NOVEMBER/DECEMBER 2011

LEDs MAGAZINE

TECHNOLOGY AND APPLICATIONS OF LIGHT EMITTING DIODES

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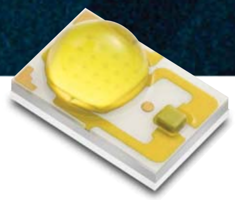

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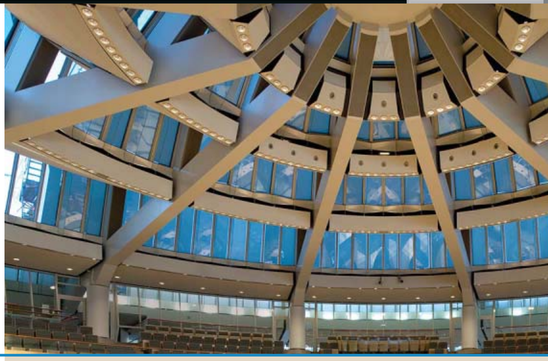
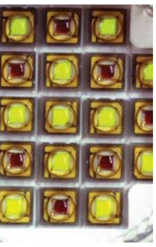


Photography: Martin Höhn.

Cover Story

The NRW parliament building in Germany is lit by concentric rings of LED downlights from Hoffmeister Leuchten that contain Fortimo DLM 2000-lm modules from Philips. See www.ledsmagazine.com/casestudies/33420.

features



columns/departments

commentary

European focus in a global LED industry

In early October, *LEDs Magazine* held its second Strategies in Light Europe conference, which featured a wide range of presentations on subjects relating to market transformation and technology in the LEDs and lighting space (pages 21 and 29). The LED lighting market in Europe is predicted to grow at a CAGR of 41% from 2010 to 2015, according to the market-research firm Strategies Unlimited. A key driver will be the growth in sales of LED retrofit lamps, driven by the European directive that has already phased out various types of incandescent lamps at 60W and above. As our article discusses, there are a number of other policy-led actions that are promoting the adoption of solid-state lighting throughout Europe. For example, 2 or 3 major demonstration projects are set to be announced shortly, and public procurement will be encouraged to lead by example by making use of energy-efficient products and services.

The European Commission has also introduced an EU Quality Charter, which is a voluntary set of criteria that is intended to promote high-quality LED lamp products and raise customer awareness. The criteria have been used by EU member countries to develop their own quality labels for LED lamps...but ultimately this might result in 27 different labels! Industry groups, notably the ELC, are calling for a standardized Europe-wide approach to lamp labelling.

Standardization provided a major discussion point at Strategies in Light Europe, with particular emphasis on the efforts by the Zhaga Consortium to provide standard interfaces for LED light engines (page 43). Three light-engine specifications have been approved to date, and Zhaga members are busy designing products according to these specs, although non-members don't have access to the details. This is perhaps understandable, as Zhaga members want to protect their interests and gain a first-mover advantage. However, this demonstrates a surprising feature of standardization efforts – in most cases, the organizations responsible do a lousy job of telling industry and other interested parties when new standards are finalized. TM-21, covering the projection of long-term lumen maintenance of LED light sources (page 37), is a good example. This is hugely important for the LED lighting industry, but there was little or no fanfare when it was finally published after years in development. And the IES charges $40 to download a copy.

Strategies in Light Europe also heard from two organizations that are working on a global basis; the Global Lighting Forum, and the IEA Annex on SSL (page 24). Both are examples of how global cooperation is working towards harmonization of standards, and test and measurement protocols, while also building a strong consensus with respect to the benefits of LED lighting. Another organization, the China-based International SSL Alliance, has similar aims. And speaking of China, the recent announcement of a firm schedule for incandescent lamp phase-out (page 17) had a positive effect on the share prices of a number of US-based companies with an interest in the LED market, demonstrating again the global dimension of the LED lighting industry.

