechanism. Should this happen it can be eliminated using a linear polarizer in front of the camera lens with its polarization axis oriented at 45° with respect to the horizontal or vertical in order to minimize any color shift (see Fig. 2). The eye sees evenly spaced rows on the display as in Fig. 2(b). We used a Canon EOS T3i to photograph the screen images.[5]

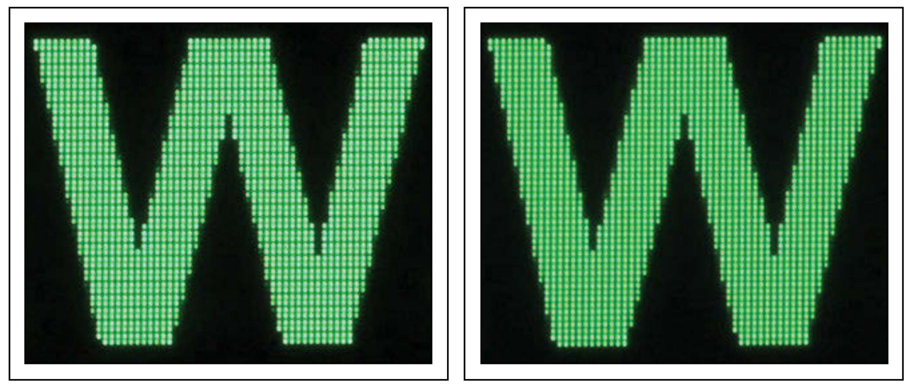


***Fig. 2:** These pixel-resolved photographs show the LG OLED FPR display using a linear polarizer to eliminate the camera-induced uneven row spacing. The left photograph (a) shows a larger row spacing between every two rows, which is not observed by the eye. The right photograph (b) is taken with a linear polarizer with its axis at 45° (relative to the vertical or horizontal) in front of the camera lens; this eliminates the camera's sensitivity to circularly polarized light so that the pixel rows appear evenly spaced as the eye sees them (55 mm lens, f/22, at 1.8 screen heights).*

If we want to visually compare a displayed image with the input image, it can be difficult using our eyes: We see a pixelated image on the display with less than a 100% fill factor, but the input image is often rendered without a fill factor, such as when just one element is examined on a computer monitor, as in Fig. 1. To make the input image appear more like the displayed image, we can magnify it and introduce a grid between the pixels (see Fig. 3). The original image is sent to the display unmodified as in Fig. 1, but to visually compare the displayed image with the photograph of the displayed image we needed an added grid simulating less than a 100% pixel fill factor. If we do not do this, we can be sometimes be fooled into thinking that the display is not doing its job correctly.

To attempt to understand reasons for any irregularities in the observed pattern, we needed to examine the details of the pixels and their subpixel contributions. We captured subpixel detail using a set of three extension tubes with a 55-mm lens set at *f*/8 placed approximately 4.5 cm from the display surface (see Fig. 4).

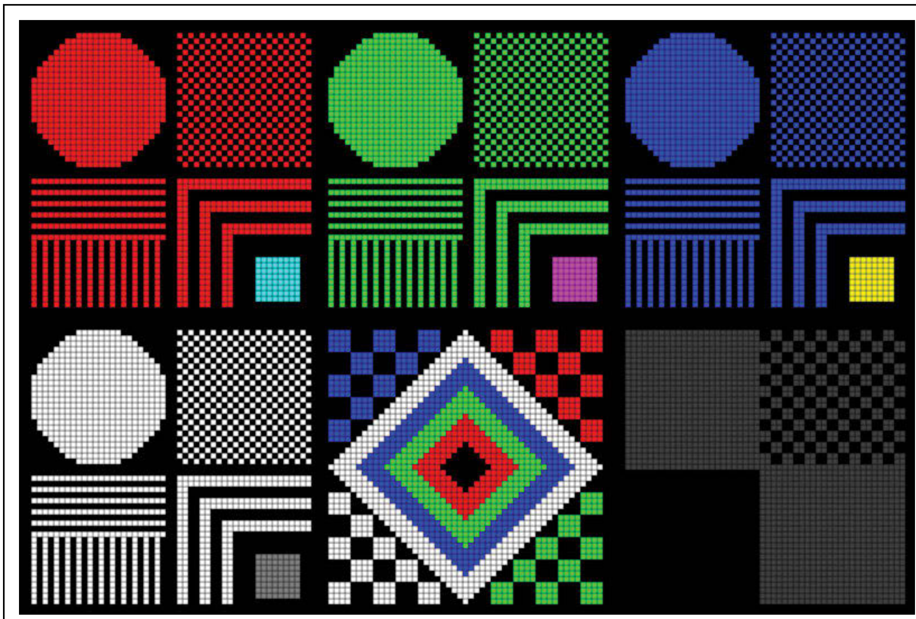


***Fig. 3:** An artificial addition of a pixel grid is used for visual comparisons with photographs of the displayed pattern. The unmodified image is sent to the display. The addition of the grid is only for visual comparisons. The pattern element is expanded 30×. Grid lines are added of a specified width (in this case 5 px); then the result is reduced to a final magnification of 5× its original size using a bilinear interpolation in MATLAB.*

Detail Rendering

We show photographs of our pattern element for the OLED displays in Figs. 5–7. Figure 5 shows the Samsung OLED with its default sharpening of 50. Figure 6 shows the same Samsung OLED with its sharpening turned to zero. Figure 7 shows the LG OLED with its default sharpening of 20. In all the figures, we show the subpixel structure in the inset

Fig. 4: The camera was set up to capture subpixel detail.

photographs at the top for the solid green color and the 1 × 1 green checkerboard. In all these three figures note that the white 1 × 1 vertical and horizontal grilles (bottom left corner) are clearly resolved, indicating full resolution of the displays, as expected. Also note in these three figures that the vertical grilles for the red and blue are smeared. This is presumably a result of the chroma sub-sampling encountered in the processing in TVs. Because of the usually large viewing distances for TVs, the eye will not resolve the red and especially the blue for the luminances involved, so there is no reason to spend the money to perfectly recreate all the colors at full resolution. Computer monitors should render such red and blue grilles perfectly, but that will not be the case for most TVs. Thus, many TVs for entertainment will not serve perfectly for a close-up computer monitor, but they will render video imagery and casual computer images adequately for the pleasure of the observer. In all three figures, the blue

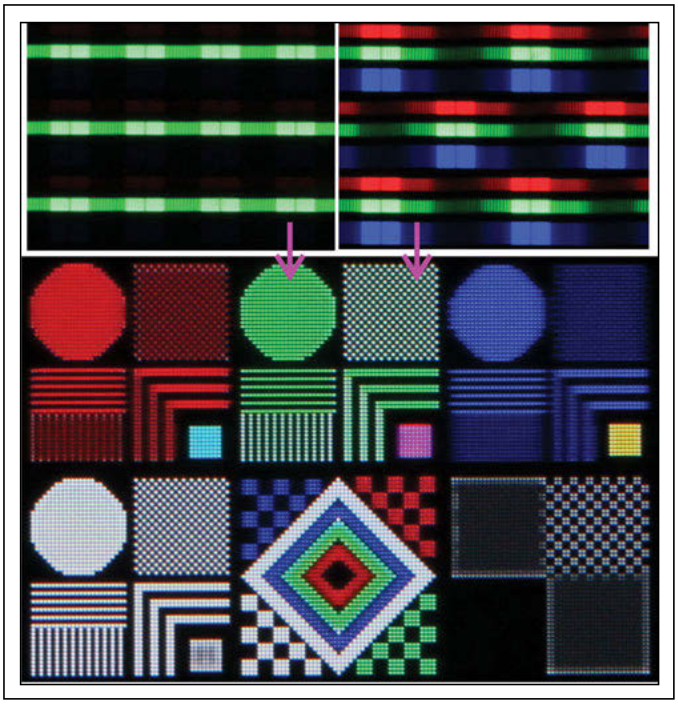


Fig. 5: This pattern element photograph shows a Samsung OLED in standard mode with its default sharpening of 50. The inset photographs above the photograph of the pattern element show the subpixel structure of the solid green and the 1 × 1 green checkerboard.

