

2016 SHOW ISSUE/DIGITAL SIGNAGE/AUTOMOTIVE DISPLAYS

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SOCIETY FOR INFORMATION DISPLAY

Information DISPLAY

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Display Industry Awards: Best of the Best



Apple iPad Pro



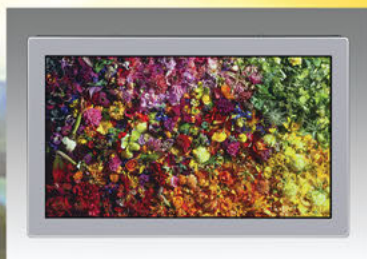
Microsoft Surface
Book Laptop

**HAPTICS IMPROVE
DRIVER SAFETY**

**THE DELICATE BALANCE OF
DAY/NIGHT CONDITIONS
FOR VEHICLE DISPLAYS**



Apple Watch



JDI 8K x 4K Module

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AT DISPLAY WEEK 2016**

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ON THE COVER: The winners of this year's Display Industry Awards are, clockwise from upper left: Asahi Glass Company's XCV Glass Substrate for Light-Guide Plates, Corning's Iris Glass Light-Guide Plate, Nitto Denko's Ultra-Thin Polarizer, Microsoft's Surface Book Laptop Computer, Japan Display Inc.'s 17.3-in. 8K x 4K LTPS TFT-LCD Module, Apple's Apple Watch with Retina Plastic OLED, and Apple's iPad Pro 12.9-in. Display with variable refresh rate.



Cover Design: Jodi Buckley

In the Next Issue of Information Display

Light-Field Technology Issue

- Light-Field Augmented-Reality HUD
- Light-Field Technology Overview
- Custom-Sizing LCDs
- Quick Takes and Trends from DW 2016
- Bulk Accumulation for Oxide TFTs: Part II

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contents

2 **Editorial: Welcome to Display Week**

■ By Stephen P. Atwood

3 **Industry News**

■ By Jenny Donelan

4 **President's Corner: Moving On, Making Progress**

■ By Amal Ghosh

6 **Guest Editorial: Vehicle Displays in the Passing Lane**

■ By Karlheinz Blankenbach

8 **Best Products of 2015: 2016 Display Industry Awards**

Each year, the Society for Information Display's Display Industry Awards Committee selects award winners that have advanced the state of the art of display products and technology in the categories of Display of the Year, Display Component of the Year, and Display Application of the Year.

■ Compiled by Jenny Donelan

14 **Frontline Technology: Understanding the Requirements for Automotive Displays in Ambient Light Conditions**

Optimizing vehicular displays for the ambient light conditions they will be used in – from dark nights to sunny days and everything in between – requires a delicate balance of settings based on carefully obtained metrics.

■ By Jan Bauer and Markus Kreuzer

24 **Frontline Technology: Haptics Help Drivers Keep Their Eyes on the Road**

An empirical user study suggests that touch displays with haptic feedback reduce driver workload by making blind operation easier and faster.

■ By Thomas Vöhringer-Kuhnt, Kai Hohmann, Andreas Brüninghaus, and Ercan Tunca

30 **Display Marketplace: New Directions for Digital Signage and Public Displays: Part 2**

The second half of our two-part series on the market dynamics of digital-signage applications for commercial (or public) displays examines the educational and corporate markets and winds up with a forward look at how OLEDs may further energize the industry.

■ By Todd Fender

34 **Enabling Technology: Sensor Architecture: The Evolution of Digital Signage and Intelligent Visual Communications**

Proximity networks and beacon software are being used to enhance the digital-signage experience for retailers, venue owners, and customers in stores and other public locations.

■ By Mark Boidman

38 **Frontline Technology: Challenges for Outdoor Digital Displays**

When designing an outdoor digital-signage system, location, hardware, sunlight readability, durability, and reliability are key components to consider. To meet these challenges, Delphi Display Systems has developed fully integrated and sealed outdoor display systems that incorporate embedded media control and robust remote management.

■ By Benjamin Medvitz

44 **Trade-Show Preview: Products on Display at Display Week 2016**

Some of the products on display at North America's largest electronic-display exhibition are previewed.

■ Compiled by Editorial Staff

56 **SID News: 2015 JSID Outstanding Student Paper**

60 **Corporate Members and Index to Advertisers**

For Industry News, New Products, Current and Forthcoming Articles,
see www.informationdisplay.org



Welcome to San Francisco

by Stephen P. Atwood

Welcome to San Francisco and Display Week 2016. This will be our 53rd year and yet in some ways it seems like the display industry is just getting started. While we have seen countless display technology innovations so far in this last half-century, I know there are many more things coming that we can yet only imagine. Display Week is where you

are most likely to see and hear about those things before they appear in products anywhere else. That is why it is always such an exciting event for me.

While you are here it is impossible to see and do all of Display Week by yourself, so invite your colleagues and divide and conquer to suit your interests. Getting the most out of your Display Week experience involves some serious planning. Take time to review the full program and mark off the things that are most important to you. Plan your days to see as many things as you can and coordinate with colleagues to make sure the things you cannot see are covered by others. Usually, there are dozens of presentations and exhibits that I know I want to attend, but I also find many surprises that I can only discover if I explore as much as possible. It is a wonderful mix of the expected and unexpected that awaits you. I have never left Display Week without at least a handful of amazing new discoveries that have since proven invaluable in my day-to-day work.

Because you cannot possibly see and do it all, we have invited a prestigious team of freelance technology enthusiasts to report on all the happenings and they will be hard at work covering everything they can. We will have daily blog updates on the *ID* Web site (www.informationdisplay.org) and a full issue of post-show coverage later in the year. The issue of *ID* you are reading now can also be useful for your planning because it features our "Products on Display" coverage, which is assembled each year by our staff to help you get the most out of the exhibition.

Maybe you are a seasoned SID member returning after many previous years, or maybe you are brand new to the display industry scene and this is your first event. If so, you are not alone. Many people discover SID through Display Week when they automatically become new members by registering for the event. Then, later on, they realize that the Society for Information Display is about much more than just one great event per year. In fact, SID offers a calendar abounding with exciting international display-industry events, some focused on a particular technology or field of research and others almost as broad as the Symposium itself.

For example, through the rest of this year you can experience other world-class events such as the International Meeting on Information Display (IMID 2016) in Korea and the 23rd International Display Workshops combined with Asia Display 2016 in Japan. However, some of the most important Society activities are those that take place regularly on a local and regional level at each of SID's 30-plus chapters worldwide. It is hard to find any industrialized part of the world that does not have some chapter activities going on. And if all that is not enough, SID's publications, online resources, and network make the organization a truly indispensable tool to a successful display-industry career. Even if you attend only one additional SID event or take even partial advantage of your local-chapter activities and the online resources, you get the value of your membership back many times over. So, if you are new to SID, I hope you find it a truly enriching experience, and do not forget about your membership after Display Week 2016 is over.

(continued on page 58)

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OSRAM Upgrades LEDs

OSRAM Opto Semiconductors reports that it has increased the luminous efficacy of its white and blue high-power LEDs by 7.5% above the previous level of its products. This has been done by optimizing epitaxial growth processes, which are now being used in all OSRAM LEDs based on UX:3 chip technology.

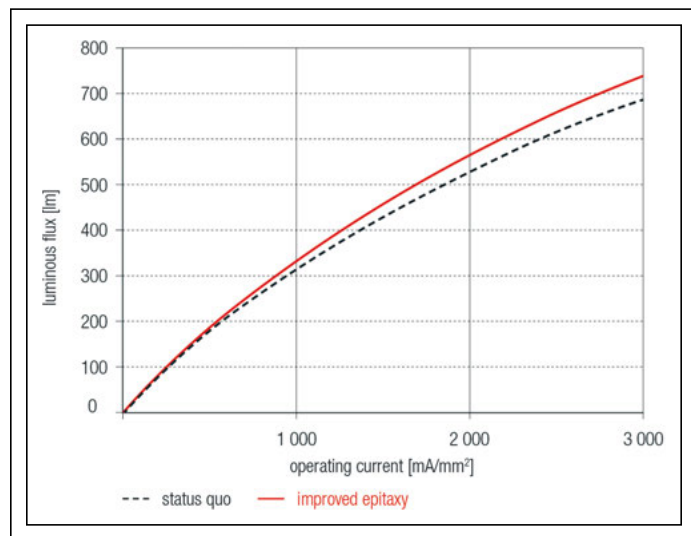


Fig. 1: By making improvements to the epitaxy, OSRAM has achieved a 7.5 percent increase in luminous efficacy of white and blue LEDs compared to existing products.

Apple Introduces New 9.7-in. iPad Pro and 4-in. iPhone SE

Mobile devices have been growing ever larger, but Apple's most recent product announcements emphasized the small – a smaller iPhone and a smaller iPad Pro.

The new iPhone SE looks like the iPhone 5S, Apple's last 4-in. phone released in 2014, but has the same processor and graphics performance as the larger and more recent iPhone 6S, as well as a 12-Mpixel camera and 4K video capture. The prevailing notion is that the new iPhone is designed to appeal to buyers who are reluctant to upgrade to bigger devices for reasons of convenience as well as economics. (Apple's pre-existing 4-in. phones continue to sell well.) The SE starts at \$399, whereas the new, larger phones start around \$650.

Apple also introduced the 9.7-in. iPad Pro, a diminutive version of its 12.9-in. iPad Pro. The new tablet weighs just under a pound and features the company's "pro" Retina display based on oxide TFTs, which offer a high con-

trast ratio and low reflectivity. It's designed to recognize ambient light to adjust colors on-screen to display the most natural hues – a feature that has not proved universally popular thus far, but can be disabled.

Apple says it made the smaller iPad Pro to cater to those who want a powerful but more commute-friendly device. No doubt it is also hoping to jump-start sales. According to CNet, though the iPad still leads the tablet market, sales went down by 25% in the holiday quarter ending 2015 December, continuing 2 years of decline.¹

¹<http://www.cnet.com/news/for-apples-iphone-se-new-ipad-pro-small-is-the-new-big/>



Fig. 2: The new 9.7-in. iPad Pros are designed to offer the power of the larger iPad Pro tablet in a smaller envelope. Image courtesy Apple.

Foxconn and Sharp Seal the Deal

Foxconn's off-and-on again takeover deal with Sharp has been approved at last by the boards of both companies, with Foxconn set to acquire two thirds of Sharp – including its thin-film-transistor liquid-crystal-

(continued on page 57)

MARKET BRIEF

Samsung Leads in Small-Display Sales, OLEDs Lead in Growth

Samsung Display led the 9-in. and smaller display market in 2015, with 23% of all revenue, followed by Japan Display at 16%, LG Display at 13%, and Sharp at 10%, according to a recent report from market research firm IHS. (April 20, 2016, *Small/Medium Display Market Tracker*, IHS).

The company's most recent report noted that while overall small-to-medium display

unit shipments did not grow in 2015, AMOLED display unit shipments grew 54%, and low-temperature polysilicon thin-film-transistor (LTPS TFT) LCD unit shipments rose 10% over the previous year. As AMOLED and LTPS TFT-LCD shipments rose, amorphous-silicon (a-Si) TFT-LCD shipments declined 10% year over year in 2015.

president's corner



Moving On, Making Progress

by Amal Ghosh

President, Society for Information Display

By the time this issue of *Information Display* is published, many of us will be at Display Week 2016 in San Francisco, California. I look forward to Display Week each year for many reasons, but chief among them is that it is the single-best event you can attend to learn about what's going on in our fast-paced rapidly changing display industry.

This year's program includes the events we have come to look forward to – the world-renowned technical symposium, short courses, and seminars; the three-day exhibition; the Innovation Zone, now in its fifth year; and the Business, Investors, and Market Focus Conferences. Tuesday's Market Focus Conference is based on touch technology; Wednesday's will feature wearable-flexible technology. The organizers of Display Week are constantly updating the show's content in order to focus on what is current, as well as what will be current a year or more from now. To this end, the committee has also designated six special focus topics as part of the technical program: augmented and virtual reality, digital-signage display solutions, lighting, TFTs and display circuits on plastic substrates, vehicle displays and user-interface technology trends, and wearable displays.

We are also featuring two new events this year: a Chief Marketing Officer Panel and the New Product Showcase. The CMO Panel, which takes place Wednesday morning, is a moderated discussion with industry leaders who will talk about sales and marketing issues related to displays, such as how to solve supply-chain issues. The New Product Showcase, which is part of the three-day exhibition, will feature many of the newest products in a designated area of the show floor. These are the products exhibitors want to highlight for the press and public. It is a great way to get a quick overview before walking the rest of the show floor.

And because it is important to have some fun, I urge you to attend one or both of our two most popular special events: the Awards Luncheon and the Special Networking Event, which both take place on Wednesday, May 25. The luncheon, which begins at noon, features the winners of the Display Industry Awards, the Best-in-Show Awards, and the I-Zone Best-Prototype Award. This year's special event, sponsored by Merck, on Wednesday evening after show hours, will be at the California Academy of Sciences. This promises to be a great time for all.

Last, by the time you read this, I will have ended my two-year term as president of SID, and the Society will have a new president, Dr. Yong-Seog Kim. I hope you will join me in welcoming Dr. Kim. He has done outstanding work for SID for many years, and I have no doubt that our organization will prosper under his leadership and guidance.

I have enjoyed serving the SID membership as president these past 2 years. During this time, the Society has made significant progress in many areas. First, the financial health of the society improved considerably. We obtained a record surplus for 2015, due in part to the Display Week conference, which has seen a significant improvement in attendance and technical paper submissions. Second, we started a Display Training School (DTS) in China, which was very successful, with many participants and new memberships for the Society. Last, the society's leadership team decided to streamline the governance structure in order to allow better representation of the chapters and more efficient operation. The corresponding bylaws change was approved by the board of directors and is on the ballot for approval from the general membership. These are very significant and important changes to the Society.

Volunteering for the Society has been one of the most satisfying activities of my career, and if you have not already volunteered in some capacity, I urge you to do so.

Enjoy Display Week and San Francisco! ■

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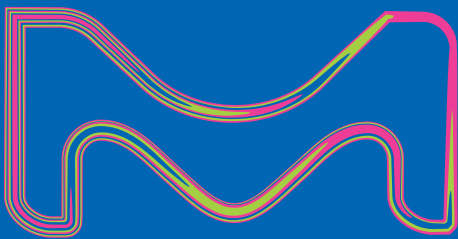
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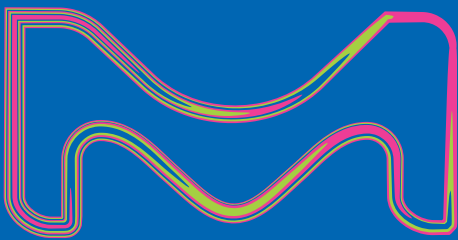


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guest editorial



Vehicle Displays in the Passing Lane

by Karlheinz Blankenbach

When I was a young electronics engineer starting out in the 1990s, the only graphics display technology suitable for ground vehicles was the CRT. Our task was to develop a monochrome monitor with analog gamma correction (digital was not feasible) and a microcontroller with a serial interface to the host system. Today, color-graphics displays with millions of pixels can take up major parts of the dashboard, as is the case for the 17-in. dashboard display in the Tesla Model S. A similar story has

taken place in terms of computing power – low-MHz single core to GHz multicore processors with a graphics processing unit (GPU) as the major component and display interfaces with speed increases from kbit/sec for 8 segments to Gbit/sec for full HD.

Today, the emphasis on displays has changed as well as their technology. Vehicle displays have grown to more than 100 million units in 2015. The driving experience and entire “look and feel” of today’s car are based significantly on display systems, and displays will become even more of an emphasis in the future as vehicles are equipped with new types of curved, free-form, flexible, and seamlessly integrated displays.

At the same time, environmental requirements such as temperature-range operability and quality (e.g., lifetime) continue to present challenges. Display makers must create state-of-the-art products that enable readability both at night and on sunny days. LCDs must have fast response times even in low temperatures and a high tolerance for quasi-static data displayed for long periods of time without burn-in. For example, displays in electric cars that need to show state of charge (SoC) when the vehicle is not in use are challenged because their operating times may grow from fewer than 10,000 hours to more than 30,000 hours.

Compounding the challenges is that display systems are not made by single companies; the entire value chain must be taken into account, from materials and component manufacturers (Tier 3, 4) to display manufacturers (Tier 2), automotive system integrators (Tier 1), and, last but not least, the vehicle manufacturer (OEM). It is also important to note that innovations in automotive displays begin in luxury cars and migrate years later to intermediate vehicles. Both are challenging – introducing the latest technology and then making it feasible at a moderate price.

In terms of those innovations, there are several categories of visual displays: driver information display (instrument cluster), head-up display (HUD), infotainment display (center stack), and rear-seat entertainment. Due to advanced driver-assistance systems (ADAS) and connected cars, more and more information will be available to the driver and passengers. This functionality will require larger and more numerous displays, as well as advanced HMI concepts such as haptic touch, gesture, and voice control in order to reduce driver distraction and workload for safety reasons. As automated operation changes the way we drive, it will be less essential to view display parameters such as speed and RPM on the instrument cluster, which will convert to more of an infotainment center. However, in the case of actual dangerous situations, augmented-reality (AR) HUDs with a large field of view should pinpoint their locations directly and not just show warnings.

We are pleased to have articles from two companies that are working in these areas in this issue of *Information Display*, which spotlights selected topics of vehicle displays. These include “Understanding the Requirements for Automotive Displays in Ambient Light Conditions” by Daimler and “Haptics Help Drivers Keep Their Eyes on the Road” from Continental. We also have a short overview of an award-winning paper from student researchers at Bosch about their efforts to develop a 3D head-up simulator that can be used in future vehicle display research. Enjoy reading these articles, and you can find out even more in the special automotive display sessions at SID’s Display Week 2016 in San Francisco. Vehicle displays will definitely keep setting the pace for innovation. ■

Professor Dr. Karlheinz Blankenbach has been involved with displays since 1990 and has conducted numerous projects related to displays (many with the automotive industry) at Pforzheim University, where he became a full professor in 1995. He is Vice Program Chair for the Vehicle Displays and User Interface Technology Trends special focus area for the technical symposium at Display Week 2016.



Networking Events

May 22-27, 2016

Looking to meet up with your colleagues in the display industry to discuss technology, business, or just socialize? The events below present just that type of opportunity:

Annual Awards Dinner, Monday:

Each year, SID recognizes individuals that have played a critical role in improving the display industry. This year’s winners will be honored at an awards banquet taking place the evening of May 23.

Business Conference Reception, Monday:

Follows the Business Conference, please note conference attendance is required for admission.

Annual Award Luncheon, Wednesday:

The annual Best in Show and Display Industry Awards Luncheon will take place at noon on Wednesday, May 25. Both awards are peer-reviewed, such that the luncheon is well-attended by captains of industry for high-level networking and recognition of the best in the industry over the last year.

Investors Conference:

The IC will feature presentations from leading public and private companies in the display technology supply chain and encourage questions and discussion between presenters and participants. Concludes with Drinks & Displays: Networking Reception with Presenters and Investors.

Market Focus Conference Reception, Tuesday, May 24:

Follows the Tuesday Market Focus Conference, please note conference attendance is required for admission.

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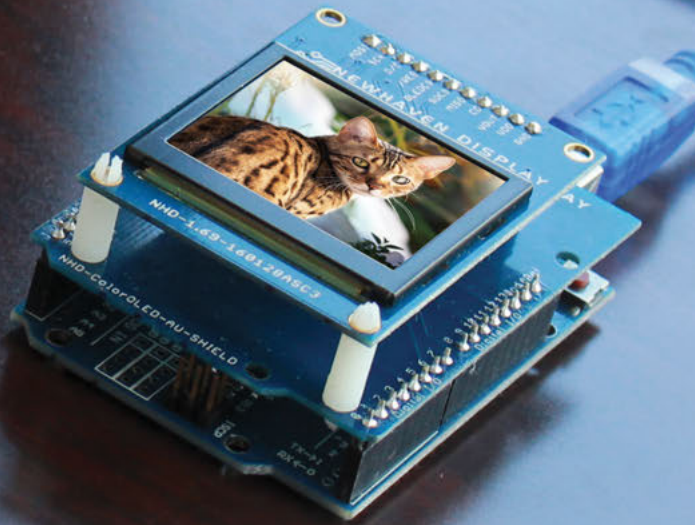
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2016 Display Industry Awards

Each year, the Society for Information Display's Display Industry Awards Committee selects award winners that have advanced the state of the art of display products and technology in the categories of Display of the Year, Display Component of the Year, and Display Application of the Year.

Compiled by Jenny Donelan

THIS year's Display Industry Award winners all address some kind of industry challenge – although the argument could be made that this is the hallmark of any great product. Our 2016 winners are definitely all great products – it was more difficult than ever for the members of the display awards committee to make their selections from the many excellent displays, components, and applications they reviewed for these awards. Where this year's winners differ from each other is whether they solve an existing shortcoming or address one that the industry has not yet realized is there.

Included in the first group are the 2016 Display Components of the Year – two light-guide plates and an ultra-thin polarizer. These components solve manufacturing problems that had threatened to halt the march to ever-thinner TVs and monitors. Polymer light-guide plates (used for edge lighting) could only be made so thin before they ceased performing adequately. Both Asahi Glass Company and Corning tackled this problem by creating glass light-guide plates that enabled super-thin edge lighting for the next generation of televisions. Similarly, polarizers that were made too thin (and currently just about everything relating to displays is being made thinner) ceased to perform well. Nitto Denko solved this problem by creating a

polarizer with new materials that do not degrade when made ultra-thin. Another member of this group is in the Display of the Year category – Apple's iPad Pro display with a variable refresh rate that helps solve the well-known challenge of having both a great-looking display and a respectable battery life on a mobile device.

In our second group, solving the challenges of the future, is Japan Display Inc.'s 8K × 4K LCD module. It is a stunning display that can be used now, of course, but it's also designed to take advantage of the 8K broadcasting content that is surely coming our way, with Japan's NHK broadcasting company as one of its main proponents. The Apple Watch and Microsoft's Surface Book laptop also fit in this category. The jury is still out on how much we need smart watches in general, but Apple is giving the product category its best shot with this watch and its slim bezel (enabled by the watch's plastic OLED substrate that folds at the edges) and a design and interface sensibility that synchs with the user's iPhone, right down to the color gamut of the displays. The Surface Book came with a surprise. Who knew that it might be possible or desirable to remove the screen of a laptop and use it like a tablet? But it works and solves the problem some people have of deciding whether to buy (or carry) a laptop or a tablet, or both.

The members of the awards committee and the editors of *Information Display* are awed by the progress of our colleagues in the

display industry as they continue to innovate, solve problems, and make beautiful functional displays. Please join us in saluting this year's Display Industry Award winners, the best of the best.

Display of the Year

This award is granted to display products with the most significant technological advances or outstanding features.

Apple iPad Pro 12.9-in. Display with Variable Refresh Rate

Apple's iPad Pro features a 12.9-in.-diagonal display with 5.6 million pixels at 264 ppi. The display incorporates an oxide-TFT back-plane to ensure fast pixel charging and improved brightness uniformity. This is the first time that a mainstream display comes with the new power-saving feature of content-dependent variable refresh rate (VRR). The iPad Pro keeps track of when content on the screen is not moving (and thus does not need to be refreshed as often) and cuts the display's refresh rate in half (from 60 times per second to 30) during these intervals.

Apple's designers achieved the flicker-free transition between 60- and 30-Hz refresh rates by engineering and integrating a low-leakage-current oxide TFT, a special negative liquid-crystal material with low flexo-electricity, advanced photo-alignment materials, and a customized new timing controller. With the help of the device's system-on-a-chip (SoC) and operating system, the display refresh rate

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automatically switches between 60 and 30 Hz, depending upon the content being displayed, achieving power saving without any degradation in image quality. The iPad Pro 12.9-in. display also features ultra-low reflectivity enabled by advanced anti-reflection coating on the cover glass surface and optical bonding between the display, touch sensor, and cover glass.

Apple believes that the success of the 12.9-in. iPad Pro display will help accelerate a general display-industry technology transition from a-Si to oxide TFTs.

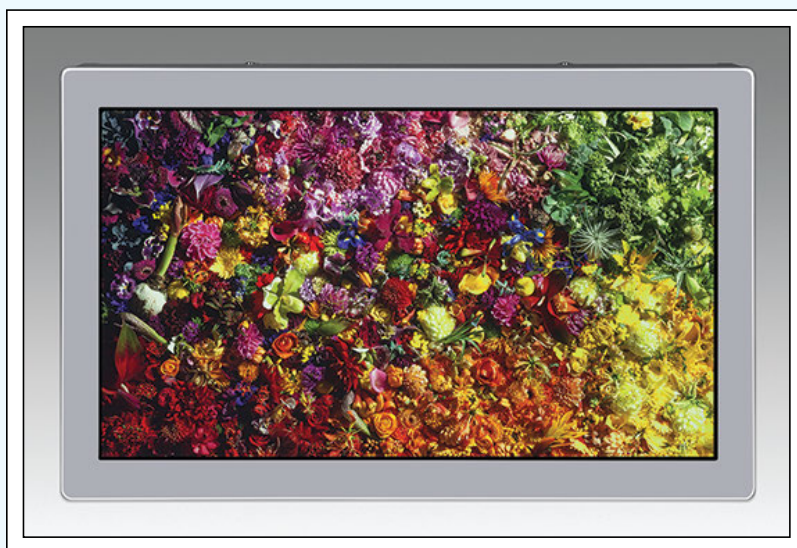
Japan Display Inc. 17.3-in. 8K x 4K LTPS TFT-LCD module

Japan Display Inc. (JDI) has developed the world's first 17.3-in. high-resolution (7680×4320 pixels) fast-response (120-Hz frame rate) LCD module. The module, which is based on low-temperature polysilicon (LTPS) technology with 8K pixels in an RGB stripe arrangement, realizes high-definition (510 ppi) images, and the fast frame rate enables the smooth playback of moving imagery. By providing a wide viewing angle, high contrast, and minimal color shift, IPS technology,

combined with the high pixel density, makes possible life-like 8K imagery that offers a sense of depth and an immersive image experience.

