TV TECHNOLOGY AND DIGITAL SIGNAGE ISSUE

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Information DISPLAY

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Nov./Dec. 2013
Vol. 29, No. 6

Crafting the Biggest, Boldest Displays

MAKING WINDOWS COME ALIVE

COLOR PERFORMANCE IN CURVED OLED TVs

THE EUROPEAN DIGITAL-SIGNAGE MARKET

THE INs AND OUTs OF VENTURE CAPITAL

MANUFACTURING CHALLENGES OF UHD TVs

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ON THE COVER: *From top to bottom are the LG55EA9800, a 55-in. curved OLED TV from LG; the KN55S9CAFXZA, a 55-in. curved OLED TV from Samsung; and the 110-in. 4K x 2K 3-D TFT-LCD TV from China Star Optoelectronics Technology.*

Cover Design: Acapella Studios, Inc.

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- Stretchable and Comformable Displays
- Displays from Nature
- The Display Materials Marketplace
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editorial

With a Little Help from Our Friends

by Stephen P. Atwood

Here at *Information Display* we have been covering the slow but steady progress of OLED technology for more than 8 years. In 2005, then editor Ken Werner stated that "Organic light-emitting-diode (OLED) display technology is the only serious current challenger to the LCD's hegemony in small- and medium-sized displays…." It took a few more years for OLED displays to really penetrate the mobile-display market, first as secondary phone displays and then as primary displays. By 2011, we were looking at 180 million units shipped and active-matrix OLED display revenues climbing above the $10 billion annual sales mark, as reported in the October 2011 Display Marketplace article, "OLEDs in Transition."

That's still small potatoes compared with the total market for LCD mobile devices, but it is significant from the standpoint of infrastructure investment, process development, materials and chemistry supply chain, *etc*. It's also significant when you consider the substantial dominance of LCD technology and its relentless march toward higher resolutions and ever-improving optical performance. It is hard to close the performance gap when the competing technology continues to improve in so many dimensions.

It was also in 2005 that Samsung stunned the display world when it first demonstrated a 40-in. prototype OLED TV. This breathtaking prototype used a white emitting layer with color filters and utilized amorphous-silicon (a-Si) TFTs in the active backplane – at a time when many others were working on low-temperature polysilicon (LTPS). We learned later that a-Si was not going to be the best approach for OLED TFTs, but the game was on in terms of defining the future for OLED as a competing technology for large-format TVs as well. And why not?

Samsung demonstrated what we all anticipated that OLEDs had several intrinsic performance advantages over LCDs owing to their nature as an emissive technology, including power consumption based on content, true black levels and very wide dynamic range, tunable color spectrums, and very fast response times. OLEDs also promised advantages from a process perspective that would make any size panel easier to produce than an LC-based one. More TV prototypes followed, and Sony even commercialized a small-format 11-in. OLED TV. But the challenges of actually producing large volumes of any size OLED TV were daunting, and a lot of practical challenges remained even into 2009, as reported in *ID* by Barry Young in his article "OLEDs: Promises, Myths, and TVs" in the September 2009 issue. At that point, a-Si backplanes were out and oxide-TFT and LTPS backplanes were still in development. It took another 3 years before the first truly production-ready OLED HDTV demonstrations appeared at CES and Display Week. Those 55-in. wonders made true believers out of us all, even though their availability was still somewhat of a mystery.

Well, here we are in 2013 and you can finally go to your favorite big-box retailer and buy a 55-in. OLED TV for slightly less than $10,000. It's a miracle! Well, actually it is more of a milepost in our industry now and the culmination of an unfathomable amount of work by countless industry experts and visionaries, some who have graciously been helping us report on this technology for so many years. And so, as we approach the end-of-the-year shopping season, we thought it fitting to put the Samsung and LG 55-in. curved OLED TVs on our cover.

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Information DISPLAY

Executive Editor: Stephen P. Atwood
617/306-9729, satwood@azonix.com

Editor-in-Chief: Jay Morreale
212/460-9700, jmorreale@pcm411.com

Managing Editor: Jenny Donelan
603/924-9628, jdonelan@pcm411.com

Advertising Sales Manager:
Joseph Tomaszewski
201-748-8895, jtomaszews@wiley.com

Advertising Sales Representative:
Roland Espinosa
201-748-6819, respinosa@wiley.com

Technicolor Offers Color and 4K Certification Programs

The Technicolor process for color motion pictures was invented in 1916. Since then, the process and the companies behind it have changed considerably, but Technicolor is still synonymous with state-of-the-art Hollywood technology. In a program designed to leverage that cachet, Technicolor began partnering with color calibration software company Portrait Displays last year to provide a color certification program for PCs and mobile devices. More recently, Technicolor also began offering 4K image certification for 2K to 4K image conversion (rather than to actual devices), supplying its first Image Certification to Marseille Networks for its system-on-a-chip designed to deliver 4K TV content.

Technicolor's color specification is based on software from Portrait Displays, which is designed to be used by OEMs to fine tune screens for color accuracy. The result should be consistent color across all certified devices. The colors seen in movies watched on certified laptops, tablets, and smartphones will match exactly those intended by the creators of the movies. The certification will also extend to online shopping – so you don't buy a yellow sweater online thinking it is green, for example – and to videos and photos taken by consumers. Licensed OEMS will be able to offer the certification logos on their products (Fig. 1).

Both the color and 4K device-certification programs were announced some time ago (the color one in 2012 and the 4K one last summer), but rollout has only recently begun, with the Toshiba BDX4600 Blu-ray player receiving 4K image certification.

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Fig. 1: *These logos will appear on color-certified devices.*

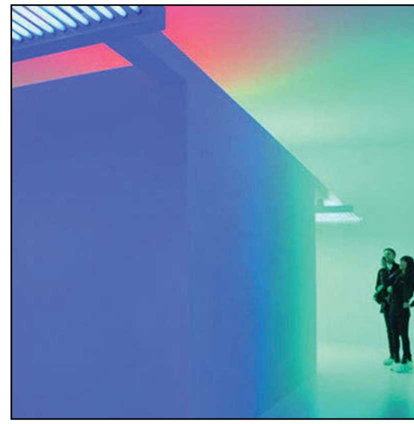

Fig. 2: *The Lightopia exhibition at the Vitra Design Museum features walk-in installations such as this fluorescent-based work by artist Carlos Cruz-Diez. Image courtesy © Carlos Cruz-DieIz & Adagp, Paris 2013.*

Lighting Exhibition Features OLEDs and LEDs

A unique exhibition under way in Germany right now features lighting technologies based on LEDs, OLEDs, and other materials. In addition to demos of state-of-the-art lighting design, including walk-in installations (Fig. 2), the "Lightopia" exhibition includes a mock laboratory (Fig. 3) designed to explain the science behind LEDs and OLEDs. The show also examines the historical role that lighting has played in shaping human environments, including its environmental ramifications. Lightopia is taking place at the Vitra Design Museum in Weil am Rhein (Germany) through March 16, 2014. The exhibition is sponsored in part by Merck, which developed many of the materials used in the exhibits.

"Innovative lighting offers new application possibilities, which require close collaboration between designers and manufacturers," says Jolanthe Kugler, curator of the exhibition. After its run at the Vitra Design Museum, Lightopia will go on tour to other museums throughout the world.

Fig. 3: *Merck contributed a mock laboratory exhibit to Lightopia that was designed to explain how LEDs and OLEDs are made. Image courtesy Merck.*

Samsung/Cheil Industries to Acquire Novaled

Samsung Electronics and Samsung affiliate Cheil Industries have signed an agreement to acquire OLED technologies and materials provider Novaled in a transaction valuing Novaled at €260 million.

According to a press release from Novaled,[1] Cheil Industries, a leading display materials supplier, will acquire a majority stake of approximately 50% in Novaled. Samsung Electronics will acquire approximately 40%.

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guest editorial

Digital Signage that Captivates

by Terry Schmidt

What catches your eye enough to make you pause? As we drive along a freeway, walk a shopping mall, or just hurry though the airport to catch a flight, we are bombarded with hundreds of messages from advertisers every day. What constitutes effective advertising? What messages, what types of displays, work best? Digital signage is a relatively young market with a wide variety of applications, venues, and hardware. This makes global tracking of this industry very difficult, but the industry appears to be burgeoning.

Dave Haynes is a co-founder of The Preset Group, which advises end users and vendors on digital-signage projects. David says: "The digital-signage industry has seen rapid growth in the last 2 or 3 years – after many years of 'next year is going to be the year this takes off.' What finally made it happen was the reduction in the costs of large-format display panels, better energy efficiency, and slimmer bezels (the frames of these displays). What has also helped are much more ubiquitous and reliable broadband, better video-compression technology (smaller file sizes), and a crazy amount of software providers, which has forced down costs." Certainly, digital signage appears to be a multibillion dollar industry with healthy growth, from U.S. $1.3 billion in 2010, projected to grow to $4.5 billion in 2016 (ABI Research) and $13.8 billion in 2017 (Global Industry Analysts).

Various building blocks of a digital-signage system encompass hardware such as eye-catching displays, servers, and media players, as well as software to organize, distribute, and display. Ultimately, however, the success of a digital-signage project boils down to the content and the content-creation software, which must satisfy the business objectives and the ROI of the customer. Simplicity and low cost are the keys to widespread adoption. Also, matching the right display technology to the application is essential. Very-large direct-view LED displays can be effective for outdoor signs such as roadside electronic billboards, but for closer viewing, high-resolution video walls can be custom designed from stackable components that range from small rear-projection displays (*e.g.*, Christie MicroTiles) to narrow-bezel LCD flat panels.

New low-cost ARM-processor-based media players, HTML5 content-creation software, and exciting new video-wall and projection-mapping displays are all contributing to make digital signage a dynamic and exciting business opportunity. Recently, the support of rich content at relatively low cost is now possible with HTML5 on affordable hardware. A notable example of this is the PiCube from Finnish company FirstView Digital Signage, which is able to display full HD (1080*p*) video and images from a credit-card-sized single-board computer (the Raspberry Pi from the UK initiative of the same name). The media-player hardware itself is free; FairView charges a monthly subscription fee for an online account with associated services to manage the content

However, the ability of digital-signage content to captivate an audience and effectively transmit a message is greatly dependant on the display that is used. A number of promising new display technologies are in development and there are also advances in the use of sensors to make digital-signage displays more interactive. Ted Sun of Sun Innovations, who presented two interesting papers on his eye-catching, transparent-screen projection technology at Display Week 2013, has written an article for this issue. He explains how this and other novel display innovations can be used to

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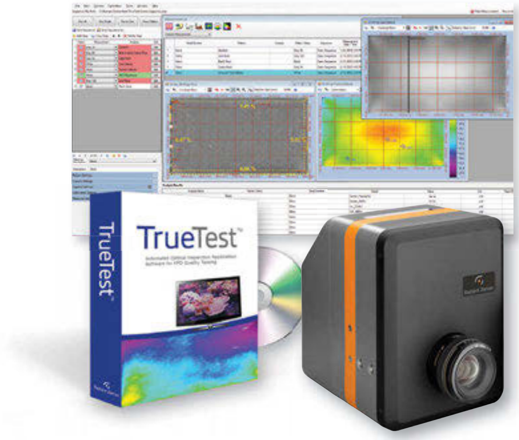

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Considering Color Performance in Curved OLED TVs

One of the creators of the IDMS (Information Display Measurements Standard) takes the measure of the very latest large, curved OLED TVs. In this first article in a series, he looks at color performance.

by Edward F. Kelley

LATE LAST SUMMER, 55-in. curved organic light-emitting-diode (OLED) TVs from both LG and Samsung were introduced to the U.S. marketplace. Commercially available large OLED TVs were novel to begin with; the addition of the curved form factor, designed to enable a more immersive viewing experience, made them even more so. The display community at large has no prior experience with these unique panels, and, therefore, this article describes the innovative work of investigating their performance and fine-tuning the measurement methods needed.

This article compares the color performance of two curved OLED TVs that have recently gone on sale in the U.S.: the LG 55EA9800 and the Samsung KN55S9CAFXZA (see Fig. 1). Both have 55-in AMOLED displays. Only one display from each manufacturer was examined, so the data presented here may not be representative of a statistical sampling of such displays (at about $10K retail price per TV at the time of this writing, this may be understood by the reader).[1] In this article, we evaluate and compare the sets' color gamuts under various conditions, viewing-angle properties, and other straightforward characteristics. In future articles, we will examine a variety of other characteristics.

The Samsung OLED employs red-green-blue (RGB) subpixels in a horizontal configuration, and the LG OLED uses RGBW (W for white) subpixels in a vertical configuration. The LG subpixels are white OLEDs covered with colored filters, and the Samsung subpixels are OLEDs that are tailored to emit the specific RGB colors (see examples of the subpixel configurations and spectra in Fig. 2).

Modern televisions can be operated in a number of different modes with numerous settings. All factory settings were used as the basis for these tests. In both cases, the overscan feature was turned off. We noted that

***Fig. 1:** The LG 55EA9800 and the Samsung KN55S9CAFXZA 55-in. curved OLED TVs were tested for this article. The LG is at the left and is mounted for measurement. A photograph is shown on the displays for visual interest, but patterns were used for measurements.*

***Ed Kelley** is a consulting physicist with Keltek LLC in Longmont, Colorado. He can be reached at ed@keltekresearch.com.*

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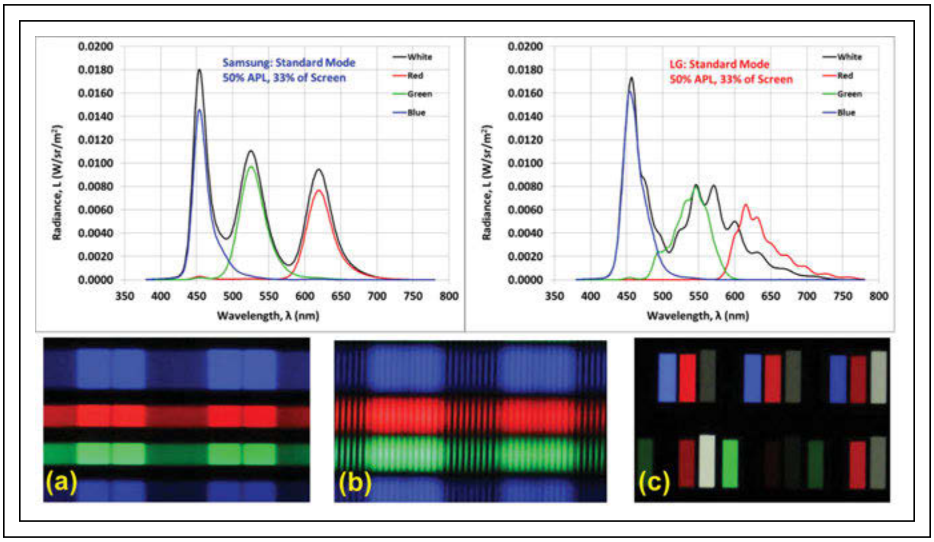

***Fig. 2:** Subpixel configurations and spectra appear for both tested units. The Samsung OLED RGB subpixel arrangement is shown in (a), where the subpixels each have two parts separated by a narrow line. The smearing between the subpixels in the black region is apparently caused by a lenticular treatment (b) covering the pixel surface. The LG subpixel arrangement is shown in (c), where the main gray scale is produced by the white subpixel and the colored RGB subpixels regulate the color; several pixels of various colors are shown (a pixel is composed of RGBW subpixels in the order of GBRW from left to right).*

both displays exhibited a behavior in which the image luminance would slowly dim when displaying a static pattern. We can speculate that this might be intended to protect the display from static image burn-in, but that was not confirmed. Unfortunately, this feature made it harder to collect consistent performance measurements based on static images. The Samsung display had an option to disable the feature; the LG display did not. This made it necessary to obtain the measurement result before the dimming occurred if at all possible. A previous review of the LG OLED display has been made by Dr. Ray Soneira and is available on the Internet.[2] For the record, we obtained results similar to Soneira's here.

The Measurement Environment

The displays were measured in a darkroom with no ambient illumination. The alignment of the center horizontal normal of the curved displays was assured by a laser alignment system to less than 0.25° along the measurement optical axis. Both displays were tilted back approximately 5° or 6° so that their central normals were pointing slightly upward from the horizontal plane. All measurements were made at screen center in the horizontal plane below the central normal – we assumed this was the design viewing direction. A spectroradiometer was used for all measurements reported here.[3] We make reference to the new IDMS document that specifies numerous measurements and recommends various practices.[4] A stray-light-elimination tube (SLET) was used for all measurements (see ICDM §5.1 p. 47 and Appendix A2.1). A SLET helps avoid stray-light contamination from bright areas when measuring dark levels.

Zero-Luminance Blacks

One of the most refreshing features of these OLED displays is their ability to show an absolute black level – a zero-luminance black. Various people have commented that such a black is not necessary for "normal" viewing, but what is "normal" viewing? When we see a movie with a sparse star field just before a spaceship enters the view, it is wonderful to see a true black between the stars rather than a dark gray with the surrounding bezel blacker than the blackness of space. Now we can see black as we would if we were in space. Theme parks may want a black screen so people won't see the display in the dark tunnel until it flashes imagery designed to scare the riders. Gamers may want to feel like they are looking out into space from their spaceship, *etc*.

All modes of these two OLED displays, save one, could show zero-luminance blacks. They could also show gray levels as low as level 1 or level 2 out of 255 levels above level 0 (black). The LG display in the THX Cinema mode can show a non-black background almost as dim as level 1 of 255 with a mottled appearance. This non-zero black for the THX Cinema mode, the apparent result of a marketing decision, is available only on U.S. models. However, all other LG modes show a zero-luminance black. If the non-black LG THX Cinema mode annoys a viewer, it is a simple matter to configure one of the two available extra Expert modes to appear like the THX Cinema mode but with a zero-luminance black. Should it be necessary, the black levels are generally adjustable in both displays to account for some ambient illumination. Because the black of the LG THX Cinema mode has a mottled appearance and is very low in luminance – of order 0.001 cd/m^2 depending upon where it is measured – we list its black luminance as "not measurable" rather than providing a possibly misleading number for the contrast.

Zero-luminance blacks make the display have an infinite contrast no matter what white level is produced (contrast is $C = C_W/C_K$ with a zero in the denominator). This is why the IDMS requires the use of the term "undefined" for such contrasts and suggests that the black and white levels be reported separately (see IDMS pp. 46 and 47). In the display industry, we seem to have reached the point where contrast (luminance ratio of white to black) has lost its meaning and quoting the white and black levels is much more relevant.

Loading

OLED displays are a current-driven pixel technology, and, like plasma displays, will exhibit loading characteristics. Figure 3 illustrates the loading of these OLED displays where a white rectangle starting at 2% of the linear dimensions of the screen expands to full screen. Note how the white luminance decreases with the increasing size of the white area; this is loading – which also occurs with saturated colors. Loading may be considered by some to be an undesirable characteristic, but it may not be noticed by most viewers, and much of the television programming does not load the screen as much as a large white or

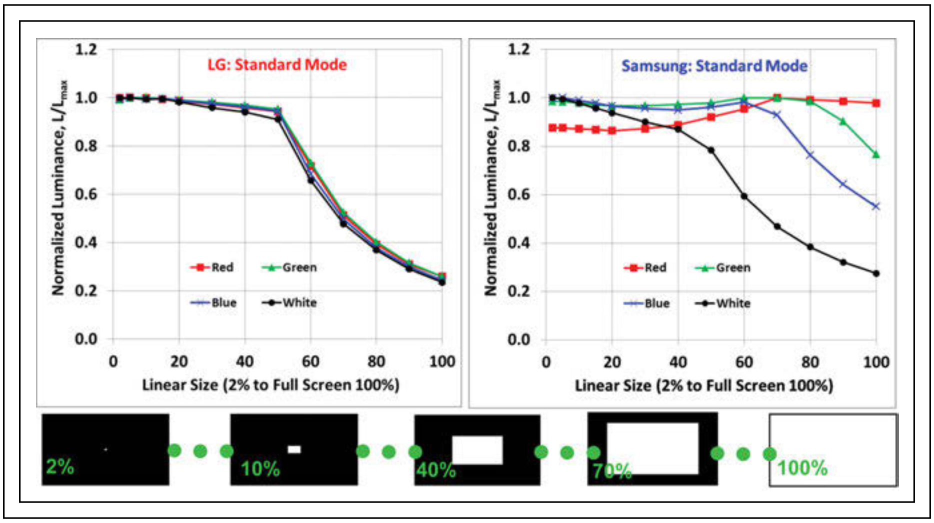

Fig. 3: Loading characteristics are tracked for the LG (left) and Samsung (right) units in Standard Mode.

colored area. Without loading, the power requirements for these displays would be much greater. Because of this loading phenomenon, a series of patterns that kept the average pixel level (APL) of the pattern a constant was needed in order to test the displays. Here, we use the term APL to refer to the pre-gamma input signal average (this is not the average luminance level). We selected a 17-level stepped gray-scale pattern of concentric overlapping rectangles with each gray level (including white) occupying the same size area on the screen and where the black level cycled in exchange with the center rectangle through the other 16 levels. The overall pattern was 33% of the size of the screen, and the APL of the rectangular pattern area was 50%, resulting in an overall APL for the entire screen of 5.43% (see Fig. 4). Unfortunately, even the 33%-sized pattern still caused loading effects in some modes.