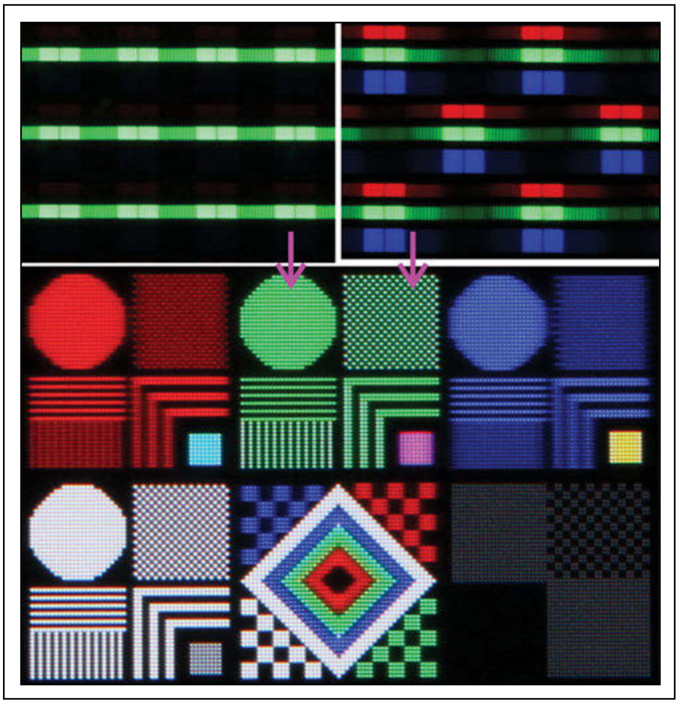
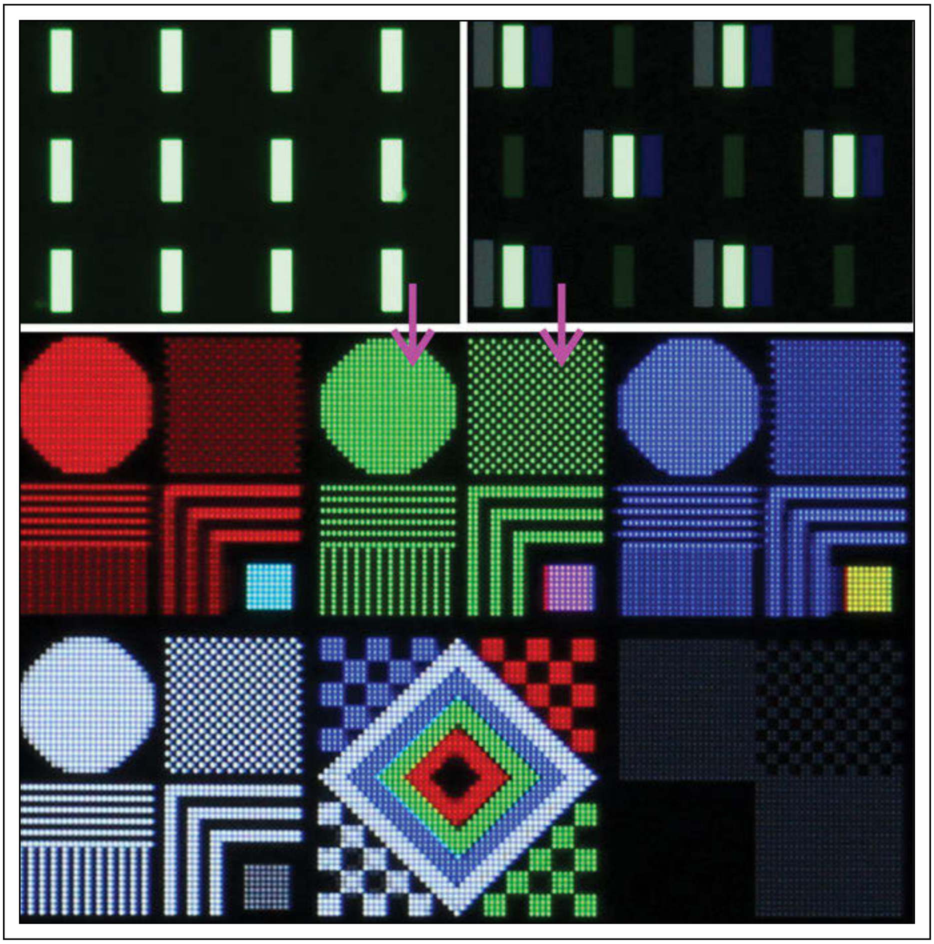


Fig. 6: This pattern element photograph of a Samsung OLED in standard mode shows the sharpening changed to zero. The inset photographs above the photograph of the pattern element show the subpixel structure of the solid green and the 1 × 1 green checkerboard. Even with sharpening turned off, there remains some visible color fade.

Fig. 7: This pattern element photograph shows an LG OLED in standard mode with its default sharpening of 20. The inset photographs above the photograph of the pattern element show the subpixel structure of the solid green and the 1 × 1 green checkerboard.



pixels are overexposed and appear to be exhibiting color fade, but such is not the case.

In Fig. 5 with the Samsung OLED sharpness setting of 50, the green 1 × 1 checkerboard appears more faded, pale, and less saturated than the red compared to their solid colors. Also note the large increase in the luminance of the 2 × 2 dark-gray checkerboard compared to the solid color. Definitely the sharpening interferes with the accurate rendering of fine detail, as expected. However, even with the sharpening turned off (to zero), Fig. 6 of the Samsung OLED continues to show a color fading, especially in the green 1 × 1 checkerboard, whereas the 2 × 2 gray checkerboard shows no sharpening artifacts. The inset photographs show the contribution of red and blue subpixels to what would be expected to be only green subpixels. The red and blue subpixels are less intense in the inset photograph of the 1 × 1 green checkerboard in Fig. 6 with the sharpening turned off, but that may be difficult to see in the photographs.

Figure 7 shows the LG OLED with no discernable sharpening artifact in the 2 × 2 gray checkerboard, despite a sharpening setting of 20. However, there is a small color fade in the green that cannot be seen in the photograph of the pattern element and cannot be discerned by the eye, but is quite visible in the inset photographs comparing the subpixel illumination in the solid green to the 1 × 1 green checkerboard. We would assume that such activation of unrelated subpixels is a manifestation of the processing algorithms used by these displays. Note some of the spillover of the white and green into the black regions of the 4 × 4 checkerboards at the bottom center of Fig. 7, which does not occur for the red or blue – presumably these are also artifacts of processing.

Fig. 8: Color fade can be a result of sharpening. The left inset magnified cut is the Samsung OLED with its default sharpening setting of 50. The right inset is the same display with the sharpening reduced to zero.

Upon careful examination of the magenta square in these three figures, note that there is a red and blue edge on the magenta square. In the Samsung OLED, these edges appear on the top and bottom because of the vertically aligned subpixels. In the LG OLED, the edges appear on the left and right because of the horizontally aligned subpixels.

How the sharpening artifacts can manifest themselves is illustrated in Fig. 8 for the Samsung OLED display. The large photograph is what appears on the screen with sharpening turned off. The two inset pictures compare the default sharpening of 50 (left inset) with the sharpening of zero (right inset). When there is such fine detail, the sharpening will cause color fade. However, as we have seen, color fade can occur when there are no sharpening artifacts.

Measurement Results

Although measurements of our pattern element are possible, it would require measuring the screen at different but nearby points, and there is always a concern in comparing different measurement points on the screen. To measure the various components found in the pattern element, we measured each component of the pattern as a centered 10% area of the screen (see Fig. 9). The spectroradiometer is placed at approximately 1.8 screen height and employs a 2° aperture (approximate measurement-field angle). It is focused on the center of the rectangle, and then the patterns to be measured are cycled through the collection. Careful attention is paid to any changes in the black level because of a pattern change. If any changes are observed, then the black background is replaced with a 1% starfield background.

We want a metric that will call attention to the effects of sharpening, which is often seen by brightening the edges of lines and a desaturation of colors in detail. Even when sharpening is not present, we also want a metric to detect any color changes in detail because of whatever processing is being done on the image that results in a change in color of detail. We can define two metrics to characterize the sharpening and the color fades (see text boxes). The sharpening is based upon how much of the white is added to the 2 × 2 gray (shade 63/255) checkerboard compared to the white level and is expressed in the percent of white. The color-fade metric is based on comparing the chromaticity coordinates of the solid color to that of the 1 × 1 checkerboard of that same color.

