DISPLAY ELECTRONICS ISSUE

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SID

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3-D Cinema Takes Center Stage at Display Week 2008

COVER: Digital 3-D cinema is exploding – growing from 84 to 1300 screens worldwide in two-plus years – wowing audiences and causing experts to proclaim that 3-D is finally here to stay. Movie studios are ramping up 3-D content; Dreamworks Animation has stated that all of its upcoming animated features, such as Monsters vs. Aliens *(pictured), which is scheduled for release in 2009, will be produced in 3-D. SID will present a special session at Display Week 2008 on Digital 3-D Cinema.* *For a preview, turn to page 34.*

PHOTO CREDITS: The *Monsters vs. Aliens* photo is courtesy of Dreamworks Animation. The crowd photo is © Corbis.

Next Month in
Information Display

Display Week 2008 Preview Issue
- SID 2008 Preview (Part II)
- SID 2008 Honors & Awards
- Commercializing LCOS TVs in China
- Standard Committees for PDPs
- *JSID* April Preview

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editorial

Where Do I Start?

There certainly is no shortage of interesting things to write about this month. Sony has announced a new partnership with rival Sharp and significant investment into a new factory to source LCDs for Sony's consumer TVs. Panasonic unveiled at CES a 150-in.-diagonal (yes, that's not a misprint) plasma TV that was made on its newest production line from a single sheet of glass (no tiling). Commercial OLED TVs have debuted in Japan – the initial rollout is small, but proof of intent from a promising technology with a lot of muscle behind it and a turbulent history. 3-D cinema is in the news with the upcoming special session at Display Week 2008, and its deployment in approximately 1300 theaters worldwide. As I started writing, I learned of the news being widely reported that Pioneer is planning to end its PDP manufacturing and form a supply agreement with rival Matsushita for 42-in. PDPs and possibly other sizes. There is never a dull moment in the display business. Fortunately, we provide coverage of these and many similar news items each month here in *Information Display* and also daily online at www.information display.org.

Today, I have the privilege of bringing to you another issue of *Information Display*, this one guest-edited by a good friend and former business partner, Lewis Collier. Lewis and I have been friends from college, but were reunited professionally when I joined him in 2000 at a small office of Anteon Corp. in Mystic, Connecticut. There, I first collaborated with him on the development of optical measurement systems for liquid-crystal–on–silicon (LCOS) microdisplays. Also under development at the Mystic facility was a technology for manipulating and compressing real-time video they explained as "Wavelet Compression." At the time, I was most impressed with how well it was suited to carrying video efficiently over a wireless interface. I was shown a number of remarkably high-quality full demonstrations of television and higher-resolution video streams using no more bandwidth than a single 802.11a channel. The transmitted images were reconstructed and displayed in real time showing little evidence of their journey – certainly much better quality than the MPEG-based implementations that were currently available. Since then, wavelet-compression technology seems to have attracted a fair amount of interest, and it is implemented in a variety of still- and moving-picture compression standards and engines such as JPEG2000, ECW, Dirac, and more. However, I have not seen any evidence of it being widely adopted for wireless video transmission – an opportunity that should not be overlooked.

Meanwhile, the team at Mystic is still working on this technology, now as part of Alion Corp., and in this month's issue we learn more about the ability to efficiently perform image enhancements in the wavelet domain from author and developer Barry Mapen. I'm grateful to Barry and the Alion team for supporting this article.

We also have a very interesting story on LED backlights and drivers from Suzanne Thomas and Steve Soos at Applied Concepts, Inc. I'll let Lewis give you the full introduction in his Guest Editorial, but I want to mention that included in Susan and Steve's article is some concrete data demonstrating a roughly 2:1 improvement in luminous efficiency using LEDs over CCFLs for LCD backlighting. If you have been following along of late, there has been much skepticism about the recent claims of light *vs.* power efficiencies from those developing LED backlights. I am convinced from the information I learned in January at the LA Chapter LED Symposium and the

(continued on page 51)

Information
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industry news

Sharp and Sony Become Latest Companies to Create LCD Joint Venture

TOKYO and OSAKA - **Sharp Corp.** and **Sony Corp.** announced in late February they signed a non-binding memorandum of intent to establish a joint venture to produce and sell large-sized LCD panels and modules. The joint venture will split out from Sharp an LCD panel plant now under construction in Sakai City, Osaka Prefecture, which will use 10th generation motherglass substrates.

Japan's business daily *The Nikkei* reported that Sony plans to invest $926 million in the Gen 10 plant, which Sharp had announced last year.

According to a joint press release, the two companies will negotiate in good faith to enter into legally binding joint venture documentation by September 30, 2008.

The parties will aim through this collaboration to further strengthen Sharp's advanced LCD technologies and Sony's competitiveness in the TV market, according to the press release. The new joint venture will seek to maximize the advantages gained from using the world's first 10th generation glass substrates to produce large-sized LCD panels and modules, with a goal of generating 72,000 substrate panels per month. These will then be supplied to Sharp and Sony in quantities corresponding to their respective investments; the current agreement calls for Sharp to own 66% of the venture, and Sony to own 34%. Sharp and Sony will also discuss and study the possibility to jointly develop components for LCD modules to further reinforce their mutual cooperation.

The name of the joint venture is still to be determined.

This is the latest in a series of partnerships and sales in the LCD market. Sharp announced a similar agreement with **Toshiba** in December that called for Sharp to provide the venture with flat-panel LCDs. Also in December, **Hitachi** announced it would sell its LCD panel subsidiary to **Canon** and its stake in IPS Alpha to **Matsushita**.

Sony is already part of a joint venture with **Samsung**, named S-LCD, formed in 2003. According to an article in *EE Times Asia*, the Sony-Samsung venture constructed new fabs in 2004 and 2006, with Sony investing some $1 billion to $1.38 billion each time. With the latest developments, Samsung may solely invest in S-LCD's Gen 10 production line, which is estimated to cost $5.3 billion to build.

According to the article, S-LCD's 10G production line is expected to bring annual sales of $4.25 billion when it begins operation; Sony is expected to buy 50% of the plant's output. Sony has bought around $2.12 billion to $3.19 billion worth of LCD panels annually from S-LCD since the inception of the joint-venture.

Sony President **Ryoji Chubachi** said during a press conference in late February that S-LCD will continue to be the main supplier for the company's LCD business.

— Staff Reports

QMT, Hisense Reveal Design of First Mobile Phone to Incorporate mirasol Displays

Qualcomm MEMS Technologies Inc. (QMT) announced in mid-February the design specifications of the **Hisense** C108 mobile phone that will become the industry's first handset with QMT's mirasol display. The Hisense C108 uses a 1.2-inch mirasol display that features a resolution of 130 ppi (128 × 96 pixels). The mobile phone is a lightweight, low-power, candy-bar style handset that weighs less than a quarter pound (80 grams), and it will begin shipping in 2008 to China and emerging mobile markets.

Based on a reflective technology called interferometric modulation (IMOD), mirasol displays harness ambient light and require no backlighting, thereby consuming significantly less power that many other displays, according to QMT. The reflective mirasol display also automatically scales to the surrounding lighting conditions, allowing users to see their content in almost every environment, even bright sunlight.

The Hisense phone is one of several portable consumer-electronics products using a bichrome mirasol display to be rolled out in 2008. Other products include a Stereo Bluetooth Device from Audiovox, the SHOW WCDMA Monitoring System from KT Freetel (KTF), one of Korea's largest telecom operators; and a leading-edge GSM watch and Bluetooth stereo headset from Foxlink.

"(The Hisense phone) shows the commercialization of the technology and where it is headed," said **Jim Cathey**, vice president of business development, Qualcomm MEMS Technologies Inc. "We didn't come out and announce products. This is a focused and targeted commercialization strategy where we target the handset and handset-accessories markets. We go after those design wins, starting first with the Tier 2 and Tier 3 OEMS, and then Tier 1."

The mirasol display is 50% reflective, meaning it reflects back 50% of the light that hits the screen, Cathey explained, and this allows it to be read in virtually any ambient lighting condition. It also makes the display extremely low power—Cathey claimed that the mirasol uses only 1 milliwatt of power when operated in most ambient lighting conditions, compared to 220-320 milliwatts for displays currently being used in multimedia-enabled handsets, such as liquid-crystal displays (LCDs). Mirasol displays have a similar cost structure to LCDs, he added, and have similar equipment sets and bills of materials, though the mirasol displays are able to remove some components such as color filters and polarizers that are common to LCDs.

For a completely dark environment, the phone comes equipped with a front light

(continued on page 52)

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guest editorial

Display Electronics: Complex, Yet Critical

by Lewis Collier

With the expected demise of broadcast TV and the need to allow my wife to tape "her shows" while playing chauffeur for the kids, we finally splurged for some new display electronics. No, not a new display, but a cable set-top box with an integrated DVR function. This, of course, led to a series of machinations regarding how to run the old (1 year is a long time in this business) 27-in. LCD TV with the newfangled box rather than (actually, while not losing) the ability to also tape with the "old-fangled" VHS. How ironic it was when I was asked to be the guest editor for the Display Electronics issue of *Information Display* while engaging in my own battles with similar demons.

As we all know, electronics affects every facet of display technology. From signal-input receivers (with all their noise and impedance-matching issues), through image processing, such as compression and display quality, to the synchronized symphony of pixel drive and illumination control, display electronics can be complicated. When setting up our new DVR set-top box, I discovered that our TV does not support any of the myriad remote-control codes. This was clearly an unexpected (and unnecessary) addition of complexity to the display processing chain. My wife, who is a self-proclaimed "non-techie," now completely understands how to use the DVR. I, however, remain at a loss as to why my TV doesn't respond to one of the hundreds of already defined codes or why there are hundreds of codes in the first place.

Soon after my entry into the display field, I often uttered my mantra of "I hate drive electronics" when faced with issues regarding rear-projection television (RPTV) electronics for driving microdisplays. I understood that the task at hand was hard, I just did not understand how hard. Years later, I have a better appreciation for just how much effort goes into bringing information-display electronics to life. I hope that the articles selected for this issue should help shed light on this issue for you, the reader, as well as showing ways in which the complexity problem can be solved.

In his article on "Image Enhancements in the Wavelet Domain," Barry Mapen of Alion Science provides insights into how wavelets can be used for video compression and how the compression processing can be used to reduce the processing power required to perform some of the basic image adjustments that all display products must provide. While demonstrated with the wavelet transform, these power-saving methods can be used with other compression techniques as well.

In "Design Considerations for LED Backlights," Suzanne Thomas and Stephen Soos of Applied Concepts help break down the requirements of LED lighting. By comparing the drive circuitry to the prevailing standard CCFL drivers, they provide a list of issues to be considered when designing or choosing LED drive electronics. The complexity of these challenges can be reduced by the choice of driver solutions. The drive solutions are not as easy as ordering one from a catalog, yet, but as LED backlights become more ubiquitous, this day will come.

Display electronics is complex. We hope that you find the information in this issue insightful and relevant to your pursuit of understanding this complexity in display electronics.

– Lewis Collier

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Technology Momentum

by Aris Silzars

One of my memorable experiences from the time I spent in Princeton was standing on the platform at the Princeton Junction train station and watching the Amtrak Metroliner trains come blasting by at full speed. The platform at Princeton Junction is quite close to the tracks so one gets to experience the full effect of a massive locomotive going roughly 100 miles per hour. The Shinkansen bullet trains in Japan also produce this same sensation of unbridled power as they hurtle through stations just a few inches from the platform.

Momentum is defined as mass times velocity. A large locomotive has plenty of mass, and at 100 miles per hour it also has considerable velocity. Our brains seem to have an innate ability to make the momentum calculation. Each time I would watch one of these trains hurtle past, I would instinctively imagine how a bug must feel just before encountering the windshield of a car going at freeway speeds.

So how should we interpret the title of this column – *Technology Momentum*? And why might we find it important to understand the implications of this concept?

In applying the concept of momentum to a discussion of technology, the equivalent of "mass" is the size of any existing enterprise or institution, and the equivalent of "velocity" is the rate of change in any given technology. The larger an existing enterprise is and the faster it is moving, the more difficult it becomes to disrupt its success. And if the existing enterprise is supported by a massive infrastructure, then it does not even have to move all that fast in order to have virtually unstoppable technology and business momentum.

Consider, for example, the competition between silicon and GaAs in the semiconductor business. For many years, it was predicted that GaAs would provide stiff competition for silicon-based products in any application requiring high-speed signal processing. However, GaAs never became a mainstream technology even for these applications. The silicon infrastructure was so massive that nearly every product that the GaAs technologists brought to market was soon eclipsed by the more powerful silicon technology base. The GaAs technologists could never achieve a high enough technology change "velocity" to overcome the more massive resources of the silicon infrastructure.

Today, we are experiencing the same phenomenon in software development. While we have all evolved to using our computers as primarily communications devices, we see Microsoft bringing yet another fancier version of Windows to market that is of little practical use to most of us. Yet the revenue stream continues to grow for Microsoft because this huge speeding train is just about unstoppable. It will take a further major revolution in computer usage before this train derails. Certainly, such derailments have happened in the past. Consider, for example, Wang and DEC. Each was a successful company until what they had to offer was replaced by a new capability that made them obsolete. We can, of course, add many other examples such as Polaroid, the film business at Kodak, and what is currently happening to CRTs.

Applying the concept of technology momentum, we can see that what finally caused the massive existing technologies to be replaced were new technologies that came along offering new developments at a faster pace or capabilities that the existing technologies simply could not address. An early hint that CRTs would not always be

(continued on page 52)


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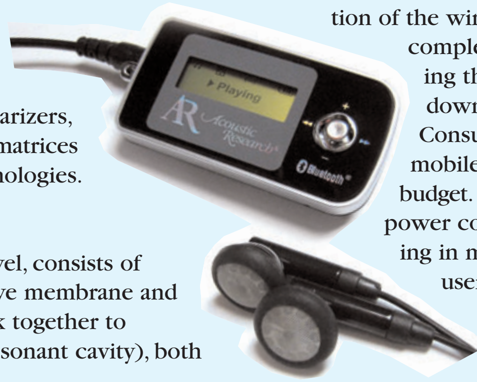
Qualcomm MEMS Technologies, Inc. (QMT)

Qualcomm MEMS Technologies, Inc. (QMT), a wholly owned subsidiary of Qualcomm Inc., has developed the industry's first direct-view MEMS display for mobile devices—mirasol™ displays—an innovative technology that offers low power consumption and superior viewability in virtually any environmental condition, including bright sunlight.

Qualcomm mirasol Technology – One of a Kind

Qualcomm's mirasol display is based on a revolutionary reflective technology called interferometric modulation (IMOD), a phenomenon that mimics the mechanisms that naturally create vibrant colors in a butterfly's wings. Though simple in structure, mirasol display's IMOD elements provide the functions of light modulation, color selection and memory while replacing the functionality provided by polarizers, liquid crystal, color filters, and active matrices provided by competing display technologies.



How mirasol Displays Work

A mirasol display, at its most basic level, consists of a self-supporting deformable reflective membrane and a thin-film stack (both of which work together to create a mirror within an optically resonant cavity), both residing on a transparent substrate.

When ambient light hits the structure, it is reflected both off the top and off the reflective membrane. Depending on the size of the gap, light of certain wavelengths reflecting off the membrane will *constructively* interfere, while others will *destructively* interfere. Certain wavelengths will be amplified with respect to others and, as a result, the human eye will perceive a color.

By applying a voltage to the thin-film stack, electrostatic forces will cause the membrane to collapse. The change in the optical cavity now results in constructive interference not visible to the human eye. Hence, the image on the screen appears black. A full-color display can be assembled by spatially ordering IMOD elements reflecting in any color wavelength.

To learn more about mirasol display technology, visit www.mirasoldisplays.com.

Qualcomm's Wireless Vision and mirasol™ Technology – A Perfect Complement

Qualcomm strongly believes that the broad delivery of wireless multimedia services is the next logical step in the evolution of the wireless industry. QMT's technology perfectly complements Qualcomm's overall strategy of increasing the capability of wireless devices while driving down cost, size and power consumption.

Consumers today are increasingly using convergent mobile devices, further taxing the device's power budget. Qualcomm's mirasol displays provide reduced power consumption and increased viewing time resulting in more time between charges: a value-add to users and service providers alike.

Qualcomm's strength and experience in the wireless market allow the company to rapidly bring mirasol displays to the marketplace. Qualcomm continues to leverage its longstanding relationships with wireless operators, handset manufacturers and content providers, its industry-leading chip position, as well as its strong financial position to accelerate the development and deployment of this technology and 3G solutions as a whole.

Qualcomm MEMS Technologies, Inc. is headquartered in San Diego, Calif., with offices in San Jose, Calif. and Hsinchu, Taiwan.

For more information on QMT and mirasol displays, visit: www.mirasoldisplays.com.

QMT Recent Milestones

Hisense – First mobile phone to incorporate mirasol displays as main display
February 11, 2008

Foxlink – Two design wins including GSM watch and Bluetooth® device
January 7, 2008

KTF – Marked QMT's entrance into Korean market with WCDMA camera monitoring device
January 7, 2008

Audiovox – The first product featuring mirasol™ displays to hit store shelves
January 3, 2008

For up to date press and media information, visit: www.qualcomm.com/qmt/press

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Image Enhancements in the Wavelet Domain

Conventionally, consumer electronics has provided a way for the user to adjust the brightness, contrast, hue, saturation, and sharpness of a display. These types of image enhancements can be applied in the image domain after decoding a compressed digital video stream. This article describes a method to perform these enhancements efficiently in the wavelet domain. The result is fewer operations per pixel and, therefore, a more power-efficient solution.

by Barry E. Mapen

CONSUMER ELECTRONICS typically provides the user with the option to adjust the basic picture quality on their displays by tweaking the brightness, contrast, hue, saturation, and sharpness. One method of doing this is to adjust the value of each pixel just before the image is sent to the display. This involves scaling (multiplication) and offsetting (addition) each pixel by the adjustment values. Because this operation is performed directly on the image that is displayed, it is considered an image-domain or spatial-domain algorithm. Alternately, the same enhancements can be achieved using fewer operations on the compressed image in the frequency domain and, more specifically, the wavelet domain. The result is a reduction in power consumption, which is critical for portable applications. This article provides a brief overview of wavelet-based image compression to understand how an image is mapped in and out of the wavelet domain and describes how to perform the same image enhancements in the wavelet domain.

Compression

Compression algorithms (codecs) seek to represent the original video sequence using fewer bits by removing redundant information. This is accomplished by trading more

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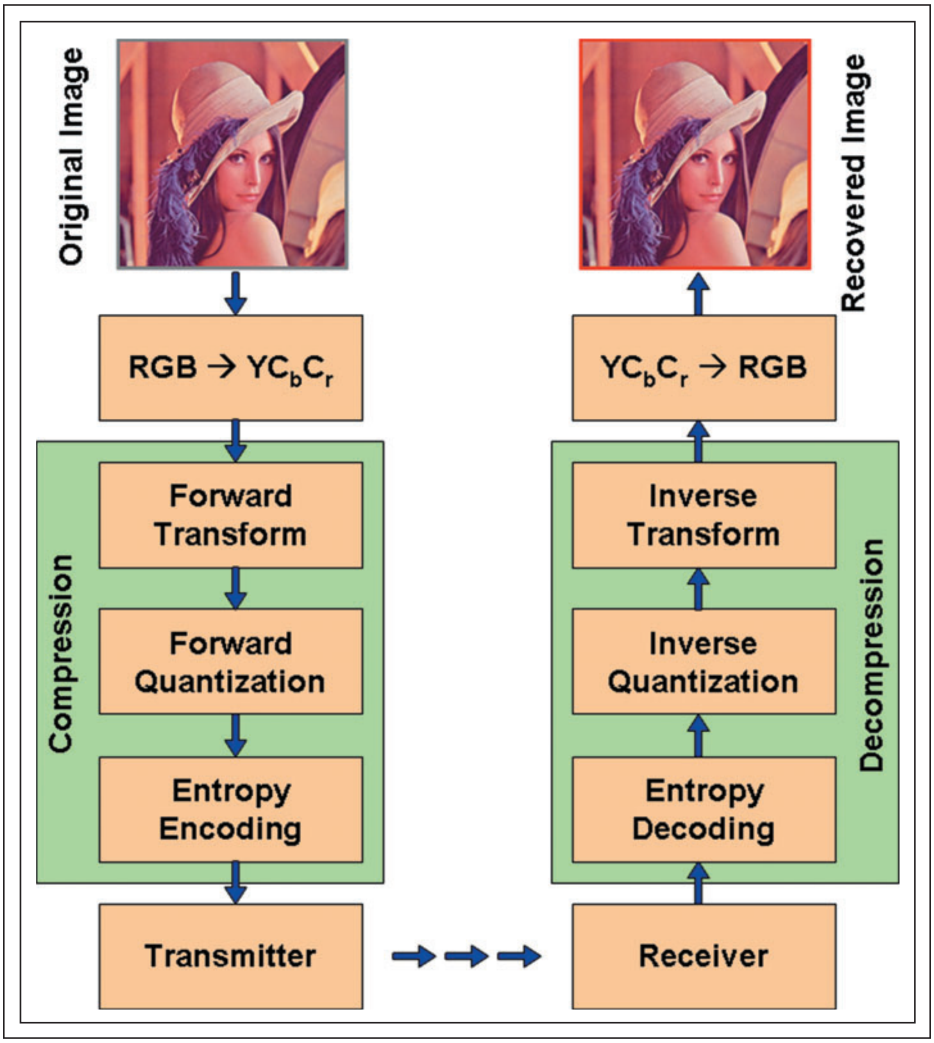

***Fig. 1:** Generic codec processing flow.*

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computational cycles (time) for fewer bits (space). This is generally done as a series of invertible processing stages (Fig. 1). The recovered image after decompression may not be identical to the original image, but it should look close enough to the original image as observed by an average viewer. This relaxation in accuracy enables lossy codecs, such as MPEG, to achieve very high compression ratios.

