AUTOMOTIVE DISPLAYS

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Display Technology for the Connected Car

OPTIMIZING VEHICLE DISPLAY PERFORMANCE

DYNAMIC BACKLIGHTS FOR AUTOMOTIVE LCDs

THE BACKBONE OF THE CONNECTED CAR

HARMAN'S RASHMI RAO EXPLORES THE FUTURE OF THE CONNECTED CAR

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ON THE COVER: *Harman's QLED technology (quantum-dot enhanced LCD) is being used to reimagine the automotive cockpit. Image courtesy Harman.*

Cover Design: Acapella Studios, Inc.

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editorial

The Acceleration of Automotive Displays

by Stephen P. Atwood

Anyone who knows me would agree that two of my favorite things to talk about are cars and displays. I love to rent cars to play with the technology, and I love to work on new ways to package and integrate displays. So the opportunity to do an issue that brings together both topics is a real treat for me.

If you look at the interior of just about any new mid-tier or higher-end car on the market today and compare it to one from about five years ago, the most striking difference you would see is the innovative use of glass and touch controls. Just about every available space in today's cars, including, of course, the center stack and the instrument cluster, houses at least one graphical display. Some models even have several separate graphical displays in the center area for climate control, audio selection, and navigation. But I'm also seeing more pop-up displays on the top of dashboards and some commercial HUDs being sold in luxury models.

A few years ago, we saw the invasion of ceiling-mounted small TV displays in the back seats of minivans. Those were of mediocre quality and intended mainly to show DVDs to keep the kids amused. Now those have become wide-screen, high-luminance HDTVs with split screens and all kinds of interactive and streaming content. Many of these displays also support touch input, removing or reducing the occurrence of traditional mechanical switches and controls. And the latest trend involves digital management of those controls. Even if those controls are still mechanical in nature, they are connected to encoders and managed by software to produce a variety of more intuitive operations than ever before. For example, a simple rotary control can now dynamically change its adjustment rate and even provide variable haptic feedback based on context. We're closing in on the all-glass cockpit. This year at Display Week I saw demonstrations of seamless integrations of conformable LCD screens with actual mechanical encoders as well as touch regions built into the screens.

One challenge of these new paradigms is making all these individual displays operate at the right luminance and contrast levels for the very demanding automobile ambient environment, and especially making them all match each other for a seamless appearance where they converge. In our first Frontline Technology feature, "Performance Optimization for In-Vehicle Displays," authors Kai Hohmann and Markus Weber at Continental Automotive explain their approach to the familiar problem of getting a large population of displays to all meet the same critical optical performance requirements and to do so both within the same vehicle and across all the different vehicles in a production run. Consider that a car manufacturer would want each occupant of every vehicle to have exactly the same high-value experience when using the displays. That's a tall order, but Kai and Markus explain an approach to achieve that solution.

A similar challenge, along with consistency, is simply getting the most performance out of each display in the widely varying bright-day to dark-night environments for vehicles. Our next Frontline Technology feature proposes the use of dynamically addressable 2D backlights for this purpose, while noting that commercial requirements mandate a more efficient and cost-effective approach than might be used in high-dynamic-range (HDR) TV applications. In "Dynamic Backlights for Automotive LCDs," authors Chihao Xu, Maxim Schmidt, Torsten Lahr, and Markus Weber

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Information DISPLAY

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

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

Global Ad Director:
Dan Nicholas, dnicholas@wiley.com

Senior Account Manager
Print & E-Advertising:
Roland Espinosa
201/748-6819, respinosa@wiley.com

guest editorial

Automotive Displays at the Dawn of Autonomous Driving

By Karlheinz Blankenbach

"From zero to hero" – could this stand for the number of displays and pixels in autonomous cars of the future? Not too many years ago, there were hardly any electronic displays in cars at all. Today's cars, even intermediate models, are equipped with at least two graphics displays. And as we will see, that number is about to expand greatly.

Level 2 autonomous driving as available today requires permanent supervision with only temporary "hands off" the steering wheel. This will evolve in the next decade to "eyes off" driving (Levels 3 and 4) for defined-use cases. In Levels 3 and 4, the driver need not permanently monitor the environment; however, he or she has to take control on being notified by the system. This provides a lot of free time for "drivers." Consequently, cars will evolve to mobile living rooms and/or offices used for leisure as well as work. Prototypes of large dashboard displays stretching from pillar to pillar have already been presented in various show cars. This setup will raise the number of pixels in a car significantly. A Level 5 car, in which the driver effectively becomes a passenger, will generally be even more of a mobile living or working space, with more displays.

Admittedly, an exception to the rule of higher levels = more displays is possible. At Level 5, a robot car with autonomous-driving capabilities in a shared-economy approach could even drive a five-year-old child to kindergarten. Such a car would have no steering wheel or pedals for driving. One could argue that displays are not strictly required in such a scenario. Passengers could simply bring their own smartphones or other display devices and use them to unlock the robot car, set the destination, and check out when leaving the car. It might be reasonable, however, to have a small touch display built in for fundamental interaction with the driverless shared car. Otherwise, we can safely assume that displays will continue to increase as the levels advance.

Pixel Proliferation

In the age of autonomous driving, significantly more time (hours) can be spent by the "driver" watching displays than today (seconds while driving). As previously mentioned, a clear trend in show cars is a huge dashboard display. These generally span from left to right with a height of about 10 to 20 inches. This increase in size will result in 20 or more megapixels at 200 ppi. The display will dominate the front interior design. Advanced human-machine interfaces (HMIs) using these displays will evolve from functional to emotional, using holistic approaches, and will certainly differentiate brands.

Augmented-reality head-up displays (AR-HUDs) will be another factor in the increase of displays and pixels. This technology will increase safety for manual driving and build trust in autonomous scenarios by depicting what the advanced driver assistance system (ADAS) sensors have detected and what the car is going to do. It will do this by highlighting lanes for wayfinding and displaying traffic signs, pedestrians, crossings, and so forth, and displaying them as overlays of the real scene. Such technology, however, requires a field of view (FOV) that is significantly higher than that of today's HUDs (up to 12° by 3°). Even 40° (H) by 20° (V) would provide

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industry news

by Jenny Donelan

LG Electronics Acquires Lighting Company ZKW Group

LG Electronics recently approved the acquisition of automotive lighting and headlight systems provider ZKW Group, a deal worth more than €1.1 billion. LG notes that this is its largest acquisition to date. Under the terms of the transaction, LG Electronics will acquire a 70 percent stake in ZKW Group, with parent company LG Corp. purchasing the remaining 30 percent.[1]

ZKW is an Austrian company that focuses on premium vehicle components and related accessories. It has a market presence in Europe, China, Mexico, and the US, and is one of the first companies to produce matrix LED headlamps and laser headlights (which higher-end vehicle manufacturers and others are starting to use to replace more traditional halogen headlamps).

According to LG, the Austrian company's offerings will specifically complement LG's growing vehicle components operation, which is designed to serve a premium automotive lighting segment that LG predicts will expand faster than traditional auto lighting. The *International Business Times*, among other publications, pointed out that the acquisition is also a strategic, longer term move by LG to gain dominance in the self-driving vehicle market. Autonomous vehicles will rely on a combination of sensors, cameras, radar, *etc*., and high-quality lighting (such as ZKW is already providing to the automotive industry) that will figure prominently in the overall system.[2] LG stated that it expects the merger to result in synergies that allow the combined companies to lead the global lighting sector in autonomous vehicle components.

ZKW had revenues of €1.26 billion in 2017 and has demonstrated an average annual sales growth rate of more than 20 percent over the past five years. ZKW products are used in European automotive brands including Audi, BMW, Porsche, and Daimler.

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[1] www.prnewswire.com/news-releases/lg-acquires-global-premium-automotive-lighting-company-zkw-group-300637248.html
[2] http://www.ibtimes.com/lg-spends-big-acquire-leading-automotive-lighting-provider-zkw-group-2675635

Vuzix Partners with Plessey Semiconductors

Vuzix, a developer of smart glasses and augmented-reality technology, including the much-touted-but-not-yet-shipping Vuzix Blade (Fig. 3), has announced that it is partnering with Plessey

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Seen at the Show . . . .

Here are just a few of the new products shown at Display Week in Los Angeles last May. For more, check out the Display Week Highlights article in this issue, as well as the in-depth post-show articles coming up in our September/October Display Week Review issue.

Tianma Intros 2 High-Luminance LCDs

Tianma Group introduced two new LCDs at the show in Los Angeles: a 10.1-in. WXGA and a 5.6-in. WXGA, both with high luminance (Fig. 1).

The high luminance of these panels results in displays with vivid color and excellent visibility, even in direct sunlight. They were designed to expand Tianma's extensive stable of industrial, outdoor-viewable products.

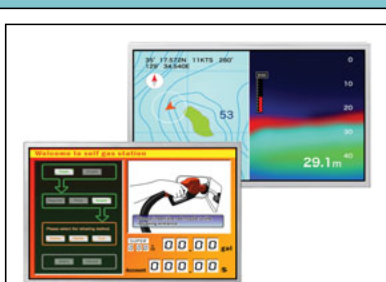

***Fig. 1:** Tianma's new 10.1-in. model has a luminance of 1,000 cd/m^2, and the 15.6-in. model has a luminance of 1,250 cd/m^2.*

CYNORA Presents Latest Blue Emitters at Display Week

CYNORA, a German company that was founded 10 years ago to develop thermally activated delayed fluorescence (TADF) technology for OLED, presented its latest high-efficiency blue emitters at Display Week. It is generally thought that in order for large OLED panels to reach their full potential, they need high-efficiency blue OLED emitters to reduce power consumption and increase display resolution.

Last fall, major panel makers (and rivals) LG Display and Samsung invested €25 million in CYNORA, imbuing the company with both cash and increased credibility. "We are working very closely with our investors, LG Display and Samsung Display, for this final phase of our material development," says Andreas Haldi, chief marketing officer at CYNORA.

E Ink Shows Full-Color Reflective Display

An eyecatcher in E Ink's booth at the show this year was the company's Advanced Color ePaper (ACeP) – a full-color reflective display (Fig. 2). The ACeP system enables the ink to produce full color at every pixel, without the use of a color-filter array. E Ink has shown ACeP before, but each year it gets a little better, and a little bigger.

This year E Ink was showing ACeP in both 32-in. and 13.3-in. sizes, with the smaller one scheduled to be commercially available first – in late 2018 or early 2019. For now, the target application is digital signage – no ACeP e-Readers just yet.

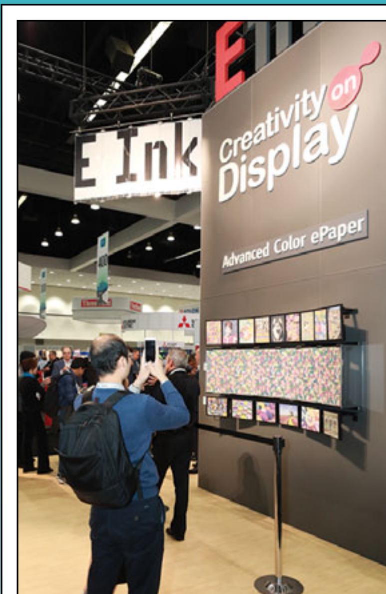

***Fig. 2:** E Ink's color e-Paper (here demonstrated at Display Week 2018) still isn't as brilliant as LCD or OLED materials – but every year it gets more colorful.*

Performance Optimization for In-Vehicle Displays

As the number and size of displays in cars continue to increase, harmonizing those displays across different applications and technologies within interior surfaces is a key task for system integrators. High-performance displays in vehicles require adjustments for specific design and performance needs. This article covers aspects of premium system design that involve optimization of white-point adjustment, color, and black uniformity for single and multiple display applications.

by Kai Hohmann and Markus Weber

DISPLAYS play a major role in automotive interior design and are destined to play an even larger role in the future, as advanced driver assistance systems (ADAS) and automated driving technology will require displays in ever greater numbers. The displays used in these systems will be installed in close proximity to each other, which necessitates the harmonization of their visual quality and appearance. Yet displays vary in terms of position, technology, display vendor, size, and purpose. Specific issues that this article addresses are white-point adjustment, black uniformity, and color adjustment – all of which gain in importance as they influence the perception of the vehicle's interior quality.

System Integration Tasks

Automotive displays provide the biggest share of the visuals within a holistic interaction environment. Typically, due to sourcing strategies, these displays come from various manufacturers, are based on different technologies, and are used for different applications such as cluster instrument, center stack, and rear-seat entertainment. Increasingly, displays are placed in prominent positions without light-shielding hoods, so that the impact of the ambient light dynamics typical in automotive applications increases. High contrasts of >1,000:1 make any deviation in black uniformity, especially at night, clearly visible. In-vehicle displays also often include touch capabilities and are more and more often curved, with a bonded 3D surface. Front-cover material options include glass and plastic, plus coatings. Designs that increasingly include seamless integration and free forms, as shown in Fig. 1, further add to the integration challenges.

It should also be kept in mind that it is not only the displays that need to be harmonized in appearance among themselves; they also need to blend in with other illuminated elements of interior design, such as switches and buttons. Obviously, the most sensitive challenge is to ensure a uniform night design.

In order for these multiple displays to perform adequately under one surface, such as a

***Fig. 1:** This prototype automotive dashboard with six OLED displays provides a good example of the type of seamless display integration and new form factors that car manufacturers are seeking to implement. Source: Continental Automotive GmbH.*

***Kai Hohmann** and **Markus Weber** are with Continental Automotive GmbH in Babenhausen, Germany. Hohmann can be reached at Kai.Hohmann@continental-corporation.com.*

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dashboard, as shown in Fig. 1, each needs to be calibrated very carefully and optimized on a system level – one that is inclusive of all device components. To achieve a uniform high-quality appearance and seamless integration into an interior concept, the authors' company, Continental, uses mature algorithm-based processes for 100 percent end-of-line measurement and adjustment of key parameters such as white point and primary colors. Note: "End of the line" in this case means at the Tier 1 supplier (Continental) before the display unit is shipped to the OEM (the car manufacturer). This focus reflects a strong position in the automotive display market: According to Q1 2017 IHS automotive market data, Continental is the number one buyer of displays for cluster instruments and among the top three buyers of displays for center stack applications.[a] The sheer number of displays and the scope of use cases make mature measurement and adjustment procedures a core integration task for system integrator companies like Continental.[b]

White-Point Adjustment

A commonly accepted method of white-point adjustment is realized by recalculating the original image data at runtime by applying different scales for red, green, and blue luminance. The maximum scales of red, green, and blue image data are fixed during production using a complex calibration procedure. The following practical look at white-point adjustment from the perspective of a large-scale display buyer for automotive applications shows the scatter range of display parameters and thus the relevance of the adjustment processes. The statistics provided are based on one type of many in-plane switching-based LCDs of different sizes and reflect a population of >100,000 measured units. The white point of each display in this group was measured from two driver viewing perspectives: for the instrument cluster display, this was a perpendicular view, while for the center stack, the view was from a 30° sideways angle. Color coordinates in x/y and luminances of white, red, green, blue, and black were measured. From these parameters the target white point and target primary colors were calculated in an iterative algorithm. Figure 2 shows the established adjustment principle in the typical CIE graph.

Inevitably, this white-point adjustment will lead to a certain loss of luminance and contrast, caused by the required luminance reduction of individual elements of the RGB mix. It is therefore essential to specify the display with a sufficient luminance overhead to compensate for a loss that can easily fall anywhere between 10 and 30 percent. For this reason, it is important to pursue a dual approach:

- The intrinsic display white point needs to be close to the target white point to minimize losses, including all tolerances of panel, color filter, LED bins, touch panel, and cover glass.
- One hundred percent of display modules need to be adjusted at the end of the line – after device assembly.

Table 1 provides exemplary results for an individual display type and make. The price

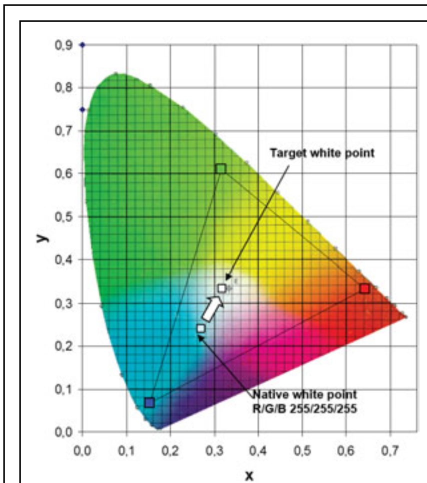

Fig. 2: The CIE 1931 color space graph shows the white-point measurement and the adjustment made to meet the target value.

Table 1: A white-point adjustment is shown for a sample display.