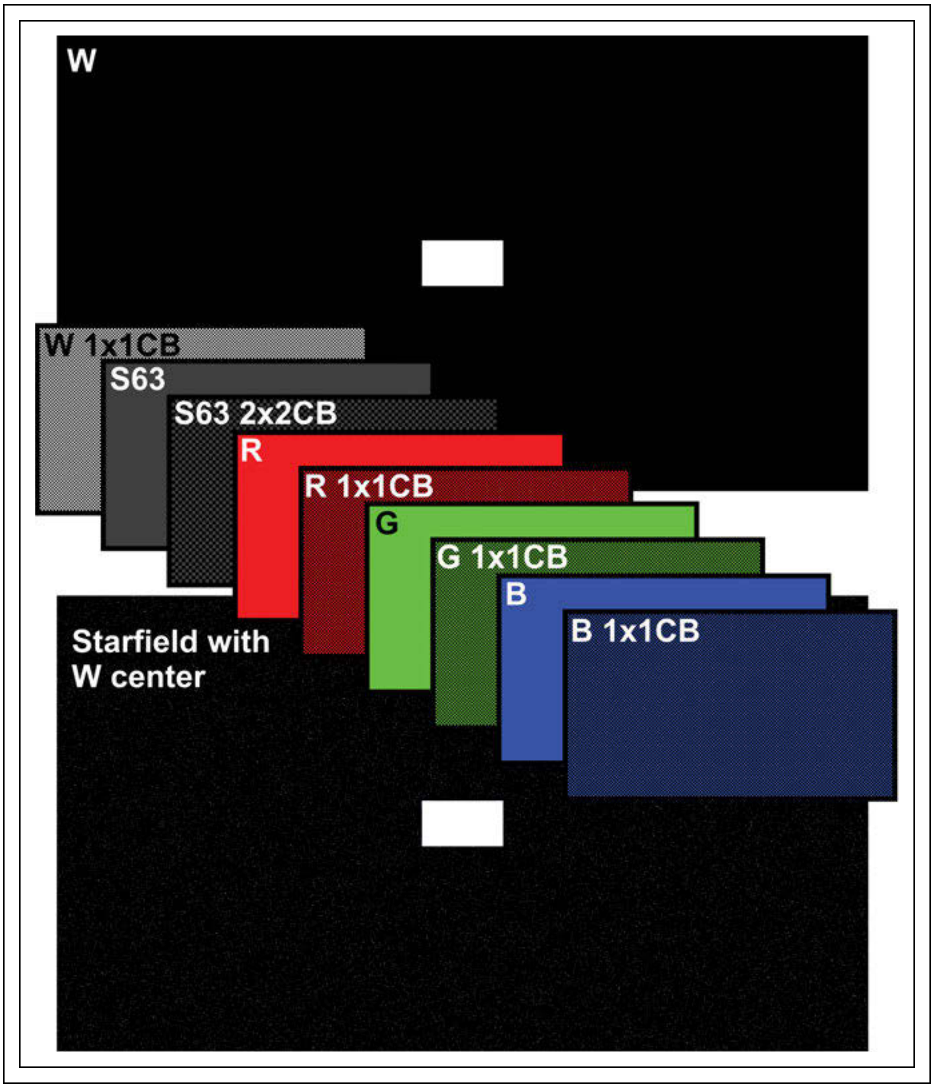


Fig. 9: Rectangles of colors and pixel checkerboards (CB) at 10% of the screen size are placed at the center of the screen to obtain the sharpening metric and color-fade metrics. If darkening of the screen cannot be adequately controlled through the display settings, then a 1% starfield pattern is used instead of a black background and the 10% rectangles are placed at the center of that starfield.

Sharpening Metric (Proposed)

Let L_W be the luminance of the white box, L_K be the luminance of black, L_{S63} be the luminance of the gray box ("S63" is for shade 63/255), and $L_{S63\ 2x2}$ be the luminance of the gray 2 × 2 checkerboard. We propose a sharpening metric S based upon the percentage of white added to the 2 × 2 gray checkerboard:

$$S_{S63} = \frac{(L_{S63\text{-}2\times2} - L_K) - \frac{(L_{S63} - L_K)}{2}}{L_W - L_K}.$$

Here, we subtract off half the net luminance of the solid gray luminance from the net luminance of the gray checkerboard and divide it by the net white luminance.

Color-Fade Metric (Proposed)

For any color Q = R, G, or B, let (u'_Q, v'_Q) be the chromaticity coordinates of the solid color, and let ($u'_{Q1\times1}$, $v'_{Q1\times1}$) be the chromaticity coordinates of the 1 × 1 checkerboard of the same color. We propose that the Euclidian separation of the two colors characterize the color fade:

$$\Delta u'v'_{Q\text{fade}} = \sqrt{(u'_{Q1\times1} - u'_Q)^2 + (v'_{Q1\times1} - v'_Q)^2} .$$

Here, we are using the 1976 CIE (Commission Internationale de l'Eclairage [International Commission on Illumination]) chromaticity coordinates.

The results appear in Table 1. It can be hard to see a few percent in the S_{S63} sharpening metric using our test pattern. However, sharpening artifacts of 10% and larger are quite visible. We highlight color fades greater than 0.04 that might be distinguishable on different parts of the display surface (see Appendix B1.2 Colorimetry in IDMS, where it discusses that a $\Delta u'v'$ of 0.04 can serve as the limit for separated colors, whereas 0.004 is the limit for adjacent colors). The table includes both the standard and theater mode results. In Fig. 10, we show the chromaticity coordinates of the data represented in Table 1 for the standard modes on all displays. The data points that are farthest from the white point are the solid colors, the data that extend farthest toward the white-point area are for the default sharpening setting, and the data points between them are where sharpening has been set to zero. The distance between the outer points and the more central points indicates the color fade. For all these displays there is not much color fade in the blue. Because the color fade for all these displays in the theater modes is small, we do not show a similar plot for the theater modes.

We have tried to present two new metrics that will help characterize displays: a sharpening metric and a color-fade metric. We have

Table 1: Sharpening and color-fade measurement results.

Display	Mode	Sharpening Setting	Sharpening Metric, S_{S63}	Red Color Fade $\Delta u'v'_{\text{Rfade}}$	Green Color Fade $\Delta u'v'_{\text{Gfade}}$	Blue Color Fade $\Delta u'v'_{\text{Bfade}}$
Samsung OLED	Standard	50 (default)	**16.9%**	**0.101**	**0.136**	0.020
	Standard	0	-0.3%	0.034	**0.091**	0.009
	Movie	0	-0.2%	0.026	**0.059**	0.003
LG OLED	Standard	20 (default)	0.1%	0.017	0.017	0.002
	Standard	0	-0.1%	0.016	0.017	0.002
	THX Cinema	0 (default)	0.0%	0.024	0.029	0.007
Samsung LCD	Standard	50 (default)	**10.94%**	**0.094**	**0.055**	0.008
	Standard	0	-0.27%	0.024	0.030	0.012
	Movie	20 (default)	1.10%	0.019	0.030	0.006
LG LCD	Standard	20 (default)	1.01%	**0.042**	**0.079**	0.003
	Standard	0	-0.26%	0.031	**0.063**	0.002
	Cinema	10 (default)	-0.37%	0.039	**0.049**	0.007

