3-D LCDs ISSUE

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September 2011
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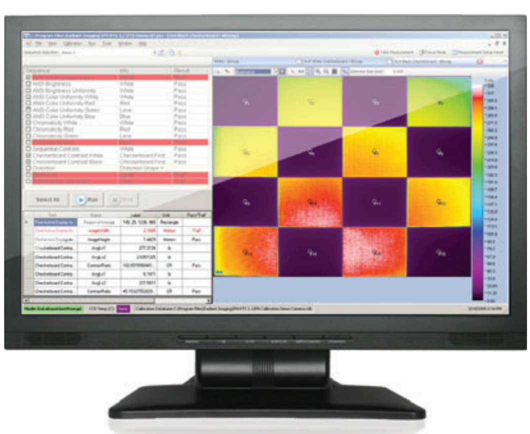

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ON THE COVER: *At the Display Week 2011 exhibition, it was clear that many display manufacturers are betting that the next direction for displays is 3-D. Excellent advances in LCD technology have been recently demonstrated to enhance the 3-D viewing experience. The need for further advances is related to the paradoxical statement that the closer a 3-D display gets to perfect, the better the display needs to be.*

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editorial

The Science Behind Making Magic

by Stephen P. Atwood

The concept of moving and still 3-D images is hardly new. The first demonstration, using red and green lenses, was in 1856 and is credited to J. C. d'Almeida, who reportedly used two stereoscopic images projected in rapid succession with lantern slides colored red and green. The audience viewed the screen through spectacles fitted with red and green lenses.[1] (This is similar to the more recent anaglyph systems that use red and cyan filters in the glasses.) This demonstration must have really ignited the imaginations of the audience of that day, appearing to be magical from their point of view.

It was more than 100 years later that I experienced a similar sense of wonder when I viewed my first 3-D slide show with a stereoscopic viewer called a "View-Master." Fisher-Price still sells these viewers, along with slide shows arranged in circular cardboard cards. If you had one as a kid like I did, you had the fun of visiting numerous exotic places and seeing all kinds of incredible sights in stereoscopic 3-D. I did not understand, at that age, the amount of technical complexity that was needed to produce those slides and make them appear so lifelike while not breaking the seemingly endless rules about consistency with the borders, keeping depth behind the image plane, aligning depth cues properly, *etc.*

It was a few years later, during the 80s, that I first started seeing specially produced 3-D movies at the Disney theme parks. I remember thinking that everyone would have a 3-D TV at home someday. I do not remember much about the technical aspects of those experiences, except that the images ignited my imagination and certainly fueled my interest in displays.

As I grew older and learned about the physics and electronics that make displays come to life, I think the magic part faded away and for a while it became difficult for me take a step back and experience with wonder what was being displayed.

What looks at first like fantasy and magic can later be revealed in science if we are able to imagine a plausible explanation and then invest enough intellectual energy into proving it. When 3-D imagery appeared in the 1940s, or back in the 1800s, I think "magic" would have been the primary explanation for most people. With our more modern context, we might also see a hologram as magical, but at the same time would accept that it has an earthly and rational explanation – and even figure it out, with a little imagination. Not long ago, we published a couple of articles in *ID* that discussed how viable real-time holograms could be produced (see July 2008). If something like that became commercially viable 5–10 years from now, would any of us really consider it magic?

Conversely, if we let our scientific imagination run loose for a few minutes, many things become possible. The Wright brothers imagined that moving air would lift a wing. Before their models and experiments, there was no practical way to see that or test it. They had to imagine it and then construct a device to test their hypothesis. It's the essence of true invention. It takes people to do this, not machines, and it comes from looking at things from a different perspective – even a fantastic one – to first imagine something might be possible and then to try and make it so.

I am a big fan of the *Star Trek* series, as I suspect many of you are as well. Along with the show's whimsical devices and imaginative application of mostly fictional

[1] http://www.widescreenmovies.org/WSM11/3D.htm

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Back to School with Rentable Textbooks

Back in July, while many students were starting to think about packing for college, Amazon.com announced the launch of Kindle textbook rentals. While e-textbooks are not new – they have been available on platforms for readers such as the Kindle and the Barnes & Noble Nook for some time – being able to rent them is.

According to Amazon, students will be able to save up to 80% off textbook list prices by renting from the Kindle Store. With the yearly cost of college textbooks ranging from $750 to $1500 or more, this represents substantial savings.

Rentals are available from Amazon's used and new textbook store.[1] If a particular textbook comes with a rental option, it is noted in the product description. Rentals are for a minimum of 30 days and for up to 360 days. Students can also extend a rental period or purchase the book they are renting at any time. With the download of the free Kindle Reading Apps for PC, Mac, iPad, iPod touch, iPhone, BlackBerry, Windows Phone, and Android-based platforms, the textbooks can be read across a wide variety of devices – no Kindles required.

In addition, Amazon is offering students the option of saving their notes and highlighted content in the Amazon Cloud system. This information will be available even after a rental expires, so if a student chooses to buy or rent again, he or she will have the same notes synched to the text.

Tens of thousands of textbooks are available for the 2011 school year from textbook publishers such as John Wiley & Sons, Elsevier, and Taylor & Francis. However, this still does not represent the full range of textbooks that are often required for college courses, according to at least a couple of university professors interviewed by *Information Display*. This is just one reason why digital textbooks, even rental ones, are not poised to take over completely from the paper-textbook market.

Other reasons include the ongoing question as to the serviceability of a digital reading and research experience compared to a physical one. According to a May 2011 study from The University of Washington,[2] students working with digital textbooks found it less intuitive to skim assignments before reading, as well as check references and illustrations. And, according to the article, "digital text also disrupted a technique called cognitive mapping, in which readers used physical cues such as the location on the page and the position in the book to go back and find a section of text or even to help retain and recall the information they had read."

Regardless of the drawbacks, the pluses of digital e-books, especially rentable ones, include their ability to lighten physical and financial loads for both students and their parents this coming semester.

References

[1]http://www.amazon.com/New-Used-Textbooks-Books/b/ref=amb_link_356891562_9?ie=UTF8&node=465600&pf_rd_m=ATVPDKIKX0DER&pf_rd_s=center-5&pf_rd_r=1KSCX72B031YZDJ214YX&pf_rd_t=1401&pf_rd_p=1309711782&pf_rd_i=1000702481

[2]http://www.washington.edu/news/articles/college-students2019-use-of-kindle-dx-points-to-e-reader2019s-role-in-academia

A Flexible and Transparent Future

At Display Week 2011, a revolving roll of what appeared to be clear plastic – but was in fact flexible glass – caught a lot of attention on the exhibit floor. The simulated roll-to-roll process in Corning's booth suggested how the material might be employed in the future for low-cost manufacturing of large-area electronics. The glass, currently being made at a thickness of 50 µm, provides the same quality of touch as sheet glass, according to Corning, but with the added benefit of higher throughput and lower cost manufacturing through the roll-to-roll process.

For the time being, the technology is actually still "in the future," although it is closer to production than when seen at Display Week 2010 in Seattle. "The ability to make glass thin enough to be flexible has been around for a while," says Corning representative Sarah Grossman. "The difference over the past couple of years is that now we are able to develop a product package that makes the glass reliable enough to use in roll-to-roll processing and an ecosystem that helps us enable customers to adopt our glass. That is what we demonstrated with our spooled demo at the latest SID conference in June."

A firm release date has not yet been set for the glass, but the company is currently aiming for a 2012–2013 time frame, according to Grossman. Samples are now available to interested companies.

Additional benefits of glass, especially as compared to plastic, include clarity and the ability to withstand heat, which becomes increasingly important during the manufacture of touch sensors. Corning researchers are currently at work on flexible glass substrates for high-resolution displays for e-book readers, smart phones, and other devices. According to the company, the material's "pristine" surface quality will also enable backplanes for a variety of applications including photovoltaics, OLED lighting, large-area sensors, and more.

–Jenny Donelan

guest editorial

New Directions for LCDs

by Phil Bos

For about 50 years, the direction of liquid-crystal technology development for displays has been clear. Displays obviously needed to be improved in the areas of diagonal size, thickness, viewing angle, resolution, response speed, contrast, and color rendition. But now, the areas that obviously needed improvement have been addressed, to the point where I am totally happy with the display on my TV, computer, phone, and tablet computer. I'm even OK with the price! So, what is next for liquid-crystal technology?

For me, the short answer is 3-D displays and electronic windows. My best justification for this is Johnny Lee's video, which you should be sure to check out if you have not already seen it: http://www.youtube.com/watch?v=Jd3-eiid-Uw

A better data point was the Display Week 2011 exhibition, where it was clear that many display manufacturers are betting that the next direction for displays is 3-D. Excellent advances have been recently demonstrated with the addition of the stereopsis cue using several different methods.

However, while the current displays are really cool, it is tempering to note that for many viewers, the experience is not what might be expected. For example, in the article "3-D TV from the Consumer Perspective" by Matthew Brennesholtz and Chris Chinnock in the November/December 2010 issue of *Information Display*, *ID*'s own Steve Atwood was quoted as feeling a bit queasy after viewing many consumer devices. This is not an uncommon reaction to 3-D displays; however, I would like to offer that the problem is not with 2-D being better than 3-D, but that further improvements in liquid-crystal technology are needed. When these are addressed, they will show the full potential of 3-D.

The need for further advances, in my opinion, is related to the paradoxical statement that the closer a 3-D displays gets to perfect (getting closer to what you think is a real window through which you are seeing real objects), the better the display needs to be. It appears that if your senses tell you that the object you are looking at is real, but there is some sort of cue conflict, your brain apparently thinks the problem is not with the display, but with you. I think this is analogous to being in a room on a boat where your sight cues tell you the room is stationary, but your balance cues tell you the room is moving. Your brain does not automatically understand that the cue conflict is from the rocking boat. It might assume you have eaten a bad mushroom that you need to get rid of. In any case, the sensation is not pleasurable or anything you would like to experience often.

But with attention to the details of the human factors of 3-D perception and liquid-crystal technology, these issues are being solved. Really good displays in which 3-D devices will allow a new level of realism and interactivity might first be expected for single-viewer applications. In this issue, there are two articles about liquid-crystal technology for flat-panel-type 3-D displays. The first, from Samsung, goes into the details of liquid-crystal technology for current devices. The other makes an attempt to point to the issues that might to be addressed in order to allow improvements in the next generation of flat-panel 3-D displays.

Regarding the window application mentioned earlier, an interesting demonstration that colleagues here at Kent State did was to place a flat-panel display in a room on the inside surface of an exterior wall, and then place a camera on the other side of the

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Liquid-Crystal Technology Advances toward Future "True" 3-D Flat-Panel Displays

Several liquid-crystal technology goals must be considered for 3-D flat-panel-display implementations to achieve high visual performance.

by Philip J. Bos and Achintya K. Bhowmik

WITH high-quality 2-D liquid-crystal displays having become commonplace, interest is now shifting toward the development of 3-D displays. It is clear from the large number of papers published in the leading display technology journals and conference proceedings that research and development efforts are increasingly being dedicated to 3-D displays, both in industry and academia. As a result, a number of consumer-electronics companies are now offering systems based on 3-D displays in the marketplace.[1] These are primarily high-definition televisions (HDTVs) in addition to some early models of notebook computers and handheld devices. However, the viewing quality or the visual performance of currently available 3-D displays lags far behind their state-of-the-art 2-D counterparts, which indicates that a large number of issues have yet to be solved.[2] In this article, we will provide an overview of the requirements for achieving a "true" 3-D display, and then point to the liquid-crystal technology goals that must be considered for high-quality 3-D flat-panel-display implementations.

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Achintya K. Bhowmik is Director of Perceptual Computing at Intel Corp., where his group is focused on developing new human-computer interaction technologies and related user experiences. He has more than 100 publications, including a book entitled, "Mobile Displays: Technology & Applications," and 23 issued patents. He can be reached at achintya.k.bhowmik@intel.com.

The requirements for the optical system of a true 3-D display can be understood by thinking of the display system as a window. Imagine the window divided into small area patches – so small that if we were to block off the entire window except one of the patches, we would see only one set of color and intensity because the patch would be too tiny to allow us to see image detail. In the depiction of the display system below, each of these window patches corresponds to a pixel. Figure 1 shows light passing through a very small patch of a window near its center.

The color and intensity of light that comes through the small patch depend on the light ray's angle. From the angle shown in Fig. 1, the viewer sees the yellow color of the walls, but at other angles the viewer would see the red color of the roof or the blue color of one of the windows. So, from each patch on the window, there are a bundle of rays emerging that is characterized by an angle, color, and intensity. What is different about 2-D and 3-D displays is the angular dependence of the pixel information.

This angular-dependent information conveys three aspects of the 3-D scene:

1. Relative motion of objects (an eye sees a different view as the viewer's position is changed).
2. Stereopsis (each eye sees a different view).
3. Focus (the angular spread of rays, intercepted by the pupil from a point in the scene, is determined by its distance from the viewer).

In adding these characteristics to a typical 2-D display to make it a 3-D display, it is also important that the resolution of the display remains high, near the limiting resolution of the eye, because the textural cues are important in the perception of depth and "realism" of the image. If we consider the "ultimate" 3-D display as one that can emulate a window as described above, we need to have a display with a high density of pixels that change color and intensity for different directions of view with very high angular resolution. If we say the eye collects a cone of rays spanning several tenths of a degree, and we would like to have an adequate angular resolution to achieve a proper focus, it is likely that we will need an angular resolution of 1º. And then if we would like the window to be viewed over a 100º field of regard, we will need each pixel to provide 1 million rays of light, each with a defined color and intensity. A 3-D display with these specifications would have its bandwidth increased by a factor of 1 million over a 2-D display with the same size and resolution, which is well beyond the current state of liquid-crystal technology.

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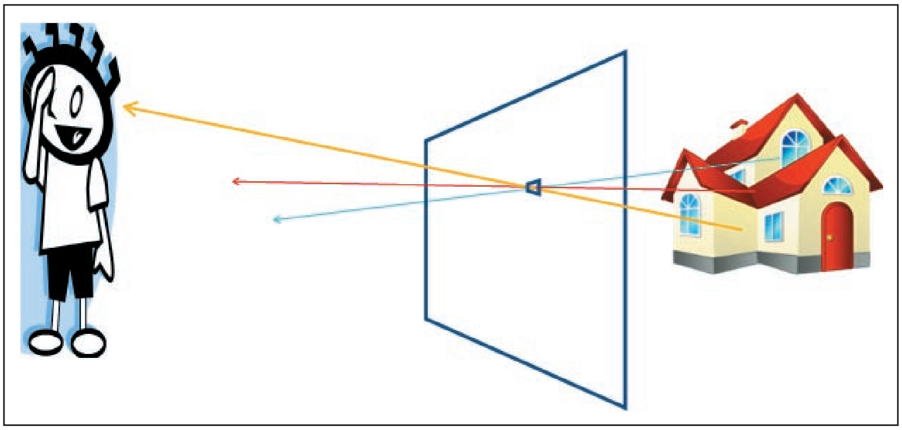

Fig. 1: The light rays passing through one "pixel" of a window come from different points of the scene. To the viewer, in the position shown, the pixel will appear yellow.

So, we need to think of a more limited solution. One method of doing that is used in theaters equipped to show 3-D films, where the scene is far away from the viewer and the viewer is sitting still. In that case, we can ignore the relative motion and focus cues of the required optical system and only provide the stereopsis cue. But this simplification may not work for scenes close to the viewer, such as would be portrayed on a desktop or a mobile display. In this case, both the cues of relative motion and focus could be significant, especially the relative motion cue (for an example of how important, check out this video from Johnny Lee, then at Carnegie Mellon University's Human–Computer Interaction Institute: http://www.youtube.com/ watch?v=Jd3-eiid-Uw). Including the relative motion cue for multiple viewers, but not attempting to take into account the focus cue, reduces the requirement on the angular resolution to that which is required to produce stereopsis and smooth motion. The angular resolution in this case might be on the order of 1° and can further be considered to be limited to only the horizontal direction. In this case, the bandwidth of a 3-D display is increased by a factor of "only" 100 over a 2-D version.

Conceptually, this could be accomplished by removing the typical backlight assembly of an LCD and putting a highly collimated "searchlight" in the form of a line that sweeps from –50 to +50° while the image on the display changes at a rate of once every 1° of sweep. But, of course, this would need to happen at a rate faster than the flicker rate, so we would need an LCD that can update a full screen in about 100 µsec. Alternatively, it could be accomplished with a parallax-barrier or lenticular-lens approach, in which we have 100 images behind each lens-let. But this would require a display that has over 100 Mpixels and image resolution would be a major challenge.

Neither of the above options is outside of the range of consideration for liquid-crystal technology, and both parallax-barrier- and lenticular-lens-based devices using a more limited number of views have shown good performance over a more limited field of regard.

Another approach that we can consider in order to reduce the required bandwidth of the system is limiting the number of viewers. A head-tracking system can then be used to determine the location of viewers' eyes, and each pixel then only needs to be able to provide light of a color and intensity corresponding to the angle of a ray leaving the pixel and headed for each eye. For a single viewer, we will need to increase our system bandwidth by only a factor of 2 (if the focus cue is left out of consideration).

A relatively easy way to do this is to use glasses on the viewers' eyes that ensure that each eye perceives each pixel on the display as having the color and intensity corresponding to its angle with respect to the pixel. The standard approaches are divided into the classes of active and passive glasses and are described in the article in this issue, "Tutorial on 3-D Technologies for Home LCD TVs" by Seonki Kim and a previous article by Jeong Hyun Kim.[3]

For the best brightness, a segmented active shutter can be considered. Segmenting is useful because if there are no shutter segments, as in the case of active glasses, the display must be black for half of the frame time, resulting in a maximum display duty cycle of about 50% (again, see the article by Kim). However, if we consider a shutter as having many segments, then the crosstalk or brightness is limited by the slower switching time of the display, as shown in Fig. 2. The duty cycle will be $(F_T\text{-}S_T)/F_T$, where F_T is the frame time and S_T is the display switching time. If we assume that F_T is 8 msec, then to achieve a duty cycle of 90% will require a switching time of about 0.8 msec. If a 75% duty cycle is acceptable, then a switching time of 2 msec is needed, which is more easily available.

Therefore, we can see that a main issue for the liquid-crystal technology is to provide a fast-switching display, as well as a fast-polarization-state controller to ensure that the correct image gets to the correct eye and a high duty cycle is maintained.

There are different factors that can be addressed to increase the speed of a liquid-crystal device. These might be divided into factors related to the material and device design. It is well established that the material factors desired for fast response are low viscosity, high birefringence, high elastic constants, and high dielectric anisotropy. Related to the device design factors, there are three that come to mind (there could be more!).

The first is to design the device so that the material flow in the cell does not slow the relaxation of the device. In electrically compensated bend (ECB) type devices, a design that accomplishes this is the pi-cell[4] and for the twisted-nematic (TN) case it is the $-3\pi/2$ device.[5] The typical switching times for these devices are between 1 and 2 msec and have been used in 3-D systems with success.

The second device design factor is to use a pretilt that is not too close to being parallel to the surface (for positive-birefringence materials) or perpendicular to the surface (for negative-birefringence materials). The reason is that the torque upon application of an electric field is zero if the director is fully perpendicular or parallel to the applied field. This factor has recently been addressed in an overview article presented at the 2011 SID Symposium.[6]

Another factor is to enhance the stored elastic energy in the field applied state so that when the field is removed, the director field

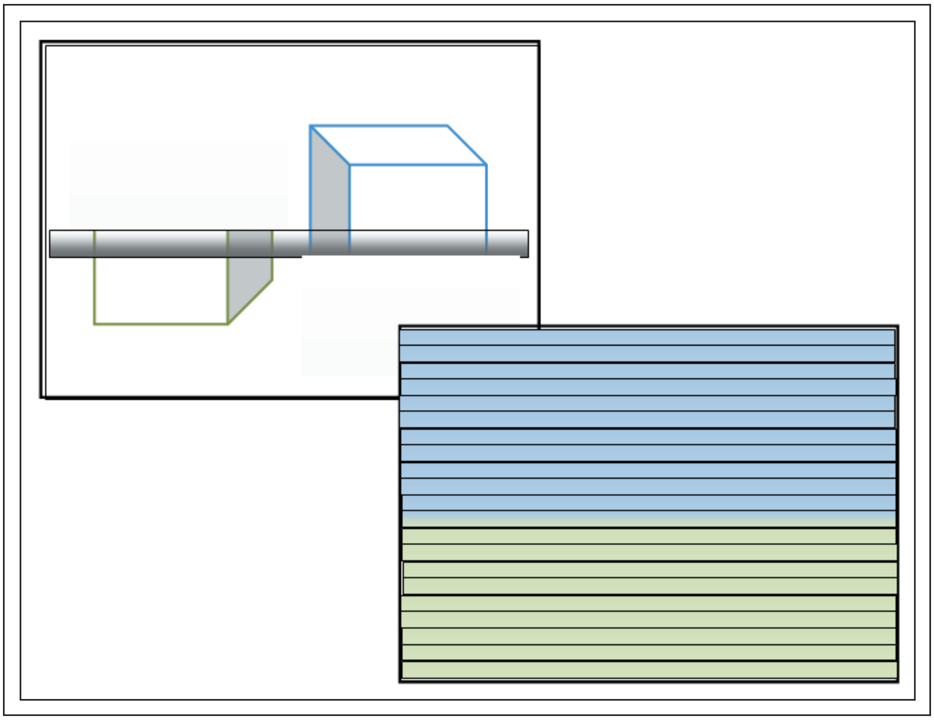

Fig. 2: With the display scanning from top to bottom, the changing image is displayed from the blue left-eye view to the green right-eye view. In front of the display is a polarization-state controller with about 20 segments, the state of which is synchronized with the scanning of the display panel. The green-colored segments are providing the polarization state that is transmitted by the right lens of the viewers' glasses, and the blue color corresponds to that of the left eye. The transition region shown in the display represents the area of the display at the instant the picture is considered where the image will exhibit cross-talk, unless this region is blanked. Assuming that the display switches more slowly than the polarization-state controller, it is this transition time that limits the performance of the system.