Parameter		Sample display		
		Before	Target	After
White	Lv / cd/m^2	1247		1020
	x (CIE 1931)	0.3000	0.3120	0.3118
	y (CIE 1931)	0.3301	0.3130	0.3130
	Contrast ratio	1217:1		995:1

for achieving this result (*e.g.,* for a specification of a ±0.005 white-point tolerance [x/y]) is a contrast and luminance loss, which was measured in this case at between 20 and 30 percent.

Measuring a population of >100,000 displays of the same model acquired for production resulted in the white-point scatter in Fig. 3, which clearly shows that the intrinsic white point of this make of display falls outside the target tolerance and that the population represents a cloud of measurement points in itself. This result is typical according to the experience of the authors and is best practice for in-plane switching (IPS) LCDs with a typical automotive backlight.

Figure 4 illustrates the effect of the end-of-line adjustment algorithms for the x-coordinate (CIE 1931) of the same display.

It could be concluded that the end-of-line white-point adjustment is a mature process that meets the tolerance-window requirements. However, the luminance and contrast

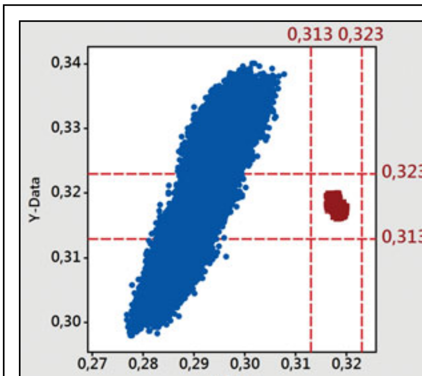

Fig. 3: This white-point scatter represents >100,000 displays from one supplier. The target tolerance field lies between the vertical and horizontal lines on the right.

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[a]IHS: Automotive Display Market Tracker Q1 2017. Page 19, Instrument Cluster Displays Shipment Share.

[b]Founded in 1871, Continental most recently generated annual sales of €44 billion and currently employs more than 238,000 people in 61 countries. The vehicle product portfolio for the company's Interior Division includes: instrument clusters, multifunctional and head-up displays, control units, access control and tire-information systems, radios, infotainment systems, input devices, control panels, climate-control units, software, cockpits, and services and solutions for telematics and intelligent transportation systems. The Interior Division employs more than 46,000 people worldwide and generated sales of €9.3 billion in 2017.

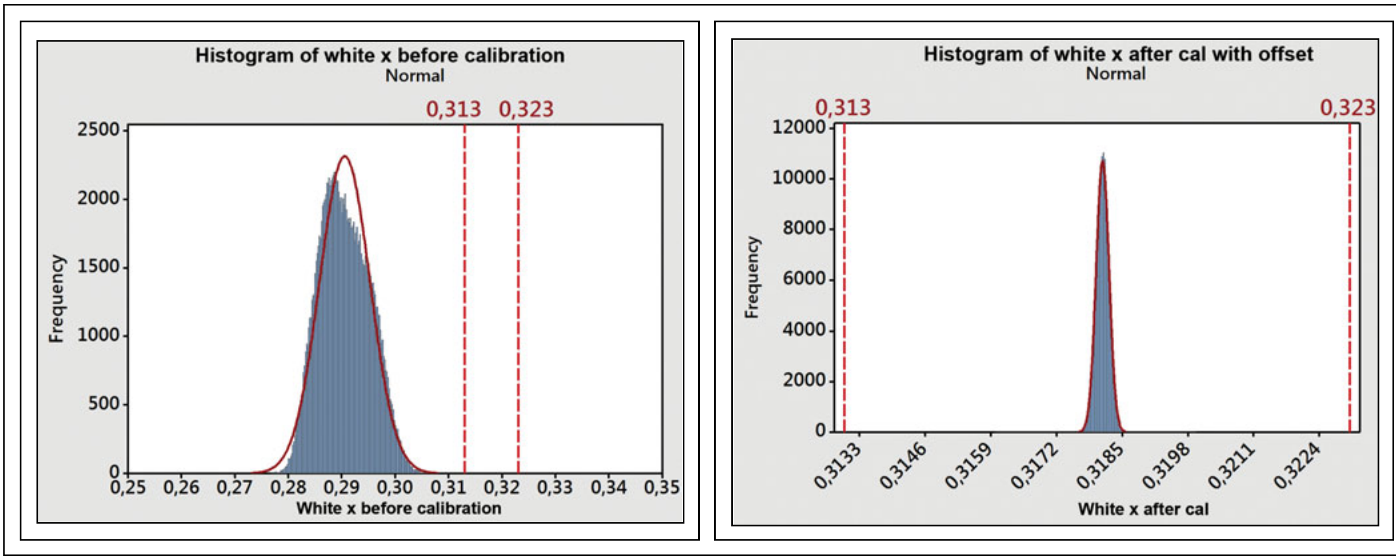

***Fig 4:** The intrinsic display white point on the CIE 1931 x-axis is shown in the left figure, and the matched white point of the same display population after end-of-line adjustment is shown in the right figure.*

losses suggest that advances in intrinsic display white-point matching by display manufacturers themselves might fruitfully be made.

Color Adjustment

Display color adjustment is in principle an expansion of the white-adjustment process. Although more complex, the underlying approach is similar. Figure 5 shows the color-gamut triangle of two LCD panels and the target color gamut to be achieved via the adjustment process.

The RGB measurement provides the basis for the adjustment that needs to be done by recalculating image data on the fly. The target of adjustment is to get the same color coordinates for red, green, blue, and gray scales on all displays. Similar to white-point adjustment, color adjustment needs to be a 100-percent end-of-line process because the tolerance chain, including display-intrinsic color differences and assembly influences such as cover/glass, touch layer, and optical bonding, encompasses so many variables that it is necessary to measure and adjust each assembled device.

The bold figures in the two right-hand columns of Table 2 show how the color-adjustment process ensures that the dominant RGB wavelengths (λ_{dom}) match the targets after adjustment. A statistical example of this adjustment process is provided in Fig. 6: the graph at the top depicts the intrinsic wavelength deviation in the red color, measured in >60,000 displays from one supplier. The effect of the adjustment process can be seen in the bottom graph of Fig. 6, in which the dominant wavelength spectrum has been calibrated to meet the target range of 623 nm (vertical line) exactly.

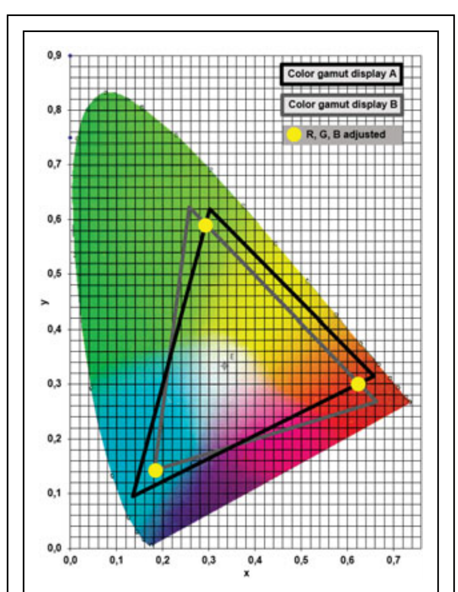

***Fig. 5:** This CIE 1931 diagram includes the color gamuts of two LCD panels and the target gamut (light-colored dots) to be met by both.*

The price paid for this effective color adjustment is a certain loss in saturation. Figure 7 (left) shows the saturation level for R before calibration; Fig. 7 (right) gives the same parameter after adjustment. This loss appears justified because the dominant wavelength, on the other hand, is the most important perceived parameter to the human eye – which can be quite unforgiving when confronted with color variations.

Table 2: Color-adjustment process data

Parameter		Sample display		
		Before	**Target**	**After**
Red	Lv / cd/m^2	237.5		230.7
	λ_{dom}/nm	620.4	**623**	**623.1**
	Sat. / %	93		89.5
Green	Lv / cd/m^2	891		655
	λ_{dom}/nm	546.3	**549**	**549.0**
	Sat. / %	85		84.7
Blue	Lv / cd/m^2	125		117.2
	λ_{dom}/nm	468.4	**469**	**468.9**
	Sat. / %	92		90.4

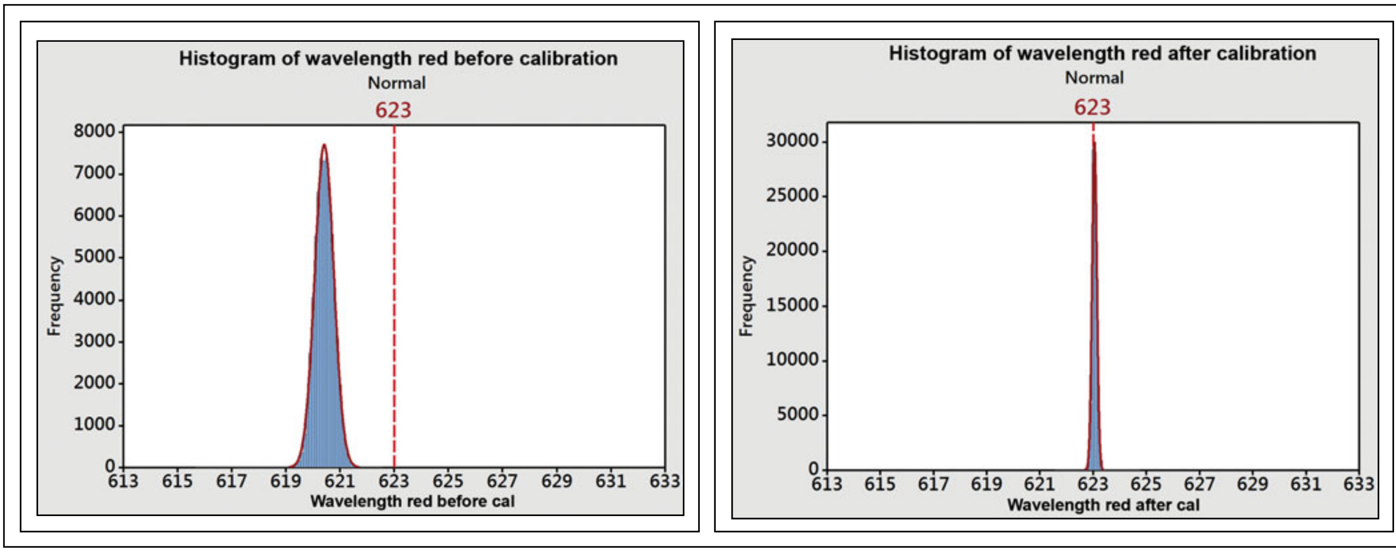

Fig. 6: The dominant red (R) wavelength as measured in >60,000 displays before adjustment appears in the figure on the left, vs. a wavelength of the same displays after R-adjustment, as shown on the right.

Black Uniformity

Mura is an equally well-known and unwelcome phenomenon of backlit displays. Figure 8 provides an example. The prominent root causes are distortion/displacement and resulting mechanical stress that influence the panel transmission and the effect of birefringence on the display glass.

To gain control over potential mura effects, Continental has defined a proprietary measurement method. This measurement jig exposes the tested display to a predefined level of displacement. Figure 9 shows the principle. One part of the display is fixed, while the opposite end is displaced by an exactly controlled mechanical force. Resulting mura is thus measured.

By using this measurement method, it can be determined how much distortion a display may be exposed to during assembly so that the device will still meet the specification for black uniformity at the end of the line. Once this sensitivity metric is in place, it becomes possible to optimize the display and/or device design in a way that reduces mura. Analyzing many different displays in this way also aids in the understanding of root causes for mura, which in turn can help to further optimize automotive display designs in a combined and coordinated effort from both the automotive Tier 1 and the display suppliers.

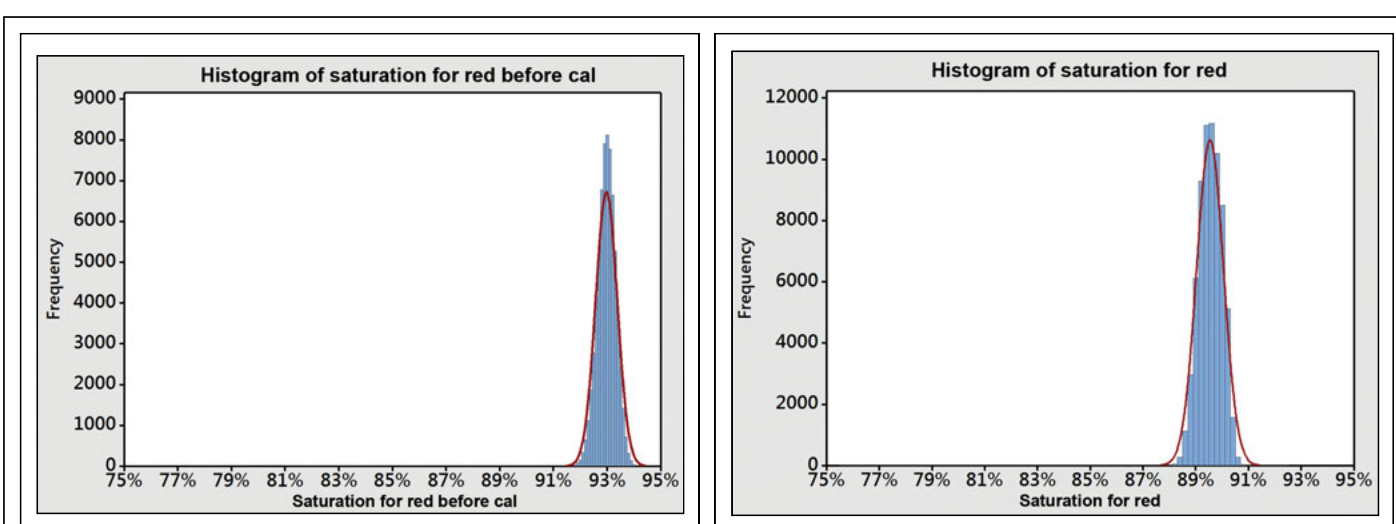

Fig. 7: At left, the color saturation level of the >60,000 measured displays peaks at 93 percent before calibration. At right, the red color saturation of the same display shows a slight drop to around 90 percent after calibration.

frontline technology

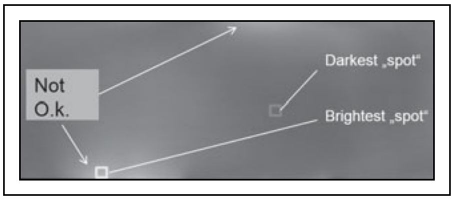

Fig. 8: *Note this example of mura caused by distortion.*

The display in Fig. 10 showed an initial black uniformity of ~62 percent without displacement. Measured in the jig, a displacement of 0.6 millimeters lowered this to ~43 percent (as depicted in Fig. 10). This type of measurement serves to quantify just how a given panel reacts to the mechanical stress that can occur during the assembly process (*e.g.*, time parameters, jigs), cushion-tape gluing, optical bonding, and flexible printed-circuit (FPC) assembly. To make this kind of reaction predictable, it is necessary to specify Designs of Experiment (DOE), which allow the analysis of root causes and their effects on black uniformity. Process maturity optimization can be advanced by characterizing multiple lots with a representative number of parts.

Key Procedures for System Integrators

The tolerance chain (meaning variations in spectral transmissions of LCD panels and spectral emissions of LEDs) of automotive displays and assembled devices necessitates adjustment procedures for white point and color. To ensure that its products meet OEM specifications, Continental has developed and implemented mature algorithms and adjust-

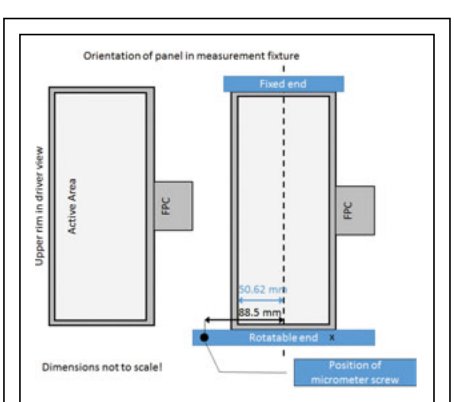

Fig. 9: *A proprietary jig shows the measurement method used to determine a panel's sensitivity to stress.*

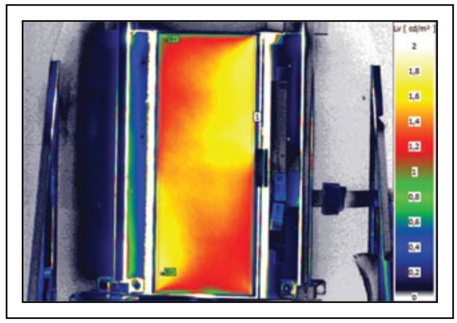

Fig. 10: *This display demonstrates a pseudo-color image of mura caused by distortion.*

ment processes. A new measurement method for black uniformity predicts sensitivity to mechanical stress. Both efforts are required to meet OEM specifications, which regularly push the boundaries of what even the latest in automotive-grade display technology can offer. To reduce adjustment-based losses, it is necessary to limit the scatter in the tolerance chain. In the case of black uniformity, it is important to develop Designs of Experiment (DOE) that help to narrow down the many factors that contribute to mura. On a system level, it remains necessary to evaluate all factors that are beyond the influence of the display supplier, which is a core task of the system integrator. ■

editorial

continued from page 2

describe how to optimize backlight addressability while minimizing extra cost and employing a conservative approach to local dimming that reduces artifacts while improving dynamic range for day *vs*. night environments.