The 17.3-in. size is standard for monitors used in video image production, and the next-generation 8K technology suits that market, as well as medical and gaming applications that require high resolution and image-quality depth. In terms of 8K broadcasting, the Japan Broadcasting Company (NHK) and its research arm have been proponents for several years. (See the article “ ‘Super Hi-Vision’ as

DISPLAYS OF THE YEAR



*The **Displays of the Year** are the Apple iPad Pro 12.9-in. display with variable refresh rate and the JDI 17.3-in. 8K x 4K LTPS TFT-LCD module. JDI display image provided courtesy of NHK.*

Next-Generation Television and Its Video Parameters” by researchers from NHK in the December 2012 issue of *Information Display*.) That article mentioned an early trial in which select groups of people in London, Bradford, Glasgow, the U.S., and Japan watched the Olympic Opening Ceremonies 4 years ago in Super Hi-Vision or 8K. Since then, there have been public 8K viewings that included the Sochi Olympics, the FIFA World Cup in 2014, and more than 15 separate viewing events in 2015. NHK, with a web site dedicated to 8K (www.nhk.or.jp/8k/index_e.html), is clearly committed to the technology, and numerous sources report that 8K will be used to broadcast the 2020 Olympics in Tokyo, as well as a portion of the 2016 Olympics in Rio this summer. High-resolution modules like JDI’s are set to take advantage of this broadcast technology.

Display Components of the Year

This award is granted for novel components that have significantly enhanced the performance of a display. A component is sold as a separate part destined to be incorporated into a display. A component may also include display-enhancing materials and/or parts fabricated with new processes.

Note: Both Asahi Glass Company and Corning are being honored for their development of a glass light-guide plate that overcomes the problems of polymer-based light-guide plates.

Corning Iris Glass Light-Guide Plate

In the early 2000s, Corning LCD glass substrates began enabling the transformation of televisions from big bulky consoles to sleek contemporary models. By 2014, Corning realized that a glass innovation was required to enable the thin LCD mega-trend to continue. Thin LCDs had become limited by challenges from using polymer light-guide plates (LGP). An LGP is used in the back-light of edge-lit LCDs to distribute light evenly throughout the display, a key factor in a crisp brilliant image.

Polymer LGPs lack the dimensional stability required for ultra-slim displays. When a polymer LGP is subjected to heat and humidity, the material can warp and expand, compromising its opto-mechanical performance. The instability of polymer requires designers to add a wider bezel and thicker backlight with air gaps to compensate for this movement.

Replacing polymer with glass solves this problem, but standard glass compositions have not met the optical requirements until now.

Color purity is another key requirement of an LGP. A combination of Corning’s proprietary fusion process and Iris Glass’ composition positions Corning’s light-guide plate offering to achieve color-shift performance that matches best-in-class material. Corning Iris Glass offers outstanding dimensional stability while ensuring superior optical performance that enables manufacturers to offer thinner TVs.

Asahi Glass Company XCV Glass Substrate for a Light-Guide Plate

Compared to conventional light-guide plates (LGP) made from acrylic resin, Asahi Glass Company’s (AGC’s) new XCV glass substrate offers more than 20 times greater stiffness and a coefficient of thermal expansion reduced by a factor of 8. This means that TVs made with this glass can be very thin (as thin as 5 mm). XCV’s resistance to heat and moisture means the bezel can be narrower and also contributes to long-term reliability, which will be useful in the future when displays may require considerably higher luminance.

Light-guide plates use the edge-lit method to transmit and diffuse light from LEDs placed at a screen’s edges, resulting in improved backlighting of the screen. Whereas existing glass materials were not suited to LGPs due to their low transmittance, XCV is highly suitable because it offers the necessary high transmittance to assure extra-bright displays.

AGC, by adopting its proprietary extra-efficient float process developed for the production of large glass substrates, is now able to mass-produce and quickly deliver XCV to meet demands from TV and display manufacturers. In addition, AGC can supply the glass with printed dot patterns, which maximizes XCV’s performance and helps manufacturers adopt the glass LGP more easily.

Nitto Denko Ultra-Thin Polarizer

The ultra-thin polarizer developed by Nitto Denko has high optical properties and low shrinkage and is considerably thinner than standard polarizers. In recent years, as displays such as LCDs and OLEDs have become ever thinner, display components, including polarizing films, have had to become thinner as well.

Polarizing film is an optical film made of a polarizer and a protection film and is one of the most important components of displays because it determines optical properties. Generally, a polarizer is made by dyeing polyvinyl alcohol (PVA) film with iodine, then stretching it in water. The higher the PVA-iodine complex is oriented, the higher the optical properties of the polarizer. Polarizers with a highly oriented PVA-iodine complex provide higher definition. However, the shrinkage force generated by the stretching process becomes a concern, particularly because the polarizer shrinks in high temperatures, and the shrinkage force of the polarizer can cause panel bending, display distortion, and dimensional variance.

In the past, many studies have been carried out to resolve the shrinkage issue of polarizers. But current technology cannot manufacture a polarizer thinner than 10 μm with PVA film. At present, the standard thickness of polarizers is still about 25 μm and the minimum thickness for practical applications is still 12 μm . This is because controlling the shrinkage force of a polarizer without losing good productivity and high optical properties is a difficult issue.

To solve this issue, Nitto Denko developed an all-new ultra-thin polarizer with a thickness of 5 μm , which is about 80% thinner than the standard polarizer made from PVA film. And the shrinkage force of this polarizer has been cut down dramatically. Dimensional variance after heating has been reduced by 60%. At the same time, the optical properties are as high as those of standard polarizers.

This new ultra-thin polarizer offers various improvements. For example, its low shrinkage force solved the panel bending issues with heating. And this new polarizer rarely causes display distortion. Furthermore, the new polarizer has drastically improved handling ability. This polarizer is making considerable contributions to the development of ever thinner LCD panels, as well as to the creation of next-generation displays, such as flexible displays and wearable displays.

Display Applications of the Year

This award is granted for novel and outstanding applications of a display, where the display itself is not necessarily a new device.

Apple Watch with Retina Plastic OLED

Apple Watch’s flexible OLED Retina display

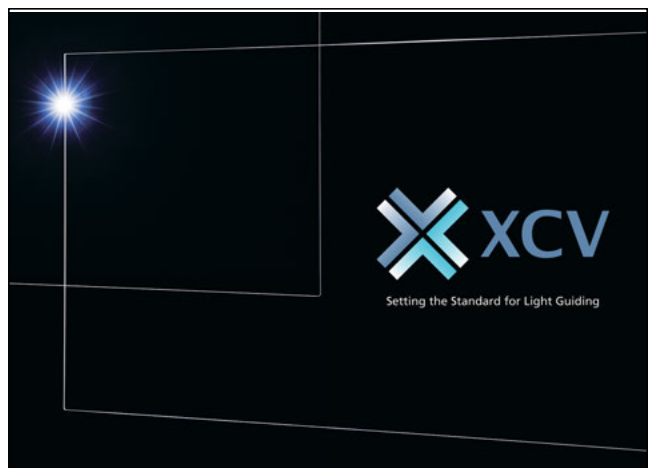
incorporates edge-folding of the display substrate to a sub-millimeter radius that allows the display to occupy a maximal and symmetric portion of the watch face. According to Apple, the emissive technology of an OLED also enables power-saving capabilities. (Bat-

tery life is still a major challenge for wearable devices.)

Apple Watch comes in both 1.34- and 1.54-in. sizes. At 326 ppi, the OLED display allows clear representations of imagery such as the sweeping second hand of a “traditional”

watch, and its deep contrast allows a seamless blending of the user interface into the physical product. Each display is calibrated to produce an industry-standard color gamut that ensures a matched appearance between Apple Watch and the user’s paired iPhone.

DISPLAY COMPONENTS OF THE YEAR



*The **Display Components of the Year** are the Asahi Glass Company XCV Glass Substrate for Light-Guide Plates, the Nitto Denko Ultra-Thin Polarizer, and the Corning Iris Glass Light-Guide Plate.*

DISPLAY APPLICATIONS OF THE YEAR



The Display Applications of the Year are the Apple Watch with Retina Plastic OLED display (left) and the Microsoft Surface Book Laptop Computer (right).

Apple Watch is designed to be a highly accurate timepiece, a personal communication device, and a health and fitness companion. The watch face is highly customizable for personal expression. With its low emissive power and carefully designed user interface, the watch has helped usher in a new era of display applications for wearable products.

Microsoft Surface Book Laptop Computer

Microsoft's Surface Book laptop has an easily detachable screen that can be used like a clipboard. Integral to these features is Surface Book's 13.5-in. PixelSense display – a screen designed for optimal image quality with touch and pen input.

The 6-million-pixel display has a resolution of 3000×2000 for an industry-leading 267 ppi to ensure that, even up close, users see smooth lines with no pixilation. The PixelSense display on Surface Book features negative liquid-crystal technology and photo-alignment to increase light transmission, overall brightness, and contrast. The resulting contrast ratio of 1700:1 makes reading easier and provides

for brilliant colors. PixelSense uses optical bonding to reduce glare and an in-plane-switching-type LCD to ensure that the display retains color accuracy over a full range of viewing angles. Every display is color calibrated.

Multi-touch capability and the Surface Pen also distinguish Surface Book from other premium laptops, allowing users to create beyond the capability of keyboard and mouse. Surface Book's 1024 levels of pressure sensitivity and reduced latency are designed to make writing or drawing on Surface Book feel as natural and accurate as writing with pen on paper. To minimize parallax, the components of the display stack were designed to be as thin as possible without sacrificing performance. This thin display stack was achieved by using cover glass that is only 0.4 mm thick, a touch sensor film that's thinner than a few human hairs, LCD glass that is 0.2-mm thick, thin polarizers that offer optimal viewing in all directions, and optical bonding with the thinnest possible adhesives. Optimization of the software and firmware, Microsoft's custom

silicon, and the efficiencies in Windows 10 combine to reduce latency so that digital ink appears instantly at the touch of the pen.

Surface Book runs Windows 10 and features sixth-generation Intel Core i5 or i7 processors. It is available with up to 16 GB of memory, an optional discrete graphics chip, and up to 1 TB of storage. ■

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Understanding the Requirements for Automotive Displays in Ambient Light Conditions

Optimizing vehicular displays for the ambient light conditions they will be used in – from dark nights to sunny days and everything in between – requires a delicate balance of settings based on carefully obtained metrics.

by Jan Bauer and Markus Kreuzer

IN recent years, graphical display systems in automotive instrumentation and information systems have progressively replaced conventional gauges, lights, and switches, adding new levels of human-machine interaction. However, in conditions such as bright sunlight or changing ambient light, it can be highly challenging to ensure good legibility as well as a high-value perception of the displayed information on the part of drivers.

At night, display legibility is generally no problem. “Brilliance,” as a result of a complex combination of contrast, black-state uniformity, luminance, color gamut, dynamic range, and the quality of the content itself, is the most important goal. In daylight, drivers encounter a high dynamic range of ambient light situations varying from diffuse to direct (directional) light conditions. Guaranteeing legibility of important and relevant information on the

display device is then the most critical task. In such cases, the perceived luminance contrast is the crucial and relevant quantity. This is determined by the light conditions, the reflection and scattering behavior of the display, the luminance of the display, and, of course, by the content itself.

Figure 1 shows a typical light condition of a type that can cause severe legibility problems. The luminance of a cloud can reach up to 20 kcd/m² in peak luminance.

Such a situation, reflected on an untreated glossy glass surface (reflection ratio 4–5%) will lead to a reflected image with a luminance of up to 1000 cd/m². If we consider that for reference – a maximum luminance of a good automotive display is in the range of 500–800 cd/m² – then guaranteeing legibility is a severe problem.

However, before going into detail, we need to understand the concept of “Illumination” and its consequences for automotive displays. In common use, illumination of objects (that are not self-emissive) within an environment will cause those objects to appear brighter depending on their reflectivity. However, quantifying this illuminance using the traditional measure of Lux (lx) is only useful if we consider a perfectly diffuse homogeneous illumination source from all directions or if

the objects are nearly perfect Lambertian scatterers (scattering the light homogeneously in all directions). In all other cases, the area of the light source as well as the direction of light incidence and observation direction are highly important.

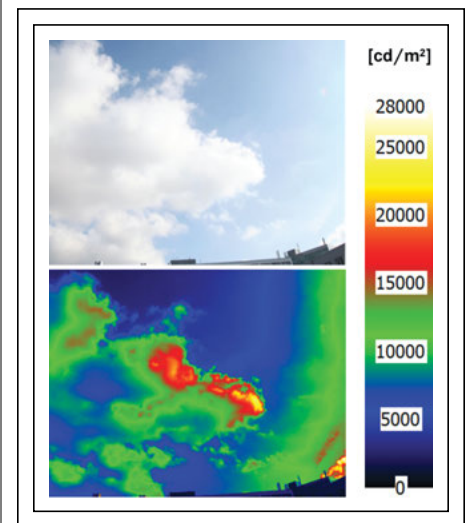


Fig. 1: At top is an image showing a typical ambient light situation for a partly cloudy day. At bottom is the corresponding false color image of luminances.

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Modern display surfaces are rarely Lambertian scatterers, and highly glossy surfaces are preferred. For such typical, only slightly scattering surfaces, it can be shown that only a light incident within a cone having an apex angle of about 20° – 30° around the reflected viewing direction (see Fig. 2) will have a significant influence on the appearance of the display content. Therefore, looking at the luminance distribution of diffuse light sources itself (e.g., clouds and sky as seen by an imaging photometer in Fig. 1) provides more insight than does looking just at the illuminance level. Only extreme bright point-light sources such as the sun (direct sunlight) have to be considered in more detail, and, here, illumination level and the illumination/observation geometry have to be analyzed very carefully. Table 1 provides an overview of typical automotive ambient light conditions.

To determine the influence of ambient light conditions affecting the perception of display content on in-car displays, we have to differentiate between two phenomena:

- Specular reflected light and scattered light from display surfaces and inner structures of the display itself (touch sensors, electrode structures, etc.)
- Veiling glare in the eye of the display observer from the stray-light effect caused in the lens and vitreous body.

The contribution from the first phenomenon comes from the internal and surface properties of the display, the direction of incident light onto the display, and the corresponding direction of observation; hence, it depends on in-car geometry (e.g., location of side windows) as well as on the position and orientation of the display. Figure 2 schematically shows a typical automotive situation with in-car geometry and ambient light conditions.

The reflected and scattered light results in an effective luminance L_r that adds up as background to the luminance distribution of the display content and hence reduces contrast and color gamut. For well-made geometric designs and highly optimized displays, it is possible to keep the reflected luminance L_r in critical situations below a critical value of 50 – 200 cd/m^2 .

The second phenomenon is a result of the surrounding luminance (L_g , e.g., represented by a glare light source – see Table 1) that is scattered in the lens and the vitreous body of

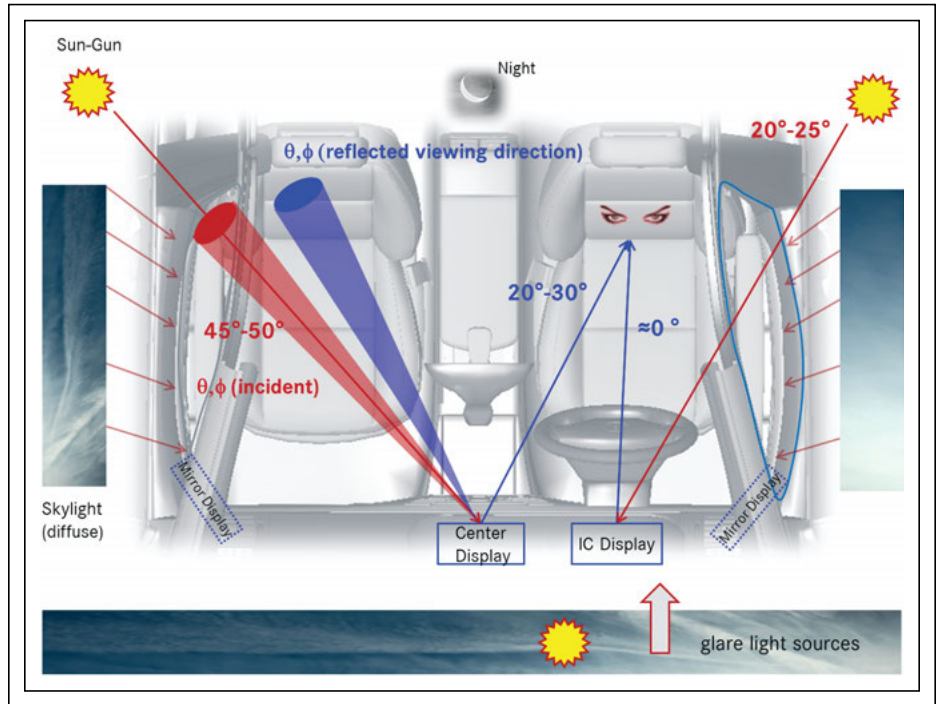


Fig. 2: This schematic visualization of ambient light conditions and in-car geometries helps demonstrate that the most critical situation would arise if the specular reflection of direct sunlight falling onto the display surface reaches the observer's (driver's) eye. As a design rule, the driver's blue viewing cone, representing the (reflected) viewing direction with an apex angle of 5° – 10° , should not leave the interior of the car. Consequently, the red cone, representing the most critical situation of direct sunlight hitting the display, should not overlap with the blue cone.

Table 1: Several typical automotive ambient light conditions are shown.¹ L_g is the luminance of the light source itself if we can consider it as an area light source (diffuse illumination). If we consider the effects of point light sources, then the illuminance E_i and the angle of incident and observation are crucial parameters that affect legibility and image quality. Average glare light sources are the result mainly of area light sources (road surface/buildings/sky) seen through the front windshield and resulting in veiling glare.

	L_g (cd/m^2)	E_i (lx)
Direct sunlight	–	2k – 100k
Cloudless sky	1.4 – 4.4k	
Cloudy	6k – 20k	500 – 10k
Rain	40 – 500	50 – 1.3k
Twilight	0.8 – 400	3 – 500
Night	0.05 – 10	0 – 50
Average glare light source	1k – 5k	—

the human eye (Fig. 3). This scattered light, called veiling glare L_v , is superimposed with the image that the observer is looking at, e.g., the display in the car. This superimposed light then influences the vision of the viewed object. For typical car geometries, a veiling glare of around $L_v = 30\text{--}35\text{ cd/m}^2$ is quite typical on a bright, sunny day with an average glare light source of $L_g = 2\text{--}3\text{ kcd/m}^2$ (for details see also Fig. 10).

As mentioned previously, the legibility of important and relevant information shown on the display device is most crucial under critical illumination conditions, and therefore the contrast ratio of such information should not fall below a certain value. The ISO norm (ISO15008²) provides the specific light conditions, and, accordingly, the corresponding criteria for the minimum contrast ratio C_r of relevant information:

- $C_r \geq 5:1$ during night time,
- $C_r \geq 3:1$ during diffuse day-time illumination,
- $C_r \geq 2:1$ at direct-sunlight conditions.

The authors have evaluated the ISO15008 standard and concluded that the provided light situations as well as contrast definitions outline a valid approach. Nevertheless, the ISO15008 does not cover the aspect of the veiling glare, so extra care has to be taken when designing display hardware and car geometry. This includes the content shown on the display as well as the dimming procedure of the display.

Perception of Display Content in Ambient Light Conditions

Under bright ambient light conditions – due to the reflected light and the veiling glare – further luminance is added to the display's luminance. With this additional luminance, the perceived optical performance of the display differs from the dark room conditions that are generally used in the specification of display parameters. The differences primarily result in three effects:

- I Degradation of the visible gray-level differentiation
- II Reduction of the visible contrast
- III Reduced perceived color gamut

The dark room conditions are represented in Fig. 4 by the green lines and curves. The effect due to the additional light (E_A) is shown by the red lines and curves. We used sample data to illustrate the effects.

The gray-level degradation appears in Fig. 4 (left). The green solid line shows the linear perception of the gray values without ambient light. In general, the perception of light is a complex non-linear relationship. A display compensates for this with a non-linear gray-value representation (often called gamma-correction). In ambient light, the additional light is superimposed with the non-linear luminance of the gray levels. In combination with our non-linear perception, this results in a reduced differentiation of especially the low gray values, as shown by the red dotted line in Fig. 4 (left).

The definition for the contrast ratio of a display is the ratio of the intended bright data luminance divided by the value of the background luminance at the same location. Simply put, how many times brighter is the intentional bright information than the unin-

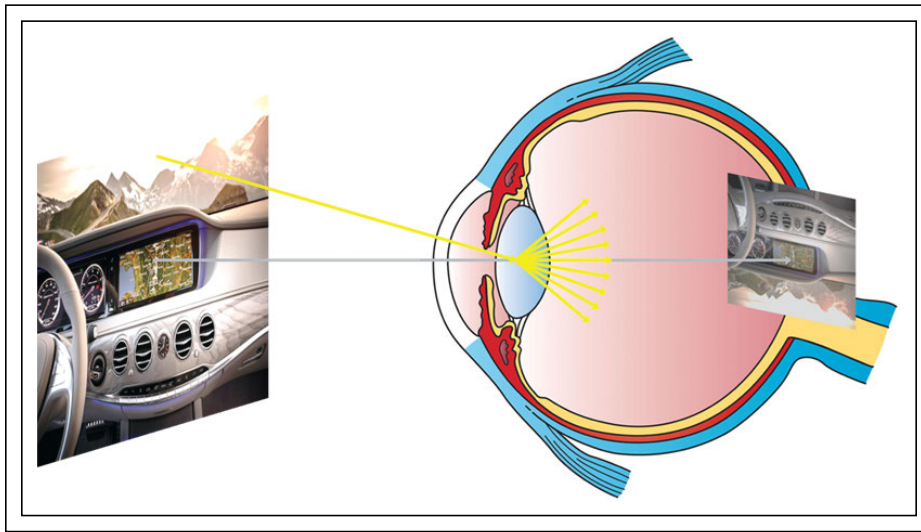


Fig. 3: This visualization shows the veiling-glare effect. The observer is looking at the display (gray arrow). The light of the sun (yellow arrow) that is visible behind the windshield is scattered in the eye. Due to the scattering, the light is distributed onto the retina, leading to an additional luminance (veiling glare) that then causes a change in perception (e.g., contrast reduction) of the display in the car.

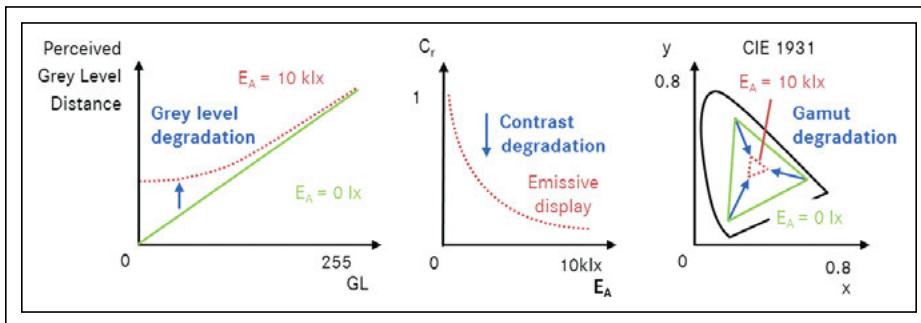


Fig. 4: Examples of the influence of ambient light to the perceived gray values are shown at left (8-bit example); center (contrast); and right (primary color gamut). Due to the added ambient light (E_A), the gray values do become less distinguishable, the perceived contrast is reduced, and a color shift in the direction of the ambient light color coordinate occurs (sample data). The ambient light $E_A = 10\text{ klx}$ is used for an illustration of the ambient-light effects, which is approximately the effect on a cloudy day. For an accurate consideration of the in-car ambient-light situation, more data, e.g., the direction of the light, has to be considered.

tentional background luminance? The smallest value of this ratio is 1:1 and at that value the display is undiscernible. With added ambient light, the background luminance is relatively more affected than the intended bright data luminance. Hence, the perceived contrast is significantly reduced, as shown in the red dashed curve in Fig. 4 (center).

For dark surroundings, the color gamut is spanned by the RGB primaries of the display, represented by the green triangle in Fig. 4 (right). The superimposed ambient light shifts those color primaries into the direction of the color coordinates of the ambient light, and hence reduces the perceived color gamut as represented by the red dashed triangle. The result is a reduction of the color contrast and is visible as a washed-out picture with a less brilliant display experience.

Beyond the effects that happen in bright ambient light, the impact of dark ambient light conditions on the perception of the display and its content also have to be considered. Here, the effect of low light adaptations of the human visual system generally results in two disadvantageous effects:

- I Disability glare
- II Whitening of the display's true black appearance

The disability glare (I) can be caused by a too bright display and/or in connection with an unsuitable light-colored graphical user interface (UI). The total emitted light from the display results in veiling glare that affects the outside view and may impact driving abilities. This effect is often seen with after-market navigation systems or smartphones when used during nighttime driving.

To minimize disability glare, suitable UIs for nighttime driving often make use of "black" as a background color in an extensive way. However, limited contrast of LCDs, restricted black uniformity, and sometimes too-bright display settings lead to a low-quality gray appearance (II) when compared to the dark environment of a car interior.

Passive Optimization of Specific Automotive Display Parameters

During nighttime driving, maximum contrast ratio (C_r), color gamut, and an appropriate UI design will dominate the display quality. Here, OLED displays and in future HDR displays would make a great difference. Meanwhile, we still have to deal with LCDs

and should try to optimize the situation as mentioned above.

Well-made UIs for nighttime driving usually consist of an on-pixel-ratio (OPR) ranging from about 5% (classical UI for entertainment and comfort functions) up to 20% (for full-area navigation maps). Here, the OPR is defined as the sum of the luminances of all display pixels, divided by the number of pixels in relation to the luminance of a white screen.

$$OPR = \frac{\sum_{i=1, j=1}^{n, m} L_{ij}}{L_w \cdot m \cdot n}$$

where L_{ij} is the luminance of an individual pixel i, j of a display with $m \times n$ pixels defined by

$$L_{ij} = L_w (f_r \cdot r_{ij}^\gamma + f_g \cdot g_{ij}^\gamma + f_b \cdot b_{ij}^\gamma)$$

where L_w is the maximum luminance of the display, γ is the gamma correction factor (typically $\gamma = 2.2$ for automotive displays) and r_{ij} , g_{ij} , and b_{ij} are the normalized gray level of the red, green, and blue subpixel ij . The weighting factors f_r , f_g , and f_b depend on the color gamut ($f_r + f_g + f_b = 1$) and account for the different contribution of the red, green, and blue pixel to the total luminance.