"relaxes" to its zero-field configuration quickly. This approach has been used in polymer-stabilized devices called "stressed liquid crystals," [7] flexolelectric devices,[8] and in blue-phase devices.[9] This approach has a drawback, however, in that it necessarily means that the torque needed to bring the director to a given field-on state goes up, and so this approach leads to a requirement for high voltages (given that the material has already been picked that has the highest practical dielectric anisotropy).

Yet another factor is to use ferroelectric liquid crystals that can be "driven" to both desired states and have a strong coupling to an applied electric field. These types of materials have been considered for commercial applications by Micron (formerly Displaytech) in high-frame-rate field-sequential displays.[10] While these devices use binary switching between two states and thus require very high frame rates for gray-scale images, analog SmC* devices are also being considered.[11]

So, there are liquid-crystal technology-based approaches that can provide acceptable response times for two field-sequential devices needed for single users, and improvements in the future will allow for faster refresh rates for multiple users.

However, for a "true" 3-D display, we may want to consider including the focus cue. If the focus cue is incorrect, it causes asthenopia (visual fatigue) after a person has been viewing the display for a short while because a spatial discrepancy exists between the accommodation plane and convergence point as illustrated in Fig. 3. It has been demonstrated that using a corrective lens of appropriate refractive power effectively reduces this discrepancy and the fatigue.[12]

Therefore, if we could determine the power of the needed corrective lens, and then provide a tunable lens of that power, it might be possible to solve the last major problem for single-user 3-D systems using a flat-panel display and glasses. The first issue of determining the power of the needed corrective lens might be accomplished by having a sensor or a micro-camera on the inside of the frames of the glasses to detect the "toe-in" of the viewer's pupils. This information will allow the computer to know the convergence point of the eyes, which is the location of the object in the 3-D scene being considered. We would like the power of the eye's lenses to be adjusted as they would be if focusing at that distance and not at the distance to the physical display surface.

By using the lens makers' formula, we can determine the required power of the corrective lens. If we call the distances from the eye's lens to the panel d_p, to the convergence point d_c, and to the retina d_r, then we would like the power of the eye's lens to be $P_e = 1/d_r + 1/d_c$ for it to be focused at the convergence plane. But for the image to actually be focused on the retina, we need the power of the electronic lens P_l to be determined by $P_e + P_l = 1/d_r + 1/d_p$. This leads to $P_l = 1/d_p - 1/d_o$. If we consider the value of d_p and d_c to be 50 and 67 cm, the power of the corrective lens, P_l, is $0.5D$, where D is the diopter.

However, we need an electrically controllable lens for this system to work. So, liquid-crystal-based lenses are another area of liquid-crystal technology that could be important toward realizing the future "true" 3-D systems that meet all of the cues required that we listed earlier (relative motion, stereopsis, and focus). Recent developments in this area were described at the 2011 SID Symposium.[13]

The above system has two drawbacks that might be considered. One is that the viewer needs to wear glasses; the other is that the focus cue is not determined directly from the 3-D display, but in fact by the user's eye convergence point. So rather than being an independent cue, it is derived from the stereopsis cue and the viewer's response to it. Correcting both of these problems will require an autostereoscopic display that comes closer to emulating the window described at the beginning of this article, where the angular resolution of the rays is high enough so that multiple rays of light will be intercepted by the pupil of each eye, evoking the focus response to form a sharp image on the retina.[14]

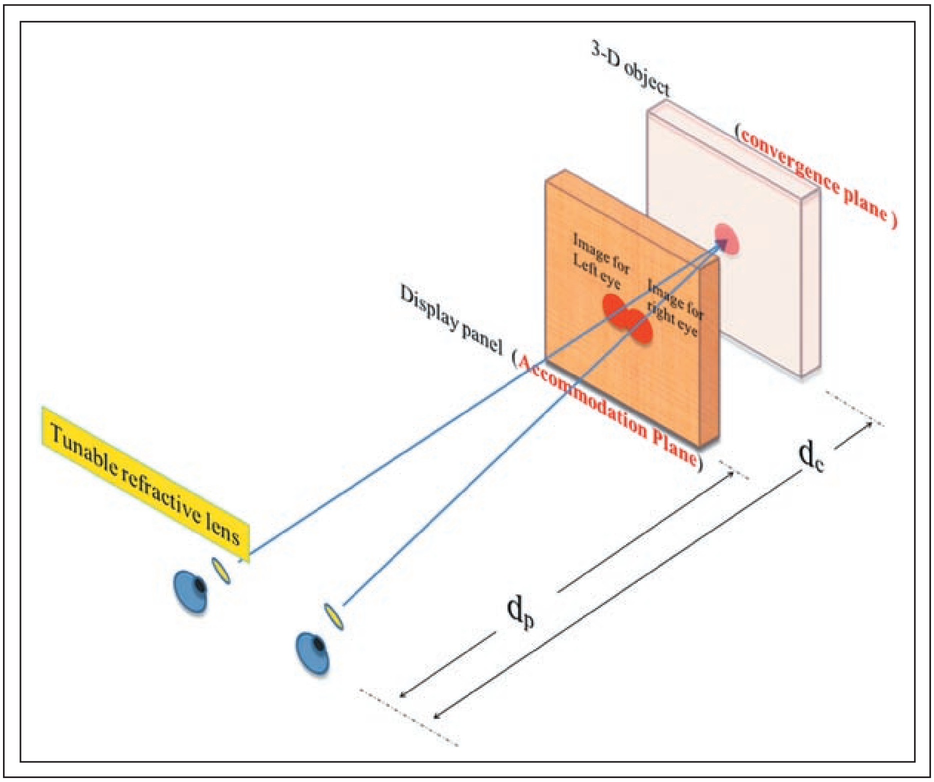

Fig. 3: The display panel is at the distance the unaided eye would focus at, whereas the convergence plane is at the distance desired for the eyes to focus to minimize eye fatigue. The tunable lens shown can correct the discrepancy.

Approaches that have been considered to yield a display of this type include holographic[15] and integral-imaging-based devices.[16] But due to the high information content required, flat-panel implementations of these approaches that can maintain all of the good characteristics of existing 2-D flat-panel displays have not currently been shown.

As first steps toward practical implementation of the above devices, lenticular-lens-based solutions are being considered.[17] Two-view devices may not be acceptable in the long term, but advances are being made. In the short term, because of the tradeoff of image quality required for 3-D, a current aspect of liquid-crystal technology development has been switchable lenses, to allow for displays to switch between a 3-D and 2-D mode.[18] As such, a device consisting of an autostereoscopic 3-D display, such as a notebook computer, could utilize the 3-D mode while displaying 3-D content such as 3-D movies or graphics applications and switch to 2-D mode while displaying 2-D content such as conventional productivity applications. Lenticular-lens-based autostereoscopic devices are making rapid progress toward having a wider field of regard while maintaining reasonable resolution. Especially notable are multi-view devices as demonstrated by Toshiba.[19] Further improvements in autostereoscopic systems are achievable by limiting the number of viewers, as discussed earlier, and designing the system with knowledge of viewer's location to be able to add a focus cue.[20] Early commercial implementations of this approach in notebook computers are making their way into the marketplace,[21] in which an eye-tracking software utilizing the built-in webcam locates and tracks the viewer's eye positions such that the images corresponding to the left and right eyes are directed accordingly. So, while the challenges of autostereoscopic systems are great, we can expect that rapid progress will continue to be made.

In summary, the realization of a "true" 3-D display that mimics the real world to give an impression that the viewer is looking through a "window" requires the display system to provide all the important visual cues: relative motion, stereopsis, and focus. In this article, we have reviewed the electro-optical system design considerations to achieve such a system. The key requirements for liquid-crystal technology to yield high-quality 3-D displays appear to be within reach, if the implementations are constrained to a limited number of viewers who are willing to wear glasses. Technology advances are being made toward autostereoscopic display systems, especially for single-user devices in the near-term and ultimately the multi-user devices of the future.

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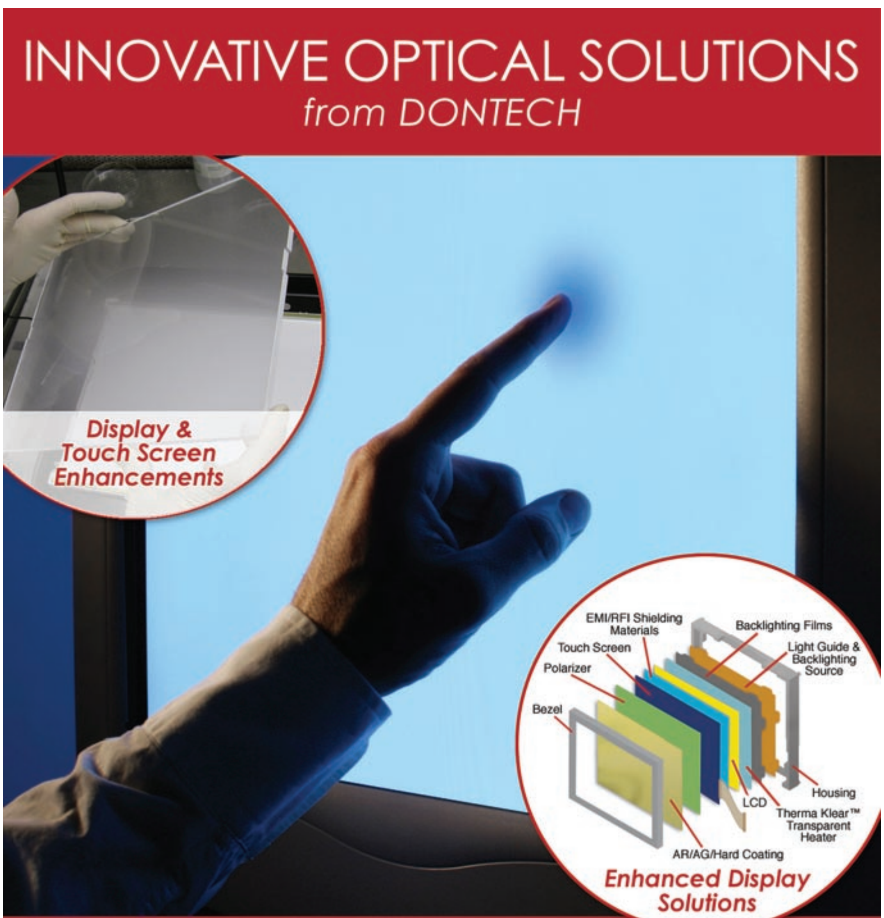

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Tutorial on 3-D Technologies for Home LCD TVs

Technical advances are continuously being made in the area of shutter-glasses 3-D systems. Knowledge of several key elements – cross-talk, fast liquid crystals, high-speed driving techniques, and LED backlights – is essential in understanding this technology, as well as what comes next.

by Seonki Kim

3-D technology has been successfully deployed in the LCD industry since early 2010. Implementation of the stereoscopic 3-D technology currently in general use would not be possible without the development of the 240-Hz LCD system. This 3-D LCD system was the result of many advances in technical areas such as liquid crystals (LCs), driving circuits, and backlight controls. The fast response time of LCs in 3-D eyewear was particularly important to good 3-D performance. This article reviews technical areas related to shutter-glasses-type 3-D systems, including a recent advance, the polarization-switching 3-D technique, and concludes with a discussion of 3-D performance in the future.

An Ideal Stereoscopic System

The high-resolution 3-D system as seen in cinemas today is currently considered the best stereoscopic 3-D solution. The left- and right-eye frames actively switch on the screen and work in cooperation with the eyewear. The same principles can be adopted for an LCD-based 3-D home system. An additional panel on the TV would be necessary to convert the optical signal from the LCD panel and match it to the optical-filter characteristics of the eyewear.

Such an idea has become closer to realization as a result of frame-rate innovations in the LCD industry. Due to technical limitations, it has until recently been much harder to raise LCD frame rates to 240 Hz and beyond compared to impulsive-type emissive displays such as plasma displays.

The operational principle for shutter-glasses-type (SG-type) 3-D is to sequentially display left- and right-eye images so that the eyewear captures the left-eye image on the left lens while the left lens is open and the right-eye image on the right lens while the left is closed. The panel transmits a reference signal to the eyewear for synchronization between the two. Therefore, in order to achieve a flicker-free image for both eyes, the SG-type 3-D implementation requires at least twice the frame rate in 3-D mode than in normal 2-D mode.[1–3]

120 *vs.* 240 Hz

Theoretically, it would be possible to implement this type of stereoscopic 3-D system with a 120-Hz double-speed frame rate known as the "120-Hz driving scheme." However, there is a trade-off between brightness and cross-talk in 3-D mode that needs to be understood. For moderate 3-D brightness, for instance, designers have had to allow an unsatisfactory level of 3-D cross-talk. In contrast, acceptable cross-talk can be achieved but at the expense of suitable brightness. The problem is related to several aspects of the LCD architecture, including response time.

It is not simple to separate two consecutive frames without overlapping images in a progressive-scanning hold-type device. Theoretically speaking, a full image with no overlap would be available only during vertical blanking intervals, and elsewhere a current image would be written over a previous image. In most cases, LC response time is not fast enough.

Thus, the need for even higher frame rates and the advent of the 240-Hz LCD system contributed to the birth of the 3-D LCD TV system because the 240-Hz system generates four frames in order to process a frame each of 60-Hz 3-D input.

With the extra frames in the 240-Hz system, however, we can enhance the 3-D brightness. Backlighting techniques are used to allow time for the switching of the lenses of shutter glasses between the left (L) and right (R) eye images. Experience tells us that the duty ratio would be optimal at 40–50% for a reasonable amount of 3-D cross-talk. For black-frame insertion (BFI) such as LBRB, the shuttering of the 3-D eyewear can be managed relatively easily.

Two frames in the 240-Hz system can be assigned to display left and right stereoscopic images. The other two can be used to minimize 3-D cross-talk (read more about cross-talk below) in two different ways. Each extra frame can copy its previous frame, making LLRR (two identical left frames and two identical right frames) in order. Otherwise, two extra frames can be replaced with black frames, making LBRB (black frames between left and right frames) (see Fig. 1). The fore-

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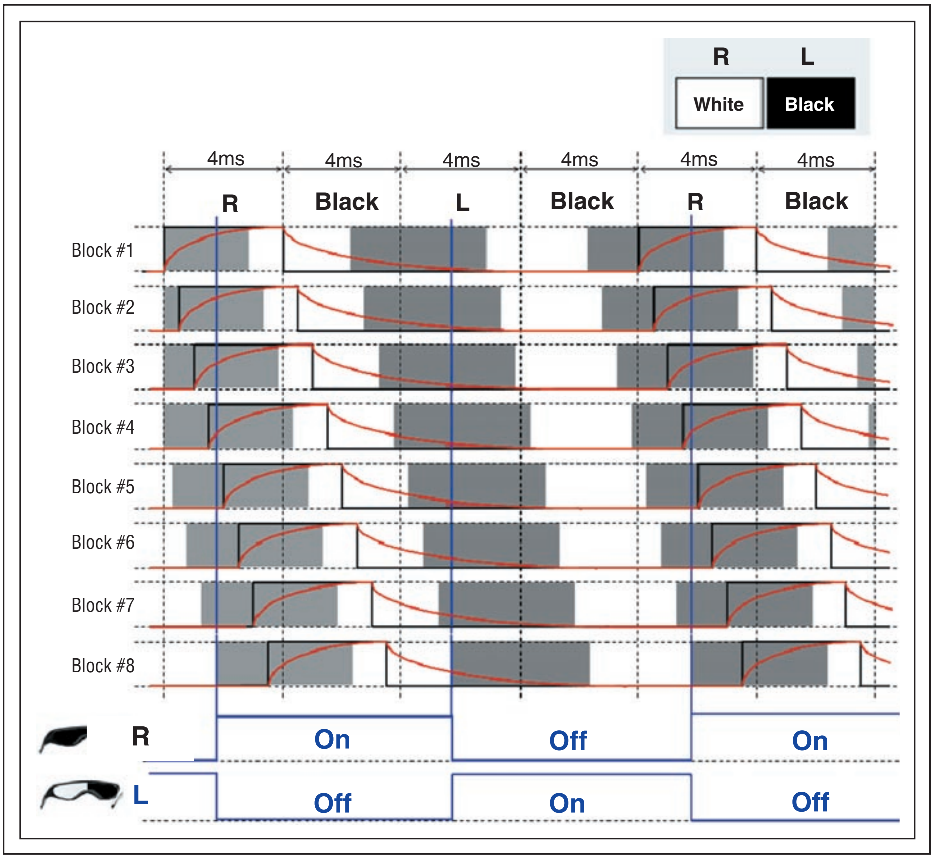

***Fig. 1:** A 240-Hz 3-D timing diagram shows eight-block LED backlight scanning under an LBRB scheme.*

going two methods can work with appropriate LED backlight techniques, which are also discussed later on.

The foregoing two methods have advantages and disadvantages from a product perspective. In slow LCs, the BFI technique is suitable. In general, 3-D brightness and cross-talk will vary on the rise (T_r) and fall (T_f) time of liquid crystals. In many cases, the slow rise and fall time of LCs can be overcome via electronic driving techniques and backlight controls.

We will now examine stereoscopic 3-D technology in terms of the following categories: cross-talk, LCs, drive circuitry, and backlight units.

3-D Cross-talk

Cross-talk is the undesired optical mixing of left- and right-eye images resulting from imperfections in the 3-D system. It is essential to understand the nature of 3-D cross-talk before discussing 3-D techniques in LCDs. Many formulas have been published, but there are no certified standard metrics yet.[4-6] The most widely used formula for 3-D cross-talk is

$$CT[\%] = \left[\frac{Lum(LB-RW) - Lum(LB-RB)}{Lum(LW-RB) - Lum(LB-RB)} \right] \times 100 \tag{1}$$

Equation (1) evaluates the luminance difference between the left and right lenses after transitioning from the white level to the black level. An optimal result would be no difference between the transitions, so that cross-talk is zero. Note that LB is the black image at the left image, LW is the white image at the left image, RB is the black image at the right image, and RW is the white image at the right image.

An LCD is a progressive-scanned hold-type device. This characteristic by definition has a negative impact on 3-D cross-talk performance. As seen earlier, the desire is to measure the time taken in switching the 0–100% and 100–0% levels; *i.e.*, the rise and fall time of LCs from the white image to the black images, and vice versa.

In 2-D mode, we are interested in the rise and fall time from 10 to 90% or vice versa. However, 3-D cross-talk has brought us to change the conventional definition in the 3-D mode.

In 2-D mode, the foregoing problem is shown as motion blur at edges of fast-moving objects, as in Fig. 2(a). In the 3-D mode, it appears as 3-D cross-talk between L and R stereoscopic images.

High-Speed Liquid Crystals

LC response is sensitive to panel surface temperature. Figure 3 shows the relationship between LC response time and panel temperature. The rise time contributes to the brightness in the 3-D mode. So, fast-rising LCs will help enable brighter 3-D images. In the 3-D mode, the LC fall time is dominant in 3-D cross-talk. Hence, LC modes with fast fall times such as the VA mode[7-9] will be beneficial to low cross-talk in the SG-type 3-D system. From a 3-D perspective, it is ideal if the rise and fall time can be smaller than the frame time.