Moving from the displays themselves to the advanced systems they help enable, our Guest Editor Karlheinz Blankenbach has provided his vision of the future of autonomous driving technology and how that impacts the need for pixels in the entire interior of the vehicle. Karlheinz was instrumental in developing our lead articles this month and I hope you will enjoy his guest editorial, "Automotive Displays at the Dawn of Autonomous Driving." Thanks, Karlheinz, for all your efforts on behalf of this issue.

A few months ago, I challenged Jenny Donelan to look at the proliferation of processors and subsystems in modern vehicles and help us understand how they all interact. In the age of the "connected car," we're seeing both a vast network of data being passed around within the car as well as multiple modalities of data being moved to and from the car to other networks. In her Enabling Technology feature, "Inside Connections: How Your Car's Components Communicate," Jenny describes the origins of the CAN bus, modern trends moving to the adoption of Ethernet, and the trend toward smaller numbers of smart subsystems *vs*. many widely distributed simple processor modules. I would venture to say that the communications networks inside my Prius today probably rival the performance and data loads of those in my working office. But the Prius is certainly more productive than I tend to be.

Another person with a lot of passion for vehicles and their displays is Rashmi Rao, currently senior director, advanced engineering and user experience, for the Connected Car Division at Harman, a Samsung Company. Rashmi is well known for her great efforts supporting SID activities as well as her many experiences as a technology innovator in a wide array of display-based products. She graciously agreed to share her views and perspectives with us in our Business of Displays: Q&A for this month. As Rashmi explains, designing displays into vehicles is a very different challenge than designing them for the traditional consumer market. This is due to many factors, including the required product lifecycles, interoperability and safety requirements, and the extremely harsh environment. This in part explains why it has taken so much longer for us to see a "surge" in display integrations into vehicles. The development and qualification cycles are much longer, for example. But the opportunities include many ways for both OLED and LCD technology to play a strong role in product strategies for the future.

Vehicle displays, and countless other technology platforms such as AR/VR, were proudly on display at Display Week this year. In our September/October issue we will bring you a full in-depth review of all the cool things that could be seen. But, in the meantime, you can get a short sample by reading our "Display Week 2018 Snapshots" – selected highlights from the at-show blog coverage from our roving reporters. I would especially mention Tom Fiske's coverage of the Monday seminars and what they revealed about trends in key technologies such as artificial intelligence (AI) and the HDR ecosystem.

From my own keyboard, I have included some commentary on the great Display Week program celebrating the 50th anniversary of the creation of LCD technology. I think this event was artfully organized with a wonderful lineup of speakers, and it made my week in LA even more memorable.

With that, and including our regular news features, this issue is a wrap. I wish everyone a great summer and much inspiration for success in the future. ■

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Dynamic Backlights for Automotive LCDs

LCDs in vehicles need to demonstrate high luminance and resolution while also saving on power usage – two features that may seem mutually exclusive. One solution is a local-dimming matrix backlight, which can significantly improve the visual quality of automotive LCDs while also conserving power. This approach, combined with emerging micro/miniLED technology, should help make industrial implementation of higher quality automotive LCDs more feasible.

by Chihao Xu, Maxim Schmidt, Torsten Lahr, and Markus Weber

Displays are installed in virtually all late-model automobiles and have become a major differentiation factor for vehicle manufacturers. Tough requirements exist for automotive display applications. These include long lifetimes and wide temperature ranges, as well as daylight readability. High visual performance, including good black levels for nighttime operations, is also very desirable. In addition, automotive display content consists mostly of artificial HMI (human-machine interface) images with high contrast. Their share of bright area is usually low. These requirements have led to liquid-crystal displays being the overwhelmingly dominant display technology used in cars today.

However, the performance of current automotive LCDs, ubiquitous as they are, is substantially lower than ideal. The high luminance required for daylight operation causes high power consumption, which in turn can affect interior design due to the requisite thermal management constraints. Emerging active-matrix OLED (AMOLED) technology offers potentially superior contrast and black levels. But certain aspects of OLED technology, including lifetime, maximum luminance, and mechanical ruggedization, are still limitations to deployment in automotive applications. If these limitations are resolved, then AMOLED technology could represent a new option for automotive displays. In the meantime, improvements in LCDs related to reduced power and higher visual quality are important topics for research and development.

Dimming LED Backlights

It is a straightforward concept to enhance LCD performance by dimming the LED backlight. This means that the LEDs are dimmed while the pixel gray values are increased to maximum transmission. This way, the power

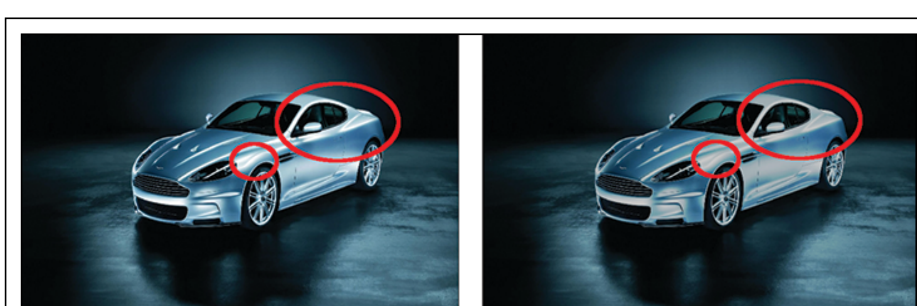

Fig. 1: *At left is an undimmed image. At right, after global dimming, degradation of image quality and brilliance is apparent, especially in the areas shown within the red circles.*

Prof. Chihao Xu *has a Dr.-Ing. degree in electrical and electronic engineering from the Technical University of Munich. He is now chair professor for microelectronics at Saarland University. His research is on local dimming of LED backlights for LCDs and digital driving for AMOLEDs. He can be reached at chihao.xu@lme.uni-saarland.de.*

Maxim Schmidt *has B.Sc. and M.Sc. degrees in computer and communications technology from Saarland University. He works at the Institute of Microelectronics (LME) as a research assistant. His Ph.D. thesis focuses on dimming algorithms for LCDs.*

Torsten Lahr *has a Dipl.-Ing. (FH) degree in electrical and electronic engineering from the University of Applied Sciences of Bingen. He is lead technical expert for display signal architecture at Continental Automotive.*

Markus Weber *has a Dr.rer.nat. degree in applied physics from Technical University of Darmstadt. He is in charge of automotive display technologies with Continental AG, Business Unit Instrumentation and Driver HMI.*

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consumption of the LED backlight, which represents 80 to 90 percent of the power consumption of the entire LCD module, is reduced. Visual quality can be enhanced as well, as explained below.

The first approach is the introduction of global dimming, meaning that the backlight is no longer constantly driven, but varies according to image content. For global dimming, all LED devices are dimmed by the same magnitude. This approach is easy to realize and can deliver good results when natural images are displayed. For HMI images, however, global dimming generates very little benefit because the maximum gray value is always included in an HMI image. For example, Fig. 1 demonstrates a globally dimmed image with a power saving rate of 40 percent. The peak luminance, a critical value for daylight readability, is reduced in the same manner. In addition, the brilliance of the displayed image deteriorates.

Local Dimming

The next step is the introduction of local dimming. Several LED units, either as a string with several LEDs in series or as a single LED, are separately controlled. This way, an adoption of the backlight distribution to the image is possible. For example, the backlight for the bright parts may be brighter than the one for the dark parts. The black level and the contrast ratio can be improved, since the light leakage is proportional to the dimmed backlight. The image in a dark environment, *e.g.*, during night operation, will appear more vivid. If the black level is sufficiently low, *e.g.*, < 0.01 nits, the display will effectively blend into the rest of the interior without a noticeable background glow.

Current state-of-the-art local dimming algorithms were developed for TV applications. Figure 2 shows a benchmark between an OLED and an LCD TV with local dimming.[1] The x-axis is the size of the white window displayed. LCDs can produce a higher luminance than OLED. However, the local dimming algorithm fails to meet the objective for white (1,000 nits) for small windows. This is a demerit for TVs and unacceptable for automotive displays.

The sorted sector covering (SSC) local-dimming algorithm was developed to substantially meet the luminance given by the image.[2] This is also indicated by the word "covering." The algorithm has two tasks – one for the determination of the LED values and one for the gray-value adaptation of every pixel. Since an image usually contains millions of pixels, the algorithm needs to be highly efficient, so that a reasonable hardware implementation is feasible. In Fig. 3, the SSC process flow is depicted.

The input image data are processed in two parallel paths. In the upper path, the image data are condensed, yielding a gray image of much lower resolution. However, this condensed image still has a much higher number of pixels than LEDs and is the input for the determination of LED pulse-width modulation (PWM) values. This way, the complexity of the local dimming problem is drastically downsized. The foundation of the local dimming process is the SSC optimization core, which considers the crosstalk between LEDs. This is described by means of the light-spread function (LSF) of LEDs. The proper consideration of crosstalk, which is unique for every LCD model, is essential for power saving and black levels. The output is a solution for LED-PWM values, which are used for the LED driver.

The described optimization problem solved by the SSC algorithm is shown in the equation below. The LSF $A_l(i,j)$, describes the contribution of the LED l to a certain pixel *(i,j)* and *x(l)* is the PWM value belonging to the LED *l*.

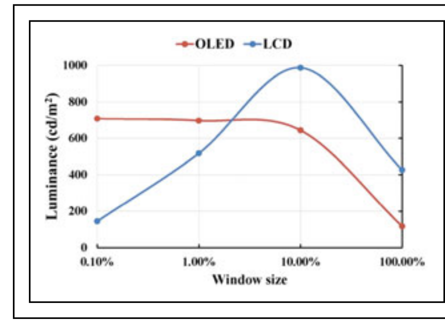

Fig. 2: *This benchmark chart shows the difference in terms of luminance between an OLED TV and an LCD TV with local dimming.*

The basic constraint is to ensure sufficient backlighting for a certain condensation pixel *c(i,j)*. The cost function of the optimization is the sum of all LED values, which is proportional to the power consumption of the whole backlight unit (BLU). The optimization is based on a greedy algorithm and executed in an iterative approach to properly consider the LED crosstalk. The power consumption as the cost function is minimized.

$$\min\left\{\sum_{l=1}^{L} x(l) : \sum_{l=1}^{L} A_l(i,j)\cdot x(l) \geq c(i,j)\right\}$$

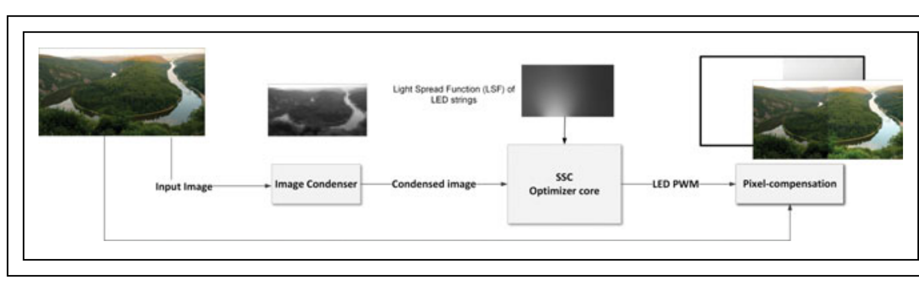

Fig. 3: *An SSC-based local dimming process flow is shown from left to right.*

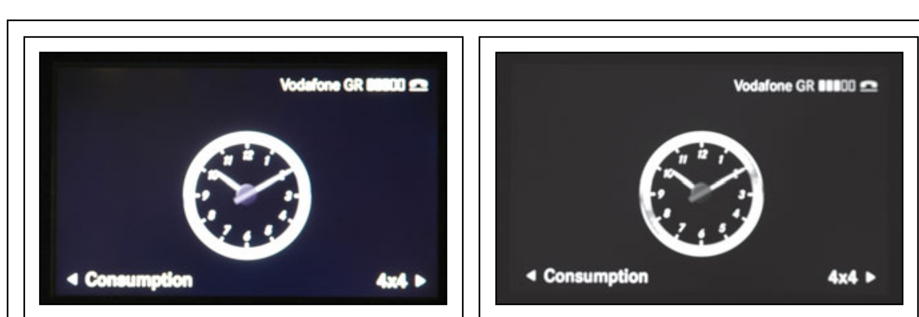

Fig. 4: *A captured image appears without (left) and with (right) local dimming.*

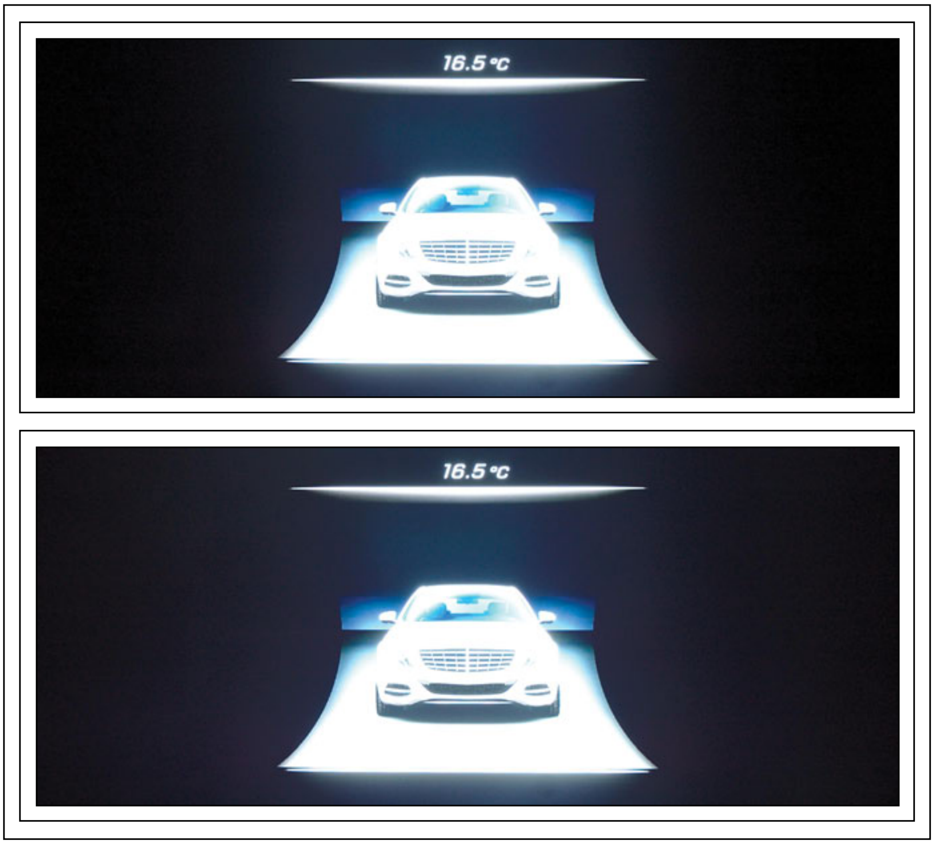

Fig. 5: The upper image, which is displayed on an LCD using LED edge lighting, shows a halo artifact. The lower image, which is displayed on an LCD with an added spatial LED filter, has a somewhat mitigated halo.

Since the brightness of each LED is individual, the backlight is no longer uniform, but unique for each image. The transmission of every pixel needs to be adapted, which is executed as shown in the lower path of Fig. 3 and is called pixel compensation. Pixel compensation can be organized in a pipeline that complies with the input of the image data. In this way, the SSC local-dimming algorithm can be realized by a few 100K gates, which can be implemented in a field-programmable gate array (FPGA) or on an application-specific integrated circuit (ASIC) at modest cost. In Fig. 4, an image is displayed without (left) and with (right) local dimming. It is obvious that for the image on the right, the contrast ratio gets much higher and the black level is significantly better.

The advantages of local dimming are, of course, welcome. However, artifacts may appear. Some are known from TV applications. These include halos, clipping, flickering, *etc*. For automotive applications, further problems arise due to the HMI content. Human viewers have certain expectations for HMI images with regard to uniform area, smooth luminance/color transition, *etc*. Deviations due to local dimming may be detected much more easily than in the case of natural images. In addition to perceivable deviations of the images displayed, the brilliance of an image may deteriorate, which is usually a differentiating factor in HMI design.