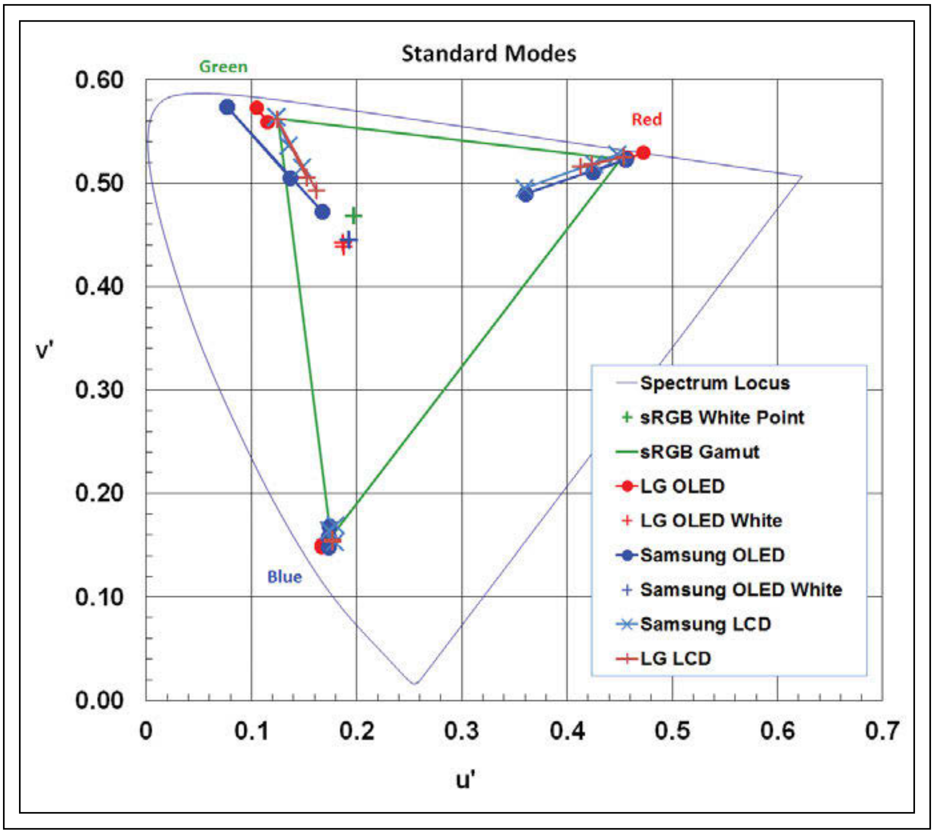
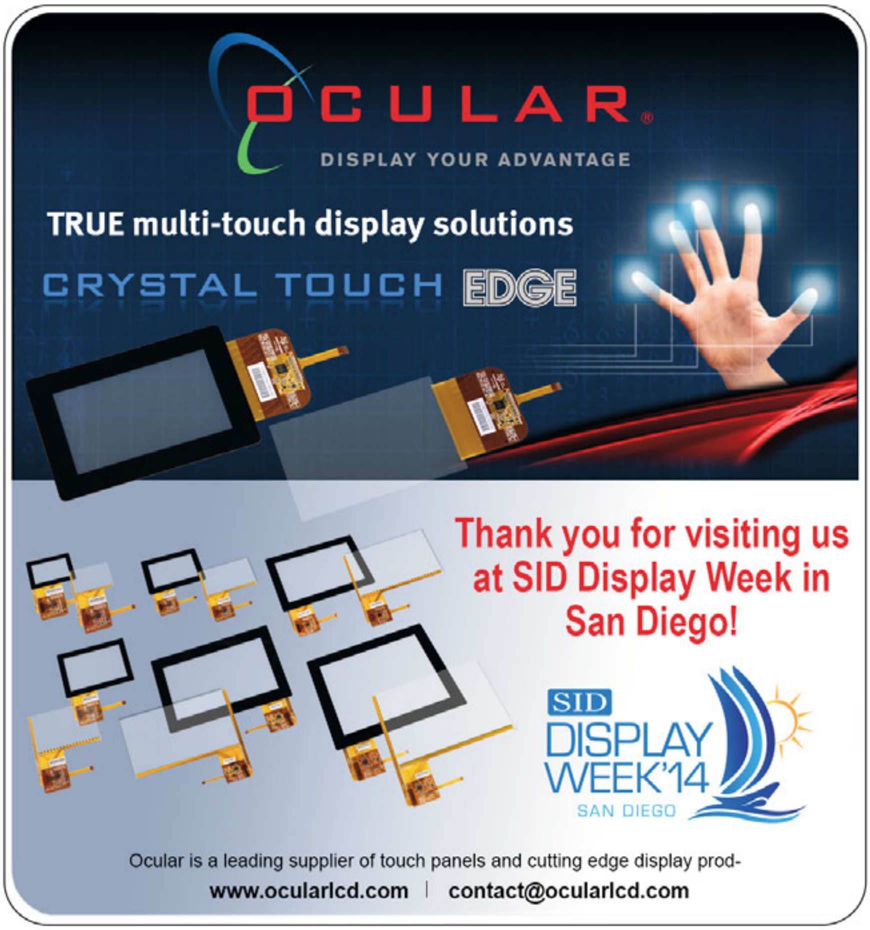


Fig. 10: Color-fade characteristics of all displays in standard mode are shown on the color diagram. The coordinates of the solid colors define the gamut and the 1 × 1 checkerboard coordinates are shown with their default settings and with sharpening turned off.



seen that sharpening can produce a color fading in detailed imagery, but we have also seen that color fade can occur when there are no sharpening artifacts present. It is important to keep in mind that these are all beautiful displays – especially the OLED displays. We develop metrics to characterize displays. Such metrics not only help users evaluate displays, but also serve to help manufacturers evaluate their own products. How these two metrics appear in the upcoming version 2 of the IDMS may depend upon further discussions and further research, but they will be submitted for consideration.

As a final aside: While measuring these displays with the LCDs next to the OLED TVs, the beautiful deep blacks of the OLED displays were clearly evident; also evident is how the OLED displays show significantly fewer viewing-angle changes. The author would like to congratulate the companies that developed the OLED displays; they are simply beautiful!

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[3]Information Display Measurements Standard (IDMS), prepared by the International Display Metrology Committee of the Society of Information display. The PDF version is available without charge; see, http://icdm-sid.org/.
[4]E. F. Kelley, "Photography of Display Surfaces Using Consumer Cameras – Three Regimes and Tristimulus Imagery," *2013 SID International Symposium Digest of Technical Papers*, Society for Information Display, Invited paper 24.1, pp. 283–286, Vancouver, Canada (May 2013).
[5]Disclaimer: The apparatus described herein are identified only for the purpose of complete technical description: The signals are provided from a computer using an NVIDIA GeForce GTX 760 board with an HDMI (high-definition multimedia interface) output. Signal integrity was tested using a computer monitor at the end of the HDMI cable inserted into the TV. The camera used for the detailed photography was a Canon T3i. Spectroradiometric measurements were made by a Photo Research PR-730. All photographs and measurements were made in a quality darkroom. ■

Small Island, Big Business

Taiwan enjoys a strong economy and a substantial presence in the semiconductor and display industries. Current challenges to Taiwan's position in the world marketplace include a shift in consumer-device preferences, uneasy relations with nearby mainland China, and a global perception that its industry executes somewhat better than it innovates.

by Jenny Donelan

THE island of Taiwan is just slightly larger than the state of Maryland – about 14,000 square miles to Maryland's 12,400.[1] Yet, it boasts the 19th largest economy in the world – one of the richest in Asia.[2] Taiwan has a formidable high-tech industry that includes numerous display companies, including AU Optronics Corp. and Chimei Innolux. It is the world's largest chipmaker. And it has a well-established tradition of technology education and startup incubation that continuously feeds this industry.

It would be difficult to list here all the computer and display companies based in Taiwan. Examples are TSMC (Taiwan Semiconductor Manufacturing Company, MTK (MediaTek), Acer, Advantech, Asus, Foxconn, and HTC Corporation. Display companies include BenQ, CPT, HannStar, Prime View International (E Ink Holdings), and the aforementioned AUO and Chimei Innolux. "Semiconductors and displays are the two biggest consumer electronics industries in Taiwan," says Tim Tsai, Deputy General Director at ITRI/DTC (Display Technology Center).

Rise of an Asian Tiger

Taiwan's rise to economic power has been rapid. In fact, the speed of industrialization and economic growth in Taiwan during the second half of the 20th century has been referred to as the "Taiwan Miracle." The nation is also sometimes referred to as one of the "Four Asian Tigers," along with Singapore, South Korea, and Hong Kong.[3]

The circumstances that led to this success are complex and involve many economic, cultural, and political factors. But to understand the trajectory of the achievement, it is worth a very quick look at the recent history of the country that over the centuries has also been known as Formosa and the Republic of China (ROC). Taiwan was ruled in the past by the Dutch, Portuguese, and Japanese. It became the ROC in the 1940s, after the Kuomintang (KMT) military regime led by Chiang Kai-Shek retreated there following the loss of mainland China in the Chinese Civil War. Stability was achieved with martial law during the 1980s. Lately, a more democratic political system has thrived.[4]

Success Factors

Despite and perhaps also because of this fluid political situation, Taiwan's economy has flourished. In the early 1950s, the new government set in place a series of law and land reforms that allowed for faster industrialization. In the 1970s, after Taiwan was expelled from the UN, its government began an aggressive process of modernizing its industry, with an emphasis on technology such as microelectronics, personal computers, and peripherals.[3] In terms of numbers, between 1952 and 1982, Taiwan's economic growth was on average 8.7%, and between 1983 and 1986, 6.9%. Its gross national product grew by 360% between 1965 and 1986.[3] The Gross Domestic Product value of Taiwan now represents 0.79% of the world economy. The total has ranged from $253.09 billion (in US dollars) in 1980 to a high of $489.21 billion in 2013.[5]

One of the reasons for Taiwan's success is purely geographical: its tactical location near China, Japan, and the Philippines. Other reasons are "soft" – an emphasis on productivity; increases in capital and labor, including the entry of more women into the workforce; and the initiative of its people.[3]

Without doubt, a primary force behind the country's success is the cultural emphasis on education, particularly in science and engineering. (In the Asian region, Taiwan is not alone in this emphasis.) In 1999, among reporting countries, more than 1.1 million of the 2.6 million S&E degrees worldwide were earned by Asian students at Asian universities. According to World Education News and Review, students graduating from the Taiwanese education system do so with some of the highest scores in the world in comparative international tests, especially in the more technical fields such as mathematics and science.[6] Taiwan also has more than 100 colleges and universities.