In general, shutter glasses for the SG-type 3-D use the TN-mode. After one lens is closed, the other lens will open. Ideally, the sum of the rise and fall time of the LC in the panel is expected to be smaller than that of the eyewear, reducing the level of 3-D cross-talk.

Ad Hoc High-Speed Driving Technique

High-speed LCD panels are facing issues from excessive electrical rise time (distributed resistance and capacitance in the drive lines, sometimes referred to as "RC") delay and nearly optimized LC response time. The charging time can be doubled-up at a frame rate twice as high. The technique has been known as the half-G2D (hG2D) technique.[10]

The world's first 480-Hz full-HD LCD TV could help eliminate skepticism with regard to LCD operation speed. Many people thought that the LCD-TV panels, particularly large-sized LCD panels, could not run faster than 240 Hz due to the limitations on RC delay and LC response time. This might be true from a conventional design viewpoint, which has a single line for the gate and another single for the data (aka 1G1D).

However, in the new design architecture (aka hG2D), two scan lines share their charging time. So, the charging time for the 240-Hz

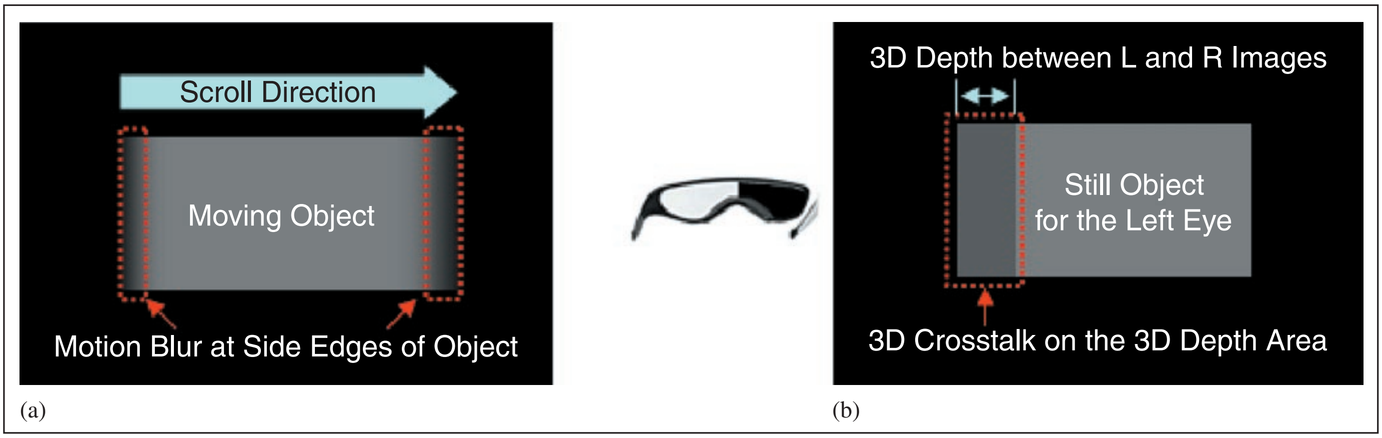

Fig. 2: Perceptions of artifacts under conditions of slow LC response differ between 2-D and 3-D: (a) motion blur is perceived on the edges of a moving object in 2-D mode and (b) as cross-talk in 3-D depth for a still object in 3-D mode.

remains same for 480 Hz. For instance, there are 1080 progressive scan lines, and each line will turn on and off sequentially in order in the 1G1D. The corresponding line-charging time in the 240-Hz FHD will be about 3.7 µsec. Likewise, the line-charging time for 480 Hz is about 1.8 µsec at the 1G1D. However, we can operate two scan lines at the same time by using hG2D, *i.e.*, line 1 and 2, and line 3 and 4, up to line 1079 and 1080. Then, the 480-Hz line charging time can be increased to 3.7 µsec at the expense of twice as many data lines, which causes a small sacrifice in aperture ratio.

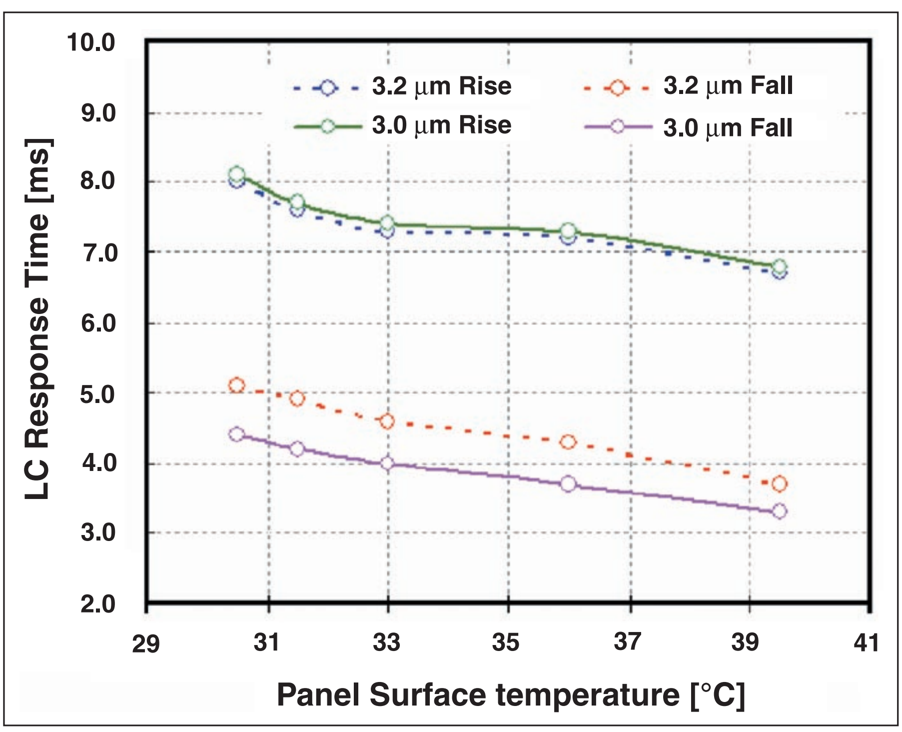

Fig. 3: Panel-surface temperatures vs. LC response results are enhanced by small-cell-gap novel LCs.

LED Backlights

LED backlights play an important role in the left frame – left frame - right frame – right frame (LLRR-type) 3-D implementation in separating consecutive frames; *i.e.*, the left and the right. There are two types of LED implementations, which are direct and edge LED structures. The direct LED implementation is beneficial for warming up the panel-surface temperature and for better thermal-energy distribution. The increase of panel-surface temperature, as seen in Fig. 3, will cause the LC mode to have a fast rise and fall time.

Meanwhile, edge-type LED bars can be located at the top/bottom sides or left/right sides according to their design and cost target. In general, the top/bottom edge types are used for a global blinking effect, but the left/right edge types are good for a scanning effect. In the scanning mode, high-directional light-guide plates (LGPs) are advantageous in lowering 3-D cross-talk by reducing the leakage of light to adjacent blocks.

Figure 1 displays the timing diagram of the 240-Hz 3-D LCD system with an eight-block scanning LED module. The black solid lines denote driving signal inputs of the LBRB block, the red solid lines show LC response curves, the blue solid lines represent the shutter-glasses timing, and the white areas indicate the period of LED-on. The black shaded areas represent the period of LED-off. The left (L) frame input is a full white image and the right (R) frame input is a full black image, which is considered one of the patterns most conducive to 3-D cross-talk. One can observe that the undesired red tail in the black shaded area can be effectively hidden by turning off the light source.

Active-Shutter 3-D System

As shown in Fig. 4, the AS 3-D system consists of a TFT-LCD image panel for image display and an active-shutter panel that is a large single-pixel LC cell that causes the image polarization to be switched between left and right circular polarization. This shutter panel is synchronized with the left- and right-eye images being displayed on the image panel and works in tandem with passive glasses worn by the observer. This system is analogous to the RealD system used in movie theatres, and the choice of circular polarization for image selection was made to reduce the sensitivity to the observer's head tilt.

The AS panel should have a faster rise and fall time than the image-display panel. The LC in the active-shutter panel would not degrade the image quality of the image panel. For instance, the OCB mode (aka pi-cell) could be a good candidate[11,12] because it inherently switches faster than the TN or VA modes.

The operational principle of the AS 3-D system is illustrated in Fig. 4. The shuttering

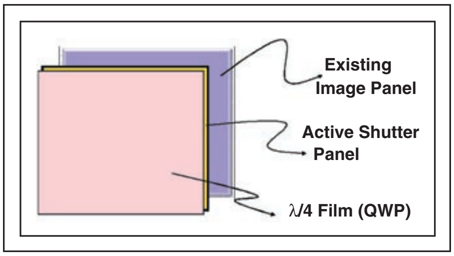

Fig. 4: This active-shutter 3-D system uses a TFT-LCD image panel, an active-shutter panel, and a quarter-wave plate.

AS panel is running in synchronization with the 3-D images on the TFT-LCD image panel. It is actively alternating or switching from one state to the other between the two-phase states of 0 and $\lambda/2$, where λ indicates wavelengths of red, green, and blue colors. The QWP symmetrically compensates the foregoing two polarization states to $-\lambda/4$ and $\lambda/4$. The lenses of the passive eyewear are characterized to $-\lambda/4$ and $\lambda/4$, whose slow axes are orthogonal to each other. Thus, the state of $-\lambda/4$ on the AS panel is captured only by the lens of $-\lambda/4$, and the state of $\lambda/4$ only by the other lens of $\lambda/4$. The AS panel, including the QWP and the eyewear, is expected to have the same optical characteristics for the three primary colors of red, green, and blue as the image panel.

A 46-in. active-shutter 3-D (AS-3-D) panel was demonstrated by Samsung (a joint project between RealD and Samsung) at CES and at Display Week 2011. Previously known as active-retarder 3-D or polarization-switching 3-D, AS 3-D requires fast on/off switching times in order to maximize brightness and minimize cross-talk.

The Driving Techniques

The driving scheme of the AS 3-D panel differs according to the operation speed of the TFT-LCD image panel. TV mainly uses 240-Hz LCD panels, but 120-Hz panels are mainly used in monitors and notebooks. Theoretically speaking, there would be no need for backlight scanning control in the 240-Hz LBRB 3-D applications. The AS panel is fast enough to complete its state transition from one state to another during the period of a black frame. However, the 120-Hz 3-D system uses no black frames for the state transition. The backlight scanning control must be implemented in the 120-Hz 3-D system, synchronizing with the segment of the scanning lines from the left-eye frame to the right-eye frame, or vice versa (Fig. 5).

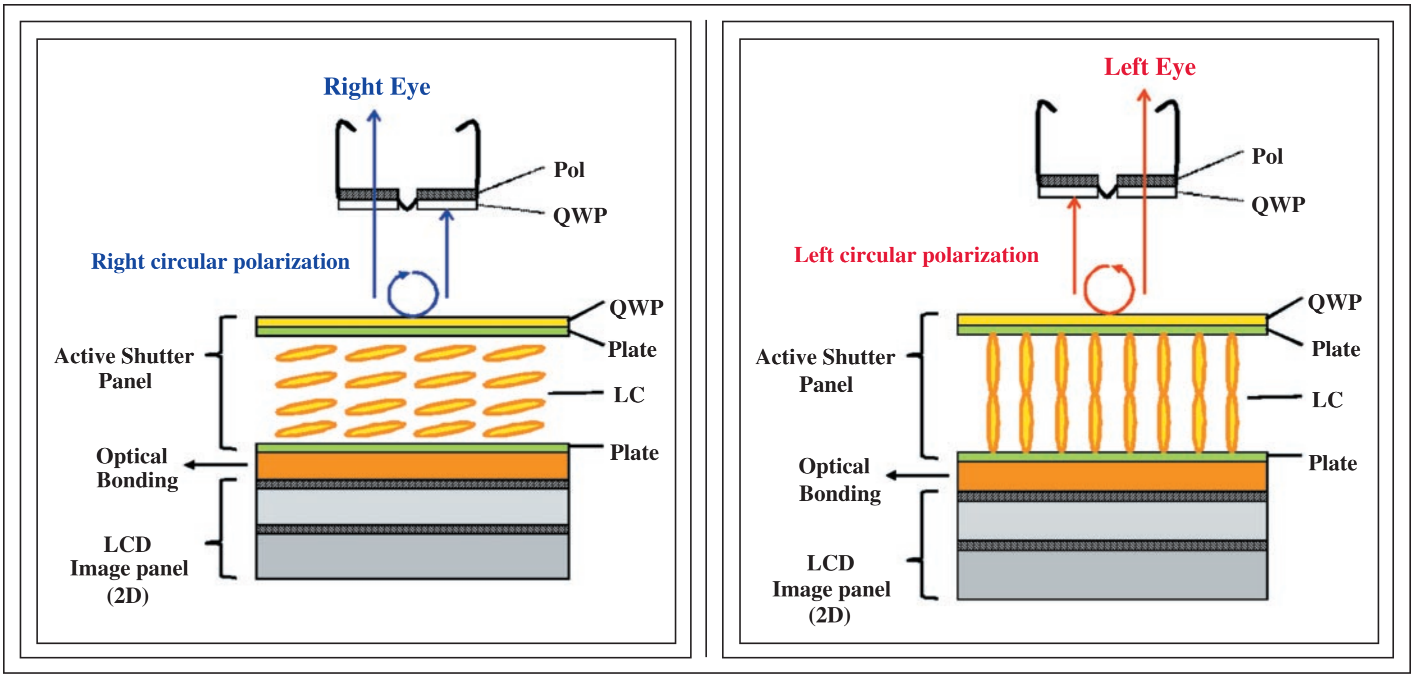

Fig. 5: The operational principle of the active-shutter 3-D system includes (a) the off-state and (b) the on-state.

Driving Optimization

As mentioned in the previous section, the purpose of the BFI in the 240-Hz 3-D system is to reduce 3-D cross-talk that is caused by insufficient LC response time. In the author's experiment, the AS panel with a pi-cell mode was fast enough to complete its state transitions in one black-frame period. The AS panel in the 120-Hz image panel had no room for BFI, so it had to be divided into many segments. The AS panel was also fast enough to follow the state transitions according to the speed of the progressive-scanning lines on the image panel.

The Future

This article reviewed some basic technical concerns related to the shutter-glass-type 3-D system and the active-shutter 3-D system. They both belong to the active-shutter 3-D category since the left- and right-eye stereoscopic images switch on the LCD panel. The active-shutter 3-D has brought the shutter function onto the panel. Regardless of the shutter position, displaying the stereoscopic images remains the same.

As we prepare the autostereoscopic 3-D technology in the future, it may be necessary to attach an additional panel for the function of an active lens. This additional panel can be free from some critical requirements for the image LCD panel, such as the TFT structure and color filter. In addition, advances in plastic materials will lower the cost. It is important to keep in mind that as we prepare the next generation of 3-D technology, we should not degrade image resolution for cost competitiveness.

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Accurate metrics for 3-D displays will be more difficult to determine than those for 2-D displays. The author suggests it may be necessary to look beyond 2-D and one-eye paradigms.

by Edward F. Kelley

THERE are presently two main competing commercial liquid-crystal-display (LCD) stereoscopic technologies for home television that requires the use of glasses: temporally multiplexed (TM) displays that use active glasses and spatially multiplexed displays that are often called patterned-retarder (PR) displays that use passive glasses. There has been quite a bit of discussion about the resolution of these displays on the Internet, where the claim is often made that PR displays have only half the resolution of TM displays because for PR displays each eye only uses half of the input image for stereoscopic imagery. This article examines this claim and attempts to understand what our eyes see in terms of resolution for the PR display compared to that of the TM display. (By "our eyes," the author means the human visual system, including the brain.[1]) This paper does not discuss other features of these different technologies – only resolution, and only resolution for the presentation of stereoscopic imagery. The use of these displays for two-dimensional imagery is not discussed.

TM Displays

Some temporally multiplexed LCDs might present information at a refresh rate of 120 Hz, but with black frames temporally interleaved with the imagery: left eye, black frame, right eye, black frame. The active glasses are synchronized with the left-eye/right-eye sequence as each eye's information is displayed. Thus, each eye would receive 30 Hz and both eyes combined would receive imagery at 60 Hz. Each eye sees the entire 1920×1080 full resolution of the input stereo imagery. Newer TM LCDs employ 240 Hz (left, black, black, black, and black, black, right, black), resulting in 60 Hz per eye.

PR Displays

In the PR displays, each horizontal line has the opposite circular polarization, and the passive glasses have a left-circular polarized filter for the left eye and a right-circular polarized filter for the right eye. In its simplest manifestation, here is an example of how the PR display generates an image: The left-eye image can be composed of the odd lines from the left-eye input image, providing 540 lines with information content interleaved with black lines. Then the right-eye image would be composed of the even lines from the right-eye input image, resulting in 540 lines also interleaved with black lines. The information lines of the left-eye image fall along the interstitial black lines of the right-eye image and vice versa. This results in a two-eye image of 540 lines from the left input signal interleaved with 540 lines from the right input signal – a spatially multiplexed display. Each eye receives a 60-Hz image at the same time; *i.e.*, each eye sees half the pixels available in the input, but the combined eyes see full resolution (1920×1080), and each pixel is addressable in the combined image. Note that if any averaging is employed that combines the horizontal lines of each left- or right-eye image in some way, then there may be a resulting loss of resolution. This will depend upon the manufacturer. If the default mode of operation of the PR display is producing some kind of strong averaging of the horizontal lines, then an update of the software that runs the display may be required to provide an improved resolution without significant processing (this was true in the author's case).

For two-dimensional viewing not requiring glasses, both display technologies are full-high-definition (HD) resolution at 1920×1080. However, various experts have claimed that because of this spatial multiplexing in the 3-D mode, the vertical resolution (horizontal lines) of PR displays is one-half the vertical number of pixels – half the HD resolution. On the surface, this seems to be a reasonable argument. Under what conditions is the claim true and are there any conditions under which it is not?

Evaluating Displays with Blinders On

Some individuals have attempted to evaluate the resolution of PR displays by viewing them with one eye and judging them accordingly. In such a case, a person would see an interstitial black line interleaved with the 540 lines of visible image (one line of image then one line of black), whereas the other eye would reverse the interleaved configuration; hence, the claim of half-resolution. Is using two-dimensional resolution patterns and one eye a fair evaluation? The equivalent for TM displays would be to evaluate the 120-Hz temporal performance with only one eye and judge them on that basis. This would result in pronounced 30-Hz flicker with the measurement being made with only one eye. Would that be fair?

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The answer to both questions is no. We have two eyes and it would seem that the performance of these displays should be evaluated on the basis of a two-eye-based metrology. However, that kind of metrology has not yet been fully developed, for example, within standards groups such as the International Committee for Display Metrology (ICDM) in its production of the Information Display Measurement Standard (IDMS).[2]

Criteria for Fair Evaluations

In attempting a comparison of different technologies, it is important to remember that display settings can dramatically affect measured and perceived resolution. Contrast, sharpness, luminance, gamma, *etc.*, can affect the perception of resolution comparisons between displays. Because of this, it is critical that the displays compared must present static patterns in their 3-D mode and that they present them in the same way, as much as possible – they must *look* the same to the extent possible. Consider the faces pattern in Fig. 1 for setting up displays supplied with the printed version of the IDMS.

The faces can look fine in one display and noticeably incorrect in another, yet the colored ramps can be deceivingly similar. Thus, before we even attempt to compare stereoscopic displays and their resolutions, we must ensure that the displays render such patterns as similarly as possible: We should set them up so that the colors and the faces look the same on both displays. That is sometimes hard to do. The perception of resolution can be especially affected by sharpness settings. The appearance of dark text on gray or colored backgrounds can show sharpening artifacts that contribute to the perception of increased resolution. There are also special patterns that emphasize sharpening artifacts, but they must be tailored for stereoscopic displays and evaluated using a 3-D display mode.

Image Examples

Figure 2 shows a single frame from the Disney movie *Tangled*.[3] If we focus attention on an isolated highlight in the right eye of the main character, Rapunzel, Fig. 2(a) shows the stereoscopic (3-D) image in the PR display, Fig. 2(b) shows the 2-D rendering also in the PR display, and Figs. 2(c) and 2(d) show magnified views of the highlight.