One way to avoid possible artifacts is to employ a "conservative" type of local dimming. This means that a large margin is reserved, *e.g.*, for the LED values. For dark images/scenes in movies, for which the maximum gray value may be just a small percentage of the full scale, significant improvement will still be achieved. In the case of HMI images, this approach will negate the positive effects of local dimming. Specific methods are needed that suppress the possible visual artifacts and deliver substantial advantages.

The peak luminance of a high-contrast image is a key parameter of the image quality and assures the readability of the image under daylight conditions. Just a fraction of the peak luminance is reproduced by most local-dimming algorithms implemented on TV sets, which is unacceptable for automotive applications. An example of such an insufficient performance is depicted in Fig. 2. This problem is solved by the adaptation of the SSC local-dimming algorithm by setting a specific condensation function. One example is demonstrated later on in Fig. 9.

Figure 5 shows two photographs of an image displayed on an LCD with 16 LEDs at the lower edge. For a better illustration of light leakage, the photographs were overexposed. For the upper photograph, the power-saving rate is 72 percent, but halo is apparent. In order to mitigate the halo, a spatial LED filter was inserted into the SSC optimization core. The lower photograph shows the resulting image, in which the halo artifact is effectively suppressed. Thanks to the dimmed

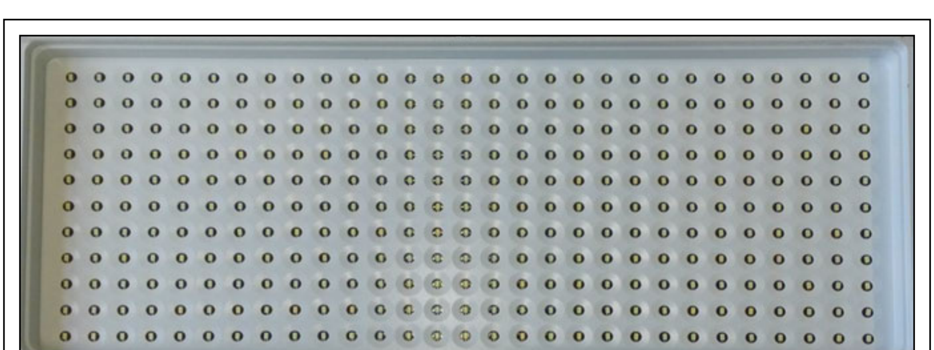

Fig. 6: This matrix backlight unit features 29 × 11 LEDs.

backlight, the black mura is much weaker. The power saving rate is 53 percent.

Matrix Backlight

At the present time, most automotive LCDs work with edge-lit backlighting. Local dimming can generate advantages for typical contents displayed in the center console. For the instrument cluster displaying content such as the images in Fig. 9 and Fig. 10, the advantages of local dimming are modest. The light-spread function of an edge-LED rather appears as a stripe, either vertical or horizontal, and does not fit into the circular structure of the content.

Therefore, direct-lit backlighting may be considered as the next step to improve display performance and enhance the value of the display. The LEDs are placed behind the panel in a matrix configuration. Figure 6 shows a photograph of such a backlighting unit (BLU). Each LED device is individually controllable. The number of LED devices may be in the range of a few hundred. A high luminance like 1,500 nits can be realized, so that good daylight readability is achieved. While the local-dimming technology will produce the advantages mentioned above, the disadvantages of a matrix LED BLU are higher costs and a thicker module. In the section titled "Further Development with MiniLEDs" in this article, a technology that may reduce these problems will be described.

A matrix LED BLU is by far the most feasible solution to significantly increase the visual quality of LCDs. The effectiveness of local dimming is not just a matter of algorithm, but also a matter of BLU design. A specific adaptation of the BLU for local dimming may leverage the local-dimming technology.

In order to limit the cost, the number of LEDs should be kept low. On the other hand, a significant improvement for typical images on the instrument cluster has to be achieved. In other words, the aim is to achieve a good trade-off between the performance and the cost for this specific application.

Figure 7 shows the light-spread functions of two adjacent LEDs. The LSF of one LED can be modeled by Gaussian distributions. A characteristic value for the BLU design is the ratio between FWHM (full width half maximum) of LSF and the LED pitch. If the ratio is too low, the uniformity of the backlight will be poor. In the opposite case, the uniformity is high, but the LSF is unnecessarily broad, so the potential of local dimming cannot be fully realized. Figure 8 shows two measured full-on backlight distributions between a few adjacent LEDs for two different ratios. The ratio for the left image is 1:1. The variation of the backlight luminance is 1:2 percent. It leads to visible non-uniformity. The ratio for the right image is 1:5. The backlight variation is 2 percent and is perceived as uniform.

According to the authors' investigations and experiments, a value of 1:5 is reasonable and can produce a sufficiently uniform backlight. For comparison, the FWHM-to-pitch ratio in Fig. 7 is 1:96, which is unnecessarily high. In order to achieve a proper ratio, several measures can be taken. The two key parameters are the number of the LEDs and the thickness of the LC module. Further parameters are the radiation characteristic of the LED and the diffuser film, which may, however, impair the black level in the remote region.

With a higher number of LEDs, the complexity of the local-dimming algorithm gets higher, while the real-time processing requirement remains unchanged. A hardware implementation for a few hundred LEDs may

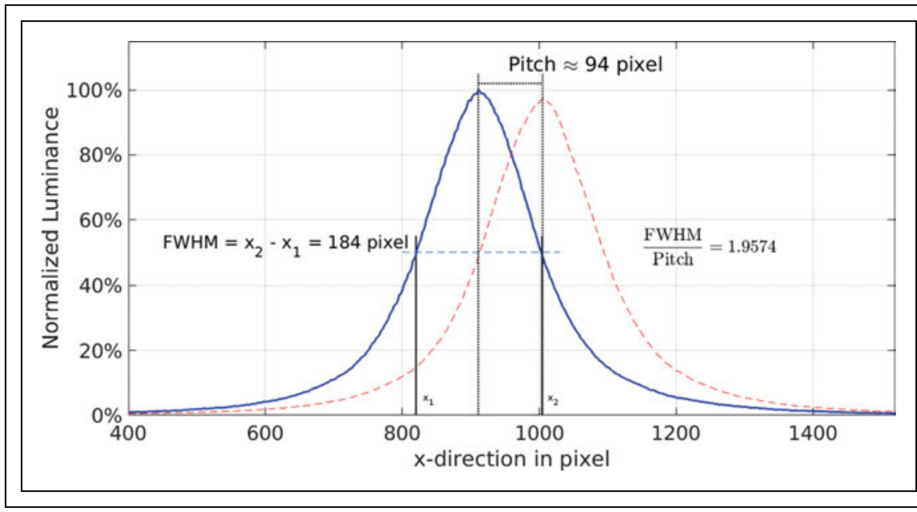

Fig. 7: *Above, two adjacent LSFs are shown with the definition of FWHM-to-LED pitch ratio.*

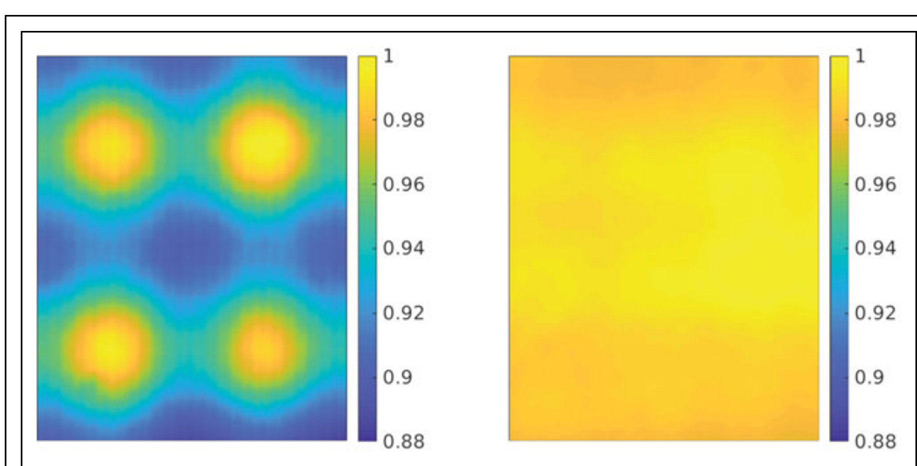

Fig. 8: *These close-ups show backlight distribution for two BLUs with FWHM-to-LED pitch ratios of 1:1 (left) and 1:5 (right).*

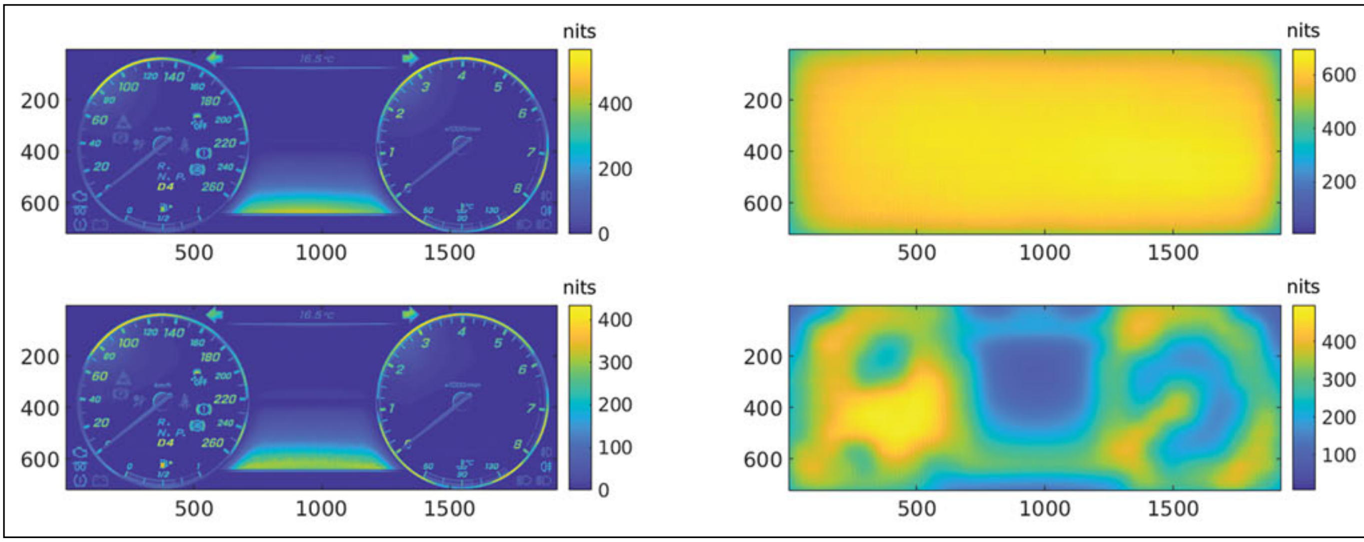

Fig. 9: Luminance measurements of an image (left) and the corresponding backlight (right) are compared in undimmed (upper) and dimmed (lower) mode.

comprise 1 Mbit of SRAM and 400K NAND gate equivalents. The SSC local-dimming algorithm has been amended,[3] so that the results are still close to the optimum, while the hardware costs have only moderately increased.

For test purposes, a representative image is displayed and measured. The image is displayed on an LCD with a BLU containing 29 × 11 LEDs in undimmed and dimmed mode. For each mode, the displayed image and the corresponding backlight distribution with full-on LCD are measured by using an image photometer (ELDIM's U-Master). The results are shown in Fig. 9. The peak luminance of the dimmed image is slightly lower than that of the undimmed image (-18 percent), as the contribution of the strongly dimmed LEDs is now missing. The black level is improved by a factor of five. The power saving rate for this image is 39.7 percent.

Further Development with MiniLEDs

In order to further achieve a better visual quality, particularly for HMIs, and to compete

(continued on page 31)

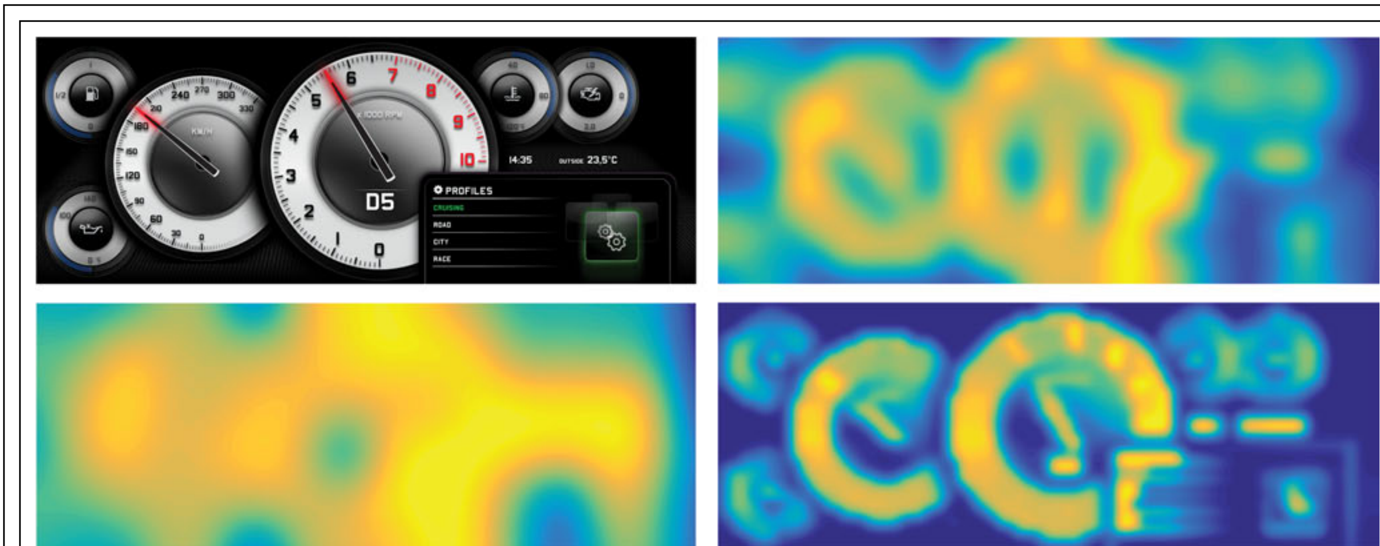

Fig. 10: The backlight distribution for a gauge display (upper left) appears after the application of local dimming with increasing numbers of LEDs. At left, 96 LEDs are used. At upper right, 319, and at lower right, 2,400.

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Inside Connections: How Your Car's Components Communicate

From dashboards to databases, a lot goes on inside the cockpit – the passenger area of an automobile.

by Jenny Donelan

IT'S strange to consider how the focal point of a car's interior is something that was originally designed to protect the vehicle's occupants from dirt and mud "dashed" up from the road. Today's car dashboards are filled with gauges, buttons, knobs, and of course, displays. And they are now called cockpits, nerve centers, product differentiators – whatever companies want to call them. But they all began as simple barriers made of wood, metal, or leather that protected passengers in horse-drawn carriages, and later on, in automobiles like the one in Fig. 1. Early cars generally had the engine under the vehicle instead of in front – so there was no need for a nose or hood.

Today's dashboards look more like the one on the left in Fig. 2, or, if your wallet is a little thicker, the one on the right.

Underneath It All

The functionality of today's dashboard is something we take for granted. We push the pedal toward the metal, and the arrow on the speedometer moves clockwise as the car goes faster. When we forget to replace the oil, the dashboard – and sometimes a disembodied voice – warns us that we are endangering our investment through neglect.

Some of this functionality has moved beyond the dashboard; to the center stack, for example, or to the steering wheel, or to the windshield, in the case of a head-up display. We are heading toward the holistic concept of the "connected car," in which everything in our car communicates with pretty much everything else, both inside and outside the vehicle.