The common compression stages are the transform, quantization, and entropy coding. Additional stages, such as motion compensation, may be implemented to increase the compression ratio, but are not necessary for performing image enhancements in the wavelet domain.

Individual video frames are characterized by the number of pixels used to represent the image, which is more formally known as the spatial resolution. Pixels are characterized by the number of colors they can represent, which is known as the color depth or spectral resolution. How long a frame is presented before changing to the next frame is the frame rate or temporal resolution. The higher the resolution in any dimension (spatial, spectral, or temporal), the more bits are needed to represent the video sequence. This leads to an explosion of data as cameras and information-display devices increase in all three dimensions every year.

To better appreciate this, consider the number of pixels displayed to a user during the course of an average movie. Most standard-definition televisions process and display 30 frames per second (fps) with a spatial resolution of 720 × 480 pixels (0.35 Mpixels). Assuming a movie is 2 hours long (7200 sec),

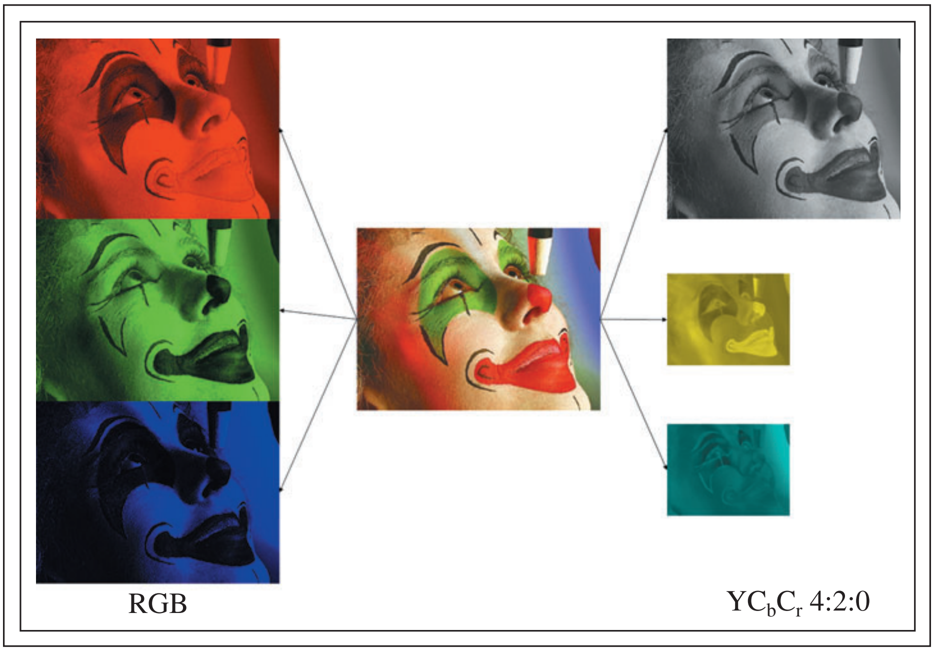

Fig. 2: *Equivalent RGB and YC_bC_r color spaces.*

then the total number of pixels displayed is 74,649,600,000 (~75 billion). High-definition television (HDTV) has a spatial resolution of 1920 × 1080 (2.07 Mpixels). This causes the number of pixels to increase by more than a factor of 5. Storing these pixels on DVDs or transporting them over networks requires compression to fit in the available space. To understand how the codec locates redundant information, we follow the original image through the processing stages.

Most of us are familiar with the three-channel red-green-blue (RGB) color space, but there are many equivalent color spaces that can represent the same image (Fig. 2). The most commonly used space for compression is YC_bC_r which uses a luminance channel and two chrominance channels. Because human vision is heavily biased to the black–and-white portion of the image, the chrominance channels may be scaled down without noticeably changing the appearance of the image. This provides an immediate reduction in the total size of the data stream by 50%

Once in the YC_bC_r color space, each channel is sent to the transform stage where it is

Fig. 3: *Calculating details lost by scaling.*

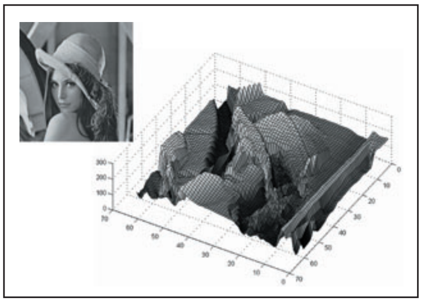

Fig. 4: Visualizing spatial frequencies.

converted from the image domain into the wavelet domain. Intuitively, a smaller image takes less space to store than a larger one. It would be great if the transform could simply scale the image down and send a thumbnail to the decoder. Unfortunately, information is lost when scaling down an image. When scaling the image back up to the decoder, the image will look blurry or pixilated. At the encoder, it is possible to scale the image back up, subtract it from the original, and send these details that were lost by scaling to the decoder as shown in Fig. 3.

At the decoder, the small image is scaled back to its original size, and the missing details are added in to fully restore the original image. Wavelets essentially scale the image down and intelligently keep track of the lost details.

The wavelet domain organizes the transformed values into groups by spatial frequency. To visualize the spatial frequencies, consider the image as a 3-D plot where the height of each pixel is its value in that channel. When viewed from directly above, the 3-D plot looks like a normal 2-D image. When viewed from a slight angle, the plateaus and valleys can be seen (Fig. 4). The constant level areas are low spatial frequencies, while the sharp transition areas are high spatial frequencies.

The transform alternately processes the rows and columns of the image by applying high- and low-pass filters (Fig. 5). These filters separate high- and low-frequency areas of the image.

The result is a smaller version of the original image and the three groups that contain the highest horizontal, vertical, and diagonal frequencies present in the image. These groups are referred to as sub-bands. This decomposition process is recursively applied on the smaller image (Fig. 6). Most images contain very little high-frequency information, which means

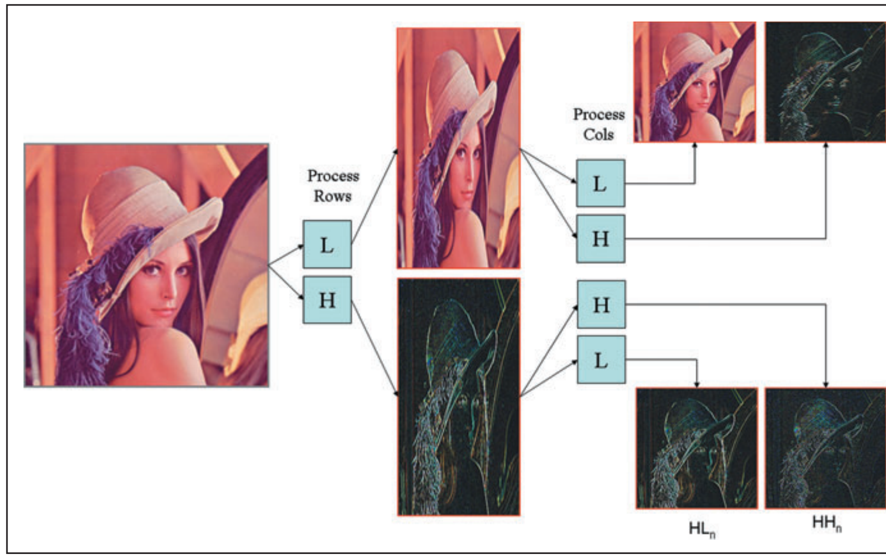

Fig. 5: Wavelet decomposition process.

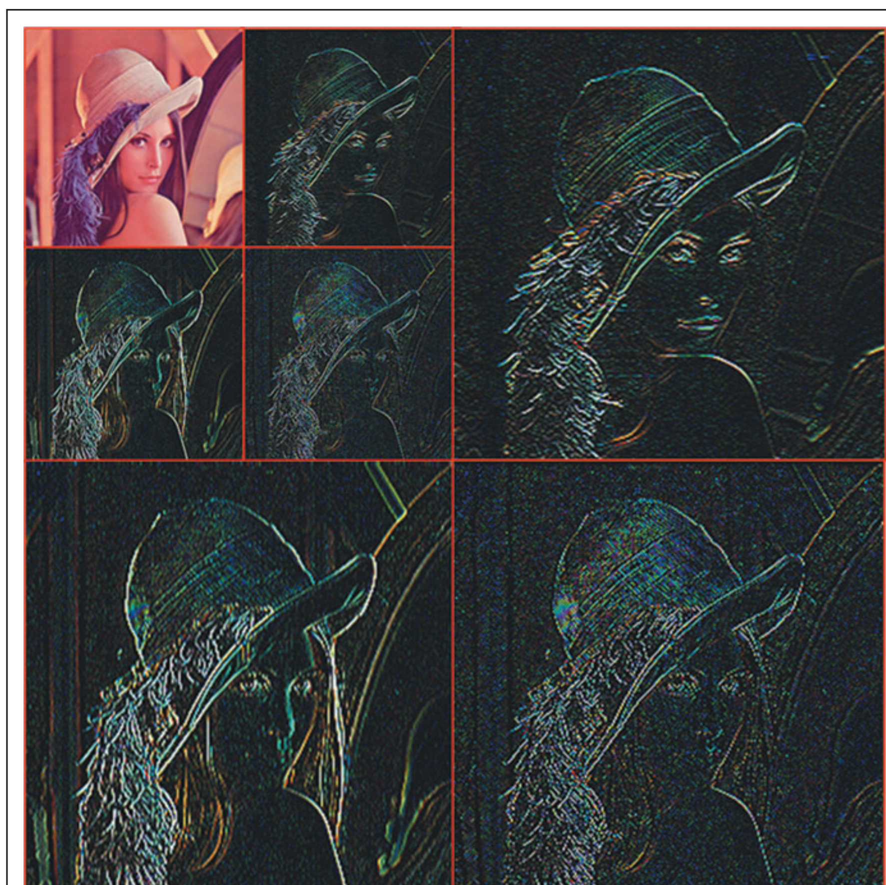

Fig. 6: Repeated decomposition.

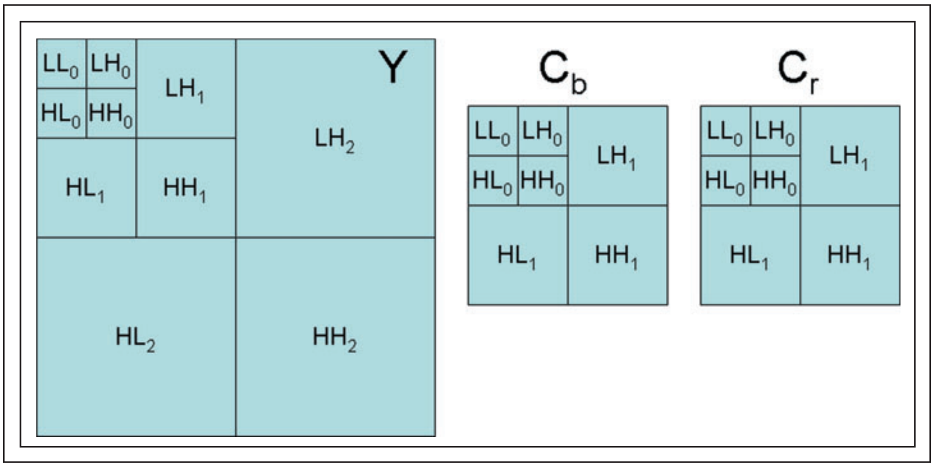

***Fig. 7:** Complete image decomposition.*

***Fig. 11:** Adding positive values (+16,384) increases the brightness.*

***Fig. 12:** Adding negative values (–16,384) decreases the brightness.*

most of the coefficients in the sub-band are zeros (black areas). These long runs of zeros can be efficiently represented by the count of zeros between non-zero coefficients, instead of sending over the values for each pixel.

The transform stage is complete when all channels of the image have been transformed (Fig. 7). For more information on wavelet decomposition, see Ref. 1.

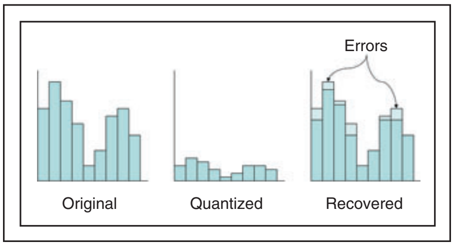

***Fig. 8:** Linear quantization error.*

The next stage, forward quantization, reduces the variance of coefficients within the band and is the largest source of information loss for most codecs. The simplest quantization technique is the linear algorithm that divides each coefficient by a constant and truncates the result. During decoding, the inverse quantization stage multiplies each coefficient by the same constant. The result is approximately the original value, but may have an error due to the truncation during the forward quantization stage (Fig. 8).

Image Enhancements

There are two key areas of the decoding process where the image-enhancement computations can be performed. The first is during the inverse-quantization stage. Instead of multiplying the coefficients in the sub-band by the same constant used for quantization, we change this constant to a new value that performs one or more of our image enhancements. Similarly, if the enhancement requires changing the value of every pixel in the final image, this can be done by modifying the pixel in the smallest sub-band that resembles the original image (LL_0). The change will ripple through the entire image as it is decoded. For reference, the starting images are provided (see Figs. 9 and 10).

Brightness

Brightness is a fixed offset added to every pixel in the image domain that causes a shift in the average value (DC level) of the image. Adding positive values increases brightness

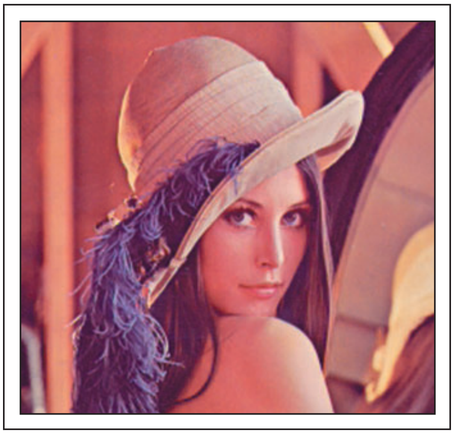

***Fig. 9:** Original color.*

***Fig. 10:** Original black and white.*

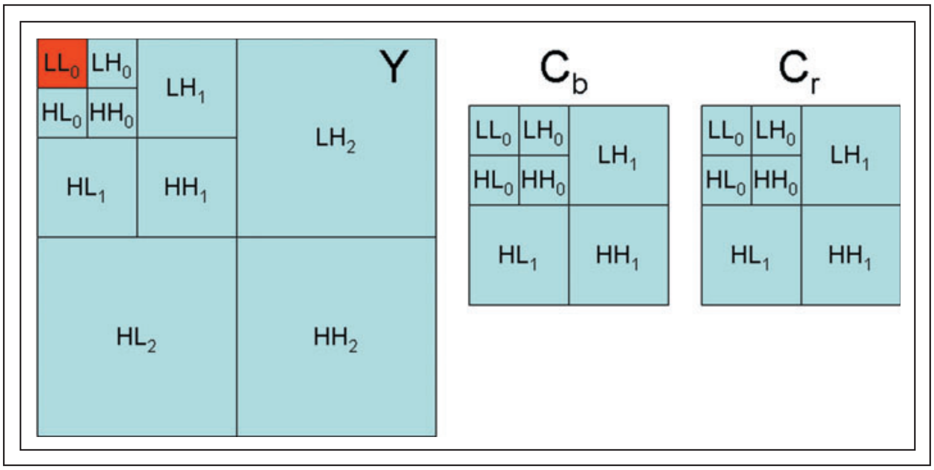

Fig. 13: *Brightness adjustment map.*

(Fig. 11) while negative values decreases the brightness (Fig. 12). Typical image domain shifts are in the range of ±31 with a full range of ±255. In the wavelet domain, this energy is mapped to the final approximation (LL_0) sub-band in the Y channel (Fig. 13). To change value, offsets can be added to every pixel in this sub-band. The range of the offset is larger than in the image domain and is dependent on the number of levels of decomposition. However, an addition is one operation regardless of the value being added. Since there are far fewer coefficients in the Y-LL_0 sub-band than in the final image, this enhancement is more efficient in the wavelet domain. The modified area is shown in red in Fig. 13 to give a relative perspective on the number of points modified.

Fig. 14: *Multiplying by values greater than than one (1.5x) increases the contrast.*

Contrast

Contrast is a constant multiplier applied to every pixel of each channel in the image domain. To avoid color shifts, the same contrast multiplier must be applied to each channel. Multiplying by values greater than one increases the contrast (Fig. 14) while values less than one decrease the contrast (Fig. 15). Typical contrast multipliers are in the range of 0-1.992. As mentioned earlier, the multiplication must be performed as part of the inverse quantization stage. Changing the value can be done once when the user sets the contrast, resulting in no additional operations while decoding and displaying.

Hue

Looking at a color wheel, hue is generally

Fig. 15: *Multiplying by values less than one (0.5x) decreases the contrast.*

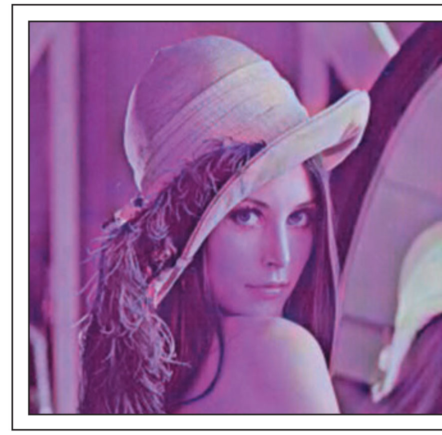

Fig. 16: *Positive angles (+10°) produce a rotation towards blue.*

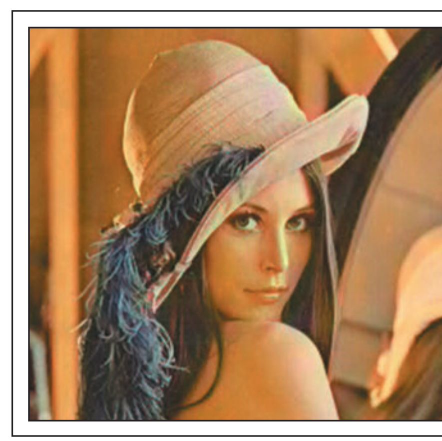

Fig. 17: *Negative angles (–10°) produce a rotation towards yellow.*

defined as a rotation of the wheel by an angle. In the YC_bC_r color space, this equates to

$$C_b' = C_b\cos(\theta) + C_r\sin(\theta),$$
$$C_r' = C_r\cos(\theta) + C_b\sin(\theta).$$

Positive angles produce a rotation toward blue (Fig. 16) while negative angles produce a rotation towards yellow (Fig. 17). Typical hue angles are in the range of ±30°. Hue is applied equally to the entire image, and thus the information is stored in the C_b-LL_0 and C_r-LL_0 sub-bands of the chrominance channels. To change the hue, compute the coefficients in C_b-LL_0 and C_r-LL_0 by the formula above. The cosine and sine of the requested angle may be computed once during set-up and used as a fixed percentage in subsequent computations. This

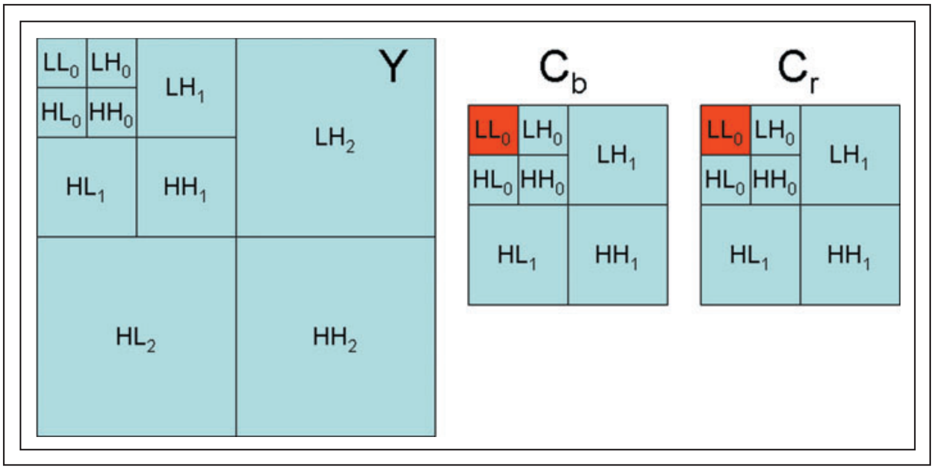

Fig. 18: *Hue adjustment map.*

Fig. 21: *Multiplying by values greater than one (1.5x) increases the sharpness.*

Fig. 22: *Multiplying by values less than one (0.5x) decreases the sharpness.*

operation is not free, but follows the same efficiency argument as brightness adjustments in the wavelet domain (Fig. 18).

Saturation

Saturation is a constant multiplier applied only to the chrominance channels in the image domain. Multiplying by values greater than one increases the saturation (Fig. 19) while values less than one decrease the saturation (Fig. 20). As with contrast, saturation multipliers are in the range of 0–1.992.

In the wavelet domain, this equates to applying the multipliers to the C_b-LL_0 and C_r-LL0 sub-bands. Similar to contrast, this can be done as a free operation by modifying the inverse quantization constant.