Figure 3 displays the comparison details. Figure 3(a) shows the manually converged

Fig. 1: *These patterns of faces were modified for (2 × 960) × 1080 use with stereoscopic displays.*

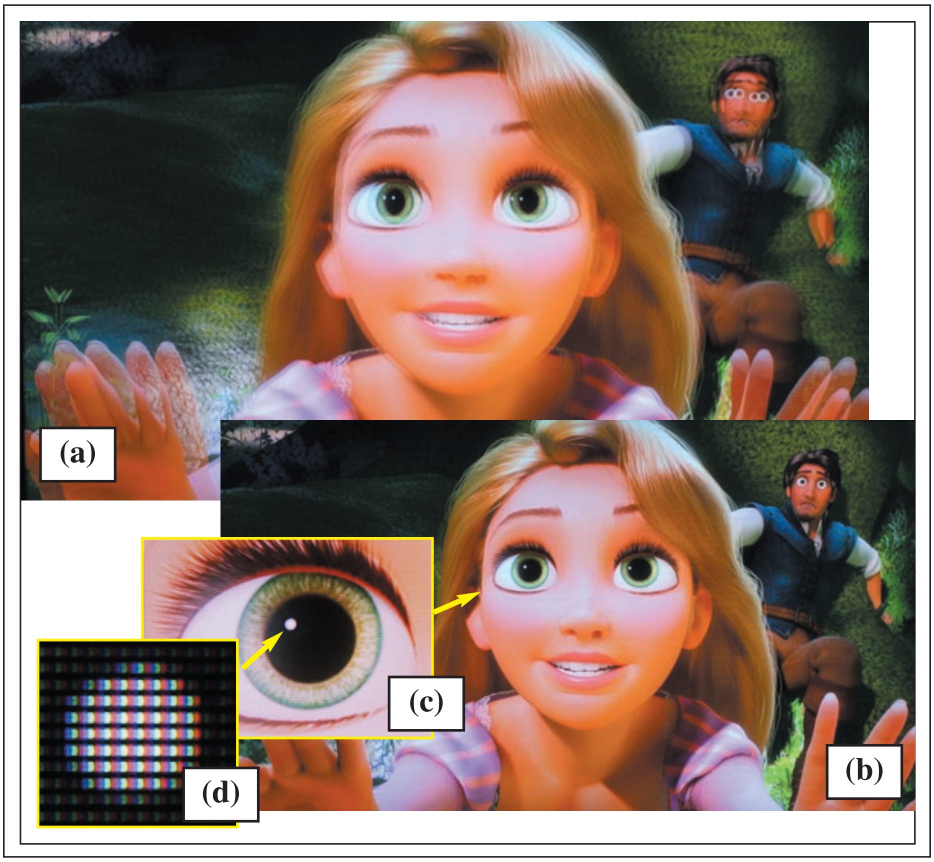


Fig. 2: *This raw photograph of a movie frame shows the 3-D PR image without glasses (a) and the 2-D image (b). The focus is on the specular highlight (c) and (d) in her right eye.*

image in the PR display, which is how it is seen with two eyes from an optimal distance from the display. (The manual convergence is achieved with common image-processing software by cutting and pasting the rows together to obtain a properly converged highlight.) Figure 3(b) shows the same 2-D image of the highlight shown in Fig. 2. A comparison between the two shows that half the resolution has not been lost. Figure 3(c) shows what the highlight would look like if the PR display were exhibiting half the resolution. Clearly, this is not what we observe in Fig. 3(a). Figure 3(d) shows the right-eye image of the TM display, which is effectively equivalent in resolution to the 2-D image in Fig. 3(b).

Differences in the appearance of images rendered by the PR and TM displays at this magnification, such as the presence of larger black gaps between the horizontal lines of the PR display, may be attributed to differences in the pixel layouts between the displays that result in different fill factors. The fact that Figs. 3(a) and 3(b) are not identical would indicate that this manufacturer is using some kind of processing, which may reduce the effective resolution slightly, but certainly not by half. However, each line in Fig. 3(a) has a different number of pixels contributing to the highlight, whereas a half-resolution rendering would be like Fig. 3(c) with line duplication.

In some cases, a likely problem with people evaluating the resolution of the PR display may arise from being too close to the display. Depending upon the acuity of our vision, if we are closer than three screen heights (see textbox[4]) from the display surface, then our eyes do something we do not realize: They will converge the interleaved horizontal lines together, perhaps by one eye moving up or down a small angle on the order of a minute of arc, a phenomenon similar to the nulling of small vertical displacements due to vertical phoria resulting from extra-ocular muscle imbalance, or this line convergence may be a cortical result – an area for further research. The author favors optical convergence as the answer because when there is any head tilt, the eyes must both horizontally and vertically converge the stereoscopic images, and with a slight head tilt, our eyes readily make the vertical adjustment without discomfort. Additionally, the converged lines are slightly brighter than the individual lines, but this is difficult to see because of the non-linear response of the eye (a factor-of-two luminance increase appears approximately 26% brighter to the eye based upon a lightness calculation). This convergence of the horizontal lines leaves black lines interleaved between bright lines (interstitial black lines), which does reduce the effective resolution of the display by half. The resulting image appears similar to what we see when using only one eye with the black interleaved lines. This line convergence with an accompanying loss of resolution occurs when we are closer than the optimum viewing distance for media imagery.

When we back far enough away from the PR display surface to reach the acuity limits of our vision, then our eyes do not converge the horizontal lines and the observed image appears without the interleaved black lines.

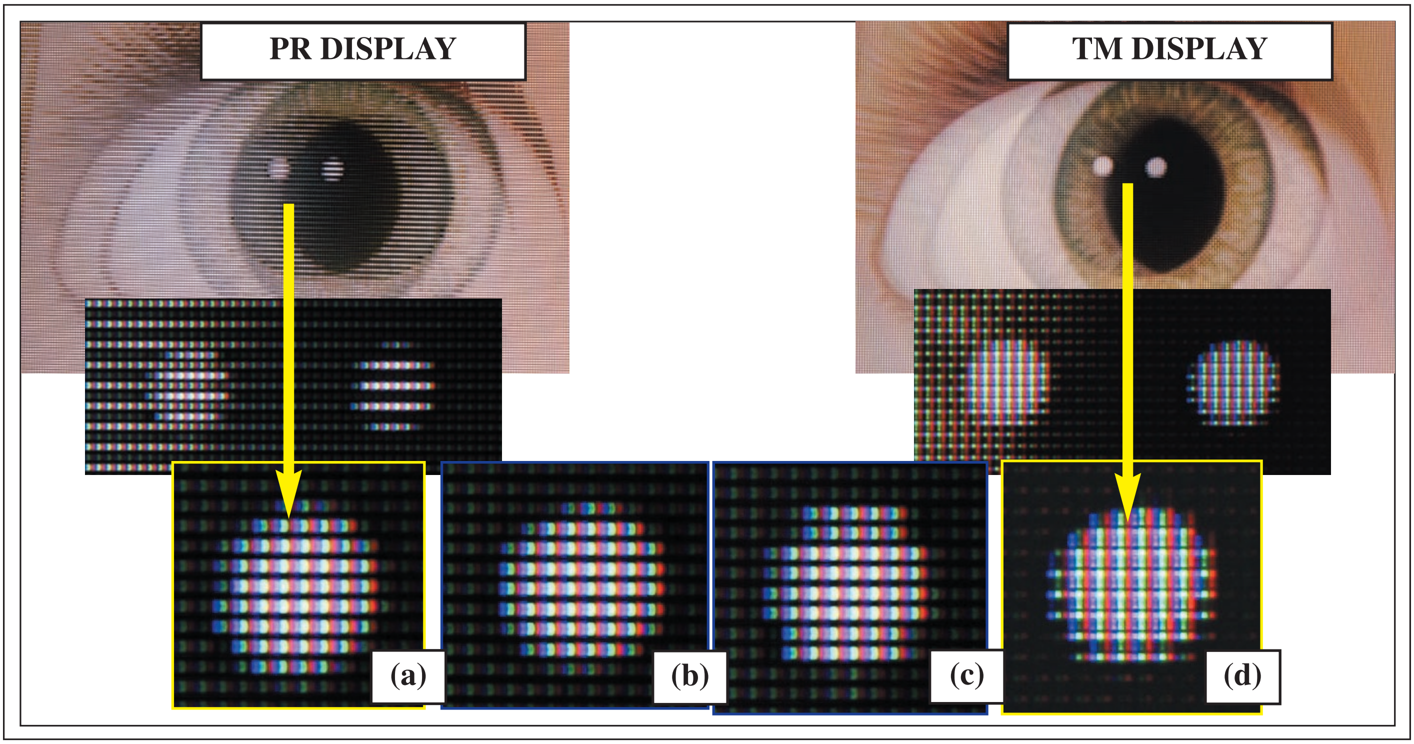


Fig. 3: A comparison of PR and TM displays shows (a) the manually converged image of the PR display (what we see at the optimal viewing distance), (b) the 2-D image of the highlight from Fig. 2, (c) a manually converged image that exhibits half-resolution that is artificially made from the image in (a), and (d) the right-eye image from the TM display.

These effects are difficult to observe without practice. You can move in close to the PR display and see those black lines clearly, but when you try to take a picture of the screen at a similar distance without any polarization in front of the camera, you do not see the black lines! This fact proves that the interstitial black lines that we observe when close are an artifact of our eyes vertically converging the bright lines together either optically or cortically. In the case of the optical vertical merging of the lines, the eyes do not have much of an angle to adjust. Horizontal angular adjustments to render objects properly are much larger. The TM displays can be viewed closer than this ideal distance without such problems and maintain their full resolution.

But aren't we losing a lot of information by eliminating half of the pixels? Perhaps not. Of necessity, there may be quite a bit of redundancy in the 1920 × 1080 rendering for both eyes. Given any single object that we look at in our artificial 3-D space, the rendering of that object is usually almost the same in both eyes. It is the retinal disparity between our eyes that provides the impression of three dimensions. Once we fixate upon an object in our 3-D view, if each eye observed a substantially different rendering of that object, then we would experience binocular rivalry and it would look strange or even create discomfort if the area over which the difference occurs is large. The 3-D effect is produced by the horizontal retinal disparity and different vergence of our eyes on each object in the scene. It is not produced by a single object having different renderings and textures for each eye. Thus, the combining of the left and right eyes in an interleaved fashion does not make most of the scene half-resolution provided that we navigate that scene from an ideal distance or farther so that the horizontal lines do not merge together. For the cases of small surfaces and objects where each eye can see different renderings, such as some glossy surfaces, more vision research will be needed to see how the stereoscopic rendering is affected by the PR display interleaving. Usually such areas are small and any interleaving disparity may not be objectionable or noticeable.

The author and a few friends compared several 3-D Blu-ray movies simultaneously on the PR and TM displays (by means of a splitter) while sitting at the correct distance from each display so that the pixels were at the limit of resolution (3.2+ screen heights). If the displays were adjusted to look the same as explained above, then the quality of the images as far as resolution is concerned appeared to be the same, full-HD resolution (1920 × 1080) in both displays. These simple observations of 3-D movies, of course, do not constitute carefully controlled vision studies.

Resolving the resolution issues in stereoscopic displays is not going to be as easy as it was for two-dimensional displays and will require further considerations, measurements, and vision studies than what have been presented here. However, what we have seen through this discussion is that two-dimensional and one-eye arguments may not be the correct way to proceed. The metrics for stereoscopic displays may need more refining through careful metrology, and the evaluation of resolution may require further vision studies.

Optimum Distance from the Display

Assuming that normal vision represents the ability to resolve two pixels at an angular separation of $\theta = 1$ arc min (1/60°), then it is possible to calculate the optimum viewing distance to see all the pixels we pay for yet not see any details of the pixel itself. Let the pixel be square with height h, and let our observation distance be z. The angle is related to these distances by

$$\tan(\theta/2) = (h/2)/z.$$

Solving for z, we find

$$z = (h/2)/\tan(\theta/2) = 3438h.$$

Or, if we measure h in units of pixels, $z = 3438$ pixels. Given a screen with the vertical number of pixels as $p_V = 1080$ pixels/V with V being the screen height, this becomes

$$z = 3.18V$$

People with better than average acuity will find that they need to sit farther away than 3.2 screen heights to obtain the optimum viewing distance.

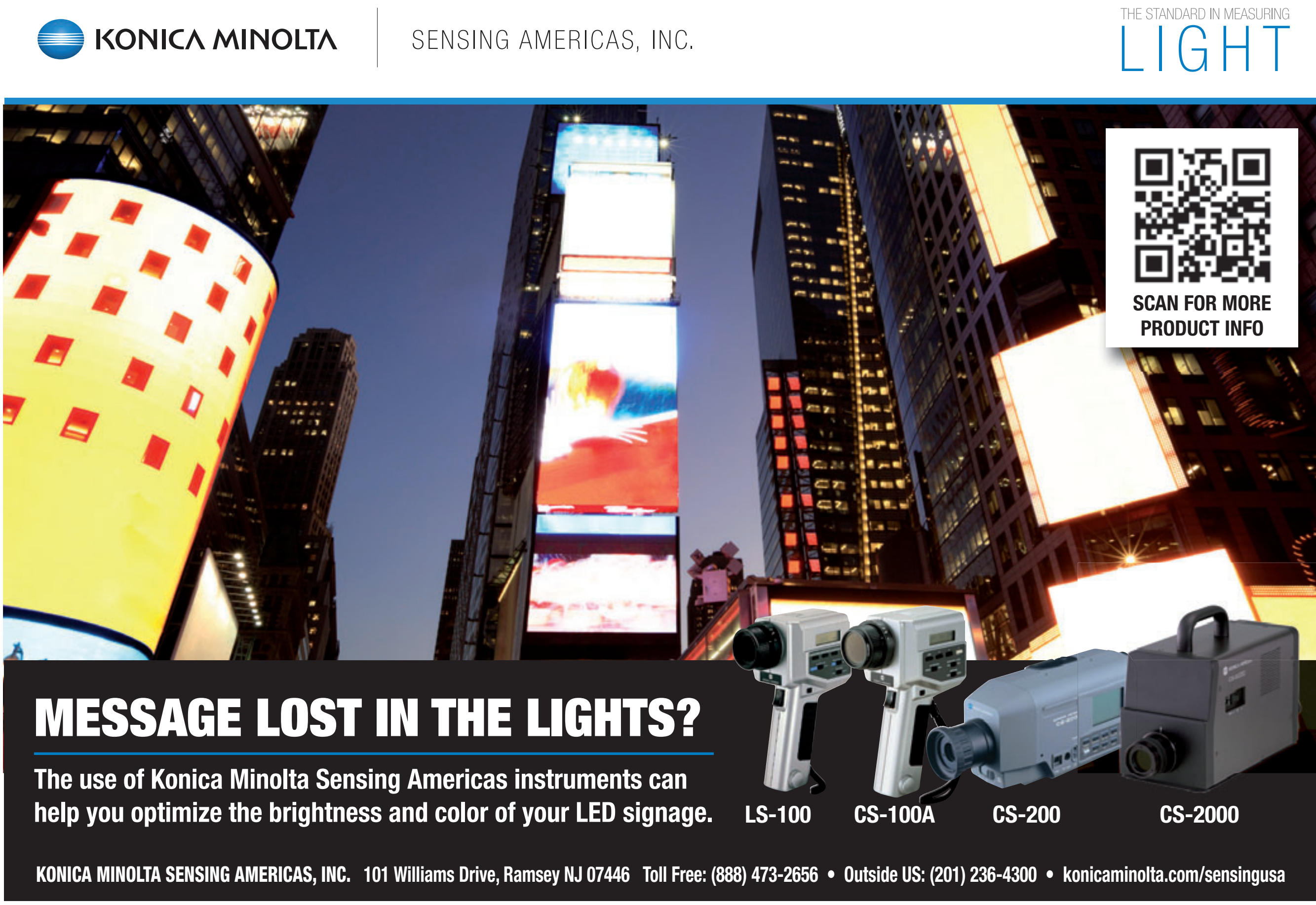
References

[1]Many thanks to Dr. Louis D. Silverstein for his help in getting the vision terminology correct and for a number of other comments that were incorporated into this article.

[2]The Society for Information Display's Definitions and Standards Committee oversees the International Committee for Display Metrology – see www.icdm-sid.org.

[3]*Tangled*, by Walt Disney Animation Studios, distributed by Walt Disney Studios Motion Pictures, © 2010 Disney Enterprises, Inc. This is a Blu-ray 3D movie. We used a frame from chapter 8 of 13 at the approximate time of 1:00:05; this is where Rapunzel is saying "easy." The exact frame is important because the highlight changes from frame to frame. As her face approaches a static position, you will note her eyes jump to her right a little (the viewer's left); we use the sixth frame after the jump. If you go to the seventh frame you will see artifacts of the scene transition in the image.

[4]*The Encyclopaedia of Medical Imaging,* H. Pettersson, ed. (Taylor & Francis, UK, 1998), p.199. ■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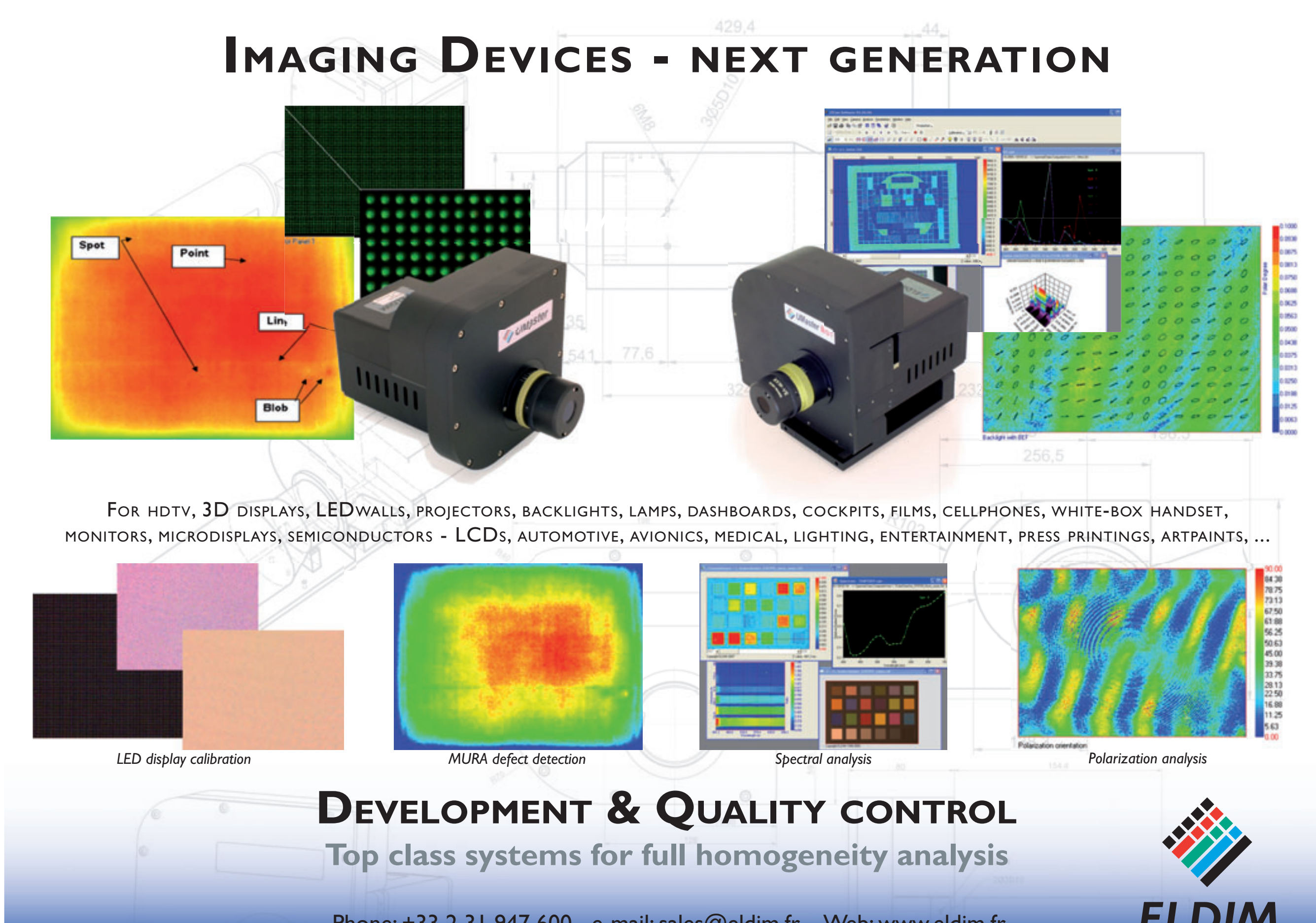
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Avnet Embedded

An Interview with Avnet Embedded Americas' Vice-President of Display Solutions

As a global distributor of electronic components and value-add embedded and display products, Avnet Embedded, a division of Avnet, Inc., has a team of experts that offer turnkey support for hardware and custom integration for any aspect involving visual performance. Avnet, Inc., is the worldwide leader in technology distribution with more than 300 locations in over 70 countries. Along with expertise in Intel, Microsoft, hard and solid-state drives, memory, and AMD product technologies, Avnet's technical experts provide customers with a single point of contact for their entire program. *Information Display* sat down with Joe Fijak, Vice-President of Display Solutions for Avnet Embedded Americas, to discuss trends in the digital-signage marketplace today.