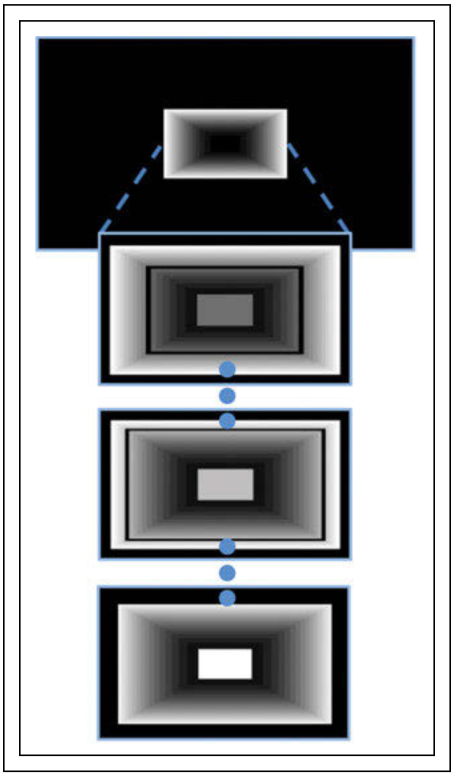

Fig. 4: The concentric 17-level 50% APL pattern covered 33% of the screen, giving an overall APL for the entire screen of 5.43%.

General Characteristics

Table 1 shows the general characteristics of the tested OLED displays as viewed from the design viewing direction (below the tilted screen normal at the center of the screen), (see Fig. 5). We refer to the signal gamut as the sRGB gamut.[5] We follow the suggestions of the ICDM §5.1 in not attempting to report infinite or unmeasurable contrasts. The uncertainties are the typical uncertainties obtained from a quality spectroradiometer. The spectroradiometer was tested against red, green, blue, and violet lasers prior to these measurements to assure that their chromaticity values appeared on the spectrum locus (*i.e.*, very close within expected uncertainties). The

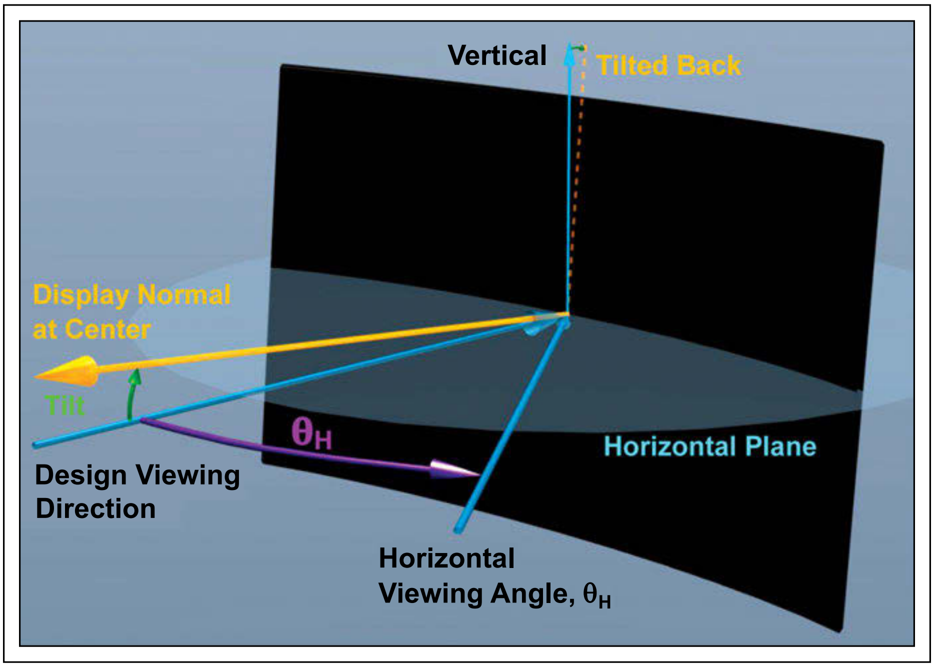

Fig. 5: The design viewing direction is shown in the horizontal plane at the center screen with the curved display tilted back.

Table 1: The above main modes used factory settings (except as noted in the main text). Measurements were made from the horizontal viewing angle in the horizontal plane of center. The pattern used as a 17-level 50% APL covering 33% of the screen with an overall APL for the entire screen of 5.43% (see Fig. 4).

Display and Mode	L_W (cd/m^2)	L_K (cd/m^2)	Contrast[a] $C = L_W/L_K$	Relative Gamut Size[b] (c.f., sRGB)	Average Gamut Size[c] ($\Delta u',v'$)	CCT (K)	Gamma[d] (γ)	Full-Screen K or W Power, P (W)
Samsung OLED								$P_K = 115$
Dynamic	489	0	Undefined	116	0.0197	12 580	Loading	$P_W = 252$
Standard	398	0	Undefined	120	0.0159	8945	Loading	$P_W = 219$
Relax	358	0	Undefined	120	0.0100	6530	2.58	$P_W = 215$
Movie	221	0	Undefined	104	0.0040	6277	2.27	$P_W = 188$
LG OLED[e]								$P_K = 51$
Vivid	373	0	Undefined	118	0.0024	11 030	Loading	$P_W = 213$
Standard	389	0	Undefined	118	0.0023	10 230	Loading	$P_W = 210$
Eco	267	0	Undefined	118	0.0026	10 010	Loading	$P_W = 171$
Game	235	0	Undefined	118	0.0024	9221	2.34	$P_W = 162$
THX Cinema (not adjustable)	130	~< 0.001	Not measurable	101	0.0034	6433	2.20	$P_W = 95$

[a]See ICDM §5.1 for a discussion of how to deal with low-level or zero-luminance blacks.
[b]See ICDM §5.18.1 Relative Gamut Area for using the sRGB gamut in the (u',v') chromaticity diagram.
[c]$\Delta(u',v')$between the centers of the sRGB gamut and display gamut.
[d]Gamma values obtained using the gain-offset gamma-offset (GOGO) model (see ICDM §6.5). A "Loading" entry means that the gamma model is not appropriate.
[e]The two Expert modes are not measured or listed because their default factory settings are very similar to the THX Cinema mode and can be completely configured as the viewer wishes as well as allow for zero-luminance blacks.

wavelength locations of mercury lines were also checked and found to be within 1 nm of their published values.

For both displays, the observed loading effects created a transfer function [$L(V)$] that could not be easily fitted with a typical characteristic gamma curve as illustrated in Fig. 6. The gray-scale curve can show a positive second derivative as the luminance increases when loading occurs. Thus, in Table 1, gamma values could only be reported for the non-loading gray scales for both displays in their dimmer modes. Figure 7 shows how closely both displays matched the sRGB signal and gamut for the 17 gray levels (the white point) and four levels of color above black for the theater modes of each display.[6] Near the center of the gamuts were two plus signs that indicated the gamut shift. These marked the center of the sRGB gamut and the center of the display RGB gamut. The metric for relative gamut size gave no indication of the amount of overlap of the two gamuts. The gamut shift metric (in $\Delta u',v'$) provided some indication of overlap, but not rotation.

Figure 8(a) shows how the gamuts changed for each display in their Standard modes; the LG exhibited an almost constant gamut with loading and the Samsung exhibited an increased gamut with loading. Figure 8(b) shows the change in the gamuts for the

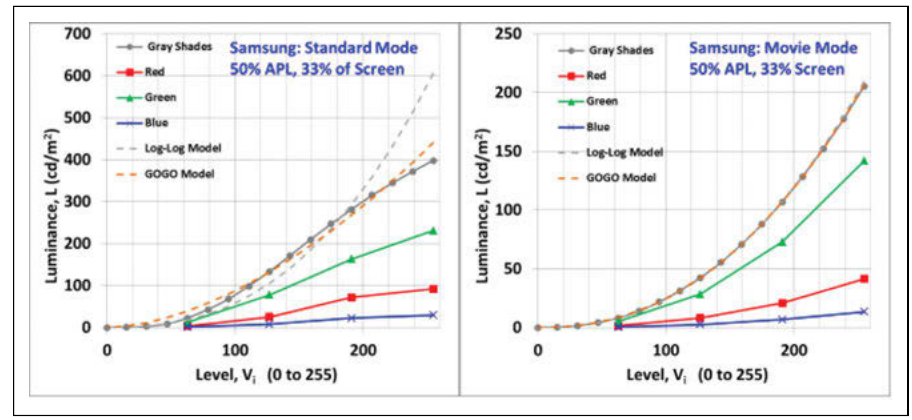

Fig. 6: *Fitting a gray scale with loading will not work properly (left) whereas modes with less luminance and without loading can be properly fit with a gamma model (right). The Samsung display is shown here; the same loading distortion of the gamma curve occurred for both displays with the brighter modes.*

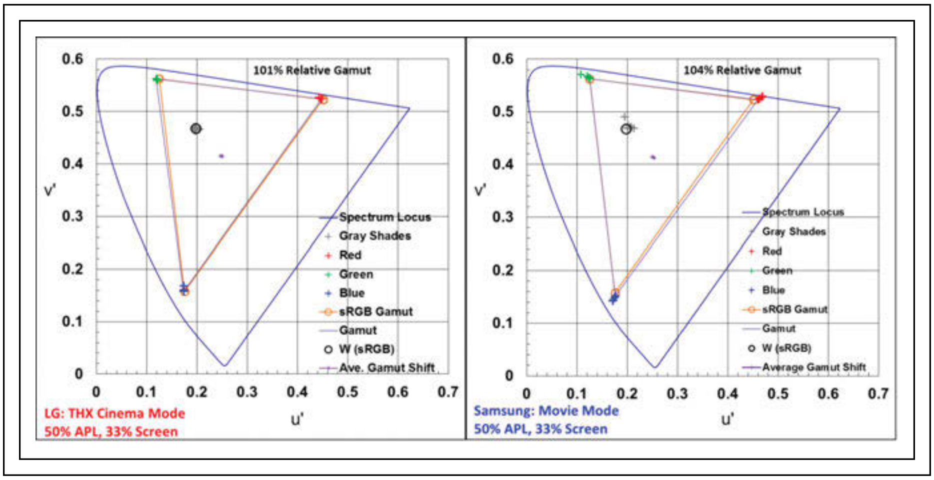

Fig. 7: Accurate gamuts and very small gamut shifts for theater modes were detected at the design viewing direction.

displays in their theater modes with a change in level. The LG display did not change very much as the RGB levels changed, but the Samsung gamut increased as the RGB levels decreased. In terms of color accuracy and reproduction of the input signal, it is better to have the gamut not change with changes in level, loading, or anything else. However, because people tend to like more saturated colors, how objectionable gamut increases are will probably depend upon whether the viewer is a critical observer or not.

Viewing-Angle Properties

A curved display has slightly different properties when it comes to viewing angle: For a single observer, it is optimal for a certain viewing distance and the viewing-angle performance is not as significant. However, for multiple off-axis observers, the curvature could make the viewing-angle requirements more severe because the angles become larger than at the screen center on the side of the screen where the off-axis viewers are located (see Fig. 5).

For this evaluation, a new way to visualize the viewing-angle performance was employed. This method considered the shift of relative color-gamut area and may eventually be considered for the next major release of the ICDM (ICDM2, see ICDM §9.8 Viewing Angle Relative Gamut Area). The relative gamut area as a function of viewing angle is graphically shown in Fig. 9.[7] That figure shows results out to 60°, but, realistically, most viewers would only use such a curved display out to 45° and probably considerably less than that. A larger gamut shift as well as a reduction in gamut size can be observed at larger angles for the Samsung display (with a very small shift at ±15°), whereas for the LG display the gamut increases for larger angles but the gamut shift remains relatively constant. The change in luminance with viewing angle is shown in Fig. 10.

It is important to recognize the scale of these (u',v') chromaticity diagrams. An expanded view of the Movie and THX Cinema modes appears in Fig. 11. The error bars on the sRGB white point represent the approximate detection limit of a color change in adjoining color blocks – a Euclidian distance of 0.004 on each side of the white point [see ICDM Appendix B1.2 Colorimetry, p. 471; some refer to this as a just-noticeable-difference (JND) for colors]. Ten times those error bars would represent the color discrimination for widely separated colors such as on two different displays. However, as gray levels darken, our ability to distinguish color diminishes, and the deviations from the white-point color are not as serious as they may appear on these (u',v') graphs. (A better metric may be the C^* metric, comparable to the ΔE^* metric, which indicates the distance from the white-color vertical line in the CIELAB color space where the darker colors are less discernible: $C^* < 2$ for the LG display and $C^* < 3.5$ for the Samsung display.)

All these results show that these TVs, especially in their theater modes viewed from the frontal direction, are almost "perfect" with respect to luminance, color gamut, gamma, and black levels, as Dr. Soneira describes.[2] However, keep in mind that once these displays are connected to the Internet and upgraded software is downloaded and installed, these characteristics could very well change.

Future articles will address other performance characteristics. In the meantime, if the hefty price tags do not dissuade you, either of these TVs can offer an unparalleled viewing experience in terms of gray and color scales, accuracy in color, and especially the wonderful absolute blacks.

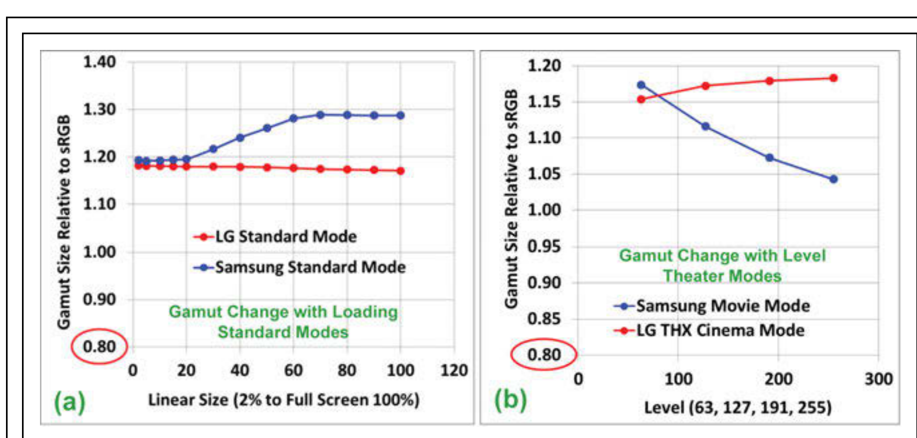

Fig. 8: Changes in relative gamut size were apparent with loading (a) for Standard modes and with level change (b) for theater modes.

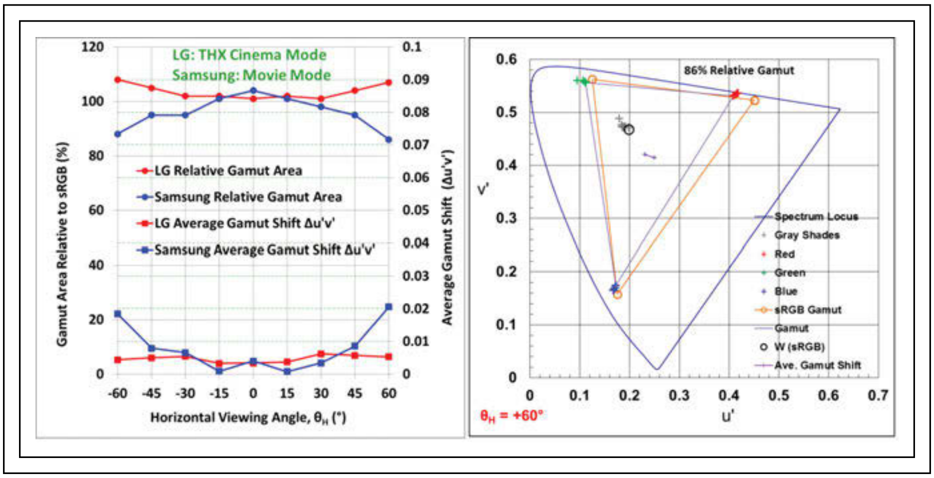

Fig. 9: A relative gamut area and shift as a function of horizontal viewing angle appears at left and one example of a gamut reduction below 100% with a shift toward the green is at right. The shift is represented by two plus signs near the center of the gamut triangles. The separation of the markers indicates the size of the shift in the display gamut compared to the sRGB gamut.

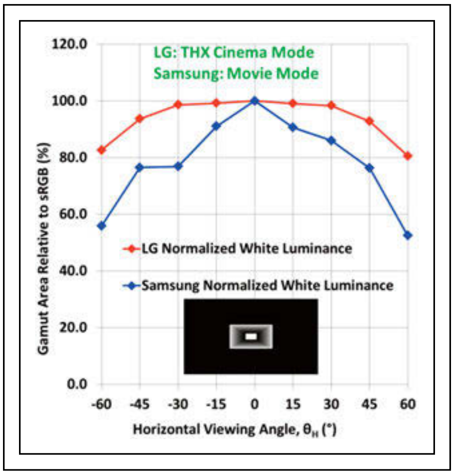

Fig. 10: The viewing-angle luminance of white is shown in "movie" modes for both units.

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[1]This work was partially funded by LG Display Co., Ltd. The company's contribution to this effort is gratefully acknowledged.

[2]Dr. Soneira reviews the LG OLED display and compares it with plasma and liquid-crystal displays. See: http://www.displaymate.com/LG_OLED_TV_ShootOut_1.htm. He uses the term "perfect" to describe several of its modes of operation. This same fine behavior is shown in both displays in this article.

[3]Disclaimer: The apparatus described herein are identified only for the purpose of complete technical description: The signals are provided from a computer using an NVIDIA GeForce GTX 570 board with an HDMI (high-definition multimedia interface) output. The signal output quality is checked using computer monitors to assure that what is delivered to the TVs is correct without artifacts. The spectroradiometric measurements are made with a Photo Research PR-730 spectroradiometer. All measurements are made in a quality darkroom.

[4]*Information Display Measurements Standard* (IDMS), prepared by the International Display Metrology Committee of the Society of Information display. The PDF version is available without charge; see, http://icdm-sid.org/.

[5]The sRGB signal requirements are specified in ITU-R BT.709-5: Parameter values for the HDTV standards for production and international programme exchange, April, 2002.

[6]These are the harmonized gray levels described in ICDM §A12.1.1 (the appendix) Table 1. The 17 gray levels are: 0, 15, 31, 47, 63, 79, 95, 111, 127, 143, 159, 175, 191, 207, 223, 239, 255; and the RGB gamut colors were measured on a five-level gray scale: 0, 63, 127, 191, 255.