Sharpness

Sharpness is perceived by increasing the amplitude of high-frequency luminance information in an image. Because of this, every sub-band *except* LL_0 in the Y-channel are scaled by a constant. Multiplying by values greater than one increases the sharpness (Fig. 21) while values less than one decrease the sharpness (Fig. 22). Typical sharpness multipliers are in the range of 0–1.992. Because of the hierarchical dependence of the sub-bands on one and other, the same constant must be used across each of the sub-bands (Fig. 23).

Results

The goal of this work is to provide more efficient methods of image-enhancement images from compressed data streams. Assuming the stream must be decoded, the comparison is between decoding and then applying the enhancement verses applying the enhancement in the wavelet domain. Table 1 summarizes the additional operations per pixel ignoring any one-time initialization operations. The fractional results are based on the number of coefficients in the LL_0 sub-band that is dependent on the number of times the decomposition process is recursively applied (γ). Simply put, these values will always be less than one. Considering how many pixels must be processed per second, the additional operations for traditional processing quickly add up.

It should be noted that the traditional counts include the added memory accesses to read and store the results since this is done as an

Fig. 19: *Multiplying by values greater than one (1.5x) increases the saturation.*

Fig. 20: *Multiplying by values less than one (0.5x) decreases the saturation.*

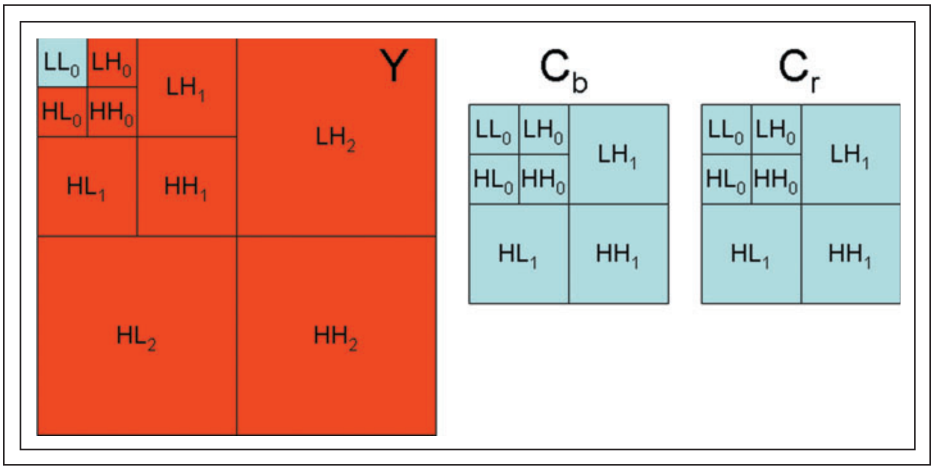

Fig. 23: Sharpness adjustment map.

independent pass over the data. Therefore, if combining multiple enhancements, the total cost would be less than the sum of those operations. For example, brightness and contrast can be implemented in a single pass requiring only one load and one store.

Conventionally, these processing steps are performed on the video image in the analog domain, before digital quantization, and, in this case, no processor power is required. Analog circuits in color TVs and video amplifiers made these adjustments in response to analog controls or knobs adjusted by the user. However, modern video-processing systems increasingly convert the incoming video signals directly to digital values at the very beginning of the processing chain before additional processing is performed, necessitating clever ways to minimize the processing burden and maximize data throughput.

Table 1: Additional operations per pixel.

Enhancement	Wavelet Domain	Traditional
Brightness	$\frac{1}{2^{2\gamma}}$	5
Contrast	0	5
Hue	$2\left(\frac{1}{2^{2\gamma}}\right)$	9
Saturation	0	5
Sharpness	0	22

Conclusions

Using the technique described herein, basic image enhancements may be implemented with little or no additional computational loading. The result is a reduction in power consumption compared with conventional decoding and then enhancing.

It should also be noted that this work can be applied to other transforms including the discrete cosine transform (DCT) used by MPEG. For a more thorough discussion of these and other enhancements in the image domain see Ref. 2, and for the equivalent enhancements in the wavelet domain see Ref. 3.

In addition, using this technique makes it possible to independently adjust multiple streams when decoding, which may be desirable for applications such as security where multiple cameras are displayed on a single monitor. Here, the image enhancements are compensating more for variations of the cameras than variations of the display.

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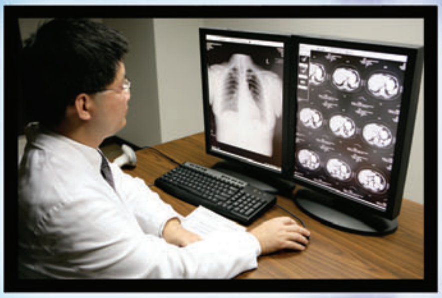

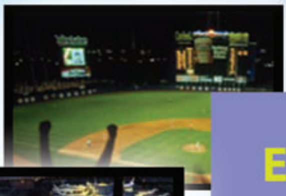

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Considerations for LED Backlight and Driver Solutions

LCD manufacturers have been fairly slow to introduce LED-backlit LCD panels into the high-performance and high-reliability markets, especially for larger display formats. However, there are solutions available today for these larger panels with edge-lit or direct-view LCD-backlight retrofits. This article will examine several LED backlighting options currently commercially available to today's engineers.

by Suzanne Thomas and Stephen Soos

ALTHOUGH THE SHIFT from cold-cathode fluorescent lamps (CCFLs) to solid-state lighting as the primary choice in liquid-crystal-display (LCD) backlighting is only in its early stages, the transition is gaining momentum and the shift seems inevitable. Due to their superior luminance and power efficiency, light-emitting diodes (LEDs) are apt to continue to grow in popularity at a rapid pace.

According to iSuppli Corp., revenues for LEDs are climbing rapidly, driven by strong demand for LEDs as backlight units (BLUs) in keypads and mobile displays. Use of LED BLUs for notebook computers finally seems to be ramping up. Additionally, LED backlights have become ubiquitous in LCDs targeted at the industrial marketplace; however, the majority of these to date are less than 6 in.on the diagonal.

For system designers considering larger display formats (6–24-in. diagonals) for industrial, marine, military/avionics, or other higher-performance and higher-reliability applications, there are a limited number of LED options available on the market today.

This article will discuss several LED-backlighting options commercially available to today's engineers, including the relative merits and challenges associated with each option. Considerations for choosing an LED driver will also be discussed.

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CCFL *vs.* LED

To date, the traditional backlight for LCDs have been CCFLs. While there are many differences between CCFLs and LEDs, as shown in Table 1, there is also one very significant similarity. Although the levels of voltage and current differ between the two technologies, both require a constant-current driving method for optimum performance.

LEDs offer many possible formats for backlighting LCD panels, such as direct-view or edge-lit and white or RGB, and the advantages of using LEDs are numerous, including

- Solid-state devices offer high reliability and long lifetime (50,000+ hours).

Table 1: Comparing CCFL and white LED characteristics

Key Characteristics	CCFL	White LED Rail
Voltage Levels	> 1500 Vpk	3–120 Vdc
Driving Method	Constant Current	Constant Current
To Achieve Wide Dimming Range	PWM Only	PWM and/or Amplitude
Light Output	Horizontally Uniform	Point Source
Light Efficiency in Backlight		Average 2:1 *vs.* CCFL
Performance Over Temperature	Cold & Hot Roll-Off	Hot Roll-Off
Warm-Up Period	Yes	No
Color Temperature	Limited Choices	Range of Choices
Life	10–50 khours	> 50 khours

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- Lower operating DC voltage.
- Improved color gamut.
- Suitable for wide-temperature-range conditions, no warm-up period required.
- Compact, flexible, and mechanically robust.
- Mercury- and lead-free, RoHS compliant.
- Electrical-to-light efficiency exceeds that of CCFLs (when effectively coupled to the light guide).

Comparing LED technology to CCFL technology is akin to comparing transistors to vacuum tubes. LEDs provide a compact, solid-state solution that operates effectively at lower voltage levels and commensurately higher currents than CCFLs. A typical individual CCFL might specify a lamp current of 5–6 mA_{rms} with a lamp sustaining voltage of 500–750 V_{rms}, which implies a consumed power of 2.5–4.5 W per lamp. A single Luxeon III LED can be driven (with suitable thermal management) at 1.0–1.5 A. With typically 3.0 V of forward voltage drop, this implies 3.0–4.5 W of consumed power.

An LED provides a predominately fixed voltage drop (V_{fwd}) over a specified range of drive current levels (I_{fwd}). As shown in Fig. 1, this implies a negative resistance because as I_{fwd} increases, the impedance of the diode must decrease in order to hold V_{fwd} constant (per Ohm's Law, $E=IR$).

It is therefore necessary, as in the CCFL world, to provide current-limiting or current control when powering LEDs. Spacing and insulation concerns associated with CCFL backlight designs are practically eliminated because LEDs require significantly lower operating voltages and do not require an ignition voltage like CCFLs.

When considering the driver from a constant-current perspective, it is evident that voltage must still be developed to move the current, but once it reaches the level where the desired current is satisfied, it will then stabilize. In this case, the stabilization point will be the total forward drop of all the LEDs connected in series.

The number of LEDs that could be connected in series would only be limited by the maximum voltage that could be generated by the LED driver. It is this generated voltage that, in turn, drives the LEDs to the desired amount of current.

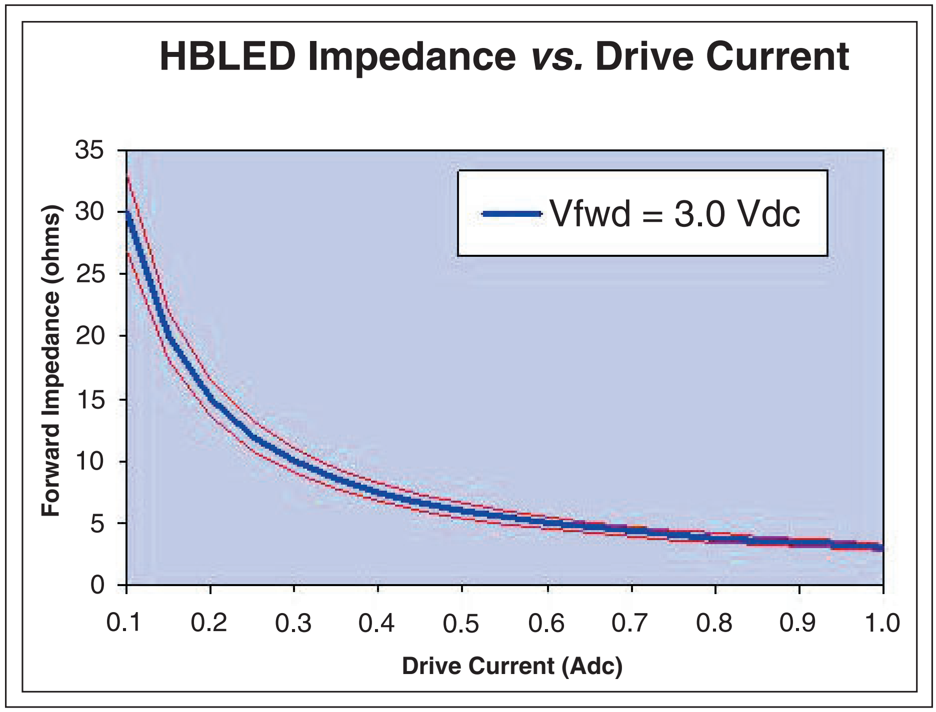

Fig. 1: High-luminance LED impedance vs. drive current.

Driver Electronics

In the past, when designing an LCD into a system, designers often would oversimplify or underestimate the challenges associated with integrating the CCFL backlight inverter. This was problematic due to the high-voltage nature of the CCFL inverter, and the tendency of this device to be noisy, to interfere with other electronics, and, at times, even cause visual anomalies on the LCD.

Surprisingly, though, driving LEDs presents system designers with some of the same problems, plus other unique challenges. Driving LEDs is not as simple as some may believe.

In the simplest application of LEDs, users could drive up to three nominal +3 V_{fwd} LEDs in series by simply using the native system voltage, +12 V_{dc}. The remaining +3 V would have to be reserved for a current-limiting resistor. This approach, albeit an inefficient one, might be very practical in low-power LED applications, such as small-format LED-backlit displays. Dimming and other control functions could be added as required.

In order to reach standard-, high-luminance, and ultra-high-luminance requirements for mid–to–large-format LCD panels, larger numbers of LEDs will be required, which means higher power. A more sophisticated constant-current-source approach is needed to efficiently supply appreciable amounts of power to these LEDs. Today, designers can choose from numerous IC LED drivers or a complete, integrated LED driver board.

IC or Complete Integrated LED Driver?

While few suppliers offer integrated, full-function stand-alone LED drivers, there seems to be a vast number of IC or chip-style LED drivers by comparison. This might create the perception that IC or chip-style LED drivers must be the ideal choice, but that is not necessarily the case. There are several key LED driver features to consider when deciding whether to use an IC to design a custom driver or an off-the-shelf integrated LED driver board. Some of these issues are

- ***Spatial Constraints:*** Does the application have a printed-circuit board or motherboard where the LED driver circuitry can reside and is there room to locate the circuitry on that board or will a separate PC board be required anyway?
- ***Development Costs:*** If there is a board on which the LED drive circuitry can reside, is there engineering expertise and resources in-house to design a circuit around chip-style LED driver(s)? Typically, these chips contain just the "smarts" or control functionality, and the

rest of the circuit must be designed and verified. Although many IC-driver manufacturers provide schematics, the economics of the design program or other factors may make an organic implementation undesirable for many companies. For applications involving multiple parallel banks of series-connected LEDs, some of these circuits can have many components and be quite complex.

- ***Life-Cycle Support:*** Is there value in having a fully tested and field-proven stand-alone LED driver design as well as the engineering and technical support from a reliable supplier? Remember, LED drivers are still power supplies. Most system designers would not entertain the idea of designing their own system power supply and, ironically, LED drivers require probably more sophistication than the power supply that is running the entire system. Without having power-supply experience, it is possible to run into problems after having thousands of units fielded.
- ***Driver Input Voltage:*** The LED driver must be able to run from a DC voltage that is readily available in the system. Some companies are promoting drivers based on a buck circuit topology, where the supply voltage for the LED drivers must be greater than the minimum required to power the LED string (or the total forward voltage drop of all the LEDs connected in series). In many cases, voltages required are 48 V_{dc} or higher, which in most systems are just not available.
- ***Driver Forward-Voltage Capability:*** One weakness of the IC or chip-style LED driver is that it is limited in the voltage that it can develop, which causes limitations in the number of LEDs that can be powered from a single IC or chip-style driver. For mid–to–large-format LCD panels, larger numbers of LEDs will be required, which would then necessitate multiple ICs and result in a highly complex circuit design and implementation of several parallel banks.
- ***Interconnection of Multiple LEDs:*** As the size of the display increases, the number of LEDs that are required also increases. In order to maintain some semblance of control of the number of wires and interconnections, the driver(s) architecture must be capable of efficiently driving multiple parallel banks of series connected LEDs, or be capable of developing higher voltages for a single but larger group of series-connected LEDs.
- ***Overall Solution Requirements:*** A full-function LED driver board, as shown in Fig. 2, may provide the flexibility to be used for LED-backlight retrofits (edge or direct view), as well as for OEM-factory LED-backlit panels. Additionally, a full-function driver may also provide enhanced control features such as wide dimming range, NVIS control capability, ambient-light sensing, and luminance feedback, which are often required for LCD systems today. Additional components and circuitry would be required to support these functions using a chip-style driver in most cases.

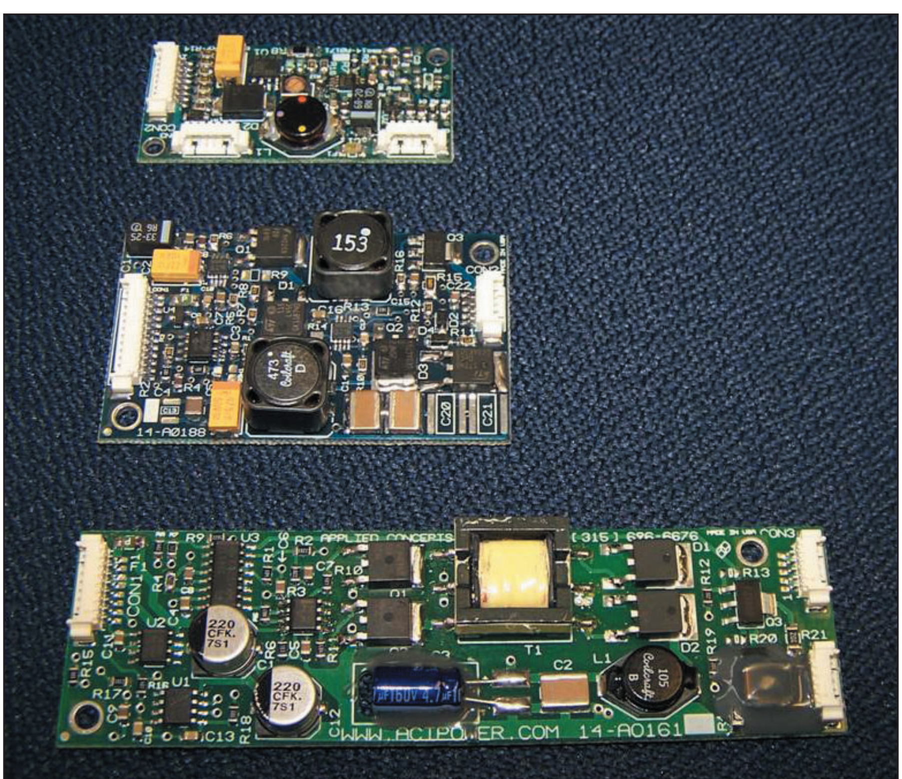

Fig. 2: *Complete, integrated LED driver boards can be used for LED retrofit backlights and for OEM LED-backlit panels.*

Configuring LEDs for Backlighting

LED-based backlights are still too new to have any interconnection standardization. The number of LEDs used will depend upon the size of the electrical and optical performance of the LEDs themselves, the LCD panel performance, luminance required, and thermal-management issues.

Interestingly, we have observed a "chicken and egg" scenario relative to the way LCD OEMs and others configure LEDs and the overwhelming number of LED IC or chip-style LED drivers as described above.

Many factory LED-backlit panels have the LED backlight configured in multiple parallel banks of series-connected LEDs, and it appears that these configurations are often chosen in order to use the IC or chip-style LED drivers, where the total forward-voltage drop of all the LEDs connected in series must not exceed that which can be generated by the chip driver. Multiple channels or banks are valuable for their redundancy; if one bank goes out (the LED fails or the driver fails), the panel remains usable. However, if they are employed due to limitations of the LED driver circuitry, multiple channel drivers create unnessessary complexity.

It would seem to make more sense to design an LED backlight to reach specific luminance, optical, and thermal performance goals, and then choose an integrated LED driver which has the capability to drive it, rather than to allow an inherent weakness (*i.e.*, limited voltage capability) of the chip-style LED driver to dictate the backlight design.

As an example, one supplier offers a 12.1-in. panel that utilizes 24 white LEDs connected in four banks of six each, as shown in Fig. 3.

The backlight requires 23 W of LED power (approximately 1 W per LED) to achieve 1000 cd/m^2. Each LED drops by approximately +3 V for a combined drop of +18 V per bank. The connections to these banks are brought out such that four independent constant-current drive sources are needed to effectively drive the panel. Each bank would consume 6 W of power at 0.33 A of drive current into the LEDs.

Making a simple change in the way the LEDs are wired internally to either two banks of 12 or one bank of 24 in series would have several advantages:

- Driver circuitry could be scaled to the appropriate power level required, thereby reducing the number of banks required and the cost associated with multiple drivers.
- Driving all of the LEDs in series allows them to be inherently driven by the same magnitude of current.

In Fig. 4, 30 white LEDs were re-wired to a single series-connected bank. In its new configuration, the backlight required just 9 W to achieve 1000 cd/m^2.

One of the advantages of a CCFL is that it provides a continuous length of light with the electrical terminations at the ends. When using LEDs in an edge-lit configuration, as shown in Fig. 4, wiring all of the LEDs in series from left to right or top to bottom allows for a simple two-wire interconnection. Depending upon how the LEDs need to be mounted within the display to obtain the best optical coupling to the light guide, the ability to string all of the LEDs in series with the electrical terminations at the end could provide a significant packaging advantage.

LED Solution Options: As previously mentioned, although limited, there are LED options commercially available to system designers today for larger display formats (6–24 in. on the diagonal).