In fact, our cars have been connected for a long time – just not connected in the way we

Jenny Donelan *is the editor in chief of* Information Display *magazine. She can be reached at jdonelan@pcm411.com.*

Fig. 1: *"Horseless carriage" was not a misnomer for the earliest automobiles. This Präsident model, built in 1897 by the Austro-Hungarian company Nesselsdorfer Wagenbau (now Tatra in the Czech Republic) would not look out of place with horse in harness attached to it. Note the dashboard on the right – future home to speedometers, nav systems, backup cameras, and more. Source: KapitanT, Wikimedia Commons.*

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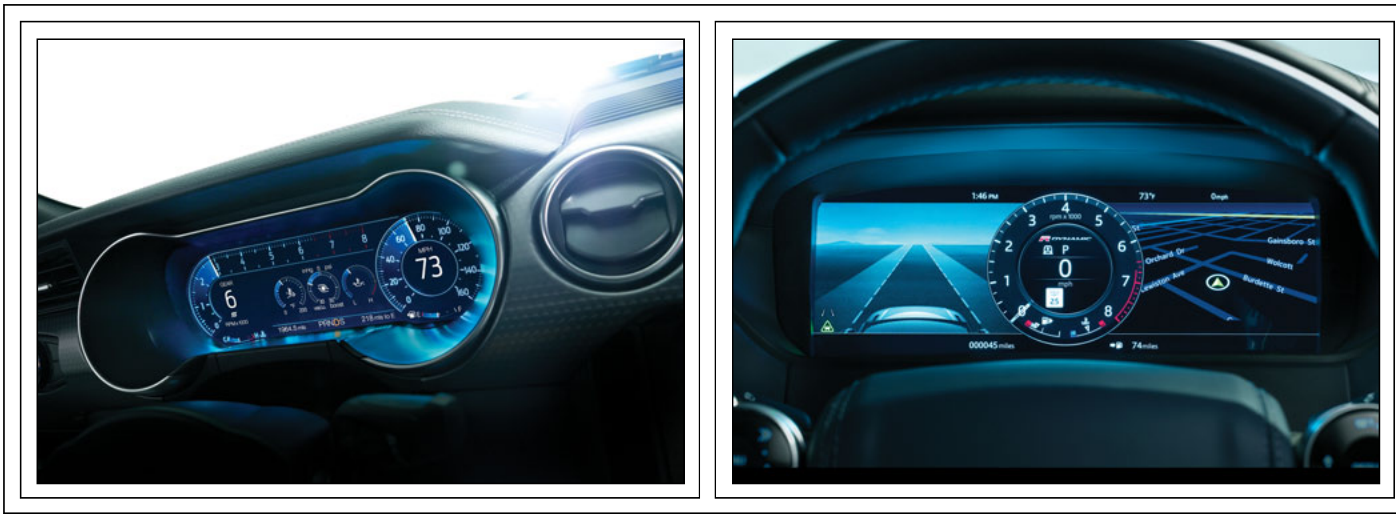


Fig. 2: On the left, Visteon's instrument cluster for the Ford Mustang includes circular displays embedded into the dashboard in a look mimicking "traditional" analog gauges. On the right, the company's cluster for the Range Rover Velar looks more futuristic, combining displays with different functions (camera, tachometer, navigation system) into one large, flat area. Source: Visteon.

are considering them now, with cameras and electronic signals and automatic updates. For most of automotive history, they have been mechanically connected with cables and levers and gears. When you depressed the gas pedal, a cable connected to the pedal pulled a lever at the throttle to inject more gas into the engine, so your car could accelerate. Another cable moved the needle on your speedometer. Cables are used in cars to this day, for various functions.

CAN Do

Between the years of purely mechanical systems and the new, exciting world of connected cars, there was a gradual increase in computerized systems used in vehicles, starting in the 1970s. By the mid-1980s, Bosch had developed a controller area network (CAN) bus that allowed microcomputers and devices to communicate with each other (Fig. 3).

CAN became the defacto standard for cars, and is the legacy system in most cars today, according to Upton Bowden, new technology planning director for Visteon Corporation, a Tier 1 automotive supplier specializing in cockpit electronics. (It should be noted that there are sometimes other networking systems in the car, such as the lower-cost local-interconnect network (LIN) bus standard, which is sometimes used to complement CAN by networking less critical subsystems.)

"CAN runs around your vehicle as a wire system," says Bowden. "It allows discrete components such as instrument clusters, radio infotainment displays, and so forth to send messages back and forth. For instance, when turn-by-turn information is coming from your navigation system, that [via CAN] gets pushed out to your instrument cluster so it can be displayed." CAN's standard transfer rate is 1 Mbit per second with data messages 8 bytes long. Starting around 2013, Bosch introduced a flexible data rate version, CAN FD, in which the transfer rate can at times exceed 1 Mbit/s and the data messages can be up to 64 bytes long.

Additional device connections might include what the industry calls a "silver box control," mounted behind a display, for example, to offer additional functionality. Many vehicles today also have TCUs (telematics control units) that do software updates via a cellular pipeline. "Before TCUs, updates and

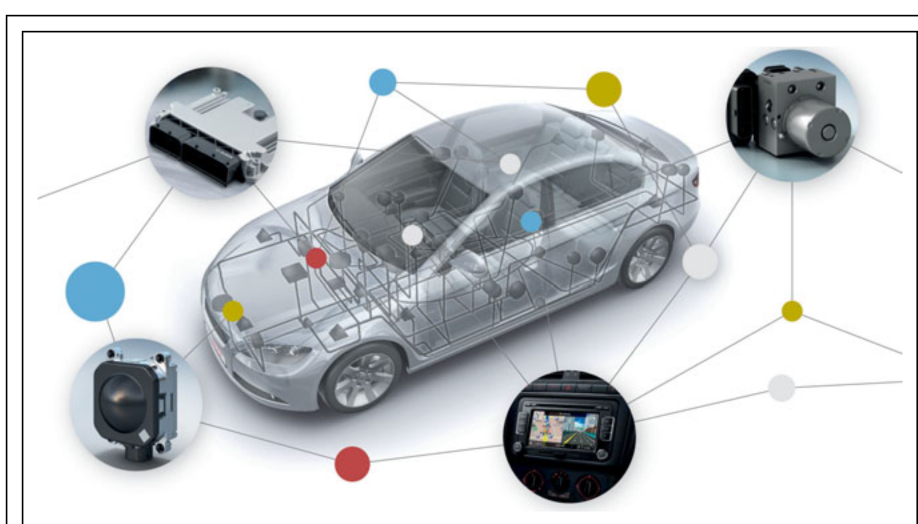


Fig. 3: This diagram from a 2013 update announcement issued by Bosch for CAN FD (CAN with a flexible data rate), depicts some of the vehicle safety and efficiency systems (such as the GPS) connected through the network. Source: Bosch.

upgrades were challenging and difficult unless you went to the dealership," says Bowden.

CAN has done a good job for a long time, but cars, or rather the features in cars, have started to outgrow it. "CAN is a cost-effective, proven automotive-grade solution, but it doesn't have high bandwidth," says Bowden. "What it's designed for is to pass messages back and forth and it works quite well for that, but not when you are trying to pass high amounts of video-resolution graphics around the car." With functionalities like rear and sideview display mirrors, head-up displays, enhanced infotainment panels, and vehicle information, combined with the need for everything to look good (200-ppi resolution, wide color gamut, etc. *vs*. the green, segmented displays of yore), the sheer amount of data flowing in and out of a car is requiring ever more computer and network power.

Ethernet Evolution

A lot of this data is being and will continue to be taken over by Ethernet, says Bowden. "That doesn't mean there aren't alternatives out there," he says "but most companies are looking at Ethernet, partly because it is very common in the consumer space today. It's a cost adder over the CAN architecture, but it also has improved performance capabilities."

Another, related trend, according to Bowden, is the integration of systems in the cockpit. "Instead of standalone components of instrument clusters, infotainment/radio, *etc*., we are seeing a move to integrate those components into a single automotive electronic control module – what we call a domain controller." This is typically a multi-core controller with a powerful processor that runs several different applications as well as the vehicle networking. "The benefit there is that now you have a single box to update," he says. "And a real benefit on the display side is that all the human-machine interface graphics are controlled from a single unit, as opposed to separate units that do their own thing, passing messages back and forth." This can be done with a GPU that enables faster, better imagery.

Such consolidation is being done industry wide, says Bowden, adding that Visteon is launching a controller product called SmartCore later this year, which he says will be the industry's first consolidated cockpit controller (Fig. 4). "We think it will be a tipping point in the automotive industry from an integration standpoint. Everything controlled by one device as opposed to a distributed system," he says.

SmartCore will work with CAN as well as Ethernet. "In general, a controller needs to have the ability to work with both networks, as many vehicles today still have legacy CAN modules," says Bowden. High-end vehicles today often have between 60 and 70 electronic modules in them, but even basic and mid-range models have 20 to 50.[1] Some of these modules might be a simple seat controller running on CAN. It could make sense to leave those kinds of traditional operations to CAN and to operate the higher end data traffic via Ethernet. So we may see two or more types of networking systems in a car.

Then You Add Autonomous….

Where all of this becomes even more complicated is in semi-autonomous and autonomous cars. The "handoff" in a semi-autonomous scenario is but one example. Let's say you get in your car to go to work. You get on the highway and the car goes into autonomous mode. You are answering emails when the car becomes aware of a situation – a traffic jam or bad weather, perhaps – that you need to deal with, immediately. The car will notify you by

[1]Mertl, Steve, "How Cars Have Become Rolling Computers," *The Globe and Mail*, May 2018.

(continued on page 35)

Fig. 4: *On the left is the "silver box" for Visteon's SmartCore controller and on the right, a demo of the interface for an upcoming generation of SmartCore. Source: Visteon.*

Journal of the Society for Information Display

Herbert DeSmet
Editor-in-Chief

Invitation to submit review papers

The Journal is soliciting review papers on any display-related topic. If you have a great idea for a review paper, please contact the editor at **editor@sid.org**.

Page charges for invited review papers will be waived.

Announcements

New impact factor

At the time of writing, Clarivate has not yet published the 2017 impact factors, but based on the available information, we expect the JSID impact factor will rise considerably again this year.

Distinguished Papers

Like last year we have created a Special Section with the '**Expanded Distinguished Papers of Display Week 2018**'. 31 papers have survived the expedited peer review process and were published online in a virtual issue before the start of Display Week (**http://tinyurl.com/edpdw18**). There were enough papers to fill 4 monthly issues (February - May). The Distinguished Papers will stay 'open access' until the end of this year.
It is noteworthy that for the 2nd year in a row the winner of the Display Week **iZone award** was also a Distinguished Paper author. See the highlighted paper by Liangyu Shi below.

Other Special Sections

In Q3 and Q4 we plan to publish 3 more Special Sections related to SID sponsored conferences: '**Best of EuroDisplay 2017**', 'Best of **IDW '17**'and – for the first time – '**Best of ICDT 2018**'.

Awards

The winner of the Best Paper Award 2017 is Dr. François Templier, for his paper '**GaN-based emissive microdisplays: A very promising technology for compact, ultra-high brightness display systems**'. **DOI:10.1002/jsid.516**.

The winners of the Outstanding Student Paper Award 2017 are Mr. Hao Chen and Ms. Juan He for their paper '**Quantum dot light emitting devices for photomedical applications**'. **DOI:10.1002/jsid.543**.
The Student Paper Award is generously sponsored by LG Display.

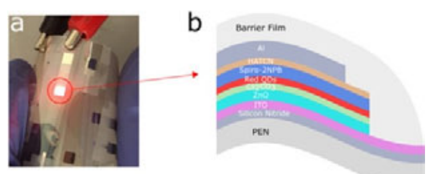
New Editor-in-Chief

Jiun-Haw Lee

On June 30th, my three-year term as the Editor-in-Chief has come to an end. From July 1st, the EiC of JSID will be Dr. Jiun-Haw Lee of National Taiwan University.

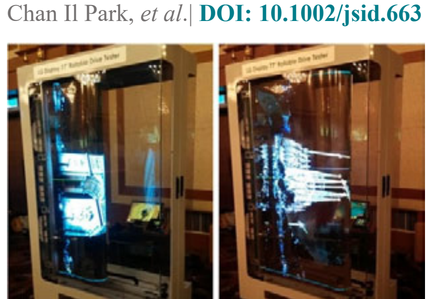
Highlighted recent papers

Flexible quantum dot light-emitting devices for targeted photomedical applications | Hao Chen, *et al.*| **DOI: 10.1002/jsid.650**



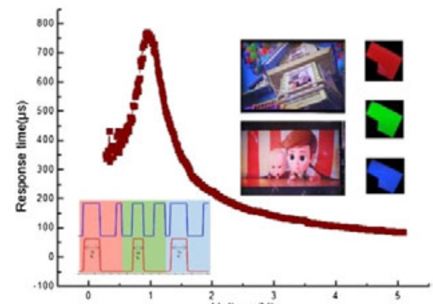
Flexible quantum dot light-emitting devices with pure color and high power density have been fabricated on plastic polyethylene naphthalate (PEN) substrates with barrier film encapsulation. Such devices could be used for treatments of oral cancers or diabetic wounds in the near term and hold potential to enable wide clinical adoptions of photomedicines.

World's first large size 77-inch transparent flexible OLED display | Chan Il Park, *et al.*| **DOI: 10.1002/jsid.663**



We successfully realized the world's first large size 77-inch transparent flexible display with ultra-high-definition resolution, which can be rolled up to a radius of 80 mm with a transmittance of 40%. The process flow and key technologies to fabricate a large size transparent flexible organic light-emitting diode panel is introduced.

Active matrix field sequential color electrically suppressed helix ferroelectric liquid crystal for high resolution displays | Liangyu Shi, *et al.*| DOI: **10.1002/jsid.664**



An active matrix 3-inch field sequential color electrically suppressed helix ferroelectric liquid crystal display prototype is demonstrated via low temperature poly silicon thin-film transistor array. 3T1C pixel circuit is designed to generate analogy gray scale by utilizing pulse width modulation method. The electrically suppressed ferroelectric liquid crystal's microsecond fast switching enables the system with 8-bit color level for each primary color.

Information about the Journal

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EarlyView: accepted papers about to be published can be accessed online via **tinyurl.com/jsidev**

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ID Interviews Harman's Rashmi Rao

Rashmi Rao is currently Senior Director, Advanced Engineering and User Experience, for the Connected Car Division at Harman, a Samsung Company, where she focuses on combining cutting-edge technologies with advanced user experience (UX) design and human-machine interactions (HMIs). She has more than 15 years of experience working for companies that include Apple, Qualcomm, and GE.

Conducted by Jenny Donelan

Information Display:
Harman has a long history in audio technology, dating back to the days when it was Harman Kardon. In fact, most people today still think of the company in terms of high-quality audio, but it has many more areas of business. I read that as of 2017, Harman had 30,000 employees and revenues of over $7 billion. Can you tell us what the company is up to these days?

Rashmi Rao:
Harman has been around for nearly 65 years. In terms of direct-to-consumer, it is true that our audio brand is the most recognized. We have four divisions: Connected Car, Lifestyle Audio, Professional Solutions, and Connected Services. Connected Car covers areas including augmented navigation, multimedia, security, and telematics, as well as displays and user experience, which is my area. Lifestyle Audio is the consumer-facing division, which handles car audio, portables, and home audio, including headphones, sold under brands like Harman Kardon and JBL. The Professional Solutions division equips concert halls and very large venues like hotels and theme parks with audio and corresponding control systems. Many of the world's famous music halls and entertainment venues have Harman Professional systems – Carnegie Hall, Staples Center, and Madison Square Garden, for example. Connected Services is our software services and Cloud/IoT arm. Something that people don't realize is that Harman has been doing automotive infotainment in cars for decades. Harman doesn't brand the infotainment systems in the car, though; OEMs do.

Rashmi Rao

My division is currently focusing on the digital cockpit, which combines both instrument cluster functions and infotainment and navigation, driving it from a single box.

ID: What changes occurred when Samsung acquired Harman in 2017?

RR: Once the announcement of Samsung's intention to buy Harman was made in Oct 2016, I was like a kid in a candy store because of the unbelievable amount of synergy with Samsung's user experience and displays. For example, we are bringing quantum-dot displays into the automotive market for the first time. We are leveraging the millions of dollars that Samsung has already invested to make QLED [quantum-dot enhanced LCD] a viable technology for television, and putting that into the automotive space. We are working with the same supply-chain partners for cadmium-free QDs that Samsung has in Korea.

And we have synergies with another division of Samsung, Samsung Display Corporation, which is focused primarily on OLED technology. This division makes the Galaxy line of mobile devices, as well as smartphones and tablets, and they are also, as you may know, the biggest OLED supplier for the iPhone X. We are collaborating with them to bring OLED displays, including flexible and transparent OLEDs, to the car. The way I think of it right now, LCD is the incumbent. We are working with that technology in terms of QLED. And we are working to make OLED technology going forward that can meet automotive requirements. Using both QLED and OLED, we, as Harman, have a two-pronged approach.

ID: By QLED, you mean QD-enhanced LCDs, correct?

This article is based on phone and email interviews conducted by Jenny Donelan, editor in chief of Information Display.

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RR: Correct. Our first phase is based on quantum-dot enhancement film; the second phase is QD glass, which is basically when you put the QD material onto the light-guide plate. Finally there will be QD pixel, which is the "Holy Grail" – electroluminescent (EL) quantum-dot materials that will self-illuminate like OLEDs, but are inorganic. This is the roadmap for both Samsung TVs and for auto.

ID: So auto displays at Harman/Samsung are in step with Samsung TVs?

RR: If you look back, the automotive industry has always leveraged the consumer technology in terms of displays. When the consumer industry started moving to very, very high resolutions for smartphones, we began seeing 2K, 4K, 550 ppi. Two years ago, that was also the language of the automotive industry. But consider most automotive displays: They are about a foot away from you. If you go from 250 ppi to 500 ppi in a car display, the human eye won't detect that much of a difference.

In 2014, Harman started looking at high-color-gamut displays for automotive. If you go from 70 percent color gamut in the CIE 1931 color space to 85 percent, you have a very perceivable difference to a viewer of an automotive display. And OLED was the only technology that could provide this visual quality.