[7]The idea for the graphical gamut-area representation has been proposed by LG Display. ■

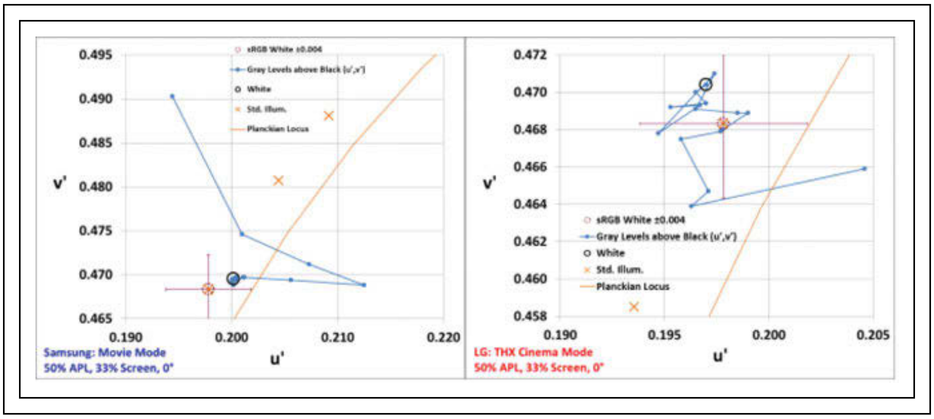

Fig. 11: The magnified area of the white point for the theater modes is represented. The error bars around the sRGB white point represent ±0.004 on each side of the white point.

Developing a 110-in. 4K × 2K TV

China Star has demonstrated a 110-in. LCD TV that has an outstanding dynamic contrast ratio of 50000:1, ultra-high brightness of 1000 nits, high-saturated color reproduction, and a 288-zone local-dimming backlight. Manufacturing a high-definition high-quality TV in such a large size brings with it special manufacturing challenges.

by Li-Yi Chen, Yu-Yeh Chen, Hung-Lung Hou, Yuming Mo, and Chung-Yi Chiu

RECENTLY, China Star Optoelectronics Technology Company (CSOT) successfully developed a 110-in. UHD (3840 × 2160) 3-D TFT-LCD TV panel. It was the world's first LCD panel to offer 4K × 2K resolution and 3-D capability. The maximum brightness of the panel is 1000 nits, achieved with less than 1100 W of power consumption via an LED backlight with local dimming. The color gamut is much larger than that of traditional LCD TV panels, with vivid primary colors due to the use of LED backlighting. The static dark-ambient contrast of the panel is greater than 4000:1. The panel's 3-D display technology uses 120-Hz shutter-glasses technology, and the large size particularly enhances viewer enjoyment of 3-D movies and games.

The goal for making this 110-in. panel was to provide a powerful sense of immersion and "reality" for the viewer. One of the most important enabling aspects for this capability is the visual angle. Studies have shown that a larger visual angle will provide a more immersive experience.[1,2] From the same distance, a bigger panel obviously can provide viewers with more information presented over a wider visual angle, as Fig. 1 illustrates. The visual angle increases by two times when the panel size increases from 55 to 110 in.

At the same time, resolution must be increased to maintain high visual quality with larger visual angles. For example, 1920 pixels spread over a wide visual angle or over a long horizontal distance and then viewed from close range results in a poor visual experience because of the low number of pixels per inch . Of course, people tend not to sit quite this close to large TVs. Even so, in a living room where the space is fixed, a larger panel with high resolution and optimal viewing angles will provide the best viewer experience.

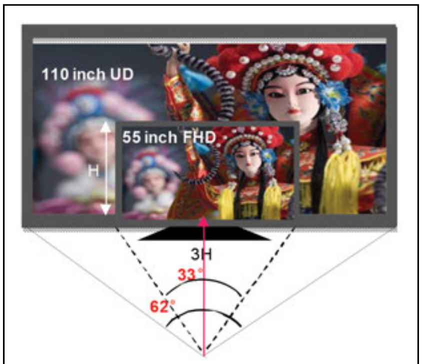

Fig. 1: The viewing angle from the same distance increases with the size of the panel.

When presented on a larger display such as one that is 110 in., full HD (FHD) does not satisfy what people expect to see in terms of imagery. Increasing the pixels per inch improves the picture performance and thus provides a better stereoscopic experience.

Manufacturing and Technology Challenges

The 110-in. panel was fabricated in a newly established Gen 8.5 fab by CSOT. There were many manufacturing challenges. Both for the TFTs and color-filter substrates, it was necessary to use multiple photolithography exposures (shots) to define the images in each mask step (Fig. 2). These multiple shots build up a patchwork quilt of the full array pattern for each step. A typical mask and panel pattern is shown in Fig. 3. Shot mura is caused by a variation of the critical dimensions in patterns and indirectly affects optical performance. For example, in the black matrix, the aperture of the pixel area controls the ratio of light transmittance. If the black-matrix dimensions change, the display luminance in that area will also change. This is especially true if the mura is located at the boundary of each unit shot in the mask. When the entire panel pattern is assembled with each unit shot in the mask, the boundary of each shot will be exposed twice because of the misalignment of the mask system. Similarly, if the two shots do not align perfectly, then the boundaries

***Li-Yi Chen**, **Yu-Yeh Chen**, **Hung-Lung Hou**, **Yuming Mo**, and **Chung-Yi Chiu** are with China Star Optoelectronics Technology Company, Ltd, Shenzhen, Guangdong, China. Y-Y Chen can be reached at yychen@tcl.com.*

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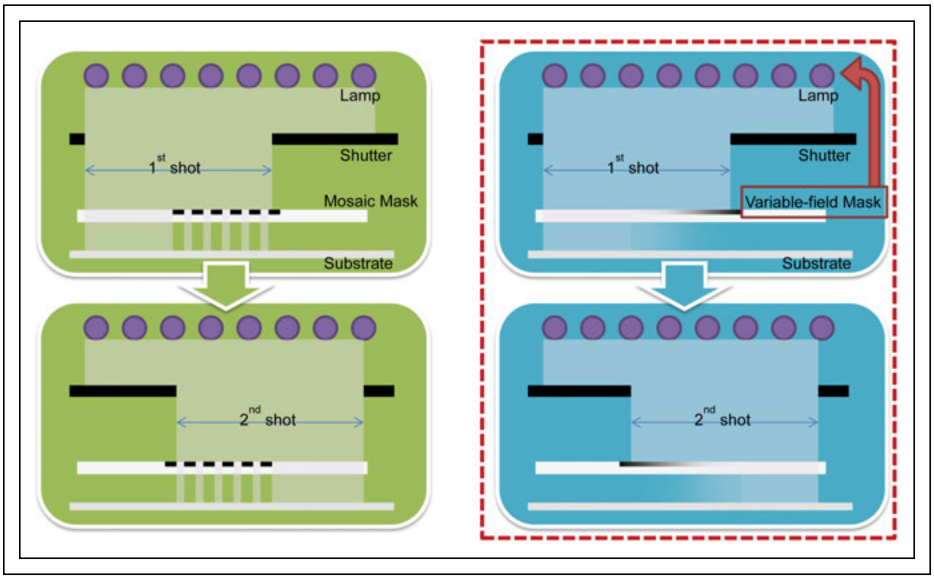


Fig. 2: Two exposure systems are shown: the mosaic (left) and variable-field (right).

between the shots will produce a pattern that is not consistent with the rest of the regions (Fig. 4). The resulting dimensions of the black matrix may then be different between the inside region and the boundary of each shot. CSOT has developed special proprietary photo recipes to solve this problem.

RC loading is a term that describes the combination of parasitic capacitance and series resistance in each TFT electrode. The larger these values, the longer it takes to establish a stable voltage level on the electrode. As the display size increases, both of these parameters also increase. To put this in perspective, consider the example of a full-HD (1920 × 1080) 55-in. LCD panel being driven at a 120-Hz frame rate. This requires a charge time on each gate of less than 7.5 µsec. With today's driver, interconnect, and line fabrication technology, this charge time can be easily achieved with some degree of design margin included. In fact, the settling time due to the RC effects is around 2 µS. However, if the resolution is only doubled in the preceding example, the available charge time is cut in half and the voltage levels on each line will not reach a stable value in time to charge the TFT cell to the correct data value. If the dimensions of the panel in each axis are then increased to roughly twice those of the 55-in. panel, the parasitic capacitance and line resistance is effectively doubled, creating an even greater challenge in achieving acceptable charge levels in each pixel cell. The settling time alone of a 110-in. 4K × 2K panel is about 8 µS. Therefore, a more innovative driving scheme was developed to overcome this limitation: the hG2d driving design.

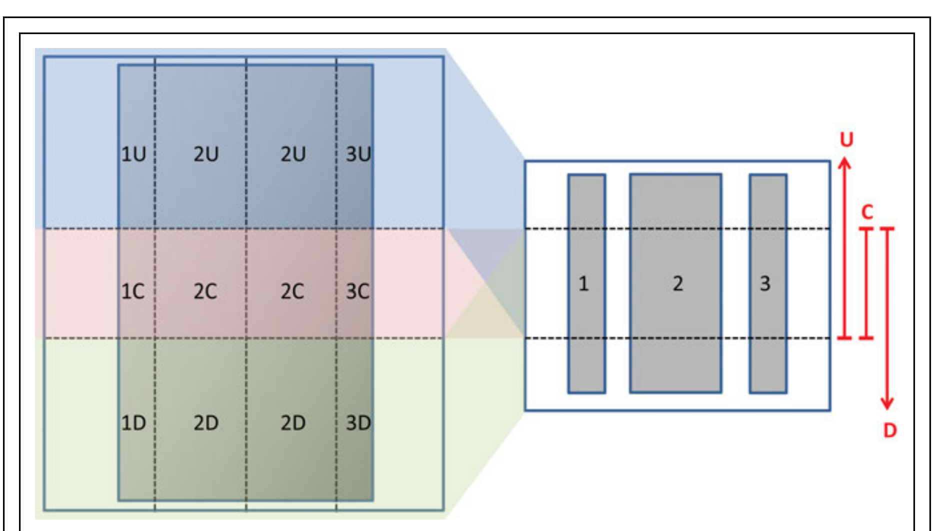


Fig. 3: Typical mask and panel patterns are shown.

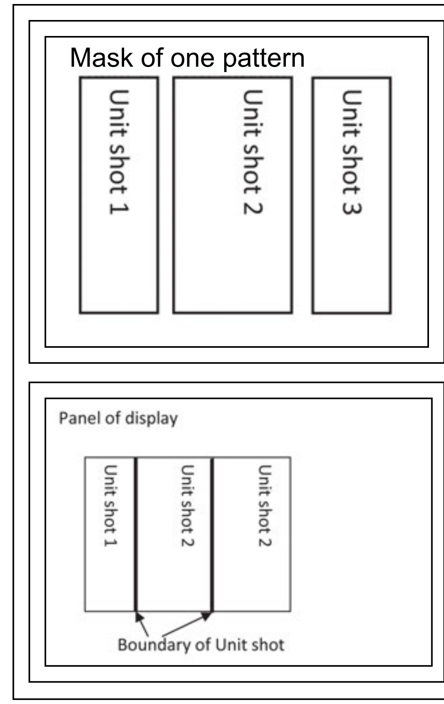


Fig. 4: Shot mura is particularly troublesome at the boundaries.

Pre-Charging Driving Scheme

Decreasing the amount of gate drivers by half and doubling the data (hG2D) driving was the first method considered to extend the charging time.[4,5] Compared with a normal 60-Hz panel, hG2D (source) drivers are used. Also, gate and source dual-side inputs were implemented in the architecture to reduce the loading impact, as shown in Fig. 5. Based on the current specifications of the IC and driver, 120 Hz with FHD is a better design. For the current Al process used, a charge time of

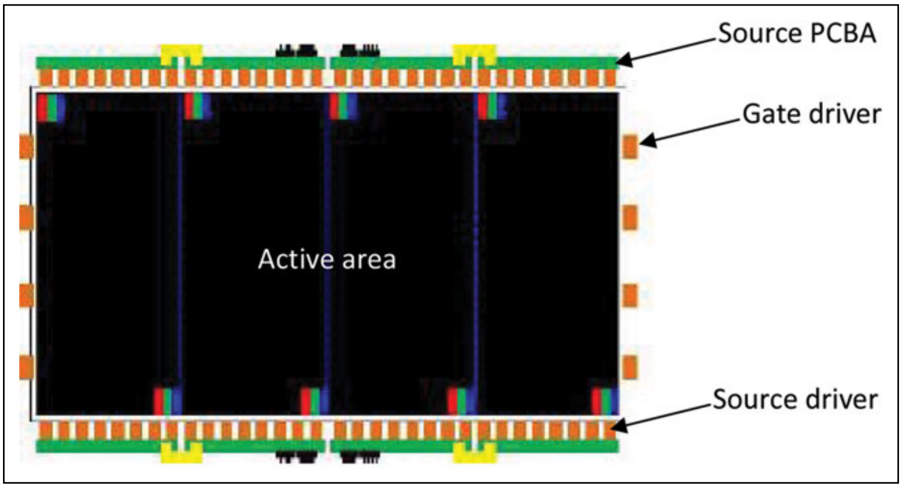
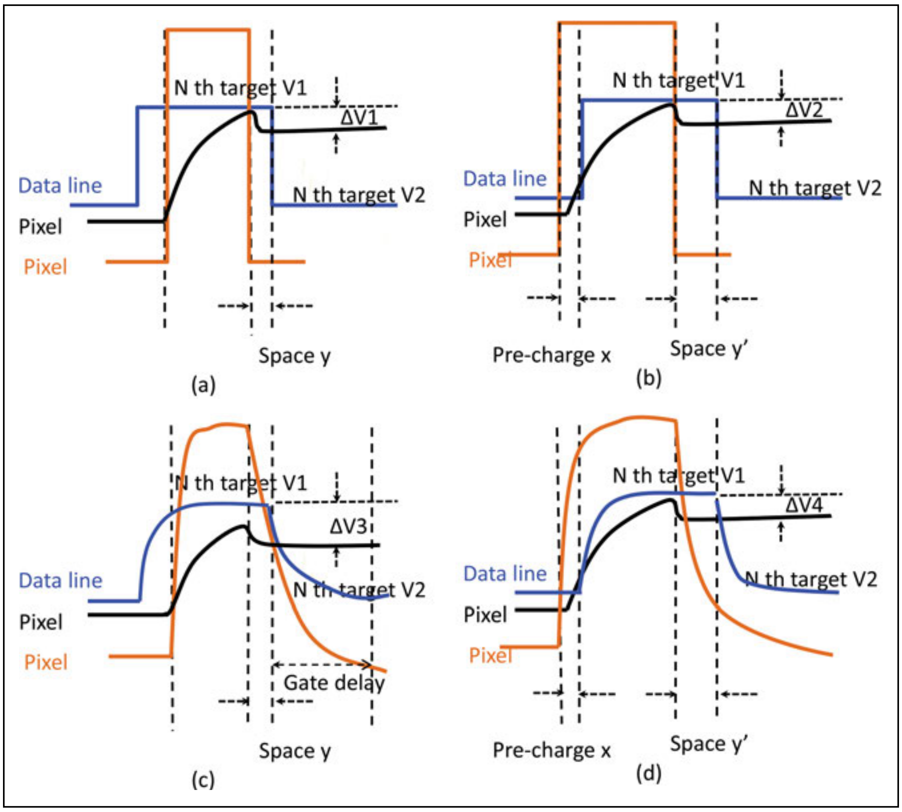


Fig. 5: This gate/source dual-driving setup was used for the 110-in. panel. Source PCBA: Transmits all display data and control signals from the control board to the source driver IC. Source Driver: Receives display data and converts digital signal to analog voltage for driving the TFT-LCD device. Gate PCBA: Transmits all gate driver control signals from the control board to the gate driver IC. Gate Driver: Controls scan line to turn on/off the TFT device line by line sequentially.



7.5 µsec is required for an 80-in. panel. However, if the frame rate is increased or the resolution doubled, the charge time is halved. Therefore, it is necessary to reduce charge time by using other methods. One approach is to turn on more than one gate at a time. When two gates turn on simultaneously, two sources of data information into the pixels are needed. Hence, the dual-data-line design with a pattern is needed in one pixel. This arrangement consists of half the gate input and twice the data input in one pixel. There are still some issues with this driving scheme and the picture performance for very large LCDs.

For an ideal initial setting of the driving waveform as shown in Fig. 6(a), the pixel voltage needs to be at a desirable value. For the ideal case, the pixel voltage should be charged rapidly to the correct value. However, the circuit resistor or capacitor usually causes distortion in this charging on the rising and falling edges. Thus, if the charging time is insufficient, the pixel voltage will not be correct. With $Vf_t = \Delta V_1$, insufficient charge flows to the LC capacitor. When this circuit scheme was used for the 110-in. LCD, the researchers encountered an enormous obstacle in charging uniformity. The distortion depends on accumulated parasitic capacitance and LC capacitance through the panel.

After propagating a distance to get to the cell, the gate and data waveforms change and overlap the undesirable area of the next target voltage, which is different from the initial setting as shown in Fig. 6(c). Hence, the target pixel voltage is difficult to achieve and suffers a voltage drop of ΔV_3, including a lack of carrier charging, feed-through voltage, and error charging to the next target voltage. To overcome this difficulty, the pre-charge concept was utilized to inject enough carriers into the LC capacitance and suppress the error charging ratio by overlapping the next target voltage.

Figures 6(b) and 3(d) depict the pre-charging setting. It is apparent that ΔV_4 is compensated and is smaller thanΔV_3. Meanwhile, ΔV_2 and ΔV_4 can be modified and are almost the same as ΔV_1. This structure allows for an extension

Fig. 6: A driving waveform is depicted with normal and pre-charge schemes. Image (a) shows an ideal waveform, (b) shows the same waveform in pre-charge mode, image (c) shows a normal setting, and (d) shows the pre-charge mode.

of the charging time and a reduction of the gate-delay influence. Figure 7 shows a schematic for gate output with and without pre-charging.

Figure 8 shows some quality issues caused by error charging. At the left of the image of the man's mouth in Fig. 8(a), there is a rough edge around the lips, which is the result of error charging. Optimizing the timing between gate and data pulse as illustrated in Figs. 6(b) and 6(d) helps to improve this phenomenon, as shown in Fig. 8(b). After optimization, it was possible to retain the well-charged performance and avoid error charging at the same time. The result was an improvement in available charging time to 15.4 µsec, which overcame the limitations due to the RC loading.

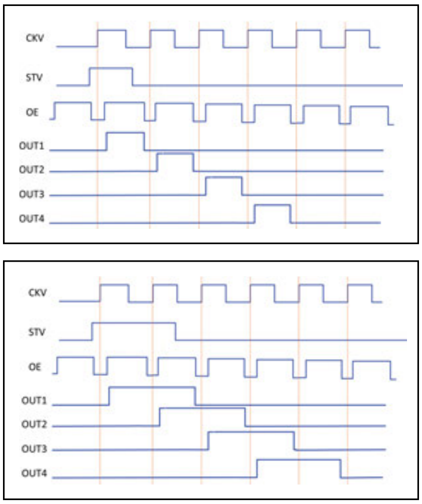


Fig. 7: On the top is the gate output charge for the waveform without pre-charging. On the bottom is the gate output charge with pre-charging. The duration of higher times should be extended. The longer charging time will overcome the lack of pixel voltage.

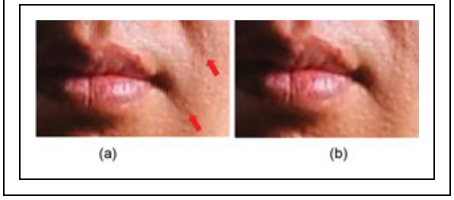


Fig. 8: The image at left (a) shows degradation due to error charging. The image at right (b) demonstrates that this has been eliminated through pre-charging modification.

UHD System Architecture

Recently, UHD systems have been in demand for high-resolution applications. Technical concerns include the bandwidth of the architecture and the data transmission of the display port. Essentially, this technology has not matured enough for commercial applications, and many system makers are still trying to integrate the hardware and software.

The major initial concerns for a 4K × 2K display are transmission line loading and image process bandwidth. Hence, a panel is usually divided into four units (1920 × 1080 by each unit) to overcome the difficulties of the panel, field-programmable gate array (FPGA), and graphics card, as shown in Fig. 9(a).

One common problem with the approach in Fig. 9(a) is that a block boundary can often be observed in the image along the center cross on the panel. The vertical boundary results from the time delay between the dual-DVI ports. The image is detected as a space shift along the center line. The horizontal boundary is caused by the signal difference of the data line. As mentioned above, the researchers adopted an FPGA (Stratix series from ALTERA) to synchronize the graphic card (from AMD) and the 110-in. panel as shown in Fig. 9(b). The cell is designed with double-sided gate/data driving to minimize the distortion caused by the RC delay. Under a specified algorithm in the FPGA, the resolution of each unit becomes 1920 × 2160, which is synchrocontrolled by opposite control boards, referred to as C/B-A and C/B-B. For commercial applications, the 110-in. 4K × 2K panel is also capable of 3-D functionality at 120 Hz.