From customer studies, we know that dimming the luminance of the display to a maximum value of $L_{night} \approx 150 \text{ cd/m}^2$ for an OPR of 5% results in the best compromise between brilliant content and optimized black-state perception while avoiding annoying disability glare. Since the dynamic range of OPR of the complete UI is quite large (at a maximum OPR = 20% the optimized dimming luminance should be around 40 cd/m^2), one has to find a good compromise for luminance settings or apply an OPR-dependent global dimming of the display. For a careful evaluation, one has to take into account that the disability glare is certainly dependent on the size of the display. In any case, manual setting of the maximum luminance should allow the driver to regulate the maximum luminance according to his preferences.

However, for an ideal ergonomic situation, we have to consider one more important point that relates to the structural integration of the display itself: By means of mounting measures and/or use of light-control films, one should avoid creating distracting reflections of

the display content in the windshield and possibly in the side windows.

In daylight conditions, the situation becomes far more challenging. The reflected and scattered ambient light results in an effective luminance L_r that adds up as background to the luminance distribution of the display content and hence influences the legibility and value perception in a crucial way.

The typical in-car situation during day-time driving can be effectively divided into two typical cases: (a) diffuse daylight and (b) direct sunlight condition. The SAE 1757¹ gives a good representative illumination and measuring setup for both typical automotive cases:

- Diffuse daylight: $L_r = L_{diffuse}$ as result of an omnidirectional light source illuminating the display surface with an illuminance $E = 5 \text{ klx}$.
- Direct sunlight: $L_r = L_{SunGun}$ as result of a directional light source with a luminous power $E = 45 \text{ klx}$ incident on the surface of the display.

As mentioned above, the ISO15008² defines the legibility criteria for daylight contrast ratios as $C_{r, diffuse} \geq 3:1$ and $C_{r, SunGun} \geq 2:1$ for all relevant information shown on a display.

However, much more interesting is the question of what conditions must be fulfilled – in terms of content creation and display properties – to ensure such requirements. To give a general answer, we consider the following points and argumentations:

1. Relevant information (text, symbols) in modern UIs is designed to fulfill the nighttime condition $C_{r, night} \geq 5:1$ and make use of the full available range. Typically, such information is designed in the same way for day and night-time operation (while other background information and, e.g., maps might be different).
2. Analyzing many such typical modern UIs, we derived the understanding that to fulfill the ISO15008 criteria $C_{r, SunGun} \geq 2:1$, the display needs to fulfill the requirement for the maximum possible contrast (black/white contrast) in direct sunlight conditions as

$$C_{r, max, SunGun} = \frac{L_w + L_{SunGun}}{L_B + L_{SunGun}} \approx \frac{L_w + L_{SunGun}}{L_{SunGun}} \geq 5:1$$

where L_w is the maximum luminance and L_B the minimum luminance of the display itself.

It is then straightforward to show that this is equivalent to the requirement

$$C_{r,max,diffuse} = \frac{L_W + L_{diffuse}}{L_B + L_{diffuse}} \approx \frac{L_W + L_{diffuse}}{L_{diffuse}} \geq 13:1$$

for diffuse daylight conditions ($C_{r,diffuse} \geq 3:1$).

At a diffuse omnidirectional illumination with $E = 5$ klx, the reflected luminance can be derived as $L_{diffuse} = 5000/\pi \times R_{sci}$ (cd/m²) by measuring the reflectivity R_{sci} of the display (diffused illumination, 8° viewing angle, sci: specular component included) as defined by international standards CIE No. 15, ISO 7724/1, DIN5033 Teil7, ASTM E 1164, and JIS Z 872.

Following this line of argumentation, we can easily derive a direct relationship between the reflectivity R_{sci} and the required maximum luminance L_w of the display as shown in Fig. 5.

For a typical display without any anti-reflection coating (AR) or low-reflection coating (LR), the reflectivity is usually around 4%, requiring a display with a maximum luminance of 600–800 cd/m². While this is quite challenging, especially if one considers that this luminance must be seen from the observer's position, it also shows that the situation improves dramatically using high-quality AR coatings ($R_{sci} < 2\%$).

Whereas the diffuse daylight situation results in a straightforward relationship between overall reflectivity and maximum luminance of the display, the situation is more complex in direct sunlight. The additional luminance $L_r = L_{SunGun}$ perceived by the observer is strongly dependent on the geometry of the incident light direction, orientation of display, and the position of the observer. Therefore, we have established a very simple experimental method to determine the reflective scattering properties of a display with a single measurement, which can be used to analyze the situation as a function of the aforementioned parameters. Figure 6 shows the schematic setup of the experimental apparatus. The display is illuminated with a directional light source of $E = 45$ klx incident at $\theta = 45^\circ$ with respect to the display surface normal. By using an imaging photometer with a conoscopic-lens setup, one can easily determine the scattering amplitude $L_r = L_{SunGun}$ as a function of observing position and display orientation.

Figure 7 shows such a measurement for a typical automotive configuration, where the

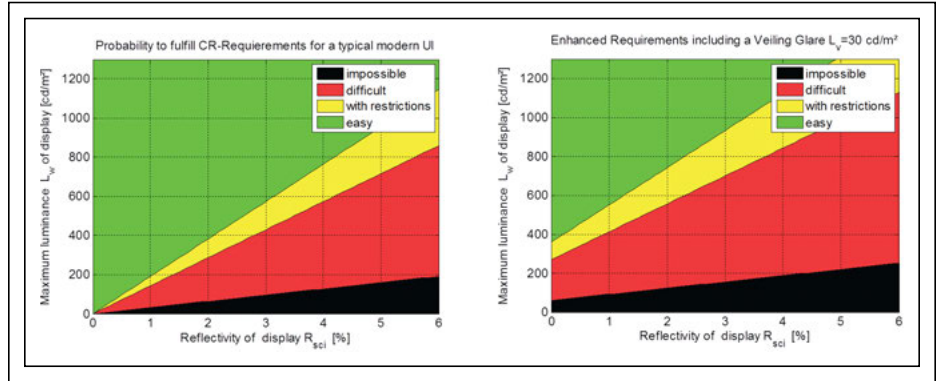


Fig. 5: The charts show the relationship between the required maximum luminance L_w and reflectivity R_{sci} of the display in ambient daylight conditions ($E = 5$ klx omnidirectional). The colored areas show the probability of fulfilling the legibility criteria for typical modern UIs. The green area (yellow area) corresponds to $C_{r,max,diffuse} \geq 13:1$ ($\geq 10:1$) respectively, $C_{r,max,SunGun} \geq 5:1$ ($> 4:1$). In the left chart, we reflect the situation according to the legibility criteria of ISO15008. In the right chart, we have included the effects of a typical veiling-glare value $L_v = 30$ cd/m².

information display is mounted in the center of the dashboard. The most critical situation appears when direct sunlight is incident on the display entering the interior of the car through the passenger side window close to the B pillar (see Fig. 2). The angle of incidence with respect to the display normal is then typically around $\theta_i = 45^\circ$ and the driver observing direction at $\theta_d = 20^\circ$ – 30° . For an in-plane geometry (azimuth angles $\phi_d = \phi_i + 180^\circ$) it can be seen that $L_r = L_{SunGun}$ would be in the range from $L_{SunGun} \approx 55$ cd/m² ($\theta_d = 20^\circ$) up to

$L_{SunGun} \approx 250$ cd/m² ($\theta_d = 30^\circ$) and as such influencing the legibility in a critical way. Therefore, the anti-glare properties of the display coating as well as the orientation of the display should be carefully chosen. For example, tilting the display by an angle ϕ_{tilt} would change the illumination/observation geometry by $\phi_d \geq \phi_i + 2\phi_{tilt} + 180^\circ$ ($\theta_d \leq \theta_i$) while keeping θ_d almost unchanged. Looking at Fig. 7, it can easily be seen that changing the orientation ϕ_{tilt} in an appropriate way could improve the legibility dramatically. It

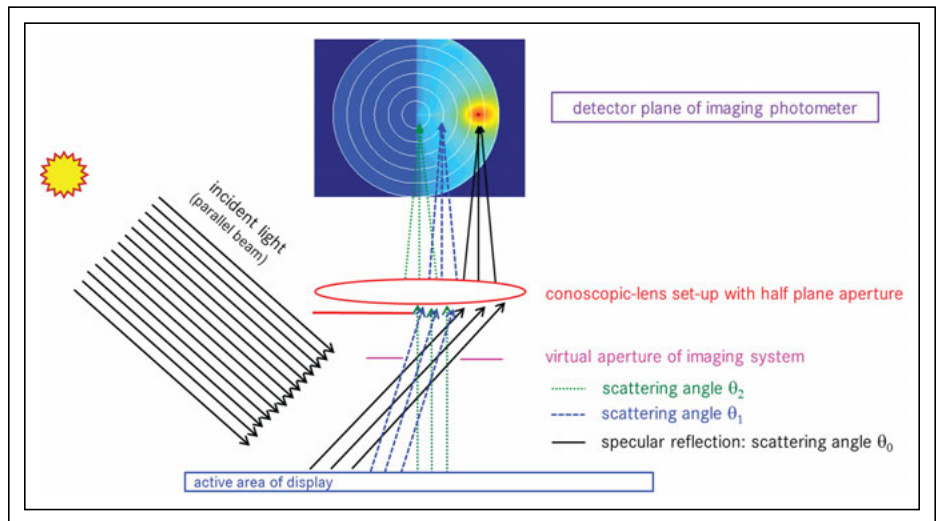


Fig. 6: These schematics show the conoscopic setup created to determine reflection/scattering properties of displays.

Fig. 7: This measurement is typical of a modern automotive display with high-quality AGAR coating. Incident light is at $\theta = 45^\circ$ (azimuth angle $\phi = 180^\circ$). The specular reflection is clearly seen as maximum scattering amplitude $L_r > 10.0000 \text{ cd/m}^2$ [at $\theta = 45^\circ$ ($\phi = 0^\circ$)].

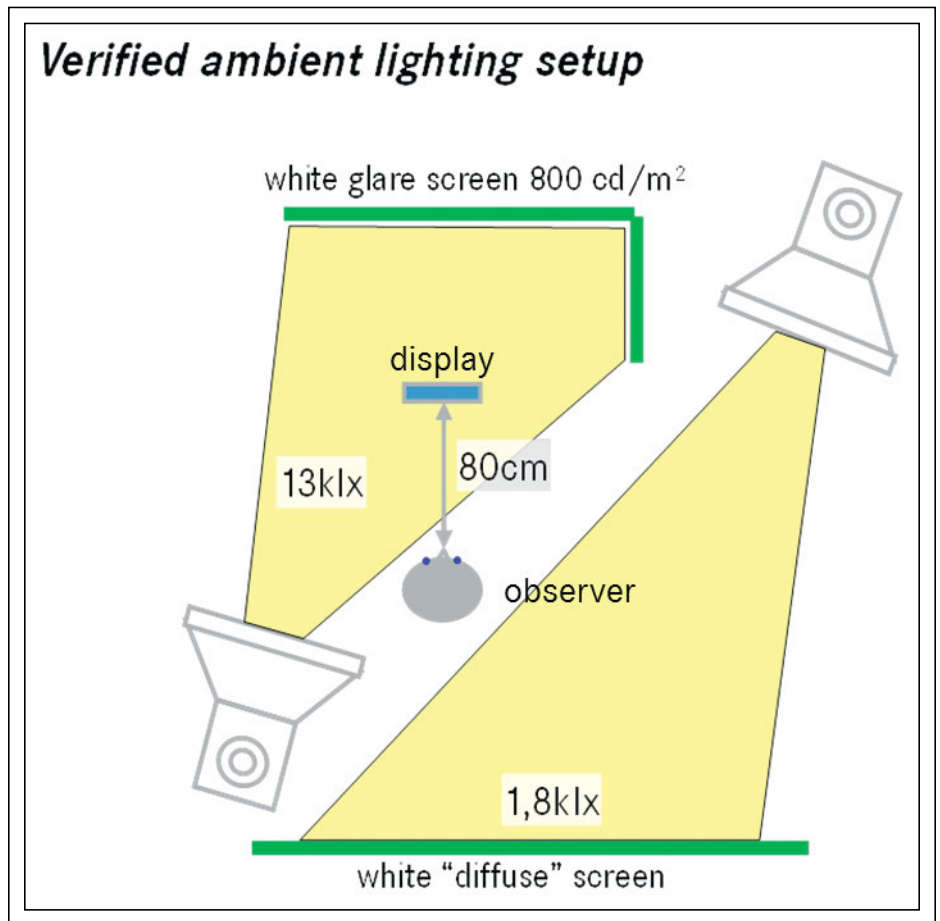
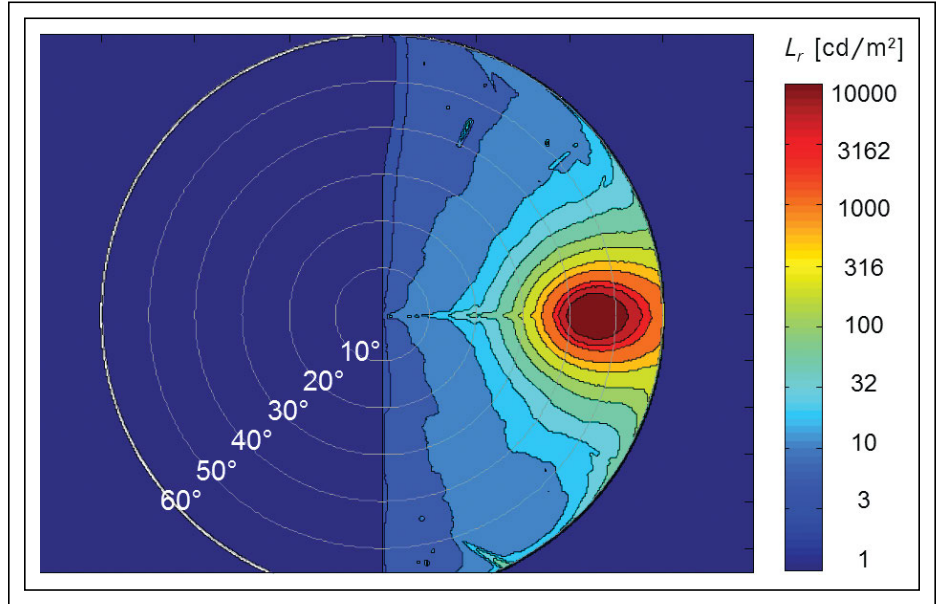
can be shown that as long as $L_{SunGun} \leq 3 \times L_{diffuse}$ (or better $L_{SunGun} \leq 3 \times L_{diffuse} + 2 \times L_v$, considering the effect of veiling glare), then the legibility is most critically affected in diffuse daylight conditions and, consequently, the relationship shown in Fig. 5 would be valid in defining the required display properties. In the opposite case, one would first have to improve the display orientation and/or optimize the scattering behavior of the display or even drive the display at much higher luminances. It is worth mentioning that not only the scattering of the display surface but also the internal scattering mechanism might have a crucial influence. Electrode configurations in particular in certain LCD technologies and pixel structures of OLED displays can lead to distinct strong asymmetric scattering behavior and could therefore badly influence the legibility if not properly handled.

Thus far, we have only talked about legibility criteria that are important to minimize driver distraction during driving. However, the general value perception is also important in terms of optimizing customer satisfaction.

Therefore, we have conducted extensive customer studies to understand what parameters influence the value perception of displays during daylight situations.³ Figure 8 shows the schematic configuration we chose to show representative image content to our customers while independently varying the luminance contrast ratio of the display, perceived color gamut (both measured during ambient light conditions without taking into account the effect of veiling glare), brightness of the display, and type of surface coating as well as the size of the display.

While details of these studies will be published elsewhere, here we would like to

Fig. 8: This verified lab set-up was created to study the influence of display parameters on the value perception of a display. A combination of diffuse ambient light, direct “sunlight” incident on the display, and a veiling-glare light source were used to simulate ambient light conditions during daylight driving.



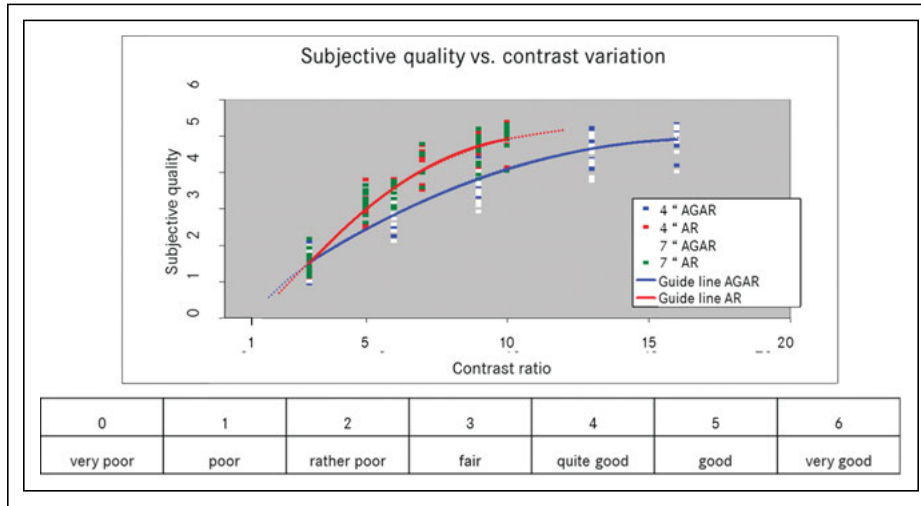


Fig. 9: Here, we illustrate subjective quality as a function of maximum contrast ratio $C_{r,max}$ (black/white contrast) in typical automotive ambient light conditions (38 subjects). The different colored data points correspond to independently changing perceived color gamut and display brightness while keeping $C_{r,max}$ at the same time constant. Different sizes of displays (4 and 7-in. diagonals) as well as two surface coatings (AR = glossy anti reflection, AGAR = matte anti-reflection/anti-glare coating) were tested. It can be clearly seen that the customers preferred glossy coatings to matte coatings even if that factor had no influence on perceived contrast and legibility.

focus on a somewhat astonishing result. As shown in Fig. 9, it can be seen that the value perception – measured as a subjective quality in a range from “very poor” to “very good” as a function of maximum contrast ratio of the display $C_{r,max}$ (black/white contrast) – is greater for displays with pure glossy AR coating at $C_{r,max} \geq 10:1$ and for strongly scattering AGAR coatings at $C_{r,max} \geq 15:1$. On the one hand, this is a surprisingly good coincidence with our derived display criteria for diffuse daylight situations to ensure good legibility in modern UIs. On the other hand, it shows that during severe sunlight conditions it will be very difficult to reach the optimum in value perception because it would require a very high maximum luminance of the display. While static optimizations such as choosing a well-adapted display orientation will have their limits, here special measures like dynamic optimization of the UI content could be helpful to optimize customer satisfaction.

Sensing Ambient Light Conditions

As mentioned above, two resulting components of ambient light (reflected light and veiling glare) are present, which mainly influence the perception of display content in

ambient light. We propose a sensor to measure the angle-dependent illumination on the display and a sensor to measure the driver-relevant luminance for the veiling glare.

The sensor for the illumination should be placed closed to the display and aligned toward the emitting direction of the display. Here, then, the illumination from different angles onto the display has to be measured.

The veiling-glare sensor should be aligned toward the line of sight of the driver. We propose a sensor measuring the luminance of the street and the horizon in the driving direction.

With both sensors it is not possible to directly measure the influence on perception. Both measurements need to be combined with a model to calculate the resulting ambient light effect. Input data to those calculation models are:

Reflected Light:

- Angle-dependent illumination of the display
- Relative driver position to the display
- Display surface information (as measured earlier)

Veiling Glare:

- Driver relevant luminance

- The geometry of the car (field of view, display, and driver location)
- The (standardized) point-spread function of the human eye

In our model to calculate the reflected light, the display reflection and scattering characteristic (bidirectional reflectance distribution function or BRDF) are convoluted with the illumination data. The output data is the (angle-dependent) reflected light. Depending on the eye position of the driver, it is possible to derive the relevant reflected light.

To calculate the veiling glare, we utilized the (standardized) point-spread function of the human eye.⁴ The point-spread function provides the characteristic of light scattering inside the eye. In our model, we calculate the resulting veiling glare at the display position by convoluting the point-spread function with the geometrically dependent luminance image of the car interior. The geometrical image that we derive from the CAD data of the car represents the visual field of the driver with $\pm 60^\circ$ horizontally, $\pm 30^\circ$ vertically (see Fig. 10). To simplify the calculation, we assumed 0 cd/m^2 for the car interior and set the window areas (blue area) to the measured glare luminance seen through the windshield. With this model, it is possible to derive the complete distribution of the veiling glare in the car interior. Based on this calculation, it is then possible to define the veiling glare relevant for the driver display (instrument cluster) and central display. For the example shown, the relevant luminance at the instrument cluster display (gray box) and the central display (white box) is around 30–40 cd/m^2 .

Active Adaptation and Optimization of Display Performance

The ambient light in the car can change quickly, e.g., when the car enters a tunnel or changes driving direction, or it can be constant for a long time, e.g., when driving at night on a highway. To address this, we combined the high display quality from the static optimization with the measurement of the ambient light situation to dynamically optimize the display performance depending on the ambient light situation. We aimed to optimize the following parameters dynamically:

- Display luminance (e.g., via backlight intensity variation)
- UI design (e.g., day/night optimized design).

- Optimization of the display's black level by local dimming.
- Optimization of the gray-level distribution for better readability.
- Optimization of the global and local contrasts.

As a basis for all dynamic optimization, we considered the display-luminance adaptation. With this adaptation, we achieved a significant optimization of the overall display performance depending on the ambient light. Based on the findings earlier in this article, we aimed to keep the contrast, at ambient light, at a ratio of 10:1 or 15:1 depending on the display surface. With a maximum white luminance of the display of around 500–800 cd/m^2 , this is possible for most daylight conditions.

An issue at night is often the integration of the display. This is caused when the LCD's black luminance is brighter than the surrounding dashboard of the car. With a high static contrast of the display, this can be addressed. An active optimization of the black level of the display is possible through using local dimming for LCDs.^{5,6}

Besides the contrast and black-level improvements for low ambient light conditions, the readability and visibility content in bright ambient light conditions is a quality criterion. We aimed to enhance the readability

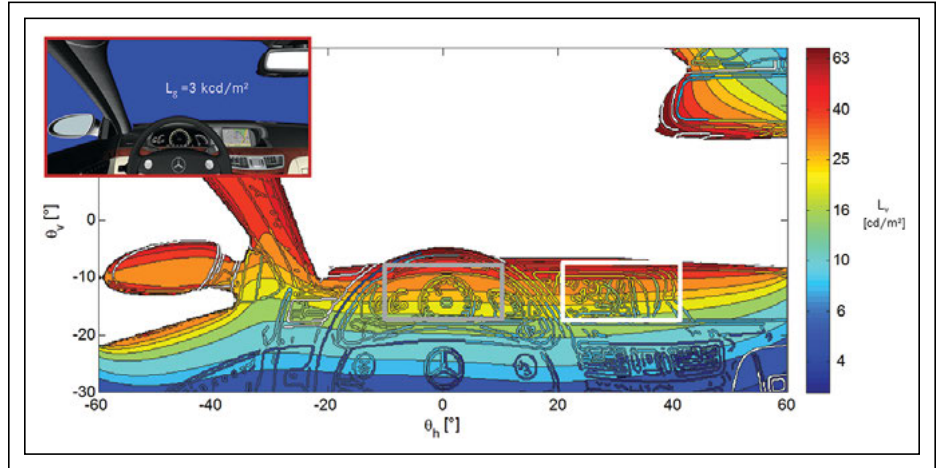


Fig. 10: Veiling-glare distribution in the car is shown with a simplified homogeneous glare luminance seen through the windshield and the side window of $L_g = 3 \text{ kcd/m}^2$. The resulting veiling glare (inside the car) is caused by the scattering in the human eye and leads to a perceived luminance that is added to the display's luminance of around $L_v = 30\text{--}40 \text{ cd/m}^2$. For the calculation, a true-scale geometric CAD model of the car interior was used. The veiling-glare distribution is calculated by the convolution of the point-spread function of the human eye with the luminance distribution truncated by the geometric model of the car. The viewing angle in the geometric model matches the driver's viewing angle $\pm 60^\circ$ horizontally, $\pm 30^\circ$ vertically.

through two different approaches – one for entertainment and the other for UI content.

Entertainment content, like movies, is often optimized for dark ambient light conditions

such as cinemas. Here, the content creators are using the dynamic range of the content to support the immersion of the viewer. For this reason, the content consists of mostly dark and medium colors, which leaves the bright colors for glare-like effects or bright flashes. In the car, due to the ambient light and the smaller displays, those immersion effects do not work as expected by the content creators and can lead to imagery that is difficult to perceive.

To reduce the effects of ambient light on entertainment content, we used a two-step algorithm: DIE & DOP.⁷ In the first step, the image (a1, A1) was analyzed and the usage of the dynamic range is optimized by the “dynamic image enhancement” algorithm (DIE, Fig. 11, a2, A2). On average, this led to an increase in contrast by more than a factor of 2. In the second step, the gray-level degradation by the ambient light (see Fig. 4, left) is compensated by the “daylight optimized perception” algorithm (DOP, Fig. 11, a3, A3). With the DOP, the gray values are remapped

Fig. 11: The images include (a1) original image, (a2) DIE enhanced image, (a3) DIE & DOP enhanced image, (A1) histogram original image, (A2) histogram DIE enhanced image, and (A3) histogram DIE & DOP enhanced image (rendered for daylight setting).

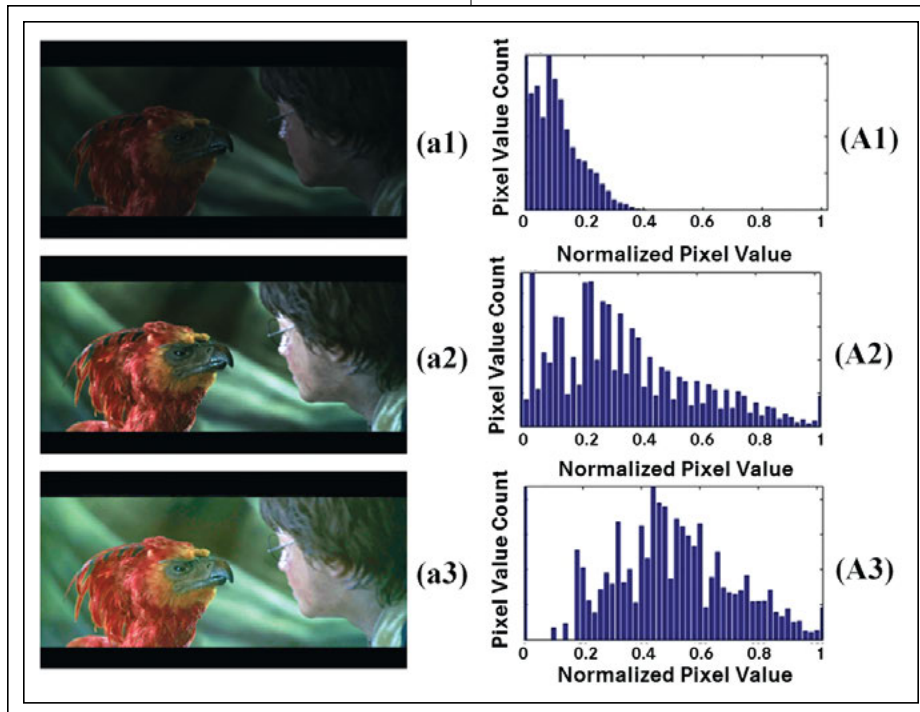




Fig. 12: Sunlight optimization of UI content appears above with an edge enhancement filter applied to gain readability of the UI content.

to achieve a linear gray value perception in the ambient light situation. As a result, the picture appears a lot more visible due to the higher contrast and details in dark gray values can be seen and differentiated.