ID: That is where QDs came in?

RR: Yes! In 2014, my group at Harman had started investigating cadmium-free QD materials for automotive but we lost access to the technology when Samsung acquired almost all the IP around cadmium-free quantum-dot materials. In Oct 2016, when Samsung announced the Harman acquisition, one of my first pitches to the executive team was for Samsung-Harman to collaborate on bringing QLED technology into the automotive market. It made a lot of business sense, because the bulk of the components were already automotive grade. The technology was ready for the market, and we were able to access Samsung's cadmium-free quantum-dot material. So high gamut is the key focus right now for Harman's automotive displays.

ID: What products are you most excited about right now that you can talk about?

RR: At CES 2018 this year, we showed a 28-in. curved QLED display as part of a Maserati Gran Turismo. It was a single 3,820 × 720 display that we drove from a single ECU but split into two 1,920 × 720 images for the center display and passenger display. In that production-intended Maserati concept we showed how we can drive up to seven displays from a single ECU because the system-on-a-chip (SOC) is powerful enough to do that now. This is a unique concept following up on what Harman won an Innovation Award for with Daimler earlier this year – the MBUX concept for the Mercedes-Benz A-Class. In the MBUX concept, there are actually two displays, laminated with a cover lens to create a seamless feeling.

Something else that gets me excited about QLED technology is that it's affordable. The automotive industry is very cost-conscious, and QLED offers the visual quality that you can get with the best technologies like OLED.

ID: Can you describe your experience of moving from the consumer space to automotive?

RR: I was in the consumer world for more than 15 years, and I worked with some of the best companies – Qualcomm and Apple – where we were shipping millions of pieces per quarter. I thought, what can beat that? It has been a humbling experience moving into automotive for multiple reasons. First, automotive is a completely different application. In the consumer world, making a display last for three years, maybe five years, is the key focus. If you have some pixels that are not working on your phone, it's okay. But it's not okay in automotive. You need to make that display last, reliably, consistently, for 15 to 20 years in some of the harshest environmental conditions. That's a seriously long period of time and a different kind of technology is required to make that happen.

Another extremely important issue is electromagnetic emissions. There are several electronics in the car that control many operations other than the infotainment system. If there is electromagnetic interference, that could be life-threatening. Taking care of this issue is one of the biggest investments that any Tier 1 or OEM company involved in automotive makes. So when we talk about making an automotive-grade product, we are talking about a level of diligence in terms of ensuring that that product is safe – that it's not interfering with other components – that goes far beyond consumer. In addition, we have to design for several head-impact and potential accident situations and ensure that the display modules and systems fail in a way that does not further endanger the occupants.

(continued on page 29)

Rashmi Rao (left) discusses a digital cockpit demo with Young Sohn, President and Chief Strategy Officer for Samsung Electronics (right). Samsung completed its acquisition of Harman in 2017.

Display Week 2018 Snapshots

ID's reporting crew traveled the aisles and session rooms of Display Week to find out what's happening in our industry.

by Information Display Staff

EACH year, *Information Display*'s expert reporters seek out the most interesting developments at Display Week and share them with our readers via daily online dispatches. This is a vital service, because there is far too much for just one person to see and do at the show (Fig. 1).

In the next issue of the magazine, we will feature full-length articles from each these reporters in their respective areas of expertise: Achin Bhowmik, AR/VR; Karlheinz Blankenbach, automotive displays; Gary Feather, emissive technology for digital signage; Tom Fiske, image quality and display metrology; Steve Sechrist, e-Paper and 3D displays; and Ken Werner, emissive materials.

In the meantime, the following short pieces offer just a sampling of what they saw on and off the show floor. If you're inspired to read more, please visit www.informationdisplay.org.

Learning About High-Dynamic Range and Artificial Intelligence

Display Week's annual Monday seminars feature speakers from various fields who share the fruits of their expertise in presentations that last about 90 minutes each. The seminars are a great way to get up to speed in areas of display technology where your knowledge might be lacking. Two notable examples this year were "High-Dynamic-Range: A Consumer Ecosystem" by Dolby Laboratories engineers Timo Kunkel and Rob Wanat, and "Artificial Intelligence: Image Recognition and Visual Understanding" by Starkey Hearing Technologies' Achin Bhowmik.

Yes, I know that Dolby has a point of view regarding high-dynamic range (HDR). And yes, it has a proprietary scheme for handling HDR content as part of its licensing business model. But its seminars and papers are always well presented and backed up by good research by knowledgeable engineers. Kunkel and Wanat enriched their talk with a description of how the human visual system works and responds to high-dynamic range scenes in the real world. This informs the company's approach of how to best acquire, deliver, and display HDR content. Kunkel and Wanat built a good case for the Dolby Perceptual Quantizer as embodied in SMPTE (a transfer function that allows for the display of HDR video with a luminance level of up to 10,000 cd/m^2 that can be used with the Rec. 2020 color space) as a good way to encode electro-optical transfer function (EOTF) for HDR displays. It will be interesting to see how HDR continues to evolve as displays improve and HDR standards and pipelines are developed.

***Fig. 1:** Show goers eagerly head onto the exhibition floor at Display Week 2018, one of the best-attended shows in recent years. Photo: Tabor Ames*

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Bhowmik delivered a great primer on artificial intelligence (AI) as applied to image recognition. He offered a brief history of AI and a description of the breakthroughs that have resulted in image-recognition performance, surpassing that of humans a few years ago. This was enabled by using programming techniques inspired by human brain physiology, advances in computing, and the availability of lots of image data for training the algorithms. He gave us a basic understanding of how "deep" neural networks are trained with some simple examples. In addition to recognizing image content, neural networks can also be trained to achieve semantic scene understanding. Figure 2 is an example of a scene recognized and described via AI.

AI has a lot of potential, and many organizations are making some big bets on its continued development. There's still a bit of work to do, however, before I would be comfortable letting AI drive my car or fly my plane. I do appreciate those email spam filters, though.…

— Tom Fiske

Full Throttle on the Show Floor

Practically every large display manufacturer – Samsung, LG Display, JDI, Tianma, and more – showcased automotive panels at Display Week. Two trends were obvious: Pillar-to-pillar dashboard displays and bended/curved ones. Figure 3 shows a demo from Visionox that integrates two convex displays in the steering wheel.

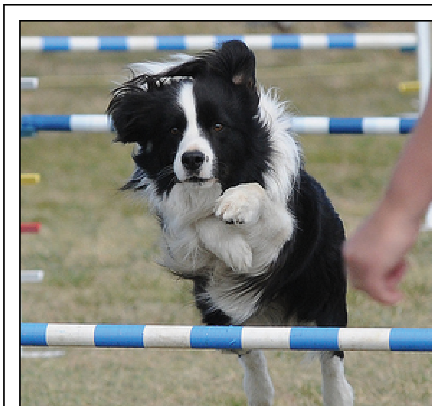

Fig. 2: *AI capabilities now extend to recognizing and describing scenes, including, as shown here, a specific animal (a dog), its characteristics (black and white), and what it is doing (jumping over a bar).*

Fig. 3: *In this demo steering wheel display from Visionox, the monitor on the right acts as a visualization of the rear-view camera, while the left display switches between operational data and touch control for an infotainment system. Photo: Karlheinz Blankenbach*

Many exhibitors were showing automotive displays that included features such as local dimming, narrow borders, and free-form designs. Advanced head-up displays (HUDs) were also in evidence.

— Karlheinz Blankenbach

E Ink's Large-Format Single-Segmented Solar-Powered Display

In its Display Week show-floor booth, low-power panel maker E Ink Holdings demoed its large-format (2 × 4-foot) single-segment, solar-powered wireless display panels. This "e tile" technology can incorporate up to 96 independent segments, each fully addressable, using an 802.xx wireless protocol. The single-segment displays were shown for the first time at Display Week 2018 in Los Angeles

The company gave demos of a 5-tile panel outdoor display (Fig. 4), using a smartphone to control the content scrolling across the top side of its booth. Each panel was powered by solar panels from the ambient light in the convention center, and we were told required less than 1 percent of the total display space.

In addition, the symposium paper, "Dramatic Advances in the Application

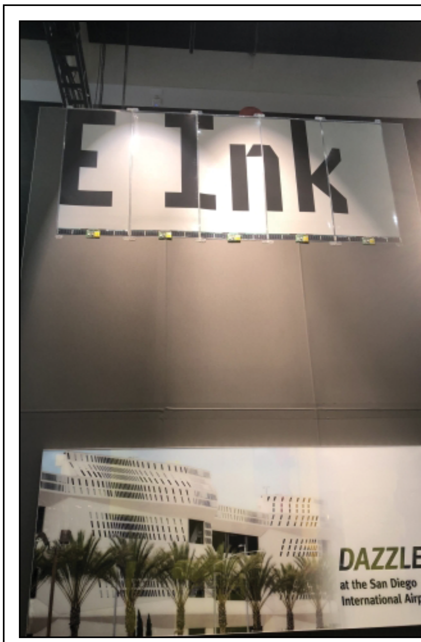

Fig. 4: *Five of E Ink's 2 × 4-foot programmable, solar-powered panels appeared along the top of its booth at Display Week. Photo: Steve Sechrist*

of Electrophoretic Displays" by E Ink's Michael McCreary provided a nice overview of what is being done with existing electrophoretic technology. One such application is the 2017 installation of more than 2,000 E Ink tiles displaying custom animations on the enormous facade of a rental car center at San Diego International Airport. (Read more about this and other E Ink installations in an upcoming issue of *ID* magazine.)

— Steve Sechrist

How to Attract Venture Capital to Your Project

The quest for the unknown drives many of us at Display Week. A passion for changing the future of the display industry is in our DNA. But to support our endeavors, we need cash. Guidance in obtaining investment was a major topic of the Business Conference at Display Week 2018.

Stephen Saltzman, investment director with Intel Capital, told listeners at the Private Equity/VC Panel discussion unambiguously titled, "What We Are Looking for from Privately Held Display Companies," that his company goes beyond the issues of market, technology, uniqueness, and prototyping. These issues are considered, but the main drivers for getting a VC or private equity group to invest in your vision are your suppliers and future customers. If they are excited about making you successful, then you are a good investment. If those around you are not personally motivated to see you succeed, investors walk away. Each of us must realize that building a passionate support team excited about our success signals great confidence to investors.

— Gary Feather

VR/AR Gets Real at Display Week

Display Week 2018 featured a special track on virtual and augmented reality (VR/AR) technologies and applications. This was quite timely, given the rapid developments on this topic in recent years, as evidenced by the increasing number of companies introducing new products, and universities offering specialized courses on the associated technologies.

The VR/AR special track in this year's conference included a keynote speech delivered by Doug Lanman of Oculus Research, a short course taught by this author, a seminar presented by Robert Konrad from Stanford University, several talks in the market focus conference, an extensive array of technical papers in the symposium, and a number of live demonstrations in the exhibit hall.

VR/AR devices promise exciting immersive experiences in the areas of gaming and entertainment, education, tourism, and medical applications, to name several. The breadth and depth of state-of-the-art results presented and demonstrated at Display Week this year showed that the virtual- and augmented-reality experience is coming ever closer to reality. When it comes to technology like AR/VR, reading about it just does not do it justice. As the character Morpheus in the much-acclaimed 1999 movie *The Matrix* says, "Unfortunately no one can be told what the matrix is – you have to see it for yourself!"

— Achin Bhowmik

Women in Tech Panelists Offer a Powerful Perspective

The second annual Women in Tech panel, organized by IRYStec founder and CTO Tara Akhavan, represented a sophomore slam dunk in terms of panelists and content. The high-powered female technologists, though not specifically from the display industry (except for Akhavan), had great insights for just about anyone in the business of technology, or even just in business. The lineup included Robinne Burrell, Chief Digital Product Officer for Redflight Mobile/Redflight Innovation; Poppy Crum, Chief Scientist at Dolby Laboratories and Adjunct Professor with the Stanford University Center for Computer Research in Music and Acoustics and Program in Symbolic Systems; Rosalie Hou, CEO with ELIX Wireless Charging Systems, Inc., and Nadya Ichinomiya, Director of Information Technology, Sony Pictures and Co-founder, Women in Tech: Hollywood (Fig. 5).

Some sample pieces of advice from the speakers:

> Robinne Burrell on career advice for young people: *"It's not all about the coding. There are so many tech areas that can get young people into the six-figure zone that don't involve coding."*
>
> Rosalie Hou on recognizing cultural/language differences in terms of effective communications: *"In multicultural companies it's very important to double-check [what has been said and what was meant.]"*
>
> Poppy Crum on leading: *"You have to be confident being lonely in your ideas."*

This was a great event that struck the right balance between general business advice and specific recommendations for women in technological fields like displays.

— Jenny Donelan ■

Fig. 5: *From left to right are: moderator Tara Akhavan and panelists Nadya Ichinomiya, Rosalie Hou, Poppy Crum, and Robinne Burrell.*

50 Years of LCD Technology

A Display Week 2018 Celebration

by Stephen Atwood

Suppose you could go back in time and speak to the early pioneers of computing technology. Who would you pick and what would you ask them? Would you start with Charles Babbage and ask him how he was able to visualize all the intricate parts of his Analytical Engine? Or would you drop in on Alan Turing and ask him, well, anything really. Just listening to him talk would have probably been an amazing experience. You might ask William Shockley whether he anticipated that his point-contact transistor would eventually give birth to the entire modern electronics age, or maybe you would just book an afternoon with Robert Noyce and talk about the evolution of integrated circuits. Whatever you decided to do, you would do it because you would be seeking a first-hand appreciation of the vision that drove those great pioneers to their achievements.

Of course, we can't actually travel back in time to meet the early pioneers of computing, but at the most recent Display Week 2018, we had the rare privilege of doing something very similar – meeting some of the pioneers and founding figures of the liquid-crystal display industry. At a special afternoon session and reception created to celebrate the 50th anniversary of LCD technology, we heard how LCDs were invented from the inventors themselves.

As we learned from Larry Weber's excellent article, "David Sarnoff, Display Industry Visionary," in the last issue of *Information Display*, the genesis for the development of LCDs came in significant part from a challenge that Sarnoff himself gave his technical staff at RCA – to develop a technology for making large-size televisions. This led at first to promising work on electroluminescent materials by Jan Rajchman, who patented the idea of a large, flat-screen, active-matrix TV. Various methods of light modulation were explored, including the idea of using electric fields to stimulate liquid crystals to selectively transmit or disperse light.

This research continued through the 1960s, until in 1969, Wolfgang Helfrich, a physicist working at RCA, conceived of a new type of LCD using the nematic phase that we now know as the twisted-nematic (TN) LCD. This approach required that the liquid crystal be placed between two polarizers. The device switched polarized light by changing its molecular alignment in response to an applied electric field. This remains the fundamental principle of operation for all LCDs today. Which brings us to Martin Schadt, the first speaker at the event, who spoke passionately about the exciting discoveries that came together to make the first TN LCDs a reality, including the rubbing effect and the first commercial room-temperature nematic liquid-crystal mixture. Helfrich eventually left RCA and joined Schadt at Hoffmann-LaRoche in Basel, Switzerland, where in the fall of 1970 they developed the first TN-mode LCD prototype.

As Hoffmann-LaRoche was underway commercializing TN LCDs, other researchers, like Fang-Chen Luo and Peter Brody, were developing active-matrix addressing, showing the first 6 x 6-in. prototype at Westinghouse. Luo, who also participated in the event, spoke rather humbly about his work and that of his colleagues, but painted a broad landscape of the technology development that occurred between the work in 1974 and the first 102-in. TFT LCD TV that appeared in 2006.

Inventor Terry Scheffer walked us down the path of continuing developments in LC technology, with the creation of super-twisted-nematic (STN) liquid crystals, and InJae Chung (LG) and Jun Souk (Samsung) each recalled their experiences in overcoming numerous technical challenges to adapt the technology into commercially viable large-size TVs.

Along the way, and over the course of the afternoon, we heard detailed accounts of many other critical achievements, such as the creation of a-Si and poly-Si TFTs, the "one-drop fill" that reduced the time to fill a panel from hours to minutes, overdrive technology to improve response time for high-quality moving images, several new LC modes to enable wide viewing angles, and countless manufacturing process developments, all from the people who were there to create and lead them.

So how big a deal is this technology, really? Let me help you appreciate the magnitude. Tell me how you would finish this sentence: "Liquid-crystal display technology is…"

Amazing. OK, easy answer. Can you be more specific?

Great for TVs, phones, tablets, computer displays, etc. Sure is! And just about every other application you can name as well. During the opening comments for the session, SID President Helge Seetzen commented that LCD technology has paved the way for the ubiquitous penetration of displays into virtually every possible application. Today most of us have LCDs in our cars; we wear them on our wrists (or more commonly, in our pockets and purses); all our new appliances have them; and they've been to outer space on the space shuttle. They are virtually everywhere.