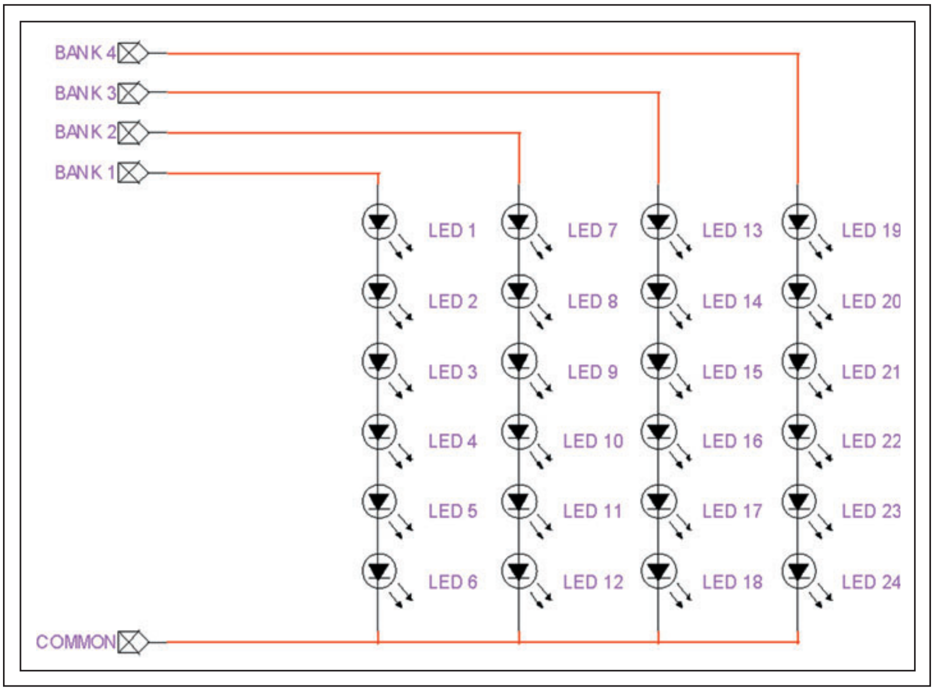

Fig. 3: An example of multiple parallel banks of series-connected LEDs.

LCD Panels with Stock LED Backlights

A number of LCD manufacturers now offer panels with LED backlights from the factory. The best case scenario for a system designer would be to find the right-sized panel that meets all of the performance specifications for the application and which comes with a factory LED backlight that is capable of meeting or exceeding the desired luminance for the application. This would likely be an excellent option from a cost standpoint.

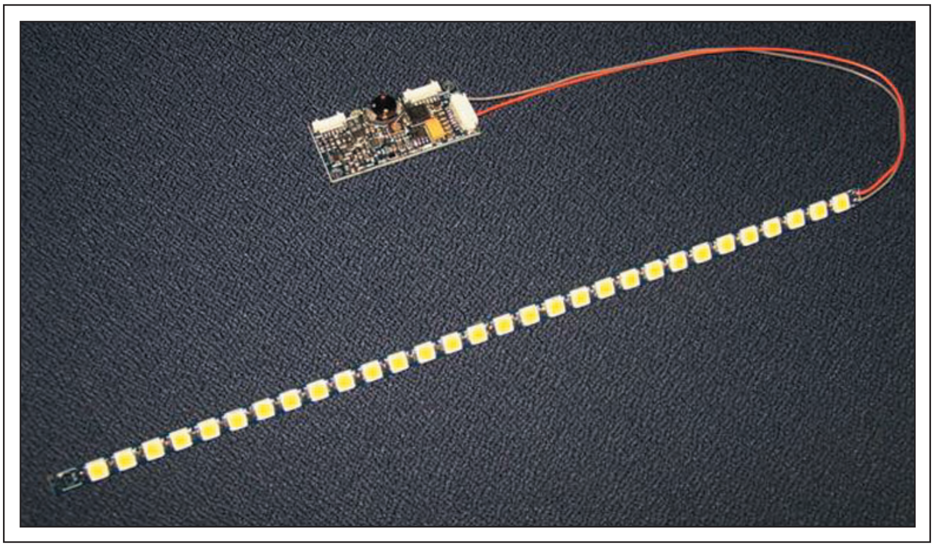

Fig. 4: An example of 30 white LEDs connected in series with a complete full-function driver.

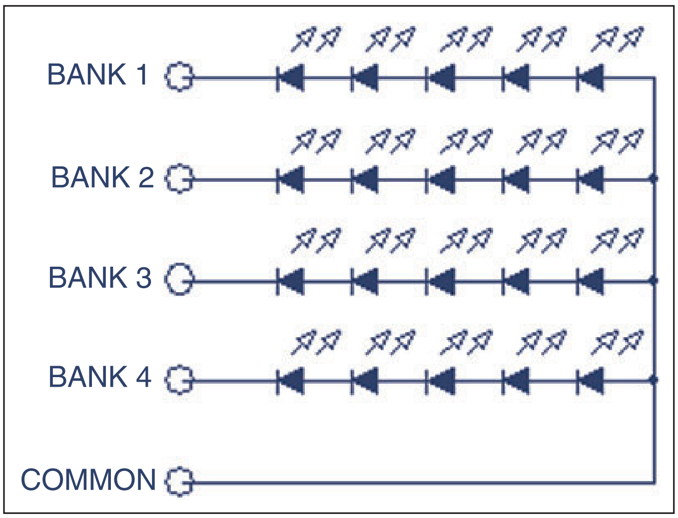

Fig. 5: Common-anode configuration.

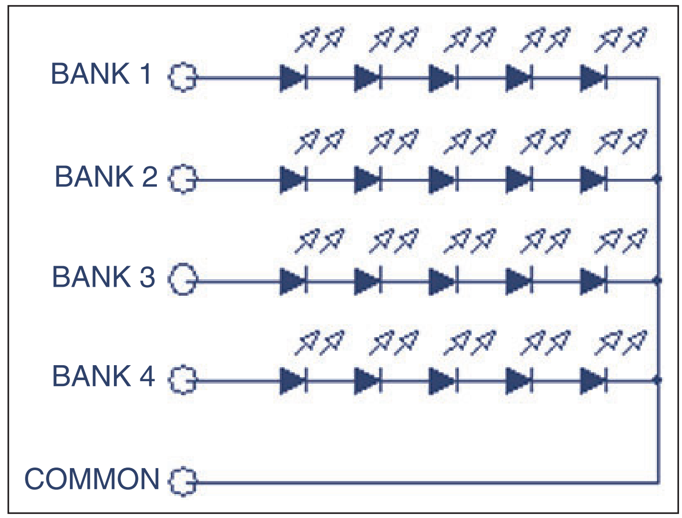

Fig. 6: Common-cathode configuration.

Unfortunately, this is the exception. Few panels today are readily available for any larger-sized formats – the majority are 6 in. on the diagonal and smaller – in mass-production quantities. Standard luminance and high luminance (up to approximately 600 or 650 cd/m^2) are possible to achieve with these panels, but ultra-high luminance (>800 cd/m^2) is not.

LED drivers will still be required for the vast majority of these factory LED-backlit panels. As mentioned above, one challenge to LED-driver suppliers is the lack of standardization in LED-backlight configuration and LED connectivity, both inside and outside these panels. Inside the backlight, some similarities exist in the way panel manufacturers configure the LEDs, which tends to be in multiple banks of series-connected LEDs, but that is where the similarities end. Some manufacturers choose a common anode connection (Fig. 5), while others choose a common cathode configuration (Fig. 6). Other panels bring out a separate cathode and anode connection for each bank, as shown in Fig. 7.

Outside the backlight, some panels have a separate, dedicated connector for the LEDs, while other panels house the LED connections on the same connector as the display data, power, and other signals.

This lack of standardization seriously challenges the ability of system designers to address connectivity of LED drivers.

Over time, we will see increasing numbers of panels with stock LED backlights from the LCD-panel manufacturers. Certainly, as the LED device efficiencies continue to improve over time, greater and greater luminance levels will be met with the factory LED-backlit panels. Until then, suppliers are offering retrofits to existing LCD panels in various configurations as described in the next section.

Retrofitting Existing Display Backlights

The first option to be considered is retrofitting the LCD backlight from the stock edge-lit CCFL to edge-lit high-brightness LEDs (white or RGB), as pictured in Fig. 8.

This approach is feasible and commonplace for panels ranging in size from 6.4 to 24 in. In fact, many manufacturers offer edge-lit panels with field-replaceable CCFLs, making a backlight retrofit fairly simple and minimally invasive to the panel itself. In most designs, the stock optics of the panels can remain unchanged.

As shown in Table 2, edge lighting with white LEDs *vs.* RGB LEDs presents both similar and dissimilar challenges. Both need effective diffusion and coupling to the display light guide, but RGB LEDs also require color sensors and color mixing, making the electrical-drive requirements quite complex. In addition, wiring of an RGB edge-lit LED might not be feasible for all panels given the limited space available in the former CCFL channel.

Although commercially available LEDs can achieve 70–90 lum/W, designers cannot underestimate how critical it is to efficiently couple the LEDs to the light guide in the panel. Using the brightest LEDs in the world is moot if you cannot effectively get the light where you need it. Suppliers have been able to overcome this challenge by offering complete LED solutions, as described below.

Some companies are offering generic LED strips or rails, in standard sizes such as 10.4 and 12.1 in. These rails are intended for use with a broad variety of panels from numerous manufacturers. Since it is critical to achieve the most efficient coupling to the light guide as possible, is becomes apparent that this approach has some inherent weaknesses. A generic rail might be a great fit for one or two panels, but might offer poor performance with many other panels. This approach also does not offer the thermal, diffusion, or spacer materials that might be necessary to the design.

Others companies are taking a semicustom approach, tailoring each LED rail (or rails) and the associated LED drivers to a specific panel or group of panels. The result is a highly efficient solution, offering a very significant improvement in power-in to light-out efficiency over the stock CCFL backlight (as described in Fig. 1). Due in part to the effective coupling of the LEDs to the light guide, these solutions typically can offer at least a 2:1 improvement over the stock CCFL backlight for panels up to 18 in. on the diagonal, which means that system designers can expect to double the luminance for the same amount of power consumed (or vice versa –

they can achieve the same luminance while consuming half the power).

Let us consider a specific example. We used a 12.1-in. SVGA TFT-LCD panel whose stock backlight consisted of two CCFL lamps, both oriented along the top edge of the panel. The luminance advertised by the LCD manufacturer for this configuration was 400 cd/m^2 typical, when the CCFL lamps were driven to a nominal 5-mA$_{rms}$ current per lamp. This luminance level was verified, and power consumption was measured at 6 W of CCFL power.

The CCFL backlight was then modified with a high-performance LED rail consisting of 31 series-connected white LEDs, plus a matched LED driver board. All of the panel's stock optics remained the same. The resulting performance of the LED backlight is as follows:

- 400 cd/m^2 with 2.9 W of LED power,
- 700 cd/m^2 with 5.6 W of LED power,
- 1000 cd/m^2 with 9.0 W of LED power.

Clearly, the LED-backlight performance exceeded that of the standard CCFL-equipped panel by more than 2 to 1. In fact, LED-backlight modifications on a range of panels (6.4–15 in. on the diagonal) from the same LCD manufacturer achieved similar performance improvements versus the stock CCFL backlights, as illustrated in Fig. 9. Comparable results have been found with panels from other LCD manufacturers as well.

For panels larger than 18 in. on the diagonal, LED-backlight retrofits can produce more modest improvements such as 1–1.5:1 improvement over the stock CCFL backlight.

Other advantages of the semicustom approach to edge-lit LED-backlight solutions include

- Support of standard-, high-, and ultra-high-luminance requirements, often using the identical LED rail(s) and driver(s).
- Allows for an open or short of one or more LEDs, without affecting the rest of the LEDs in the rail.
- Produces *better* luminance uniformity across the face of the LCD because the luminance variation across the length of the channel tends to be more consistent for an LED than for a CCFL.
- Withstands shock and vibration in an edge-lit configuration equal to or better than the CCFLs being replaced.
- Offers a quick design-to-market cycle because none of the display mechanicals or optics need to change, so little to no tooling cost or time is required.

Drawbacks to the edge-lit LED retrofit approach include

- High cost of high-brightness LEDs.
- Limited space available in the former CCFL channel offers limited design choices and flexibility.
- Stock CCFL backlights are discarded.

A second backlight retrofit option is modifying the LCD with a direct-view LED backlight (white or RGB), or with an LED BLU, which consists of optical films, a light guide, and edge-lit LED assemblies. These options are quite similar to existing aftermarket high-brightness CCFL backlights that have historically been used for achieving ultra-high luminance (>800 cd/m^2).

Drawbacks to this approach include

- Panels must be completely disassembled in order to use this approach, making it a much more invasive modification option.

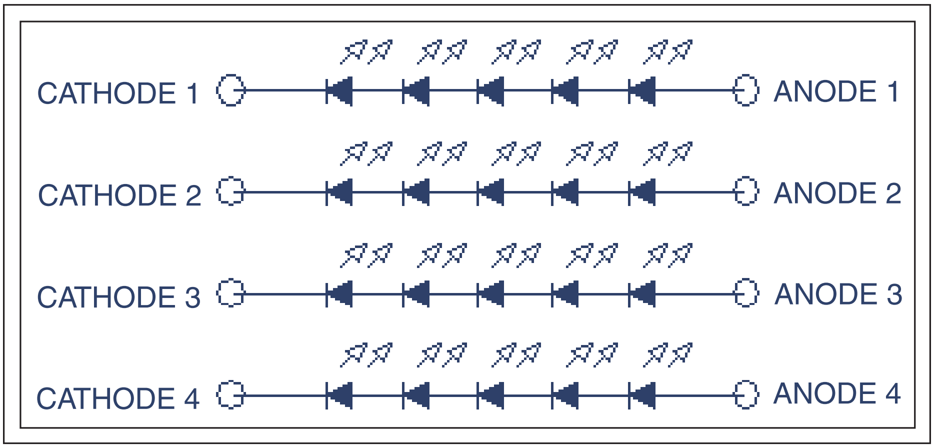

***Fig. 7:** Independent connections.*

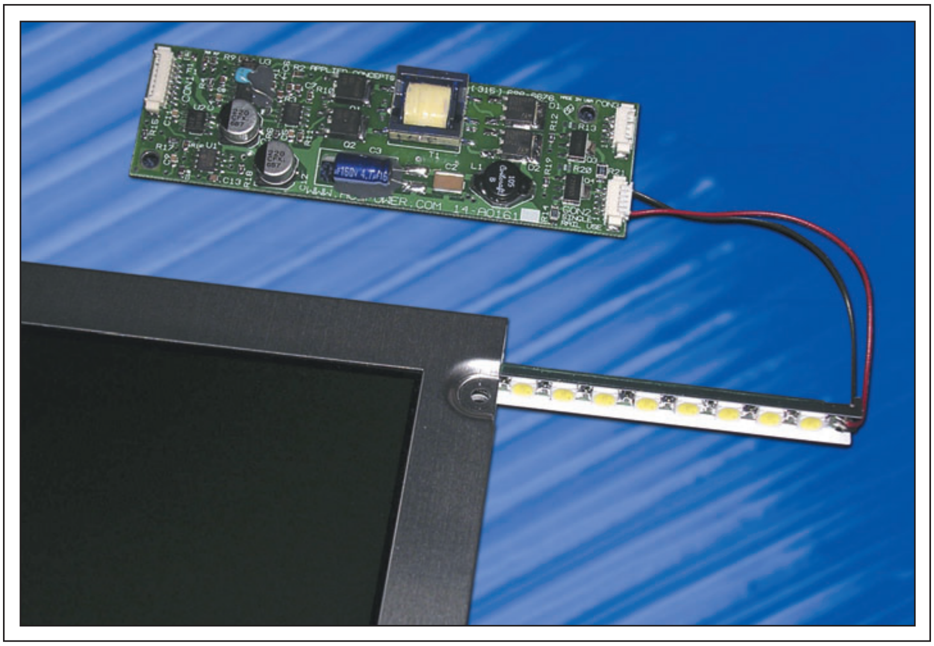

***Fig. 8:** Edge-lit LED solution with an LED driver.*

LED backlighting options

Table 2: Design considerations for white vs. RGB LEDs.

	LED type	
Characteristic	**White**	**RGB**
Direct-backlit optical areas that would need to be tailored differently for LEDs *vs*. CCFLs	Diffusion	Color mixing & diffusion
Edge-lit optical areas that would need to be tailored differently for LEDs *vs*. CCFLs	Coupling to light guide	Coupling to light guide & color mixing
Color temperature	Statically variable	Dynamically variable
Color sensor required	No	Yes
Color accuracy	+/– 7% over LED lifetime	+/– 3% system accuracy
Number of LED drive channels	1	3
Electrical drive requirements	Modest	Complex
Lifetime	25–50 khours	50 khours

- Presents a greater optical design challenge due to the point-source light nature of the LEDs.
- Requires an increase in thickness in the Z dimension to assure uniformity of luminance across the face of the LCD panel.
- Many optical components of the stock LCD are discarded, including CCFLs, light guide, and films.
- A direct-view LED backlight will cost more than an edge-lit backlight, will have a longer design-to-market cycle, and may involve significant tooling costs and time.
- LCD-manufacturer warranty will be void.

If there is a compelling reason to use RGB LEDs, this approach might be advantageous, as the disassembly of the panel and the resultant increased depth to achieve luminance uniformity also makes space available for the

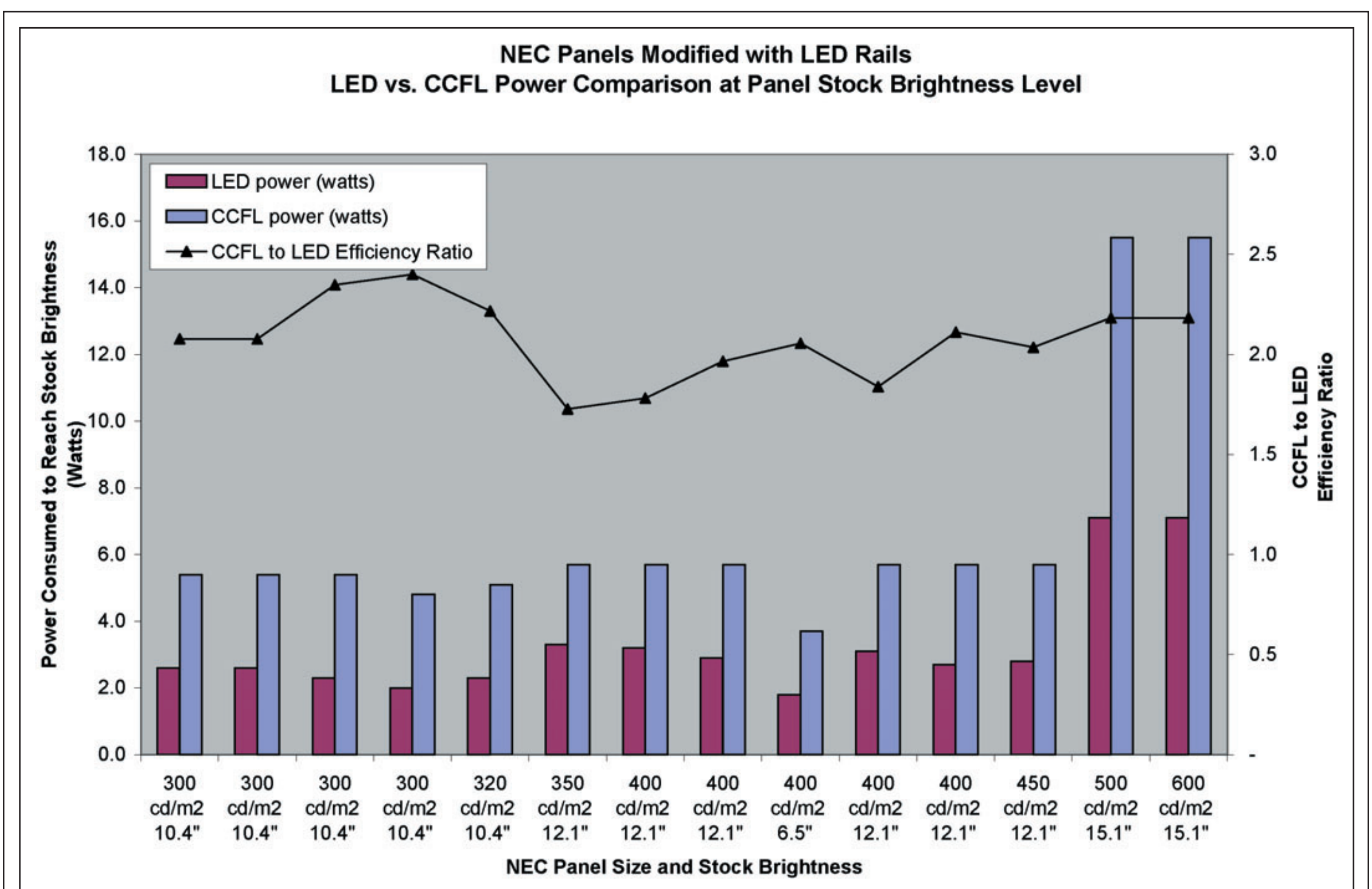

Fig. 9: Comparison of stock CCFL and LED retrofit backlight luminous efficiencies.

complex wiring required. Otherwise, the direct-view backlight seems to be a brute force approach that is largely unnecessary because luminance and optical goals have been shown to be achievable employing an edge-lit approach.

Regardless of which backlight retrofit method is employed, thermal management is a significant challenge for high- or ultra-high-luminance applications, especially when the display product is located in a high-operating-temperature environment because the performance and life of LEDs degrade in high-temperature conditions. For some LED solution suppliers, good thermal performance is more a result of the configuration of the LEDs, proprietary drive techniques, and driver technology than the use of traditional thermal-management techniques such as heat-sinking and convection, although these methods could also be employed in extreme applications. A thermal-management problem does not have to be solved if it does not exist to begin with.

Although beyond the scope of this article, there are a number of additional LED design considerations that should not be overlooked, such as the challenges of color chromaticity and differential aging, as well as the use of various optical feedback and color-management methods, and the assessment of high-power low-density *vs.* low-power high-density approaches.