Such algorithms have already successfully been implemented in a series of in-car entertainment functions. A new approach aims to optimize the UI content. In opposition to entertainment content, the UI is daylight and sunlight optimized. This means the complete dynamic range (black to white) is utilized by the UI. Hence, a global remapping of the gray values to achieve a better dynamic range utilization, as it is applied for DIE, is most likely not possible. The compensation of the gray-value degradation DOP can be applied, but the ISO15008 specification has to be considered carefully, as some contrast levels for bright colors can be degraded by DOP. To enhance the readability, especially for sunlight conditions, it is possible to optimize the local contrasts by local enhancement such as edge filtering and or un-sharp masking of the picture as shown in Fig. 12.

In summary, we have shown that the quality and legibility requirements of automotive displays at night and in ambient light conditions are complex but can be analyzed in detail. Consequent configuration of the display location and orientation as well as passive and dynamic optimization and adaptation will optimize legibility and minimize driver distraction. In the future, new approaches such as local dimming and HDR-UI concepts will enhance the value perception of in-car information and infotainment systems.

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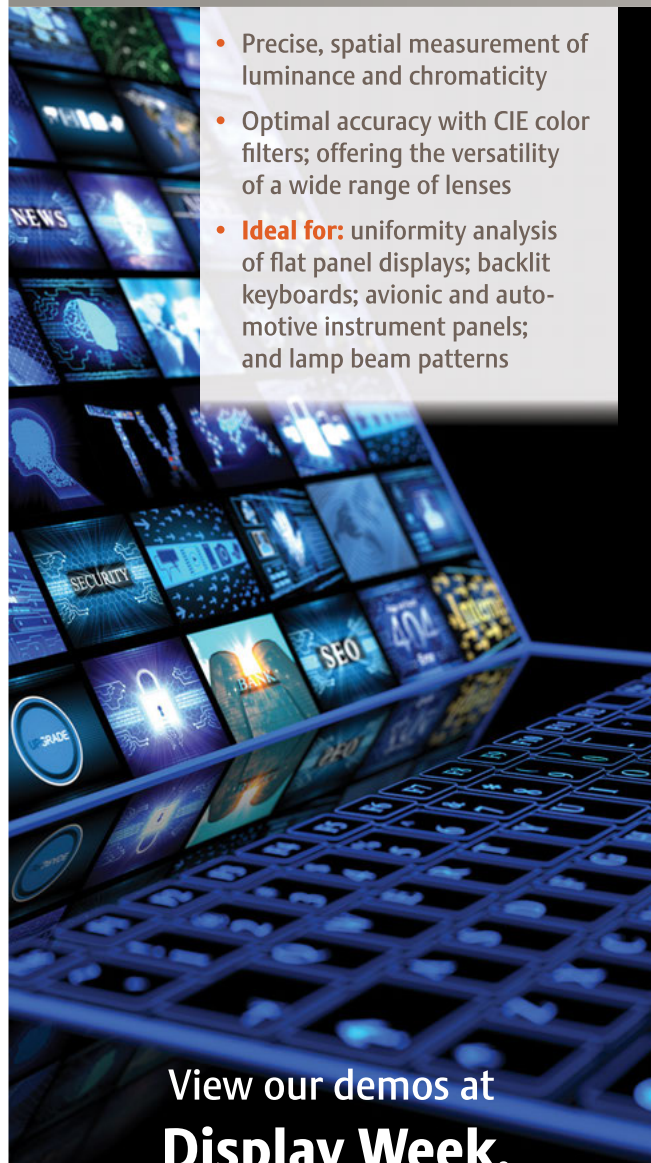
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Haptics Help Drivers Keep Their Eyes on the Road

An empirical user study suggests that touch displays with haptic feedback reduce driver workload by making blind operation easier and faster.

by Thomas Vöhringer-Kuhnt, Kai Hohmann, Andreas Brüninghaus, and Ercan Tunca

INFORMATION DISPLAYS have become an indispensable element of the vehicle dashboard. In many vehicles, a center-console display is an essential part of the control functions for driver information systems. The size and visual quality of displays in instrument clusters are continually increasing, to the point where the display sometimes becomes the entire instrument cluster. There is no doubt that displays have become a core element of a vehicle's human-machine interface (HMI).

Managing Distraction

Displays for the automotive HMI have to meet a long list of tough automotive-specific requirements, including a very wide range of ambient temperatures, sunlight readability, ruggedization, power efficiency, *etc.* Therefore, automotive display technology and vehicle integration are a special field within display technology. A different challenge relates to human distraction. Compared to smart phones (which are often used in vehicles but that is a separate area of concern), display technology in a car has to be designed in a

way that minimizes driver distraction during a "secondary task" scenario, leaving enough visual, manual, and cognitive resources for the primary task of driving.

Successful utilization of display technology in the vehicle requires an appropriate control concept, high-performance hardware with suitable features, and ergonomics that facilitate "blind" operability to reduce eyes-off-the-road time. The question is how to optimize human interaction with the car through display ergonomics and the role of displays within a holistic HMI concept.¹

Displays Support the Ideal of an Holistic HMI

The role of displays extends far beyond showing information. There would be no ergonomic way of controlling the wealth of functions in a modern car without display technology. In many cases, the displays are part of a control concept that combines hard keys and/or a central control element. In other cases, the display itself combines the two elements of information and control action. Touch displays in the center console, for instance, integrate the presentation of information and menu/button manipulation, which frees the driver of any mental transfer between separate places of visual information and command action. Any operation of touch displays has an immediate effect and maps to direct manipulation of objects in the analog

world, while operating in-car devices indirectly (*e.g.*, by rotary push buttons) involves a separation of action and reaction. Indirect operational paradigms also vary widely across car makes and models. Depending on the interior design and control concept of a specific car model, the element of touch can also be provided by a separate touch pad in combination with a display.

The benefits of displays as controller devices in vehicles reside in the high degree of freedom they offer with respect to interface design and in the experience users have with them in their daily lives. This level of freedom can be utilized within a holistic HMI concept. The term holistic refers to an approach across systems. This approach interconnects hardware and software components to dynamically support users' preferences, needs, conditions, and environment. A holistic HMI aims at a safer and more intuitive driving experience with enhanced joy of use. Drivers will be in constant interaction with their vehicle. They can enjoy intuitive 'user-manual-free' driving with display systems, control elements, and other components.

The Technical Side of Haptic Displays

Standard touch display technology requires constant visual control. In order for users to see that the desired function has indeed been activated, they depend on visual cues. Concepts requiring permanent manual-visual

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coordination are not state of the art for automotive applications, where looking away from the traffic situation is critically to be avoided.² Therefore, developers at Continental have recently added haptic feedback to touch displays to provide an experience that users are familiar with from using conventional switches or buttons.

The haptic display shown in the cross section below (Fig. 1) was recently employed in a user study that tested the benefits of haptic feedback. Its actuators consist of an electromagnetic spool and a permanent magnet. As a finger moves across the display and passes the borders of soft buttons or presses a button, the buttons generate haptic feedback that can be clearly felt by the user. Also, the force applied by the user's finger is measured constantly. The actuators are fitted behind the touch display and are located under the screen's bonded layers (cover glass, capacitive sensor, display). The conditions of use in vehicles and the basic principle of active haptic feedback require an especially

rigid structure. This technical solution can be scaled to larger display sizes to serve a variety of vehicle manufacturers' requirements. An application of the haptic feedback display of 12.3 in. is already available as a customer demonstrator.

As the user's finger slides over the surface, search haptics enable the sensing of virtual borders between "buttons" (menu elements), without requiring the user to look at the display. Highly sensitive force recognition ensures that accidental touches can be distinguished from intentional operational commands. When the user presses his finger onto the selected "button," a haptic signal will confirm that he has made a successful entry. The haptic signal is not visible to the eye because the deflection is only a tenth of a millimeter, using a very high acceleration to ensure reliable detection of the impulse. Type and intensity of the haptic feedback are freely configurable so it can be adapted to brand-specific OEM requirements. Personalization by the end-user is also theoretically possible.

This specific demonstrator has four electromagnetic actuators underneath the moving display surface. The number of actuators depends on the display size and mass and the specified acceleration on the final cover glass; the minimum number of actuators is one. The user will sense the vibration/haptic impulse anywhere on the screen because the entire screen is actuated. The range of feedback elements is theoretically unlimited. It can vary from a soft single impulse up to a strong long-lasting vibration.

Usability and User-Centered Design

The above-mentioned haptic feedback application is the direct result of a user-centric design process that our researchers employ to ensure that an HMI supports drivers. Haptic feedback is a technical feature serving one purpose only – to make secondary task operation safer for the driver. The first promising observations with haptic feedback were gained with a touchpad input device.³ Adding haptic feedback to this control element reduced driver distraction while increasing user efficiency during control tasks.

To determine whether haptic feedback could improve the performance of drivers at the HMI level as well, we carried out a user study with a dedicated focus on blind operability of touch displays.⁴ A vehicle mockup, including driver seat, steering wheel and pedals, and an in-vehicle information system HMI presented on a Continental touch display system, was installed in the ergonomics laboratory at the Center of Competence HMI in Babenhausen. The primary driving task was to handle a vehicle on a country road, going at a constant speed of 70 km/h and facing oncoming traffic (instructions were given to keep the vehicle inside the right lane and follow the street accordingly). The traffic environment was provided by an open-source driving simulator software.⁵ We chose this setting because German accident statistics show that rural roads are one of the most dangerous driving environments.⁶ The simulated test duration was 45 sec for each trial, during which the driver was always given a secondary task. To complete the task, the driver had to choose one of four functions on a main menu, then activate one of six functions on a sub-menu, make a choice on a list of pre-filtered functional elements, and operate a numeric block with 12 keys. This action had to be carried out with haptic feedback acti-

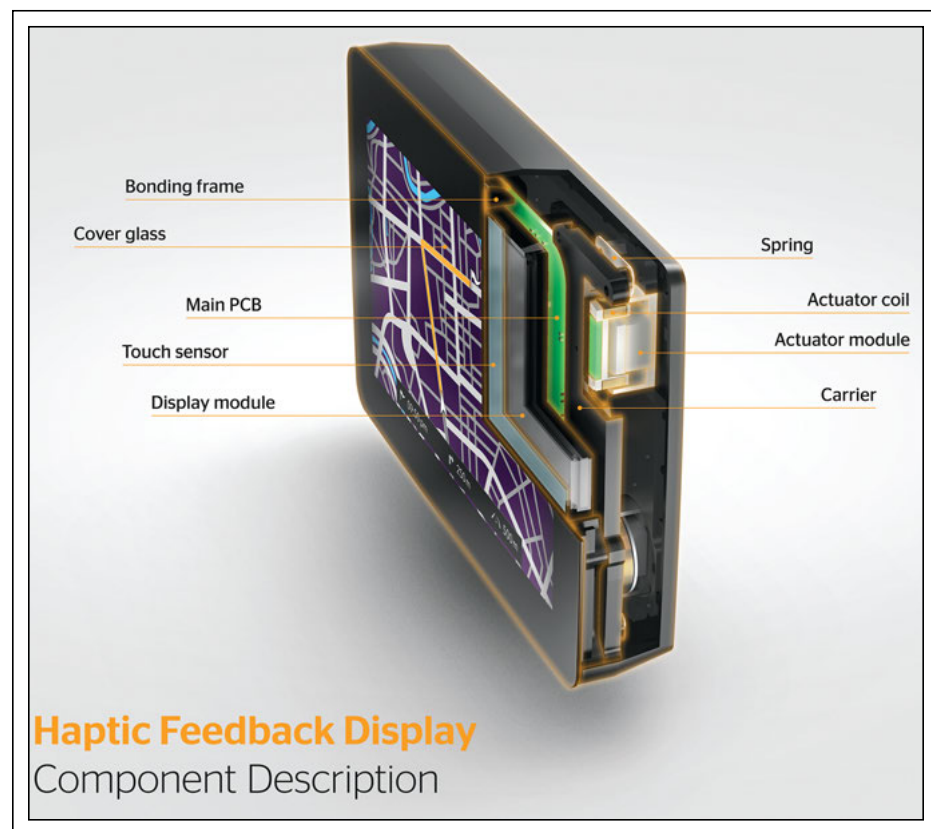


Fig. 1: This cutaway of a touch display shows components used to provide the haptic feedback.

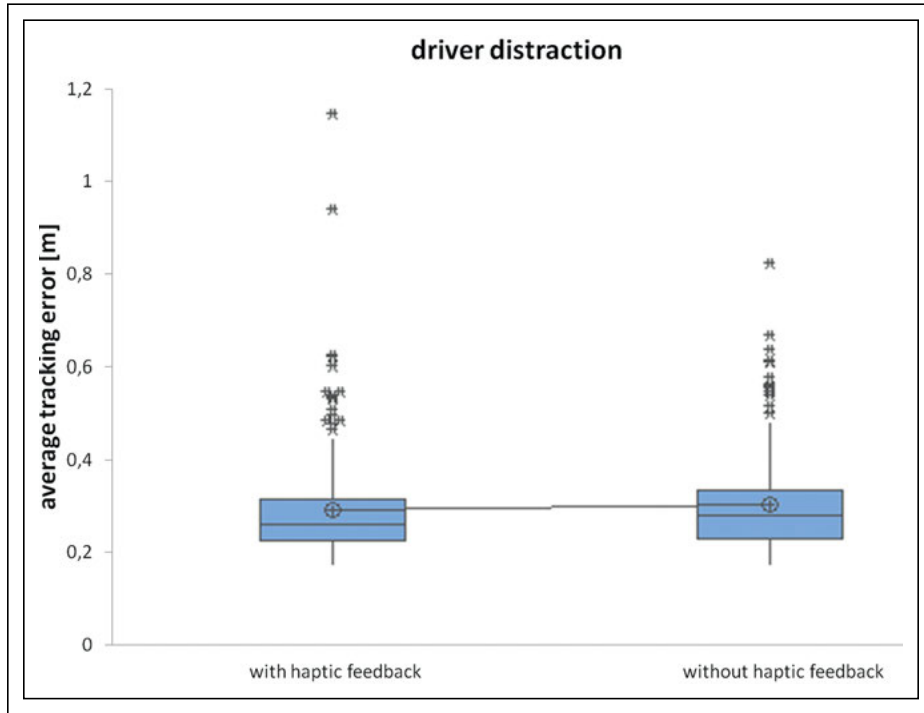


Fig. 2: Driving on a safe trajectory: Results are shown with haptic feedback (left) and without haptic feedback (right).

vated and not activated in a randomized order parallel to the main driving task.

Haptic Feedback Study Results

Twenty-six test users (17 male, 9 female, average age 38.8 years, average annual mileage 20,000 km) carried out the 45-sec drive with and without haptic feedback, respectively. The driver performance (lane deviation from ideal path) was measured and the subjective assessment of the users themselves was scanned via a standardized questionnaire measuring intuitive use.⁷ As described above, the main criterion of driver performance was maintaining a safe trajectory throughout the simulation. In detail, the study revealed the following:

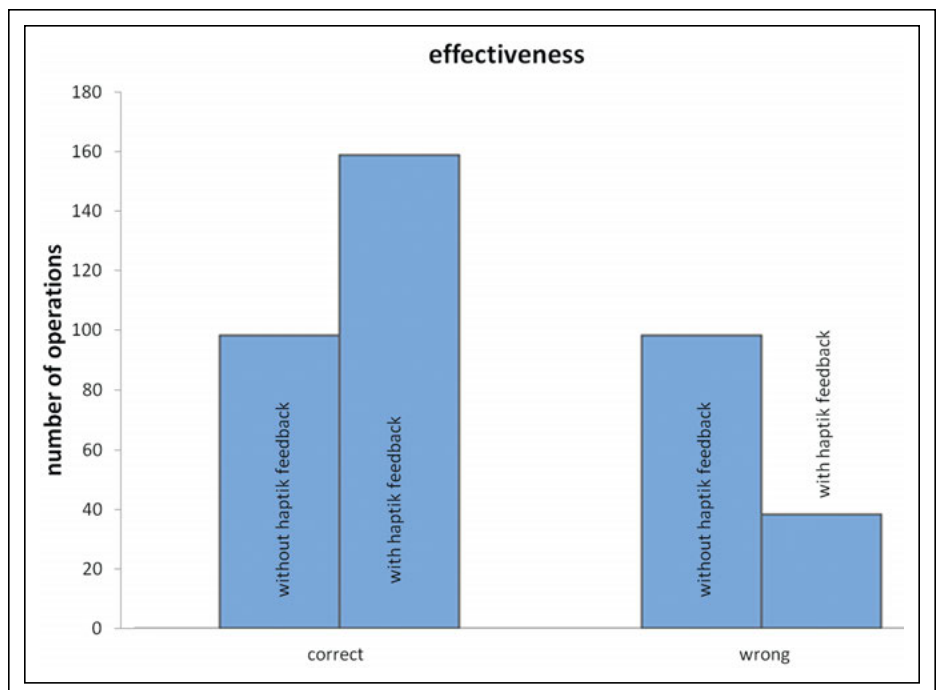
- There is a certain scattering in the control over the trajectory. Unfortunately, a few clear outliers among the test drivers watered down the results to some extent. However, as a tendency, it is still visible that haptic feedback reduces the amount of deviation from a safe trajectory (Fig. 2).

Fig. 3: Effectiveness of carrying out the secondary task: Current operations are at left; wrong operations at right.

- The effectiveness of control operations with haptic feedback was higher than without. The number of correct actions

was noticeably higher, while the number of erroneous actions was considerably lower. Haptic feedback reduced the error rate from 50% (without haptic feedback) to a mere 19.5% (Fig. 3).

- Measuring the efficiency of carrying out the secondary tasks was also affected by a certain number of outliers, which made it difficult to pin down the actual effect (Fig. 4).
- Measuring the subjective workload showed a clear effect across all test drivers. They unanimously perceived the workload as much lower with haptic feedback. The scale ranged from 0 (0 no effort at all) to 150 (= maximum effort felt). Without haptic feedback, the average result was 40. With haptic feedback, the number dropped to 20. Statistically, this effect is highly significant (Fig. 5).
- The questionnaire results also advocate the use of haptic feedback. Without exception, details such as the low mental workload, easy achievement of goals, low perceived effort of learning, fast familiarizing with the control concept, and low perceived error rate confirm the satisfaction with haptic feedback across all test drivers. This effect is statistically also highly significant (Fig. 6).



Adding up these findings – lower error rate, less stress, greater satisfaction – one can conclude that haptic feedback improves the performance of operating an automotive HMI and considerably reduces driver distraction.

Haptics Prove Helpful

The test users confirmed that the haptic feedback provided helpful guidance during the control action. In real-life driving conditions, the influence may be even greater as one can assume that test drivers will want to perform well “under observation” in a lab environment. In a more relaxed everyday driving situation where no one is observing the driver’s behavior, haptic feedback is likely to make more of a difference because one thing is sure – when a control action goes wrong, the driver will try to execute it again. To avoid making another mistake, the driver will likely pay more attention to the secondary task than during the first attempt. As a consequence, a lower error rate will translate into reduced driver distraction because it reduces the total number of control actions and therefore reduces the effort for secondary task completion.

Continental Interior Division has been examining and improving driver information technology for more than a century and has made advancing displays for the vehicle HMI a core focus since the 1990s. We plan to use the aforementioned research to continue our quest for optimization through haptic feedback designed to help minimize users’ distraction when they access displays for secondary tasks while driving. Continental has a haptic feedback application for a touchpad input device in mass production since 2014. It is currently built into the Mercedes C- and S-class vehicles.

Few things can be as annoying as a driver who approaches you not paying attention to the road ahead. In many cases, the cause will be a secondary task the driver is attempting to carry out. To minimize the visual share of a driver’s control actions, haptic feedback provides guidance through a sensory channel that is far less overburdened than the visual channel. In other words, haptic feedback confirms that “What you feel is what you get.”

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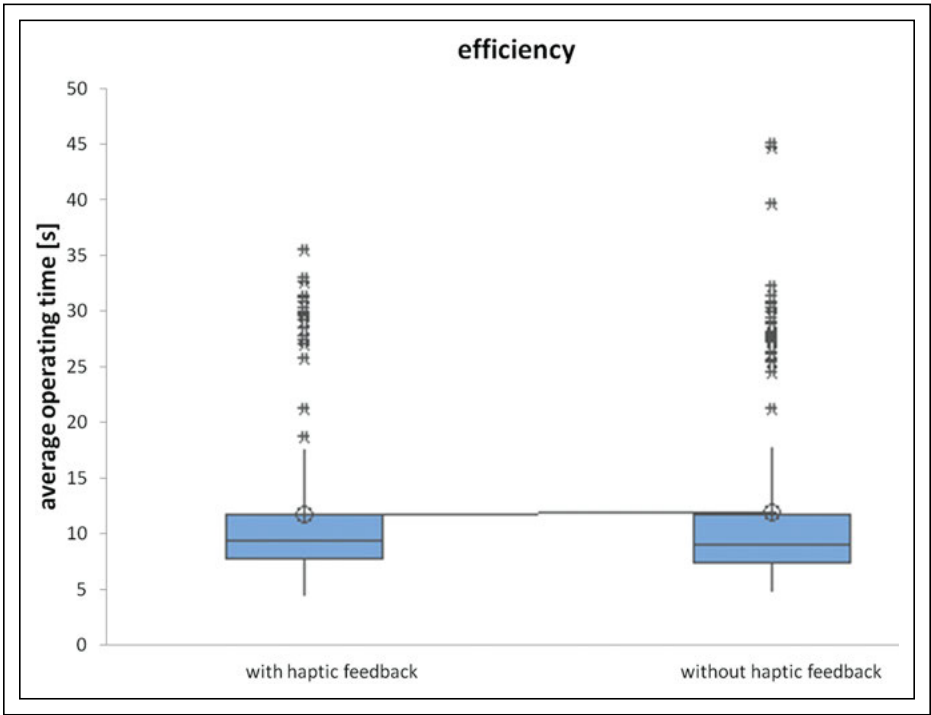


Fig. 4: Outliers mask the actual effect of haptic feedback on control efficiency: Results with haptic feedback are shown at left and without haptic feedback at right.

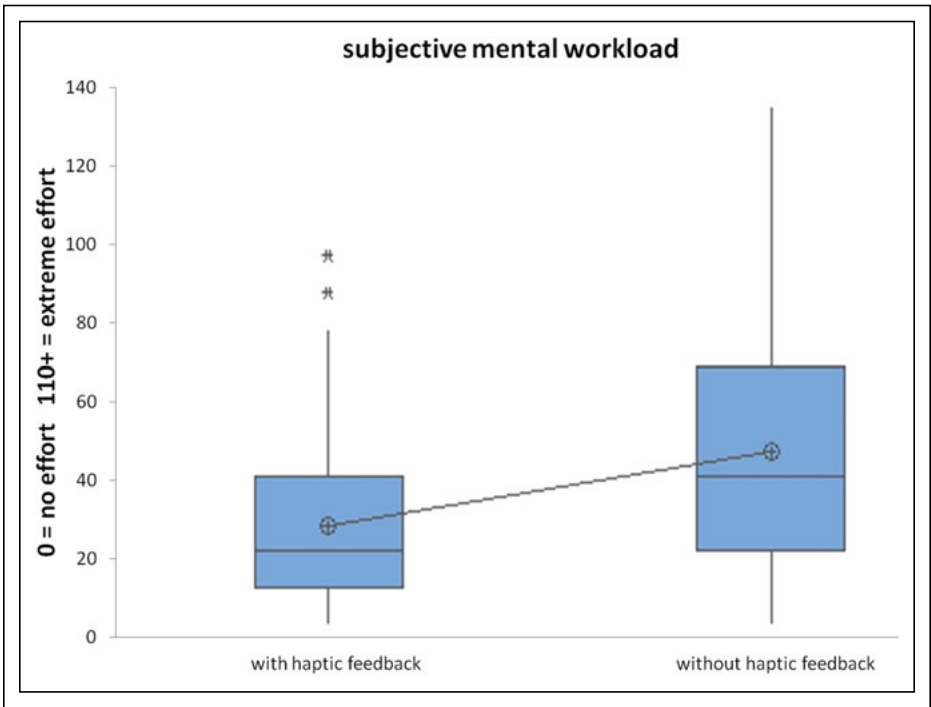


Fig. 5: Haptic feedback reduced the subjective workload by half: Results with haptic feedback (left) and without haptic feedback (right).