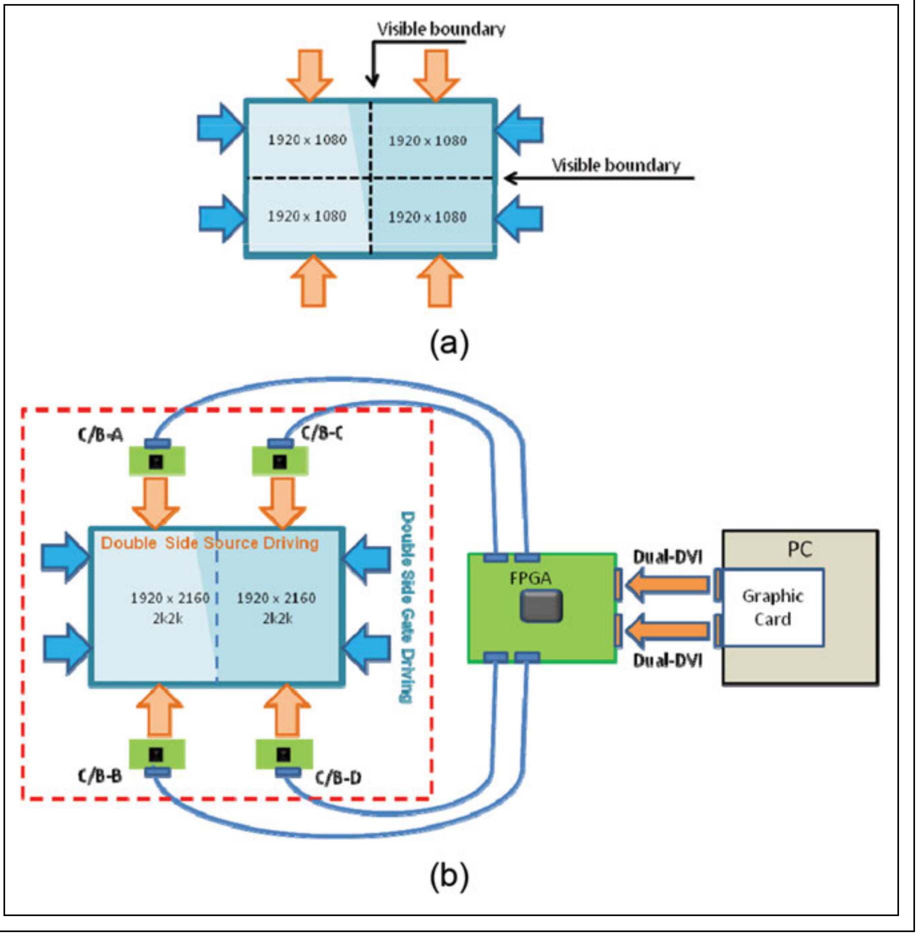


Fig. 9: Shown is (a) a diagram of a popular current panel driving concept and (b) the proposed alternate architecture for a UHD system.

Advanced Mura-Free Technology

Because the 110-in. panel size was larger than the photomask size on the Gen 8.5 production line, it was not possible to complete the production of the entire panel by using only one shot. Stitching-mask technology was therefore used in the development.

As is well known, controlling the uniformity of stitching areas is extremely difficult. Uniformity issues or mura often appear as a result of multiple time exposures at the shot stitching point.

In the early stages of the project, the shot mura could be easily seen on the panel. After the researchers fine-tuned the process parameters, the shot mura was greatly reduced. In Fig. 10, reduction of shot mura is apparent in the middle of the image on the right.

Besides process optimization as mentioned above, another solution uses algorithm adjustment in the graphics engine. This system compensation was also developed and adopted for mura suppression in critical areas. The adjustment flow, or "de-mura" function, is a software-based approach to fine-tuning the gray levels of the panel in the areas where there is mura that cannot otherwise be fixed as depicted in Fig. 10.

Based on this algorithm with FPGA coding, the panel demonstrated improved performance, as shown in Fig. 11.

Fig. 10: Shot mura reduction can be seen in the image at right (center of image).

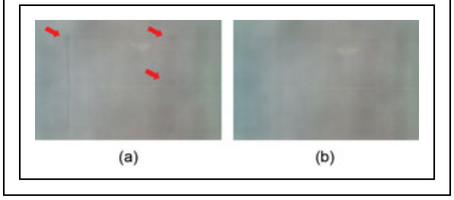


Fig. 11: Panel performance is depicted before (a) and after (b) algorithm adjustment.

3-D Stereoscopic Technology

3-D functionality was incorporated into the 110-in. LCD by using the L-R field-sequential method combined with active shutter glasses.

In order to prevent crosstalk, the designers had to adjust the turn-on sequence of the backlight to minimize the ratio of overlapping. Based on a direct-type LED backlight, they utilized a vertically scanning backlight consisting of 16 sections to improve the 3-D performance. After optimized sequences between the LED backlight, glasses and LCD, a crosstalk performance of 2.5% could be achieved with a comfortable visual quality. Changes in the detailed gray levels with a fixed right-eye observation and left-eye patterns resulted in good uniformity, as shown in Fig. 12.

Creating a 110-in. UHD LCD TV

Table 1 summarizes the main characteristics of the UHD LCD TV. A 110-in. panel with such high performance is a significant achievement. The brightness can exceed 1000 nits, the resolution is four times that of standard HD, and the TV has extremely realistic color reproduction. This large-size and high-resolution technology was made into a commercial product that is vailable now from several Chinese retailers. (The TV won the Society for Information Display's Display of the Year Silver Award for 2013.) CSOT hopes that it has created a completely new viewing experience that establishes a brilliant landmark for LCD-TV technology in particular.

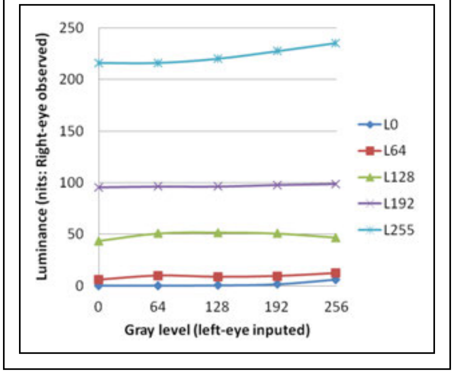


Fig. 12: 3-D luminance stability (crosstalk) is shown with gray-level switching.

Table 1: The TV's main parameters are shown.

Specification	Output
Diagonal screen	110"
Frame rate	120 Hz
Resolution	3840 x 2160 (R/G/B)
Brightness	1000 nits
Color coordinate	(0.275, 0.28)
Contrast	4200:1 (Static) 50000:1 (Dynamic)
Color saturation	92%
View angle	178°/178° (H/V)
Gray to gray	6.5 ms
3D crosstalk	2.5%

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Novel Emissive Projection Display Digitizes Glass Windows

An innovative emissive-projection-display (EPD) system consisting of a fully transparent fluorescent screen and a blue-light-emitting digital projector can be used for digital signage on the windows of buildings or vehicles. The screen can be applied to any window without obstructing the view through the glass.

by Ted X. Sun and Botao Cheng

SINCE the invention of the cathode-ray tube (CRT), efforts to further develop emissive display technology have been considerable and include field-emission displays (FEDs), plasma-display panelss (PDPs), and, recently, organic light-emitting diodes (OLEDs), among others. Compared with a backlit panel such as a liquid-crystal display (LCD) or a reflective display such as a microdisplay-based projection system, emissive displays may offer significant advantages, *e.g.*, large viewing angle, superior image quality, and color richness.

With the idea that a combination of emissive and projection technology might be used for a new type of digital-signage application, Sun Innovations developed an emissive-projection-display (EPD) system that uses fluorescent emission and projective excitation. This system can be readily applied to commercial advertising and digital signage; it can turn a glass window of any size or shape into a fully transparent digital sign with an unlimited viewing angle.

Fluorescent Emission and Light-Projective Excitation

The EPD system consists of a fully transparent fluorescent screen and a projector source that has a light output that operates in the blue-to-violet wavelength range.[1] The screen technology is based on down-conversion fluorescent nanomaterials, with high fluorescent quantum efficiency for brighter emissive images. Unlike conventional phosphor screens in CRT or plasma displays, this type of structureless emissive screen can be mass-produced economically through a roll-to-roll manufacturing process.

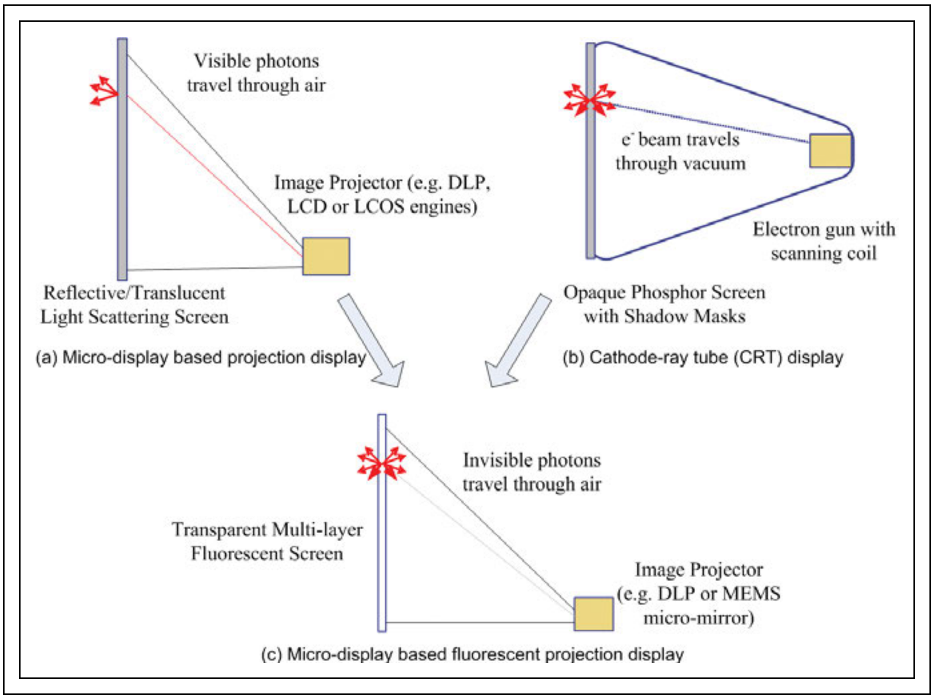

Fig. 1: (a) The conventional projection display, (b) the CRT, and (c) the projection-based fluorescent display are shown in simple schematic form as a basis for comparison.

Ted X. Sun and Botao Cheng are with Sun Innovations, Inc., in Fremont, California. Ted Sun can be reached at ted@sun-innovations.com.

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[Figure 1] compares EPD with a direct-view CRT and a conventional projection display. CRT technology, while obsolete due to volume and weight, offers an excellent basis for comparison due to its superior display qualities, including high image contrast and large viewing angles. In a conventional projection display [Fig. 1(a)], visible light passes through a micro-imager device (microdisplay) and is projected onto either a reflective (for front projection) or a scattering screen (for rear projection), which are also largely opaque. In a conventional CRT display [Fig. 1(b)], images are formed on an opaque phosphor screen that is excited by raster-scanned electrons in a vacuum tube. In Fig. 1(c), an EPD employs the projector as an excitation source for the fluorescent materials in the screen. Hence, it combines the superior image quality of an emissive display such as a CRT and the image scalability of projection with a fully transparent screen.

Novel Color-Rendering Approach in EPDs

As opposed to other emissive display technologies (*e.g.*, CRT or PDP), EPD employs a homogeneous, structureless fluorescent screen to eliminate the need for projector-to-screen alignment. Three layers of vertically stacked transparent fluorescent films can be addressed separately by excitation light in multiple discrete wavebands.[2] Figure 2 shows the working principle of the full-color EPD.

In order to display full-color images, the transparent fluorescent screen can be constructed by stacking films (*e.g.*, red, green, and blue fluorescent films) with distinctive absorption and emission characteristics. The projector encodes the original color image into the projected light at several excitation wavebands (three for full-color displays). On the screen, light of each waveband will excite its corresponding film and generate color emissions at visible wavebands (RGB). Each fluorescent layer absorbs its designated excitation light with high efficiency, but passes visible light and the excitation light of other wavebands. Since each fluorescent film is very thin, high-resolution and full-color images are synthesized in a direction perpendicular to the screen. Such a color-rendering method is completely different from a conventional full-color emissive display (*e.g.*, CRT, PDP, and OLED), which lays out the RGB pixels in the in-plane direction.

Recently, Sun Innovations developed materials that can be effectively excited in three separate wavebands in the range of 350–500 nm. Researchers at Sun measured the emission color of the fluorescent film. The blue film can be excited by a UV light in the range from 380 to 420 nm; the red film can be excited by light from 350 to 380 nm and the green film can be excited by light from 430 to 470 nm. The color coordinates on the CIE 1931 and CIE 1976 system are listed in Table 1. The dominant wavelength is 618 nm for the red, 438 nm for the blue, and 532 nm for the green.

The display color gamut of the fluorescent screen can achieve performance similar to that of conventional CRT displays. The quantum efficiencies (QEs) of fluorescent conversion among the RGB emission films vary in the range of 40–60%. Since the emissive materials on the screen have extremely fine particle sizes in nanometer ranges, the image resolution on the screen is principally dependent on the resolution of the projector. An EPD can be

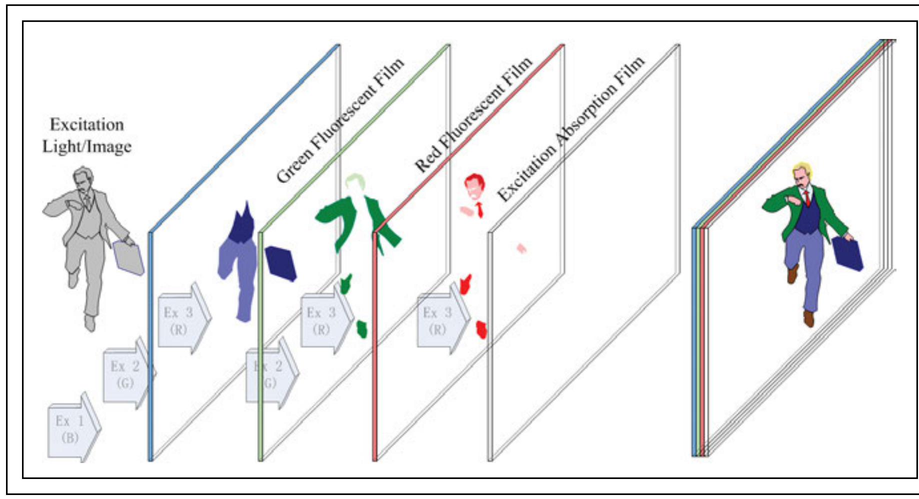

Fig. 2: *The full-color image-formation process takes place in multiple layers of transparent film. The excitation light has three wavebands; each excites a specific film/layer and generates visible emission at one of the RGB wavebands.*

Table 1: The color coordinates of EPD film are listed for red, green, and blue.

	x	y	u’	v’
R	0.678	0.322	0.492	0.526
G	0.378	0.594	0.161	0.57
B	0.148	0.132	0.138	0.277

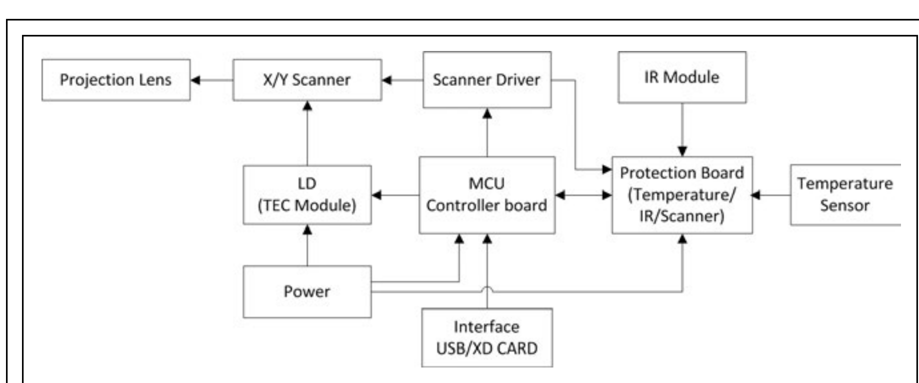

Fig. 3: *This possible system architecture for a laser projector uses a galvanometer scanner.*

readily implemented onto existing glass windows or windshields. It offers an extremely cost-competitive display solution, with scalable projection and a flat screen that can be economically manufactured roll-to-roll.

The Projector in an EPD

The EPD system requires the projector to output UV/blue light onto the fluorescent screen. There are several technical platforms for the design of the projector. For example, a galvanometer or MEMS scanner-based laser engine with a UV/blue-light laser could be used, or a DLP projector with a gas-discharge lamp, UV/blue-light LED, or laser.

Figure 3 shows a possible design architecture for a laser projector based on a galvanometer scanner. The projector consists of a controller board, protection board, LD optics module and LD driver, X/Y galvanometer and drivers, projection lens, power board, temperature sensor, IR detection, and I/O interface.

A microcontroller unit (MCU) embedded in the controller board serves as the master controller of the projector and provides the link between image display and input data read. There is a temperature sensor built into the system for monitoring the LD status. Galvanometer drivers will feed back scanner status to the MCU; if the scanners behave abnormally, the MCU will shut down the entire system to prevent a stationary laser beam emitted from the projector. An IR detection module is employed to execute the safety function, ensuring that the safety level of the laser display is Class 3a or less. Should someone or something accidentally enter the laser-projection space, the MCU will shut down the system and will not restart it until the person or obstacle leaves the projection area. Such IR sensors can define a "virtual" barrier on the solid angle of projection to prevent any accidental exposure of the laser image to humans or animals and making the projection system safe for operation in the public.

Results and Demonstration

Sun Innovations has developed and demonstrated a laser-vector scanning projector system named Line-Art, in combination with a full-color fluorescent screen (Fig. 4). Three laser diodes with dominant wavelengths of 375, 405, and 445 nm, respectively, were combined to create the projector's light source. The fully transparent display screen includes three different layers of fluorescent materials. As shown in Fig. 4, the resulting emissive image is easily visible in normal ambient room light. The viewing angle of the emissive surface is unlimited. The screen is fully transparent but presents a slight green cast due to the visible-light excitation of the green screen.

Instead of a laser projector with a galvanometer scanner, a DLP-based projector with a gas-discharge lamp as a light source can be used.[3] In Fig. 5, a commercial DLP projector with a UHP lamp has been modified to output light in the approximate wavelength range of 360–410 nm in order to excite a single blue or white emission from the screen. The estimated UV intensity at the screen surface is about 0.3 mW/cm^2. A water-clear, single, blue fluorescent film was utilized in this example. A fully transparent white, red, and dual (red/blue) screen, all without body color and haze, are other options.

Sun has also recently developed a projector based on a DLP scanner and LED or laser sources. Solid-state sources such as high-power LEDs and lasers have excellent power and a spectrum matching the excitation of the emissive materials of the screen. They are also smaller, consume less energy, and offer significantly improved optical efficiency and reliability (with a lifetime >10,000 hours).