Conclusion

LCD manufacturers have been fairly slow to introduce LED-backlit LCD panels to address the needs of industrial, military, avionics, and other high-performance and high-reliability markets, especially in larger display formats.

Despite this, a number of suppliers today offer LED-backlight solutions for these larger panels with edge-lit or direct-view LCD-backlight retrofits, or designers can choose to design their own LED-backlight solution.

Although LEDs are becoming the backlight technology of choice, offering numerous benefits, there are still some significant challenges for system designers to overcome which include

- The cost is still higher than that for CCFLs. Designers must find a balance between the desire to meet optical and luminance goals and keeping the LED count as low as possible.
- Thermal management is a major challenge for high- or ultra-high-luminance applications, especially when the display product is in a high-operating-temperature environment because the performance and life of LEDs degrade in high-temperature conditions.
- Complexity and cost of system design can vary significantly depending on the choice of LEDs (white *vs.* RGB) and configuration (series connected LEDs *vs.* multiple parallel banks of LEDs).
- LED drivers are a necessity whose complexity should not be minimized. ■

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show review

2008 Consumer Electronics Show Review

The 2008 Consumer Electronics Show (CES) was a veritable treasure trove of display innovations in all shapes, sizes, and technologies. Part 1 of this review, which appears here, touches on displays designed for TV and/or monitor applications. Visit www.informationdisplay.org for Part 2 of this article, which will cover embedded touch systems, wireless trends, and personal eye wear.

by Steve Sechrist

OVER THE PAST FEW YEARS, the Consumer Electronics Show (CES) has taken on great importance to the display community. This is where the display technologies first unveiled at meetings such as SID's Display Week make their commercial debuts, while some new display concepts are also introduced. This makes CES a must-attend event each year, and the 2008 edition did not disappoint. Between the emergence of nearly immersive displays, much thinner flat-panel displays, gorgeous OLED and PDP displays, and 3-D TVs that are moving into mainstream markets, display products seemed to be around every corner in Las Vegas in January.

Each year at CES and other trade shows, Insight Media gives out the Best Buzz awards to the products that create a "buzz" at the show because of their uniqueness, innovation, styling, boldness, or just plain "coolness." The products featured in this article all received Best Buzz awards for 2008. Let's look at some of the top display products that got people talking at this year's CES.

Nearly Immersive Displays

The prospect of nearly completely immersing a viewer within a display seemed to be one of the themes that manufacturers were exploring with their introductions at CES. The new display product that garnered the most attention and buzz at CES – the Alienware curved-screen display prototype – clearly fits this description (Fig. 1). This is actually a product from a new start-up company, Ostendo, that OEMs its 42.4-in. curved-screen technology to both Dell's Alienware group and NEC.

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***Fig. 1:** This 42.4-in. curved display from Ostendo was the display products that garnered the most buzz at this year's CES.*

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The LED-based DLP engine couples the light from four XGA-resolution microdisplays onto the screen. Each engine is oriented in an unusual 3:4 aspect ratio and projected onto the curved screen with blending in the overlaped regions. The result is an image with 2880×900 pixels, which was chosen because it is twice the WXGA resolution (1440×900). According to J. B. Daines, Ostendo's Vice-President of Sales and Marketing, this will be the mainstream PC resolution in 2008.

"We have hooked up this display to new PCs with Vista and the standard graphics card, to older PCs with XP and fairly new graphics cards, and to a new Macbook Pro, and in all cases the PC connected easily to the curved display using a single output from the graphics card," Daines explained.

The result is an immersive-display experience that can be achieved on a desktop. We have already seen multi-panel displays demonstrated, but creating a continuous image has tremendous advantages. At the show, the display was connected to a racecar-driving platform, creating huge interest and lots of buzz. This is cutting-edge technology innovation that hits the mark with the gaming segment.

The extremely strong and favorable response to the display at CES took Alienware a bit by surprise, but it helped the company establish that there is strong demand for such a product. However, the company recognizes there may also be some "tweaks" needed before bringing the product to market. These include some improvements in the illumination stage to eliminate some visible bands of light where the images are blended.

"The geometry of the blending is solid and stable over temperature, but the uniformity of the brightness and color is what was causing the blending problems," Daines stated. "This will be corrected with our new optics."

Alienware worked with Ostendo to help mold the features and size of the basic technology to fit the needs of its market – PC-based gaming. NEC highlighted the curved display at Macworld 2008, and the company hopes to release it commercially by Q4 '08. NEC is strong in areas such as corporate enterprise, satellite imaging, financial markets,

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Fig. 2: Panasonic unveiled the world's largest unitary flat-screen display, a 150-in. PDP that features 4000×2000 pixels, about four times the amount of a full-HD display.

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Fig. 3: Samsung's 14-in. AMOLED display showed off the best image quality of any display at CES.

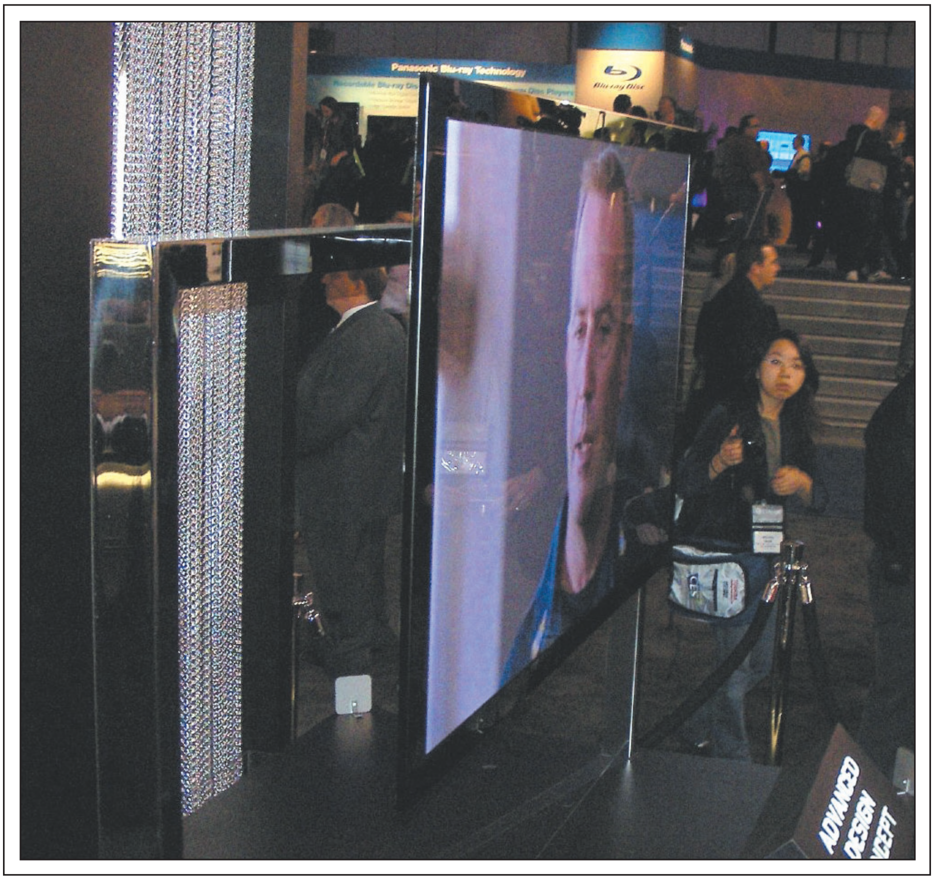

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Fig. 4: Pioneer demonstrated a 9-mm-thick 50-in. 1080p plasma monitor with image quality matching any of its current KURO HD line.

3-D CAD/CAM, broadcast, and medical imaging – markets where a curved-screen display will offer a value proposition. But at Macworld, additional interest was generated for the curved screen for use in digital-image editing, digital photography, and Web development. The fast speed of the system and wide color gamut were appealing to attendees.

For these and some of the other markets NEC is targeting, the display must be able to show crisp text over the blend region. Currently, the display offers an on-screen resolution of 71 dpi – nearly identical to most common PC displays at 72 dpi.

NEC said the curved display is likely to be offered for around $5000 or a bit higher, and it will likely target financial markets and graphic designers to start, with medical imaging to follow. But adoption will depend on how much more users are willing to pay for the immersive, fast, wide dynamic range, and wide color gamut the display offers.

While the Ostendo display creates a nearly immersive environment with a curved display, Panasonic's approach to immersion is raw size. At CES, Panasonic blew away all previous "World's Largest Size" claims with its whopping 150-in. PDP (Fig. 2), which is now the largest unitary (no tiling) flat-screen display in the world, taking the title from Sharp's 108-in. LCD TV.

The image quality of Panasonic's PDP, as well as size, was impressive. Full HD on a screen this size would not have been quite good enough, so Panasonic built a panel with 4000 × 2000 pixels – that's 8 million pixels instead of the approximately 2 million pixels in a full-HD display.

The 150-in. PDP is made on a full sheet of glass from Panasonic's current fab, the same size glass that Panasonic normally uses to make eight 50-in. PDPs. The company said volume production is scheduled for 2009 from its new Amagasaki manufacturing line.

OLED Displays

The best image quality at the show did not come in such a large package. Rather, that distinction belonged to Samsung's 14-in. full-HD (1920 × 1080) AMOLED display (Fig. 3), which was a full order of magnitude in size smaller than the 150-in. PDP. Packing 1920 × 1080 pixels in a super-slim 14-in. OLED display rendered images in a photographic-like quality that as yet is unmatched by any other display.

Pixels were virtually non-existent on the super-thin (2 cm) screen, and the emissive pedigree of this OLED image gives the soft subtle hues and crisp bright tones that rival a mirror image of reality. With the question of image quality resolved, all Samsung has to do now is find a way to replicate it in mass quantities at an affordable price.

Samsung did a wonderful job of showcasing both the 14-in. as well as its 31-in. OLED TV, the latter of which stole most of the thunder from Sony's recent shipping of the XEL-1 11-in. OLED TV. The crowds came to the Samsung booth in droves to see the future of emissive TV with a bright, colorful image that rivals any currently shipping flat-screen TV.

Both panels were supplied to the Samsung Electronics America group by Samsung SDI based in Gyeonggi-do, Korea. The panels are currently made at the Tong Nang factory, said Samsung Senior Manager Tae Ill Yoon. Other specs the company was willing to divulge include a contrast ratio of 1,000,000:1, a color gamut of 107% of the NTSC standard, and brightness of 550 nits. Most impressive was its thinness and weight – 40% lighter than comparably sized displays (current-generation LCDs).

PDP Displays

As amazing as the OLED displays were, the best technology demo at CES was not an OLED display, but rather Pioneer's Super Black and Super Thin PDP demos. The company showed there is plenty of life in the PDP segment with an amazing demo of low black levels on a next-generation KURO plasma monitor. The demo began in a darkened room with the faint glow of two plasma monitors – when the video came on, one realized there were three monitors in the room.

As Insight Media's Pete Putman said, "The blacks on this new KURO were so good that objects on the screen appeared to be floating in mid-air, while the colors had plenty of pop. If surface-conduction electron-emitter-display

(SED) technology wasn't officially buried yet, this demo did the trick."

Outside the booth, Pioneer also showed a 9-mm-thick 50-in. 1080*p* plasma monitor (Fig. 4). That's about 1/3 of an inch, and the image quality was as good as any current-model KURO display! It was so thin we had trouble getting a clean photo of it.

3-D Displays

At CES, we also saw a new awareness building in terms of the possibilities for 3-D TV. Long thought to be many years off, the possibility of creating a real 3-D TV market sooner rather than later has dawned on many players. 3-D TVs using projection, PDP, and LCD technology all generated quite a bit of excitement at the show.

In the 3-D Enabled Laser TV space, we liked Mitsubishi's demonstration of a Laser TV that can operate in 3-D mode. The TV is based on DLP technology using active shutter glasses. The product was demonstrated for the media in a special event unveiling the Laser TV. Image quality was superb – offering one of the best 3-D images we have seen, with great colors, high contrast, and virtually no ghosting (crosstalk between left- and right-eye images) or other visual artifacts to mar the illusion of 3-D.

Mitsubishi has not only created a very compelling 3-D TV, but it is also trying to create a new TV category – Laser TV. We think this summer the company will come to market with a 65-in. model. For the 3-D mode, it uses the same "SmoothPicture" technology as Mitsubishi's other DLP TVs, which can be easily adapted to display stereoscopic images – once the content is properly formatted over an HDMI input.

In its effort to differentiate its PDP-TV products from those offered by other companies, Samsung has turned to stereoscopic 3-D. Most of Samsung's DLP RPTVs are already 3-D enabled, but now it has extended 3-D to PDPs. This is the first time a major CE company has said it would commercialize a glasses-based stereoscopic PDP TV.

To produce the 3-D effect, Samsung borrows the same checkerboard sampling methodology it uses on DLP TVs and runs the PDP at 120 frames/sec. For the left-eye image, a checkerboard-sampled version of the image is displayed on the PDP. This is synchronized with the shutter glasses to allow this image to be seen by the user. The same is done for the right-eye image in the second half of the frame. Samsung undoubtedly modified the phosphors somewhat to speed up their response, especially in the green, so as to lower crosstalk or ghosting between the two images. This crosstalk is more visible than that for RPTV sets, but it is acceptable. Users can buy a $150 3-D kit when the sets go on sale in March.

Lots of buzz surrounded the SpectronIQ 3-D demonstration of its 3-D LCD-TV product – a 46-in. model that will ship this summer. This is a big deal because it is the first time we expect to see a 3-D LCD-TV sold in the U.S. through major big box stores. In addition, it is the first set to include a decoding chip that will allow the display of 3-D content from an ordinary DVD or Blu-ray player. The only rub is that studios will need to press special disks with this encoded 3-D version, but it is a big step in creating an easy-to-use consumer 3-D TV market.

Spectron IQ will use a 3-D technology called Xpol or micro-pol. It is a line-interlaced technique whereby alternate lines contain the left- and right-eye images that can be seen in each eye using passive polarized glasses (cheaper than active glasses). Sensio Technologies, Inc., of Montreal, Canada, will provide the 3-D codec.

LCDs

CES demonstrated that much thinner LCD TVs will be coming from many players. But Hitachi stood out for marshalling the skills of several Hitachi companies to produce what will probably be the first commercially available LCD TV in North America with a cabinet that is 1.5 in. thick or less (Fig. 5). The acrylic front panel came from the automotive division and the fanless convective cooling system was designed by the mainframe computer group. The thin power supply is a custom Hitachi creation.

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Fig. 5: *Hitachi brought together several of its companies to produce what will probably be the first commercially available LCD TV in North America with a cabinet that is 1.5 in. thick or less.*

But these technologies were put to much more startling use in a technology demonstrator Hitachi had tucked away in a sheltered area to one side of the exhibit area. They showed a 32-in. LCD TV only 0.75 in. thick – a stunning achievement not yet matched by any other manufacturer, and one that was highly appreciated by the relatively few people who found their way to this corner of Hitachi's booth.

Conclusion

There were many more interesting display developments at CES, but there is not enough room to detail them all here, including small-embedded touch systems, wireless trends, and even personal-eye-wear products that stole the show. To get the full details of these and other products, log on to the *Information Display* Web site at www.information display.org.

Acknowlegments

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Coming at You: 3-D Digital Cinema to Take Center Stage at Display Week 2008

The emergence of 3-D digital cinema in the past two-plus years has been called the most important cinematic development since the introduction of color. After decades of waiting, 3-D cinema seems to be here to stay, thanks to technology advances spearheaded by the adoption of digital projectors in theaters across the globe. Learn all about 3-D in cinema at a special session featuring some of the world's most renowned and accomplished 3-D artists and technicians at Display Week 2008 in Los Angeles.

by Michael Morgenthal

IF you are a pirate who wears an eye patch, this story isn't for you.

For everyone else who use both eyes, the emergence of stereoscopic 3-D digital cinema in the past two-plus years is one of the most exciting developments to come along in both the cinema and display industries in decades. Of course, display-industry veterans and the movie-going public have heard these promises before regarding 3-D, only to see the trend pop up and then quickly fade in the 1950s, the 1970s, and the 1980s.

Those involved in the movie business insist that this time is different – that after decades of waiting, 3-D cinema has arrived and is here to stay. Hollywood studios and A-list directors are signed up to produce a slew of digital 3-D feature movies over the next couple of years. The number of digital 3-D–enabled screens has jumped from less than 100 just 2 years ago to more than 1300 worldwide (as of March 1, 2008), with many deals pending to expand that reach even further.

Why are they so convinced that 3-D cinema is no longer a fad? Technology advances, led by the adoption of digital-cinema projectors, have finally enabled the seamless projection of pixel-perfect 3-D movies that are comfortable and entertaining to watch. Audiences have responded to the limited slate of 3-D films thus far, making *Hannah Montana/ Miley Cyrus: Best of Both Worlds Concert Tour* the highest-grossing 3-D film in history. Theater owners are thrilled to have an attraction to bring the public back to movie theaters, and one that allows them to charge a premium on top of the regular ticket price.

Clearly, this is 3-D's best chance to gain widespread acceptance. And with Display Week 2008: The SID International Symposium, Seminar & Exhibition taking place in Los Angeles, the entertainment capital of the world, this May, show organizers have put together a fascinating special session highlighting the latest advances in 3-D cinema.

The session will take place Wednesday, May 21 from 2:15 to 6:00 pm and will feature six all-star presenters from across the entire spectrum of the 3-D digital-cinema process, from content creators to the camera designers to the post-production designers to the 3-D system designers. The session will include demos of 3-D digital cinema, thanks to RealD, which is providing the special silver screens, projectors, and glasses necessary for the demos. The special session will take place in a hall with a capacity of approximately 2500 people.

All of these 3-D professionals are quite evangelical about the prospects for 3-D digital cinema, quick to espouse its virtues and brush off those who dismiss this as the latest 3-D fad. This time, they argue, everything has changed – including the possibilities for expanding 3-D technology past the theater and into myriad other environments, including the home.

"We're really at the point where (3-D content) is going to evolve, it's not going to disappear," explains Phil McNally, Global Stereoscopic Supervisor at Dreamworks Animation, whose credits have earned him the nickname, "Captain 3-D." "We're already past the 18-month (lifespan) of the 1950s 3-D boom, and what we have this time is not this sudden peak (of 3-D releases) and then drop off. This has been a steady build that is just starting to take off now, the curve is going up. (3-D has) always been boom and bust. This time around, movies have come out that have proven the case. Financially they proved it at the box office, but more importantly, technically they've proved that it can be done and doesn't hurt (the audience). Now what we

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have to prove is creatively, what can we do with the opportunity. That will take a lot longer."

Hollywood has taken up the challenge. Jeffrey Katzenberg, the CEO of Dreamworks Animation, has called 3-D digital cinema the most important development in filmmaking since the advent of color and has vowed that his company will only produce 3-D animated features from now on. Academy-Award-winning director James Cameron, a long-time avid fan of 3-D, is slated to release the eagerly anticipated *Avatar* in 2009 and has said he will never direct another movie in conventional 2-D. Several other Oscar-winning directors, including Steven Spielberg, Robert Zemeckis, and Peter Jackson, have signed on to direct 3-D movies in coming years. (For a list of scheduled 3-D releases, see the "Future Digital 3-D Movies Releases" sidebar.)

These will follow on the heels of several digital 3-D releases over the past two-plus years. The first was Disney's animated *Chicken Little* in November 2005. More recently, in 2008, *Hannah Montana/Miley Cyrus: Best of Both Worlds Concert Tour*, a 3-D concert film starring the teen sensation, set box-office records for its release date – it brought in $45,000 per screen on its opening weekend, compared to $11,000 per screen for the next-closest movie that weekend – and is now the highest-grossing 3-D movie ever at nearly $64 million. *U2 3D* (Fig. 1), another concert film starring the iconic Irish rock band, has been very well received.

This has been music to the ears of theater operators, who for years have seen declining attendance in the face of DVDs and today's 500-channel cable- and satellite-TV universe. Exhibitors view 3-D digital cinema as a way to drive traffic back to their auditoriums because it is an experience that can only be achieved in the theater. In addition, they are able to charge a premium (on the order of $1–$4 per seat) for 3-D features due to their uniqueness, which further helps their bottom line and allows them to recoup the investments they made in digital projectors. To date, there has been little to no resistance by filmgoers to the higher prices, exhibitors report.

"The first real mega application for digital cinema, the first place it began to give you a return on investment (ROI), was the fact that it was an enabling platform for 3-D," explains Jeremy Devine, Vice President of Marketing

Fig. 1: "U2 3D," released in February 2008, is one of the first live-action theatrical movies in digital 3-D.

for Rave Motion Pictures, a Dallas-based movie exhibitor that is the largest theater circuit in the U.S. to be 100% digital (445 screens), of which 37 are 3-D–enabled screens. He states that revenues for 3-D features are 2.5–3 times what a 2-D film will generate. (Devine will not be a presenter at Display Week.) "If you didn't have this killer application, digital would enable you to run some of this other universe of alternative content, such as operas, rock concerts, some sporting events, and some animated and anime product coming down the pike. The reality of those is that the return has simply not been as dramatic as 3-D, so it probably would have retarded our adoption process (of digital cinema)."

The Perfect Storm

Currently, there are approximately 1300 3-D–enabled screens worldwide, the majority of which are in the U.S. But according to both RealD and Dolby, the two primary 3-D system providers who will both be presenting during the Display Week special session, many deals are pending that would up the 3-D screen count dramatically. The growth has already been dramatic – when *Chicken Little* was released in 3-D in late 2005, there were only 84 digital 3-D–enabled screens worldwide.