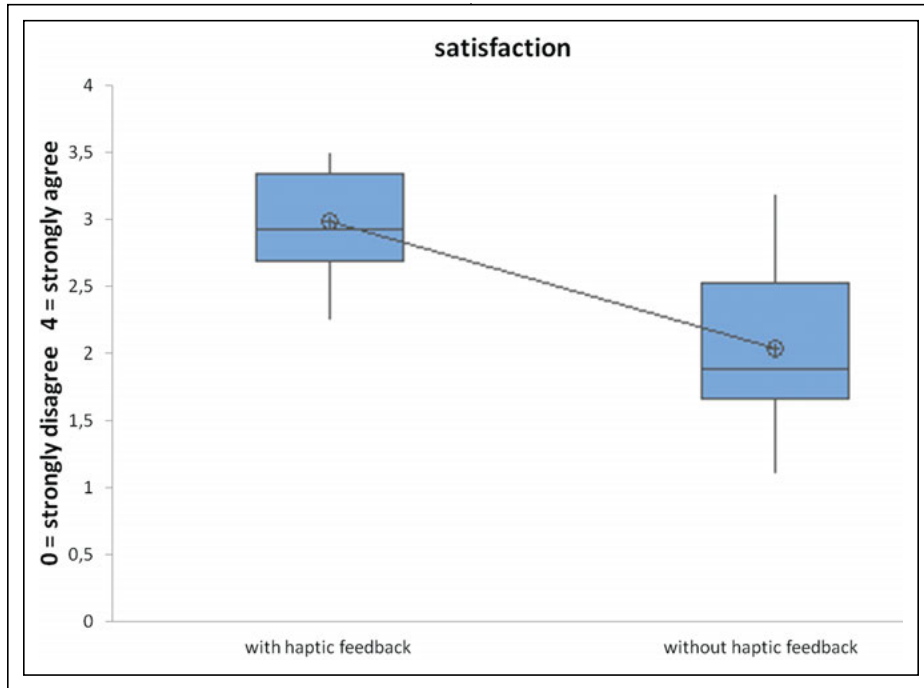


Fig. 6: With haptic feedback (left), drivers are more satisfied with their control actions than without (right).

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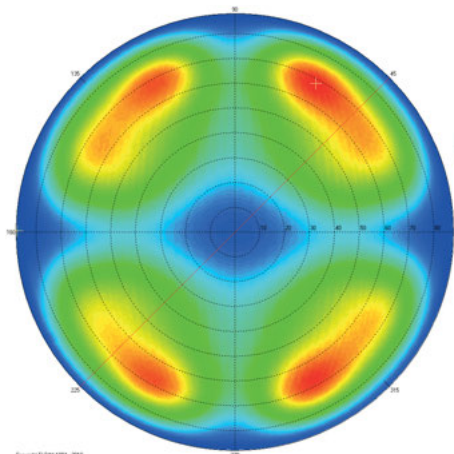
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New Directions for Digital Signage and Public Displays: Part 2

The second half of our two-part series on the market dynamics of digital-signage applications for commercial (or public) displays examines the educational and corporate markets and winds up with a forward look at how OLEDs may further energize the industry.

by Todd Fender

IN the first part of this two-part series (January/February 2016), we looked at the growth of the public-display industry, which has rebounded substantially since the global recession in 2008–2010 and at the factors affecting that growth. Positive influencers include LCD panels that are larger, brighter, and have smaller bezels, including those with alternative aspect ratios, as well as the recently emerged fine-pixel-pitch indoor direct-view LED displays. Potential negatives involve the proliferation of televisions as public displays, which threatens a portion of the public-display market by enabling customers to use readily available and cheaper TVs in lieu of purpose-built digital-signage displays. We also discussed the future of UHD and HDR displays, which will undoubtedly multiply in the public-display market, where trends tend to mirror trends in TVs.

In this article, we look at displays used for the education and corporate markets, where LCD technologies and integrated touch solutions seem to be edging out the prevailing projection-based technology. And, last, we look at a new digital-signage contender – OLEDs with mirror and transparent versions to enable new applications.

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The Rise of the Interactive Flat Panel

An important sector of the digital-signage market is represented by the large displays that are used for sharing information in classroom and corporate settings. Among the earliest and best-known examples are the projection-based digital whiteboards (trademarked as SMART boards by the Canada-based Smart Technologies), which were widely introduced in classrooms beginning in the 1990s.

A battle is now being fought between competing technologies in the conference room and education markets. The current champion continues to be front projection. However, the front-projector market is forecasted to lose share in developed regions at the expense of interactive flat-panel displays. [For the purposes of this article, interactive flat-panel displays can be defined as LCDs featuring integrated optical, infrared (IR), projected-capacitive, or surface-acoustic-wave (SAW) technologies. The term Integrated touch is defined as touch technologies integrated at the brand or set level and sold through distribution or direct to the end user by the brand (NEC, Sharp, etc.). It does NOT refer to those units that are integrated by third-party integrators (those entities that are in business to integrate and add value to existing products) and then sold to end users.] These interactive displays are gaining a foothold in corporate and education verticals due to advantages over front projectors that include higher resolution and brightness, less heat

emission, and the potential for greater collaboration. According to the Q1'16 IHS Public Display Market Tracker, shipments of integrated interactive LCDs will increase at a 18% CAGR from 2016 through 2020.

In one corner, projector companies BenQ, Casio, Dell, Epson, and Sony are not going down without a fight. They all revealed ultra-short-throw front projectors at InfoComm last year, and many of these projectors now integrate with pen- or finger-touch capability on a generic whiteboard or on a wall for education and classroom settings.

Typically, targeted at the K-12 education market, these short-throw/ultra-short-throw projectors are a more affordable option for deployments of displays larger than 70 in. (A 65-in.+ display is believed to be the ideal size for this application since it is approximately the same size as many of the whiteboards that have been installed over the last decade or so). In K-12, acquisition cost is often the main or sole consideration when institutions budget for capital expenditures. Decisions often come down to choosing between buying 10 projectors at \$200 each and equipping all classrooms with their own projector or buying one 65-in. flat-panel display for \$2000 and equipping only one room.

In the other corner, several other companies such as Cima NanoTech, Infocus (which has expanded its product line to include flat-panel touch products in addition to projection) Smart Technologies, Sharp, ELO Touch

Solutions, FlatFrog (which uses what it calls InGlass Technology, an optical in-glass touch technology), and many others have recently showcased various multi-touch flat-panel LCDs featuring optical imaging or projected-capacitive technology. In higher education facilities, many are choosing flat panels over projection since colleges and universities usually have deeper pockets and can consider costs such as installation and average life expectancy, *etc.*, as part of the purchase. In addition, flat panels are viewed as more sophisticated and collaborative displays that can interact easily with a variety of devices.

Additionally in this corner is the 800-pound-gorilla Microsoft, which a few years ago acquired Perceptive Pixel and more recently announced the launch of the Microsoft Surface Hub 55-in. FHD and 84-in. 4K IR-based collaboration displays. It is evident that Microsoft has identified this product solution as a way to more deeply entrench itself in the corporate world and beyond. However, at \$22K for the 84-in. display, it will be interesting to see what the actual demand will be after the early adopters finally receive their units.

In 2015, 61% of integrated touch LCDs over 55 in. were between 60 and 69 in., mainly due to a large installation of 65-in. displays for the education market in Turkey (Fig. 1).

Moving forward, the main sizes of integrated touch displays will be 55, 65, and 70 in. By 2020, these sizes will combine to total 83% of the market.

Trends Both Ebbing and Growing

As mentioned above, trends in digital signage often follow those in consumer TVs. Curved TVs, launched a few years ago into the global consumer television market to some fanfare, represented just slightly over 2% of sales in Q2'15, according to the IHS TV Sets (Emerging Technologies) Market Tracker Report. The same report forecasts that by 2019 only 2.3% of all shipments will be curved. This data indicate that curved displays will not be a major player in the digital-signage market. In addition, practical considerations suggest that since the majority of digital-signage solutions strive for the thinnest and flattest displays possible (in theory, digital signage is attempting to replace paper advertisements, posters, and fliers) curved displays will not be popular. Also, there are limitations in many public

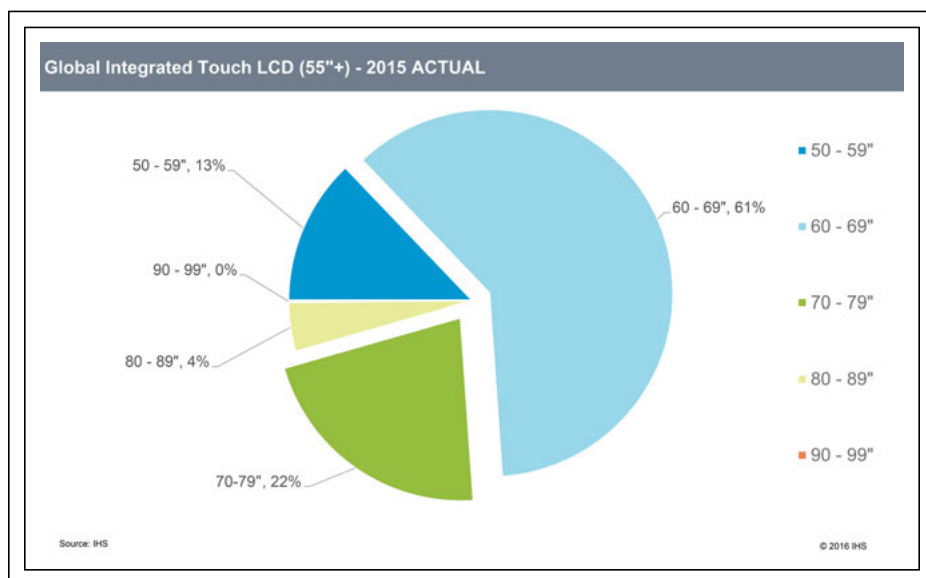


Fig. 1: Last year, the majority of integrated flat panels sold world-wide were in the 60–69 in. category.

spaces as to how far a display can protrude from a wall; in the U.S., that is 4 in., according to the Americans with Disabilities Act.

OLEDs, on the other hand, have potential in the digital-signage market, independent of their success as a TV technology. Currently,

OLED displays are primarily used in the consumer market for smartphones, MP3 players, and cameras. In terms of wider market adoption, OLED displays are facing many obstacles. Notably, the price of production is high (the cost of an LED-backlit LCD TV is



Fig. 2: Samsung recently demonstrated its 55-in. transparent OLED technology. Image courtesy Samsung.

display marketplace

one-quarter or less than the price of an OLED TV), and the blue color in the display has a relatively short lifespan compared to that for the other colors. It is true that the latest consumer OLED panels are claiming life spans of 30,000 hours to half-brightness, which means they can be used 24/7 for 3 years (the standard life expectancy to which a public display is held). However, there still may be an issue of OLED image retention or image burn-in, either of which will cause many in the industry to experience déjà vu based on the nightmares related to early plasma displays' inability to show static images without permanent damage or significantly reducing the life expectancy of the display.

Moreover, recent developments imply that OLED displays may be positioned to enter the digital-signage market on a larger scale. Both transparent and "mirror" OLED technologies have been developed that hold a great deal of potential for numerous applications. Some OLED panels are designed to generate light in both directions (front and back), and this feature creates an opportunity for expansion in new applications such as bi-directional signage.

Mirror OLED displays (under development) that offer a personalized shopping experience – for example, an interactive fitting room that enables customers to see how clothes, shoes, or jewelry look on them before making their purchase decision – have been demonstrated. In this case, the display works in conjunction with 3D cameras and software.

Transparent OLED displays allow users to view what is shown on a glass video screen while still being able to see through it, enabling them, for example, to overlay digital images onto real objects that sit behind the glass. The digital information about the product behind the OLED display allows retailers to create augmented reality. These transparent OLED displays can also be used as interior windows, room dividers, and partitions for informational purposes (Fig. 2).

Both LG and Samsung have announced or displayed large-screen OLED products. Samsung Display recently introduced its mirror and transparent OLED display panels, aimed primarily for retail digital-signage applications for personalized shopping and informational browsing. LG Electronics currently does not have a transparent OLED display in its portfolio of commercial products, but LG Display (its parent panel

supplier) has basically gone "all-in" on OLED technology for televisions.

In the second half of 2014, a new OLED project between Sony and Panasonic in Japan, called JOLED, was created to combine R&D efforts to develop transparent OLED display panels for digital-signage and other applications. The newly established company will develop methods to mass-produce displays at low cost by combining Sony's knowledge of advanced semiconductor technology and Panasonic's technology to make panels from organic materials. JOLED was supposed to finalize details of its new plant to manufacture prototype OLED panels in late 2015 and decide by the end of 2017 whether mass production of the panels is viable.

Public displays, regardless of technology, size, or features are clearly becoming ubiquitous. Hopefully, companies, institutions, and governments will realize their goals of reducing costs, improving communications, and increasing awareness with their target audiences through digital signage. This will not come without challenges. As hardware costs decrease and performance improves, more focus will be on the software and the content shown on the displays. We have already reached a point where simply using these displays to replace printed materials is not enough. With cameras and other sensor equipment being attached to the display, companies are now capturing data on the public. (See the article, "Sensor Architecture: The Evolution of Digital Signage and Intelligent Visual Communications" also in this issue.)

Will this negatively affect the growth of public displays or are these tactics just a forgone conclusion and now generally accepted as long as there is a perceived benefit? This, in itself, is a whole other discussion. ■

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Sensor Architecture: The Evolution of Digital Signage and Intelligent Visual Communications

Proximity networks and beacon software are being used to enhance the digital-signage experience for retailers, venue owners, and customers in stores and other public locations.

by Mark Boidman

A key aspect in the recent development of digital-signage systems is the increasing amount of personalized and real-time content being delivered to viewers. Enhanced display devices, including tablets and kiosks, now have the ability to leverage collected data to drive contextually relevant content displayed on digital signage. This article will discuss how digital-signage enhancements, specifically proximity networks and beacon software, are being integrated by digital-signage manufacturers, allowing retailers and venues to personalize the visual experiences customers have when traveling through stores and other public locations.

Proximity, Beacons, and Digital Signage

Proximity-based communications include the variety of technologies that allow consumers to connect to a nearby retail location via mobile devices. These technologies, with beacons the best-known among them, are being installed together with digital signage to create an experiential in-store environment – connecting shoppers, brands, advertisers, mobile apps, retailers, and venues to enable a personalized interactive digital shopping experience.

Beacons function as signal transmitters that can be configured with the help of a mobile app. Powered by Bluetooth technology,

beacons are portable and can be embedded within digital signage to use smartphones as the primary end receivers (Fig. 1).

Impact on Retailers

Several leading retailers, including Macy's, Target, Nordstrom, and Neiman Marcus, have already begun to integrate beacons into their marketing and omnichannel strategies.

Whether deployed to send personalized deals, recommendations, or rewards to customers; remind a shopper in a bricks-and-mortar loca-

tion of recent online purchasing intent; attach information regarding product features where items are displayed; or to cross-promote merchandise in other departments through push notifications to a shopper's mobile device – the opportunities to effectively, and ideally without friction, engage the connected consumer at the point of sale are considerable. In addition to driving sales and conversion, retailers are using beacons to obtain more detailed in-store analytics and are analyzing the data in an effort to further increase store-

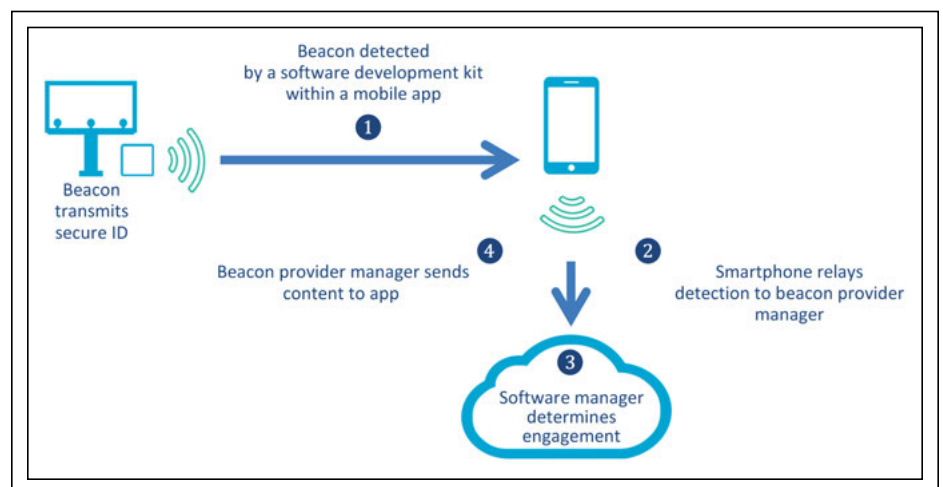


Fig. 1: The flowchart from mobile-engagement-platform developer Gimbal (owned by Qualcomm) broadly outlines the beacon communication process. The beacon software works together with a software-development kit and mobile application to track and then provide relevant content to consumers.

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front conversions and customer-visit durations and frequency. U.S. in-store retail sales influenced by beacon-triggered messages are estimated to grow from \$4.1 billion in 2015 to \$44.4 billion in 2016, according to Business Insider Intelligence.

Retailers who have begun to implement beacon technology are garnering critical consumer insight through the software. Online coupon service RetailMeNot now enables retailers to offer beacon-powered deals, allowing customers, in turn, to find digital promotions and discounts from a variety of retailers and brands. Furthermore, beacon technology extends beyond the traditional retail space. Today, conferences, transit authorities, stadiums, fitness centers, museums, and events regularly use beacons to communicate with attendees in real time. The annual SXSW music and film festival, for example, deploys approximately 1,000 beacons across its venues to provide the event's 100,000+ attendees with information on schedules, artists, and social-media engagement opportunities.

The beacon implementation process intersects significantly with digital signage placed in retail locations (Fig. 2). Operators of

stadiums, stores, and other venues have to decide the most effective way to communicate with visitors and potential consumers, while also leveraging beacon technology to its full potential. Daktronics and Panasonic are two large electronic-equipment specialists with experience in making sure a venue's digital displays work seamlessly with beacons installed on-site. For example, Whole Foods partnered with Panasonic to install beacons that worked both with its Powershelf system (a system that allows management to update prices at a remote location and automatically forward changes to electronic labels on shelf merchandise *via* an inductive coupling connection) and Whole Foods' existing mobile application. This is an example of how companies are beginning to tailor their technology to the client. A major enabling factor is Heterogeneous System Architecture (HAS) (discussed later on in this article), which is making it easier for coders to manipulate code on a product-by-product basis.

Impact Beyond Retail

Even outdoor venues, including sports stadiums, theme parks, and gas stations, have

begun to deploy beacon technology to deliver geo-located personalized deals and messaging. Outdoor venue operators have realized that they can use this new technology to communicate with visitors in an inexpensive efficient manner and perhaps, more importantly, during live events, which previously had not been possible. The NFL, for example, used Qualcomm's Gimbal product to deliver personalized messages and advertisements *via* its NFL mobile app at MetLife Stadium and Times Square during Super Bowl XLVIII. Just as in other retail environments, outdoor venue operators have come to realize not only the opportunities now available to supply visitors with relevant deals and information, but also the significant commercial benefits that can result from pursuing these opportunities.

It is also worth noting that beacon implementation in outdoor venues has not been exclusively added for commercial benefit. The Los Angeles Zoo and Botanical Gardens, while using beacons to promote deals throughout the park, has also implemented beacons to change the way visitors interact with and learn about its animals and exhibits. Through beacon-powered notifications, visitors have the ability to take themselves on a guided tour and bring the information they learned home with them; overall, the result is an enhanced, interactive learning experience.

A number of companies that operate in the digital-signage space are working to maximize the opportunity for clients to interact more seamlessly, more often with potential customers, which has been made possible by improved beacon technology. For example, TouchTunes Interactive Networks, the largest in-venue interactive music and entertainment platform, launched Attract TV in March 2015. Attract TV allows venues to deliver dynamic custom messages within their locations and allows consumers to interact with conference screens via social media. Beacons connected with TouchTunes' mobile-app work with the Attract TV platform to detect users and facilitate communication between venues and attendees while on conference or event grounds. Through its implementation of beacons, TouchTunes has been able to offer specific rewards to users while allowing venues to acquire more complete sales and consumer-related data.

Developments in HSA

Among the recent technological developments geared toward improving the interactive shop-

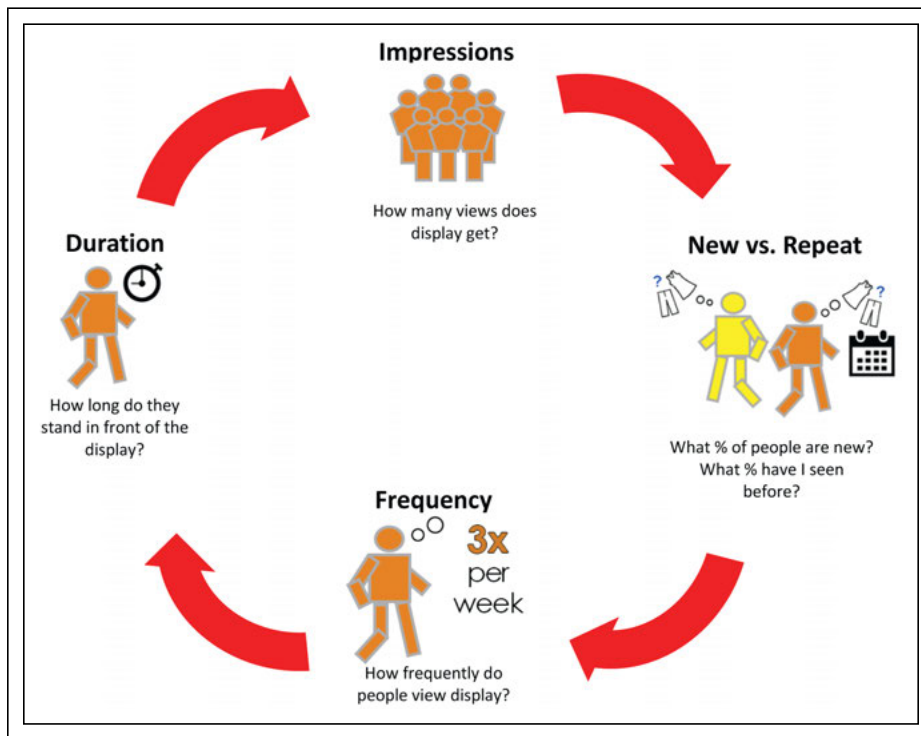


Fig. 2: The flowchart describes, at a high level, four key analytical opportunities that beacons provide to retailers in terms of customer insight.

ping experience is HSA. Central processing units (CPUs) and graphic processing units (GPUs), the two main processing units that run general and graphic programming tasks in computers, were designed as separate functional processing elements in computer-programming systems. This means that the two units have separate memory space, which has always led to an inefficient use of memory storage and has made sharing memory challenging. HSA allows coders to create data structures in a single unified memory address space. This, in turn, allows CPUs and GPUs to share memory regions and exploits the capabilities that come with running two parallel execution units throughout the application development process. Overall, the goal of HSA is to eliminate inefficiencies associated with sharing data, code, and work items among different computing elements.

So what does this mean for beacon technology and digital signage? With more efficient coding capabilities, both in terms of time and cost, coders can create tailored applications for retailers at a fraction of the historical cost. Cost is the largest limiting factor for beacon-technology adoption, and with HSA technology making beacon software less expensive, more retailers can begin to experiment with, and implement, this technology.

Eddystone: How Google Is Breaking Ground with HSA

Google is taking advantage of the technological improvements that come with HSA technology, having announced in late 2015 that its Chromebox (desktop computer running Chrome OS) product will soon double as a Bluetooth beacon device. Essentially, signage networks that run on Chromeboxes will soon be able to use the Chromebox device in place of beacons.

This new feature is made possible by Eddystone, an open Bluetooth 4.0 protocol designed by Google developers that offers the leading-edge enhancement of allowing retailers to communicate with a shopper without a proprietary application installed on his or her mobile device. Because shoppers will still have to opt in under their phone settings, their personal information and overall data security will be protected. Once shoppers enter a store outfitted with Eddystone technology, provided they have opted in, they will receive a black bar on the top of their smartphones alerting them to any current deals or venue information.

Just as HSA enables coders to write one set of code that can communicate between the CPU and GPU on software and hardware devices, Eddystone is designed to support multiple data-packet types, such as a Web site or mobile application. Eddystone differentiates itself from traditional beacon providers by making it easier for developers to contribute to the open-source code and for hardware manufacturers to implement Google's low-energy beacon format on any platform that supports Bluetooth beacon software. As Fig. 3 shows, Eddystone technology administers the beacon across any nearby API or application and subsequently sends relevant information to a shopper's phone.

Using technological developments, such as the ones listed above, retailers and venues with existing mobile applications can easily adopt beacon technology in a cost-efficient manner. Increasing mobile engagement in bricks-and-mortar locations has become a top priority; retailers are trying to find the easiest and most effective way to target customers when they visit their store. By eliminating the need for shoppers to download a retailer's

mobile application, as long as they have opted in to receiving beacon notifications, retailers can begin communication with shoppers as soon as they walk through the door. Because this approach also eliminates the need to promote a store's proprietary mobile application for users to download upon entry, retailers are also able to enjoy additional savings on marketing dollars. Companies will be able to aggregate all of the data from participating customers in real time, which will allow for better more-targeted live advertisements.

We expect that as HSA in particular continues to create more efficient data structures by allowing coders to write one set of code that will run across all platforms and devices, we will see widespread adoption of this new interactive technology.