Other "Transparent" Digital Display Technologies

There are a number of other display technologies in the commercial market that claim to be transparent, including a TFT-LCD-based transparent "display box," conventional head-up displays (HUDs), transparent OLEDs, and holographic projection screens (Fig. 6). The display box places an LCD module with 15–20% transparency in front of a bright light-box assembly. It is best used in an enclosure such as a vending machine; it does not perform as well on an open glass window without a strong and stable backlight. A conventional HUD is a virtual image display, using a glass window or windshield as a transflective "mirror" for digital projection. A HUD has an extremely limited viewing angle,

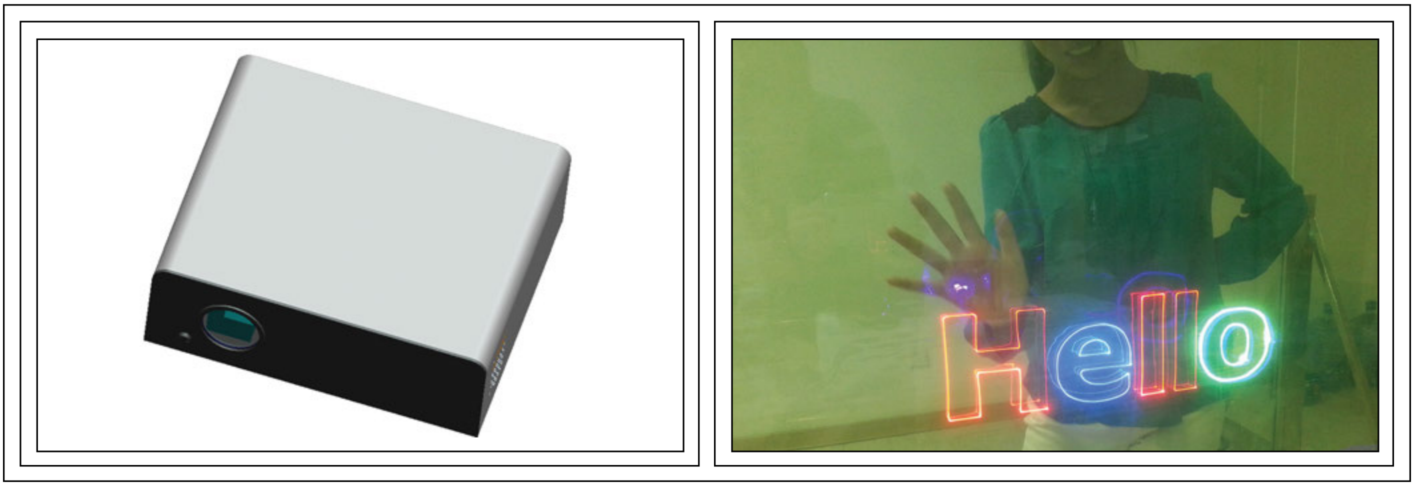

***Fig. 4:** The Line-Art projector based on a galvanometer scanner (left) is used in a full-color (RGB) EPD display system that uses a clear fluorescent multi-color screen (right).*

limited image size, and is typically used in vehicles only for the driver. Both transparent OLED and holographic screens are only partially transparent, with significant haze and poor image contrast in well-lit environments.

Advantages of EPD

Compared with the other commercially available transparent display technologies, the EPD offers significant advantages for a digital-signage solution on glass windows or clear panels:

1. EPD offers an unlimited viewing angle due to the isotropic nature of the fluorescent emission. The image is equally bright on both sides of the transparent projection screen.
2. EPD presents a water-clear screen whether an image is being displayed or not. The screen has virtually no haze; the visible-light transmission is around 90% and can reach 95% with anti-reflective coating. It is a true see-through display system for either front or rear projection.
3. The projected image does not go through the emissive screen; there is negligible physical penetration for projected lights, unlike a holographic projection screen.
4. Like a projection display, the EPD screen has no pixel structure. The EPD screen can be manufactured roll-to-roll.
5. As with a projection system, the display image size is scalable.
6. Like an emissive display (*e.g.*, PDP or CRT), the image quality of an EPD is excellent, with a good color gamut and image properties that are largely independent of viewing angle.
7. It is versatile. In addition to a fully transparent display on a window, it can be applied to a black substrate[4] to create a front-projection display with superior image contrast in bright ambient light, at lower projection power.

Fig. 5: *The display shown uses a transparent and water-clear EPD based on DLP projection with a UHP lamp source.*

Applications

The EPD system is able to turn any clear surface into an emissive digital display. It allows audiences to experience a vivid, high-definition image while clearly seeing through the transparent screen. This enables a wide variety of potential applications for displaying digital information.

Applications in the digital-signage market include storefront windows and other in-store advertising displays; shopping malls; window glass in airports, train, subway stations, and other high-traffic public areas; large advertising displays on the glass walls of buildings; HUDs for various vehicles; and much more.

An example of EPD technology in use is the Line-Art projection system (shown in Fig 4), which displays messages and animations on storefront windows using a scanning laser projector. The system enables text and pictures to appear to float in air with no apparent display boundary. They appear to float in air like an animated neon sign. This system offers commercial brands a fresh, exciting

Fig. 6: *Shown above are several transparent display technologies and their applications.*

Fig. 7: EPD technology (left) on the window of a home-furnishings store in the San Francisco Bay Area enhances a product launch; at right, EPD enables a dynamic transparent display showcase for jewelry.

Fig. 8: The EPD product launch at World-Expo 2010 (Shanghai) featured six red Chinese words on the glass.

look and is designed to maximize the customer experience and attract foot traffic to increase sales. Figure 7 shows one frame of a continuous animation displayed on the window glass of a furniture store in the San Francisco Bay Area.

As an example of an in-store application, Fig. 7 demonstrates a digital showcase for jewelry or watches. The EPD projector is beneath the products and projects onto transparent fluorescent film that is mounted on the showcase's cover glass. In this way, the showcase has been turned into a novel transparent digital display without affecting the viewing of the articles inside. Furthermore, if combined with an interactive module such as a transparent touch film, the digital display showcase could enable people to search for product information on the cover glass of the product cabinets in an interactive fashion.

EPD systems have also been applied successfully in various exhibitions. The window glass of a booth or hall can display creative, dynamic, and see-though signage, including traffic-stopping commercials. Figure 8 shows an example: the EPD product launch at World-Expo 2010 (Shanghai, China).

The Line-Art-based EPD system can also potentially be used to create large advertising displays on the glass curtain walls of modern buildings. The unique display screen presents the projected image, while being highly transparent to visible light. Figure 9 is a computer rendering of such a display on the glass curtain wall of a hotel building. Up to 10,000 sq. ft. of the digital display can be produced with a screen and a high-powered laser projector for glass-wall laser displays at night.

For such an application, a high-powered laser projector would be placed on either side of the glass screen for front or rear projection. An additional UV layer would block the laser light from penetrating the screen and reaching viewers. Since the screen is water clear, the windows continue to provide natural light and an uninterrupted view. Any advertising displayed by the projector would be viewable from miles away at night. Such a display would be easier to install and disassemble and more cost-effective than a large LED sign, without affecting the aesthetics of the building or the functioning of the windows.

As a final example of a signage application, the full transparency and large viewing angle of the EPD system make it ideal for displaying information on the windshields or other windows of cars, trucks, trains, buses, aircraft, and other vehicles. The EPD system could function as a novel HUD and could utilize any part of a windshield as the display screen.

A problem facing almost all projection displays in such an application is the degeneration of image quality due to intense sunlight. In order to reduce the influence of sunlight and improve the contrast, the display screen can be used in conjunction with a tinted film, which basically eliminates the overlapping excitation wavelengths from sunlight. Figure 10 shows a clear 50-in.-diagonal image on glass facing direct sunlight. This large HUD product with unlimited viewing angles has HDMI and VGA interfaces and is ready to be implemented in many commercial vehicles (Fig. 11).

A Clear Future for Novel Applications

Sun Innovations has spent the past 6 years developing a novel transparent emissive projection display that combines the high quality of an emissive display with the scalability of digital projection. It enables the display of digital images on windows or windshields without affecting the view or the transmission

Fig. 9: *This artist's rendering shows how a high-powered EPD system could be applied as a very large-scale display on the glass-curtain wall of a commercial building at night.*

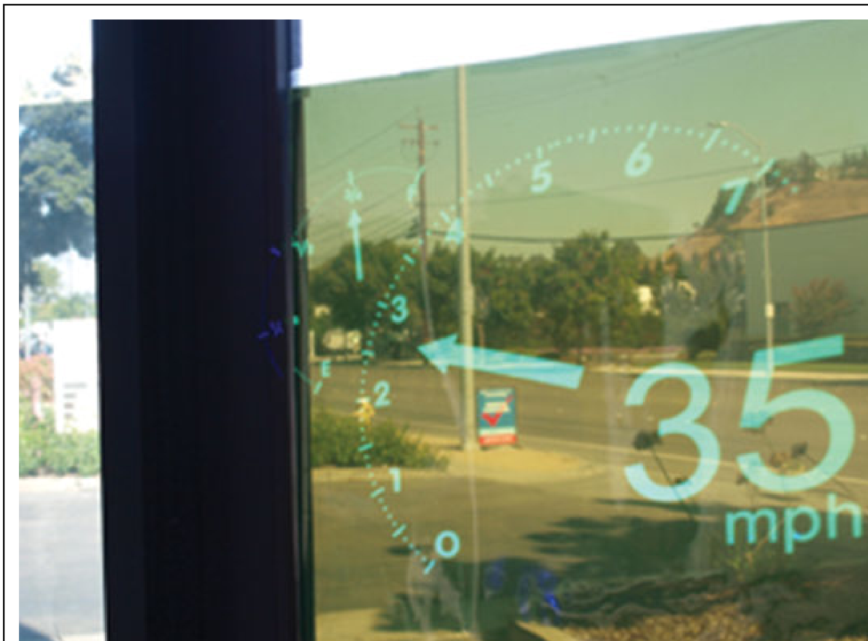

Fig. 10: *An EPD screen with a transparent green emissive film and tinted film is applied on a window facing direct sunlight.*

Fig. 11: *The current EPD HUD product as shown in Fig. 10 can be readily implemented onto various vehicle windshields, including (clockwise) cars, tractors, trucks, and ships.*

of light through the glass. This innovative new display system has many commercial applications where information or advertising needs to be presented on glass, without affecting the view through the glass.

While the technology is still in development, multiple products have been developed over the past few years, including a laser animation display based on scanning laser projectors and a transparent information display (including HUD) on glass. The superior image quality, unlimited viewing angles, best-of-class clarity, economy, and ease of implementation make the EPD the potential technology of choice to digitize the glass of the future.

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Public Displays in Europe (and elsewhere)

Public displays have been slow to make inroads in many European markets, although there have been pockets of progress. It is difficult to generalize about the digital-signage market in Europe, let alone the Middle East and Africa because every country is a market unto itself, with unique economic, cultural, and regulatory requirements.

by Bob Raikes

PUBLIC DISPLAYS are a fascinating topic for those of us who love to see how markets work. These displays can be broadly divided into two groups. There are those that "inform," such as flight or train displays. These "inform" displays have a cost for a purpose. "Promote" displays are those that may be partly or wholly funded by advertisers – the kind of display that might be seen in an airport terminal or a shopping mall displaying products or services for sale rather than time tables.

The European market is something of an enigma. At one level, it is considered a single market. However, the region has some of the countries with the highest incomes per capita, but also big countries with incomes that would be normal for a developing region. From Norway at $47,545 per capita, the region goes down to Albania at $4,090 per capita for 2012. This means a huge difference in the way that economies and advertising work.

Europe also has a wide range of cultures, which makes it much harder to develop advertising campaigns that are effective across the whole region. As soon as you put a person into a scene in an advertisement, it can evoke a wide variety of different reactions in different countries. In some regions, for example, showing computers being used in an office can lead to a surprising range of views on, for example, how and whether women are included in the scene. Of course, the sheer number of languages makes pan-European advertising and media more challenging as well.

__Bob Raikes__ is an experienced manager and analyst and a specialist in the European display market. Since 1994, he has published the weekly Display Monitor *newsletter, the journal of record for the display industry. His company, Meko, researches and publishes data on the European display market. He can be reached at bobr@meko.co.uk.*

Markets

Retailers are also broadly national. Although there are companies that have some success in a number of markets (*e.g.*, Carrefour in grocery and Media Markt/Saturn in electronics), even those companies tend to work a bit differently in the different regions, as buying behaviors vary. Retail is the biggest market for digital signage, so the decisions in this segment have a big influence on the rest of the industry. Some of the electrical retailers such as MediaMarkt simply make use of the low-cost TVs that they sell as digital signs in their stores to draw attention to promotions and offers. High-end fashion retailers in London, Paris, Germany, or Milan often invest heavily in digital signage of different kinds to make their stores more dynamic and more easily changeable according to the season.

Projects and display networks in other markets for digital signage, such as banking/financial services and transport, are also usually based on national boundaries. Digital out-of-home (DOOH) advertising is also a very national market because of different views on how out-of-home advertising should be used and because of different local planning restrictions and local and national government regulations. For example, the UK has a good number of large light-emitting-diode (LED) displays and video walls that are deliberately placed next to the busiest roads to catch attention, while in Sweden temporary licences for roadside signs were withdrawn as a result of research on driver distraction.

In sum total, the public-display market for Europe, whether digital signage or DOOH, is fundamentally a collection of national markets rather than one regional market.

Scale, Scale, Scale

The market, then, is very fragmented and this means that digital-signage projects are more difficult to develop. This is not connected to displays or display-related technology, but because in any application like this, the development of content is one of the most significant cost elements. When that content needs to be delivered in multiple languages, or with different visuals because of varied cultural norms, the costs and complications go up. And as costs go up, the viability of networks, especially those funded by advertising, come under pressure. Although infrastructure costs are a factor in roll-outs, it is the cost of creating and maintaining high-quality content that is the biggest challenge.

When the content costs are divided over smaller populations than those of China, the

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U.S., or Japan, the cost may simply be too much to support digital-signage projects. There are many that go through a "pilot" stage, but do not get to a full roll-out. A proportion of projects get as far as roll-out, but some commercial networks, hoping to raise revenue by selling advertising, have already been closed and removed because of the difficulty of making a profit. At this stage of the market, that's a pity. In Germany alone, the networks PosterTV, Cityboomer, and CityUp have closed down. Cityboomer was a network that was set up to provide digital-signage space funded by advertising, but went from IPO to bankruptcy in less than 2 years.

At the 7th OVAB Digital Signage Conference in Munich, in September 2013, it was pointed out that a number of global multinationals that have tried to establish businesses in the region have failed to obtain scale and growth in their businesses. Part of the reason is that so much of the installation and support needs to be tailored to the local geography and that means a lot of input from partners in each country. (Interestingly, although billed as a European event, the audience was dominated by players from the German-speaking countries of Germany, Austria, and Switzerland)

NEC is developing its Vukunet platform, which it calls a "Universal Digital Place-Based Ad Server," to try to make it easier for European advertisers to identify networks that they can use for messaging, and as a way to deliver the content for play-out quickly and easily. Vukunet, which launched in the U.S. a couple of years ago, is an automated ad delivery platform for digital out-of-home media that is designed to allow owners of screen networks located in public venues to earn revenue by showing advertisements. Vukunet claims that its web-based platform is the first universal inventory management, ad delivery, billing and payment, and reporting system to work across hundreds of operating networks. The displays themselves are primarily large liquid-crystal displays (LCDs) used singly or in groups as video walls.

Geographic Focus

The digital-signage market in Europe is strongly centered on Western Europe. Although the UK was the earliest market to develop, with a strong position in the largest market 7 or 8 years ago, the growth in that country has been somewhat more limited in recent years (although there was a good boost to installations and investment around the very successful Olympics in 2012). CBS Outdoor and Clear Channel are two of the major players.

Germany became the largest market at the end of 2008 and has kept that position, although very close to the UK in volume when it comes to displays. The transport industry in Germany has been very strong in adopting and investing in digital signage. Ströer is a large media company that has been influential in developing the German market.

France has grown steadily year on year as a market for digital signage and saw only a slight slow-down after the financial crisis in 2008. The European Soccer Championships in 2016, which will take place in 10 stadiums throughout France, should help with investments in preparation for the tournament. JC Decaux, based in France, is a strong global player in the conventional-signage business and has also been heavily involved in digital signage.

The Nordics have been developing well over recent years, and Russia, after a number of years of limited development, has seen very good growth in the last few years and most recently with the build up to the Sochi Winter Olympics. Outside the West, the Nordics, and Russia, the digital-signage market has been much slower to develop. The countries along the Mediterranean have been slow for the last several years, although there are interesting projects here and there, such as a kiosk-type display in Milan's transport system that was developed by M-Cube with software supplier Scala using Samsung displays (Fig. 1).

Brands

Most of the display brands that are active in digital signage in Europe are the major global brands such as Samsung, NEC, and LG. Samsung has a very dominant position currently and both that company and LG, which is the third largest supplier, have subsidiaries in all the major countries as well as regional companies to allow a lot of local contact and management. NEC is the second largest brand and has a strong history of working closely with its resellers on projects and integration.

There are a number of small vendors locally, with most of them concentrating on national markets. However, the region also has specialist suppliers such as Conrac, which is a significant global brand in the Flight Information Display (FID) market.

Hardware

All of the brands supply global digital-signage products, as, unlike TV, there is no need to deal with regional tuner and broadcast issues. Europe was an early adopter of LCDs, and plasma-display panels (PDPs) have been much less important than in some markets, such as the U.S. LCD volume surpassed that of PDP volume in the middle of 2006, and PDP volume dropped to less than 5% of the market by 2011. Smaller stores still like to use 32-in. sets, which maintain a share of 15% or so, but 40–47-in. sets make up 60–65% of the market. 55-in. sets are the ones that have the best growth at the moment. In Eastern and Southern Europe, commercial TVs are quite regularly used for digital signage where professional-quality displays might be used in the main economies.

Hard-to-Grow Public-Display Sales

One of the frustrating factors for the major display brands is that within a project the cost of the hardware, including the display itself, is

Fig. 1: This interactive kiosk-type LCD is connected to Milan's transport system and offers a touch interface for users to find information on train schedules, weather, and events.

often only a relatively small portion of the total cost. Even within the hardware budget, only a portion of this goes to the display, with costs associated with installation, mounting, cabling, networks, media players, and warranty and service. This makes it quite difficult for companies that are used to driving volume by reducing prices, as has been the practice in the TV and monitor markets.

Channels

The major multinational distributors such as Ingram Micro and TechData have interests in this market; Ingram has a specialist group at the European level and TechData owns TDMaverick, a specialist subsidiary for audio-visual products. However, most A/V distributors are organized on a national basis. That means that brands need to support the distributors with national representation and support.

Software and Architectures

The Out-of-Home Video Advertising Bureau (OVAB) Europe is a trade association that is working to develop standards and has published standards for audience measurement and service levels. These standards should help the development of commercial networks that can deliver advertisements to consumers, which should drive revenue growth from advertising, a major challenge for the market. One of the challenges on a global level is that the digital-signage market has too many software packages. Although there are larger companies such as Scala, it has been suggested that there may be as many as 700 different packages available in Europe! That causes real problems in support and development and leads to complications in developing multi-national content. Software developers that want to supply products through the full area of the region have to make decisions not only about the languages that their software will support on the displays, but how many languages can be used within the software to develop the content.

This year, Samsung was the first to launch new digital-signage products based on adding "Smart TV" systems-on-chips (SoCs) to its digital-signage products. These are relatively light clients, but can be used in conjunction with software from Scala, Signagelive, and others. The company has been developing tools to help smaller resellers sell simple solutions to small- and medium-sized enterprises (SMEs). At present, it is not clear that this strategy will gain traction, but it's an innovative and positive approach to expanding the market for digital signage, especially in SMEs.

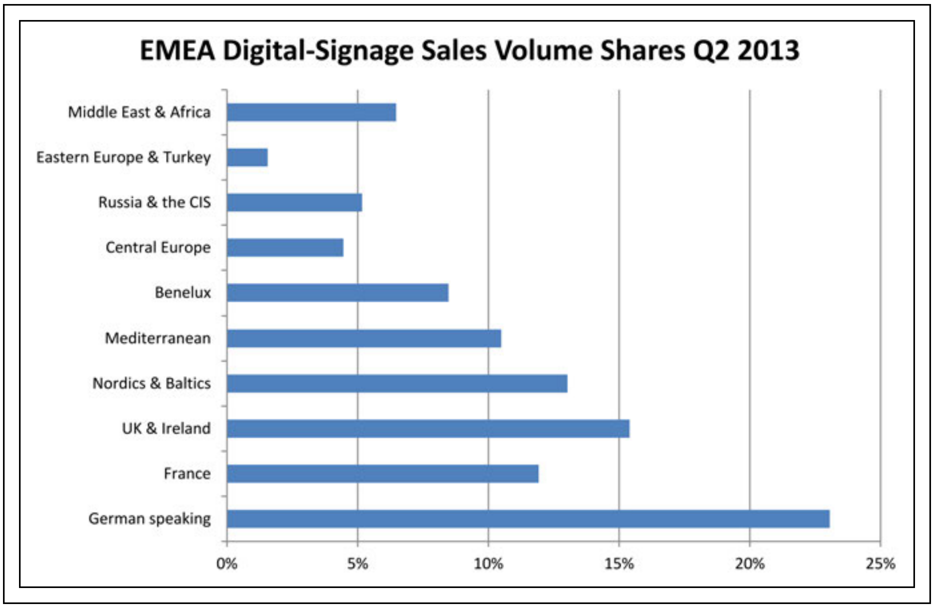

Fig. 2: Digital-signage sales volumes by relative percentages show that German-speaking countries, the UK and Ireland, and the Nordics are currently the heaviest users. Source: Meko, Ltd.