Engineering is an extremely popular field in Taiwan, and engineering degrees represent about one-quarter of the bachelor degrees awarded in the country (out of roughly 65,000 degrees a year). These numbers reflect government policies that encourage students to focus on high-tech manufacturing industries.[1]

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One of the best-known Universities in Taiwan is National Chiao Tung University (NCTU), which is world-renowned for science and technology. The university was founded in Shanghai in 1896 and moved to Xian during World War II. In 1958, NCTU alumni, in cooperation with Taiwan's Ministries of Education, Communications, Economic Affairs, and National Defense, jointly recommended that a branch of the University be established at its present location in Hsinchu, Taiwan. There are now five branches of Chiao Tung University in existence: four in mainland China and one in Taiwan. Three of these universities are very well-known: Shanghai CTU, Xian CTU, and Hsinchu NCTU in Taiwan.[7]

H-P. Shieh, NCTU Professor and Vice-Chancellor at National Chiao Tung University (who received SID's Slottow-Owaki Prize this year), has advised more than 100 M.S. and Ph.D. students in display-related fields in 20 years' time. Shieh helped found the Display Institute (DI) at National Chiao Tung University (NCTU) and has assisted other major Chinese universities to establish display-related institutes in their engineering schools.

In the late 1990s, says Shieh, NCTU was well-known for microelectronics and photonics, but didn't have the same foundation for the study of displays, which were becoming significant to industry in Taiwan at the time. "Of course, NCTU already had substantial resources in microelectronics fabrication, labs, and expertise, which made my job of establishing the DI much easier," says Shieh. Training new generations of display scientists obviously keeps the momentum going for the country's display industry as a whole.

Another driving force for technology and industry in Taiwan is the Industry Technology Research Institute (ITRI), created in 1973 as a non-profit R&D organization. ITRI has played an important role, as its Web site states, "in transforming Taiwan's economy from a labor-intensive industry to a high-tech industry."

ITRI has assisted in the creation of more than 240 start-ups and spin-offs. TSMC, mentioned earlier, is one of these. TSMC is now the largest semiconductor company in Taiwan and one of the most important semiconductor makers in the world. ITRI is also a major employer, with approximately 6,000 employees, 1,300 with Ph.D.s and 3,000 with M.S. degrees. According to ITRI, it has cultivated more than 140 CEOs in the local high-tech industry and holds more than 20,000 patents.[8]

Government and Business Climate

Currently, Taiwan is a great place to do business and do business with, in part because of its supply chain, according to an AUO spokesperson who says "Taiwan has the world's most sophisticated display-industry chain, with nearly two decades of development." AUO also has fabs and factories in mainland China, Eastern Europe, and Singapore (in addition to Taiwan) that range from Gen 3.5 to Gen 8.5 (Fig. 1). Displays are big business in Taiwan. AUO is the 23rd largest company in Taiwan. Hon Hai Precision (Foxconn) is the largest.[9]

In terms of foreign investment, the trade and business environment in Taiwan is fairly open. For example, the government allows foreigners to own 100% of their companies in Taiwan. The World Bank ranks Taiwan 17th overall (out of 189 countries) for ease of doing business, in terms of factors such as starting a company, getting construction permits or lines of credit, *etc*.[10]

According to a World Bank report, in 2012, Taiwan was the United States' 11th largest trading partner in goods, placing it ahead of markets such as India and Italy. It was also the 16th largest U.S. export market overall and the seventh largest export market for agricultural products. The report noted that Taiwan's banking and systems are well developed, and "there are no foreign exchange regulations that would significantly hamper a U.S. exporter from receiving payment for goods shipped and services provided."[10]

Challenges Ahead

Taiwan's enviable economic position has been threatened in recent years. One reason is that its strength has been in PC and PC-component manufacturing, an area with declining sales. Sales of smartphones, on the other hand, for which Taiwanese companies control less than one-fifth of the market, are rising briskly, according to a 2013 article in *The New York Times*. The *Times* also noted that while Taiwanese manufacturing has always been known for its discretion (very few leaks) and high-quality final engineering and mass production of consumer electronics devices, it is less well-known for coming up with new products.[11]

Another challenge has been a certain restlessness on the part of the young engineers trained in Taiwan. "For the past 5 years," says Shieh, "very few of my students go on to join display companies; most of them join TSMC. This is certainly reflected by their stock price – AUO is about NT$10/share and TSMC over NT$100/share." But even the semiconductor companies are finding it more difficult to get the best engineers. Another *Times* article last year reported that the COO of a major chip company in Taiwan said his industry was losing intellectual talent to companies such as Apple, Facebook, and Google.[12]

Yet another ongoing trial is Taiwan's relationship with mainland China, which over the years has been complicated and strained. Currently, mainland China is a member of the UN; Taiwan is not. Trade between the two entities has not always been freeflowing, although it certainly exists, and in recent years has become easier, according to sources interviewed for this article. However, now that mainland China is an engineering and manu-

Fig. 1: AUO's Gen 8 TFT-LCD fab in the Houli district of Taiwan reflects the country's green initiatives; it received LEED platinum certification in 2011.

facturing powerhouse of its own, it is more of a rival to Taiwan than formerly.

In June 2014, Zhang Zhijun, director of mainland China's Taiwan Affairs Office, visited the island to officially discuss relations, the first openly permitted visit by minister-level officials in the 60 years since the Chinese Civil War.[13] The subject of the visit was trade, yet discussions of trade agreements are often wrapped up with touchy political issues such as the possibility of unification, which many in Taiwan do not welcome. At press time, there was also talk of a trade agreement between China and South Korea that could threaten agreements Taiwan currently has with China.[14]

Lastly, Taiwan has sometimes been perceived as a country of skilled end-of-pipeline manufacturers more than innovators, a country with education and corporate systems that do not nurture innovation. This is a deep criticism in a global business climate that currently values innovation and disruptive technology above all else. It's also somewhat unfair considering ITRI's startup record and the recent success of Taiwanese companies like Asus, which has recently delivered a number of notebooks with innovative features, such as a notebook/tablet transformable that took an innovation prize at CES this year.

In any event, recent articles like *The New Yorker*'s "The Disruption Machine: What the gospel of innovation gets wrong" and the discussions it has sparked indicate that some in the business world are questioning the advisability of relentless innovation.[15] Perhaps hard work and attention to detail, which the Taiwanese companies do so well, will take innovation's place as the secret ingredient behind industrial success! Whatever happens, it seems likely that a nation that has survived numerous occupations, martial law, and more, only to rise as a technology powerhouse, will probably adapt and adjust as necessary to retain its major player status.

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eyes and ears can only absorb so much information so quickly, and we are increasingly being challenged by having too much available information and not enough human bandwidth to deal with it. At the same time, the interactivity community is still in its infancy, developing techniques such as eye tracking and hand/body gesture interpretation to manage the flow of information in and out of our digital display devices. One example is the recent demonstration of a rapidly evolving interactivity technology from Intel discussed in the media by Dr. Achin Bhowmik (http://betabeat.com/2014/06/intels-new-laptop-can-read-your-emotions-make-everything-3d/). In this latest work, Bhowmik and his team have given tablets the ability to recognize complex body gestures, read facially expressed emotions, and render digital equivalents of the living world they see from their electronic eyes. This and similar innovations will no doubt enable a new range of complex interactions between people and their computers that we have not yet fully imagined.

Before the iPhone came out, how many of you thought about using multiple finger gestures to access data on your screens? Other than a few games, there were few practical examples of multi-touch interactions, and then overnight it all changed. Consider a smartphone with a screen that is too small for all the data being presented. If users cannot zoom and pan that imagery with gestures, the device is almost worthless. It's a complex dependency that exists between all the information available on our digital devices and their modes of interactivity. One must keep pace with the other if wearable and portable computing trends are to truly integrate themselves into our lives.

There is no current answer to the problem of vast quantities of available information and limited human bandwidth with which to interpret it. That's a topic for another day. I think what we are seeing is the beginning of an exciting and rapidly evolving field of interactivity science that will explode in the next decade in ways that so far only the best science-fiction writers have started to imagine. The possibility of realizing virtual-reality interfaces and holographic interactive displays is getting closer, and when it arrives it will be better than anything that has been imagined.