What are the LCD product trends in the market today?

Liquid-crystal displays (LCDs) are ubiquitous. With the proliferation of smart phones, tablet computers, and other consumer devices, the demand from industrial OEMs for smaller category displays (up to 10.2 in.) has soared. OEM customers are seeing the benefits of these demands with more supplier choices, more product choices, and a better-performing product, taking advantage of visual, mechanical, power, and other feature-set improvements driven by the consumer-product market. Thin-film-transistor LCDs (TFT-LCDs) still dominate in this space; however, active-matrix organic light-emitting diode (AMOLED) displays – which have historically been exclusively used in consumer product applications – are poised to enter industrial applications. Improvements in manufacturing and technology will one day position AMOLED displays as the preferred display technology for many industrial applications.

With regard to medium-sized LCDs (10.4–19 in.), the product trend continues to be the shift from the standard aspect ratio of 4:3 to wide-format aspect ratios of 16:9/16:10. This trend is driven by the overall acceptance of wide-format LCDs in the consumer-product markets. LCD manufacturers are quickly releasing wide-format LCDs in 10, 12.1, 13.3, 14.1, and 15.6-in. sizes (18.5-in. wide format has been a standard in monitor sizes for some time). OEM customers now have a fantastic selection of long-life, well-supported, wide-format LCDs in desirable sizes, as well as the industry standard in 4:3-aspect-ratio formats that are on supplier roadmaps for years to come.

With the explosion of large-format digital-signage applications and the wide adoption of large-screen LCD TVs, OEM demand for larger displays (>23 in.) is increasing and advances in consumer-grade products are finding their way into LCDs designed for OEM applications. Higher-brightness, low-power LED-backlit panels, smaller mechanical footprints, panels with wide temperature ranges, and construction techniques that stand-up to harsh environments are emerging on LCD-manufacturer roadmaps.

While, historically, manufacturers of large-format LCDs almost exclusively catered to the consumer-TV market, most now offer the same or even industrial-grade versions to be used in non-TV applications such as signage, kiosks, gaming, military, and other point-of-information applications. Additionally, the previously mentioned technological advances that have made LCD TVs lighter, brighter, thinner, and less power hungry have opened up new applications in the non-TV markets. Signage and point-of-information applications, for example, require a lighter and thinner LCD, with best-in-class visual performance to allow for creative installation techniques. LCD manufacturers have heard the call from industrial OEMs and are creating versions of large-format LCDs with feature sets suitable for high-ambient-light, rugged, and extreme-temperature applications.

What are the technology trends for TFT-LCDs in the market?

There are many emerging trends in TFT-LCD products and the technologies behind them. OEM customers are taking advantage of lower power, better-performing displays, and, in some cases, improving the performance of an existing end-product. Advancements being made in the TFT arena are enabling the creation of new products that were not possible just a few years ago. Three key areas of technology advancements are visual performance, backlighting methods, and mechanical formats. While there have been a number of additional TFT-LCD technology improvements, these are the key areas that have driven the expanded use of TFT-LCDs in the OEM market.

- ***Visual Performance:*** Within the past 2 years, luminance levels of 400–500 nits have replaced 250–300 nits as the standard. Luminance levels up to 1500 nits are now common factory options. LED backlighting and specific improvements to the LED itself make this possible. Advances in LCD technology have allowed for higher contrast ratios, which make for richer colors, a whiter white, and darker black ratio. Another improvement in visual performance is tied to viewing cones – or how far from the LCD's center a user can move away and still see the same quality image. LCD makers are offering wide-viewing-cone technologies in many LCD sizes. In some instances, a user can move 89° off-center in any direction and still see the image exactly as it is appears when viewed directly on center.

- ***Backlighting:*** A TFT-LCD backlighting system is the most important element affecting both quality and consistency of the displayed image on an LCD. Conventionally, the LCD backlight has been constructed out of one or more cold-cathode fluorescent lamps (CCFLs) mounted along the edges of the LCD or spaced uniformly over the back of the display. Today, it is more likely to be a string of light-emitting diodes (LEDs) arranged along the edges of the LCD or as a matrix over the back of the LCD assembly. LEDs are becoming the backlighting technology of choice. LEDs are already commonly used to backlight a wide range of consumer devices such as cell phones. Today, the use of LEDs in LCD backlighting is rapidly growing from the smaller LCD panels to applications across the entire spectrum of LCD sizes, even into the 23-in. size range.

  The advantages of LED backlighting are as follows:
  - Mercury-free
  - Little EMI
  - Better optical performance
    - Crisp white, improved contrast, and color depth
  - Longer life, up to 100k hours of operating life
  - Immunity to vibration
  - Low operational voltage
  - Does not require a high-voltage inverter
  - Many LCDs have LED drive electronics integrated
    - LED drive circuits are easy to embed on customer boards
  - Precise control over intensity
  - No warm-up time, instant-on to 100% brightness
  - Allows for thinner LCs
  - Less affected by ambient temperature extremes

- ***Mechanical Formats:*** The proliferation of LCD-based consumer products with wide-screen LCDs (DVD, TV, in-car applications, smart phones, and tablets) has had an effect on the overall LCD offering from all major LCD manufacturers. One of the key areas is the migration from a 4:3-aspect-ratio LCD to a wide-screen-format LCD with common aspect ratios of 16:9 or 16:10. For many reasons, OEM customers are designing/re-designing their end-products with wide-format LCDs in mind and the mainstream LCD makers such NLT (formally NEC), Sharp, Optrex, and many others are rising to the demands of customers. Today, OEM customers can buy long-life, well-supported, wide-format, industrial-grade TFT-LCDs in sizes from 3.5 to 15.6 in. Larger sizes such as 18.5–23 in. that are designed for LCD-monitor purposes are now also available with the industrial customer base in mind.

No conversation about LCD technology advances is complete without mentioning 3-D. Driven by consumer 3-D television demand, LCD makers such as NLT, AUO, Sharp, and others are developing 3-D LCDs in small sizes/formats for non-consumer applications such as medical imaging. Although current 3-D LCD offerings in the industrial market are scarce, the demand is high and the technology is rapidly improving.

What are the latest trends in touch-screen technology?

While analog-resistive touch sensors, with easy, low-cost integration, have achieved the greatest application and market penetration and are widely used in many consumer and industrial applications, a number of technologies have advanced or emerged to threaten their market position. For example, the advent of the Apple iPhone has ushered in a huge change in the touch-screen business with the commercial introduction of Projected-Capacitive touch technology (PCT). PCT sensors outperform resistive touch sensors in visual performance and durability and are ideal for multi-touch functionality. Today, you would be hard pressed to find a consumer hand-held device such as smart phone or tablet PC that did not include PCT technology. Fortunately for the industrial OEM, many PCT manufacturers are releasing roadmaps for PCT sensors in sizes used in a wide range of non-consumer applications. However, PCT is not for everyone. There are applications for which the technology is not ideal, and until there is widespread adoption of the technology in the non-consumer markets, there is a cost-premium for PCT.

Other technologies such as Surface Acoustic Wave (SAW), with crystal-clear visual performance, have advanced and now offer multi-touch functionality. Newer technologies such as Acoustic Pulse Recognition (APR) from TE Connectivity/ELO TouchSystems offer single touch with optics and durability of pure glass. Dispersive Signal Technology (DST) from 3M also offers glass-like optics with multi-touch functionality. There has also been an increase in the suppliers of Resistive Matrix Touch (RMT) sensors. RMT sensors act like a standard resistive sensor in that they are low cost, easy to integrate, and can be used in almost every application. Construction methods of RMT also allow for dual-touch functionality although with some limitations.

There are more than 13 active touch-sensor technologies on the market today. PCT is the fastest growing; however, as stated, even after reaching price parity with more mature technologies, PCT may not fit all applications. The Advanced Display Group of Avnet Embedded has a complete understanding of all touch technologies – and with a line card covering all of them is well positioned to help our customers make the best choice.

What are the most common trends for value-add services for LCD modules?

Currently, Avnet is seeing a rise in customers requesting services related to LCD visual-performance enhancements and touch-sensor integration. Neither of these can be performed in a normal manufacturing environment nor without proper training and equipment. Avnet offers a number of in-demand visual-enhancement services, such as passively enhancing brightness, controlling viewing cone or reflections, EMI shielding, and infrared blocking. Other services in this category include active backlight enhancement using LED technology and optical bonding of protective material, touch sensors, or other visual-enhancement material to the front of an LCD. Avnet also covers the equally in-demand service of touch integration.

What are the most exciting new products being introduced and the applications for their deployment?

Among the most exciting products we see coming out are transparent LCDs. A transparent LCD is similar to a standard LCD in the way it processes data and generates an image; however, behind the LCD structure, the backlight sub-structure is omitted and a user can see through the LCD as if it were glass. An example application might be the beverage case or commercial refrigerator in a local supermarket. By integrating a transparent LCD in the front door of the case, the store could potentially sell advertising space or display-related product data and information directly in front of the product – without obscuring the customer's view. Other applications might include store windows and product showcases. ■

Joe Fijak is Vice-President of Display Solutions for Avnet Embedded Americas. With responsibility for the sales and marketing of displays and display solutions, Joe has a constant finger on the pulse of trends in the LCD marketplace. Joe is an industry veteran, with more than 30 years of experience in electronic distribution and 20 years dedicated to display and embedded product sales. Joe joined Avnet Embedded in January of 2010. For more information on display products from Avnet Embedded, visit: www.em.avnet.com.


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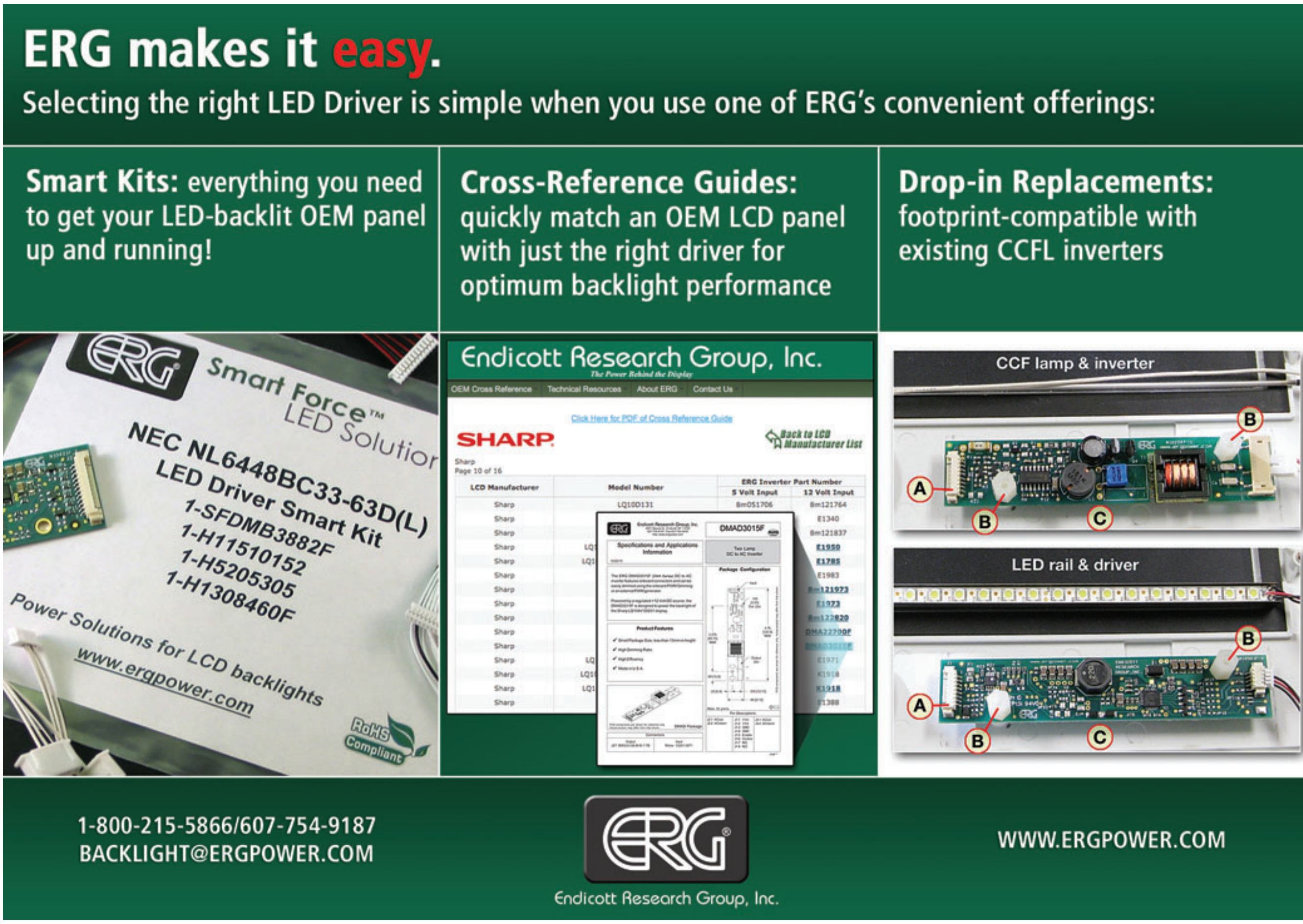

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Large TFT-LCD Panels Shift into High Resolution

Pixel densities are increasing, but at different rates, depending on device, application, and end-user desire.

by Paul Semenza

HIGH RESOLUTION has become a key feature for smartphones and other mobile devices that display information content approaching that of PCs and TVs. Because these devices are viewed at close range, users can appreciate the high pixel density. Mainstream TVs – even "high definition" ones – as well as notebook and desktop displays, are still typically at modest resolution. But there are two market segments in which TFT-LCD panel makers, as well as the device makers, are looking to move to higher resolutions: high-end TVs and tablets.

TV: High Definition Not High Enough

It is clear from discussions across the supply chain that the industry is moving toward 4K × 2K (3840 × 2160) resolution TVs, which have four times the information content of current 1080*p* products. These have been called quad-full-HD (QFHD), ultra-definition (UD), and other terms to represent that the resolution is four times that of full HD (1920 × 1080). Panel makers have all demonstrated prototypes, and almost all plan to mass-produce these panels in 2012 (Table 1).

From a broadcast or packaged media point of view, any increase in content format is still a long way off, with many markets still to make the move even to HD. It is also hard to justify in terms of image quality: If you watched TV from farther away than 3 m (10 ft.) you would need a screen size of at least 55 in. to notice the difference. Any smaller, and it would be beyond the resolution of the human eye.

However, 4K × 2K displays enable the possibility that a TV could simultaneously display four full-HD (1920 × 1080) inputs. Another possibility is 2K/HD zoom mode, which can accept 2048 × 1080 or 1920 × 1080 signals and scale them to the full screen by doubling the size horizontally and vertically. There are other reasons to introduce higher resolution, even where it is not viewable. The most obvious is for passive 3-D glasses. Doubling the number of lines is necessary to restore 1080 lines to each eye and would overcome the main objection to passive 3-D. However, the ability to produce a retarder film with such fine resolution has yet to be demonstrated. (For another viewpoint with regard to the passive-retarder approach to 3-D and perceived resolution loss, see the article "Resolving Resolution" in this month's issue.)

Achieving 4K x 2K TVs will not be cheap. 4K x 2K video requires four times the signal bandwidth and memory, and it will require significant post-processing if the up-scaling is going to be worth viewing. Pixel rendering or pixel simulation uses a processor to simulate the pixels and scale the standard-definition content into ultra-high definition. Toshiba has implemented such an approach with its cell processor technology. It uses a 1-TB storage system built into the cell processor's personal video recorder.

In the convergence enabled by connected and "smart" TVs, 4K × 2K can virtually enlarge the TV screen's desktop within the same panel size, so the screen appears larger. A larger desktop can offer space for multiple sources, such as broadcasting, HDMI inputs, apps, and the Web. Furthermore, video conferencing and IP cameras can be put onto the TV desktop side-by-side. Because of this, TV displays can serve as a large dashboard on the wall with home networking (broadband router connected, other TVs, PCs, and other CE devices).

Tablet PCs: A Bigger Smartphone?

While displays used in notebook PCs and desktop monitors have improved greatly over the past decade in terms of viewing angle, color gamut, and form factor, there has been very little change in pixel density. Mainstream notebook PC and desktop monitor formats such as 14-in. 1366 × 768, 15.6-in. 1366 × 768, and 21.5-in. 1920 × 1080 have pixel densities that fall into the range of 100–110 ppi (pixels per inch). Given the mostly fixed viewing distance of 50–60 cm for these applications, the market has decided that anything over 100 ppi is acceptable and that there are few benefits to going higher.

However, given the different usage modes for tablet PCs – closer viewing distance, content consumption over content creation – the requirement for pixel density is between

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Table 1: These five LCD panel makers are planning for 4K × 2K. Source: DisplaySearch.

Maker	Size (in.)	Native Resolution	Panel Technology	3D Technology	Sample Showcase	Mass Production (Estimate)
AUO	65	3840 × 2160	Oxide TFT	Lenticular Lens	October 2010	Q2 ’12
LG Display	84	3840 × 2160	Oxide TFT	FPR (Film Pattern Retarder)	October 2010	Q2 ’12
Samsung	70	3840 × 2160	Oxide TFT		October 2010	Q2 ’12
	70	3840 × 2160	Oxide TFT	240Hz, Shutter Glass	October 2010	Q2 ’12
	82	3840 × 2160			2009	
Sharp	64	4096 × 2160			March 2007	
	60	3840 × 2160	Oxide TFT, Photo Alignment		Q4 ’12	2012
Chimei Innolux	56	3840 × 2160			Medical	Now

smartphones and notebook PCs. Tablet PCs have a bigger screen than smartphones and better usability (size, user interface, startup time) than notebooks. At the same time, market competition between tablet PC makers and the need for product differentiation are pushing resolutions higher (Table 2).

This trend can be seen in the competition between 9.7- and 10.1-in. tablet PCs. Currently, nearly all 10.1-in. tablet PCs are 1280 × 800 formats (150 ppi); this is higher than the iPad’s 1024 × 768 pixels (132 ppi). The next iPad, however, is likely to move up to 2048 × 1536 resolution or 264 ppi. Consequently, panel makers are now planning to increase 10.1-in. resolution to 2560 × 1600, which is over 300 ppi.

A similar trend can be seen in the other key size for tablet PCs, 7 in., for which current resolution is typically 1024 × 600 (169 ppi). Panel makers are now developing 1280 × 800 and 1366 × 768 resolutions for 7-in. panels (over 200 ppi); 1920 × 1080 resolution (314 ppi) is possible in the future. The Android OS platform seems to be encouraging higher resolutions in large screens (Table 3).

It will be a challenge for panel makers to develop 300-ppi panels. Higher pixel density means tighter design rules in panel fabs and makes process stability more difficult, due to glass substrate size and equipment limitations. For example, in Gen 5 and 6, design rules are typically 3–4 μm for amorphous-silicon (a-Si) and 2–2.5 μm for low-temperature polysilicon (LTPS). A 3–4-μm pixel design rule can achieve 200–250 ppi, enabling such products to be produced in existing Gen 6 a-Si fabs. Above 250 ppi, LTPS is necessary, and the largest existing fabs are Gen 4, typically used

Table 2: Both 9.7- and 10.1-in. tablet PC panels are compared in terms of pixel density, brightness, and other factors. Source: DisplaySearch

	9.7 in.		10.1 in.		
Resolution	1024 × 768 XGA	2048 × 1536 QXGA	1280 × 800 WXGA	1920 × 1200 WUXGA	2560 × 1600 WQXGA
Pixel Density (pixels per inch)	132	264	150	224	300
Thickness (mm)	3.4	3.0	3.15	3.0	2.39 (target)
Brightness (nits)	400	550	400	400	700 (target)
Color Saturation (%)	50	50	50	50	50
MP Time	Q1 ’10	Q3 ’11	Q2 ’11	Q3 ’11	Q2 ’12
Tablet PC Brands	Apple, HP, white box brands	Apple	Acer, ASUS, Lenovo, Motorola, Dell, Samsung, LG, Amazon, Toshiba, white box brands	Acer, ASUS, Samsung (under consideration)	ASUS (under consideration)

Table 3: These screen configurations are available from emulator skins in the Android SDK. Source: Android (http://developer. android.com/guide/practices/screens_support.html).