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DATE: October 2011
PRESENTERS: Costa Politakis, Future Lighting Solutions
Dan Sullivan, Philips Lighting

Light and Color - Methods of Achieving High CRI with LEDs

DATE: October 2011
PRESENTER: Marc Dyble, Osram Opto Semiconductors

Efficient Driving and Safe Monitoring of Multiple LED Arrays

DATE: October 2011

Creating Highly Efficient, Highly Reliable Lighting Designs with Multiple LED Strings

DATE: November 2011
PRESENTER: Alexander Craig, Fairchild Semiconductor

An LED Luminaire Solution For Indoor Area Lighting

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PRESENTER: Valentin Kulilov, ON Semiconductor

Diagnosing and Solving Thermal Challenges in Next-Generation LEDs

DATE: November 2011
PRESENTER: Boris Marovic, Mentor Graphics

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FEATURED *article*

strategically speaking

Chinese LED manufacturing – more than just LEDs

Significant investments and subsidies have enhanced Chinese companies' capabilities to produce not only LED chips and packaged devices, but also materials and equipment used in LED manufacturing, as TOM HAUSKEN explains.
www.ledsmagazine.com/features/8/11/1

ADVERTISERS *index*

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OUTDOOR

LED highway-lighting project in China features a million Cree LEDs

More than 10,000 LED street lights from Kingsun Optoelectronic Co. Ltd., a lighting provider based in China, have been installed along nearly 75 miles of roadways in Shenzhen, China. The LED fixtures, which were installed along one tunnel and four highways, together use more than a million Cree XLamp XP-G and XP-E white LEDs.

Kingsun installed 270W and 300W RL2R Apollo LED luminaires, designed to average more than 20 lux, the Chinese national standard for illumination of main roads. The company anticipates a 60% reduction in energy consumption compared to the high-pressure sodium (HPS) fixtures that were replaced. According to the Energy Management Contract (EMC) business model implemented by Kingsun, the energy savings associated with the Shenzhen project can be put toward the installation's upfront costs for an estimated return-on-investment of four years (page 51).

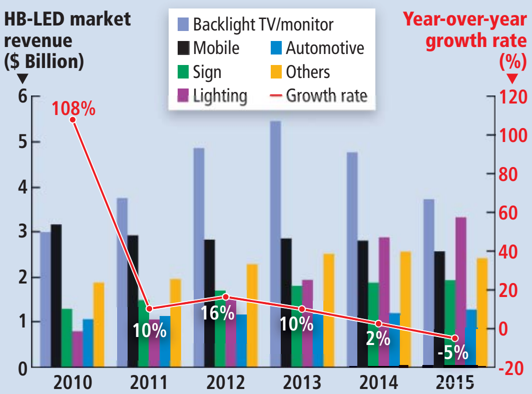
In related news, Cree has announced a new upper level of performance for its XLamp XP-G LEDs, which deliver up to 140 lm/W in production quantities. Cree described its XLamp XP-G LEDs as "the industry's premier LED optimized for directional lighting, used in a variety of applications from street and area lighting to PAR replacement lamps to high-output flashlights." Cree also stated it is the first LED supplier to publish 10,000 hours of lifetime data, which can allow customers to project TM-21 reported lifetimes of 60,000 hours, or nearly seven years. ◂