By now you may have guessed that the themes of this issue include Touch and Interactivity as well as Tablets. I'm really pleased to be able to offer it to you, thanks in large part to the efforts of our Guest Editor Bob Senior, who is well-known in our industry and a respected expert in the area of touch.

We begin with a discussion of digital pens in the Frontline Technology feature, "Technologies and Requirements for Digital Pens," written by On Haran, research manager at N-trig. The simple act of writing on a tablet computer is built on many layers of technology considerations, choices, and innovations that make up the intuitive experience we have come to expect. Also on the topic of tablet computers, we welcome back author and technology analyst Ray Soneira to reveal his latest tablet test results in "Tablets Are Trending Better, Bigger, and Brighter." In a way, the real story behind this year's latest offerings is that there is not a bad one in the field, but among all the great performers there are a number of important differences in the displays being used and we are grateful to Ray for educating us with his work.

There is another recent trend in front of us lately, that of finding a better transparent conducting material than indium-tin-oxide (ITO) to use in touch screens and similar applications. We all know the 900-pound gorilla is ITO, and no one expects that to change in the immediate future, but we have all realized that ITO has limiting optical and electrical properties, especially for flexible backplanes. Recent developments from several new entrants have produced some promising alternatives. One such innovator is Canatu with the new material it calls Carbon Nanobuds. As authors Anton S. Anisimov *et al*. describe in their Frontline Technology article, "Printed Touch Sensors Using Carbon NanoBud Material," they developed a hybrid of carbon nanotubes and fullerenes in a special process that can achieve both high light transmission and high electrical conductivity at the same time – a balancing act that ITO cannot match. If you are thinking this is a niche market application, please note that Touch Display Research forecasts that non-ITO transparent conductor market revenue will increase from $206 million in 2013 to $5 billion in 2020. That's a lot of revenue to be captured by one or a few of the leading developers for this technology in the next 6 years.

That data point I just referenced came directly from this month's Display Marketplace feature written by Jennifer Colegrove and aptly titled, "New Trends in Touch." In her analysis, Jennifer expands on the marketplace for several critical topics in the touch-screen ecology, including ITO replacement materials, active pens, and "touchless" interactivity. There is a lot of money going into touch and interactive technologies in the next few years and, as I said earlier, I think we have just started to think about this technology from a real human-experience point of view.

This month we have some other topics of interest to offer as well, including the third installment in our curved-display metrology series by author Ed Kelley. In this Frontline Technology feature titled "Rendering of Detail in Televisions," Ed looks at the various methods used by designers to render and enhance features and details in the leading-edge curved OLED and LED-backlit LCD TVs. Along with his detailed analysis of measurements and methods, Ed proposes new metrics for "Sharpening" and "Color-Fade" that may soon become part of the next release of the ICDM. On this and everything that Ed publishes, he welcomes your comments and ideas for his work, and we are sincerely grateful for the education he has given all of us in this field.

Next, we have a new installment in our Regional Business Review series this time looking at the tremendous growth of the display industry in Taiwan. With a total GDP of nearly US $500 billion, this tiny island is home to a number of pivotal semiconductor and display manufacturers. Our own Jenny Donelan tackles the tough questions about how this came to be and what drives this engine of growth and development in her contribution titled "Small Island, Big Business." From a seemingly unlikely start, the people of Taiwan have put hard work, education, and investment to work to build a bright future.

Finally this month, I have some sad news that many of you already know. In April, we lost two giants of the display industry, men with a lifetime of achievements in the field of displays who will be sadly missed by many of us. Bernie Lechner, a universally acknowledged expert in TV technology and a past SID president, was someone I admired from my earliest days at SID. He played a critical role in the development of active-matrix LCDs as well as the creation of high-definition TV in the U.S. Always approachable, always happy to teach, and always supportive, Bernie

(continued on page 43)

continued from page 3

Amazon Has Its Own Smartphone

Amazon recently announced the Amazon Fire Phone, its first-ever smartphone. The glass-backed Fire Phone has a 4.7-in. display with a resolution of 315 ppi. It runs on a 2.2-GHz Snapdragon 800 quad core processor and comes with 2 GB of RAM. Notable features include "dynamic perspective," which produces a somewhat three-dimensional imagery effect; Firefly technology, which captures and processes information including barcodes, text, music, videos, and actual products (that you can then buy); and its price – $650 without a contract.

Early reviews have been mixed. The price is high for a phone that does not have the high-concept design or functionality of an iPhone or a Galaxy. The Firefly feature has caused some critics to dismiss the product as a "shopping phone" and also raises privacy issues. (Firefly works through camera and algorithm recognition of physical and media products that are then linked to Amazon with an option for purchase. These Firefly scans are stored on Amazon's servers until the user deletes them.) Last, the "dynamic perspective" is seen by some reviewers as a gimmick. This feature uses four camera sensors and proprietary algorithms to track head and phone movements and thus allow users to look "around" imagery. Dynamic perspective could certainly be a boon to shopping and gaming applications. An SDK is available. In any event, consumers will soon have a chance to register their own reactions – the phone, which is exclusive to AT&T, was scheduled for release this July.

– Jenny Donelan

The Amazon Fire Phone represents the mega-retailer's first foray into the smartphone business. Image courtesy Amazon.

Product News from Display Week

(continued from page 3)

in one place. Manufacturers have responded to the problem of cracked or shattered display screens with the adoption of hardened cover glass such as the ion-exchange Gorilla Glass from Corning. Natoco from Japan may have the solution for the rest of the case. The company was exhibiting some of its novel materials in the booth of chemical company Nagase at Display Week. One particularly interesting demo was a paint that can heal itself when scratched. The booth demonstration had two glossy black panels mounted side by side. When you scrubbed them with a wire brush, the scratches were clearly visible. However, the scratches on the panel using the Natoco coating slowly disappeared, and in a matter of a few minutes the surface was restored to a pristine state.

–Alfred Poor

Algorithms Provide Water Resistance

Demonstrations of touch-panel water resistance could be seen in a number of booths at Display Week this year; it's part of the trend of enhancing projected-capacitive (p-cap) touch to make it more environmentally resistant. Most often, water resistance is achieved by operating a touch panel in two modes and switching back and forth between them: self-capacitance (using only the top electrode layer) and mutual capacitance (using both electrode layers). Self-capacitance is unaffected by water, while mutual capacitive sees water as a touch. Solomon Systech, a Hong-Kong-based touch-controller supplier, demonstrated water resistance using only algorithmic support on a 4-in. true single-layer mutual-capacitance p-cap touch panel. This is an achievement because it's very difficult to distinguish water droplets from touches using only mutual capacitance.

– Geoff Walker

Solomon Systech's single-layered projected-capacitive water resistance is based on algorithms. Photo courtesy Geoff Walker

SID 2015 honors and awards nominations

On behalf of the SID Honors and Awards Committee (H&AC), I am appealing for your active participation in the nomination of deserving individuals for the various SID honors and awards. The SID Board of Directors, based on recommendations made by the H&AC, grants all the awards. These awards include five major prizes awarded to individuals, not necessarily members of SID, based upon their outstanding achievements. The **Karl Ferdinand Braun prize** is awarded for ***"Outstanding Technical Achievement in, or contribution to, Display Technology."*** The prize is named in honor of the German physicist and Nobel Laureate Karl Ferdinand Braun who, in 1897, invented the cathode-ray tube (CRT). Scientific and technical achievements that cover either a wide range of display technologies or the fundamental principles of a specific technology are the prime reasons for awarding this prize to a nominee. The **Jan Rajchman prize** is awarded for ***"Outstanding Scientific and Technical Achievement or Research in the Field of Flat-Panel Displays."*** This prize is specifically dedicated to those individuals who have made major contributions to one of the flat-panel-display technologies or, through their research activities, have advanced the state of understanding of one of those technologies. The **Otto Schade prize** is awarded for ***"Outstanding Scientific or Technical Achievement in the Advancement of Functional Performance and/or Image Quality of Information Displays."*** This prize is named in honor of the pioneering RCA engineer Otto Schade, who invented the concept of the Modulation Transfer Function (MTF) and who used it to characterize the entire display system, including the human observer. The advancement for this prize may be achieved in any display technology or display system or may be of a more general or theoretical nature. The scope of eligible advancement is broadly envisioned to encompass the areas of display systems, display electronics, applied vision and display human factors, image processing, and display metrology. The nature of eligible advancements may be in the form of theoretical or mathematical models, algorithms, software, hardware, or innovative methods of display-performance measurement, and image-quality characterization. Each of these above-mentioned prizes carries a $2000

SID honors and awards nominations

Nominations are now being solicited from SID members for candidates who qualify for SID Honors and Awards.