	Low Density (120) ldpi	Medium Density (160) mdpi	High Density (240) hdpi	Extra High Density (320) xhdpi
Small Screen	QVGA (240 × 320)		480 × 640	
Normal Screen	WQVGA400 (240 × 400)		WVGA800 (480 × 800)	
	WQVGA432 (240 × 432)	HVGA (320 × 480)	WVGA854 (480 × 854)	640 × 960
			600 × 1024	
Large Screen	WVGA800 (480 × 800)	WVGA800 (480 × 800)		
	WVGA854 (480 × 854)	WVGA854 (480 × 854)		
		600 × 1024		
Extra Large Screen		WXGA (1280 × 800)	1536 × 1152	2048 × 1536, 2560 × 1536
	1024 × 600	1024 × 768	1920 × 1152	2560 × 1600
		1280 × 768	1920 × 1200	

to produce panels smaller than 10 in. In addition, tablet PC panels require the use of wide-viewing-angle technologies such as IPS or FFS, which are not produced on all fab generations.

There are other challenges to the production of high resolutions; one is power consumption. Low power consumption is an important feature for tablet PCs, but higher resolution increases power consumption because transmission is lowered; at the same time, tablet PCs require high brightness for outdoor usage. Therefore, more LEDs are needed in the backlight unit, which entails higher cost, increased heat, and a thicker backlight unit, making it more difficult to achieve thinness and light weight. The typical strategy of panel makers is to design the panel for high brightness and make the brightness adjustable, which increases battery lifetime through the use of dimming. While the standard brightness of 9.7-in. panels used in the iPad is 400 nits, 200-nit panels are being used in white-box tablet PCs in China.

Another challenge is the panel interface. The most common interface, LVDS (low-voltage differential signaling), requires increased numbers of the cables and connectors to deal with high resolution, making it harder to achieve a thin panel design. The larger number of signals increases the transmitter and receiver pin counts, increasing cost, and can result in a frequency shift, making transmission more difficult and increasing electromagnetic interference (EMI). Thus, for formats with more than 1500 rows, eDP (embedded DisplayPort) may be necessary. The eDP interface enables the use of a simple connector and lower pin counts, but to date has only been used in mobile and all-in-one PCs.

Finally, the shift to higher pixel densities could impact the development of new display technologies. Innovations that enable higher pixel density – such as metal-oxide TFTs and non-RGB pixel architectures including PenTile (developed by Clairvoyante, now part of Samsung Electronics) – will be in demand. For other technologies, such as AMOLED technology, for which pixel density is currently limited by manufacturing technologies, the move to high pixel densities could serve as a barrier to entry. As seen in Table 1, oxide TFT is a leading approach for achieving high pixel densities on large panel sizes in a cost-effective manner. Oxide TFTs are being pursued for TFT-LCD as well as AMOLED backplanes, and could serve to level the playing field to some extent.

High Hopes for High Resolution

Both 4K x 2K and 300+-ppi tablet displays represent a chance for panel makers to differentiate themselves and for device makers to create added value. Both require technical innovations in panel manufacturing as well as in interfaces and video processing. In the near term, the costs will likely limit such high-resolution products to a niche, but if consumers can be convinced that there is a significant benefit in terms of the capabilities of these products, high resolution can enter the mainstream. ■

Transparent Film and Substrate Technology for Touch Screens and Flexible-Display Applications

Flexible electronic displays with touch screens are increasingly used in demanding outdoor environments. Design engineers are challenged to develop optical systems that meet a wide thermal range (–40° to +85°C) and comply with diverse optical, electrical, and mechanical parameters. This article describes possible solutions, including transparent thin-film anti-reflective and conductive coatings. Also discussed are technologies being currently employed such as conductive transparent oxides [e.g., indium tin oxide (ITO)], carbon nanotubes, and silver nano-particles. The optical and mechanical properties of substrates used in the fabrication of flexible displays and touch screens are also reviewed.

by Jeff Blake and Richard Paynton

A great deal of interest surrounds the use of flexible displays with touch screens for a variety of commercial, industrial, and military applications. A June 2010 Display Bank report[1] estimated that the market for flexible displays will exceed $2.4 billion in 2015 and $30 billion by 2020. Their attractiveness over rigid, glass displays/substrates is based on their attributes such as lighter weight, thinner profile, potential lower manufacturing costs, and their ability to be incorporated into a wide variety of products. Applications being investigated and developed for flexible technology include wrist-mounted displays, electronic books and paper, cell phones, and tablet computers. An "unbreakable" display that provides good optical properties, requires low power, and is cost-effective would certainly be in great demand. Technology applicable to flexible displays is already being used in the manufacture of photovoltaics, RFID tags, solid-state lighting (OLEDs), touch screens, and, most recently, transparent displays.

As appealing as this technology is, display and touch-screen design engineers now face significant technical challenges in the development and manufacture of flexible-display systems, including:

- ***Display and touch-screen format:*** The flexural modulus must be defined for use in product fabrication and functionality. In order to have a complete user-interface system, both the display and touch screen must be flexible and compatible.
- ***Display technology and material processing*:** As described in Table 1, material limitations exist in the development of transmissive (*e.g.*, LCDs), reflective (*e.g.*, cholesteric displays), and emissive (*e.g.*, OLEDs) materials for use in flexible-display applications.
- ***Substrates:*** Plastic films, flexible glass, or metal backplanes: Limitations include gas permeability, lower processing temperatures, and mechanical durability for plastic films; impact resistance and flexibility for glass; and transparency and surface roughness for metal foil.
- ***Touch-screen technology:*** Resistive touch screens require physical contact of the conductive layers for activation. At the same time, separation needs to be maintained between the top and bottom films while they are not in use. If the touch screen is flexed, it could generate a false activation or signal distortion as well as sensitivity variations.
- ***Coatings:*** ITO, the most common transparent conductive material used in resistive and capacitive touch screens and many displays, will crack when flexed to too small of a radius. Promising nanomaterials such as graphene or carbon-nanotube (CNT) coatings are just becoming widely available for commercial applications and should offer alternatives as technologies mature. Alternative conductive materials (CNTs and silver nanoparticles) are generally more flexible than ITO and can be readily patterned. Current market-barrier issues that are

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being addressed include cost, transparency, and sheet resistance.

To address these issues, a variety of new materials, optical coatings, films, and manufacturing processes are necessary to aid in the development of flexible displays and improve the mechanical durability and functionality of flexible-display/touch-screen systems. Designers must have a complete understanding of the construction, properties, and interaction of various materials used to manufacture flexible touch screens and displays. These include current common flexible substrates such as PET (polyethylene terephthalate) and PEN (polyethylene naphthalate), barrier films, transparent conductive coatings such as ITO, graphene coatings, and silver nano-particle and CNT coatings.

Assessing Flexibility

In order to select the appropriate materials, the engineering design approach must consider the necessary degree of material flexibility and mechanical, optical, and electrical properties. Authors such as Fihn and Ekkaia[2] have developed a hierarchy of display and touch-screen flexibility as follows:

1. ***Rollable:*** The display or touch screen can be completely rolled (360°) repeatedly without being damaged.
2. ***Bendable:*** The edges of the display or touch screen can meet repeatedly without damage.
3. ***Semi-flexible:*** The screen can deflect at least 45° many times without damage.
4. ***Mostly rigid:*** The screen can deflect somewhat, but may sustain damage if bent too far or too often.
5. ***Rigid:*** Use of some flexible materials; however, damage most likely will occur if screen is flexed.
6. ***Completely rigid:*** The screen uses all rigid materials, such as glass that cannot be flexed without damage.

The primary types of flexible displays are shown in Table 2. There are many variations of these types of displays under development at universities, government labs, and R&D centers worldwide.

Table 1: Material limitations exist in the development of transmissive, reflective, and emissive materials for use in flexible-display applications

Material or Process	Use in Display or Touch Screen	Limitations or Issues
Substrate: flexible glass	Front surface cover of flexible display or touch screen	Can break, limited flexibility, may be difficult to process R2R
Substrate: PET (polyethylene terephthalate)	Front surface of flexible display or front and rear surface of a touch screen	Requires high-performance gas-barrier coatings to prevent the damage of displays (*e.g.,* OLEDs), relatively low processing temperature may limit some manufacturing processes to be used, birefringent
Substrate: PEN (polyethylene napthalate)	Front and rear surface of flexible touch screens and liquid-crystal encapsulant in flexible displays	Requires high-performance gas-barrier coatings to prevent the damage of displays (*e.g.,*OLEDs), relatively low processing temperature may limit some manufacturing processes to be used, birefringent
ITO coatings	Transparent conductive coatings used in the production of flexible displays and touch screens	Brittleness of ITO may limit use in some flexible display applications
Graphene & CNT coatings	ITO replacement materials used as a transparent conductive layer in displays and touch screens	Transmission, resistance, cost and availability may limit near term applications

Most commonly, the rigid glass used in typical LCD touch-screen displays is replaced with lightweight, transparent, flexible films such as polycarbonate, acrylic, polyethylene naphthalate (PEN), or polyethylene terephthalate (PET). As shown in Table 3, the trade-offs for using flexible films instead of glass include less optical transparency, lower processing temperature (due to plastic film's higher coefficient of thermal expansion, which causes potential distortion and lower glass-transition temperature), and high oxygen and water permeability (which, in the case of OLEDs, will quickly destroy the display). The advantages of using flexible substrates include lighter weight, increased impact resistance, and lower material and processing costs when produced with high-speed roll-to-roll (R2R) processes.

The obvious advantage of higher throughput R2R processing is somewhat offset by the required lower processing temperature and the potential for inducing stress into the films during processing. Common deposition processes used to deposit dielectrics and semiconductor materials (*e.g.*, silicon oxide or silicon nitride) in the production of flexible displays include plasma-enhanced chemical vapor deposition (PECVD) as well as printed, gravure, or spray coating. Process selection, in addition to material throughput, is typically dictated by the thermal stability, moisture, and oxygen performance of the organic and inorganic materials being deposited. In addition, printed electronics require very accurate registration (sometimes as accurate as 1 µm) of materials deposited and removed via photolithography. Due to the relatively high coefficients of thermal expansion (CTE) of plastic films such as PET and PEN, the processing temperature must be controlled in order to minimize the delamination of deposited materials as well as the proper registration of printed circuits and coatings.

Transparent Thin-Film Conductive Coatings

In flexible-display manufacturing, organic materials are often deposited in a wet chemical process (*e.g.*, sol-gel condensation) at atmospheric pressures in a combination of a vacuum or sputtering deposition of inorganic conductive metals or metallic oxides. The addition of post-processing films to improve the optical, mechanical, or electrical performance of flexible displays includes adding

Table 2: Different underlying technologies for flexible displays all come with advantages and disadvantages.

Display Type	Description	Attributes	Limitations	Commercialization Stage
Liquid-Crystal Display (transmissive)	Full-color high-resolution displays using novel flexible materials	Good resolution, luminance, and contrast. Can be equipped with touch sensor for user interface.	Requires substitution of transparent plastic materials for glass LC encapsulation	Demonstrated technology (*e.g.,* Toshiba, Fujitsu)
Liquid-Crystal Display (reflective)	Medium-color high-resolution displays using novel flexible materials	Good resolution and contrast. Can be equipped with touch sensor for user interface.	Requires substitution of plastic materials for LC encapsulation and can be made with metal backplanes	Demonstrated technology
Electrophoretic	Typically monochrome electronic paper-type display	Low cost, fairly developed technology. Generally used PET films.	Requires low-temperature processing. Technology has been demonstrated with plastic and metal backplanes.	In commercial production (*e.g.,* E Ink, AUO)
Organic Light-Emitting Diodes	Color emissive (does not require backlights). AMOLED and OLED technology has been demonstrated.	Very good color saturation and viewing angle	Flexible materials used need to have very low oxygen and water permeability. Plastic films require complex transparent high-performance gas-barrier coatings.	Demonstrated on low-rate production scale with PEN and PI films (*e.g.,* Sony, Samsung)
Cholesteric	Low-power, monochrome, or full-color (using three colored layers) graphical. Uses bistable, cholesteric liquid crystals.	Low cost does not require polarizers or backlights; is being produced in R2R process; can be activated with electrical current or pressure	Is not high resolution, which limits applications and has slow response times. Limits applications that require high refresh rates (*e.g.,* video).	In commercial production (*e.g.,* Kent Displays)
Light-Emitting Diodes	Individual LEDs are applied to flexible substrates (*e.g.,* PET)	Can be very bright	Not high resolution	Demonstrated on small scale

anti-glare or anti-reflective front-surface films, conductive films, or conductive grids for electromagnetic interference/radio-frequency interference (EMI/RFI) shielding. In the case of resistive or capacitive touch screens, a patterned conductive coating or grid provides the location of the XY coordinates in touch-sensor activation.

Key parameters in selecting transparent conductive coatings include photopic transmission, absorption, and reflection in addition to coating resistance, durability, and cost.

Transparent thin-film conductive coatings offer excellent optical properties on most flexible and glass substrates. A transparent thin-film conductive coating is typically deposited onto an optical medium using a high-vacuum coating process (*e.g.*, ion-enhanced e-beam evaporation or DC magnetron sputtering). These high-energy processes can create very dense films. The durability of a specific coating is greatly dependent upon the optical substrate, the specific materials deposited, and the deposition method. The base material of optical plastic substrates often must be treated with an additional hard-coat layer for the conductive coating to have adequate durability and conductivity properties. As shown in Fig. 1, transparent conductive coatings are used as the primary sensor in resistive touch screens.

Typical transparent conductive films include transparent conductive oxides (TCOs), such as indium-doped tin oxide (ITO), aluminum-doped zinc oxides (AZO), and metal-alloyed films (*e.g.*, alternating layers consisting of Ag alloys and ITO) for EMI/RFI shielding purposes. Increasing the conductivity of the coating will increase the average attenuation level over the frequency range of 100 kHz through 20 GHz. Typical conductivities for transparent thin-film conductive coatings for this purpose range from 1 to 100 Ω/sq. Unfortunately, there is an inverse relationship between light transmittance and conductivity. At very high conductivities, metal-alloyed films offer better cost/performance options over TCOs when applied to plastics. They can be cost effectively deposited in resistances down to 2 Ω/sq. while maintaining moderate total luminous light transmittance performance (typically >68%T_L). The photopic transmission of metallic coatings quickly decreases as the conductivity increases. Additionally, metal alloys have an inferior mechanical and galvanic durability.

By contrast, TCOs become costly to apply to plastics for resistances below 30 Ω/sq., but can be applied to glass to values below 1 Ω/sq. A low-resistance coating on glass will offer high performance but cost more because it is deposited in a batch vacuum process rather than a web or continuous process.

Table 3: The trade-offs for using flexible films instead of glass include lower optical transparency, lower processing temperature, high permeability to oxygen and moisture, and softer substrate surfaces.

Substrate	Visible-Light Transmission (VLT) (380–780 nm)	Glass Transition Temperature (T_g) in °C	Water-Vapor Transmission Rate at 38°C, ASTM E-96 Procedure E	Gas Permeability of Oxygen	Coefficient of Thermal Expansion (cm/cm x 10^{-5}/°C)	Refractive Index @ 589 nm
Polyethylene terephthalate (PET)*	85–88%	150	>100 (12 mil thickness) to >2,200 (1 mil thickness) cc/100 in.^{2}/24 hours	>2 (0°C) to >12 (50°C) cc/100 in.^{2}/atm/mil	4.32	1.64–1.67
Borosilicate glass**	91.7%	557	—	—	0.72	1.52

*DuPont Mylar polyester film
**Schott North America D 263 glass.

Additionally, most TCOs can be fully integrated into a multi-layered dielectric stack as part of a broadband anti-reflection (AR) coating. An AR coating reduces surface reflection losses and increases transmitted light. A fully enhanced TCO can have a total luminous reflection of a broadband white light source (*e.g.*, illuminant D_{65}) of less than 0.5%. Furthermore, the photopic absorption of TCOs tends to be very low, often less than a few percent at fairly high conductivities (*i.e.*, <10 Ω/sq.). High transmissivity and low reflection of the materials used to construct the display/touch screen generally equate to higher display system luminance and efficiency.

ITO Replacement Coatings

ITO is the current leading transparent conductor used in displays and touch screens due to its high-performance optical, electrical, and durability properties. However, in order to reduce cost and improve performance, there are significant efforts being made in the marketplace to find a suitable replacement for ITO. Indium, the dominant component of an ITO coating, has a potentially limited availability and, as such, is subject to high costs and price volatility. ITO is also a brittle ceramic material and not ideal for highly flexible electronics. Materials such as silver conductive inks (for grid and irregular patterns), graphene, PEDOT-PSS, and other CNT-based conductive coatings are being developed and commercialized by a variety of organizations and companies.

For flexible electronics, these alternate materials offer the potential of greater durability when subjected to repeated bending. In order to offer a viable ITO replacement material, CNTs or silver conductive inks (or silver nanowires) must provide optical transparency in the range of 85–90% and sheet resistance in the 10–400-Ω/sq. range. The conductive layers of most resistive touch screens are in the ranges of 200–500 Ω/sq. For most flexible displays, the transparent conductive layers need to be approximately 1–50 Ω/sq. in order to create 100–300 × 10^{-6} Ω-cm pixel electrodes.[3] In addition, the CNTs and silver nanowires must provide a material or processing cost advantage. ITO-coated films, with a cost range of $10–40 per square meter, are currently less expensive than most carbon- or silver-based nano-coatings. This may be partially due to the scale or production volume of ITO coatings compared to the alternative materials. This scenario is expected to change over the next few years with the advent of more efficient and larger-format R2R processing in the production of nanomaterials. Current CNT-coated films offer a coating resistance in the range of 300–450 Ω/sq. with a transparency of 82%, which makes them viable candidates for ITO replacement materials used in touch screens. Silver nanoconductive coatings and grids can produce a sheet resistance of < 20 Ω/sq., allowing them to be used as flexible-display conductors. Table 4 shows the nominal transmission and reflection of transparent conductive coatings and grids used to construct resistive and capacitive touch screens and flexible displays.

Fine Conductive Grids (FCGs)

FCGs that offer low sheet resistance and good optical properties can provide X and Y coordinate locations for touch screens and flexible circuits or offer EMI/RFI shielding. A fine conductive grid pattern is typically made of conductively plated woven stainless steel or copper mesh, or with a printed/patterned metal coating on a surface of the substrate (*e.g.*, PET). Both technologies have high open areas (*e.g.* > 85%) and excellent conductivities (*e.g.*, from 100 to < 3 m Ω/sq.). For more details, please refer to our article, "Optical Enhancement and EMI Shielding for Touch Screens," in the May/June issue of *Information Display* or online at www.information display.org.

Printed or selectively metalized conductive grids are typically produced via the deposition of silver nano-particles or conductive inks.

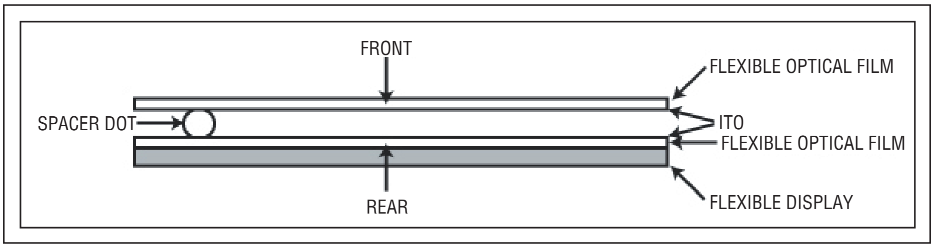

***Fig. 1:** A typical flexible resistive touch-screen construction shows the spacing between the layers.*

Table 4: Typical transmission and reflection values are shown for various types of conductive meshes, grids, and films. [Openings per inch (OPI).]

Conductive Ground Plane Mesh Composition	Open Area %	Photopic Transmittance Value	Photopic Reflection
50 OPI SS mesh Ag pl. & blk; 0.0012-in. wire diameter	88.4	80–85	0.15–0.35
80 OPI SS mesh Ag pl. & blk; 0.0011-in. wire diameter	83.2	77–83	0.15–0.35
MEM100-80, etched Cu transparent conductive grid; 0.0005-in. grid width	88–90	85	0.8–1.2
CNT transparent conductive film	100	82	<10
Silver printed transparent conductive grid 100 OPI, 0.0008-in. grid width	84.6	80	<8
10-ohms/sq ITO coating with no index matching	100	85-88	7.0–10
Index matched 10-ohms/sq. ITO coating	100	>93	<0.5

Alternatively, metalized films can be patterned using photolithography, etching, or a similar technique. The process is amenable to R2R coating and results in flexible, highly conductive, transparent substrates. It should be noted that other touch-screen technologies, such as emerging optical touch-screen technologies based on sensors, eliminate the need for transparent conductive materials. As such, optical touch screens could be good candidates for the emerging flexible-display/touch-screen market. Currently, projected capacitive is the leading candidate.