MORE: www.ledsmagazine.com/news/8/10/13

MARKETS

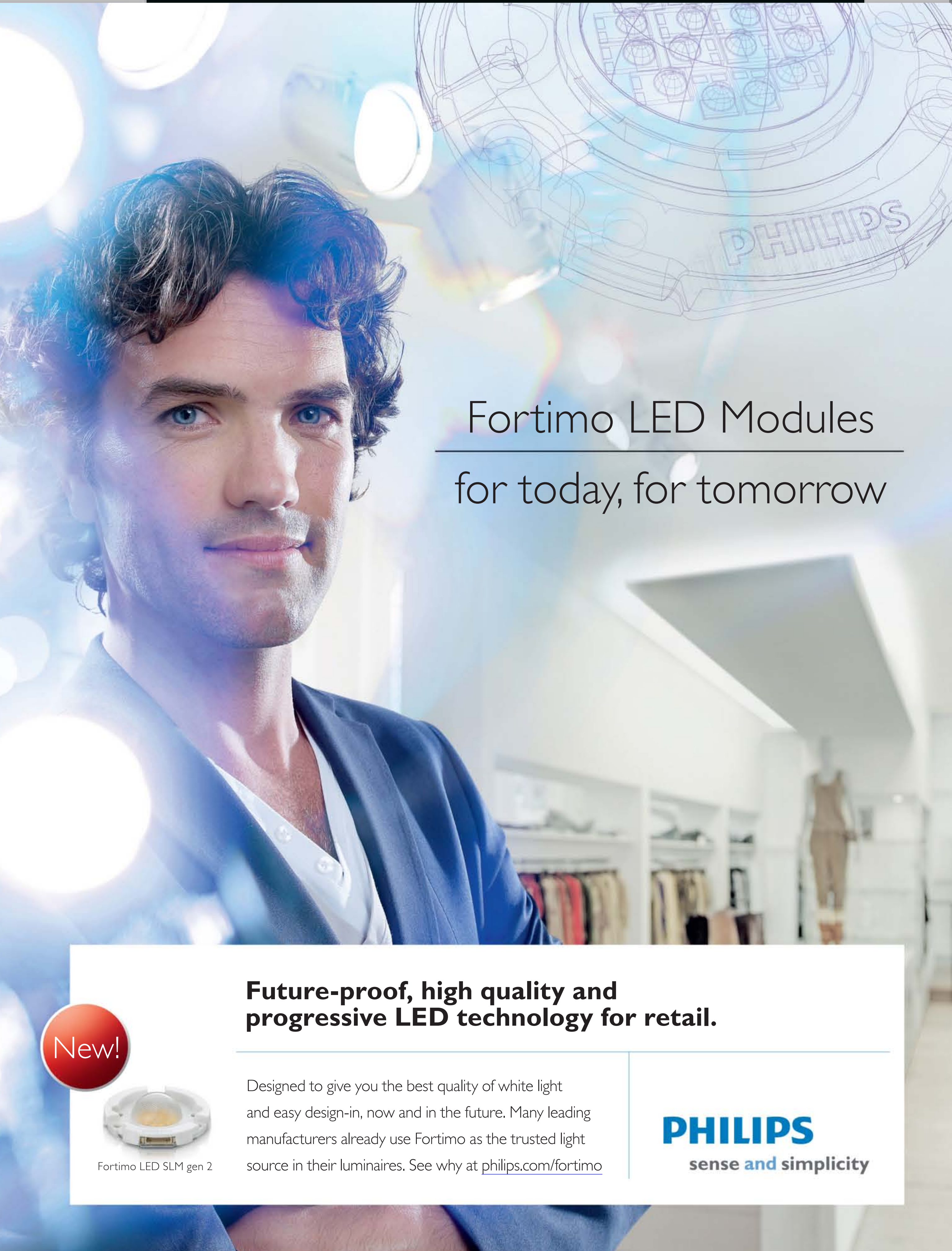
HB-LED revenue growth will reach nearly 10% in 2011

In 2011, the total high-brightness LEDs (HB-LED) market is expected to grow by 9.8% year-over-year, reaching a total revenue of $12.3 billion, according to a new report from Strategies Unlimited, a market research firm based in Mountain View, CA. The report outlines trends and expected growth in HB-LED revenue, which is expected to peak in 2014 at $16.2 billion and subsequently fall to $15.3 billion in 2015. This dip will be temporary, as lighting will take over as a strong engine for growth after 2015.