- KARL FERDINAND BRAUN PRIZE. Awarded for an outstanding *technical* achievement in, or contribution to, display technology.
- JAN RAJCHMAN PRIZE. Awarded for an outstanding *scientific* or *technical* achievement in, or contribution to, research on flat-panel displays.
- OTTO SCHADE PRIZE. Awarded for an outstanding *scientific* or *technical* achievement in, or contribution to, the advancement of functional performance and/or image quality of information displays.
- SLOTTOW–OWAKI PRIZE. Awarded for outstanding contributions to the education and training of students and professionals in the field of information display.
- LEWIS & BEATRICE WINNER AWARD. Awarded for exceptional and sustained service to SID.
- FELLOW. The membership grade of Fellow is one of unusual professional distinction and is conferred annually upon a SID member of outstanding qualifications and experience as a scientist or engineer in the field of information display who has made widely recognized and significant contribution to the advancement of the display field.
- 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. These awards may be made for contributions in one or more of the following categories: (a) outstanding technical accomplishments; (b) outstanding contributions to the literature; (c) outstanding service to the Society; (d) outstanding entrepreneurial accomplishments; and (e) outstanding achievements in education.

Nominations for SID Honors and Awards must include the following information, preferably in the order given below. Nomination Templates and Samples are provided at *www.sid.org/awards/nomination.html*.

1. Name, Present Occupation, Business and Home Address, Phone and Fax Numbers, and SID Grade (Member or Fellow) of Nominee.

2. Award being recommended:
   Jan Rajchman Prize
   Karl Ferdinand Braun Prize
   Otto Schade Prize
   Slottow–Owaki Prize
   Lewis & Beatrice Winner Award
   Fellow*
   Special Recognition Award

   *Nominations for election to the Grade of Fellow must be supported in writing by at least five SID members.

3. Proposed Citation. This should not exceed 30 words.

4. Name, Address, Telephone Number, and SID Membership Grade of Nominator.

5. Education and Professional History of Candidate. Include college and/or university degrees, positions and responsibilities of each professional employment.

6. Professional Awards and Other Professional Society Affiliations and Grades of Membership.

7. Specific statement by the nominator concerning the most significant achievement or achievements or outstanding technical leadership that qualifies the candidate for the award. This is the most important consideration for the Honors and Awards committee, and it should be specific (citing references when necessary) and concise.

8. Supportive material. Cite evidence of technical achievements and creativity, such as patents and publications, or other evidence of success and peer recognition. Cite material that specifically supports the citation and statement in (7) above. (Note: the nominee may be asked by the nominator to supply information for his candidacy where this may be useful to establish or complete the list of qualifications).

9. Endorsements. Fellow nominations must be supported by the endorsements indicated in (2) above. Supportive letters of endorser will strengthen the nominations for any award.

E-mail the complete nomination – including all the above material by **October 8, 2014** – to fan.luo@ieee.org with cc to office@sid.org or by regular mail to:
Fan Luo, Honors and Awards Chair, Society for Information Display,
1475 S. Bascom Ave., Ste. 114, Campbell, CA 95008, U.S.A.

stipend sponsored by AU Optronics Corp., Sharp Corporation, and Samsung Display, respectively.

The **Slottow–Owaki prize** is awarded for ***"Outstanding Contributions to the Education and Training of Students and Professionals in the Field of Information Display."*** This prize is named in honor of Professor H. Gene Slottow, University of Illinois, an inventor of the plasma display and Professor Kenichi Owaki from the Hiroshima Institute of Technology and an early leader of the pioneering Fujitsu Plasma Display program. The oustanding education and training contributions recognized by this prize is not limited to those of a professor in a formal university, but may also include training given by researchers, engineers, and managers in industry who have done an outstanding job developing information-display professionals. The Slottow–Owaki prize carries a $2000 stipend made possible by a generous gift from Fujitsu, Ltd., and Professor Tsutae Shinoda.

The fifth major SID award, the **Lewis and Beatrice Winner Award,** is awarded for ***"Exceptional and Sustained Service to the Society."*** This award is granted exclusively to those who have worked hard over many years to further the goals of the Society.

The membership grade of **SID Fellow Award** is one of unusual professional distinction. Each year the SID Board of Directors elects a limited number (up to 0.1% of the membership in that year) of **SID members** in good standing to the grade of **Fellow.** To be eligible, candidates must have been members at the time of nomination for at least 5 years, with the last 3 years consecutive. A candidate for election to Fellow is a member with ***"Outstanding Qualifications and Experience as a Scientist or Engineer in the Field of Information Display who has made Widely Recognized and Significant Contributions to the Advancement of the Display Field"*** over a sustained period of time. SID members practicing in the field recognize the nominee's work as providing significant technical contributors to knowledge in their area(s) of expertise. For this reason, five endorsements from SID members are required to accompany each Fellow nomination. Each Fellow nomination is evaluated by the H&AC, based on a weighted set of five criteria. These criteria and their assigned weights are creativity and patents, 30%; technical accomplishments and publications, 30%; technical leadership, 20%; service to SID, 15%; and other accomplishments, 5%. When submitting a Fellow award nomination, please keep these criteria with their weights in mind.

The **Special Recognition Award** is given annually to a number of individuals (membership in the SID is not required) of the scientific and business community for distinguished and valued contribution in the information-display field. These awards are given for contributions in one or more of the following categories: (a) ***Outstanding Technical Accomplishments,*** (b) ***Outstanding Contributions to the Literature,*** (c) ***Outstanding Service to the Society,*** (d) ***Outstanding Entrepreneurial Accomplishments,*** and (e) ***Outstanding Achievements in Education.*** When evaluating the Special Recognition Award nominations, the H&AC uses a five-level rating scale in each of the above-listed five categories, and these categories have equal weight. Nominators should indicate the category in which a Special Recognition Award nomination is to be considered by the H&AC. More than one category may be indicated. The nomination should, of course, stress accomplishments in the category or categories selected by the nominator.

While an individual nominated for an award or election to Fellow may not submit his/her own nomination, nominators may, if necessary, ask a nominee for information that will be useful in preparing the nomination. The nomination process is relatively simple, but requires that the nominator and perhaps some colleagues devote a little time to preparation of the supporting material that the H&AC needs in order to evaluate each nomination for its merit. It is not necessary to submit a complete publication record with a nomination. Just list the titles of the most significant half a dozen or less papers and patents authored by the nominee, and list the total number of papers and patents he/she has authored.

Determination of the winners for SID honors and awards is a highly selective process. Last year less than 30% of the nominations were selected to receive awards. Some of the major prizes are not awarded every year due to the lack of sufficiently qualified nominees or, in some cases, because no nominations were submitted. On the other hand, once a nomination is submitted, it will stay active for three consecutive years and will be considered three times by the H&AC. The nominator of such a nomination may improve the chances of the nomination by submitting additional material for the second or third year that it is considered, but such changes are not required.

Descriptions of each award and the lists of previous award winners can be found at *www.sid.org/awards/indawards.html*. Nomination forms are available at *www.sid.org/awards/nomination.html* where you will find Nomination Templates in both MS Word (preferred) and Text formats. Please use the links to find the Sample Nominations, which are useful for composing your nomination since these are the actual successful nominations for some previous SID awards. Nominations should preferably be submitted by e-mail. However, you can also submit nominations by ordinary mail if necessary.

Please note that with each Fellow nomination, only five written endorsements by five SID members are required. These brief endorsements – *a minimum of 2–3 sentences* to a maximum of one-half page in length – *must state why clearly and succinctly, in the opinion of the endorser, the nominee deserves to be elected to a Fellow of the Society. Identical endorsements by two or more endorsers will be automatically rejected* (no form letters, please). Please send these endorsements to me either by e-mail (preferred) or by hardcopy to the address stated in the accompanying text box. Only the Fellow nominations are required to have these endorsements. However, I encourage you to submit at least a few endorsements for all nominations since they will frequently add further support to your nomination.

All 2015 award nominations are to be submitted by October 8, 2014. E-mail your nominations directly to fan.luo@ieee.org with cc to office@sid.org. If that is not possible, then please send your hardcopy nomination by regular mail.

As I state each year: "In our professional lives, there are few greater rewards than recognition by our peers. For an individual in the field of displays, an award or prize from the SID, which represents his or her peers worldwide, is a most significant, happy, and satisfying experience. In addition, the overall reputation of the society depends on the individuals who are in its 'Hall of Fame.'