Growth in Flexible Technology Means Growth in Related Materials

The growth in applications for flexible displays with touch screens is being driven by the market demand for lighter, less costly, and more functional user-interface devices. In addition to the material and process technologies used in the fabrication, flexible electronics can be applied to other emerging markets such as photovoltaics, smart cards, and solid-state lighting. Consequently, rapid market growth is forecasted for transparent conductive materials such as ITO, CNTs, and silver nanocoatings and conductive grids used in the production of flexible displays and touch screens.

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SID 2012 Society for Information Display Awards Display of the Year

Display Taiwan Round-Up

Next-generation autostereoscopic displays represent just one of the emerging trends from the summer 2011 show.

by Steve Sechrist

PICK any hot technology trend in the display industry and it is likely there is a Taiwan connection, from next-generation AMOLED backplanes to proliferating low-power e-paper displays, to new autostereoscopic 3-D eye-tracking technologies that eliminate dead-zone viewing, to power-over-Ethernet displays that lose the AC power cord. These and many more technologies could be seen at Display Taiwan, which took place in June in Taipei's Nangang Exhibition Conference Center.

The exposition, which was hosted by several technical associations, included over 600 booths of all sizes and 45,000 visitors. LED lighting, solar, and a Living Green pavilion were featured in addition to displays. Conference sessions included Photonics and a Display Business and Technology Forum. Invited speakers came from the EU, Japan, U.S., and, yes, Taiwan, covering key areas in commercial lighting (such as GaN/Si), with sessions on LEDs and photovoltaics, plus display sessions on optics, e-Paper, lasers, OLEDs, and 3-D.

The opening ceremony was highlighted by a visit from the President of Taiwan, Ma Ying-Jeou, who presented Photonic Awards to several companies. The host groups for the event included TAITRA (the Taiwan External Trade Development Council), TCA (Taipei Computer Association), PIDA (Photonics Industry & Technology Development Association), and SEMI Taiwan, underscoring the trend in multi-discipline collaboration in producing a show of this size.

This event was well worth the trip – I have created a wrap-up by display-technology category to help readers who could not attend to home in on their particular area of interest.

Steve Sechrist is an 18-year technology and display-industry veteran who has held positions as a Sr. Analyst and Editor for Insight Media for the past 6 years. He serves on both national and local SID committees as well as the local Pacific Northwest SID chapter. He can be reached at sechrist@ucla.edu.

3-D

Probably the most compelling technology shown at Display Taiwan was next-generation autostereoscopic 3-D, particularly the developments in the mobile-display space.

AUO Corp. was showing a new 15.6-in. autostereoscopic 3-D technology based on a switchable lenticular lens approach that uses eye tracking to determine where the (single) user is looking.

The on-board camera in a laptop tracks the eyes and algorithms adjust how the 3-D image is mapped to the pixels to present a consistently clear image. The "SuperD Player" application software developed by AUO and the image-processing chip tie in the camera and hardware display technology and are at the heart of the system. The company claims the technology is "dead-zone free" (Fig. 1).

The player's 3-D content can be scaled to cover the entire screen, or a portion of it. From what I saw, the single-user technology is compelling and the 3-D imagery fantastic. In 2-D mode, the display delivers full-HD (1920 × 1080) pixel resolution and offers a brightness of 260 cd/m^2. In 3-D mode, AUO said the resolution drops to 1366 × 768, with the optimal viewing distance at 50–90 cm (Table 1).

Rotating Autostereoscopic Display Using Multi-Primary Square Pixels

Changhwa Picture Tubes (CPT) showed, for the first time, a unique 10.1-in. autostereoscopic display based on a multi-primary square pixel that rotates between portrait and landscape mode (*i.e.*, as required by iPads). The approach adds a fourth primary (subpixel) and changes the shape of the pixel to a square to accommodate full rotation between the two views: horizontal (landscape) and vertical (portrait) (Table 2).

I met with Pei-Lin Hsieh of the CPT Innovative Product Division (R&D center), who told me the unique display design requires a square pixel to rotate between the two modes for use in tablets and other displays showing

Table 1: AUO's 15.6-in. autostereoscopic laptop

	Switchable Lenticular Lens
Display	15.6-in. glasses-free 3-D
3-D Resolution	1366 × 768 HD
2-D Resolution	1920 × 1080 Full HD
Brightness (3-D mode)	260 cd/m^2
3-D Viewing Angle	30°
Optimal Viewing Distance	50–90 cm

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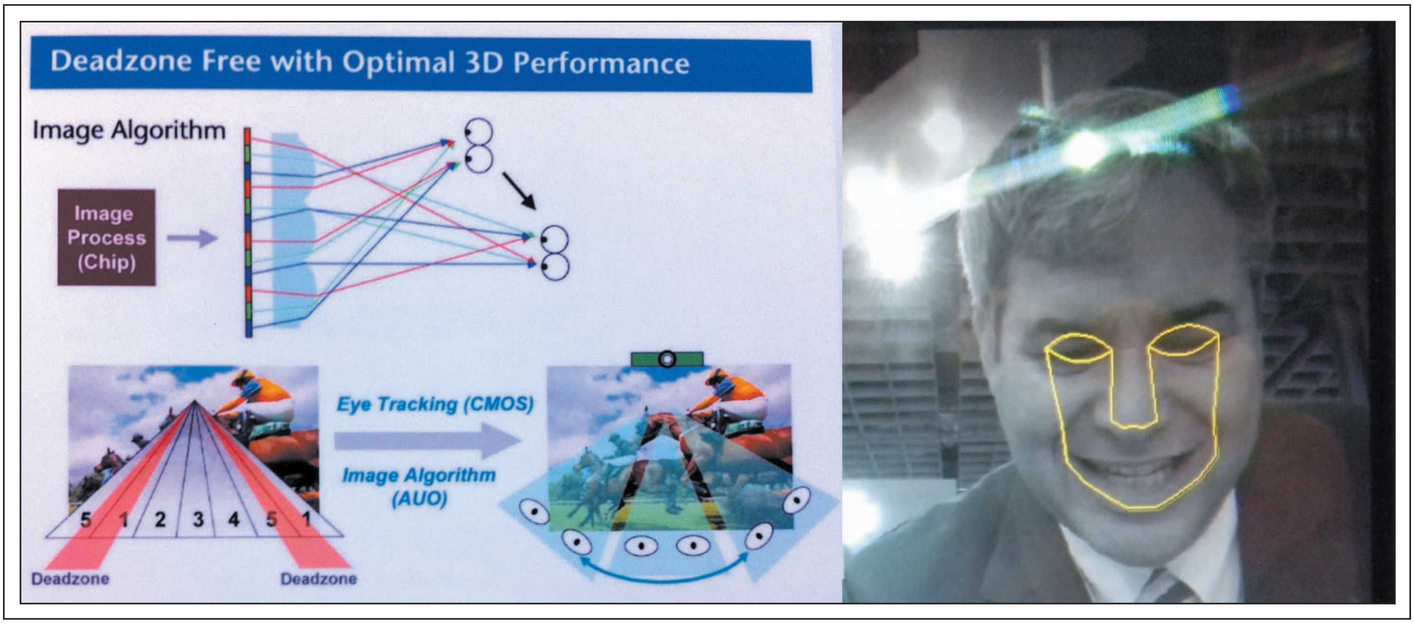

Fig. 1: AUO's eye-tracking technology eliminates autostereoscopic dead zones.

glasses-free 3-D. CPT created a multi-primary pixel using RGBW in a box shape (rather than the conventional rectangular shape), which offers a total display resolution of 1024 × 600 pixels. Hsieh also told me the company had to create a unique color-filter structure to match the square-pixel format. Algorithms enable the display of the three zones of RGBW.

In the booth, the company showed its new prototype in both H and V mode, next to a reference display that the technology beat hands down. The 10.1-in. display prototype supports three zones in the autostereoscopic mode. Hsieh said she may have a chance to come to the U.S. and present the technology in a paper at Display Week in Boston next spring. Let's hope so.

Other mobile 3-D displays shown by CPT included a 9.7-in. passive 3-D panel integrated into an Apple iPad using the pattern retarder approach (circular polarizer). The display was XGA with a luminance of 300 nits and switchable 2-D/3-D modes. There was a 21.5-in. touch version of this patterned retarder 3-D technology on hand as well.

CPT also showed a 21.5-in. LC retarder-based 3-D system it claimed offered full 3-D resolution. This is a standard shipping panel that is now selling as the company is looking to differentiate using smaller 3-D displays going forward. This one features linear polarized 3-D glasses (45° and 135°), a fast 5-msec response time, 1920 × 1080 pixels, a brightness of 225 cd/m^2 at a contrast ratio of 1000:1, and 170° (H) / 160° (V) viewing angle. This unit was shown integrated into an Apple iMac.

NewSight 3-D

One other 3-D technology at Display Taiwan came from the NewSight Japan company and its charismatic president Kyoto Kanda. The company showed a range of autostereoscopic devices, from a 42- to an 8.4-in. display. NewSight offers both a film-overlay solution, used to upgrade an Apple iPad at the show, plus lenticular screens for larger displays up to 80+ in. on the diagonal (Fig. 2).

The Newsight 3-D parallax-barrier approach uses an overlay film, special 3-D media player, and precision placement over the LCD to create the autostereoscopic effect. Essentially, the technology subdivides the LCD image into "…complex repeating segments," according to the company's Web site, "that when viewed and then integrated by the human binocular vision, present 3-D views of the screen." Reports on-line indicate this approach creates the 3-D effect by allowing different sets of pixels to be viewed for each

Table 2: CPT's Portrait/Landscape Rotating Autostereoscopic 3-D Display

	Square-Pixel Prototype Display
Display	10.1-in. glasses-free 3-D with unique square-pixel design
Module Size	222.72 (H) × 125.28 (V)
Resolution:	1024 × 600 × 4 (subpixels) multi-primary
Brightness	340 nits
3-D Viewing Angle	30°
Color Gamut	58%
Contrast	400:1
Optimal Viewing Distance	60 cm
Interface	LVDS

Fig. 2: Kyoto Kanda's wide range of AS 3-D displays at Display Taiwan.

eye using slits cut into the barrier material overlay placed on the LCD. The technology also requires a special "eight-tile" format media player that can be used with 2-D and 3-D content. NewSight showed off this technology in April of 2010, at Finetech Japan, on a 70-in. Sharp LCD.

Kanda told me the technology was now being applied to Sharp's 82-in. LCD panel to create the world's largest single-glass glasses-free 3-D display. This is to debut at FPD International in Yokohama, Japan, later this year.

Fig. 3: Arthur Lang of Powertip demonstrates 3-D imagery on a portable display.

Active-Shutter-Glasses OEM Powertip

Powertip Technology was showing off a liquid-crystal (LC) panel for active-shutter 3-D glasses as well as a host of small autostereoscopic displays for mobile apps such as cell and smart phones and 3-D video cameras (Fig. 3). The company targets TV, notebook, and monitor applications for 3-D glasses and is already providing LC panels for several manufacturers. Powertip also makes its own off-the-shelf universal shutter glasses that Arthur Liang, VP at Powertip, told me had a factory price, depending on quantity, as low as $20. He said most OEM customers were marking up the price of the glasses to $100 (Table 3).

Powertip said its active-shutter LC technology control board and 3-D displays are all completely customizable for its OEM customers. Representatives also showed me a range of small 3-D LCD panels in sizes from 7 to 2.8 in. Other non-3-D displays included a 4.3-in. sunlight-readable transmissive display and a 4.3-in. capacitive-touch display with 800 × 480 resolution that targets the smartphone market.

Table 3: PowerTip Active 3-D Shutter Glasses specs

Glasses Type	Active Shutter
Sync Signal	Infrared
Frequency	120 Hz
Response Time	2 msec
Contrast	2000:1
Transmittance	39 ± 2%
Battery Type	3.7 V / 100 mA Li ion
Weight	55 g

Alternative Power for Displays

Perhaps one of the more interesting trends to surface at Display Taiwan was DC-powered technology, with examples shown by both 3M and CPT. 3M characterized its initiative in a "Potential Future State" presentation shown in the Display Taiwan booth using an old IEEE standard, 802.3af. The move by 3M and others toward DC power for displays may be just the first step, as I think additional connected devices will also be announced. 3M's first iterations of ditching AC came in both Power-over-Ethernet (POE) and USB 3.0 (Fig. 4).

Supporting material from 3M also cited a potential drop in the cost of new equipment installations, with no professional (high power) electrician or national electrical code oversight needed (Table 4).

3M is targeting a reference monitor design that consumes less than 20 W of power, mak-

Table 4: Specs for 3M's USB 3.0-Powered monitor

23.6-in. WLED BLU at 1920 × 1080
200 cd/m^2
Power: 9 W
Liquid-crystal module 6.5 W
Weight: 2500 grams
No AC power cord, No VGA cable, USB 3.0 only

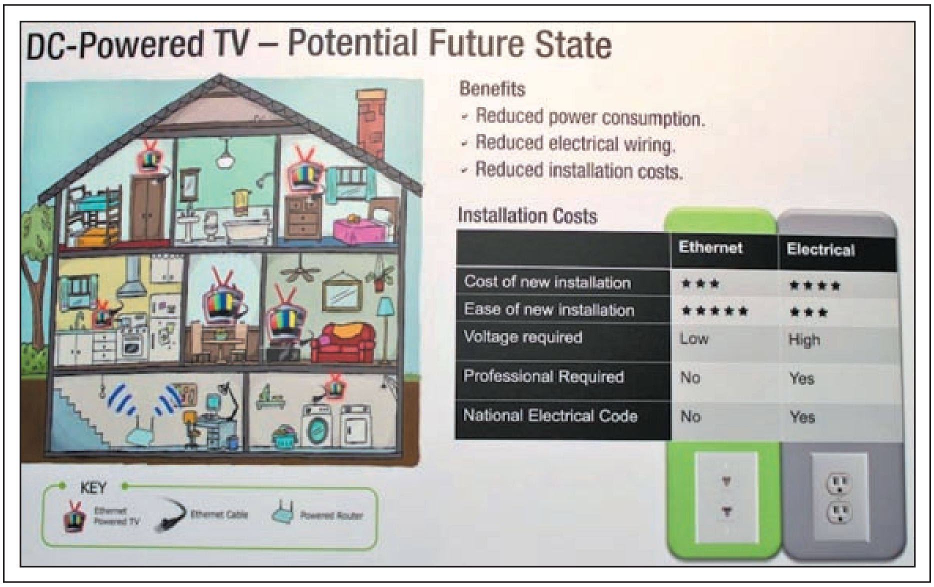

Fig. 4: 3M showed this DC-powered home alternative concept at Display Taiwan.

ing it a good candidate for the POE design that includes 25.5 W of power in its spec. Not only will the Ethernet cable carry power, but content as well, in this single-wire design that offers energy efficiency to the display.

CPT's low-power display offering included a 10.1-in. display at 1024 × 600 pixel resolution, powered by a single connector, plus two other displays, an 18.5-in. display at 1366 × 768 and a 21.5-in. display at 1920 × 1080 that required two USB 3.0 connectors' worth of power to work.

Alternative Displays

One of the more interesting alternative displays shown at Display Taiwan this year was the transparent 15.6-in. display called "Show Box" located in the CPT booth. This was positioned by the company as a new signage application that does not use a color filter and offers high transmittance, high color gamut, and a see-through (optically transparent) panel that can serve as an advertising medium (Fig. 5).

Fig. 5: CPT's shadow-box transparent display is being demonstrated for signage applications.

The main idea behind the transparent panel is to showcase objects with an addressable (color) transparent window in front. Specifications, details, features, and benefits can all be added to highlight the product within a shadow-box-like display, or even conceivably (in future iterations), as a partial shop window.

Ignis a-Si AMOLED Backplanes Slated for Mass Production

Small-OLED panel-maker RiTDisplay was also at Display Taiwan showing off its 3.5-in. OLED with an announcement that the company will bring this technology into mass production by the end of this year. It's significant in that this OLED panel uses the active-matrix backplane from Ignis Innovation, the company that made a business out of pixel-circuit packages for AMOLED displays with a "drop-in" technology approach into the current TFT manufacturing base. According to Ignis, the "AdMo" technology is an "…in-pixel, self-adjusting, and autonomous circuit solution that constantly adapts to changing driving and environmental conditions" (Fig. 6).

The company claims these backplanes are much less expensive than the LTPS backplanes used by current OLED-market-leader Samsung. Earlier this month, Digitimes reported that RiTDisplay will use two of its six existing PMOLED production lines for making AMOLED panels.

RiTDisplay said it is using the Ignis AdMo for amorphous-silicon, but recent statements show the technology to be still "under development." What RiTDisplay showed was an HVGA (320 × 480) pixel-resolution OLED (small molecule) with a density of 166 dpi, luminance of 200 nits, and a contrast ratio of 10,000:1 with a power consumption of 150 mW. The company claims the emissive display is angle "free," offering a full viewing plane. The colors did pop, and Ignis's claims of mura (brightness variation) removal and image sticking seemed to be working in the prototype units on display.

New Large-Panel LCDs

Other larger panels shown at Display Taiwan included a new 55-in. super-narrow bezel LED-based LCD for video walls from ChiLin. I was told that panel was simultaneously being shown at the InfoComm exhibition in the U.S. during the same week as Display Taiwan. This is a panel that boasts a

Fig. 6: RiTDisplay's 3.5-in. AMOLED HVGA panel uses an active-matrix backplane from Ignis Innovation.

5.7-mm image-to-image gap, the same as the Samsung U-series panel (Fig. 7).

The company was also showing a 1-in.-larger 56-in. medical-imaging display with full color in a whopping 3840 × 2160 pixel resolution. Coincidently, CMO launched a panel with just the same specs back in February 2006. ChiLin will target medical and other high-resolution applications for this display, with pricing to be announced.

E Ink Holdings Displays

Perhaps the best way to complete this Display Taiwan round-up is with E Ink Holdings. The company was on hand at Display Taiwan with an array of new products that illustrate just how pervasive e-Paper displays may become in the not-to-distant future. The demonstrations were very similar to what the company showed just weeks before at SID, so you may have had a look if you attended Display Week. New to the booth was the latest 6-in. Nook touch display (based on Pearl) that is now shipping to strong reviews in the press.

Of late, E Ink has been enjoying a powerful display offering that dominates the e-book reader (EBR) category. The company will ship between 20 and 30 million panels this year and plans to triple last year's display-manufacturing capacity by September 2011. Much as Apple dominates the tablet market today, E Ink Holdings is the most profitable display maker in the e-reader space. Its sister company Hydis is another display industry darling in the small-LCD-panel market, expanding smartphone and tablet viewing angles by licensing its FFS IP with a huge profit upside.

All this was not lost on Taiwan President Ma Ying-Jeou during his tour of the Expo. He spent a good deal of time in the E Ink booth with his entourage and a mass of reporters in tow. Ying-Jeou is a Harvard Law grad who, during his time in the U.S., lived in the same Cambridge, MA, neighborhood as the original E Ink Corp headquarters. E Ink display VP of Marketing Sriram Peruvemba prepared a special gift for Taiwan's Chief Executive, an E Ink in-glass picture of the old Harvard Yard made from the new E Ink EPH material that powers the Nook and Kindle readers. Peruvemba presented the gift to the Taiwanese President, who lingered in the booth among concept devices such as "Rosey" the E Ink music stand and the ruggedized E Ink powered snowboard that potentially

Fig. 7: ChiLin's 55-in. narrow-bezel tiled LCD has a "pencil-thin" image-to-image gap.

displays vital weather information and other data, real time, even during the ride down the mountain. (These were shown at Display Week as well.) We can look to E Ink to eventually integrate its displays into devices, clothing, medicine bottles, and just about anything that can add benefit, information, or yes — even whimsy — to our daily lives.

The Age of the Display is Upon Us and Taiwan is Planning for a Central Role

Displays in Taiwan are a big deal, as evidenced by the fact that this multi-consortium event attracted 45,000 visitors this year. The Taiwanese show also commanded national media attention and received a visit from the country's president. But perhaps even more important to the display industry, some key next-generation technologies were shown that point the way to the future of displays.