Regulations

There are a number of extra pressures on the market in Europe, especially in the countries in the European Union. One of the simple ones is the EU Directive 90/269/EEC – which covers the manual handling of loads and effectively limits the maximum weight that can be lifted by a single individual. Environmental issues are very important in every part of the European market. The French government, among others, has environmental regulations (the Grenelle II law which came into force in July 2012) that limit advertising using digital signs.

Middle East and Africa

The Middle East and Africa have many of the challenges that beset the market in Europe in culture, language, and content. In addition, the region has some particular current problems. In the Middle East, one of the most important economies is Egypt and the political situation in that area is causing a lot of multinational consumer companies to cut their advertising budgets. The effect of this drop in advertising revenue is having a "knock-on" effect on the entire region and impacting digital signage and DOOH revenues. Nevertheless, the market in EMEA is on a steady rise. Meko divides the EMEA geography into 10 regions. In Q2 2013, the MEA market represented 8% of the total market (compared to 7% for the small countries of Benelux) (Fig. 2).

An interesting project in Africa is Solar Powered Advanced Rural Communication (Sparc). In much of rural Africa, there is little TV because of the lack of electrical power. However, phones and smartphones have very high penetration.

In the Sparc project, digital-signage kiosks are being set up using solar power (Fig. 3). They communicate with the "cloud" by using mobile-phone technology, which is widely available (it's just GPRS, but that, combined with satellite-sourced video, provides enough data for simple advertising). The terminals were developed with Amscreen, which claims to be Europe's largest DOOH network (and has display networks in the UK, Germany, Poland, Switzerland, UAE, Oman, Kenya, Angola, and South Africa, totaling around 6,000 displays).

The Sparc system allows advertisers to create simple local advertising at very low cost and with detailed control of where the

Fig. 3: Solar-powered digital-signage kiosks such as these are providing Internet connectivity (and digital advertising) to areas of rural Africa that are largely without electricity.

content plays (down to individual kiosk level). Few individual consumers can afford newspapers, and with little TV advertising this kind of advertising can have a significant impact on small businesses and local economies as well as for national brands that cannot use TV.

A Challenging Market

There are opportunities in the EMEA digital-signage market, with steady growth. However, entering the market with an aim of getting a significant share needs a commitment to developing business in multiple regions over a period of time. Products need to be built to professional standards and for long life as buyers are very demanding. It's critical to develop relationships with the channel partners and key integrators in multiple countries to support the scale needed to be an active player over the long term. ■

The Display Business Environment in Europe: Together but Different

This article, the second in an occasional series that looks at business environments around the world, describes historical, economic, and other conditions that affect display companies doing business in Europe.

by Jenny Donelan

THE first thing to understand about the business environment for display companies in Europe is that there is not one environment, but many. While every region of the world has its internal differences, these differences are especially pronounced in Europe, where countries have their own laws, languages, and customs that in some cases go back more than a thousand years. The 28-member European Union has created a measure of political and economic uniformity, with the Euro its most visible result, but the EU has not homogenized Europe. The EU has also been losing favor in many member countries.

That said, the European business "environment" does have some common characteristics that distinguish it from other regions, such as Asia and North America. These include a proud history of scientific research and discovery that continues to this day, a stronger manufacturing presence than might be guessed, and a consumer culture that favors long-term relationships over the next new thing. Europe is slowly and steadily recovering from a poor economy, although many of the southern nations are not yet in anything resembling recovery mode.

In terms of environmental issues, Europe, and specifically the European Union, has tended to promote policies more proactively than is the case in North America and Asia. Restrictions on incandescent bulbs began in Europe, by EU directive, in 2009, and they were banned outright for home use in 2012.[1] (In the U.S., the bulbs are being phased out as well, but far more slowly.) The EU has a non-binding objective to cut energy use to levels 20% below business-as-usual projections by 2020 and has, in addition to the light-bulb laws, instituted numerous measures pertaining to recycling, emissions levels, and water quality.[2,3] Across the region, regulations and standards tend to be set at an EU level, which makes navigating any hurdles somewhat more predictable than would have been the case pre-EU. That said, the Nordic nations and the German-speaking countries tend to be the most sensitive to environmental issues – they are the "California" of the EU.

Jenny Donelan is the Managing Editor of Information Display *magazine. She can be reached at jdonelan@pcm411.com.*

Material Foundations

Many core display discoveries have been made in Europe. This year marks the 125th anniversary of the discovery of cholesteric liquid crystals, a joint effort between Austrian chemist Friedrich Reinitzer and German physicist Otto Lehmann.[4] Years later, George Gray's research team at the University of Hull in the UK made major research contributions that led to liquid crystals being usable for displays.[5]

Materials continue to be an area of strength in this region. The Fraunhofer Institutes in Germany currently contribute significant research to OLED, LED, and liquid-crystal technology, and Novaled is a powerhouse in OLEDs, with an emphasis on lighting. Germany's Merck, founded in 1668, is the world's largest producer of liquid crystals. Another German firm, OSRAM, a mere 100 years old, is a major player in LEDs.

Europe is also home to a number of equipment companies, including Germany's Aixtron, a maker of deposition systems; France's ELDIM, which makes cameras and measurement equipment; and Sweden's Micronic Mydata, which manufactures pattern generators and surface-mount technology.

Measurement instrumentation has been a European specialty for years; in addition to ELDIM, there are Instrument Systems, LMT Lichtmesstechnik Berlin GmbH, X-Rite, and BYK-Gardner, all located in Germany. (For an update on recent consolidations in the German instrumentation industry, see the May/June Industry News.) Much of the experimental work is performed by the companies. "There is not much R&D at universi-

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[5]http://www.hull.ac.uk/chemistry/research/LCgroup/history.htm

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ties related to instrumentation for display applications," says Richard Distl, a Managing Director of Instrument Systems, adding that his company puts a lot of effort into R&D on its own, with current projects including 2-D color measurement for homogeneity analyses of displays.

Well-established display system integrators in this region include Barco (Belgium; projectors and digital signage), Conrac (Germany; industrial, marine, and ruggedized displays), and GDS (Italy; digital signage and more), which compete globally in their respective markets. The French-Italian semiconductor company ST Microelectronics (with headquarters in Geneva) does a reportedly hefty business making the MEMs gyroscopes and accelerometers for the iPhones 4 and 5.[6] When it comes to making the products that end users love to buy, Finland's Nokia is probably the prime example. This 150-year-old company began as a paper mill and transformed its portfolio over the years to include electronics, including the hugely successful Lumia smartphones. The company's smartphone business was recently purchased by Microsoft.

Such acquisitions are a familiar story in Europe. According to market analyst Bob Raikes of Meko, "Once out of the R&D phase, [European] companies often end up being bought by the global display makers." As examples, he offers Liquavista (a Dutch company originally spun off from Philips) being acquired by Samsung (and later by Amazon), Germany's Novaled by Samsung and Cheil Industries, the UK's Cambridge Display Technology by Sumitomo in 2007, and Scotland's Forth Dimension (a maker of near-to-eye technology) to Kopin in 2011.

It should be noted that acquisitions do not always mean that operations cease in the home country. Nokia, for example, will retain many operations in Finland post-acquisition. Instrument Systems continues to operate in Germany since being acquired by Konica Minolta, as does Cambridge Display Technology in Cambridgeshire, UK, since its acquisition.

Continental Manufacturing

Europe does not spring to mind as a hotbed of manufacturing. Common associations for this region tend to be more along the lines of limited land for building, strict environmental regulations, and some of the world's highest paid workers. But, in fact, manufacturing in Europe still makes sense in many markets, says Raikes, pointing out that being close to the people who are buying the goods and having access to the latest technology and skilled workers can offset the cost savings of assembling in Asia. "There are also tariff barriers," he says. "TVs imported to Europe from Asia carry a 14% duty, unless they come from Korea, in which case a free-trade deal with the EU will bring the duty down to 0% by 2016."

One of Europe's answers to low-cost manufacturing, a sort of "onshore/offshore" movement, has been Eastern Europe. A minor manufacturing boom began there about 10 years ago, notes Raikes, with most of the factories geographically arranged in a ring that is referred to as "JOG," for "Just Outside Germany." To paraphrase writer Mark Morley in his Driving B2B blog from October of last year, Eastern Europe is an appealing location for manufacturers for several reasons. First, many of its countries – Hungary, the Czech Republic, Slovakia, and Slovenia – border Western Europe. Second, costs for both services and labor tend to be low, and many local governments are eager to offer incentives to incoming manufacturers. The transportation infrastructure, in terms of roads and waterways, is in place.[7] Last but not least, some countries, Hungary and the Czech Republic most notably, have a long tradition of precision manufacturing as well as scientific innovation. Hungary, in particular, already has manufacturing momentum, and companies from all over the world, such as Foxconn, Denso, Philips, and others have manufacturing operations there.[7]

Manufacturing does exist outside Eastern Europe as well. Nokia has operations in Finland; Barco has factories in Belgium, *etc.* There is a certain eagerness on the part of many countries to renew economic opportunity in the form of homeland manufacturing. The UK's Raspberry Pi is a poster child of sorts. This credit-card-sized computer, designed to plug into a TV and keyboard and enable word processing, spread sheets, *etc.*, was created by a not-for-profit group primarily to enable accessible computing for kids on a global basis. The first Pis were made in China in 2011, but operations have been "resourced" to a Sony factory in Wales. In October 2013, UK production exceeded 1 million boards, a piece of news that was widely and fondly reported around the world.[8]

Retail Conservatism

Electronics buyers in Europe like good design and good value and are unlikely to replace electronics as rapidly as do their North American and Asian counterparts. Says Raikes: "They are happy to pay for good products as long as they are likely to last – think of the success of German cars!" Display companies looking to expand into Europe, he notes, should be aware that buyers tend to be less tolerant of product failure and may require a higher level of warranty and service than North Americans.

Another factor to consider is that for European electronics consumers, bigger is not always better. Homes in Europe tend to be more compact than in North America and apartments are more prevalent, so the very largest TVs may simply not be practical here. It is worth noting that 3-D did not induce Europeans to buy new TVs any more readily than it did North Americans, so it will be interesting to see how UHD will fare. There is some promising movement. In January of this year, Eutelsat Communications launched the first dedicated demonstration UHD channel in Europe.[9] Reporter (and *Information Display* contributing editor) Steve Sechrist wrote in a *Display Daily* blog that "4K content and delivery, long considered the gating issue for mainstream UHD adoption, is developing at a fast pace in Europe as evidenced by the recent IFA in Berlin." He noted new UHD satellite and cable signal announcements, Internet delivery of UHD signals, and new SOC chips and STBs designed to enable 4K content delivery.[10] If the quality and value are there, Europe can be very forward-thinking, Raikes notes, pointing out the previous successes of 3G and mobile technology in general.

[6] http://www.edn.com/design/consumer/ 4396870/Teardown—Inside-the-Apple-iPhone-5

[7] "Why Eastern Europe Could Benefit from the 'Perfect Storm' Currently Brewing in the High Tech Industry," by Mark Morley: http://www.gxsblogs.com/morleym/2012/10/why-eastern-europe-could-benefit-from-the-perfect-storm-currently-brewing-in-the-high-tech-industry.html

[8] www.raspberrypi.org.shtml

[9] http://news.softpedia.com/news/Europe-Welcomes-the-First-4K-UHD-TV-Channel-320926.shtml

[10] http://www.display-central.com/free-news/display-daily/in-eu-4k-content-delivery-gets-ready-for-prime-time/

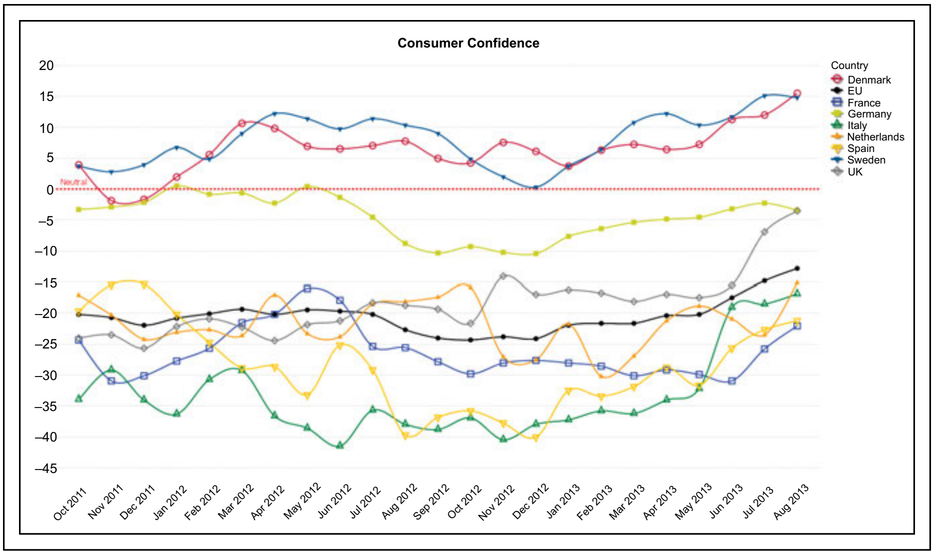

***Fig. 1:** Consumer confidence is higher in Sweden and Denmark than in the other depicted nations, but almost all countries show an upward trend in 2013. Source: European Commission/ Meko.*

In terms of consumer confidence, this is recovering, but slowly (Fig. 1). Southern Europe continues to be in an economic slump. Greece and Spain had unemployment over 25% at press time, Raikes says, and France, Italy, and Poland were all above 10%. Northern Europe is faring better. "Germany, in particular, is doing well," Distl says. "Capital equipment industry and machinery is very healthy and this is driven by export sales, mainly." A few countries in Europe are struggling, he adds, but even outside Germany, the overall outlook is more positive than negative. "I see this when talking to customers and others," he says.

Another factor to note is that retailers tend to be national rather than regional. Key electronics retailers are MediaMarkt/Saturn in Germany and Benelux, Dixons in the UK, and Darty in France. This is a reflection of both local tariffs and buyer tradition. Global retailers such as Best Buy have not been successful in Europe, with the exception of Amazon, says Raikes.

Lofty Goals

Because Europeans – at least some Europeans – have money to spend, and there is a long tradition of technical excellence at both the commercial and the university level, Europe can look very tempting to a display company looking to sell or make displays there. Even though total display sales have dropped somewhat since 2010, the EMEA market for TVs, desktop monitors, and digital signage still tops 100 million units for 2013, according to data from Meko. But Raikes likes to compare Europe to the Alps – from a distance, they are beautiful and compelling, but once you are in them, you face harsh conditions. Mistakes are easy to make unless you know the territory quite well. If you are willing to make the effort to learn, however, and play according to the local rules, you may find it a rewarding landscape.

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The Ins and Outs of Venture Capital

Raising venture capital funds is an exciting and often necessary step for your start-up. It's also fraught with potential pitfalls that could cost you your company. The third article in our venture capital series examines key terms used in investment deals and offers valuable insights into the venture capital business model.

by Helge Seetzen

THUS FAR in this Venture Capital series, we have covered the fundamental three "P's" of building a technology venture: people, product, and pesos. But the last often comes with a bit more paperwork than the first two. In this article, we will look at common structures for venture capital deals, the motivations of the players involved in venture funding, and some of the pitfalls that could destroy your company (or your stake in it) if you are not careful.

At the highest level, an investment deal is an exchange of ownership for money. The previous article in this series, "Raising Capital for Technology Ventures" in the September/October 2013 issue, discussed some of the valuation mechanics, but as a reminder, an investment deal sets the amount of capital to be invested and the pre-investment valuation for your company (often called "pre-money"). The sum of the two gives the post-money valuation of the company and effectively the post-money ownership. For example, a pre-money valuation of $4 million with an investment of $2 million means that the new investors will own one-third of the company after closing. Sounds simple, right? If only it weren't for those pesky terms …

Helge Seetzen *is CEO of TandemLaunch Technologies, a Quebec-based company that commercializes early-stage technologies from universities for its partners at major consumer electronic brands. He also co-founded Sunnybrook Technologies and later BrightSide Technologies to commercialize display technologies developed at the University of British Columbia. He has published over 20 articles and holds 30 patents with an additional 30 pending U.S. applications. He has a Ph.D. in interdisciplinary imaging technology (physics and computer science) from the University of British Columbia.*

Entire books have been written about investment terms, but we will try to cover at least some of the key ones, as well as some of the tricks used in the inherently asymmetric game of term sheet negotiation.[1] To start with, most investments these days are made in exchange for so-called preferred shares. As the name implies, these have some characteristics that make them preferable to common shares, which are generally the type of share capital held by founders, employees, and inventors.[2] Those preferences can vary greatly, but we will cover at least some of the more common types:

Straight vs. Convertible: Later-stage venture investments are almost always straight purchases of shares for money. But early on it is often difficult to accurately value a company. Convertible debentures, a form of debt that later converts into shares, are a way to solve this problem by deferring the valuation discussion to the next round of financing. The money invested through the convertible debenture is available to the company immediately, but the investors only receive their shares when the next round closes (usually on the terms of the next round with some discount on the new valuation to reward them for investing early). Convertible debentures also usually have a time limit and convert at some fixed share price, usually low, if the deadline is missed.

[1]Asymmetric because the investor is usually a financial professional who has made dozens if not hundreds of investments, whereas the entrepreneur is usually a technologist or business builder raising money for the first or second time in her life.

[2]If your investor is the rare kind that still takes common shares then you can pretty much ignore the rest of this section and count your blessings.

Example:
The Start-up

Emilie, our intrepid entrepreneur, sets out to build her display company – SuperTech, Inc. She partners with John and Steve on equal terms (300K shares each) and reserves 10% of the company for employees (100K shares). After some initial efforts, they convince an angel investor to provide $300K in seed capital on a convertible debenture with a 25% discount to the next round.

Contributor	Shares	Ownership
Founders & Employees	1,000,000 Common	100%

Interest and Dividends: Some preferred share deals include a required minimum dividend (*e.g.*, each year the company has to pay

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out $1 per share to the holders of the preferred shares). For convertible debentures, this usually takes the form of annual interest on the debt instead. In both cases, the amount might have to be paid out or just accrued for conversion into more preferred shares. Unless the amounts are exorbitant, these clauses are generally not a problem – just take the expected cash drain into account when budgeting your operations.

Example: Enter the Venture Capital Investor

Emilie's convertible debenture carries a 10% annual interest that accrues. As luck, at the author's wishes, would have it, she raised her second round of financing exactly one year after the convertible debenture at a valuation of $4 per share ($4 million pre-money valuation). The second round with a venture capital investor brings $2 million into the company in exchange for 500K preferred shares ($2 million divided by $4/share). The debenture holders have invested $300K plus $30K in accrued interest and get 25%, so they receive 110K preferred shares ($330K divided by the discounted $3/share).