Future Impact

Developments in proximity networks, both in terms of technology as well as retailer and venue implementation, are happening quickly. Retailers and venues are creating applications that fully utilize the information and advertising capabilities that come with having one-on-one

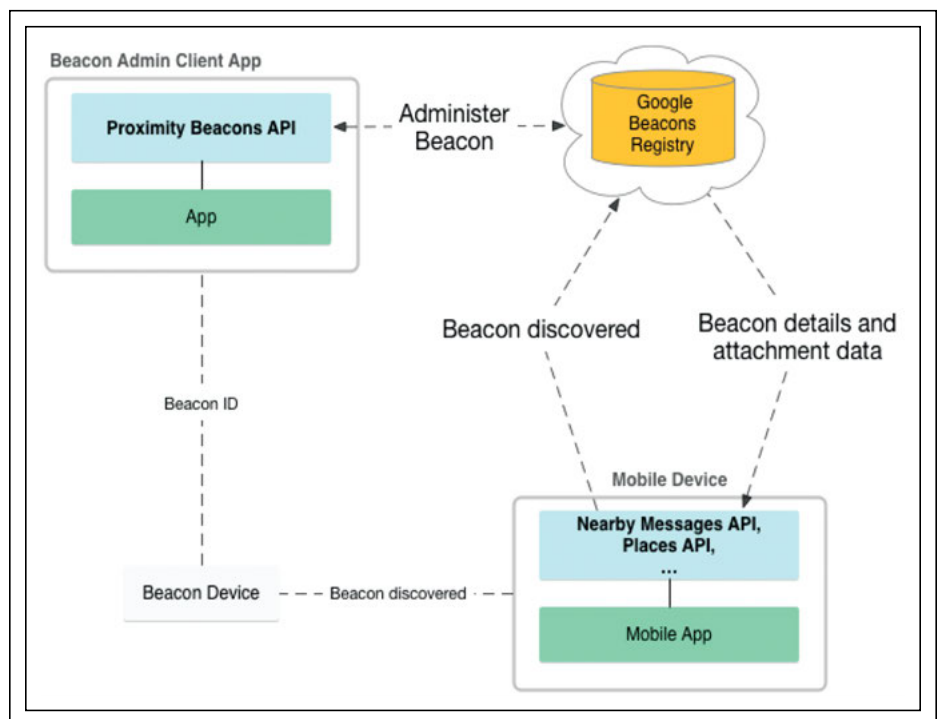


Fig. 3: The Eddystone protocol administers a beacon across nearby APIs or applications and sends any relevant information to a shopper's mobile device. Source: developers.google.com/beacons/overview?hl=en

real-time communication with customers. This rapid innovation, fueled by HSA, will give rise to a new era of digital signage, where it will increasingly become more economical to install beacon or beacon-type technology and develop in-store applications that go beyond covering a venue's walls with conventional screens. Connected consumers expect to have real-time information available whenever and wherever they want, and HSA innovation will help venues and retailers deliver something more than digital signage – intelligent visual communications. ■

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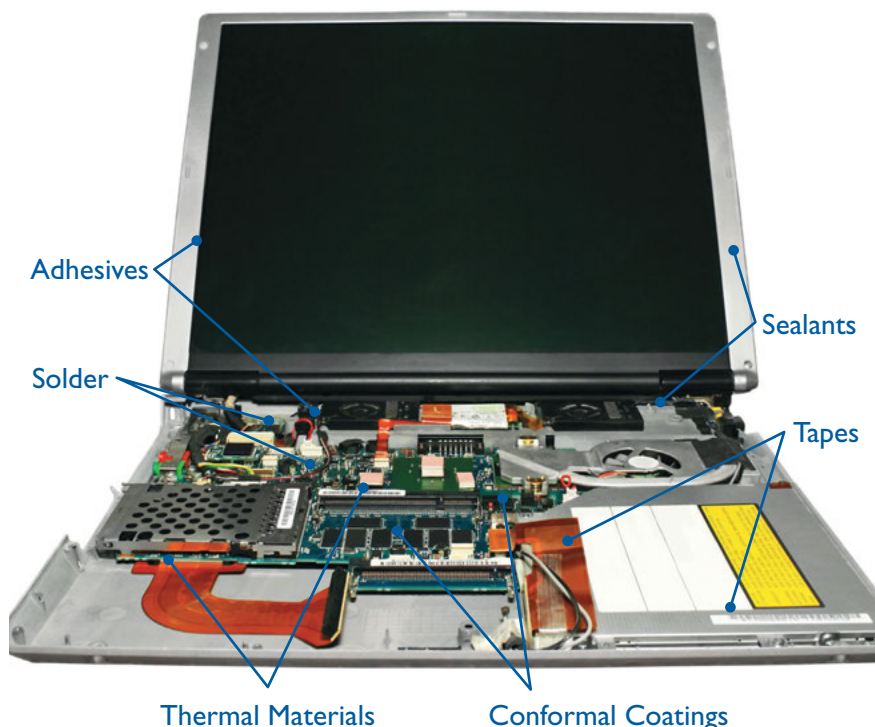
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Challenges for Outdoor Digital Displays

When designing an outdoor digital-signage system, location, hardware, sunlight readability, durability, and reliability are key components to consider. To meet these challenges, Delphi Display Systems has developed fully integrated and sealed outdoor display systems that incorporate embedded media control and robust remote management.

by Benjamin Medvitz

DIGITAL SIGNAGE is appearing in more and more areas of our lives. Significant technological advances are making it cost effective for almost any business to incorporate LCDs in sizes up to 60 and 72 in. with only a moderate investment. System-on-chip (SoC) technologies are enabling not only smart TVs for consumers but integrated displays with media players and embedded computers for interactive signage applications available out-of-the-box.

With the unprecedented speed of innovation and mass-market ability to deliver LCD screens at rock-bottom prices, many customers want to utilize these technologies outdoors or provide combined indoor-outdoor systems and expect that similar technologies at similar price points will deliver an equally impressive experience.

However, the outdoor environment is harsh and unforgiving. With temperature extremes from -40°F to +125°F and above, direct sunlight day in and day out, sand, rain, snow, sleet, fog, and high winds, the challenges of making electronic displays work reliably outdoors are significantly greater than in indoor controlled environments. The mass-market technologies that have made ultra-inexpensive LCD TVs ubiquitous cannot be fully leveraged for outdoor use, and sales

volumes for outdoor displays are low enough that economies of scale do not provide the same results as those seen in indoor displays.

There are many companies that provide outdoor display systems today, with widely varying features, reliability, performance levels, and price points. Selecting the right outdoor display for digital signage can be complicated. Each project's critical parameters, including display placement, brightness, maintenance, required display lifetime, and others, have a significant impact on display selection and ultimate project success.

In this article, we will review many of the challenges unique to outdoor digital signage for smaller displays from 12 to 72 in. – those ideal for LCD technology. Backlight luminance, heat management, sunlight management, polarization, serviceability, and lifetime are all factors. We will also discuss options and solutions recommended by our company's researchers.

Bright Enough?

Display luminance is measured in candelas per square meter, or "nits." Indoor TVs and monitors typically provide white luminance levels of 300–400 nits. By comparison, a white outdoor surface in direct sunlight can reflect 10,000 nits!

We perceive a world of almost constant brightness throughout our day. Thanks to the human eye, which is able to automatically adjust to widely varying luminance levels, we do not often have to consciously think about

the brightness of a room or environment. We are able to discern features and objects in our environment by the contrast between light and dark or between differing colors. In very bright outdoor environments, we typically only see high-contrast features, while in darker environments we can see more subtle variations between light and dark. While this adjustment is usually automatic, occasionally we notice it, for example, when we enter a darker building on a sunny day and need time for our eyes to "adjust" before we can see any detail or when we leave a dark theater on a sunny day and everything appears too bright to be seen until our eyes adjust.

Information on digital displays is presented with a constant level of contrast between light and dark areas. In a dark room, the luminance of an LCD backlight provides the maximum light level in the lightest areas of the display. The display technology determines the minimum light level in dark areas of the display, commonly measured in reference to the maximum light level as a contrast ratio. When displays are used outdoors, however, the entire environment is much brighter due to ambient light from the sun. Our eyes adjust for this brightness, reducing our sensitivity and requiring greater contrast for us to be able to discern features or information on displays. Displays that appear bright in darker rooms may be so dim outdoors as to be unreadable if the backlight luminance is not high enough to overcome the high levels of ambient light from the sun. If the backlight is bright enough

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but the display's contrast ratio is too low, or if too much of the outdoor environment's ambient light reflects off the face of the display, it gets "washed out" as our eyes become unable to clearly discern between light and dark areas of the information on the display. For outdoor displays to provide clear information and crisp images, they must be able to provide both enough luminance and enough contrast ratio to overcome the very bright ambient light from the sun.

Displays marketed as "high brightness" or "sunlight readable" start at a luminance of 700–800 nits, with many going beyond 2000–3000 nits. An 800-nit display looks far better outdoors than a 300-nit display, but will still require shade structures, ambient-light management methods, or other means to avoid being washed out in direct sunlight. Each layer of the touch screen, protective face glass, and other coatings on the front of the display will further reduce the available luminance by 10–20%, requiring additional backlight energy or even more careful management of environmental conditions to maintain readability.

As mentioned above, the contrast ratio between bright and dark areas of the display is also critical to outdoor readability, as human eyes become less sensitive to small luminance changes in environments with high ambient light. Anti-reflective coatings on the front face of the display can reduce the reflected light outdoors, greatly improving the observed crispness and contrast of the display. Displays that exceed 1500 nits and dark-room contrast ratios of 1000:1 or more will usually appear clear and crisp in direct sunlight, similar to those shown in Fig. 1.

Another thing to consider when selecting an outdoor display is the expected lifetime. All backlight technologies reduce in luminous output (or efficiency) as they age. This characteristic of a display is registered in a standard "mean time to half-brightness" (MTTH) measurement. For an 800-nit display operated 24 hours 7 days a week, an MTTH of 50,000 hours means that after 5.7 years of operation, the peak white display luminance will now only be 400 nits. The challenge for MTTH is that it is also highly dependent on temperature. When a display is in direct sunlight most of the day, it gets hot. Add this to the internal heat from the display electronics itself and it can get really hot inside the display enclosure! A display with a



- Direct sunlight readable
- Ultra high brightness backlights (1500+ nit)
- No need for shade structures
- Will remain readable for many years

Fig. 1: These outdoor LCDs (with some key features listed above) are used for a restaurant drive-thru menu and order confirmation application.

50,000-hour MTTH at a temperature of 25°C (77°F) may only have a 20,000-hour MTTH at a continuous temperature of 55°C (131°F).

Keeping Cool in the Sun

Think about how hot the inside of your car gets when it is left outside on a sunny day. The heat is unbearable, even if the outdoor temperature is comfortable, due to the greenhouse effect of trapped infra-red energy from the sun inside the car. The effects are the same for outdoor displays. If an LCD panel gets too hot, the liquid crystals inside the panel may be permanently damaged. The liquid-crystal fluid gets too hot and the entire system changes its phase state. Once the liquid-crystal fluid overheats, it becomes an isotropic liquid and is no longer able to translate the polarization angle of the light based on electrical stimulation and natural birefringence alignment. We call this effect "clearing" and the temperature at which the LCD exhibits this phenomenon is known as the "clearing temperature." In displays that have a normally black mode, this results in large areas of the LCD blackening and becomes unreadable, similar to the artifacts shown in Fig. 2.

Recent advancements in the technology of LCD materials and construction have yielded great improvement in the high-temperature operation of displays. While some conventional TN-LCD panels have clearing tempera-

tures as low as 50°C, new fluid formulations such as those in LG's high-brightness in-plane-switching (IPS) displays allow for clearing temperatures up to 110°C.

There are two general ways of managing temperature inside outdoor displays. Some utilize outside air to cool the components of the display, similar to rolling down the windows in your hot car. It keeps the interior temperature from getting too hot, but allows dust, dirt, sand, and all kinds of contaminants into the display. These displays often feature advanced inlet filters to keep these hazards out, but will require regular cleaning and replacement. If you do not have a robust maintenance staff and budget, this maintenance will soon be overlooked and these displays are likely to fail after only a short life, either due to overheating from clogged filters or from contamination let in from degraded or failed filter elements.

Utilizing outside air is also a problem if the LCD panel is not optically bonded to cover glass. If there is any space between the LCD and the front glass of the display, outside air provides an excellent opportunity for condensation and fog to form between the display and the glass, obscuring the display.

The other main option for temperature management is to seal the unit and utilize advanced thermal management within the display to keep the internal temperature from getting too high (Fig. 3). Sealed units offer



Fig. 2: The liquid-crystal mixture in the LCD at right has suffered from isotropic blackening effects, which can occur as a result of high temperatures.

the advantages of being maintenance-free and more flexible on installation locations because they do not require a supply of outside air. Sealed units often represent a higher up-front cost because the structure of the display needs to be more robust to provide the environmental seal, but this pays off over the life of the system by avoiding many of the challenges and maintenance requirements of utilizing outside air for cooling.

Direct sunlight, especially on the face of the display, also adds a significant amount of heat to the enclosure. With sunlight power at around 93 W/ft.², the solar heat gain in an enclosure through the display face can often exceed the heat generated by all of the internal display and power components combined (Fig. 3).

A variety of advanced films and coatings are commonly used to reduce this solar heat gain before it enters the display. Infrared light (IR) blocking and reflecting filters can dramatically reduce the solar heat gain of an outdoor display while maintaining excellent readability. Critical parameters of filters include the percentage of IR rejection (good filters are 98–99% blocking), optical transmissivity or percentage of visible light passing through the filter (many exceed 80% today, some over 90%), and the ratio of IR absorbed to IR reflected. Filters that reflect IR are preferred over absorptive filters as the absorptive filters result in thermal gain at the filter

surface from absorption of the infrared light energy.

Polarization

Typically, all the light emitted from an LCD panel is linearly polarized. Standard LCDs have this light vertically polarized along the

short side of the display (vertical when the display is in landscape mode). Some specialized LCDs are horizontally polarized for optimal viewing in portrait orientation or at an arbitrary angle. Our eyes perceive all polarizations of light, so we do not notice the polarized nature of LCD panels.

When outdoors, however, many people wear polarized sunglasses to cut down on outdoor sun glare. These sunglasses are vertically polarized, as most sun glare comes from horizontal surfaces (like water). If a standard linearly polarized LCD panel is mounted outdoors in portrait orientation, the light will be horizontally polarized from the LCD and will be entirely blocked by the sunglasses. The display will appear to be black to anyone wearing polarized sunglasses. Using special vertically polarized LCDs can mitigate this problem, but the selection of display then becomes dependent on its intended orientation (landscape or portrait) and can increase project costs and complexity.

Even standard displays mounted in landscape orientation or specialized displays with arbitrary polarization angles may suffer readability and brightness problems if people with sunglasses view the display at an angle, as shown in Fig. 4. A viewer who tips her head by 45° will see less than 70% of the brightness of the display.

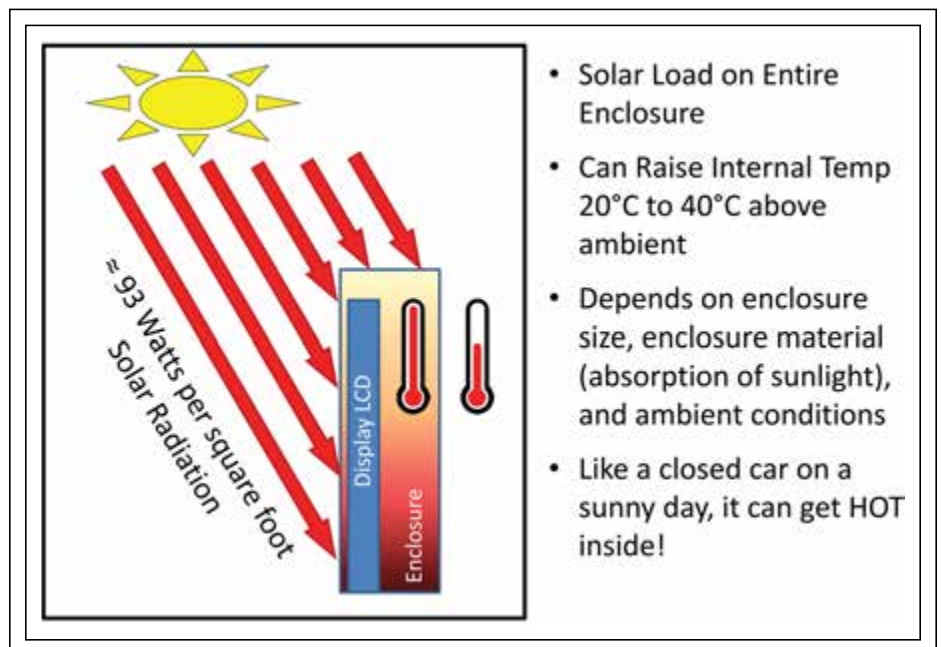


Fig. 3: Solar loading is one of the many environmental stresses faced by outdoor displays.

Some advanced displays available today incorporate $\frac{1}{4}$ -wave circular polarizing wave-plate filters, also known as wavelength retarders. These filters marginally reduce native brightness of the display, but they convert the linearly polarized light from the LCD to circularly polarized light so that it can be easily viewed through polarized sunglasses in any orientation.

What Happens When Something Breaks?

The market opportunity for outdoor LCD signage has been recognized by many of the major display brands. Samsung recently released a line of fully sealed, 2000–2500-nit full-HD displays in sizes ranging from 47 in. up to 72 in. NEC and LG Display provide high-brightness systems in “open frame” formats for system integrators.

Fully factory-sealed units can make on-site repair simple – just replace the entire module with a new one. That simplicity can be blunted, however, by the cost and bulk of shipping full display units whenever anything

goes wrong inside the unit. Fully sealed displays without adequate media players incorporated into the units can also result in complex systems with multiple sealed modules (display, media player, power source) and the need to environmentally seal multiple video and network interconnections.

Modular display systems provide a compromise between the simplicity of full-unit replacement and the complexity of component-level repair and maintenance. These systems provide an integrated display, media player, and power supplies designed to operate together. They are often in one enclosure and provide for modular replacement of only the elements that may fail. This saves considerable cost and time in keeping an outdoor digital display operating. Smaller modules can be pre-stocked and replaced when needed, and the large and bulky display panel itself is only removed and replaced if it is the element that fails.

What About the Source Video?

Most outdoor displays available today provide

for a variety of video signal inputs similar to indoor displays, including HDMI, DVI, and DisplayPort. Thus, it can be tempting to utilize the same source player hardware as for indoor units. Unfortunately, the temperature and environmental issues that displays face, as well as security issues in unprotected outdoor spaces, make this selection much more difficult.

Most player hardware is designed for indoor use and to utilize external air for cooling. Many systems, including compact Intel Next Unit of Computing (NUC) player PCs and industrial fan-less indoor media players, are only rated for temperatures up to 50°C. Even high-temperature players must be mechanically attached to the displays and power, video, and network connections and secured against tampering.

Display manufacturers such as Samsung and LG include integrated player software for their branded solutions and a small subset of third-party solutions. Other companies, such as Delphi Display Systems, include full-media-player computers in the same sealed enclosures as the display. These integrated players have the advantage of being secure and designed as a unit for full outdoor operation.

Updating Media

Whether your media player is integrated into the display or attached to it, media updates can also be challenging outdoors. Choices are similar to indoor environments, but the complexity and cost structure can be very different (Fig. 5).

Wi-Fi systems that are ubiquitous indoors often behave very differently outdoors, and many require specific antennas and signal boosters to ensure reliable connection. Effects of weather and temperature extremes on the signal and antenna materials, the difficulty in routing cabling to outdoor antennas, a combination of large open spaces and sometimes significant obstructions to radio-wave propagation, and the typically far greater distances between router and display outdoors all contribute to unique challenges in implementing reliable outdoor Wi-Fi connectivity. Wired Ethernet, easily installable into a building’s drop ceiling plenum, can be nearly impossible to add to outdoor environments. Permits, trenching, hardscape replacement, and durability requirements of cables for outdoor use may dwarf the cost of the actual display.

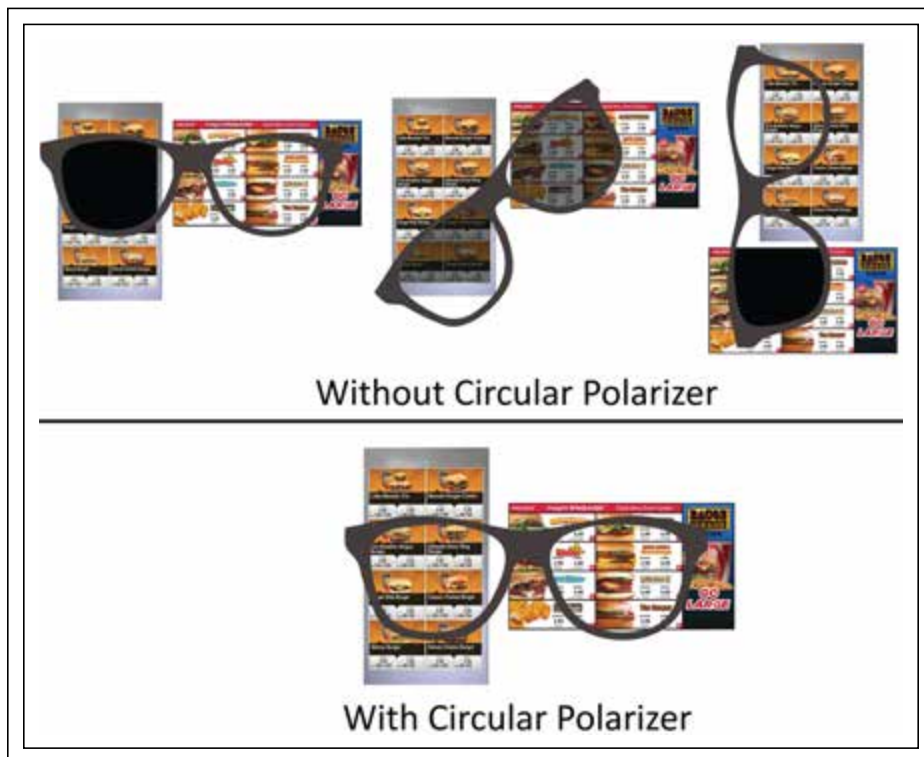


Fig. 4: Depending on the orientation of the display, polarized sunglasses affect an LCD’s visibility in different ways (top). Displays outfitted with circular polarizer films (bottom) are still viewable by viewers with polarized sunglasses.

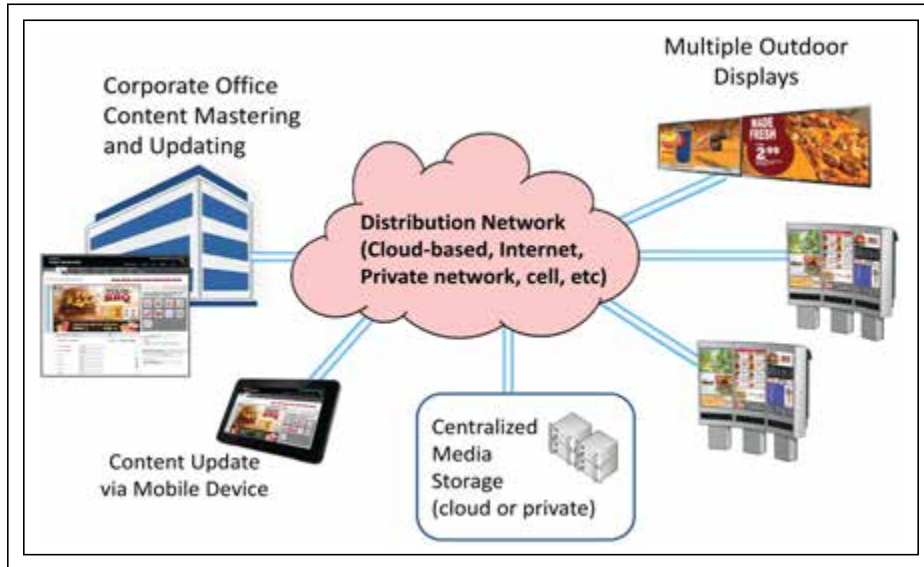


Fig. 5: A typical outdoor digital-signage system comprises several elements in addition to the displays themselves, including media storage, a content delivery mechanism, and content mastering.

Cellular updates, often too complex or costly for indoor systems, can be the most reliable choice for outdoor installations. Cellular data systems are designed for outdoor and mobile use, optimized for the multipath reflection and fading effects of outdoor obstructions, and easily cover wide areas. Antenna selection and positioning are concerns, but strong cellular signals and carriers that are ubiquitous in urban and suburban areas make it easy to provide content updates without requiring infrastructure modifications or a dedicated Wi-Fi infrastructure.

Outdoor Displays: A Unique Animal

Delivering the right message and ensuring compelling or informative content is a primary concern for all digital-signage systems. When incorporating smaller outdoor displays into a digital-signage system, location, hardware, sunlight readability, durability, and reliability are key components that must be considered. While many outdoor display options are available today, they fit very different applications and there is no single solution that is optimal for all installations. Ignoring the environment, display longevity, and maintenance concerns can result in an outdoor signage installation that can become dim and unreadable in a few months to a few years, or fail entirely. Understanding the

different environmental and maintenance requirements for an outdoor digital sign greatly improves the designer's chances of selecting the right display and ensuring years of compelling, reliable messaging for outdoor display systems.

Delphi Display Systems' signage is environmentally sealed, providing a more robust and maintenance-free solution for customers. Many of its systems also incorporate ¼-wave polarizing filters for better visibility with polarized sunglasses. Future challenges include innovations to significantly reduce the cost of outdoor signage systems, improve outdoor display energy efficiency and power management, incorporate fine-pitch LED displays and OLED technologies into robust outdoor systems, further improve the visual clarity and contrast ratio of outdoor display solutions, and provide innovative off-grid zero-energy display systems for outdoor applications where reliable power is cost prohibitive. ■

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Meet With Leading Companies Like These



Products on Display at Display Week 2016

Some of the products on display at North America's largest electronic-display exhibition are previewed.

by The Editorial Staff

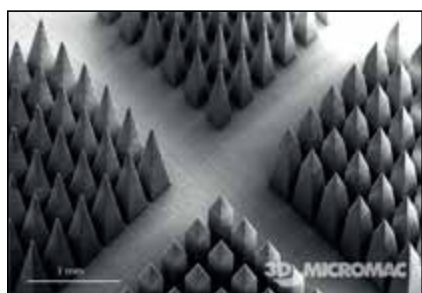
THE SID 2016 International Symposium, Seminar, and Exhibition (Display Week 2016) will be held at the Moscone Convention Center in San Francisco, California, the week of May 22. For 3 days, May 24–26, leading manufacturers will present the latest displays, display components, and display systems. To present a preview of the show, we invited the exhibitors to highlight their offerings. The following is based on their responses.

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3D-Micromac AG, the industry leader in laser micromachining, will introduce its FSLA™ (Flow Supported Laser Ablation) technology at Display Week 2016. The sophisticated machining strategy is perfectly suited for the generation of structures such as taper-free holes or even holes with negative taper and columns with rectangular walls in glass, sapphire, and other transparent materials. Typical



dimensions of those structures are in the range of a few 10 µm up to a few 100 µm. The machining, performed by an ultrashort-pulsed laser, is stress-free and without thermal impact. The achievable wall roughness is ~ 0.5 µm (Ra). The FSLA™ technology opens up new vistas for the production of shaped holes and nozzles and surface modifications in display glass or sapphire.

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www.admesy.com
Booth 747

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The Admesy Atlas 2D analysis system is the ultimate 2D imaging CCD combined with a spectrometer, opening up an unprecedented range of capabilities and flexibility. The Atlas was developed amongst other things for display and LED panel markets to test characteristics such as luminance, color uniformity, mura, white-point adjustment, etc. The Atlas combines several fundamentally different devices in one solution giving it unprecedented capabilities and flexibility. Thanks to the software, the operation of the Atlas is very user-friendly. The Atlas consists of a high-level 2D RGB imaging CCD, colorimeter, or spectrometer (380-780 nm) with optional flicker measurement.