Make no mistake, the information age is upon us and that means we are also in the age of the display – and Taiwan is showing us that things have only just begun, demonstrating this with both viable creative solutions and a national (even political) commitment to play a key role in the display industry well into the coming decade. ■

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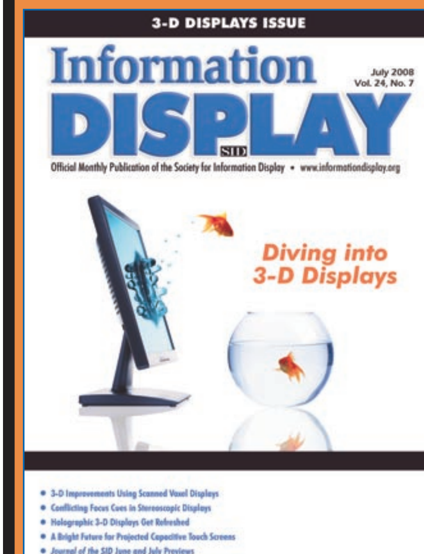

Display Week 2012

June 3–8, 2012
Boston Convention & Exhibition Center
Boston, Massachusetts, USA

History in the Making

SID DISPLAY WEEK
Boston 2012

Boston is a city with a rich history of innovation and progress. It serves as the perfect host for the 2012 SID International Symposium, Seminar & Exhibition. Display Week will be held June 3–8 at the Boston Convention & Exhibition Center. The exhibition will be open from June 5 to 7.

Display Week is the once-a-year, can't-miss event for the electronic-information-display industry. The exhibition is the premier showcase for global information-display companies and researchers to unveil cutting-edge developments in display technology. More display innovations are introduced year after year at Display Week than at any other display event in the world. Display Week is where the world got its first look at technologies that have shaped the display industry into what it is today; that is, liquid-crystal-display (LCD) technology, plasma-display-panel (PDP) technology, organic light-emitting-diode (OLED) technology, and high-definition TV, just to name a few. Display Week is also where emerging industry trends such as 3-D, touch and interactivity, flexible and e-paper displays, solid-state lighting, digital signage, and plastic electronics are brought to the forefront of the display industry. First looks such as these are why over 6500 attendees will flock to Boston for Display Week 2012.

Advancing Science Education

Retired scientists and engineers are volunteering their time to improve science education in U.S. elementary and secondary schools by joining with teachers to develop and present hands-on experiments and demonstrations. Additional volunteers, including members of SID, are needed to sustain and expand these programs into more school districts.

by Joseph A. Castellano

NUMEROUS STUDIES over the past 20 years have shown a decline in the number of U.S. college graduates seeking careers in science and engineering. In 2005, the National Academy of Sciences published a report concluding that America must vastly improve K-12 education in science, technology, engineering, and mathematics (STEM) in order to increase the science and engineering talent pool needed to sustain and strengthen the nation's commitment to basic research.[1] The U.S. has more than a million senior citizens over 60 years of age with degrees in the STEM fields. Volunteer programs that started in the early 1990s have recruited volunteers from this group to assist teachers in advancing STEM education.[2]

One of the earliest such programs, RESEED (Retirees Enhancing Science Education through Experiments and Demonstrations), is aimed at stimulating greater interest in science among students at the middle school level (grades 6, 7, and 8). With a grant from the National Science Foundation, Professors Alan Cromer and Christos Zahopoulos of Northeastern University founded RESEED in 1991 to assist middle-school physical-science teachers in the New England region. Eventually, hundreds of volunteer retirees were trained and RESEED programs were replicated at new sites across the country. RESEED was established in the San Francisco Bay Area with the help of Professor Zahopoulos and has since evolved into an independent, not-for-profit organization called RESEED Silicon Valley.[3]

Joseph A. Castellano, a Life Member of SID, has been associated with RESEED Silicon Valley since 2006. He helps teach eighth-grade physical science at Bret Harte Middle School in San Jose, California. He can be reached at drjcast@aol.com.

RESEED's Goals and Objectives

The ultimate goal of RESEED and programs like it is to help students improve their understanding of science concepts and facts as well as the scientific method. The main objective of RESEED Silicon Valley is to increase student proficiency in STEM education at the middle school level. RESEED volunteers (see Fig. 1) provide regular science content support to educators who often experience gaps between their preparation as teachers and the scientific knowledge they need in the classroom. Volunteers are drawn from the large reservoir of retired and other science and technology professionals who have valuable knowledge, experience, time, and an interest in teaching young students.

RESEED Volunteer Activities

Before retirees are matched with a teacher–partner to work with students in actual schools, they take several days of training, typically with other volunteers who have experience in the program. The focus is on examples of experiments and demonstrations that are used as well as pedagogical questions on how children learn. In addition, selected volunteer retirees relate their experiences in the RESEED program to new members.

A new volunteer typically meets with his or her teacher–partner before the beginning of the school year to work out the schedule of days that the volunteer will be available. In addition, the volunteer and teacher discuss the overall plan for the laboratory experiments and demonstrations planned for the first month. This enables the volunteer to prepare the experiments, demonstrations, or lectures that will be given on the day(s) he or she will be working at school. Most volunteers perform experiments and demonstrations one or two days per week in the classroom and spend another day preparing material in advance or doing research to find interesting demonstrations and experiments.

The most important factor for success is a good working relationship between the volunteer and the teacher. Most RESEED volunteers describe a high level of competence and dedication among the middle-school science teachers they work alongside. However, the preparation of lesson plans, teaching, grading test papers, meeting with other faculty members and school administrators as well as keeping abreast of the changes in state standards and the latest scientific developments put tremendous restraints on their time. Thus, many teachers need and welcome the help of volunteers to assist with their classroom activities. Specifically, some of the help provided by RESEED volunteers includes:

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Fig. 1: RESEED-SV volunteer Howard Cohn demonstrates static electricity.

- Designing and building experimental set-ups that the students will conduct themselves.
- Presenting live demonstrations of chemical reactions, emission of light, electrical conductivity, magnetism, motion, forces, and other scientific principles. The idea is to show that science can be fun. Some examples of the laboratory procedures used are described on the RESEED-SV Web site.[3]
- Relating the physical principles that are being taught to real-world experiences.
- Presenting lectures using audio-visual aids (photos, videos, animations, drawings, *etc.*), typically using a personal computer and compact projector. A list of some of these presentations appears on the RESEED-SV Web site.[3]
- Meeting with individual students and with groups of two or three to answer their questions and explain the fundamental principles in different ways.
- Gathering supplies, assembling or repairing lab apparatus, setting up equipment, and other tasks that help improve the learning experience.

A major goal of the RESEED program is to have students become knowledgeable about how science applies to most of life's endeavors. Volunteers strive to relate the scientific principles they teach to real-world experiences and to show that the discovery of new concepts, devices, or materials can be exciting and rewarding.

RESEED volunteers genuinely enjoy working with young people and teaching them fundamental scientific principles. The hope is that some of the students will select a scientific or engineering discipline as a career. Many volunteers report that their RESEED experience has been one of the most satisfying and rewarding of their careers.

Benefits to Students and Teachers

Students are the ultimate benefactors of RESEED. They tell evaluators that they are inspired to learn science by the presence of the RESEED volunteers. Teachers say RESEED retirees help them become more prepared to teach science by acting as content resources and by modeling what scientists do and how they think. Surveys show that the teachers also feel inspired, develop more confidence and understanding, and appreciate the highly schooled minds and extra pair of skilled hands. Some teachers say students enthusiastically anticipate the volunteer's visit each week. One teacher reports that state test scores rose from 85 to 95% Proficient and Advanced with only 2% Below Basic as a result of the RESEED volunteer's efforts (Fig. 2).

Affiliated Organizations

In addition to RESEED Silicon Valley, there are a number of similar programs that provide meaningful assistance to teachers and students by volunteer scientists and engineers. Another program that was formed in the early 1990s is Teaching Opportunities for Partners in Science (TOPS), which is based in Stockton, CA, and led by the San Joaquin County Office of Education. TOPS targets elementary schools in five northern California counties; its volunteers are expected to commit a few hours each week and participate for the entire school year. Other organizations are located in Fairfax County, VA; Las Cruces, NM; Topsham, ME; Washington, DC; Montgomery County, MD; Boston, MA; Santa Fe NM; and Los Altos, CA. A list of these organizations appears on the American Association for the Advancement of Science Web site.[4]

More Volunteers Needed

Although approximately 75% of volunteers continue to participate in RESEED Silicon Valley from year to year, the other 25% cannot because of health issues or other circumstances. This creates a continuing need for more volunteers to join the program. Recent

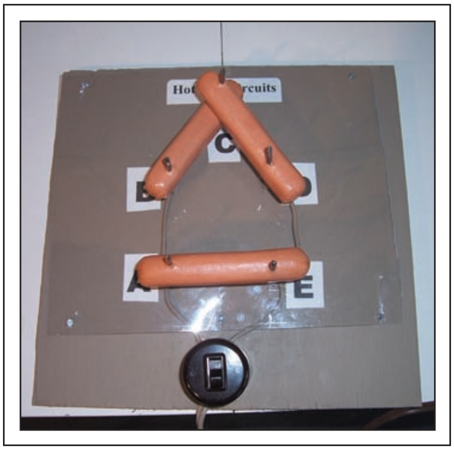


Fig. 2: This RESEED volunteer-built demonstration, called "Hot Dog Circuits," shows parallel and series connections. It is used in conjunction with a lesson on Ohm's Law. The hot dogs are cooked during the experiment (but not eaten).

retirees from industry, academia, or organizations such as SID are encouraged to consider volunteering for this worthwhile endeavor. RESEED's volunteer coordinators work very hard to place volunteers with partner–teachers in schools near their homes. Many of the retirees have been recognized by their schools, their communities, and even by their town officials. Some retirees find a whole new life in RESEED and spend a significant portion of each week preparing for their day in school.

Anyone who is retired or considering retirement and can volunteer some of his/her time and talent, please visit our Web site[3] and complete the form on the CONTACT US tab. RESEED Silicon Valley offers an opportunity to use your technical knowledge and experience to support teachers and work with children.

References

[1]"Rising Above The Gathering Storm," National Academy of Sciences (2005).

[2]D. G. Rea and K. M. Nielsen, "A Volunteer Army for Science," *Science* **329**, 257 (2010).

[3]More information is available at the RESEED Silicon Valley Web site: http://www.reseed-sv.org.

[4]A list of senior scientist and engineer programs nationwide is available on the Web site of the American Association for the Advancement of Science: http://www.aaas.org/ programs/education/SSE/activities/othervolunteer.shtml/ ■

continued from page 2

science is a strong sense of identity with being explorers who rely on our humanity rather than technology alone. Imagination is a critical element of humanity that separates us from the most advanced technology we can envision. Even the IBM scientists that developed Watson still are not much closer to actually defining an algorithm for human imagination.

So, now let's pretend the context of *Star Trek* is actually a credible look into our own future. Then let's imagine how some of the show's so-called technologies can, or already have, become real. Communicators are an obvious example. Look at your iPhone and think about it. Have you ever visited a hospital and had an MRI or CT scan? If so, you might begin to think that the sick-bay technology of a starship seems a lot closer to reality. Long-range scanners that can peer thousands of light years into the universe are already in orbit around the earth and robotic deep-space exploration spacecraft with similar scanners are in development right now. Consider energy sources: Atomic power and anti-matter. Atomic power was already proven science when *Star Trek* launched, but now we have published results on physical experiments that more than slightly resemble matter/anti-matter reactions. And then, of course, we have the numerous embodiments of 3-D displays that on *Star Trek* are conveniently called holograms or holographic projections. If I sit in my living room today and watch *Avatar* on my 3-D LCD TV, it does not take much more imagination to believe I am on the holodeck of a spacecraft or in a virtual world somewhere – well, except for the glasses, and I suspect we will not need to use those for much longer.

When I spoke at the interactive devices session on Wednesday afternoon at Display Week, I learned that my imagination was not running wild enough because some of the commercially viable virtual-world technologies that were talked about there are already way ahead of what I can experience right now. What this means is that we really are living in a time of "wow!" and what is happening today with 3-D displays is just the tip of the iceberg of astounding new innovations coming very soon.

Myself, I have thankfully re-discovered my imagination and found almost magical qualities in some recent entertainment experiences. Even as I write this I am watching a plasma TV that literally displays people larger than they would be in real life and I daresay a lot better looking. I'm amazed at how much the new technologies have enhanced my entertainment experiences and I'm not exaggerating when I reveal that my kids for a long time believed me when I told them it was done with magic. If you are one of those who are working on the next extraordinary innovation, please do not get lost in the details, and if you are someone that provides the money or climate to foster innovation, reward the ones with vivid imaginations and help keep the magic of innovation alive and well.

This month the theme of our issue is LCD technology, and most of it is focused on 3-D and organized for us by our Guest Editor Dr. Phil Bos, Associate Director of the Liquid Crystal Institute and a Professor in the Chemical Physics Interdisciplinary Program at Kent State University. Phil, along with Dr. Achin Bhowmik, Director of Perceptual Computing at Intel Corp., also authored our first frontline technology feature this month, "Liquid-Crystal Technology Advances Toward Future 'True' 3-D Flat-Panel Displays." This article is a great primer on the challenges of making a truly great stereoscopic display system and goes well with my theme of turning imagination into good science. This is the first of a two-part feature that is scheduled to continue next month.

A complementary view of the 3-D LCD space comes from our next frontline technology feature, "Tutorial on 3-D Technologies for Home LCD TVs," written by Dr. Seonki Kim of Samsung Electronics. Dr. Kim details, among other things, the mechanisms for utilizing fast-switching-mode 240-Hz LCDs to produce excellent stereoscopic image separation while maintaining high luminance and contrast. These two features together form a really solid foundation for understanding the state of the art in 3-D television today as well as where it may be going soon.

This month we added a third frontline technology feature after receiving a submission from Dr. Ed Kelley titled simply "Resolving Resolution." The title belies the real meat of the story, which is an innovative and possibly controversial view of the actual perceived resolution of patterned-film-retarder stereoscopic displays. We worked with Ed through the review process of several drafts and I believe this is a "don't miss" contribution to the field of 3-D display-performance characterization. Dr. Kelley is, of course, well known and highly respected by many in the display metrology field and a well-known visionary in that field.

Our view of the display marketplace this month comes from Paul Semenza of DisplaySearch, who contributed "Large TFT-LCD Panels Shift into High Resolution." Paul describes the latest manufacturing investments for large-format 4K × 2K LCDs coming as soon as mid-2012 for commercial introduction. Yes, that is not a typographical error – 3840 × 2160 or even 4096 × 2160 panels in sizes ranging from about 60 to over 80 in. It's hard to imagine but yes, by now I'm getting good at it again. They will not fit into everyone's budget, but for some this may be the next new standard. We always value Paul's insights, which also include a look at tablet PCs and other possible applications for high-resolution panels.

"Transparent Film and Substrate Technology for Touch Screens and Flexible Display Applications" is the focus of our applications topic for this month, contributed by authors Jeff Blake and Richard Paynton of Dontech. The myriad of different ways to coat and process materials to make touch screens, EMI shields, and even flexible displays themselves is ably surveyed by Jeff and Richard. I am very pleased they were able to build this overview for us and I believe many readers will find this a useful reference for their ongoing work.

Keeping up with all the display conferences and trade shows around the world is a daunting task. We try to pick a few each year and give you a glimpse of what is hot at each one. Back in June we sent Steve Sechrist to Display Taiwan, held at Taipei's Nangang Exhibition Conference Center, to have a look for us. He picked the most interesting finds to write about and we are pleased to include them this month.

In addition to these features we also have our regular departments covering Industry News, SID News, and, of course, a great Guest Editorial from Dr. Phil Bos. However, one more item I feel compelled to bring to your attention to is a great story we received from longtime industry veteran Dr. Joseph Castellano, who is a strong supporter of a program called RESEED (Retirees Enhancing Science Education through Experiments and Demonstrations). This effort, staffed by

(continued on page 52)

SID 2012 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 7, 2011** – to fan.luo@auo.com or sidawards@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 Mobile 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 2012 award nominations are to be submitted by October 7, 2011. E-mail your nominations directly to fan.luo@auo.com or sidawards@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

Professor Yang Yang Named to Tannas Chair

Yang Yang, a professor of materials science and engineering at the UCLA Henry Samueli School of Engineering and Applied Science, has been named the holder of the Carol and Lawrence E. Tannas, Jr., Endowed Chair in Engineering.

The Society for Information Display was founded at UCLA in 1962, and the chair is the first in the world dedicated to the area of electronic information displays. It was established with a gift from Lawrence Tannas, Jr., a UCLA Engineering alumnus and executive in the electronic-information-display industry, and his wife Carol. Tannas is a longtime SID member, and the president of Tannas Electronic Displays, Inc., a company specializing in the research, development, and licensing of intellectual property for preparing liquid-crystal displays used in avionics.

Yang's research focuses on conjugated polymers and organics, polymer LEDs (light-emitting diodes), and related polymer electronic, photonic, and bio-devices. His work with polymer solar cells has led to the creation of higher quality and more affordable and energy-efficient materials for use in consumer-electronic devices such as flat-panel televisions, plasma displays, and cell phones, as well as electronic information displays.

"It is a tremendous honor to become the Carol and Lawrence E. Tannas, Jr., Endowed Chair," Yang said. "I am particularly impressed by Mr. Tannas' vision and contributions to the area of electronic-information-display technology. I look forward to using this endowment to enrich education here at UCLA Engineering, as well as enhance research that will help create more energy-efficient display technology."

Yang is the faculty director of the Nano Renewable Energy Center at the California NanoSystems Institute at UCLA and serves as Director of the Center for Organic Opto-electronics Technologies at Zhejiang University in China. He is also the faculty adviser for the UCLA student branch of the Society for Information Display (SID).

"It is gratifying to know that our gift will help UCLA Engineering for many generations to come by supporting the teaching and research activities of a distinguished faculty member like Professor Yang," Tannas said.

This article is based in part on an announcement from Wileen Wong Kromhout at UCLA. For more information, see http://newsroom.ucla.edu/portal/ucla/yang-yang-named-to-carol-and-lawrence-210177.aspx

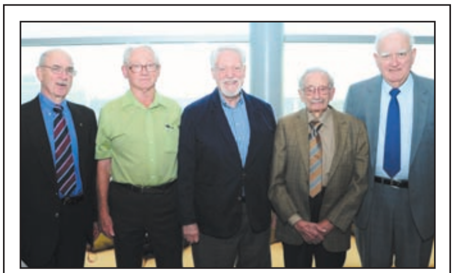
Charter Members Gather at Display Week in SID's 49th Year

At Display Week 2011 in Los Angeles, four charter members of the Society for Information Display came together to celebrate the society they helped create at UCLA nearly 50 years earlier.

In the fall of 2010, members of SID's Los Angeles chapter initiated a search for charter members. In a list they found that was dated 1966, 64 people had been designated as charter members, with two additional people named as founders. The search team discovered one of the founders, Rudolph Kuehn, who was not able to travel to Los Angeles for Display Week 2011. And they found eight charter members: Tom Curran, Philip Damon, Dail Doucette, Donald Gumpertz, Robert Knepper, Lou Seeberger, Erv Ulbrich, and Richard Winner. Four of these individuals and their wives attended a special reception during Display Week in LA, where each spoke briefly about the organization, its founding, and ongoing success.

Next year, for the 50th anniversary of the inception of SID, the SID Los Angeles Chapter will install a building plaque at UCLA honoring the society. ■

– Jenny Donelan



At the SID President's Cocktail Reception at Display Week 2011 are SID historian Robert Donofrio and charter members Robert Knepper, Dail Doucette, Lou Seeberger, and Erv Ulbrich.

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hundreds of volunteers with degrees in the science, technology, engineering, and mathematics (STEM) fields, is aimed at stimulating greater interest in science among students at the middle school level (grades 6, 7, and 8). Most volunteers are retirees and Dr. Castellano is appealing to all of you who are near or in retirement and want to share some of your extensive hard-earned experience with students. I love this concept and can easily imagine the next generation of great scientists and engineers getting their inspiration through a program like this. Imagine that maybe the inventor of the first real-time holographic 3-D virtual-world TV system is just entering 7th grade now. You could be the one who brings the vision, and hence the reality, to our next generation just by giving your time to inspire that student – doesn't seem like that much of a leap, does it? ■

guest editorial

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wall, outside, looking outwards. So when you looked at the display, it was as though you were looking through a real window to the outside. It was amazing how easy it was to consider the "fake" window real, and how it provided a sense of greater openness to the room. While this application is apparently not of current interest, this could change, considering the popularity of windows. It could be that the market for this type of application could be even more significant than 3-D computers and TV displays. ■

***Phil Bos** is Associate Director of the Liquid Crystal Institute and a Professor in the Chemical Physics Interdisciplinary Program at Kent State University. He is the inventor of the pi-cell and an alignment method for SmC* devices. His research interests include novel liquid-crystal devices and applications. He can be reached at pbos@kent.edu.*

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The following papers appear in the September 2011 (Vol. 19/9) issue of *JSID*.
For a preview of the papers go to sid.org/jsid.html.

Papers Based on Presentations from the 17th International Display Workshops (IDW '10)

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