To understand why digital projectors make such a difference for 3-D, it is important to realize the limitations of the previous film-based incarnations of 3-D movies. While there are several methods for tricking the eyes into thinking they are seeing movies in 3-D, all of them require that two versions of the movie be projected simultaneously. Stereoscopic glasses use various techniques to separate the two movies so that the left eye sees one version and the right eye sees the other, creating the 3-D effect.

Film-based 3-D movies require two projectors to show both movies simultaneously, which leads to a multitude of problems that could cause the two films to be out of synch for a number of reasons: the two projectors could shake or be misaligned, a frame from one of the films could be spliced out by a projectionist, one of the films could get scratched up or broken after multiple viewings, or the films could be misaligned. Any of these factors could contribute to audiences complaining of eye fatigue or even getting nauseous, and this was a big factor in why 3-D movies were never viewed as more than a fad, quickly bubbling up in the 1950s, 1970s, and 1980s, and then disappearing again.

However, today's digital projectors can present both movies at the same time from the same projector at 144 frames per second (fps), allowing the images for the left eye and right eye to alternate. This led to the development of systems allowing for the separation of the images for each respective eye.

"Once we got digital projectors that could run at 144 frames per screen, RealD with their Z Screen technology came up with a way to use that 144-frames-per-second capacity to flash the left–right eyes alternately, triple flashing 6 fps, three per eye," McNally explains. "The digital delivery system has quite literally pixel-perfect alignment – everything is square, it's all coming through the same lens, it's a single projector – so the one digital-cinema projector in a theater can either do 2-D or 3-D with very little modification." (See Table 1.)

RealD's system uses circular polarized light, an active shutter that fits over the lens of the projector, and passive, inexpensive disposable glasses to direct the proper images to each eye (Fig. 2). RealD currently has 1200 3-D–enabled screens worldwide, which

Table 1: A comparison of the RealD and Dolby 3-D Systems

	RealD	Dolby
Method	Circular Polarization	Color Interference
Screen Needed	Special Silver Screen	High-Gain White Screen
Debut	2005	2007
Glasses	Passive, Inexpensive, Disposable	Passive, Expensive, Reusable
Screens Worldwide (Approximate as of March 1, 2008)	1200	100

require the installation of special silver screens. RealD debuted its system in 2005 with *Chicken Little*.

In 2007, Dolby introduced its 3-D system, which has been described as "anaglyph on steroids." It utilizes color-interference technology whereby a wheel-type filter inside the projector splits each of the RGB elements in the light source and projects them onto a high-gain white screen – the first half of the RGB spectrum is for the left eye and the second half of that spectrum is for the right eye (Fig. 3). Audiences use more-expensive, reusable passive glasses to view the movies. Dolby currently has about 100 screens worldwide, including screening rooms in many studios because they like the flexibility of being able to view 3-D and 2-D movies consecutively, according to Jeff McNall, Cinema Product Manager for Dolby.

"We look at (the emergence of 3-D digital cinema) as the perfect storm," explains Rod Archer, Vice President of Engineering for RealD. "The advent of digital cinema was coming along anyway. On the content-creation side, the computers and the computer graphics and the tools needed to create a 3-D movie had only recently been created. These technologies occurring at the same time have made it possible to do this."

No matter which system is used, the true genius of both systems is how they make the 3-D process so easy for any projectionist. McNally, who has been an amateur 3-D photographer since 1990, explains that stereo enthusiasts have long rigged home digital projectors for 3-D viewing, but this demanded a great deal of knowledge. The new systems offer push-button ease, meaning that there are a limitless number of screens that could be converted to 3-D.

"A lot of people have been doing this as hobbies at home for years, even with low-end digital projectors and polarizing them the way they did stereo in the past," McNally says. "When RealD showed up with a single-projector solution, that was the breakthrough because now you do not need an expert to run the projector, and the biggest problem with 3-D in the past is that you always needed expertise in the projection room.

"What RealD did was put the expertise into the technology and bring it down to the normal expertise you need in the projection room. The 3-D aspect of it was built into their hardware at that part, and it's fantastic. The thing that has always killed 3-D in the past was bad presentation … any (theater) that has a digital projector can turn it into a 3-D projector, and as long as they can read the right buttons to kick it into that format, it's going to work."

This simplicity has captured the imagination of the Hollywood studios and has convinced them and everyone else in the 3-D movie business that this time around 3-D is here to stay.

"It is pretty amazing," continues McNally, whose 3-D credits include *Chicken Little*, *Meet the Robinsons* (2007), and the forthcoming *Monsters vs. Aliens* (Fig. 4). "We've been literally waiting 150 years for the technology to become acceptable. When sound was introduced, they had problems in the first couple of years, which they overcame. 3-D

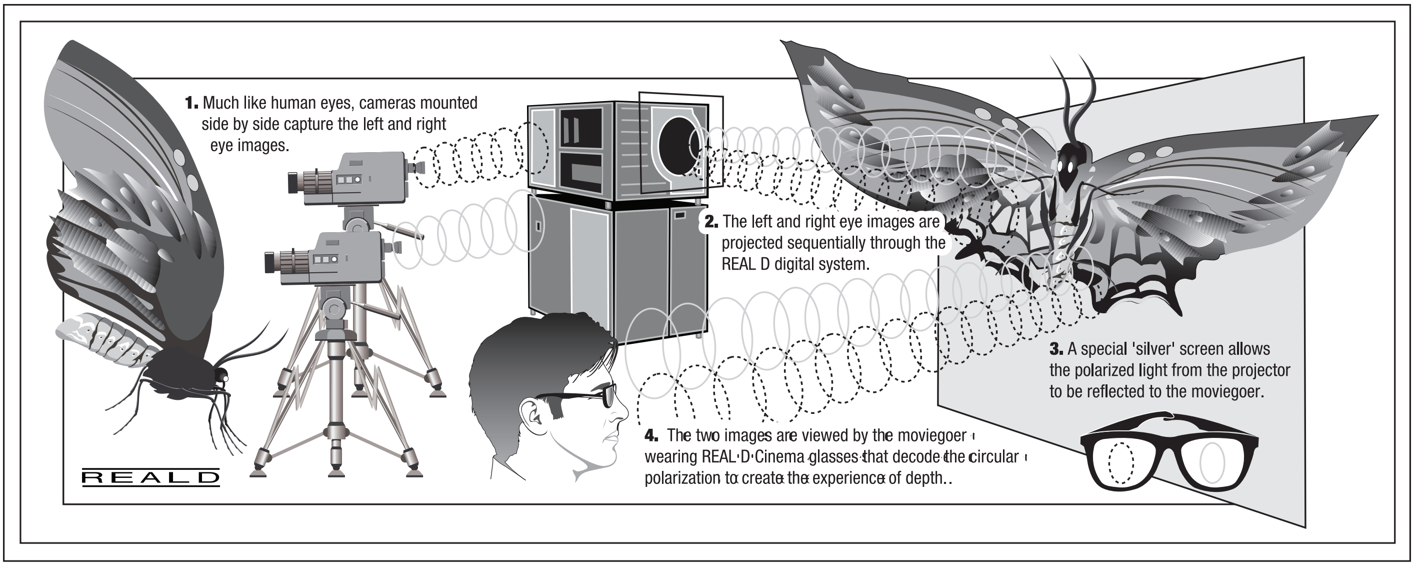

Fig. 2: *An illustration of RealD's 3-D technology. Image courtesy of RealD.*

has been in this perpetual loop of failing the first few years. It would run for a while, everyone would get fed-up, then it would come back, everyone would get fed up again, and on and on. This time, it has come back, and it's at the point now where the only thing that (could go) wrong now is the artists controlling the content. The blame cannot be placed on the system that projects it anymore, it is now down to the people who make the content as to whether it will be good or not. That is what is so exciting."

By all accounts, the 3-D movies to date have been of high quality, but there is cer-

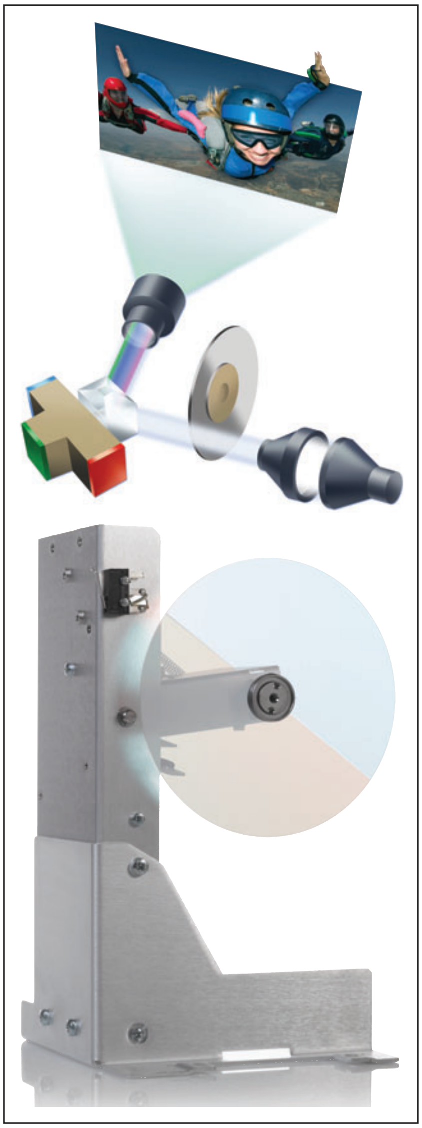

Fig. 3: *(Top) Dolby's 3-D system illustrated: the light path through the projector. The filter wheel goes into the light path before the image is formed. This allows for higher lamp power as well as no modulation of the actual image. The result is no degradation to the image. The Dolby 3-D system uses six color bands – three for each eye. (Bottom) A rotating-filter-wheel assembly installed in the existing projector is inserted between the lamp and picture elements for 3-D and retracts for 2-D. Images courtesy of Dolby Laboratories, Inc.*

Future Digital 3-D Movie Releases

Here is an unofficial list of digital 3-D movies scheduled for release in the next few years. These do not include IMAX 3-D releases, which are film-based. All dates are for the first worldwide release and are subject to change.

Film Name	Director	Scheduled Release	Format
Journey to the Center of the Earth	Eric Brevig	July 2008	Live Action
Fly Me to the Moon	Ben Stassen	August 2008	Animation
Niko & the Way to the Stars	Michael Hegner Kari Juusonen	October 2008	Animation
Bolt	Byron Howard Chris Williams	November 2008	Animation
Final Destination 4	David R. Ellis	January 2009	Live Action
My Bloody Valentine	Patrick Lussier	January 2009	Live Action
Monsters vs. Aliens	Rob Letterman Conrad Vernon	March 2009	Animation
Toy Story 3D*	John Lasseter	October 2009	Animation
A Christmas Carol	Robert Zemeckis	November 2009	Animation
Avatar	James Cameron	December 2009	60% CGI, 40% Live Action
Frankenweenie	Tim Burton	December 2009	Animation
Crood Awakening	Chris Sanders	2009	Animation
How to Train Your Dragon	Peter Hastings	March 2010	Animation
Shrek Goes Fourth	Mike Mitchell	May 2010	Animation
Toy Story 3	Lee Unkrich	June 2010	Animation
Step Up 3-D	John Chu	2010	Live Action
ReBoot	TBA	2010	Animation
Alice in Wonderland	Tim Burton	2010	Live Action/ Performance Capture Animation
Tintin**	Peter Jackson Steven Spielberg	TBA	Animation

*Toy Story 3D is the re-release of the original Toy Story that was released in 1995. It is being completely reproduced for 3-D.
**Tintin is expected to be a trilogy, with one movie directed by Jackson, one by Spielberg, and the third by an as-yet unnamed director.

Fig. 4: *Dreamworks Animation plans to release "Monsters vs. Aliens" in 3-D in 2009. CEO Jeffrey Katzenberg has insisted that all future animated features from his studio will be produced in 3-D. Image courtesy of Dreamworks Animation*

tainly a learning curve for the film makers because shooting in 3-D – especially live action – is far different from shooting in 2-D.

"The art of cinematography is literally turning space into flat, and all of the techniques we're familiar with – depth of field, moving cameras, all of that – it's a flat graphic art," McNally explains. "The poetry of cinematography is the fact that they have been able to do it and actually represent a spatial world in a flat environment. Now we're at the point not where we need to convert real space into a flat graphic, but we have to convert flat space into a movie space – and they are different because there are different levels of comfort that you can tolerate in the real world that you can't necessarily tolerate in the theater. The fact that the screen is big in scale and has been blown up means that it is different from real life as well. So now, we're in a new interpretation phase. I call it a 3-D–to–3-D conversion process. That's really what we're doing – we're capturing real-life space and manipulating that into a 3-D movie space.

"Now we're starting to look at everything more on the Z axis and less on the X-Y axes, and staging the action on the Z axis and less on the X-Y axes. It's not like one excludes the other – they are all there as part of the story-telling technique. I think for movies up to this point, the majority of shots are composed on the X-Y axes because that is the only thing we have to deal with. Of course, there are Z space shots such as cars flying down the road – there are a lot of shots that play straight across the frame. I think the bias will switch over time so films will have a majority of shots playing down the Z axis and a minority of shots used across the flat plates of the frame. It will just work better in 3-D."

But those expecting 3-D to mimic the campy horror films of the 1950s, 1970s, and 1980s that used 3-D to have a monster jump out of the screen into a viewer's lap could be somewhat disappointed. The new 3-D cinema is much more about representing spatial relationships on screen in ways that have never been possible before.

"We did have a small portion of the public and journalists who saw this and were disappointed that there were not more incredibly obvious 3-D effects," recalls Devine. "Some of these 3-D films that have come out – everyone screams and enjoys the spear coming toward the screen or the ball bouncing into the audience's lap, but I thought with what's happening now, it may have been missing the point. That is the novelty of this application, but the real beauty of this now is you are getting people who are trying to tell the story within a 3-D universe. During *Chicken Little*, instead of just a little ball that bounced out and delighted the 5-year-old, I love the scene where Chicken Little is talking to his father in the car, and there is a wonderful texturing of the imagery. The father is in the front seat and Chicken Little is in the back seat, and it's not a dramatic moment really for kids, but there is this incredible use of depth, and it immerses you in a 3-D universe."

McNally points to *U2 3D* as a film that has really broken new ground from a visual 3-D point of view. While noting that co-director Catherine Owens is a sculptor, McNally referenced the rich spatial layering of shots that in a 2-D medium would have contained too much information on the screen for human eyes to process accurately.

"They create the space in a way that the layers are separate, and you've got multiple spaces happening at the same time, and your brain can understand that spatial relationship, whereas if it were a flat movie, you would struggle to unravel the confusion that was going on," McNally adds (Fig. 5).

Fig. 5: *This shot illustrates how the directors of "U2 3D" use 3-D spatially to increase the amount of content on the screen; in 2-D, this shot would be too visually confusing. Phil "Captain 3-D" McNally likens this shot to seeing color for the first time. Image courtesy of 3ality Digital. ©U2 Ltd.*

He credits 3Ality, another Display Week special-session presenter, with developing the camera technology to allow for such striking visual effects. 3Ality built micromotors into the camera rigs that, during the zoom of a lens, adjust the camera to get rid of any optical shift problems caused by filming with two cameras simultaneously.

"Optical lenses, when you move the focus, it's going to shift the image very slightly," he explains. "It doesn't matter at all in 2-D movies. In 3-D, if you have the two eyes shifting in opposite directions, that's not going to be a pleasant experience.

"We're probably going to go through some bumps in the production of live-action film. I think it's good that computer-graphics (CG) films have come first – it shows it can be done comfortably and successfully. I think all of the CG films that have come out have shown … to create a comfortable 3-D movie – you can watch it, you can deliver it – that problem has been solved. Live action is the next barrier in terms of getting the crew on live action to work toward the tolerances that are easier to do in CG because we can reshoot to get that tolerance dialed in. I suspect that it will be a bumpy ride. There is going to be some abuse along the way, and the eyeballs are not going to thank us for it, but we'll get past it."

Beyond Cinema?

Once they do get past these issues, the next question will be, how soon digital 3-D technology, particularly a "one-button" approach, can be transferred to the home and other environments. There are already 3-D–enabled rear-projection DLP televisions on the market – according to Insight Media, 500,000 3-D–enabled RPTVs from Mitsubishi and Samsung were sold in 2007, representing 75% of DLP RPTV sales for the year. In late February, Samsung unveiled a 3-D plasma television (Fig. 6).

But the issue of content is perhaps the biggest stumbling block to date, and it is further complicated by use in the home environment, that discussion is split between captured programs such as movies and TV shows and live events such as sporting events and concerts.

For live broadcasts, the NBA did an experimental 3-D broadcast of its 2007 All Star Game for viewing in theaters, utilizing RealD's system. Horton says that the technology now exists to allow for this to occur on a more regular basis. The key is for a process, such as Quantel's, that does not require rendering of the images to make them 3-D – it would need to be done in real time.

"Picture the Super Bowl – you can't just say, 'Sorry guys, can you stop the game in the middle because we haven't rendered convergence on you yet?'" he posits. "That's not going to work terribly well. Or, 'Would you mind doing that touchdown over again because I didn't have a chance to cut the left eye and the right eye quickly enough?' We can do live 3-D now.

"If you think about sporting events, you can plan for a lot of things, but some things you can't plan for. You certainly don't want to do render, render, render, render, render, if you're in the middle of the Super Bowl and you're trying to put together a highlights package for the end of it. (Quantel doesn't) need to render a thing as far as stereo goes. That is highly unusual."

As far as pre-recorded content, McNally says he is not sure about plans for the studios to release 3-D movies on DVD, and that right now is the focus on the complete immersive theater experience.

"For 3-D and movies in general, the bigger the screen, the more immersive the experience," he states. "Seeing that 3-D is a spatial experience and it is about immersion, the home projection systems seem to be the step that is closest to the big public theater. The smaller TV boxes are one step down from that in terms of immersion. Of course, the big

Fig. 6: In February 2008, Samsung introduced what it called the world's first 3-D plasma-display-panel (PDP) TV. The 50-in. "PAVV Cannes 450'' PDP TV features a 1,000,000:1 contrast ratio and was developed in co-operation with Electronic Arts (EA), the world's largest game contents provider. Image courtesy of Samsung.

projection TVs these days are getting pretty big as well. It seems to me that you have millions of projectors out there, whatever the numbers are. People are using DLP projectors in the home. You have DLP 3-D technology in one or two TV designs, and there is a whole market for 3-D projectors, which I can't imagine that that would increase the cost of production given that the TVs are already selling for normal prices."

And that brings the discussion around to what the 3-D community wants to say to the display industry – that 3-D is here to stay, but for it truly to become the revolutionary development it promises to be, the display industry must get on board.

"It is quite clear that the display technology that you need for stereo 3-D will not be one technology but many," Horton says. "The answer you might need for a big arena might be different from what you need in the home, including the viewing glasses, and would certainly be different from games, and mobile phones are a special case, and so on. What we're trying to do for the display community is to be vendor neutral, and say, whatever display technology is out there, by one means or another we will support it.

"Pretty much everyone is going to be jumping on the stereo-display bandwagon this year. Anybody who was skeptical about it, by the end of this year, if they are still skeptical about it, they are going to have a little bit of commercial issue with that…If the general public wants this, the studios want this, and the broadcasters want this, and it can now be done, as the camera problems, post-production, and compression problems are being solved, exactly what is your basis for not getting involved in this technology?"

McNally says that the display industry has yet to respond to the professional needs of 3-D filmmakers, and he is anxious to see what display manufacturers are able to generate for the professional market. Right now, 3-D filmmakers use DLP RPTVs, which occupy a large footprint.

"We have all kinds of limitations on what we can use, and that is why the projection idea has come up quite a few times," he explains. "Why has the DLP projector not been released in 3-D when it's already in the TVs? I don't know the answer. A big projection TV is a big piece of furniture. The projector that is up in the ceiling is a small piece of furniture that clears an office or a home, and the pull-down screen has a pretty small footprint as well."

"The display community has an interest in this to see how 3-D comes together, how movies are created, how they are displayed," says Dolby's McNall. "It is always interesting to look at the front end to determine the future. Everything starts off as a professional application before it makes it as a consumer application, so let's look at the growth in this professional application, and then stand back and see how it can impact things down the road."

The first step for many in this process will be the special session at Display Week 2008. For when it comes to 3-D, seeing truly is believing.

To wit: Horton tells a story of a Quantel road show in October in Rome, where the company was presenting to a consortium of Italian broadcasters and filmmakers. The music during the demo was loud, and representatives from another group meeting in the same conference center came over to complain. Quantel asked them if they would like to see the 3-D demo, and they were so impressed that they stopped the other conference entirely so all of those attendees could watch the Quantel presentation. Horton says the group – the Association of Italian Book Publishers – was completely blown away.

"We love to do our stereo events to non-industry people as well as industry people," Horton concludes. "Show me a non-industry person who wasn't completely blown away by one of our demos and I'll show you someone who is a pirate with an eye patch."

For information on the Special Session on 3-D in Cinema, as well as all of the other components of Display Week 2008, visit www.sid2008.org. ■

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Edited by Aris Silzars

Novel 120-Hz TFT-LCD motion-blur-reduction technology with integrated motion-compensated frame-interpolation timing controller

Sang Soo Kim
Bong Hyun You
Nam Deog Kim
Brian H. Berkeley

Samsung Electronics Co.