Complicated. Sure is. Over the past 50 years, dozens of different fields of science and technology had to converge to create what we have today. While most other innovations are built on previous foundations, LCDs are somewhat unique in that developers had to for the most part build their own foundations as the technology evolved from

Stephen Atwood is the executive editor of Information Display. *He can be reached at satwood@atwoodracing.com.*

inventor George Heilmeier's first demonstrations of the electro-optic effect of dynamic-scattering liquid crystals at RCA in 1968. Key areas such as semiconductor physics, material science, fluid mechanics, optics and electro-optics, and lots of chemistry have been called upon to get where we are today.

Rocket science. No, maybe not quite that complicated, but let's come back to that.

Resilient. For sure! Over the last 50 years, countless development efforts have evolved the technology from its simple roots in passive-matrix monochrome TN-mode text displays. During the 1970s and 80s, critical advancements such as rubbing to establish alignment, passive- and active-matrix addressing to control pixel arrays, and STN and dual-domain modes all helped improve viewing angles and contrast to a point where the technology really began to show promise. Along the way, amorphous-silicon and poly-silicon technologies were also developed to support the practical fabrication of thin-film transistors (TFTs) for active-matrix switching. By the 1990s, LCDs were starting to find practical applications in places such as avionics, and eventually they became a critical component in the evolution of laptop computers. But there were still many performance limitations to overcome, including response time, color gamut, and viewing angle.

While LCDs performed well and were crucial to laptops, CRTs were well established as the performance standard for televisions, and a lot more development was needed to make large-screen LCDs that could compete. In the next decade, numerous innovations such as overdrive, faster switching and higher frame rates, additional LCD modes such as vertical alignment (VA) and in-plane switching (IPS), copper electrodes, dual-side drive, and many more all converged to displace CRTs, and achieve never-before-seen television screen sizes. Along the way came the iPhone and the enabling of a whole new class of consumer devices built around the LCD screen. At each milestone, a new threshold of performance was exceeded, and the industry continues to evolve today with quantum-dot backlights, glass-based light guides, 4K and 8K resolutions, stereoscopy, and many more innovations that were on display at Display Week's exhibition.

Based on vegetables. Huh? OK, well that's actually true – carrots, specifically. While LCD technology is now 50 years old, the first discovery of the materials now classified as "liquid crystals" dates back 130 years to 1888, when scientists first identified a compound extracted from carrots that exhibited physical properties not yet seen. Among the strange properties were the existence of two melting points, the reflection of circularly polarized light, and the ability to rotate the polarization direction of light. Austrian botanical physiologist Friedrich Reinitzer observed that cholesteryl benzoate melted at 145.5 °C (293.9 °F) into a cloudy liquid, and at 178.5 °C (353.3 °F) it melted again, and the cloudy liquid became clear. Merck first started offering liquid-crystal materials for scientific study at the turn of the 20th century but it wasn't until the 1960s that scientists started looking at LCs for display-type applications.

Unlikely. Maybe. Consider what might have happened if the early pioneers of LCD technology had foreseen all the development work

Fang-Chen Luo (left) and Martin Schadt (right) were among the LCD pioneers who spoke at the 50th Anniversary LCD Event at Display Week 2018 in Los Angeles.

that lay ahead, and the problems that had to be solved from 1968 to today. Would they have taken it on? Of course they would have! As I listened during the presentations from pioneers including not only Schadt, Luo, Chung, Scheffer, and Souk, but also Koji Suzuki, Kenji Okaoto, Mark Verrall, and William Doane, I could still hear the passion in their voices and the love of the challenge that they had taken part in. However, I wonder what their business leaders might have said if they had all sat down in one room around 1990 and assessed what was ahead of them:

- Investments measured in the tens of billions of dollars to develop the technical and manufacturing infrastructure needed for today's commercial successes.
- A market place that almost immediately oscillated between over- and under-supply and invoked commodity-style pricing pressures.
- Products with unique capabilities but limited exclusivity to key markets.
- Consistent and relentless competitive pressure at every turn.

Would those leaders have decided to move forward? Certainly several early entrants did not choose to do so, and others took up the challenge anew along the way and became dominant players. Congratulations and much respect goes to those who did recognize the possibilities of this technology and fought hard for it with vision and courage.

Unstoppable. It sure seems that way! Many competing technologies have been developed to displace LCDs in major applications. Through the years we've heard the phrase "LCD killer technology" many times – at least a couple of times each decade while I have been in this industry. Some, like plasma TV, have had commercial successes, and other more recent contenders, including organic LED, are gaining a foothold, but nothing seems poised to make a sizable impact on the world domination of LCDs.

There seems to be an almost cosmic serendipity surrounding LCDs and their supporting science. A few years back we considered the unique threat that was coming from OLEDs and their much wider color gamuts, incredibly thin form factors, and potential for very high resolutions. At that same time, along came quantum-dot technology, more new LC modes, and also oxide TFTs to battle back each of these per-

50 Years of LCD Technology

formance threats. Suddenly LCDs could achieve 4K and even 8K resolutions (and very high pixel densities) with extremely wide color gamuts and much higher refresh rates. The large-screen HDTV beachhead that OLEDs were poised to take reverted back to LCDs once again.

So is it rocket science? Well, in some ways it certainly feels like it. While LCDs are not literally as complicated as a space craft, their development has employed what might be a similar order of magnitude of engineers and scientists, and probably crosses the boundary to almost as many science and technology disciplines. LCDs have clearly occupied a similar timespan in human history as modern space programs. They have traveled beyond Earth's atmosphere and might even be on other planets someday soon. Those who contributed to the fundamental sciences used in this field can be uniquely proud that their work lives on and enables such a broad swath of products, applications, and economic activity around the world.

And, on a selfish note, I just want to say what a privilege it was to hear these great technology leaders talk so passionately about their work. Congratulations to Chair Shin-Tson Wu and the entire committee from SID for this special, well-organized program at Display Week 2018. ■

business of displays: Q&A

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This is also what makes the automotive industry take longer in terms of products to market. We have longer lifetimes between generations. There is some hesitation to change things that are working, because that means you have to go back and look at this new thing and make it work reliably and consistently, all over again. That's another reason why we are taking the two-pronged approach for displays – it leverages what the industry has already built (LCDs) and also looks forward with OLED.

ID: Why head toward OLED when quantum-dot-enhanced LCDs perform so well?

RR: OLED can actually offer a lot of advantages. Everyone talks about increasing the range of electric vehicles, but then you turn around and add bigger and bigger displays to them, which consume a lot of power, and you're back at the beginning. Earlier smartphones had small displays because the backlighting advances couldn't keep up with the increase in size and power and that is going to happen in electric vehicles as well. Then, when you start expanding to the autonomous realm, you are completely changing the paradigm from minimizing driver distraction to maximizing driver interaction. You want to have the driver look at the screen, and to look at the screen for longer periods of time. OLEDs are perfect for this because they are very light, and when you reduce the total weight of the car, it consumes less power. Also, because OLEDs are an emissive technology, you only use power when the image is lit or being driven or you're changing or writing content, so OLEDs will have a huge impact on electric and autonomous vehicles and displays as we move forward.

With QLEDs, we are looking at doing something very similar to what the television industry does, which is localized dimming with a direct backlight that we locally turn off and on. We are offering two product categories for the QLEDs, QLED and QLED Premium. The first is basically just adding the QD film; the second is the QD film plus the localized dimming.

ID: When will OLED displays be ready for cars?

RR: I believe we will see OLED displays being shipped to OEMs by 2019. Volumes will be low but we are surely getting to the path of larger adoption. We are solving those fundamental issues of image sticking and encapsulation, as well as reliability in a wide range of temperatures, and lifetime.

ID: People in the display industry are looking to automotive (as well as to AR/VR) to keep profits and progress rolling. Will there be enough volume and innovation in displays for cars for that to happen?

RR: This involves standardization of sizes. Phones today are nearly all 4.5 or 5.5 inches, or 5.7 for the larger sizes. Tablets are 9 or 12 inches. Standard sizes for monitors are 15, 19, and 21 inches. And so forth. There is a specific, ideal number of panels you can have on a mother glass for a given generation of display fabrication, which allows you to have the maximum volume and yield. When you figure that out, you have mass adoption at the right price point.

Right now, if you look at the auto industry. BMW has a distinctive 8.8-in. trapezoid-shaped display. Volvo uses portrait-sized displays that are 8 or 10 inches. Audi uses 8- or 9-inch landscape displays. Each of these car makers has designed the car to incorporate these brand-recognizable sizes and shapes of displays. If you want to have more displays in your car – 10 or 12 or more – you are not going to customize every display for every car-line. That won't make the price point. There should be a trend toward standardization of sizes in automotive, as has happened in every other industry.
I think this is a key trend to watch for.

However, it doesn't mean that every car is going to look the same. These standard-size displays can be combined (as in the Mercedes-Benz MBUX concept at CES) and used in different ways to create a unique user experience. In-car technology is becoming one of the key reasons why people buy a particular car.

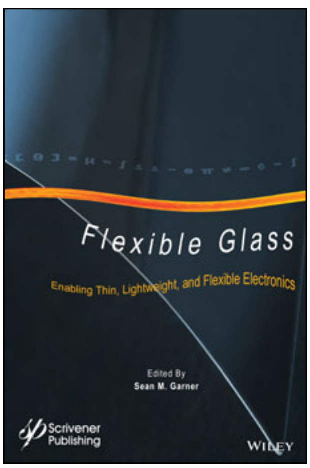
ID: Let's say it's 2028. You are riding in a car. What does the interior look like?

RR: Besides lots of displays, there will be another technology we haven't even talked about that is going to be disruptive – head-up display technology. I don't mean the HUDs we see today in premium brands. I mean augmented reality and immersive, multidimensional 3D with a very large field of view. We will see prototypes for that kind of display technology in the next six months. If it is 2028, there won't be a car without this. ■

Flexible Glass: Enabling Thin, Lightweight, and Flexible Electronics

This new compilation by authors from a range of companies and institutions will be a useful resource for practicing engineers, engineering students, and others with an interest in flexible glass and electronics.

By Ioannis Kymissis



Flexible Glass: Enabling Thin, Lightweight, and Flexible Electronics presents a compelling argument that flexible glass has arrived. Ultrathin glass is now available from a variety of suppliers, and this volume, featuring contributions by a variety of experts and edited by Sean M. Garner of Corning, builds the case that the material has extraordinary performance, with the best optical properties of any flexible substrate, excellent thermal properties, and infinite barrier protection against water vapor and oxygen. The authors also discuss the equally important availability of a range of unit operations for high-throughput handling, coating, and treating of flexible glass, which allows for the development of new electronic and optical systems that take advantage of the material's unique properties.

In the first of the book's three major sections, Corning-affiliated authors discuss the fabrication of flexible glass, its mechanical and barrier properties, and its formulation. They describe the mechanics behind ultrathin glass's flexibility as well as how the fusion-draw process enables the formation of perfect sheets of ultrathin glass that allow for a reasonable radius of curvature without breaking. One chapter provides a review of fracture mechanics, the mechanical testing of glass sheets, and the longevity of glass. Another describes the significant improvement that can be made to the durability of glass sheets when formulated for a reduced modulus. This is an emerging area in flexible glass.

The other two sections of the book are by authors who are not affiliated with Corning. The first discusses the unit operations available for glass processing and coating. The authors, from the Center for Advanced Microelectronics Manufacturing in Binghamton, New York, demonstrate roll-to-roll deposition, photolithographic patterning, and wet-processing tools in a roll format for the development of several new structures. The deposition and patterning of indium tin oxide (ITO) films are also showcased. The authors compare the performance of flexible glass head to head with two other high-performance flexible films for roll-to-roll coating operations, polyethylene naphthalate (PEN) and polyethylene terephthalate (PET), and demonstrate that the barrier properties and surface quality of flexible glass offer significant performance improvements.

A chapter by authors from the Fraunhofer Institute for Organic Electronics in Dresden discusses plasma processing associated with roll-to-roll and sheet-fed flexible electronics processing, as well as the considerations associated with roll-to-roll atomic layer deposition processing. Of particular interest is the applicability of flexible glass to more energetic processes (such as ion beam-assisted deposition), which offer higher-quality and more stable films than traditional processes but are challenging to incorporate in process flows using polymer substrates. The authors also discuss the use of heating and ultrafast annealing (*e.g.*, with flashlamps or excimer lasers) for the improvement of film characteristics. In another chapter, authors affiliated with VTT Finland present results for solution-based printing on flexible glass, making a compelling case for the applicability of flexible glass to printing. They cite mechanical properties (*e.g.*, mating with gravure rollers), surface cleanliness, and surface cleaning and treatment options as evidence that flexible glass is an exceptional choice.

The third and final section of *Flexible Glass* describes several applications of the technology. Authors affiliated with the US National Renewable Energy Laboratory in Golden, Colorado, discuss the applicability of flexible glass to photovoltaics. The demands of photovoltaic devices for transparency, UV stability, weatherization tolerance, and water exclusion are very high, and the applicability of flexible glass as a substrate or laminate is considered in this context. A group from the University of Stuttgart discusses the use of flexible glass in displays, including stress management, the fabrication of thin-film transistors (TFTs), and the integration of drive electronics. Researchers from the University of Pittsburgh discuss the use of flexible glass as a component in integrated waveguides, presenting several new processes for structuring, cladding, and patterning. The final chapter, from mPower Technology and Vivint Solar, lays out the potential use of flexible glass as a substrate for the integration of heterogeneous elements in a 3D integrated circuit (3DIC), including electronics, photovoltaics, and sensor devices. The authors show a demonstrator that incorporates a high-voltage photovoltaic cell and discuss the potential cost scaling for such a platform.

A Healthy Range of Concepts and Authors

I was especially impressed by the diversity of voices in this book. While Corning is the only glass supplier among the contributors, the rest of the authors hail from a variety of institutions around the world and include many of the top practitioners and institutions involved in flexible electronics research. Each chapter is well referenced and reviews literature by the authors as well as by other experts as appropriate for the section.

This book does a good job of mixing a review of fundamentals into the discussion of new technologies and concepts. In addition to an unusually comprehensive and clear discussion of the mechanics of flex and fracture (which by itself would make an interesting book), the authors were not shy about discussing a number of other interesting and related topics, starting at a foundational level. For example, the review of ITO doping and the tradeoff of ITO doping with oxygen vacancies and transparency is particularly helpful. Additional educational sections include a review of optical properties such as haze, an explanation of water-vapor transmission requirements for thin-film electronics, and a discussion of the sheet resistance of transparent conductors. This coverage expands the accessibility of the book to students and engineers from outside the field who may not be well versed in issues specific to flexible electronics, and bolsters the work's usefulness as a guide to many of the issues associated with flexible electronics beyond the topics relating to flexible glass.

In this context, I think *Flexible Glass* is a good resource for institutional libraries and the personal libraries of those interested in flexible electronics (and new substrates), while also serving as a textbook for specialized courses, and as an update on issues relating to flexible electronics. It has the fundamentals needed to serve as an excellent textbook in several related topics, and features enough recent and cutting-edge results to provide an update to those interested in considering flexible glass specifically and flexible electronics generally. It is also available on Knovel, which means that it's already in many institutional libraries. Overall, this is a highly recommended reference and a great read covering the field.

Flexible Glass: Enabling Thin, Lightweight, and Flexible Electronics is edited by Sean M. Garner and published by Scrivener Publications and Wiley, 2018.

Ioannis Kymissis *is an associate professor in the electrical engineering department at Columbia University and former editor in chief of the* Journal of the Society for Information Display. ■

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with AMOLED in terms of visual quality, a higher LED resolution for the BLU is required. On the other hand, the costs must not drastically increase. Recent developments in microLED technology offer a new perspective. In contrast to a display with millions of pixels, a BLU with a few thousand LEDs already has a high resolution for this application. The assembly process of a few thousand LEDs on a substrate is much easier to set up than that of millions. In order to achieve a sufficiently high backlight luminance like 10K nits, the area of such an LED device has to be much larger than a microLED pixel. Thus, instead of microLED, the term miniLED has been introduced for this application. The area utilization of a miniLED is significantly higher than that of a microLED. Also, a passive-matrix operation of the matrix miniLED is feasible and reasonable; for example, by applying multiline addressing and multiple scanning. Such an arrangement can realize high luminance for high dynamic range (HDR) and is at the same time thin. The daylight readability, even for novel interior designs or convertible cars, can be guaranteed. The two issues, *i.e.* the high-power consumption and the limited contrast of the LCD, can be solved by local dimming.