Contributor	Shares	Ownership
Founders & Employees	1,000,000 Common	62%
Angel Investor	110,000 Preferred	7%
Venture Capital Investor	500,000 Preferred	31%

Anti-Dilution Preferences: A variety of preferences deal with anti-dilution. This can take the form of straight share capital adjustments, warrants, or similar mechanisms, but all boil down to keeping the investor whole if the company has misjudged a particular financing valuation. A common scenario is an optimistically priced seed round followed by a series A round that adjusts the valuation of the company back down to market prices. (For more about seed rounds and series rounds, see "Raising Capital for Technology Ventures," Sep./Oct. 2013.) In that scenario, anti-dilution preferences would retroactively give the seed investors more equity at the expense of common shareholders (*e.g.*, founders, employees, *etc.*). Anti-dilution formulas are usually benign, broad-based, and weighted-average, but some clauses, such as full ratchets, can get nasty.[3]

Example: The Fine Print Rears Its Head

Over the next 2 years, Emilie's business hits a few snags. None are fatal, but she probably was a bit too aggressive with her $4 million pre-money valuation of the last round. Either that or Steve just isn't selling enough! She goes back to her VC investors to see if they might be willing to put in some more money, even at a lower valuation, to keep the company afloat. The investors seem amenable to investing another $1 million at a pre-money valuation of $2 million. This is not an optimal outcome, but Emilie, John, and Steve are willing to accept the loss of another third of their company as the price of keeping it alive.

That's when their lawyer explains the anti-dilution clause of their original deal. The new valuation is lower than the previously raised amount, causing the full ratchet iterative anti-dilution calculation to converge on a price of $0 per share and thus handing the VC investor 100% of Emilie's company regardless of how much he actually invests. Game over.

Special Consent Requirements: Preferred shares often come with additional control benefits, such as the ability to force the appointment of seats on the Board of Directors or veto certain business decisions. Within reason, those are benign preferences that serve as an exaggerated minority protection. Note that the biggest control benefit often does not appear explicitly in the term sheet: Most companies have bylaws or shareholder agreements stipulating that each class of shares must vote independently for major decisions in the company such as an acquisition, new financing, or change of business strategy. So even if your new investors own only 10% of your company, but 100% of those 10% are preferred class shares, the investors might very well be able to dictate company decisions simply by holding their share class hostage for all major decisions.

[3]If none of these words make any sense to you, I recommend reading Brad Feld's very good explanation here: http://www.feld.com/wp/archives/2005/03/term-sheet-anti-dilution.html

Example: Almost Saved by the Sale

Emilie starts to panic as soon as her lawyer is done with the explanation of anti-dilution. The choices seem horrible: the only way to keep the company alive is to effectively lose her ownership in it. The only option out of this mess seems to be the sale of the business. The team members cut their salaries, tell their families good bye for now, and plunge into the crazy whirlwind of startup acquisitions. After several months, they have an offer from MegaCorp, Inc., to buy SuperTech, Inc., for $5 million. Proudly, Emilie goes to her board and explains the last-minute rescue deal. It turns out that the VCs do not like the deal and instead advocate a re-launch plan with new leadership and new financing (wiping out both Emilie's job and ownership). Fortunately, Emilie and her fellow founders still have majority control of the company so this cannot happen – right? In fact, accepting the acquisition offer requires a shareholder vote with both the common shareholders (which Emilie wins easily) and the preferred shareholders (in which Emilie and her friends do not get to participate). Motion denied.

Liquidation Preference: Liquidation preferences function like a LIFO buffer – last in, first out – for investor's cash ahead of all other shareholders during an exit, public offering, or similar liquidity event. A basic 1× liquidation preference is practically the default for all venture financings these days, ensuring that investors get their money back first. Some investors push for higher multipliers or so-called participating liquidation preferences, which can make things rapidly more difficult. The latter ensures that the investors first get their money back at some multiple and then participate in the remaining cash according to their ownership of the company – a structure usually reserved for the desperate or innocent entrepreneur.[4]

[4]Such a participating liquidation preference with a multiple is often used as a mechanism to force entrepreneurs to pursue high-risk strategies even against their economic interest (see the sidebar on venture capital compensation).

Example: Modest Payout, Major Lessons

In desperation, Emilie turns to the original angel investor, Jenny, and explains all her troubles. Jenny is by far the smallest shareholder of SuperTech, Inc., so legally she doesn't carry much weight. But she has done a number of deals together with the VC and has a lot of stature in the local investment community. Using that leverage, Jenny is able to work out a deal where the founders cancel 100K shares each, but the MegaCorp deal can go ahead. The final ownership distribution still leaves Emilie with 15% of the company and the team collectively with 53%.

There is, however, that little line about a 2× participating liquidation preference in the investment agreement. After another trip to the lawyers, the situation doesn't look quite as rosy. The holders of preferred shares have collectively invested $2.3 million, so the first $4.6 million of the MegaCorp purchase price is theirs. The remaining $400K is then split between all shareholders.

Contributor	Shares	Ownership	Payout
Founders & Employees	700,000 Common	53%	$212,000
Angel Investor	110,000 Preferred	8%	$632,000
Venture Capital Investor	500,000 Preferred	39%	$4,156,000

The VC has turned its $2 million investment to a bit over $4 million, a solid 108% return. Jenny, our angel, also made the same return on her $300K (though Emilie does not feel so bad about that). When all the dust has settled, Emilie gets a check for 60K (15% of $400K) – not much for 3 years of hard work, but it comes with a lot of lessons learned about life and investment terms! Now, MegaCorp is talking about something called "earn out".[5]

As the story of poor Emilie hopefully illustrates, understanding these investment terms is critical. First-time founders would be well advised to have advisors (or co-founders) who have been through the cycle a few times, especially if the amounts involved are dazzling. Of course, venture capitalists are not inherently evil – I am essentially one myself, though my company invests on common shares – but the incentive model and economics of venture investing mean that Emilie's story is not particularly uncommon. (See the sidebar, "Venture Capital Goals and Compensation.) These investment terms of engagement essentially give savvy investors a high degree of downside protection at the expense of other shareholders. Usually, none of this matters if the company consistently grows, but such terms can trigger very dramatic changes to the wealth distribution in the company as soon as key milestones are missed (and usually do not allow for any recovery later on).

A Common Founding Valuation Misconception

There is a commonly held but incorrect belief that "founding" somehow creates value. A common example is the lone engineer who leaves his $100K/year employment to start a new venture for which he approaches angels for an investment against a valuation of $1 million. Magically, so the mistaken belief goes, $1 million of free value has been created by declaring the business "founded." Not so. Assuming that the founder commits to working on the venture for free for a year, the value of the venture is essentially $100K (the approximately fair market value of the engineer's future contribution). Having spent $500 to incorporate an entity does not make anything more valuable.

This, of course, does not mean that founders should not receive significant rewards in the company, just that "founding" itself does not create value. Assembling a team, inventing concepts, building product, and making sales – these things all create value. If our lone engineer goes out for a year and does all of these things, then his venture might very well be worth $1 million. It could also be worth nothing – the engineer has effectively invested his $100K in fair market value compensation and now rides the same uncapped rollercoaster of valuation from $0 to millions based purely on the value of the venture with no consideration for the amount sunk into getting it to that point.

Apart from making for amusing anecdotes in discussions with first-time entrepreneurs, this has some serious consequences:

(a) Accelerator (or other "pre-activity") investments are often made at very low effective valuations precisely because the founder contribution is limited to future work at fair market value (e.g., Ycombinator, grandfather of all Accelerators, invests in teams of 2–4 people at an effective valuation of ~$200K, which is very closely comparable to the combined earning power of most of those people during the 3–9 months that they will not be drawing pay).

(b) Founders who leave ventures early really should have reverse vesting mechanism in their share allocation to largely remove them from the capital table of the company (similar to and ideally on the same terms of other employees who leave early). Anything else ascribes a magic power to the "first guys" and will create nothing but morale problems for the remaining people (who then have to work extra hard just to make the quitter rich).

(c) Major contributors joining during the same "valuation stage" as the founders should get founder-like equity grants (*e.g.,* joining a venture a few weeks after it was "founded" should not magically lower your equity stake by 10× compared to founders of similar function).

Of course, this does not mean that the ownership gap between founders and other employees can't still be huge. Contributors who join at future valuation stages will, and should, have major reductions in comparable equity. Similarly, people who invest little in the form of lower salary or similar risk contributions generally will not receive much of a stake in the new venture regardless of their time of arrival.

[5]Acquirers often add requirements to a deal that key contributors, like Emilie, have to remain on-staff for 2–4 years to actually get their payout. This is frequently done by locking up their payout or converting it into vesting options of the acquirer. Emilie's troubles might not be over yet.

Getting Rich

So you have raised money, avoided the worst of the financial terms, and even built a nice little venture with growth momentum. Now what? The first thing to remember is that nobody gets rich from receiving shares. (A related issue is that of founding valuation: See the sidebar, "A Common Founding Valuation Misconception.") The concept of shares is probably the source of the biggest misunderstanding in the entrepreneurial community and the root of countless frustrations in start-up board rooms across the world. Let me repeat this: getting lots of shares will not make you rich. Why is that?

Shares, like all other considerations in a business, are given in exchange for something of comparable value. As a founder, that's usually your time and possibly your reputation. As an investor, the exchange is more straightforward – for cash. As an inventor, it will be for the value of your contributed intellectual property. And so forth. Any such exchange is highly unlikely to yield significant wealth for anybody involved regardless of when or how you do it. As a founder you will get a lot of shares; as a later-stage employee you will get fewer shares, but ultimately you are still trading beans for carrots at market prices. Even if you somehow manage to trick the other side into giving you a bit more value in the exchange, say, by elevating your reputation or the value of your idea, it is virtually impossible to turn that into significant wealth gain – especially since the monetization of such wealth will ultimately require several other seasoned valuators to buy into your price.[6] The inability to understand the exchange nature of equity has led to some odd behaviors – such as companies creating millions of penny shares instead of thousands of dollar shares so that people feel like they "own" more.

Emilie's example shows that share ownership itself, and the manipulation of valuation, rarely help very much. Few ventures have happy outcomes if they continue to raise money at flat or nearly flat valuations. Instead, each round of financing is an opportunity to generate wealth, even if it will be illiquid for a while. Most successes follow a fairly steady climb of valuation until they finally hit the cash-out jackpot during an initial public offering or acquisition.

So, if not by amassing shares, how does one get rich as an entrepreneur? The key is to increase share value – make those shares

Venture Capital Goals and Compensation

Unlike angels or other direct investors, venture capitalists do not invest their own money. Instead, they are paid to manage the capital of others, their so-called Limited Partners (LPs). Like all human beings, VCs act upon incentives, but those are subtly different from the straightforward goals of direct investors. The latter, including the actual LPs of VC funds, want to invest money and get more money back in return. That's not entirely the case for their fund-managing VCs, though. Most VCs are paid using the "2 and 20" model, which provides an annual management fee of 2% of the total capital as well as 20% of any carried interest (return on invested capital after return of the principal investment). While this sounds straightforward, it introduces two fundamental alignment conflicts involving the VCs, their LPs, and effectively, the entrepreneur:

(a) *Downside Misalignment:* The management fee covers the operating cost of the fund, but also generally provides the fund managers with high compensation – regardless of whether the fund performs or not. A traditional $200 million fund running for 10 years will pay out a solid $40 million to the 3–8 fund managers even if the entire $160 million of invested capital goes down the drain.[7] This creates what, thanks to the recent Wall Street debacle, we now know as a "moral hazard."

(b) *Upside Misalignment:* As bad as the moral hazard of downside protection is, it pales in comparison to the impact of upside misalignment. Even though the fund managers' participation in the upside by 20% appears to nicely align their success to that of the entrepreneur and LP, it creates a curious disconnect: Imagine two $10 million investment opportunities available to a VC. One is guaranteed to double your money in a year. The other has a 10% chance of yielding $150 million during the same year. From the perspective of any rational investor, including the LPs and entrepreneur, the first option is preferable with an expected exit value of $20 million vs. $15 million for the second. Unfortunately, VC math is different. The first opportunity will yield $2 million for the fund manager (20% × $10 million in gained interest). The second will yield $28 million if it works (20% × $140 million) and $0 if it doesn't for an expected value of $2.8 million ($2.8 million × 10% probability). In other words, the VC is encouraged to make bad investments by virtue of its compensation structure.

Combined, these two elements of the VC compensation structure encourage VC fund managers to push their companies toward high-risk avenues – often up to and beyond the point of reasonable risk taking for their LPs and entrepreneurs. A viable counter argument might be that a venture capital firm could somehow increase the probability of the big wins occurring so that its LPs and entrepreneurs might still benefit from the skewed compensation model. Unfortunately, that doesn't seem supported by market observation: for almost 20 years, the VC industry has consistently returned less money to its LPs than much safer asset classes such as blue chip stock indices.[8] This by no means implies that taking venture capital is fundamentally wrong for a new venture – in fact, it is often the only viable option – but it is important to understand the biases introduced by venture capital and incorporate those into your strategic planning.

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[6] In other words, even if you manage to convince an innocent angel investor that you invented the LCD in 2013 and thus your company should be worth $100 million, it is unlikely that any acquirer will ever actually pay that $100 million in the future – thus leaving you with the satisfaction of having tricked the angel but not much else.

[7] I will ignore more advanced elements of VC compensation such as the distinction between committed and invested capital, hurdle adjustments, stacking of parallel funds, and so forth – these structures are complicated enough as it is.

[8] If you are curious about this situation, I recommend reading the Kauffmann Foundation study titled "We Have Met the Enemy … And He is Us," released in 2012, which describes the authors' last 20 years as a major LP and concludes with the observation that the abysmal returns are a direct consequence of the alignment problems outlined in this sidebar: http://www.kauffman.org/research-and-policy/we-have-met-the-enemy-and-he-is-us.aspx.

worth more after you receive them. Increasing your number of shares tenfold is virtually impossible in a fair exchange, but multiplying their value 10 times can be done. It will require significant growth of your business, careful husbanding of resources, development of innovative products or services, and, above all, a good eye for opportunities that maximize value increase. And therein lies the magic of entrepreneurship.

As a corporate employee, your compensation is largely decoupled from the value of your work product. If you invent the next big thing, you might get a 20% increase during a promotion, but your company will gain millions or billions in value. Not so for the entrepreneur. If you raise money at a $1 million valuation and then use that money to achieve a new valuation of $10 million, you have just created a massive amount of wealth – for yourself and your other shareholders. The next article in this series will discuss ways to monetize your hard-earned equity through exits, licensing, and public offerings. ■

Highlights from EuroDisplay 2013

by Ian Sage and Alasdair Campbell

For the fourth time since 1987, EuroDisplay – the Biennial International Display Research Conference (IDRC) – came to the UK. The September 2013 event, co-sponsored by the Society for Information Display and the Institute of Physics, had, as always, a distinct European flavor compared to other display-related meetings. The program this year provided a concentrated insight into the part that Europe and the UK in particular continue to play in the invention and development of cutting-edge display technologies. The venue this year was Imperial College, the prestigious, science-based university in the heart of London's museum district and a stone's throw from famous landmarks such as Hyde Park (Fig. 1).

Three plenary presentations started off events with a show of strength from the European display research and development community. Two of the technologies described originated in Cambridge University's Cavendish Laboratory. Jeremy Burroughs (Cambridge Display Technology) provided an excellent summary of the latest developments in solution-processed organic semiconductor-based display technologies. Improved efficiencies have been achieved in light-emitting- polymer (LEP) based OLEDs through such factors as emissive dipole alignment, and triplet-triplet annihilation has been shown to boost the singlet yield of fluorescent polymer OLEDs from 25 to 40%. For lighting and backlights, 6-in. tiles with a slot-die-cast white-emitting LEP have achieved 42 lm/W. Polymer-based electrochemical-cell OLEDs currently have a long turn-on time, but could be used in low-cost flexible devices. Improved organic TFT performance for backplanes has also been achieved by lowering contact resistance through improved formulation design.

Henning Sirringhaus (University of Cambridge) took as his theme the rapid improvements in solution-processed organic semiconductor and oxide TFTs. Such TFTs can be used in both backplanes and driver circuitry for flexible displays that are shatter-proof and robust and feature novel form factors and usage modes. AMOLED drive currents require TFTs with mobility values of about 2 cm^2/V-sec, but TFT instability can require compensation circuits with values of 5–10 cm^2/V-sec for video. Oxide TFTs can easily reach these values, but normally require processing at temperatures too high for plastic substrates. Sirringhuas has developed a sol-gel method for oxide TFTs with wet-atmosphere processing at temperatures of 250°C and has used dopants such as Ba (barium) and Sr (strontium) instead of Ga (gallium) to produce much higher stability. Donor-acceptor polymer organic field-effect transistors (OFETs) have also been achieved with values of 5–10 cm^2/V-sec.

The quality of liquid-crystal displays (LCDs) is so routinely excellent that the underlying technology is largely lost to view. Michael Heckmeier (Merck KGaA) provided a broad overview of the electro-optic effects used in the latest devices and the special material properties required by each. Each leading type of display occupies its own place in the applications field, with different types of VA-mode devices dominating TV displays and in-plane switching (IPS) and fringe-field switching (FFS) displays used in computer and mobile devices. Not only the liquid-crystal fluids but their accompanying reactive monomer materials are crucial for PS-VA devices and optical films. Heckmeier continued by describing emerging device modes such as blue phase and uniformly lying helix displays, which offer the promise of still faster response speed and higher-quality images.

Fig. 1: Tower Bridge by night was just one of many iconic views that EuroDisplay 2013 attendees could take in during the special event dinner cruise along the Thames.

Beyond the Status Quo

A number of presentations gave views of displays which, if realized, will greatly extend the capabilities of present technologies. One of the highest profile initiatives is the drive toward ultra-high-resolution (8K) television technology, referred to as Super-Hi Vision and presented by a team of authors from NHK. The highly ambitious specifications for such a system include a screen resolution of around 7680 × 4320, combined with frame rate, color gamut, and bit depth all exceeding HDTV standards. Such a system will provide an immersive experience based on very-large-diagonal displays. No technologies currently satisfy all the requirements of the proposed new standards, while impressive demonstration devices that achieve the target resolution and approach other specifications have been made using plasma, LCD, and projection systems. This talk stimulated a lively audience discussion, centering on the practicality of such systems against their requirements for bandwidth, power, and footprint.

Adrian Travis (Microsoft Corp.) and Adrian Geisow (Hewlett-Packard Laboratories) each presented stimulating talks describing a re-think of LCD technology. The Hewlett-Packard work addressed the unsatisfactory performance of reflective color displays and described the company's work in providing bright, saturated colors using a stacked subtractive-color dichroic LCD. In the past, attempts to exploit subtractive-color stacks have suffered from absorption spectra in the colorants, which are far from ideal and result in poorly saturated "muddy" colors. Geisow described how to radically improve color rendering by incorporating color-selective reflectors between the dichroic LCD layers; each reflector avoids the corresponding color of light having to traverse the layers deeper in the display stack, and the brightness and saturation are markedly improved. Reflectors can be based on vacuum-coated multilayers or on cholesteric polymer layers.

Travis described radical approaches to power savings in LCDs, based on providing steered backlight illumination that directs light specifically toward the users' eyes by making use of head-tracking. Steering the output light to follow the user while maintaining a compact form factor presents a real challenge, which has been overcome using a hybrid system incorporating one small and one linear tracking mirror, allowing a compact grating to scatter light into the correct optical path in a slab waveguide. Such a system allows steering of light in the x-y plane, but this is not sufficient for a display backlight, which should also converge light toward the eye. A switchable grating in the waveguide synchronized with the optical scan angle allows this, and Travis offered his audience the prospect of future displays with a near-zero power budget.

Herbert deSmet (CMST, Ghent) presented truly futuristic work directed toward the ultimate goal of incorporating a viable display into a contact lens. Even the generation of an image on the retina from such a close distance is difficult; deSmet described how projection from an array of LEDs equipped with pinhole apertures and microlenses could achieve this, albeit with limited resolution. A large range of materials-related problems have to be solved in order to provide air permeation to the cornea as well as barrier properties to protect electronic components from water and the eye from contact with any toxic materials. Power from organic photovoltaic or inductive pickup sources could provide enough energy to run a display as well as additional devices such as biosensors to monitor conditions like diabetes or glaucoma.