When you nominate someone for an award or prize, you are bringing happiness to an individual and his or her family and friends, and you are also benefiting the society as a whole."

Thank you for your nomination in advance.

— Fan Luo
Chair, SID Honors & Awards Committee

SID Announces New Officers

The Society for Information Display recently announced its new Executive Committee Officers and Committee Chairs. SID's new President is Amal Ghosh, who is currently Senior Vice-President at eMagin Corp. Yong-Seog Kim, a faculty member at Hongik University in Korea, is President-Elect. Helge Seetzen, CEO of TandemLaunch, is the new Treasurer; Takatoshi Tsujimura, General Manager and Department Head of Konica-Minolta's OLED Business, is Secretary; and Brian Berkeley, Senior Vice-President of Engineering at Samsung Display in San Jose, will serve as Past-President.

New chapter directors and committee chairs are as follows: Sanjiv Sambandan, India Chapter Director; John Vieth, Canada Chapter Director; Larry Tannas, Jr., Archives Chair; Aris Silzars, Bylaws Chair; Seonki Kim, Program Chair for Display Week 2015; and Shin-Tson Wu, General Chair for Display Week 2015.

Best in Show and I-Zone Winners Named at Display Week

SID's Display Awards Committee recently selected five Best in Show winners and one Best Prototype at Display Week 2014 in San Diego. The winning Best in Show products were as follows:

Small Exhibit Category

Nanosys: *For its true-to-life display experience with high dynamic range and wide color gamut* (made in partnership with Dolby)

GroGlass: *For its AR-coated glass and acrylic that virtually eliminate reflection*

Medium Exhibit Category

AU Optronics Corp: *For its WQHD ultra-high-resolution smartphone displays*

Large Exhibit Category

LG Display: *For its UD OLED TVs*

BOE: *For its 8K x 4K display*

The Best Prototype winner, selected from the exhibitors at Display Week's Innovation Zone, was ***Ostendo Technologies***, which demonstrated a novel display device called the Quantum Photonic Imager (QPI).

An article describing the 2014 winning products in detail will appear in the September/October post-show issue of *Information Display*.

* * The Passing of Two Display Giants * *

Bernard J. Lechner Was SID President, TV Expert

by Phil Heyman and John van Raalte

Bernard J. Lechner, one of the world's leading experts on television systems and electronic displays, passed away Friday, April 11, 2014, at the age of 82. Lechner spent 30 years at RCA Laboratories in Princeton, New Jersey, in positions of increasing responsibility, from member of the technical staff to Staff Vice-President for Advanced Video Systems Research. He retired in 1987 to become a much sought-after independent consultant. Among many other contributions he made in the mid-1960s, Lechner led a small team of engineers who developed the technology to matrix-address liquid-crystal displays that is still in use today.

Lechner was a strong supporter of the Society for Information Display in its formative years and was a principal architect of SID's International Symposium, Seminar, and Exhibition (Display Week), as well as of the original IEEE co-sponsored Biennial Display Research Conference. Among his many efforts on behalf of SID, he served as program and general chair for the technical symposium and also as Honors & Awards chair for several years. In 1971, the Society for Information Display (SID) named him the first recipient of the Frances Rice Darne Award, and, in 1983, he was named the first recipient of the Beatrice Winner Award. He was elected to the SID Board of Directors in 1972 and served as Treasurer, Secretary, Vice-President, and President of SID. He was also a SID fellow.

Bernard J. Lechner (right) receives the first-ever Beatrice Winner Award at Display Week in Philadelphia in 1983 from John van Raalte, the author. Photo courtesy John van Raalte.

Lechner is widely known for his extensive contributions to the development of HDTV standards. During 1989 and 1990, he served as a member of the U.S. delegation to the final meetings of the Comité Consultatif International des Radiocommunications (CCIR) in Geneva concerning international HDTV standards. In 2000, he was honored by the Advanced Television Systems Committee (ATSC) as the first recipient of the ATSC Outstanding Contributor Award, which has become an annual award named in his honor. The National Academy of Television Arts and Sciences awarded two Emmys to the broadcast camera projects for which Mr. Lechner led the research teams.

During his career, Lechner received two RCA Laboratories Outstanding Achievement Awards.

In 1996, he was awarded the David Sarnoff Gold Medal by SMPTE for his contributions to the technologies essential to today's television systems. In 2001, he received the SMPTE Progress Medal Award, its highest honor. In 2002, the National Association of Broadcasters (NAB) presented the NAB Television Engineering Achievement Award, its highest technical honor, to Lechner. He was an inaugural member of the Academy of Digital Television Pioneers. In August 2011, the IEEE presented the Jun-ichi Nishizawa Medal to Lechner – along with T. Peter Brody and Fang-Chen Luo – in honor of their pioneering work on liquid-crystal display technology, which set the stage for the proliferation of today's flat-screen televisions, monitors, and mobile phones.

George H. Heilmeier Was LCD Pioneer

by Joe Castellano

Liquid-crystal pioneer Dr. George H. Heilmeier passed away on April 22, 2014, in Plano, Texas. He and his team at RCA built the first liquid-crystal display that operated at or below room temperature.

Heilmeier received his B.S. degree in electrical engineering from the University of Pennsylvania in 1958 and upon graduation was recruited by RCA to join the company's doctoral study award program in conjunction with Princeton University. He focused on parametric amplification, tunnel-diode down-converters, millimeter-wave generation, ferro-electric thin-film devices, organic semiconductors, and electro-optic effects in liquid crystals.

George Heilmeier poses with a prototype in 1968. Photo courtesy Joseph A. Castellano.

In the fall of 1964, he began experimenting with methods to produce a color display using liquid crystals. It was Heilmeier's idea to "dope" host nematic liquid crystals with guest "dichroic dyes" to produce a color effect, which he dubbed the guest-host effect. Soon after this discovery, he and his colleagues discovered a technique to electrically switch a liquid-crystal cell from a transparent state to a highly scattering opaque state, which he called the dynamic scattering effect. Based on this effect, he and his team built the first liquid-crystal display that operated at or below room temperature in 1966. (While at RCA, Heilmeier worked with fellow display pioneer Bernard Lechner, who also passed away in April 2014.)

Heilmeier spent much of the 1970s at the United States Department of Defense. In December 1977, he left government to become Vice-President at Texas Instruments; in 1983 he was promoted to Chief Technical Officer. From 1991 to 1996, he was president and CEO of Bellcore (now Telcordia), ultimately overseeing its sale to Science Applications International Corporation (SAIC). He served as the company's chairman and CEO from 1996 to 1997 and afterwards as its chairman emeritus.

Heilmeier received numerous awards, including the David Sarnoff Team Award in Science, Industrial Research Institute Medal, the National Academy of Engineering Founders Award, two Department of Defense Distinguished Civilian Service Medals, the IEEE Medal of Honor, the Kyoto Prize, the Draper Prize, and the National Medal of Science. He was also inducted into the Inventors Hall of Fame.

On a personal note, I was privileged to be a member of George's team when we built that first liquid-crystal display. He was not only an outstanding team leader, but a trusted and valued mentor and friend over many years. ■

editorial

continued from page 38

mentored many in this industry and it was a great privilege to attend one of his seminars or speak with him one-on-one. I will always be grateful for what he taught me and how it helped my career.

George H. Heilmeier was a pioneer in liquid crystals who developed the first LCD that operated at or below room temperature. Later in life he led several high-profile technology companies and received numerous prestigious recognitions for his ongoing work. I did not have the privilege of knowing George personally, but everyone who has spoken to me about him has described his many great attributes, including his leadership and his dedication to mentoring. He will certainly be missed by many in our great field.

With that, I wish you all a happy summer and hopefully a positive life-work balance. Don't forget the most important things are not the great displays and touch screens we all work on, but the people in our lives who support us and give us the ability to do what we do. ■

guest editorial

continued from page 4

industry today and in the immediate future. Another area of increasing importance to the industry is the use of pens. I'm delighted, therefore, that On Haran, Ph.D., the research manager at N-trig, has written a superb primer on the subject that deals with the big picture, but also provides information on the detailed user experience issues that are so important in this area. For my third article, I make no apologies for bringing to a wider audience a revised version of the Display Week 2014 symposium paper presented by my own company, Canatu. I leave it to you to read, enjoy, and draw your own conclusions. Thank you to all the authors. ■

__Bob Senior__ has worked in the technology market for 30 years, 24 of which have been in the sphere of touch and human interfaces.

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