Abstract — Samsung has developed a high-resolution full-HD (1920 × 1080) 120-Hz LCD-TV panel using a novel pixel structure and a motion-compensated frame-interpolation (McFi) single-chip solution. Our latest work includes launch of a 70-in. full-HD panel, the world's largest LCD TV in mass production, with a 120-Hz frame rate. A serious problem involving the charging time margin has been completely overcome through the use of a new alternative 1G-2D pixel structure and a new driving scheme. Compared with conventional dot-inversion driving, our new dot-inversion method, which is a spatial averaging technique, can save power because the column drivers are operated using vertical inversion driving. In addition, McFi, which merges individual ME/MC and timing-controller (TCON) ICs and memories, has been developed and applied in a mass-production product for the first time ever. The McFi solution provides 120-Hz driving with the lowest possible system cost. Motion-picture response time (MPRT) has been reduced from 15 to 8 msec. Moreover, for the case of 24-Hz film source mode, motion judder has been completely eliminated. As a result, a lineup consisting of 40-, 46-, 52-, 70-, and 82-in. LCD-TV panels with high quality and manufacturability has been made possible.

The new advanced 1G-2D pixel structure and driving method have enabled the module composition shown in Fig. 16. In large-sized or high-speed-driven LCD TVs, source drivers are typically located at both the top and bottom of the panel. However, our 70-in. panel only requires a single bank of column drivers, resulting in lower cost and a simplified module assembly process.

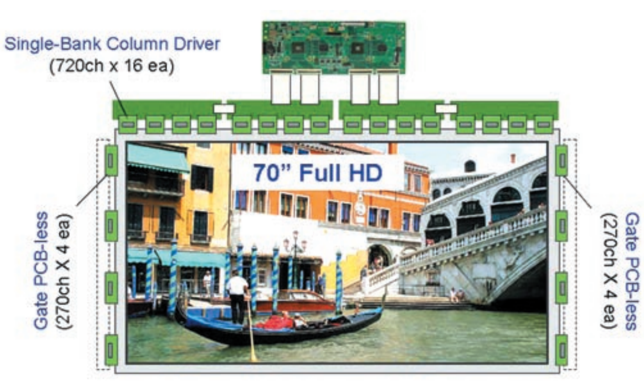

FIGURE 16 — Module structure with single-bank source drivers.

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A 2-in. a-Si:H TFT-LCD with embedded backlight control TFT sensors with various channel widths

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Eung Bum Kim
Jae Hwan Oh
Ji Ho Hur
Jin Jang

Kyung Hee University

Abstract — A 2.0-in. a-Si:H TFT-LCD with embedded TFT sensors for the control of the backlight intensity according to the ambient light intensity has been developed. Two types of a-Si:H TFT sensors with various channel widths were embedded into a TFT backplane with bottom- and top-gate structures for measuring the ambient light and backlight illumination, respectively. The output signal, measured by a readout IC, increased with backlight intensity until 20,000 lux.

TFT-LCDs with LED backlight units have the advantages of wide color gamut, tunable white point, high dimming ratio, long lifetime, and environmental compatibility. But the light intensity of an LED is temperature dependent. Color and white luminance levels are not stable over a wide range of temperature due to inherent long-term aging characteristics. In order to minimize color-point variation and brightness variation over time, optical feedback is a key technology for LED backlighting systems.

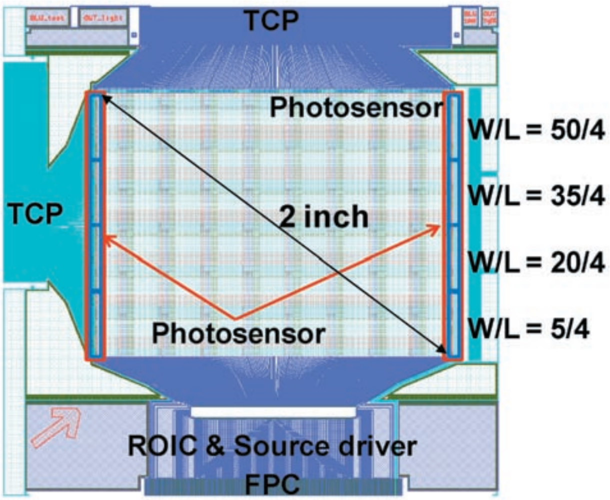


FIGURE 2 — The design of a TFT backplane with TFT photosensors for controlling backlight brightness.

Thermally adaptive response-time compensation for LCDs

Ki-Chan Lee
Seung-Hwan Moon
Nam-Deog Kim
Brian H. Berkeley
Sang Soo Kim

Samsung Electronics Co.

Abstract — This paper presents thermally adaptive driving (TAD) technology for response-time compensation (RTC) of an LCD with an integrated sensor. The TAD system is comprised of an analog sensor, an analog sensor signal conditioning, and a digital feedback algorithm. The integrated thermal sensor provides accurate temperature measurement of the liquid-crystal layer. The TAD controller has an eight-step look-up-table (LUT) and compensates response time based on the panel temperature. The TAD system reduces response time by nearly 34% over the temperature range 0–60°C. This paper also presents a thermal sensor which has been integrated onto an LCD. The sensor uses metal (Mo/Al) film as a temperature detection layer, and its fabrication requires no manufacturing process changes. The sensor shows very good linearity, sensitivity, and reliability.

Considering backlight and ambient heat-source dependencies, the best place to measure the panel temperature is on the LCD panel itself. Furthermore, the best internal placement point is at the same layer as the actual liquid crystal. It is impractical to make a thermal sensor that is sufficiently thin and small to be installed within the liquid-crystal layer. It is also difficult to attach an external sensor and its circuitry to the LCD glass along the narrow black border around the edge of the panel. Moreover, doing so would increase production cost and process time. We have developed a new technology for measuring LCD temperature accurately. Our approach uses a gate metal resistor sensor integrated onto the LCD panel, as depicted in Fig. 1.

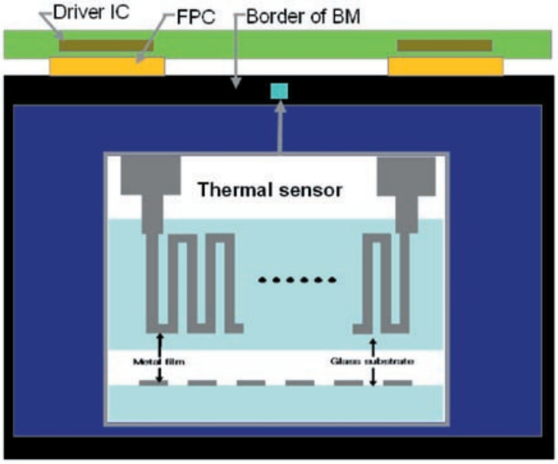


FIGURE 1 — Metal-film-type thermal sensor integrated onto an LCD panel.

Passive-matrix-driven field-sequential-color displays

Y. W. Li
L. Tan
H. S. Kwok

Hong Kong University of Science Technology

Abstract — Passive-matrix-driven field-sequential-color (FSC) displays were successfully fabricated. It makes use of a new multiplex driving scheme that does not depend on voltage averaging. Instead, a transient response of the liquid crystal is employed. An addressing and response time of less than 70 µsec and 2.0 msec, respectively, are used. Scanning time compensation is also introduced to improve the brightness uniformity of the display.

The response time for 0 V → 12 V switching is only 150 µsec. Furthermore, the no-bias free relaxing time τ_D is found to be less than 2 msec for any driving voltage. In other words, if the data voltage V_D and scanning voltage V_S can be selected according to this criteria, the LC cell can be addressed and totally relaxed within about 2 msec. A modified driving method is therefore proposed and is depicted in Fig. 2. The total pixel response time, τ_{TOTAL}, contains three time individuals: τ_1, $\tau_2 + \tau_3$, and τ_4. τ_1 is the LC addressing time with the selection pulse $V_{SEL} = V_S + V_D$.

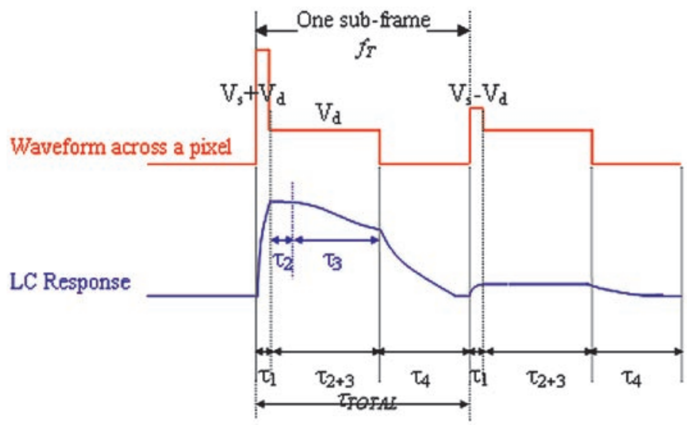


FIGURE 2 — Waveform across a pixel and corresponding optical response of this pixel.

An electrophoretic LCD: Switching with threshold and video rate

David Sikharulidze

Hewlett-Packard Laboratories

Abstract — Here, an electrophoretic liquid-crystal (EPLC) display, which employs a suspension of pigments with liquid crystals and exhibits switching with threshold and fast response, is presented, enabling video rate. The dielectric anisotropy of the LC medium, allowed by applying voltage switching between states with high and low dielectric permittivity, is responsible for this unusual electrophoretic switching.

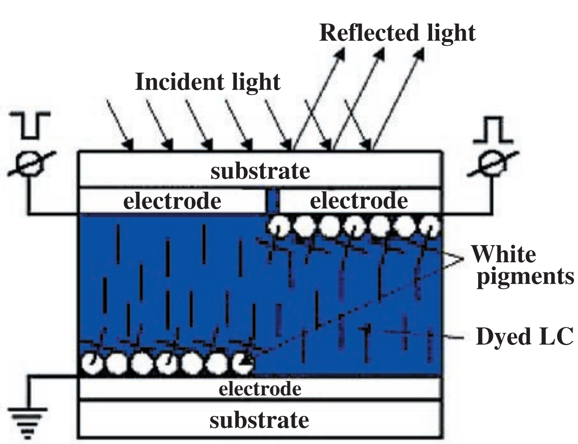


FIGURE 1 — A schematic representation of an EPLC display with dyed liquid crystal and white pigments.

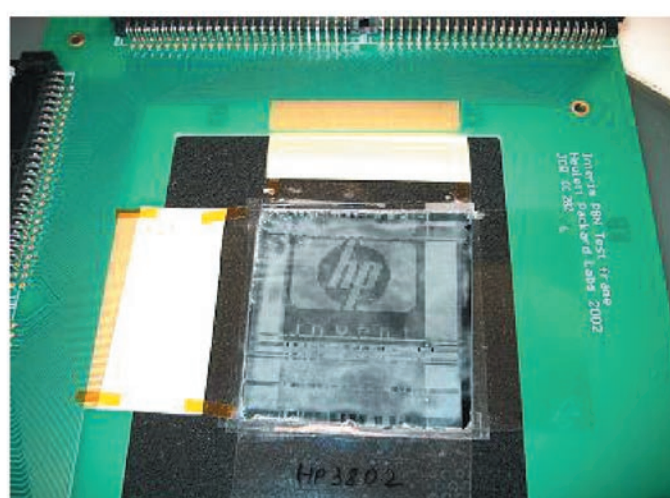


FIGURE 10 — Plastic version of 85-dpi 100 × 100 passive-matrix-addressed EPLC display with black dyed LC and white pigments, controlled by a 40-V electrical driver.

Novel application of ink-jet-printing technology in multi-domain alignment liquid-crystal displays

Pei-Ju Su
Yi-An Sha
Jyh-Wen Shiu

Industrial Technology Research Institute

Abstract — Based on the drop-on-demand characteristics of ink-jet printing, the multi-domain alignment liquid-crystal display (LCD) could be achieved by using patterned polyimide materials. These polyimide ink locations with different alignment procedures could be defined in a single pixel, depending on the designer's setting. In this paper, the electro-optical design, polyimide ink formulation, and ink-jetting technology was combined to demonstrate the application of multi-domain alignment liquid-crystal-display manufacturing. The first one was a multi-domain vertical-alignment LCD. After choosing the horizontal alignment material pattern on the vertical alignment film, the viewing angle reached 150° without compensation film. The second one was a single-cell-gap transflective LCD by integrating the horizontal alignment in the transmissive region and hybrid alignment in the reflective region in the same pixel. In addition, this transflective LCD was also demonstrated in the form of a 2.4-in. 170-ppi prototype.

The schematic cross section of the test cell is shown in Fig. 2. The LC molecules aligned vertically in the vertical alignment nematic (VAN) region. In the hybrid alignment nematic (HAN) region, the LC molecules oriented vertically on one side of the glass and horizontally on the other. While both the VAN and HAN liquid crystal exist in the same pixel, the LC molecules away from the alignment layers turn into random orientation.

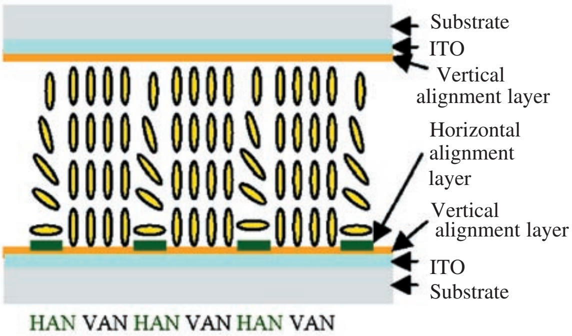


FIGURE 2 —The schematic cross section of the test cell. The HAN mode is adapted by ink-jet technology.

Analysis of image sticking on a real MVA Cell

Ritsu Kamoto

Micro Analysis Lab

Abstract — Image-sticking phenomenon is one of the most important issues affecting LCDs, especially LCD TV. It is known that image sticking is caused by residual DC voltage. An analysis of the cause that induces image sticking on a real LCD cell is very difficult to perform and is rarely reported. In this paper, the impurities that cause boundary image sticking on a real MVA cell were analyzed by examining a cross section of a cell, the bulk LC layer, the vicinity of the LC layer, the LC layer/PI alignment film interface using microanalysis methods such as infrared micro-spectroscopy (μ-IR) and micro-sampling mass spectrometry (μ-MS). It is clarified that there is quite a bit of aromatic acid at the boundary of the image-sticking area than in the normal area at the LC/PI alignment film interface on the color-filter side, not the TFT side, and it is assumed that aromatic carboxylic acid, a negatively charged material, is condensed at the LC/PI alignment film interface on the color filter side by an electrically driven DC component inducing an electric-condenser residual DC voltage.

A sample normally black, MVA-mode active-matrix LCD, combined with a TFT array and color filter (CF), was tested. The cell was electrically driven with a 1-cm-wide stripe pattern for several hours under the usual electrical conditions, and it was observed to appear on an ~0.5-mm-wide gray line at the boundary area between the driven stripe and the non-driven area of a halftone mode, inducing boundary image sticking. After marking the gray-line area on glass, electrically driven shut down and quenching, the cell was cut off to analyze the gray-line area (boundary image-sticking area, abnormal) and undriven area (normal) for comparison.

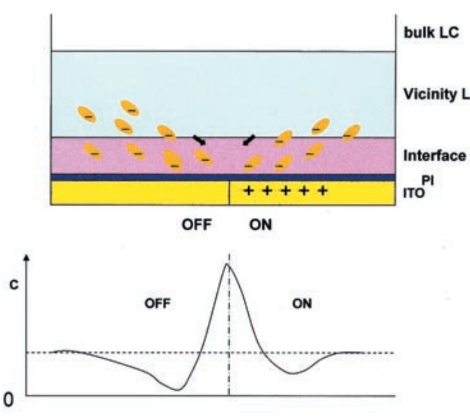


FIGURE 20 — Schematic diagram of boundary image sticking (the residual DC voltage). Upper: model diagram. Lower: concentration diagram of impurities.

In-line manufacturing tool using belt-source evaporation techniques for large-sized OLED devices

Changhun Chriss Hwang

OLEDON Co., Ltd.

Abstract — Whether or not the manufacturing of the large-sized OLED devices in display and lighting industry succeeds will strongly depend on the concept of a thermal evaporation source and the manufacturing tool. The most important factors in OLED-device manufacturing are the organic material utilization and the TACT time. An in-line tool for OLED manufacturing using a novel belt-source evaporation technique is proposed. The belt source maintains the organic film uniformity at 3% and provides high material utilization of over 80%, and the in-line system can achieve this in 1-min TACT time.

The belt-source evaporation technique has been developed as a new vacuum thermal evaporation as shown in Fig. 17. The organic molecules evaporating from the LPS sources are deposited on the lower area of the belt plate during motion. Once the deposition area of the belt arrives at the substrate position, the shutter closes the LPS sources so that organic gas is no longer emitted on metal plate. Then, the sheet heater provides radiation heating to the metal plate and the organic film preliminary deposited on the metal plate sublimates all the way down in a way of flashing evaporation, through a shadow mask to the substrate.

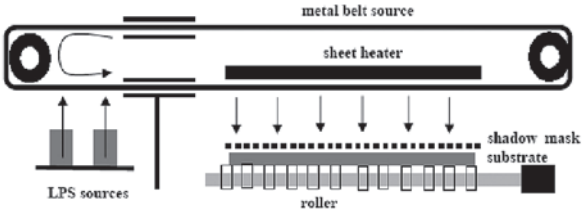


FIGURE 17 — Belt-source evaporation.

Advances towards high-resolution pack-and-go displays: A survey

Aditi Majumder
Ezekiel S. Bhasker
Ray Juang

University of California

Abstract — Tiled displays provide high resolution and large scale simultaneously. Projectors can project on any available surface. Thus, it is possible to create a large high-resolution display by simply tiling multiple projectors on any available regular surface. The tremendous advancement in projection technology has made projectors portable and affordable. One can envision displays made of multiple such projectors that can be packed in one's car trunk, carried from one location to another, deployed at each location easily to create a seamless high-resolution display, and, finally, dismantled in minutes to be taken to the next location – essentially a pack-and-go display. Several challenges must be overcome in order to realize such pack-and-go displays. These include allowing for imperfect uncalibrated devices, uneven non-diffused display surfaces, and a layman user via complete automation in deployment that requires no user invention. The advances made in addressing these challenges for the most common case of planar display surfaces is described. First, a technique to allow imperfect projectors is presented. Next, a technique to allow a photometrically uncalibrated camera is presented. Finally, a novel distributed architecture that renders critical display capabilities such as self-calibration, scalability, and reconfigurability without any user intervention is discussed. These advances are important milestones towards the development of easy-to-use multi-projector displays that can be deployed anywhere and by anyone.

FIGURE 10 — Left: Initially, every display unit thinks that it is the only display unit present and is therefore solely responsible for displaying the whole image. Middle: After configuration identification, each display unit knows the display configuration – total number of projectors, and total display dimensions – and their own coordinates in the array. Thus, they know which parts of the display they are responsible for but still do not know the relative orientations of their neighbors. Thus, the image is not seamless. Right: after alignment, each display unit matches geometrically and photometrically with its neighbors to create a seamless display.

LED packaging by ink-jet microdeposition of high-viscosity resin and phosphor dispersion

Isao Amemiya
Yuko Nomura
Kenichi Mori
Miho Yoda
Isao Takasu
Shuichi Uchikoga

Toshiba Corp.

Abstract — An ink-jet-printing method applied to the microdeposition of high-viscosity resin, including optimization of phosphor dispersion for light-emitting-diode (LED) packaging was examined for the first time. An ultrasonic ink-jet-printing method was used, in which ink droplets are ejected by a focused ultrasonic beam from a nozzle-less printhead. To fabricate white LEDs, high-viscosity phosphor-dispersed resin was deposited to form an encapsulant dome. Two types of methods to control phosphor sedimentation for color uniformity were examined; one is heating the lead frame during the resin deposition, and the other is hydrophobic surface treatment of the lead frame base enabling the fabrication of a small encapsulant dome. For light direction control, a silicone microlens was deposited on an encapsulant dome using the ink-jet method. The results show that ultrasonic ink-jet printing is an applicable technique to optimize and modify on-demand optical characteristics of LED devices.

Figure 1 shows the fundamental principle of the ultrasonic ink-jet printhead where an ultrasonic beam generated by transducers is focused on the free liquid surface by an acoustic lens and a droplet is ejected. Ultrasonic ink-jet printing has the following advantages: (1) nozzle-less structure, which leads to less clogging and uniform droplet size with no tails; (2) a small restriction of ink properties, such as high viscosity and large-particle inclusion; (3) droplet size depends on an ultrasonic wavelength (the droplet diameter is approximately equal to the wavelength), that is, the size is controllable by transducer frequency; and (4) simple head structure, *i.e.,* no need for a narrow ink path and chamber.

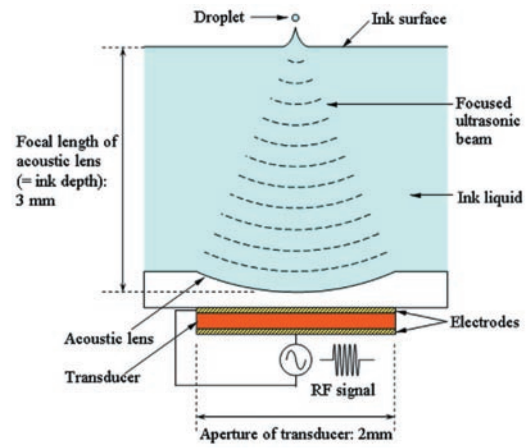


FIGURE 1 — Schematic of ultrasonic ink-jet printhead.