In Fig. 10, a source image and three simulated backlights with 16 × 6, 29 × 11, and 80 × 30 LEDs are shown. It is obvious that with a higher LED resolution, matching between the image and the backlight improves. For a very high resolution like 80 × 30, a very good representation of the image is achieved. This means that the visual quality will be excellent. The LED power-saving rates are -29 percent, -50 percent, and -70 percent, respectively. Also, a very high luminance can be produced without problems such as image sticking and other lifetime issues. The thermal management will be simpler due to the low power consumption, and overheating can effectively be avoided.

During the night, the brilliance of an image will provide a very strong impression to the driver, which is not just a matter of contrast ratio, but depends also on the size of the black area. One measurable quantity is the share of black pixels in the image, as introduced in an upcoming IMID paper by two of the authors and their colleagues.[4] For a very high resolution like 80 × 30 LEDs, it can be expected that an OLED-like visual quality will be achieved.

The authors can also predict that a high-resolution matrix BLU such as a miniLED BLU may allow LCDs to achieve near-ideal performance and fulfill automotive requirements under daylight conditions. The cost should be in a reasonable range, and an industrial implementation is realistic. Furthermore, such a BLU will allow new designs such as curved and non-rectangular displays. New HMIs and interior design features will become feasible as a result.

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Seeking Nominations for 2019 SID Honors and Awards

By Shin-Tson Wu

In our professional lives, there are few greater rewards than recognition by our peers. For an individual in the field of displays, an award or prize from the Society for Information Display, which represents his or her peers worldwide, is a most significant, happy, and satisfying experience. In addition, the overall reputation of the Society depends on the individuals who are in its "Hall of Fame." When you nominate someone for an award or prize, you are bringing happiness to an individual and his or her family and friends, and you are also benefiting the Society as a whole.

On behalf of the Society for Information Display's Honors and Awards Committee, I invite you to participate in the nomination of deserving individuals for next year's honors and awards. The SID Board of Directors grants awards based on recommendations made by the Honors and Awards Committee. Recipients do not necessarily have to be members of SID. Seven major prizes are awarded to individuals based on their outstanding achievements. The seven major prizes are as follows:

The **Karl Ferdinand Braun Prize** is awarded for ***"outstanding technical achievement in, or contribution to, display technology."*** This prize is named in honor of the German physicist and Nobel laureate Karl Ferdinand Braun, who invented the cathode-ray tube (CRT) in 1897. Scientific and technical achievements that cover either a wide range of display technologies or the fundamental principles of a specific technology are the prime reasons for awarding this prize to a nominee.

The **Jan Rajchman Prize** is awarded for ***"outstanding scientific and technical achievement or research in the field of flat-panel displays."*** This prize, named for the Polish computer pioneer, is specifically dedicated to individuals who have made major contributions to flat-panel-display technology or, through their research activities, have advanced the state of understanding of flat-panel technology.

The **David Sarnoff Industrial Achievement Prize** is designed to honor ***"outstanding recipients who have had a profound, positive effect on the display industry over a period of***

SID Honors and Awards Nominations

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

- **KARL FERDINAND BRAUN PRIZE.** Awarded for an outstanding *technical* achievement in, or contribution to, display technology.
- **JAN RAJCHMAN PRIZE.** Awarded for an outstanding *scientific* and *technical* achievement or research in the field of flat-panel displays.
- **DAVID SARNOFF INDUSTRIAL ACHIEVEMENT PRIZE.** Awarded to individuals who have had a profound, positive effect on the display industry over a period of many years.
- **OTTO SCHADE PRIZE.** Awarded for an outstanding *scientific* or *technical* achievement in the advancement of functional performance and/or image quality of information displays.
- **SLOTTOW–OWAKI PRIZE.** Awarded for outstanding contributions to the education and training of students and professionals in the field of information display.
- **PETER BRODY PRIZE.** Awarded to honor outstanding contributions of young researchers (under age 40) who have made major-impact technical contributions to the developments of active-matrix-addressed displays.
- **LEWIS AND BEATRICE WINNER AWARD.** Awarded for exceptional and sustained service to the Society.
- **FELLOW.** The membership grade of Fellow is one of unusual professional distinction and is conferred annually upon an SID member of outstanding qualifications and experience as a scientist or engineer in the field of information display who has made widely recognized and significant contributions to the advancement of the display field.
- **SPECIAL RECOGNITION AWARDS.** Presented to members of the technical, scientific, and business community (not necessarily SID members) for distinguished and valued contributions to the information-display field. These awards may be made for contributions in one or more of the following categories: (a) outstanding technical accomplishments, (b) outstanding contributions to the literature, (c) outstanding service to the Society, (d) outstanding entrepreneurial accomplishments, and (e) outstanding achievements in education.

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

1. Name, present occupation, business and home address, phone and fax numbers, and SID grade (Member or Fellow) of nominee.

2. Award being recommended:
   Karl Ferdinand Braun Prize
   Jan Rajchman Prize
   David Sarnoff Industrial Achievement Prize
   Otto Schade Prize
   Slottow–Owaki Prize
   Peter Brody Prize
   Lewis and Beatrice Winner Award
   Fellow*
   Special Recognition Award

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

3. Proposed citation (basis for the award nomination). This should not exceed 30 words.

4. Name, address, telephone number, and SID membership grade of nominator.

5. Education and professional history of candidate. Include college and/or university degrees, positions, and responsibilities of each professional position.

6. Professional awards and other professional society affiliations and grades of membership.

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

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

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

E-mail the complete nomination – including all the above material – by **October 15, 2018**, to swu@ucf.edu with cc to office@sid.org or by regular mail to:
Shin-Tson Wu, Honors and Awards Chair, Society for Information Display,
1475 S. Bascom Ave., Ste. 114, Campbell, CA 95008, US

many years, and are broadly recognized across the industry." The Sarnoff Prize was created last year in honor of RCA visionary David Sarnoff to honor individuals whose contributions to the display industry may be outside the technical realm.

The **Otto Schade Prize**, which honors pioneering RCA engineer Otto Schade, is awarded for ***"outstanding scientific or technical achievement in the advancement of functional performance and/or image quality of information displays."*** The advancement for this prize may be achieved in any display technology or display system or can be of a more general or theoretical nature. The scope of eligibility encompasses the areas of display systems, display electronics, applied vision and display human factors, image processing, and display metrology, and work may take the form of theoretical or mathematical models, algorithms, software, hardware, or innovative methods of display-performance measurement and image-quality characterization.

The **Slottow–Owaki Prize** is awarded for ***"outstanding contributions to the education and training of students and professionals in the field of information display."*** This honors Professor H. Gene Slottow of the University of Illinois, an inventor of the plasma display, and Professor Kenichi Owaki of the Hiroshima Institute of Technology, an early leader of the pioneering Fujitsu Plasma Display program. This prize recognizes outstanding educational and training contributions made not only by professors in formal universities but also by researchers. It may also include training given by researchers, engineers, and managers in industry who have done an outstanding job developing information-display professionals.

The **Peter Brody Prize** is awarded to honor ***"outstanding contributions of young researchers (under age 40) who have made major-impact technical contributions to the developments of active-matrix-addressed displays"*** in one or more of the following areas: thin-film transistor devices; active-matrix-addressing techniques; active-matrix device manufacturing; active-matrix display media; and active-matrix display-enabling components.

Each of the above-mentioned prizes carries a $2,000 stipend.

The seventh major SID award, the **Lewis and Beatrice Winner Award**, is awarded for ***"exceptional and sustained service to the Society."*** This award is granted exclusively to those who have worked hard over many years to further SID's goals.

Fellow Nominations

The membership grade of **SID Fellow** is one of unusual professional distinction. Each year the SID Board of Directors elects a limited number (up to 0.1 percent of the membership in that year) of **SID members** in good standing to the grade of **Fellow**. To be eligible, candidates must have been members for at least five years at the time of nomination, with the last three years consecutive. A candidate for election to Fellow is a member with ***"outstanding qualifications and experience as a scientist or engineer in the field of information display who has made widely recognized and significant contributions to the advancement of the display field"*** over a sustained period of time.

SID members practicing in the field recognize the nominee's work as providing significant technical contributions to knowledge in their area(s) of expertise. For this reason, endorsements from five SID members are required to accompany each Fellow nomination. The committee evaluates nominations on five weighted criteria: creativity and patents, 30 percent; technical accomplishments and publications, 30 percent; technical leadership, 20 percent; service to SID, 15 percent; and other accomplishments, 5 percent. When submitting a Fellow award nomination, please keep these criteria and their weights in mind.

Special Recognition Awards

The **Special Recognition Award** is given annually to a number of individuals (membership in the SID is not required) in the scientific and business community for distinguished and valued contributions in the information-display field. These awards are given for contributions in one or more of the following categories: (a) ***outstanding technical accomplishments***, (b) ***outstanding contributions to the literature***, (c) ***outstanding service to the Society***, (d) ***outstanding entrepreneurial accomplishments***, and (e) ***outstanding achievements in education***. When evaluating nominations for the Special Recognition Award, the committee uses a five-level rating scale in each of the five categories listed above, and the categories have equal weight. Nominators should indicate the category in which a Special Recognition Award nomination is to be considered by the committee. More than one category may be indicated. The nomination should emphasize the candidate's accomplishments in the category or categories selected by the nominator.

How the Nomination Process Works

While individuals may not nominate themselves for an award or election to Fellow, nominators may, if necessary, ask a nominee for information that will be useful in preparing the nomination. The nomination process is relatively simple, but requires that the nominator and perhaps a few colleagues spend some time preparing the supporting material that the committee needs in order to evaluate each nomination. It is not necessary to submit a complete publication record with a nomination. Just list the titles of the most significant half-dozen or fewer papers and patents authored by the nominee, and list the total number of papers and patents he/she has authored.

Determining winners for SID honors and awards is a highly selective process. On average, fewer than 30 percent of nominees receive awards. In some years, some major prizes are not awarded due to a lack of sufficiently qualified nominees. On the other hand, nominations remain active for three consecutive years and will be considered three times by the committee. For more information about the awards or to download a nomination form, go to www.sid.org/About/Awards/IndividualHonorsandAwards.aspx. The site also provides samples of previous successful nominations to guide the composition of your nomination. We prefer to receive submissions by email, but if necessary you may mail your submission to SID headquarters.

Please note that each Fellow nomination requires written endorsements from five SID members. Identical endorsements by two or more endorsers will be automatically rejected (no form letters, please). Only the Fellow nominations are required to have endorsements, but I encourage you to submit at least a few endorsements for all nominations.

All 2019 award nominations, including support letters, must be submitted by October 15, 2018. Email your nominations directly to swu@ucf.edu with cc to office@sid.org.

Thank you in advance for your nomination.

— Shin-Tson Wu
Chair, SID Honors and Awards Committee ■

guest editorial

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augmented-reality capability covering major traffic scenarios but not objects at close distances.

Without doubt, in the future, cars ranging from intermediate to luxury will incorporate a wide range of display sizes, from 1 to 100 inches. For private, fully automated cars, turnable seats will be standard and displays are likely to appear in places like door panels, behind the back seat, and integrated in tables (or armrests). This will add the equivalent of 2 to 4 UHD-equivalent (8 megapixel) displays. Premium, fully automated private cars will end up with approximately 100 megapixels in displays, which is 20× more than today's high-end cars with rear-seat entertainment. This will have a huge impact on computing and graphics power as well as data rates for video interfaces. Factor in all the algorithms for autonomous operation, and cars will evolve toward supercomputers on wheels.

We are pleased to have several articles in this issue of *Information Display* that spotlight selected topics in automotive displays. These include "Dynamic Backlights for Automotive LCDs" by authors from the University of Saarland and "Performance Optimization for In-Vehicle Displays" from the experts at Continental Automotive GmbH. Also featured is an interview with Rashmi Rao, senior director, advanced engineering and user experience, for the Connected Car Division at Harman, in which she talks about materials and overall trends for automotive displays.

Enjoy reading these articles. I hope you were able to attend some of the special automotive display sessions at the 2018 Display Week Symposium and the joint SID/DSCC Automotive Display Market Focus Conference or see some of the numerous demos on the show floor in Los Angeles last May. If not, you can always read my article on automotive display highlights from Display Week 2018 in the next issue of this magazine.

__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 has been a full professor since 1995. He is vice chair of the SID technical symposium subcommittee for automotive/vehicular displays and HMI technologies and a member of the International Committee for Display Metrology (ICDM). ■

industry news

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Semiconductors, a developer of optoelectronic technology, to develop advanced display engines for Vuzix waveguide optics.

Vuzix stated in a press release that Plessey's Quanta-Brite light engine will enable less energy consumption and improved battery life for its next-generation product, enabling Vuzix to cut a significant amount of volume from the display engine of its waveguide based smart glasses, while at the same time delivering improved optical performance at a reduced cost. Quanta-Brite is based on Plessey's proprietary gallium-nitride-on-silicon (GaN-on-Si) technology.[3]

The Vuzix Blade isn't commercially available yet, though it won four Innovation Awards at CES this year and received a great deal of positive media attention in Las Vegas. For example, *The Verge* reported that it is "the first device Vuzix has developed that contains nearly every aspect of the display and its power source within the eyewear frames." The reporter, who tried the glasses at the show, pronounced them "the real deal," similar to Google Glass, but better.[4]

After CES, Vuzix announced its Vuzix Edge program for early adopters, along with a tentative ship date of second quarter 2018 for the product. In mid-June, the company announced a software-developer kit for the Blade, but not product availability. Vuzix has been making shipping products (available on Amazon) for several years, and has Blade agreements with a number of technology partners, including the aforementioned Plessey, so it can be presumed that these good smart glasses will eventually come to those who wait.

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[3]https://ir.vuzix.com/press-releases/detail/1635/vuzix-announces-partnership-to-develop-next-generation-ar

[4]https://www.theverge.com/2018/1/9/16869174/vuzix-blade-ar-glasses-augmented-reality-amazon-alexa-ai-ces-2018 ■

***Fig. 3:** The Vuzix Blade smart glasses are relatively streamlined compared with other models. Source: Vuzix.*

enabling technology

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shaking your seat or steering wheel or via an audible notification, or by a combination of all three. You need to be able to understand what the situation is and take control immediately. This is where a very rich user experience will be needed – one that will recognize threats, make it obvious what they are, recommend activity, and allow the driver to take over – very quickly and accurately. It's all got to work, every time.

"One of the things we know from consumer research as well as testing systems ourselves is that the success and acceptance of autonomous driving is going to be largely based on consumer trust," says Bowden. "Trust in the system, trust that the car can do the driving. One of the things that builds trust is visual feedback, so as a passenger, you see that the car is aware of its surroundings. You can look up at any time and see that it's tracking lanes and following road signs." Such a system will not come cheap in terms of computing power or display quantity and quality. An Ethernet connection between the systems and the domain controller would be a must, says Bowden.

Our Future Is Someone Else's Past

As quaint as the car at the beginning of this article appears to be, it is only 120 years old and was state of the art in its time. Years from now, an "antique" 2018 Honda Odyssey minivan with its multitude of display and communication systems and its 15 cupholders might amuse future generations, for reasons we can't even imagine yet. ■

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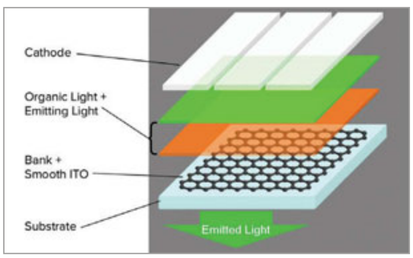

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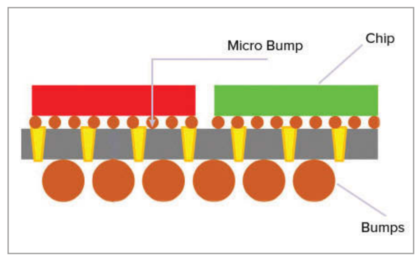

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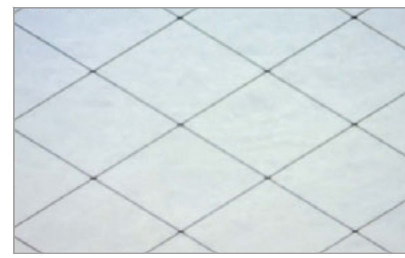

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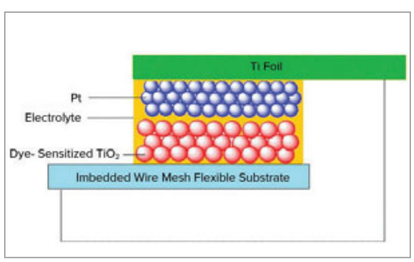
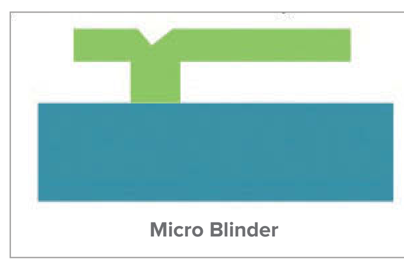


Flexible Dye Cell



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