Holographic Futures

In consecutive talks, Tim Wilkinson (University of Cambridge) and Jamieson Christmas (Two Trees Photonics) gave contrasting and fascinating views of their approaches to holographic displays. Wilkinson began from the fundamentals of off-axis holography and succinctly described an efficient approach to generating holograms that can be projected to a screen, or alternatively viewed directly using the eye's lens to provide the Fourier imaging element. A wide field of view is then available. This increase in image size requires higher-resolution pixels at the SLM than are available from standard liquid-crystal–on–silicon (LCOS) configurations. The problem arises from the LC pixel rather than limitations of the underlying silicon, and Wilkinson went on to describe approaches to ultra-high-resolution devices achieved through the use of nanotube arrays in the pixel to concentrate the electrical field into smaller volumes. This challenging approach has borne some fruit; a static hologram based on submicron-resolution nanotube arrays shows plasmon-enhanced diffraction efficiency and a diffraction angle up to 70°.

Jamieson Christmas was this year's recipient of the Ben Sturgeon award, given annually by the UK & Ireland chapter of SID to mark a significant development in display science. In his award lecture, Christmas described for the first time his use of holographic principles to provide a light engine for 2-D head-up displays (HUDs). Improved algorithms for hologram design minimize computational load, and the use of a holographic light modulator leads to a substantial improvement in the overall optical and power efficiency of the system. The technology is understood to be targeted at road vehicle use and is under intense development for inclusion in high-end cars in the near future.

Organic Electronics Workshop and More

Several additional presentations covered OLEDs, other organics, and oxide TFTs – areas that are moving forward, particularly with regard to new device architectures, new materials, and flexible displays. The conference included a one-day workshop on organic electronics, which covered not only organic light-emitting diodes (OLEDs) and organic thin-film transistors (OTFTs) and their use in displays, but many other areas of the field. The workshop began with presentations from Peter Skabara (University of Strathclyde) on organic semiconducting materials, which explored the design rules for achieving properties such as a particular energy gap and from Anna Hayer (Merck KGaA), who focused on solution-processable OLEDs, how they work, and how to maximize performance.

Ian Underwood (University of Edinburgh) discussed designing and driving active-matrix OLED (AMOLED) displays, and Alastair Buckley (University of Sheffield) described the production of OLED microdisplays based on his industrial experience of a startup. Buckley covered all the challenges in going from "lab to fab." Ifor Samuel (University of St. Andrews) finished off the morning session with a presentation on organic lasing and optical amplifiers, and how these devices can be used as sensitive explosive detectors.

The afternoon workshop session started with a presentation from Giles Horowitz (École Polytechnique Paris) on the use of OFETs in biomedical devices. This was then followed by a detailed presentation from Soeren Steudel (IMEC) on the fabrication of flexible large-area organic electronics circuitry using a batch process, while Gerhard Klink (Fraunhofer EMFT) followed with a talk on the roll-to-roll processing of organic electronics on foil. Following this was a presentation from Jonathan Halls (Solar Press) on the large-area roll-to-roll processing of organic solar cells and a presentation by Ilkka Kaisto (VTT) on the commercialization of large-area organic electronics

Other OLED presentations at the main conference included one on major advances in lighting made possible through optical modeling and design to increase light outcoupling in the forward direction, reclaiming the 75% of light lost horizontally in the organic, ITO, and substrate layers. By using a Si microsphere stamp to pattern a hexagonal grating structure on the internal substrate surface of the OLED, and combining this with an external macrolens and a high-index substrate, Franky So (University of Florida) was able to achieve an impressive 230 lm/W.

With regard to novel OLEDs under development, Russell Holmes (University of Minnesota) reported a high-efficiency OLED consisting of continuously graded electron-transport and hole-transport materials, and Matthew Fuchter (Imperial College London) reported a circularly polarized OLED based on a conventional LEP doped with a helically shaped chiral small molecule.

State of the Art of Displays

The above presentations represent only some of the ground-breaking research presented at EuroDisplay 2013. The conference was a unique opportunity to learn about the latest and future developments in display technologies – from OLEDs and LCDs to holograms and contact lens displays. Although speakers came from all over the world, the event offered a uniquely focused look at the work now being done at companies and universities in Europe. The next conference in the series to be held in 2015 is now being planned by the Mid-Europe chapter and again promises an event to look forward to.

__Ian Sage__ is the SID European Convention chair. He can be reached at ian.sage@tiscali.co.uk. __Alasdair Campbell__ is Vice Chair of the SID UK and Ireland Chapter. He can be reached at alasdair.campbell@imperial.ac.uk.

SID Appoints Senior Members

Senior Member Dr. Yasushi Motoyama

Senior Member Patrick Green

SID's Senior Membership Grade Committee has elevated Yasushi Motoyama of the Japan Chapter and Patrick Green of the Pacific Northwest Chapter to Senior Members, in recognition of their outstanding professional achievements and volunteerism. Motoyama has been a member of the Society since 2002. He currently conducts plasma-display research at NHK Science and Technology Research Laboratories. Green has been an SID member since the early 1980s. He is an engineer with Planar Systems. ■

SID The Society for Information Display

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SUSTAINING MEMBERSHIPS

Sustaining or corporate members of SID are companies and universities who are deeply involved in the display industry, typically providing papers for the Digest or JSID and speakers for events, as well as providing minor financial support to SID. In return they receive discounts, free memberships, and valuable marketing benefits that enhance their brand and business opportunities.

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- Online access to the Digest of Technical Papers, Journal of SID, Information Display Magazine, and proceedings of many affiliated conferences and their archives
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- Optional multiple year discount: $190 for two year membership (5% discount) or $270 for three year membership (10% discount)
- Discounts on SID-Wiley book series on display technology
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- Networking infrastructure including chapter technical meetings, access to SID's online job mart, online member search, and more!

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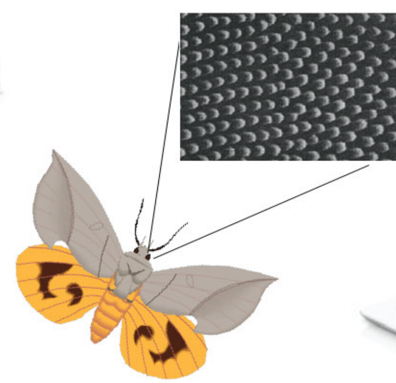
This Year, Be Part of SID's Display Industry Awards

Nominations are now open



The year's hottest displays, display applications, and components. They'll all be competing for SID's annual Display Industry Awards. So get creative and tell us why your exciting, innovative product picks should be selected.

Submit your contenders today for the Display Industry Awards. Remember, it's the industry's most prestigious honor, given annually by the Society for Information Display (SID). SID members and non-members alike can nominate one or more products, choosing from any of those introduced into the market during this calendar year. Self nominations are encouraged.

For more information, or to submit a nomination, visit: **http://www.sid.org/About/Awards/DisplayIndustryAwards.aspx**. All nominations must be received by **December 31, 2013**. The Display Industry Awards will be announced and presented at Display Week, the annual SID International Symposium, Seminar and Exhibition, to be held in San Diego, California, June 1–6, 2014.

CATEGORIES:

Display of the Year Award
Granted to the display with the most significant technological advances or outstanding features.

Display Application of the Year Award
Granted for a novel and outstanding application leveraging a display.

Display Component of the Year Award
Granted to a novel component that significantly enhances the performance of a display.

Gold and Silver Awards are presented in each of the three categories.

SID 2014 Display Industry Awards
Society for Information Display

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The remaining stake of approximately 10% is currently held by Samsung Venture Investment, which will maintain its current shareholding. The transaction includes a €30 million contingent payment, which is conditional on reaching certain milestones.

Most industry experts say the acquisition is clearly designed to bolster Samsung's OLED expertise, making it more competitive in developing large OLED TVs for the mass market, for example. Cheil Industries' CEO Jong-Woo Park had this to say in Novaled's press release: "Leadership in [the] future display market will be determined by technological capacity," and "this acquisition is expected to generate significant synergy in new-generation OLED materials R&D and will play a critical role in enhancing Cheil Industries' market position as a global leader in electronic materials."

[1]http://www.novaled.com/press_news/news_press_releases/newsitem/cheil_industries_to_acquire_novaled_ag/

Apple Announces New Products before the Holidays

As *Information Display* was going to press, Apple announced new iPads and computers, as well as a free version of the OS X upgrade Mavericks. A thinner, lighter version of the company's larger (9.7-in.) tablet, named the iPad Air, was scheduled to go on sale Nov. 1, at prices starting at $499. A new iPad mini with a Retina display (2048 × 1536) and a more powerful processor (A7) than previous versions was slated for availability later in November for $399. The company also announced an updated line of Retina MacBook Pros and a new Mac Pro desktop in what is perhaps the company's most minimalist design yet – a small black cylinder.

New Deposition Systems Target Metal-Oxide TFTs

Applied Materials, a manufacturer of systems for the semiconductor, flat-panel display, and solar photovoltaic industries, recently announced new deposition systems for manufacturing large-sized and ultra-high-definition LC and OLED displays. The Applied Materials AKT-PiVot 55K DT PVD, Applied AKT-PiVot 25K DT PVD, and Applied AKT 55KS PECVD systems are designed to work with metal-oxide films to manufacture smaller, faster thin-film transistors required to create high-resolution displays.

Metal-oxide-based TFTs enable low-power high-resolution smart phones and tablets as well as some OLED TV technologies. Future 4K TVs are also expected to use metal-oxide TFTs. However, this technology has proved challenging in terms of uniformity and scale in mass production. The uniformity and particle control of Applied Material's PVD and CVD systems is designed to help realize the newest display technologies with high yield in mass production.

Applied Materials's AKT-PiVot DT PVD systems (55K for 2200 mm × 2500 mm and 25K for 1500 mm × 1850 mm substrates) use the company's proprietary rotary cathode array technology to deliver uniform, homogeneous, and low-defect active-layer deposition for metal oxide as well as interconnect metals and pixel electrodes (Fig. 4).

Applied Material's new AKT 55KS PECVD system brings precision PECVD technology to 2200 mm × 2500 mm size substrates. The system deposits a dielectric-layer interface for metal-oxide transistors with a new advanced-quality silicon oxide (SiO_2) process that minimizes hydrogen impurities to improve long-term transistor stability and optimize screen performance.

2013 Marks 125th Anniversary of Liquid Crystals

Last September, at a scientific forum hosted by the German Chemical Society in Darmstadt, Germany, liquid-crystal-manufacturer Merck helped mark the 125th anniversary of the discovery of liquid crystals. Key properties of cholesteric liquid crystals were discovered by Austrian scientist Friedrich Reinitzer and German physicist Otto Lehmann in 1888.

A highlight of the forum was Merck's exhibition featuring items dating back to those original discoveries, as well as future-oriented developments such as a smart window in which liquid crystals are used to modify the light transmission properties of the glass.

This year also marked the passing of LCD pioneer Rudolf Eidenschink, who performed groundbreaking research in liquid crystals at Merck for many years. Eidenschink received SID's Karl Ferdinand Braun Prize in 2011. His obituary can be found in the In Memoriam section of *Information Display* online.

– Jenny Donelan

***Fig. 4:** Applied Materials' new AKT-PiVot DT PVD system is designed for metal-oxide deposition for large-sized panels (up to Gen 8.5).*

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These TVs are also the subject of our first Frontline Technology article this month. Being good engineers and scientists, we do not generally spend too much time gushing over new creations. We like to get our brains busy scrutinizing and analyzing them instead, and no one is better at this than well-respected industry metrologist Dr. Edward Kelley. Ed got his hands on one of each of these 55-in. OLED TVs and hustled them over to his optical measurement lab, where he got to work not only testing their performance but also road testing his new ideas for OLED display metrology that will soon appear in the next revision of the ICDM Display Measurement Standard (DMS).

In the first in a series on this research titled, "Considering Color Performance in Curved OLED TVs," Ed reports on the color and video performance of the two TVs as well as the methods for getting accurate and reproducible measurements for comparison. There are clear differences in performance between today's OLED and LCD TVs, and there are some differences in performance between the two OLED TVs. It's too early to declare a winning technology, but for an almost perfect HDTV viewing experience these curved OLEDs are certainly ready to deliver.

However, one attribute that LCD technology can still claim dominance in is the ability to scale to extremely large sizes, such as 110 in. The most recent achievement in this area is the world's first LCD panel to offer 4K × 2K resolution and 3-D capability – and China Star Optoelectronics Technology did it at 110 in., with a luminance of 1000 cd/m^2 and an amazing 50000:1 dynamic contrast ratio. In their Frontline Technology feature titled, "Developing a 110-in. 4K × 2K TV," authors Li-Yi Chen *et. al*. explain why 4K × 2K resolution is important for panels in this size range as well as how much more immersive the really large screen experience can be.

There were actually several very complex technologies combined in this effort, including a two-dimensional dynamic LED backlight, a novel pixel addressing and driving scheme, and a custom video system architecture that includes custom calibration algorithms to optimize the panel performance in various ways. We were especially pleased with the very detailed explanation of how the developers overcame the challenges of tiling many side-by-side photolithography exposures to form the internal structures of the panel and how they overcame the charge time limitations in a panel this size. For those of us who do not work on the manufacturing side of LCD technology, this represents a rare and very vivid glimpse into the kinds of challenges that must be overcome by innovative manufacturers like China Star. I really learned a lot from this article and I think you will also. By the way, we thought it fitting to add this display to our cover as well.

Continuing with our theme of large-area displays, we also turn our attention to digital signage. To get a glimpse of the state of this industry, we invited veteran contributor Terry Schmidt to serve as our Guest Editor this month. Terry explains in his guest column, "Digital Signage that Captivates," how far the industry has come in the last few years owing to the reduction in prices for large-area displays suitable for signage applications as well as a rapid expansion of the tools available to create and manage sign content. Without a content infrastructure that is affordable and easy to implement, the ROI for a digital sign system just will not add up. But those ingredients now exist, and the recent proliferation of so many novel developments is a testimony to this.

One new development that could become a player in this market is the Emissive Projection Display (EPD) with a transparent fluorescent screen described by authors Ted X. Sun and Botao Cheng in our next Frontline Technology feature titled, "Novel Emissive Projection Display Digitizes Glass Windows." Just imagine, if you can, a digital image that appears to be floating in mid-air that is visible from any 2-D viewing angle. Traditional projection systems require opaque or translucent screens to render their images. Transparent LCDs can render seemingly floating images but require a strong local source of ambient light for viewers to see them. The EPD system, however, produces the viewable image by fluorescent emission, very similar to how phosphor screens on CRTs operate. The result is a self-illuminated image that can appear on any transparent glass surface driven by front or rear UV light projection. This technology was first presented at Display Week 2013 and is now described for us in detail in this issue.

Of course, digital signage is driven by commerce and culture. Different regions have different commercial and cultural needs. In Europe, there are somewhat unique cultural barriers to widespread deployment caused by the diversity inherent in the many different countries that make up the region. As we learn from author and analyst Bob Raikes in this month's Display Marketplace feature titled, "Public Displays in Europe (and Elsewhere)," there is no one formula that can work across the entire European market, and even trying to think of the continent as one large market for digital signage is probably not worthwhile. Bob did a great job of breaking it all down for us in many different dimensions and his analysis shows what Terry Schmidt also said, that the recipe for success must include low-cost high-value content creation and distribution that is regionally targeted.

The overall display marketplace in Europe is very complex, owing in part to the vast diversity of independent countries involved – diversity in terms of culture, economic standing, consumer preferences, historical factors, *etc*. Europe has been slower to recover from the economic recession and the European Union countries tend to lead the way in areas like environmental regulations and ergonomic standards, making it harder to do business there than in other parts of the world. Nonetheless, there is a plethora of innovation, development, and consumption opportunities to be seen when you dive into the details, as our own Jenny Donelan has done for the next installment in our Regional Business Review, "The Display Business Environment in Europe: Together but Different." Jenny explains how in several ways the consolidation of regulation and standards activities within the EU makes it easier to navigate and negotiate business than it used to be. Also, European companies continue to make some of the most important contributions to display technology such as liquid crystals from Merck, measurement technology from Eldim, and OLED materials from Novaled, and, of course, the innovative and ever popular display-based consumer products from Nokia.

Our last but hardly least feature this month is the next installment in our Venture Capital series by Helge Seetzen. In this month's article titled, "The Ins and Outs of Venture Capital," Helge tackles the thorny details of venture funding: valuations, preferred stock, dilution, liquidation, and other things you need to understand before diving in to your new venture. If you are lucky enough to cash out someday with heady gains after all your efforts, I hope you will send Helge a thank you note for his hard work and dedication in compiling this groundbreaking series for *Information Display* that will continue next month as well.

And so, here we are at the end of another great year for *Information Display*. I sincerely hope all of you have a great holiday season and have enjoyed the efforts of our truly dedicated staff, including our Managing Editor Jenny Donelan, our Editor-in-Chief Jay Morreale, our colleagues at Wiley publishing, Simone Taylor and Joseph Tomaszewski, and the continuing support of the SID Executive Committee, Publications Committee, and all our great Guest Editors throughout the year. Without the relentless efforts of these people, *ID* would literally cease to exist.

There is one more person I want to mention before I close – our Editorial Advisor Allan Kmetz. Allan has been a mentor and trusted advisor to *ID* for many years. Allan reviews and edits the final copy of practically every feature article that goes into *ID*, bringing to the task both a strong technical perspective as well as a great sense of clear language and style. Many times he unlocks details we do not fully understand or reminds us of things that may be confusing to readers not so skilled in the art. It is hard to overstate how much he has contributed to the accuracy and integrity of this endeavor.

Beyond his role with *ID*, Allan Kmetz is a Fellow and Senior Member of SID as well as a Past-President. He is an active member and past-officer of the SID Mid-Atlantic Chapter. He has served as both lecturer and organizer of the SID Seminars and as a program committee member, program chair, and general chair of the SID Symposium and the IDRC. We are all grateful and look forward to Allan's continued support of *ID* in the coming year.

From all of us at *ID*, we wish you a safe, healthy, and prosperous holiday season. ■

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capture the attention of an increasingly difficult-to-reach target audience. If you can capture someone's attention for a few moments on a busy escalator at an airport, for example, the potential reach of each advertising dollar may be very large.

Even theater exhibitors, who are masters of advertising to specific captive target audiences in their pre-shows, are showing interest in digital signage as a business. For example, Canada's largest theater exhibitor, Cineplex Odeon, recently completed a $40+ million deal to buy EK3 Technologies, a digital-signage company in London, Ontario. Cineplex Odeon surely has big plans for EK3's patented technology both inside theater lobbies as well as for advertising in other locations.

The displays typically used for digital signage range from large, daylight-readable direct-view LEDs employed for roadside billboards and marquees (the Las Vegas strip comes to mind) to TV-sized conventional LCD panels that are used, for example, to show menus in fast-food restaurants and coffee shops. Special temporary venues can also present opportunities for "projection mapping," where cleverly designed advertising can be projected on outdoor buildings during evening-hour special events such as trade shows.

In many cases, while the display itself may be only a small part of the total cost of a digital-signage system, it plays an essential role in the system's impact and effectiveness. As such, innovative new display technologies such as smaller seams for video walls, larger flat panels, transparent seamless glass displays, and larger, lower-cost OLED panels will always be well received in the digital-signage arena.

The opportunities in digital signage are many, as are the pitfalls. Most developers learn the hard way to heed the 3–7-sec attention-span rule-of-thumb for content creation! To assist in education on effective techniques, several organizations, blogs, and trade shows have sprung up. For example, a prominent web organization at www.DOOH.com serves what is called the Digital Out Of Home market (DOOH). *Digital Signage Today* (www.digitalsignagetoday.com) has well-organized research papers in addition to its regular newsletter. Futuristic videos of what soon may be possible, as well as countless news items and links to other resources for planning of new systems, can be found with keyword searches online. Take a look at these web sites to gain a sense of the near-limitless possibilities of this exciting and growing area of display technology and applications. ■

***Terry Schmidt** is a pioneer and recognized expert in the field of high-performance projection. He can be reached at terryschmidt12@gmail.com.*

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Advertising Sales Manager
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Hoboken, NJ 07030
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Advertising Sales Representative

Roland Espinosa
Wiley
111 River Street
Hoboken, NJ 07030
201-748-6819
respinosa@wiley.com

Sales Office – Europe

George Isaacs
12 Park View Court
The Paddock, Eaton Ford
St. Neots, Cambridgeshire
PE19 7SD U.K.
+44-(0)-1480-218400
george@gandg.demon.co.uk