Evaluation of single-, pre-emphasis, and dual-driving methods in large-sized TFT-LCDs

Yoo-Chang Sung
Oh-Kyong Kwon

Hanyang University

Abstract — As the panel size and the frame frequency of TFT-LCDs increases, driving issues become much more important for larger-sized and higher-resolution TFT-LCDs. In our previous paper, the pre-emphasis driving method was proposed to shorten the driving time of the data line with heavy loads of the large-sized TFT-LCDs. This paper proposes a simulation model based on the evaluation results of the developed pre-emphasis source driver, and the issues of driving the data line with heavy loads are reviewed. The single-, pre-emphasis, and dual-driving methods are compared in terms of their driving time and power consumption for large-sized TFT-LCDs with various resistances and capacitances of the data lines. At a panel load of 250-pF capacitance and 15-kΩ resistance in full-HD resolution, the pre-emphasis driving can reduce the pixel driving time to 66% with a 54% increase in the analog power consumption.

Figure 7 shows the optimized simulated waveform of pre-emphasis driving at the load condition of 350-pF capacitance and 20-kΩ resistance. There are six voltage waveforms that are the three points of data-line potential, and there are another three points of the pixel electrode potential of the near, central, and far-end nodes of the data line. The potentials of all the points of the data line are within the range of V_{NEAR} and V_{FAR}, and the pixel electrode potentials of all the pixels are within the range of V_{NEAR_PIXEL} and V_{FAR_PIXEL}.

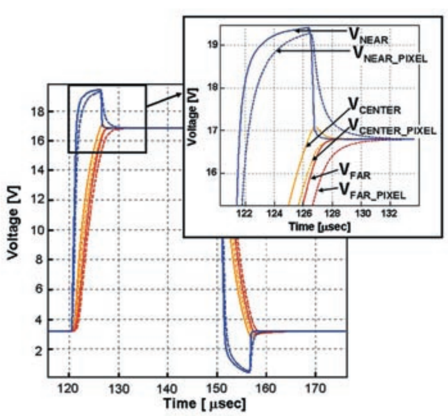


FIGURE 7 — The simulated voltage waveforms of the pre-emphasis driving method at the data line resistance of 20 kΩ and the data line capacitance of 350 pF.

Electrical models of TFT-LCD panels for circuit simulations

Hyunwoo Park
Sungha Kim
Soohwan Kim
Youngkwon Jo
Suki Kim
Richard I. McCartney

Korea University

Abstract — As thin-film-transistor liquid-crystal-display (TFT-LCD) panels become larger and provide higher resolution, the propagation delay of the row and column lines, the voltage modulation of V_{com}, and the response time of the liquid crystal affect the display images now more than in the past. It is more important to understand the electrical characteristics of TFT-LCD panels these days. There are several commercial products that simulate the electrical and optical performance of TFT-LCDs. Most of the simulators are made for panel designers. However, this research is for circuit, system, and panel designers. It is made in a SPICE and Cadence environment as a commercial circuit-design tool. For circuit and system designers, it will help to design the circuit around a new driving method. Also, it can be easily modified for every situation. It also gives panel designers design concepts. This paper describes the electrical model of a 15-in. XGA (1024 × 768) TFT-LCD panel. The parasitic resistance and capacitance of the panel are obtained by 3-D simulation of a subpixel. The accuracy of these data is verified by the measured values of an actual panel. The developed panel simulation platform, the equivalent circuit of a 15-in. XGA panel, is simulated by HSPICE. The results of simulation are compared with those of experiment, according to changing the width of the $\overline{\text{OE}}$ signal. The proposed simulation platform for modeling TFT-LCD panels can be especially applied to large-sized LCD TVs. It can help panel and circuit designers to verify their ideas without making actual panels and circuits.

LCD panels can be modeled by resistors and capacitors as shown in Fig.1.When row (gate) and column (data) line signals propagate through each line to the other side of panel, they are delayed by the resistance and capacitance in each line. Each row and column line should be together with the V_{com}, common electrode. The V_{com} is made of indium tin oxide (ITO). It is not a perfect conductor and has resistance. Therefore, the V_{com} model should be made to consider voltage changes of neighboring pixels.

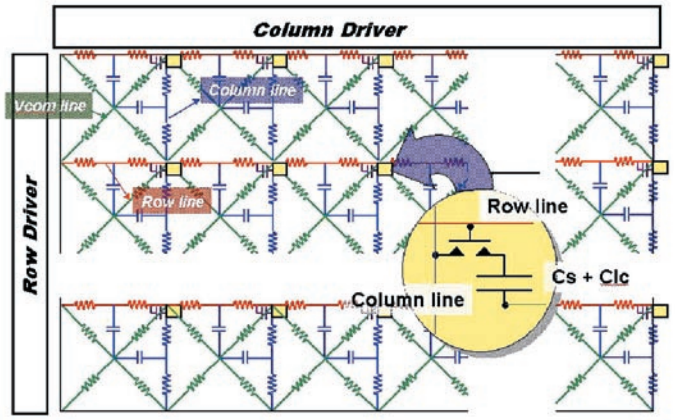
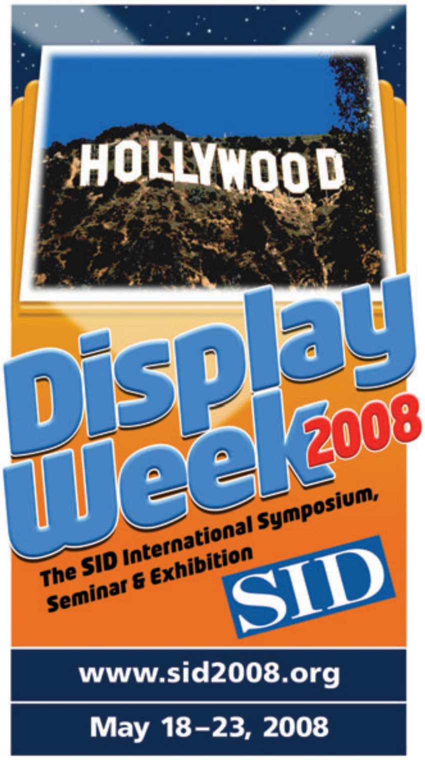


FIGURE 1 — The simplified TFT-LCD panel.



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continued from page 2

demonstrations and data presented by Applied Concepts that the potential of LED backlighting efficiency is being realized in designs today.

We also bring you this month a first look at some of the most exciting aspects of the upcoming SID International Symposium, Seminar, and Exhibition (Display Week 2008): the special session on 3-D Cinema to be presented Wednesday afternoon, May 21. Organizers Brian Berkeley from Samsung Electronics, Brian Schowengerdt from the University of Washington, and Rod Archer from RealD have arranged an all-star lineup of speakers and live demonstrations from companies including Dreamworks, Sony Imageworks, 3ality Digital Systems, Quantel, Dolby Laboratories, and RealD. Not only will the presentations be exciting, but RealD will be providing special silver screens, dual projectors, and glasses that will enable actual demos by the presenters. This will be an exciting event for all of us who will be attending and a major milestone in the history of the Symposium as well. Check out managing editor Michael Morgenthal's article previewing this special session and looking in-depth at why, this time around, 3-D looks like it is here to stay.

Meanwhile, exciting headlines keep coming; the days are getting longer, warmer, and brighter; and there continues to be no end of things to write about.

– Stephen P. Atwood

continued from page 6

the dominant display technology came when the first laptop computers appeared with LCD monochrome screens – with poor contrast and slow response. Even thought they were markedly inferior to CRTs in image quality, they represented the only way to achieve the desired portability.

Now, suppose that you are a clever inventor with a new idea for a superior display device. Let's say that you have demonstrated in your laboratory that you can bring to market a superior large-screen television. Your preliminary estimates show that it will also be cheaper to produce products based on your idea than the current crop of large LCDs and plasma panels. What are your chances of success?

Unfortunately, not very good. The existing companies making large-screen televisions are multibillion-dollar enterprises. Supporting them is an equally large infrastructure of production-equipment suppliers. All this represents a massive worldwide business infrastructure. Not only that, the progress in improving image quality and driving costs down continues to be rapid. So the momentum of these combined organizations is truly awesome. In order to overcome this huge existing technology momentum, your tiny organization of a few engineers would need to have near-speed-of-light velocity. This would mean that what you have invented must be truly revolutionary. An improvement of a few factors of two or even an order of magnitude may not be enough.

Of course, one possible solution could be to approach one of these large enterprises to see if they would like to license your idea. That may work if you do it with some care. A less-desirable outcome could be that they simply implement your idea and then use their near-infinite resources to make it difficult and very expensive for you to obtain legal relief.

The motivation of financial rewards can also cause some entrepreneurs to try to create the perception of significantly larger momentum for their new technologies than most of us would find justifiable. This is typically done by promoting their new technologies in the popular press as "revolutionary" or "breakthrough" and/or by promising results that are not yet achievable. Using our technology momentum model, what we have here is a "virtual velocity" that makes the momentum seem much larger than it really is. Should we think of this as similar to phase velocity that creates an imaginary momentum whereas real momentum depends on group velocity, *i.e.*, real demonstrated progress?

This technology momentum can be scary stuff – just as scary as watching that massive train suddenly hurtling past just a few inches from the platform where you are standing. On the other hand, just as it is important to be standing on the platform and not on the tracks when this event takes place, it is important to understand the dynamics of these technology-based businesses.

In the worldwide display community, we are currently in a period of massive manufacturing build-up of both LCD and plasma technologies. We are also beginning to see the first hints of serious efforts to bring OLED technology to market originating from some of the larger display companies, who have what it takes to create the momentum to make this a potential success. They have the "mass" in terms of resources, and OLED technology is demonstrating good "velocity" in how critical problems are being solved. As an emissive technology for portable devices, OLEDs technology may have a number of interesting features to offer.

The next 10 years look very promising for these and several other display technologies. The momentum is definitely there to carry us along at a fast pace. The interesting challenge will be to see if any smaller and more entrepreneurial efforts can generate sufficient velocity to succeed in this world of massive and dominant corporations.

As always I would enjoy hearing your opinions on this topic and others.

Aris Silzars *is a Contributing Editor of* Information Display *magazine. He can be reached by e-mail at silzars@attglobal.net or by telephone at 425/898-9117.*

We are always interested in hearing from our readers. If you have an idea that would make for an interesting Business of Displays column or if you would like to submit your own column, please contact Aris Silzars at 425/898-9117 or email: silzars@attglobal.net.

QMT Reveals Design on First mirasol Phone

(continued from page 3)

with a single LED that does not significantly increase the power consumption (about 30 milliwatts).

QMT thinks the mirasol offers huge benefits for everyone in the handset value chain. Industrial designers don't have to worry about designing phones with bigger batteries. Handset manufacturers can save money by not having to purchase larger batteries. And consumers will benefit from having a phone that can be seen in most lighting conditions, and one that does not to be recharged frequently, a big bonus in emerging markets.

But the segment that QMT is most interested in attracting with its mirasol displays is the wireless carriers, Cathey detailed. A phone that needs to be charged less often is on more frequently, meaning that carriers can cash in on what is termed "available revenue time"—the time when people can be downloading content, be online or send text messages with their phones, for which the carriers can charge a premium.

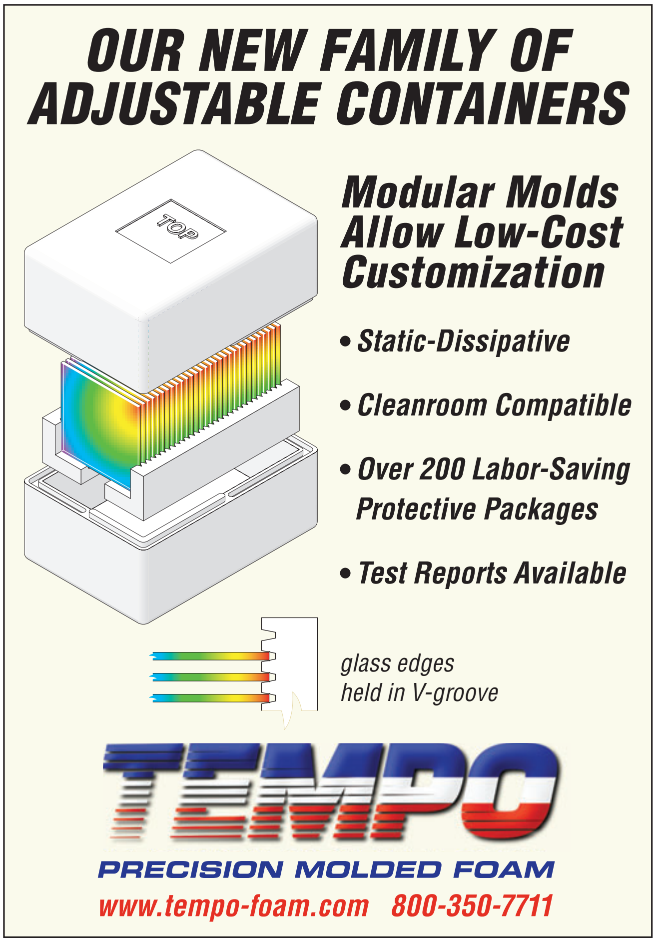
"People may think it's trivial if the phone isn't on for an hour, but if you have a million teenagers with dual-usage models, that's a billion minutes a day of non-available revenue time," Cathey stated. "That's time that they can't download another ringtone or MP3, or surf the net. "

Cathey continued that QMT attracted a lot of attention from carriers at February's Mobile World Congress 2008 in Barcelona. QMT would like to see the carriers push the handset makers to adopt the mirasol displays.

The next step for mirasol technology is full color. Cathey said that while QMT has not announced its commercialization plans for full-color mirasol displays, he expected "significant" announcements at Display Week 2008 in May. He could not confirm if this indeed was the commercialization of full color mirasol displays, which the company demonstrated for the first time at Display Week 2007.

"The investment that Qualcomm is putting into this is not just for monochrome or bichrome (displays)," he added. "You have to go full color."

— Michael Morgenthal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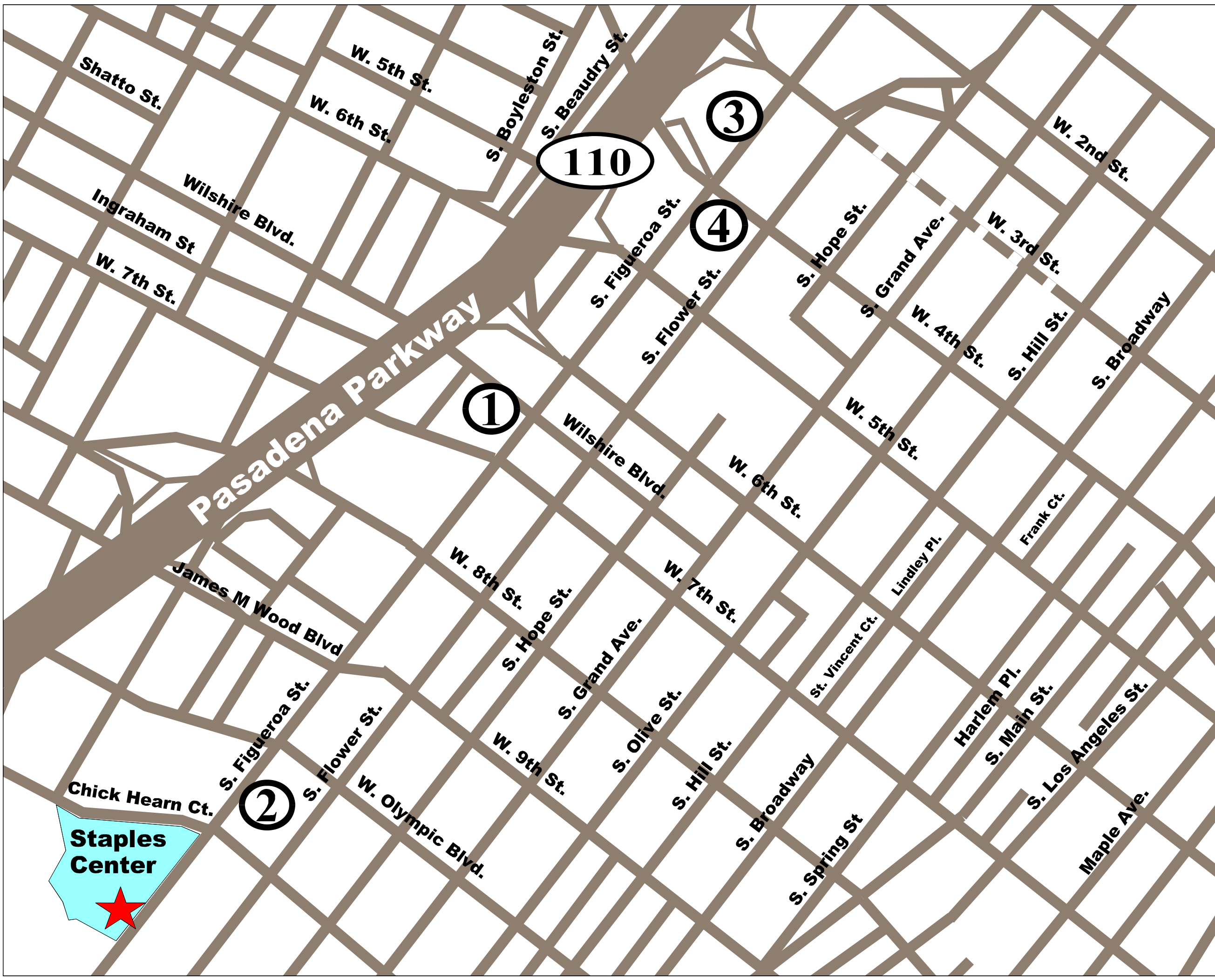

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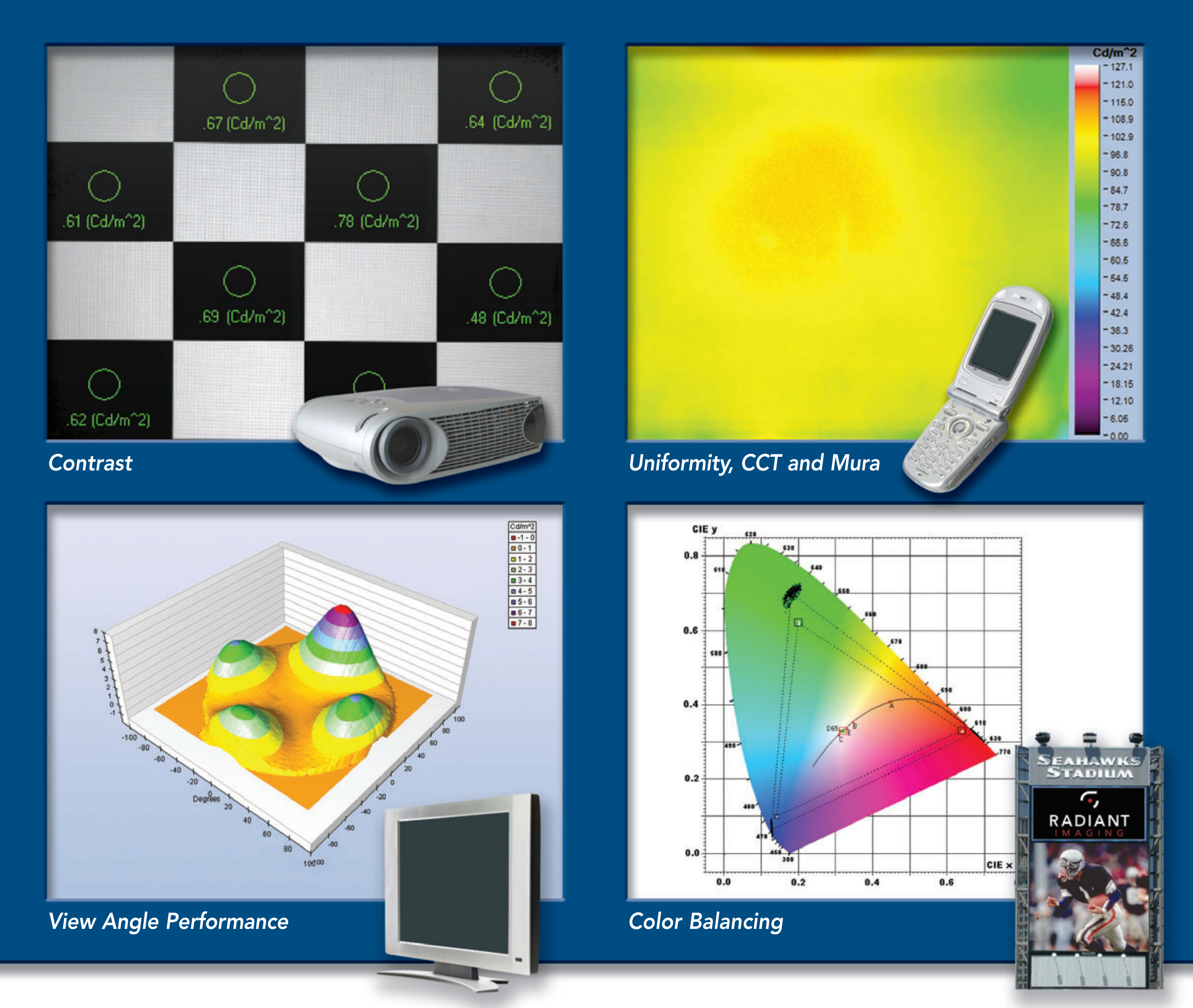

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