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Booth 717

65-in. 8K TFT-LCD Module

BOE Technology Group Co. will feature a 65-in. 8K Super TFT-LCD Module featuring Bright View 8K resolution with a total thickness (minimum) of 3.8 mm. Bright View is BOE's patented delta-type pixel arrangement. The aperture ratio of the panel is 20% higher than that for the stripe-type pixel arrangement. With the application of a glass LGP, the minimum thickness of the module will reach 3.8 mm.



trade-show preview

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Hybrid Transparent Conductive Films

CHASM will showcase AgeNT™ hybrid transparent conductive films which combine silver nanowires (AgNWs) and carbon nanotubes (CNTs) in a novel way to achieve superior performance and lower cost than AgNWs or CNTs alone. Applications include touch buttons and sliders, touch screens, displays, smart windows, smart cards, ePaper, wearable electronics, photovoltaics, lighting, etc. The AgeNT manufacturing process is called "Print & Wipe" (patents pending) and all steps are scalable for mass-production. The first product version is called AgeNT-75, with a typical sheet resistance of $75 \Omega/\square$ at 99% visible light transmittance (excluding substrate).

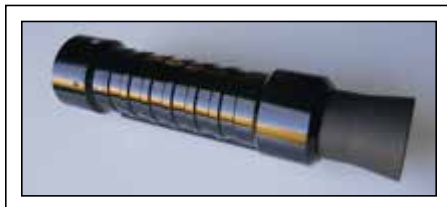


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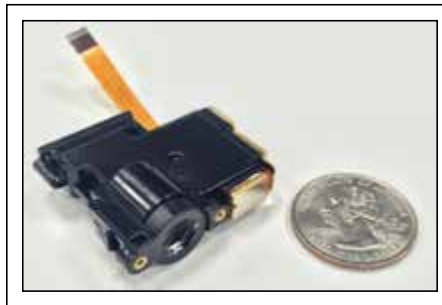


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www.colorlink.co.jp
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Color Link's E5 high-optical-efficiency pico-projector module utilizes a 0.26-in. LCoS display featuring a resolution of 1280×720 (720p HD), brightness of 16 lm (typical), and contrast of 600:1 (center).

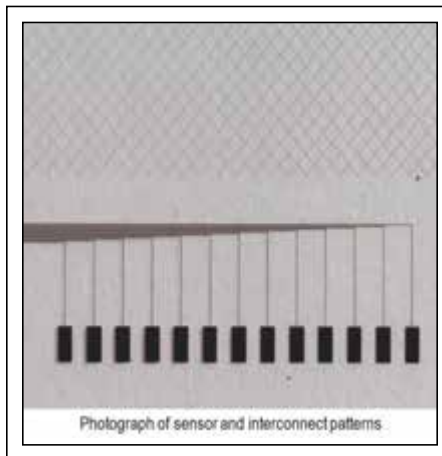


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www.daido.co.jp/en/index.html
Booth 1447

Promising Alternative to ITO

Daido Steel will feature STARMESH, Cu mesh that is one of the promising alternatives to ITO for large-format capacitive touch displays because of its low resistivity and low cost. However, some issues of adhesion, corrosion, and reflectance still exist. Daido Steel has developed new Cu alloys which satisfy these critical requirements and opens the possibilities for applications such as mobile PCs, electronic blackboards, as well as next-generation flexible displays and circuits.



DNP

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www.dno.co.jp/eng/
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Shelf-Label Projection Screen

The "Shelf Display" is a projection screen designed for electronic shelf labels in retail stores. The screen is fit to the size of the shelf edge, and images are projected from a small projector inside the shelf. They can display the price tags, commercials, and/or highlights of the merchandize to catch the attention of shoppers. This electronic shelf-label system has been developed by The Kroger Co. and the screens for the system are provided by Dai Nippon Printing Co., Ltd.

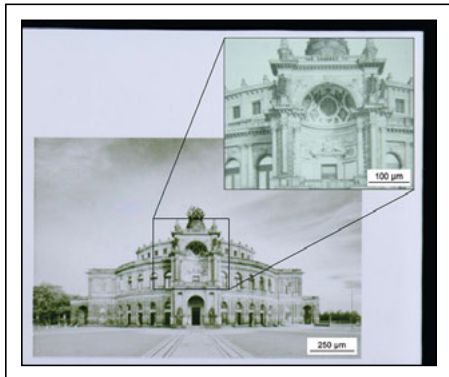


FRAUNHOFER INSTITUT FÜR ELEKTRONIK (FEP)

Dresden, Germany +49-351-2586-0
www.fep.fraunhofer.de
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Fraunhofer FEP will present OLED samples for which the emission has been modified by using a focused electron-beam process. The method provides the opportunity to modify the emission after finalizing and encapsulation the OLED to various shapes at high resolution in lateral dimensions and to adjustable intensity profiles, e.g., any gray level.



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Booth 1021

Advanced Materials

Fraunhofer ISC develops advanced materials based on hybrid polymers, sol-gel materials, and organic polymer composites for display technologies. This includes flexible and transparent gate insulators and passivation materials for backplanes, printable transparent conductive oxides (TCO), amorphous semiconducting oxides (ASO), and thermally stable transparent dielectrics, flexible touch screens, and novel input methods, light-guide solutions, and new design options for flexible and transparent displays. ISC also offers diffractive optical and holographic optical elements for head-mounted microdisplays as well as porous films for liquid crystals to get switchable optical elements and sophisticated optical structures to improve the performance of 3D displays.



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Booth 1347

Custom Automotive PCAP Touch Panels

Fujitsu Components America's FID-154 custom automotive PCAP touch panels support 10 simultaneous inputs, gesturing, and gloved finger operation of HMIs in center-stack display applications such as backup cameras and navigation, infotainment, and radio systems. Available in glass-film-film or glass-glass structure, the automotive touch panels feature 90% (typical) transparency as well as palm suppression and hover functionality. They are scratch and moisture resistant, have a -40 to +85°C operating temperature range, and an operating lifetime of 10 million taps. Sizes range from 7 to 9 in. on the diagonal, with designs, border/logos, and optional surface treatments available.

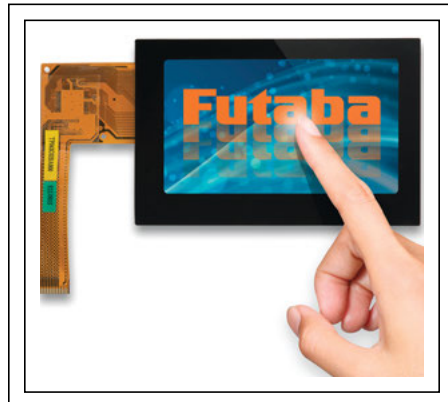


FUTABA CORPORATION OF AMERICA

Schaumburg, IL, USA +1-847-884-1444
www.futaba.com
Booth 229

Capacitive Touch-Panel Products

Futaba's capacitive touch-panel products were developed using the thin-film formation technologies perfected by electronic-component manufacturing processes. With their outstanding sensitivity and resistance to harsh environmental conditions, they are finding an increasing number of applications in general household products and in vehicle equipment that requires a high level of reliability.

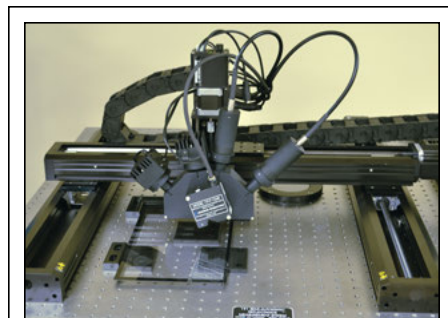


GAMMA SCIENTIFIC

San Diego, CA, USA +1-858-279-8034
www.gamma-sci.com
Booth 515

Reflectance and Transmission Measurement Systems

Complete your inspections faster and achieve higher standards of quality with accurate repeatable reflectance and transmission measurement systems from Gamma Scientific. Controlled optical geometry and industry-leading spectroradiometer performance offer quick and accurate reflection/transmission measurements for any glass or polished transmissive element. When measuring reflectance, Gamma Scientific's unique technology allows manufacturers to perform single-sided inspection on the first surface while excluding the second surface. With handheld semi-automatic and fully automated options, Gamma Scientific reflectometers have tremendous flexibility and can be used for R&D, QA, and production line testing.



trade-show preview

GERMAN FLAT PANEL FORUM (DFF)

Stuttgart, Germany +49-711-18560-2566
www.messe-stuttgart.de
Booth 1005

A Display Platform of Expertise and Know How

Of German origin, the DFF is a growing international organization of companies and institutions from all parts of the flat-panel-display value chain not limited to Germany. The DFF provides a unique networking platform for professional displays and applications. For maximum benefits for our members, we offer plenary meetings, focussed working groups ("automotive displays," "display system integration"), newsletters, and workshops.

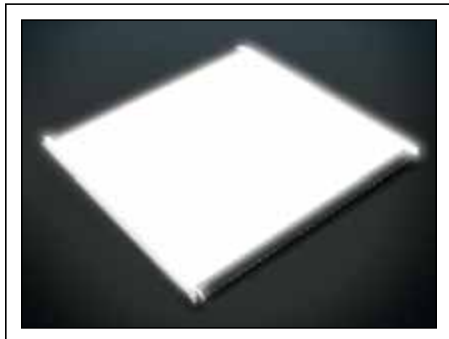


GLOBAL LIGHTING TECHNOLOGIES

Brecksville, OH, USA +1-440-922-4584
www.glthome.com
Booth 1037

LED-Based Light Guide

Global Lighting Technologies has introduced a 4 × 4 in. LED-based light guide with higher efficiency, better durability, longer life, and lower cost than a comparable OLED panel. It is intended as a superior solution for applications considering similar-sized OLED panels with similar diffused-light output, albeit at a much lower cost. The light guide assembly is only 3.5 mm thick. The panel itself measures a slim 2 mm while offering enhanced light extraction. The current product provides an efficiency of over 115 lm/W while producing up to 250 lm when fully powered.



GOOCH & HOUSEGO ORLANDO

Orlando, FL, USA +1-407-422-3171 x206
www.GHinstruments.com
Booth 405

Imaging Colorimeter/Photometer

G&H Instruments' MANTIS Imaging Colorimeter/Photometer delivers ultra-fast high-resolution spatially resolved measurements of luminance, chromaticity, and color temperature. It's compact, rugged, and ideal for full-field measurements of automotive and aerospace lighting and displays in high-speed-production test measurements.



INSTRUMENT SYSTEMS

Munich, Germany +49-89-454953-0
www.instrumentsystems.com
Booth 706

High-Speed 2-in-1 Imaging Colorimeter

Instrument Systems will present the LumiCol 1900, a novel high-speed 2-in-1 imaging colorimeter, especially designed for manifold test applications of display production lines. It combines the benefits of an RGB CMOS camera with those of a high-accuracy spot colorimeter. Using the colorimeter as a reference for the camera enables fast and precise display-area characterizations with respect to luminance, chromaticity, contrast, or uniformity. Moreover, it offers typical spot colorimeter functionality as flicker measurements or the adjustments of white balance and gamma. The new "LumiSuite" software is optimized for automated production processes or quality control, but is likewise suitable for R&D applications.



IOP PUBLISHING

Bristol, UK +44-(0)-1179--297-481
www.iopcorporate.com
Booth 210

Scientific Publishing

IOP Corporate covers the hottest topics, the fastest-paced research areas, and the subjects with the highest patent applications. IOP has published over 600,000 articles from more than 140 years of scientific study. Stop by to learn more and sign up for your free trial or go to iopcorporate.com to start searching today.

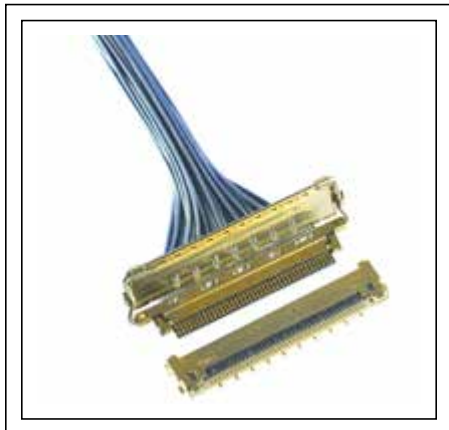


I-PEX

Austin, TX, USA 1-512-339-4739
www.i-pex.com
Booth 205

Display Connector

The I-PEX Cabline improved the 0.4-mm-pitch display connector by covering the solder tails with a shield. The added shielding eliminates EMI emissions from the high-speed graphics signals as they pass through the solder tails into the circuit boards. The Cabline CA receptacle was already designed with additional shell grounding contacts under the connector to squelch any common mode energy. The CA II design completes the shielding of the entire microcoaxial wire interconnection eliminating any interference with WiFi antennas. Additionally, the contact design has been enhanced to accept the AWG34 diameter center conductor delivering more power for display backlights.

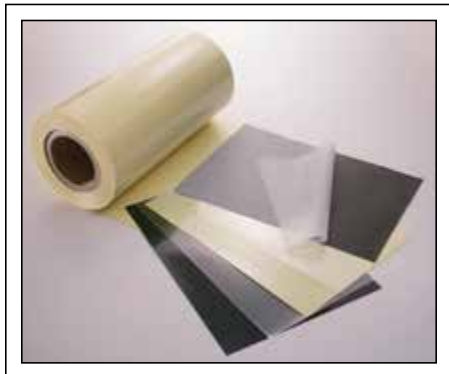


IWATANI CORP.

Tokyo, Japan +81-3-5405-5797
www.iwatani.co.jp
Booth 1221

Silicon Optically Clear Adhesive Technology Solution for Optical Requirements

Iwatani Corp. provides specialized high-performance film and industrial tape products for electronic devices. The ISR-SOC series, a product of Iwatani's silicon optically clear adhesive (OCA) technology, has high durability, heat resistance, and flexibility suitable for specialized displays such as reflective, flexible, and OLED. Its low refractive index improves the visual quality of the display. With its innovative technologies and superb performance, the ISR-SOC series allows customers to freely develop custom design concepts. Iwatani also provides various types of industrial tape products.



KOREA INSTITUTE OF SCIENCE AND TECHNOLOGY (KIST)

Seoul, South Korea +82-2-958-6379
www.kist.re.kr
Booth 1438

Autostereoscopic 3D Display

KIST will feature an autostereoscopic 3D display, the High Density Multi-View (HDMV) display, for which any type of special eyewear glasses are not required to view 3D images, and motion parallax is provided as well. By minimizing optical noise (*i.e.*, crosstalk) and moiré phenomenon, and expanding the viewing zone, this product not only provides more natural motion parallax, but expresses the remarkable depth of objects, enough to feel more realistic 3D images.



KYOCERA DISPLAY DIVISION

Plymouth, MI, USA +1-734-416-8500
www.kyocera-display.com
Booth 429

High-Resolution TFT-LCD

Kyocera Display Division will introduce their new 12.1-in. WXGA (1280 × 800) TFT-LCD. It features Advanced Viewing Technology (AWV) that achieves a 170° viewing angle in both vertical and horizontal directions. The 1500-nit super high brightness makes this product ideal for outdoor applications exposed to direct sunlight. The wide aspect ratio allows more content to be displayed. Other features include a wide operating temperature of -30°C to 80°C and 100K hours of LED backlight lifetime.



LEIA

Meno Park, CA, USA 1+512-567-9768
www.leia3d.com
Booth 504

Full-Color Holographic Multiview Display with Touch

LEIA will feature its 5.5-in. full-color "Holographic" 3D multiview display with Hover Touch which lets the user visualize and manipulate 3D content above an LCD screen.



LUMINIT, LLC

Torrance, CA, USA 1+310-320-1066 x314
www.luminitco.com
Booth 611

Direction-Turning Film

Optimal viewing angles are not always possible in display panels because of space and design limitations. Luminitt's Direction Turning Film (DTF) can help. This transparent optical component takes the image created by a flat-panel display and directs it by 20° up, down, left, or right to attain an optimal angle for the viewer. DTF can be used either within the display under the LCD or on top of the LCD in the display. DTF can also be incorporated in double-sided film with the DTF on one side and a Luminitt Light Shaping Diffuser® on the other side.



trade-show preview

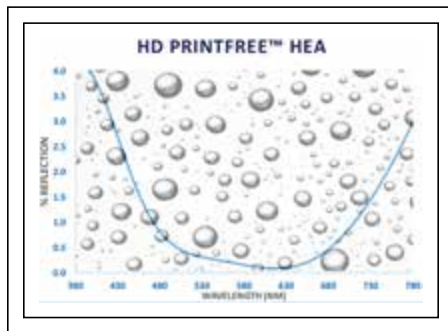
MAC THIN FILMS

Santa Rosa, CA, USA +1-707-791-1650
Booth 310

High-Efficiency Anti-Reflection (HEA) Thin Films

MAC Thin Films will introduce a highly durable PrintFree HEA at Display Week 2016. The HD PrintFree HEA combines best-in-class anti-reflection performance with a superior anti-fingerprint easy-to-clean anti-smudge treatment. This product is well suited to demanding display applications that would benefit from the following characteristics:

- Brightness < 0.5%
- Rub resistance greater than 1,000,000 Cheese Cloth strokes
- Easy cleanability
- Excellent Haptics.



MITSUBISHI ELECTRIC US

Cypress, CA, USA +1-714-229-3838
www.mitsubishielectric.com
Booth 1421

3.5-in. QHD TFT-LCD Module

Mitsubishi Electric's AA035AE01, a 3.5-in. color TFT-LCD module in quarter HD (960 × 540) format, provides half the resolution of full-HD (1,920 × 1,080) screens both horizontally and vertically (16:9 aspect ratio). The QHD format allows smoother undistorted conversion from full HD, making it well suited for studio video monitors, professional digital camcorders, and other digital broadcasting equipment. Features include:

- High-resolution 313-ppi [0.081(H) × 0.081(V)]
- Super-wide viewing angle, high contrast ratio, and 72% color gamut of NTSC standards
- 170° super-wide horizontal/vertical viewing angles and 800:1 high contrast ratio
- Slim and lightweight (4.0 mm and 43 g).



MY POLYMERS LTD.

Nes Ziona, Israel +972-8-9350-101
www.mypolymers.com
Booth 1409

Low-refractive-Index Liquid OCA

LOCA-133, with a refractive index of 1.33, exhibits strong adhesion, previously unattainable with such low-index adhesives. This Liquid OCA enables the lamination of glass, PMMA, PET, and PC. This unique combination of strong adhesion and low



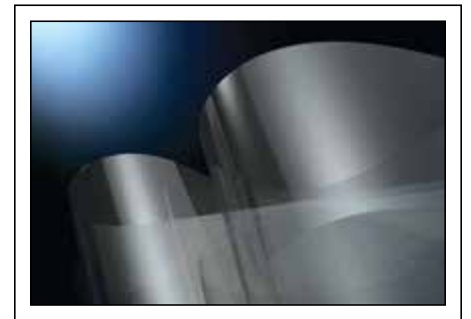
refractive index enables new applications, such as bonding the backlight-unit light guide to the reflector film, or bonding the light guide to the diffuser film, or to the lens array. LOCA-133 is used in various touch-screen technologies, such as FTIR. The lower-cost LOCA-135 addresses the different cost and performance requirements of various segments of the display industry.

NIPPON ELECTRIC GLASS CO.

Osaka, Japan +81-6399-2711
www.neg.co.jp/EN
Booth 737

Ultra-Thin Glass

G-Leaf is NEG's ultra-thin glass with a thickness of 0.2 mm or less, developed by overflow forming technology. G-Leaf is extremely light, smooth, and excellent in flexibility that makes the glass bendable while keeping the conventional characteristics of glass. G-Leaf is a new material expected to contribute to the advancement of technologies and products in a wider range of fields. Coating with various functions (ITO, anti-reflection, anti-glare, and anti-fingerprint) can be added to the glass.



PILKINGTON NORTH AMERICA

Toledo, OH, USA +1-800-221-0444
www.pilkington.com/na
Booth 1440

Novel Glass

The NSG Group is pleased to introduce NSG glanova™, a novel glass composition developed for chemical strengthening. Produced by the float process, this cost-effective material provides the advantages of soda-lime glass while achieving strength and breakage properties approaching that of aluminosilicate glass. The product's low iron content provides high light transmission and excellent color rendering. These features give a new option as cover glass for smartphones and tablets. NSG glanova™ is available in a range of thicknesses and sizes with a variety of fabrication options.



PPG INDUSTRIES

Pittsburgh, PA, USA +1-888-774-2001
www.ppgindustrialcoatings.com
 Booth 1109

Display Coatings

PPG offers a broad product line of transparent coatings for display glass substrates that includes anti-smudge (AS), anti-glare (AG), low-reflective (LR) and anti-reflective (AR) coatings. Each of these products can be combined into complete pre-engineered, pre-stacked, and pre-packaged transparent coatings solutions. PPG operates multiple global research and development centers and has worked closely for decades with consumer-electronics manufacturers to engineer innovative coatings for plastic, metal, glass, and composite substrates. As a result, PPG coatings are trusted to protect, beautify, and enhance the performance of the world's most popular electronic devices.



QUADRANGLE PRODUCTS

Englishtown, NJ, USA +1-732-792-1234
www.quadrangleproducts.com
 Booth 1048

eDP and DP Cables

Quadrangle Products now supports eDP, DisplayPort, and Mini DisplayPort style cables. An increasing number of LCD panels are becoming to incorporate the eDP-style display interface for their display data connections, as opposed to the more commonly seen LVDS/TTL interfaces. Quadrangle Products are equipped for common eDP and standard DisplayPort connectors. The more common eDP cables are also available. As always, custom eDP/DP cables are also a possibility. Quadrangle's Engineers will help to guide customers through the various design and construction challenges that can be associated with eDP and DisplayPort cables.



RADIANT VISION SYSTEMS

Redmond, WA, USA +1-425-844-0153
www.RadiantVisionSystems.com
 Booth 529

Ultra-High-Resolution Imaging Colorimeter

Radiant Vision Systems will feature the ProMetric® I29, an ultra-high-resolution imaging colorimeter developed for high-volume displays and consumer electronics manufacturers. The high spatial resolution of the I29 makes it capable of detecting very small flaws that are easily missed by human inspectors. Mura, particles, scratches, and other defects in flat-panel displays can be identified and quantified using Radiant's TrueTest™ Automated Visual Inspection software to provide objective and repeatable pass/fail criteria. The I29 has been engineered for optimal measurement speed, which means the shortest possible cycle times are achieved. The ProMetric I family of imaging colorimeters also features 2, 8, and 16 MP models.



REALD

Beverly Hills, CA, USA +1-310-385-4000
www.reald.com
 Booth 743

Privacy Display

RealD will feature Intelligent Privacy, a novel dynamically controlled privacy display for sensitive data. The product combines computer vision and RealD's IntelliLight directional backlight technology. The smart privacy software alerts the user to visual hackers and automatically blocks the screen to unauthorized observers. The IntelliLight based display electronically switches to allow the user to continue to work while blocking the content from prying eyes. The smart privacy mode including face recognition can identify approved users versus unauthorized observers. It can identify environments where privacy is of concern such as on an airplane or coffee shop and automatically switches to privacy mode.



RIVERDI

Gdansk, Poland +48-58-7703-116
www.riverdi.com/uxtouch/
 Booth 1441

TFT-LCD Modules

trade-show preview

Riverdi has widened its offer in the range of TFT-LCD modules with specially designed projected-capacitive touch for the uxTouch series. This series is available in a variety of sizes, but the newest is 5 in. with a resolution of 800×480 , distinguishing a brightness of 510 cd/m^2 , 20-pin ZIF with a 0.5-mm raster and SPI/QSPI interface. The Riverdi 5-in. uxTouch is one of the first display modules with such a diagonal that has a built-in EVE (embedded video engine), enabling quick implementation of applications.



ROFIN-BAASEL LASERTECH GmbH & CO. KG

Stamberg, Germany +49-(0)8151-776-0
www.rofin.com
Booth 1112

Laser Micro Material Processing

The StarFemto is a versatile tool providing excellent results in industrial laser applications such as high-precision cutting, surface structuring, drilling, and marking of almost all materials without thermal damage. This reduces the number of process steps, increases yields, and facilitates new features and applications in industries such as electronics, semiconductor, micro technology, and medical device manufacturing. ROFIN makes the difference with the Hybrid MOPA architecture – its robust design as well as with easy system integration and maintenance.



SEEFRONT GmbH

Hamburg, Germany +49-40-4162256-80
www.seefront.com
Booth 1017

3D Autostereoscopic UHD Monitor

SeeFront's 24-in. autostereoscopic 3D monitor delivers a cutting-edge 3D experience at the utmost freedom of movement for a single user. SeeFront 3D® Technology combined with an UHD display panel with 3840×2160 pixels offer color fidelity, high brightness, and true 3D depth at the highest possible resolution. The SeeFront SF3D-240CQ will work with all 3D-enabled applications supporting 1080p side-by-side (half) and 720p frame packing according to HDMI standard.

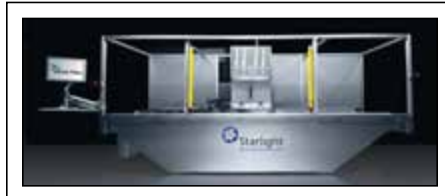


SENSOR FILMS

Victor, NY, USA +1-585-738-3500
www.sensorfilmsinc.com
Booth 1343

Digital Manufacturing Platform

The Starlight Digital Manufacturing Platform delivers industrial ink-jet deposition technology for rapid patterning of functional materials on plastics, transparent conductive films, glass, and metal. Starlight has two 7-head print bars for multi-material multi-pass operation providing up to 1200×4800 dpi. Starlight's Xerox M-Series piezo head has a stainless-steel jet stack with 880 individually addressable jets operating up to 43 kHz and an adjustable drop size from 15 to 30 pL. Starlight prints 60- μm features up to 26×24 in. in area, and wider configurations are available. A heated vacuum platen operates at up to 81 fpm for a single-print-pass mode.



SHARP MICROELECTRONICS OF THE AMERICAS

Camas, WA, USA +1-360-834-2500
www.sharpsma.com
Booth 729

High-Contrast FHD LCD

Sharp's new 15.6-in. (diagonal) TFT-LCDs stunning full-HD (FHD) visual performance is complemented by extremely crisp definition via a 1500:1 contrast ratio (typical). The combination makes it perfect for viewing high detail in nearly any ambient-lighting situation. Its excellent viewability is enhanced by a wide $170^\circ(\text{H}) / 170^\circ(\text{V})$ viewing angle. The module features a built-in LED driver, simplifying the design process.



SOLOMON SYSTECH LTD.

Shatin, Hong Kong +852-2207-1111
www.solomon-systech.com
Booth 1234

Bistable Display Driver IC

Solomon Systech's bi-stable display driver IC with the SSD1627 controller can drive up to 132 segments and enable color as well as black and white display. It is designed with a programmable display waveform and built-in DC/DC converter for a wide voltage range. SSD1627's newly designed 15-V cap-lite charge pump reduces the external capacitor number. It also has new features enabling flexible panel routing, partial display update, and fast content update to avoid refresh-induced blink. The low-power-consumption feature makes SSD1627 an ideal solution for handheld smart devices. SSD1627 also supports both SPI and I2C interfaces and allows cascading with additional ICs to increase segment number.



SUN-TEC AMERICA, LLC

Scottsdale, AZ, USA +1-480-922-5344
www.sun-tec.net
Booth 1214

Flexible Lamination Manufacturing

Sun-Tec will feature the TMS-22TS, a laminator that offers users complete manufacturing flexibility by performing flex-to-flex, flex-to-rigid, and rigid-to-rigid substrate lamination work. It is ideal for displays, touch sensors, and other flexible hybrid electronics (FHE) applications in a production or an R&D environment. By using the Sun-Tec proprietary "tail-stopper" mechanism to enable out gassing during a rigid-to-rigid substrates lamination, trapped air between the substrates is significantly reduced. Additional features of the TMS-22TS include PLC storage for 100 production recipes, programmable digitally controlled lamination speed and pressure settings, min/max substrate processing of 10/22-in. on the diagonal, and a placement accuracy of +/- 0.2 mm.



SUPERIMAGING

Fremont, CA +1-510-6511329
www.sun-innovations.com
Booth 214

New Blue-Ray Plus LED DLP Projector

Sun Innovations' newest high-power Blue-Ray Plus (405 nm) LED DLP projector offers compact body design for easy integration, high optical efficiency, low power consumption, long LED lifetime, bright emissive display with unlimited viewing angles, standard HD video interface with HDMI and serial port to support PC control and custom development. Features include a water-clear emissive screen that adheres to any windshield or glass; scalable display size with unlimited viewing angles; bright blue, white, or red information display viewable in daylight; fully absorbed projection light; a DLP Light-Crafter E4500MKII with a 0.45 WXGA chipset; and compatibility with HD-video or image, HDMI, and USB interfaces.



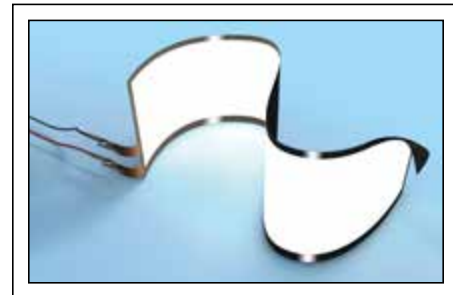
TESA SE

Norderstedt, Germany +49-4088-8990
www.tesa.com/industry/electronics
Booth 415

Display Solutions

Tesa's solutions for displays include Optically Clear Adhesives for the bonding of displays and barrier adhesive tapes for OLED encapsulation, suitable for flexible-panel production. Among the barrier tapes available, a product range consisting of an UV-curable barrier adhesive is offered. In an uncured state, the tape shows very good conformability and wetting performance. Low polarity and a getter function activated by UV-curing make this adhesive

a highly effective barrier against oxygen and water-vapor while the tape still remains flexible and highly transparent. The barrier tapes are perfectly applicable for rigid and flexible devices and can be used in roll-to-roll processes.



TFD

Anaheim, CA, USA +1-714-630-7127
www.tfdinc.com
Booth 1205

Large-Area Flex PET PEN Heater

TFD, Inc., has developed a large-area flex PET PEN Heater on roll-to-roll (1 x 20 m), which can be applied on large windows, LCDs, as well as automotive and other applications. These heaters can take 5-230 V and 1-25 A.



TIANJIN ZHONGHUAN QUANTUM TECH CO., LTD.

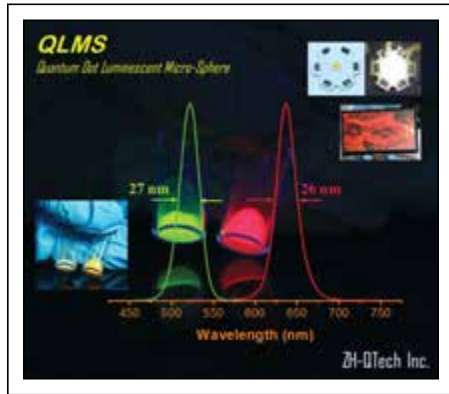
Tianjin, China +86-22-8643-5936
www.zh-qtech.com
Booth 306

Quantum-Dot Luminescent Micro-Sphere

The Quantum-Dot Luminescent Micro-Sphere (QLMS), developed by ZH-QTech Co., Ltd., is a new type of highly robust quantum-dot (QD) composite featuring high efficiency, narrow full width at half-maximum (FWHM), and excellent long-term operation stability. QLMS is fully compatible with current LED packaging process and can be used as phosphors for direct on-chip applications, i.e., a tube or film is no longer required. QLMS will make it more convenient and

trade-show preview

cost efficient for manufacturers to adopt QDs in flat-panel displays with wide color gamut and LED lighting with high color rendering.



TIANMA NLT USA

Chino, CA, USA +1-909-590-5833

www.tianma.com

Booth 905

High-ppi Tablet Display

Tianma will introduce the highest-ppi tablet display in the World at Display Week. This new 10.4-in. LCD product has achieved a ground-breaking pixel-pitch performance of 847 ppi, with a real pixel resolution of 4320×7680 (or $8K \times 4K$). This product brings never-before-seen performance and clarity to popular tablet display size and other high-end applications. Based on LTPS and negative liquid-crystal technologies, this product reached a new level of ultra-high resolution and sharper picture quality.



UNIVERSAL DISPLAY CORP.

Ewing, NJ, USA +1-609-671-0980

www.udcoled.com

Booth 604

PHOLED Color Board

At Display Week 2016, UDC is showcasing its phos-

phorescent OLED (PHOLED) Color Board. The Color Board demonstrates a selection of its high-performing energy-efficient red, green, blue, and yellow UniversalPHOLED® phosphorescent emitters. With Universal Display's proprietary Universal-PHOLED technology, OLEDs can be up to four times more efficient than conventional fluorescent technology. In an increasingly energy-conscious and environmentally minded world, PHOLED technology and materials are critical for meeting the OLED design requirements of the world's consumer and lighting needs.



WESTAR DISPLAY TECHNOLOGIES

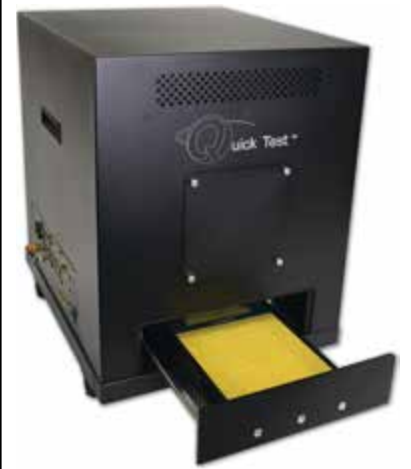
Saint Charles, MO, USA +1-636-300-5115

www.westardisplaytechnologies.com

Booth 404

Mobile Display test System

Westar Display Technologies will demonstrate QuickTest II+™, an upgrade to Westar's industry standard QuickTest II automated test system. The QuickTest II+™ characterizes mobile displays up to 9 in. and includes a camera, spectrometer, and a Westar TRD-100A that provides measurements of uniformity, color, contrast, luminance, cross-talk, response time, flicker, and more. The system includes the Westar T-Drive SD-100 video test pattern generator and a computer with our QuickTest™ software which allows the user to easily create custom test scripts. QuickTest II+™ can be extended with several options including reflection measurement, custom display fixtures, and more.



WESTBORO PHOTONICS

Ottawa, Ontario, Canada +1-613-729-0614 x521

www.wphotonics.com

Booth 1314

12-Mpixel Resolution Imager

Westboro Photonics will feature the WP6120, a resolution imager with scientific-grade thermoelectrically cooled interline CCD sensors having 12 Mpixels and optimized for low-light applications requiring the highest sensitivity. By using electronic image bracketing technology, the colorimeters can measure a dynamic range of over 100,000:1 within a scene. This 12 megapixel resolution imager features 16-bit A/D conversion and temperature regulation to $\pm 0.1^\circ\text{C}$, enabling precise and accurate measurements of even the finest details. Backlit keyboards, keypads, or automotive/avionic panel graphics and control elements can be quickly and reliably measured with sufficient resolution for even the smallest characters. The lightweight compact format allows the WP6120 to be easily integrated into most measurement scenarios. The accompanying Photometrica® software provides extensive analysis capabilities with automation and scripting tools embedded directly in the software. A selection of calibrated lens options is also available to accommodate a diverse suite of applications.

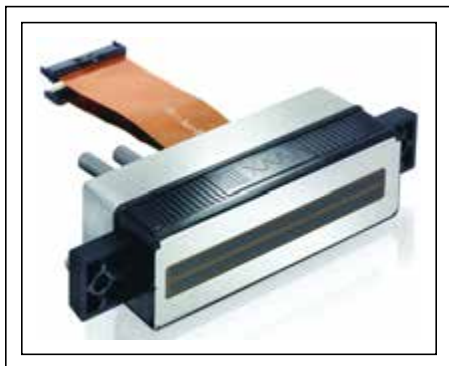


XAAR

Cambridge, UK +44-1223-423663
www.xaar.com/en
 Booth 1247

Printheads

The Xaar 1003 AM range of printheads offers a robust solution for fluid deposition on an industrial scale. The printheads enable the precise fluid control essential for advanced manufacturing processes, with drop volumes ranging from 1 to 160 pL, depending on the printhead variant. Xaar's patented TF Technology® (fluid recirculation) ensures continuous fluid flow directly past the back of the nozzle during drop ejection, keeping particles evenly distributed in suspension and the nozzles primed, radically improving reliability even in the most challenging of industrial applications. ■



Information DISPLAY



Information Display welcomes contributions that contain unique technical, manufacturing, or market research content that will interest and/or assist our readers – individuals involved in the business or research of displays.

Please contact Jenny Donelan, Managing Editor, at jdonelan@pcm411.com with questions or proposals.

Turn to page 59 for a list of 2016 editorial themes, with approximate dates for submitting article proposals.



Submit Your News Releases

Please send all press releases and new product announcements to:

Jenny Donelan

Information Display Magazine

411 Lafayette Street, Suite 201, New York, NY 10003

Fax: 212.460.5460 e-mail: jdonelan@pcm411.com

JSID Outstanding Student Paper Describes a System to Study Crosstalk in 3D HUDs

With the idea that if head-up displays (HUDs) are increasingly common in high-end automobiles, 3D HUDs are a logical next step, a doctoral student and a group of researchers in Germany recently set out to create a system to study crosstalk in 3D HUDs. (Crosstalk in such displays is likely to present significant challenges.) Their goal was not to solve actual crosstalk problems at this point, but to develop an accurate system that would allow for such research to proceed in the future.

The resulting *Journal of the SID* paper, “Exploring crosstalk perception for stereoscopic 3D head-up displays in a crosstalk simulator,” by Simone Höckh, Annette Frederiksen, Sylvain Renault, Klaus Hopf, Michael Gilowski, and Martin Schell, was recently named the *JSID* Outstanding Student Paper of the Year for 2015. The paper was selected by *JSID*’s associate editors through a voting process. “The selection committee appreciated the versatility and potential of the reported simulation setup, which enables its application to the very specific but very relevant case of stereoscopic head-up displays used in vehicles,” says Herbert De Smet, a Professor at Ghent University and Editor-in-Chief of *JSID*.

Höckh, Frederiksen, and Gilowski are with the Corporate Sector for Research and Advance Engineering at Robert Bosch GmbH in Stuttgart. Höckh is a Ph.D. student at the Technical University Berlin who anticipates a Dr. rer. nat. degree in 2016. She also participated in a Ph.D. program at Robert Bosch GmbH from 2013 to 2016, with Gilowski serving as her internal Ph.D. supervisor. She is now employed at Bosch. Schell, who is a professor at Technical University Berlin, is Höckh’s university thesis advisor. He is also with the Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, in Berlin, as are Renault and Hopf. The research described in the paper was conducted at Bosch.

3D HUDs and Crosstalk

Head-up displays in automobiles show information, such as the speed and the speed limit, in such a way that it “floats” beyond the windshield in front of the driver without blocking the view. In some cases, HUDs can augment reality by digitally emphasizing road hazards

and oncoming cars. Höckh’s research team described an autostereoscopic see-through augmented-reality HUD system that could show several planes or virtual-image distances in such a way as to sort relevant information for the driver. For example, information about the car, such as its speed, could be shown closer to the driver, whereas navigational information, such as arrows for turnoff, could appear farther away. Given the pace of display development for automobiles, “an autostereoscopic 3D HUD seems a logical consequence,” says Höckh.

Such a system does not exist yet commercially, but if it did, note the authors, crosstalk, in which “ghost” images appear to the viewer as a result of the separation of right and left views, would be a major issue. Crosstalk not only creates a lack of fidelity, but eyestrain and headaches. It could also prove a dangerous distraction to the driver.

Setting Up the System

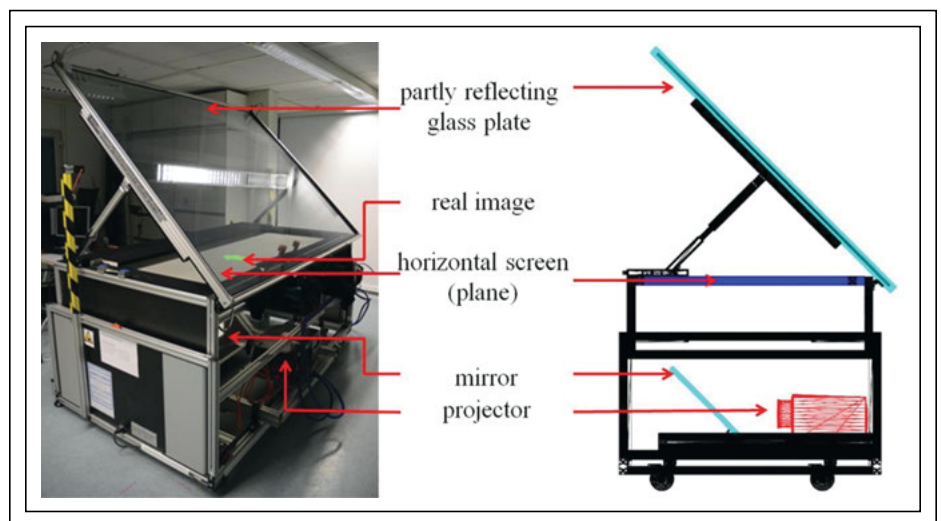
The researchers set about creating an ambitious system capable of studying crosstalk in a HUD. The hardware consisted of a projector (controlled by a workstation), mirror, horizontal screen (plane), and a partially reflecting glass plate (see Fig. 1).

One of the biggest challenges of the setup, says Höckh, involved the software. “Usually

in 3D visualization software,” authors Hopf and Renault explain, “two perspectives are rendered separately. For a simulation of crosstalk, image sections of both views have to be combined.” For this purpose, the team members from Fraunhofer HHI developed a novel rendering pipeline within Fraunhofer’s 3D-API, Workbench3D, which supported a scalable transfer of image information between the left and right view.

The study included 24 subjects (19 male and 5 female) with an average age of 30.5 years and vision that was either normal or corrected to normal. The test sessions consisted of two parts: the first addressed changes in the participant’s visibility threshold and the second, the variation of the acceptability threshold of crosstalk depending on screen parallax, object type and color, illumination, and contrast. Each participant went through both parts of the study consecutively.

The objects initially appeared without any simulated crosstalk. The supervisor slowly increased the crosstalk value until the participant announced the visibility of crosstalk. Then, researchers asked the participants to adjust the crosstalk value themselves, thereby allowing them to increase and decrease the simulated crosstalk prior to their decision for their individual acceptance threshold. Both visibility and acceptability were recorded.



For the setup of the stereoscopic 3D head-up-display simulator, an observer was positioned on the left of the setup and looked through the glass plate to the right.

Results

The researchers found that both crosstalk visibility and acceptability thresholds depended most strongly on contrasts. The higher the contrast, the lower the thresholds. These and other results, they report, appear to be consistent with existing literature relating to studies performed with conventional 3D displays. In this way, the results indicate the functionality of the system the team created. “However,” they wrote in their article, “further research, especially including a realistic background designed to operate an augmented-reality application, has to be performed.”

Höckh explains that her team’s work was part of an industrial and application-oriented research project designed to identify user-oriented requirements that such a system would have to fulfill. She adds that the results presented in the paper could also be interesting for other autostereoscopic 3D augmented-reality applications – not just HUDs for vehicles. “As both the hardware and the software are designed to allow for the variation of many parameters associated with the perception of crosstalk, the simulator is a very versatile and potent setup regarding further investigations of crosstalk disturbance in a stereoscopic 3D HUD,” she concludes.

Each year a subcommittee of the Editorial Board of JSID selects one paper for the Outstanding Student Paper of the Year Award, which consists of a plaque and a \$1000 prize. The award is sponsored by LG Display. ■

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continued from page 3

display (TFT LCD) business – for \$3.5 billion. The two companies had been poised to make the transaction earlier this year, with Sharp agreeing in February to accept a \$6.2 billion bid from Foxconn. Then Foxconn received a list of “contingent liabilities” from Sharp, said by numerous unconfirmed sources to be in the area of \$2.5 billion. At this point Foxconn put the acquisition on hold for further research, until announcing the new deal at the end of March. Presumably the new and lower price reflects the “liabilities.”

Foxconn, the world’s largest electronics contract manufacturer – perhaps best known as the maker of Apple’s iPhones – stands to gain both IP and market share with this acquisition. According to David Hsieh, Senior Director at market research firm IHS, Foxconn is already a leading supplier of TFT-LCDs through its subsidiaries Innolux and Century. “The convergence of Foxconn’s business with Sharp’s TFT-LCD business and other innovative developments, such as active-matrix organic light-emitting diodes (AMOLEDs) and larger TV displays, creates a powerhouse with the largest TFT-LCD production capacity and research capabilities in the world,” says Hsieh.

For Sharp, a 100-year-old company known for its innovative display products, some kind of acquisition seemed inevitable. Financially, the company has been struggling; it received two bank bailouts in the last 4 years. In the final 9 months of 2015, Sharp posted a net loss of about \$960 million.

Sharp is not all alone these days. Around 2012, articles with titles like this one from CNET began proliferating: “The era of Japanese consumer-electronics giants is dead.” The article began, “Once venerable names in consumer electronics such as Sony, Panasonic, and Sharp have been besieged by competition from rivals in the U.S., South Korea, and, increasingly, China.”² Oft-cited reasons for this state of affairs include a failure to react nimbly to changing markets, an emphasis on building machinery vs. writing code, and sometimes a lack of innovation.

This last reason does not apply to Sharp, which has in recent years introduced a number of display innovations, including a new indium (In), gallium (Ga), and zinc (Zn) (IGZO) technology that earned it (with co-developer Semiconductor Energy Laboratory) a 2013 Display of the Year award from SID. Hsieh offers a few ideas about why a highly innovative, well-regarded company like Sharp might fall on difficult times.

“First,” he says, “Sharp is excellent at developing new technology but comparatively slower than its competitors to bring these technologies to market. Hsieh believes that Foxconn’s skill with the commercial aspects of the display business (it has handled its key customer Apple well for several years) may be a positive addition for Sharp.

Hsieh also mentions that competition from Korean, Taiwanese, and Chinese companies who have been very fast to commercialize products and ramp up capacity put pressure on Sharp, as well as on other Japanese companies. Last, he adds, “Sharp’s costs (due to the higher overhead in Japan) and organizational structure and culture hamper the company in terms of making fast reforms – even though they have great innovative technology development.”

Hsieh reports that Foxconn’s Innolux subsidiary is already in the process of increasing its production capacity with a Gen 8.6 TFT-LCD fab in Taiwan. It is also building three Gen 6 low-temperature polysilicon (LTPS) TFT-LCD fabs in Taiwan and China. With the acquisition of Sharp, currently the leading maker of high-resolution LTPS TFT LC smartphone displays, low-power oxide-TFT LC tablet displays, and a-Si based TFT LC automotive displays, Foxconn is also probably eager to invest in an AMOLED fab for flexible smartphone displays, says Hsieh. In terms of TFT-LCD production capacity, the new company will account for 21% of the global capacity in 2016, surpassing LG Display, Samsung Display, and BOE, according to IHS’s *Display Supply Demand & Equipment Tracker* report. ■

²<http://www.cnet.com/news/the-era-of-japanese-consumer-electronics-giants-is-dead/>

continued from page 2

Our cover story this month is the annual Display Industry Awards, which recognize the most innovative display products and technology from all of 2016. The list of choices for these awards was overflowing with worthy recipients and I can honestly tell you as a member of the DIA committee that the final selections were really the best of the best. This year's recipients cover the gamut from components such as light guides and polarizers, to wearable displays, all the way up to stunning implementations in tablets and notebooks. As you read the synopsis of each award winner compiled by Jenny Donelan, I am sure you see that great innovative is alive and flourishing in our midst.

In addition to the Awards and Show coverage this month we also have some great technical articles addressing current topics in both automotive and digital-signage applications. The adoption of electronic displays in cars has finally become a hot topic after so many years of intense speculation and anticipation. Finally, we are seeing some really creative ideas taking shape to both improve the flow of information to drivers as well as enhance the safety of the driving experience. Many ideas also make the cockpit more attractive and bring the feeling of the 21st century to the dashboard.

Our guest editor Dr. Karlheinz Blankenbach with Pforzheim University has brought us two great stories involving the special considerations associated with electronic displays and controls for driver use. The first is "Understanding the Requirements for Automotive Displays in Ambient Light Conditions" by authors Jan Bauer and Markus Kreuzer. This very thorough and complete work examines all the unique challenges associated with ambient-light intrusion into the driver's cabin and how that affects the required design considerations for electronic displays. The second article addresses the understandable concern of keeping drivers focused on the primary task of driving when there are so many distractions that modern displays and touch controls introduce. In their Frontline Technology article, "Haptics Help Drivers Keep Their Eyes on the Road," authors Thomas Vöhringer-Kuhnt *et al.* explain how control interfaces that implement haptic feedback can greatly reduce the amount of errors in control actions as well as reduce overall distraction. When drivers can find and adjust things in the cabin such as climate controls

without looking away from the road they are both safer and presumably more satisfied. To put this in more context, please read Dr. Blankenbach's guest editorial titled "Vehicle Displays in the Passing Lane" and then enjoy the articles introduced.

While we are on the topic of vehicle displays, I want to also recognize this year's JSID Outstanding Student Paper of the Year for 2015, a very creative effort aimed at exploring how potential drivers would perceive cross-talk artifacts in 3D head-up displays. To achieve this, authors Simone Höckh, Annette Frederiksen, Sylvain Renault, Klaus Hopf, Michael Gilowski, and Martin Schell all worked together to create a novel stereoscopic 3D head-up-display simulator and studied a significant number of test subject observers. You can read more about this in our SID News feature written by Jenny Donelan.

Digital Signage is also getting a lot of attention these days, partially because the infrastructures of displays, input sensing, and content distribution are much more mature and partially because tangential technologies such as wireless beacons and mobile devices are also maturing, allowing developers to implement a broader range of their imaginations in real systems for lower cost.

We saw back in our January issue some of the really creative ways digital signs are being implemented. In this issue, we explore some more related topics, such as how proximity networks and wireless beacons can be used to create a truly personalized marketing experience, as explained by authors Mark Boidman and Ben Freeberg in their Frontline Technology article titled "Sensor Architecture: The Evolution of Digital Signage and Intelligent Visual Communications." Next, we welcome back author Todd Fender with the second installment of his two-part Display Marketplace feature on "New Directions for Digital Signage and Public Displays." In this second part, he moves from surveying the technology and the overall marketplace to looking more closely at the educational and corporate markets, plus he suggests how OLEDs may further energize the industry. Finally, in this section we feature a Frontline Technology look at the "Challenges for Outdoor Digital Displays" from Benjamin Medvitz, who explains some of the most important design aspects related to outdoor and harsh environment displays. He also helps explain the technical and business trade-offs between using commercial low-cost

television-type panels vs. more heavily ruggedized industrial-grade panels for your signage project.

Before I end this month, I want to thank outgoing SID President Amal Ghosh for his very successful and dedicated leadership of SID. I have known Amal for many years and I highly respect both his professional work in his field and his personal commitment to SID. At the same time, I also want to welcome our new incoming President Dr. Yong-Seog Kim and wish him much success in the years ahead.

Thank you all for coming and have a wonderful week in San Francisco! ■

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Event Date	Event Description	Closing Date
January/February	Digital Signage, Materials Special Features: Digital Signage Technology Overview, Digital Signage Market Trends, Oxide TFT Progress Report, Alternate Display Materials, Top 10 Display Trends from CES, Chinese Business Environment Markets: Large-area digital signage, in-store electronic labeling, advertising and entertainment, market research, consumer products, deposition equipment manufacturers, fabs	December 28
March/April	Display Week Preview, Flexible Technology Special Features: SID Honors and Awards, Symposium Preview, Display Week at a Glance, Flexible Technology Overview, Wearables Update Markets: Research and academic institutions, OLED process and materials manufacturers, consumer products (electronic watches, exercise monitors, biosensors), medical equipment manufacturers	February 29
May/June	Display Week Special, Automotive Displays Special Features: Display Industry Awards, Products on Display, Key Trends in Automotive Displays, Insider's Guide to the Automotive Display Industry Markets: Consumer products (TV makers, mobile phone companies), OEMs, research institutes, auto makers, display module manufacturers, marine and aeronautical companies	April 21
July/August	Light Fields and Advanced Displays Special Features: Overview of Light-field Display Technology, Next-generation Displays, Market Outlook for Commercial Light-field Applications Markets: Research institutions, market analysts, game developers, camera manufacturers, software developers	June 20
September/October	Display Week Wrap-up, Emissive Technologies Special Features: Display Week Technology Reviews, Best in Show and Innovation Awards, Quantum Dot Update, A Look Forward at Micro-LEDs Markets: OEMs, panel makers, component makers, TV and mobile phone companies	August 25
November/December	Applied Vision Special Features: Advanced Imaging Technology Overview, Current Key Issues in Applied Vision, Real-World Applied Vision Applications Markets: Medical equipment manufacturers, game developers, research institutions, OEMs, software developers	October 24

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Instrument Systems	C3		
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Sensing America.....	13		

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