Other highlights from the new report, entitled "High-Brightness LED Market Review and Forecast – 2011," include a discussion of LED prices, which have plummeted 20-40% in most applications, making LEDs more of a commodity. LED lighting revenues will see a 33% compound annual growth rate (CAGR) through 2015, with LEDs representing an average of 30% of the bill of materials. Approximately 83% of worldwide LED-lit signs were manufactured in China in 2010, and the region will continue to dominate in this respect. The local signage market in China is expected to grow at 14% CAGR through 2015. LEDs in the automotive market reached $1.1 billion in 2010, propelled by increased use in daytime running lights and headlamps. Exterior automotive lighting is expected to enjoy a 10% CAGR through 2015. ◂

MORE: www.ledsmagazine.com/news/8/10/9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FINANCE

Bridgelux raises $15 million

Bridgelux hopes to quicken its pace in transitioning to gallium-nitride-on-silicon (GaN-on-Si) LED chip manufacturing using a new $15 million funding round. The company believes GaN-on-Si technology will lower the manufacturing costs for LEDs, thereby spurring SSL growth. Bridgelux didn't specify how the new funding, provided by existing investors, will be utilized. The company recently announced that it had manufactured cool-white LEDs with an efficacy of 160 lm/W in the lab on 8-in silicon wafers, though production of such LEDs is still two years away (www.ledsmagazine.com/news/8/8/15). At the time the company identified challenges such as uniformity issues across 8-in wafers and low chip-yield as roadblocks to manufacturing GaN-on-Si LEDs in production. ◄

MORE: www.ledsmagazine.com/products/33258

EVENTS

PennWell acquires The LED Show

Tulsa, OK-based PennWell Corp., the parent company of *LEDs Magazine*, has acquired The LED Show conference and exhibition from founder James Highgate, who will remain with the show as a consultant. This past July, The LED Show attracted more than 3000 attendees and 87 exhibitors to Las Vegas. Registrants included architects, electrical engineers, home builders, hotel engineers, and lighting designers; these came from all corners of the globe. PennWell will hold the 2012 solid-state lighting event in Las Vegas from July 30 to August 1, 2012.

Highgate said, "I am pleased that PennWell, as the world's leading and most respected provider of information to the LEDs and lighting community, will further promote and enhance the event." ◄

OLEDs

Cintelliq releases OLED market report

Cintelliq Ltd, a Cambridge, UK-based market-research firm specializing in OLEDs, has released a report that indicates OLED and LED lighting will compete in a number of applications over the next decade. The report is entitled "OLED Lighting: Products, Pricing, Capacity, Cost and Forecasts 2011-2020." Cintelliq analysts project that the OLED lighting market will be worth $2.8 billion by 2020, with panel pricing in the $10/klm realm. "By 2020, production capacity will be equivalent to more than 60 million 2-foot fluorescent tubes," said Craig Cruickshank, lead analyst with Cintelliq. "Between 2015 and 2020, OLED lighting is poised to become a serious competitor to LED lighting for a growing number of home and office applications." ◄

MORE: www.ledsmagazine.com/news/8/10/22

FINANCE

EcoSense closes $13 million funding

LED lighting manufacturer EcoSense Lighting has closed a $13 million Series B financing round led by Bain Capital Ventures. EcoSense Lighting provides LED lighting fixtures for architectural, industrial, and residential applications. The New York, NY-based company says that the financing will support its continued product-development initiatives and fuel the growth of its engineering and sales teams. "With its exponential energy and cost savings, breadth of applications and earth-friendly, sustainable components, we see incredible potential in the LED illumination market," said Jeffrey Glass, managing director of Bain. "EcoSense has the right team, the right strategy and a level of traction in the professional lighting market needed to be a strong leader in this advancing industry." ◄

MORE: www.ledsmagazine.com/press/32767

CONTROLS

Osram, Acuity make acquisitions

Osram Sylvania has acquired full control of Encelium Technologies, a maker of lighting-control systems and software based in Teaneck, NY, from investment firm Townsend Ventures. Osram said that the acquisition of Encelium and its "cutting-edge lighting control software" for commercial buildings was the next logical step for the company to become "one of the leading providers of LED lighting solutions." Osram pointed to a recent McKinsey study, which estimated the market for control components in lighting systems at EUR2 billion ($2.75 billion) in 2010. McKinsey expects the market to double by 2016 and triple by 2020, based on the energy savings that can be achieved by combining SSL and control systems.

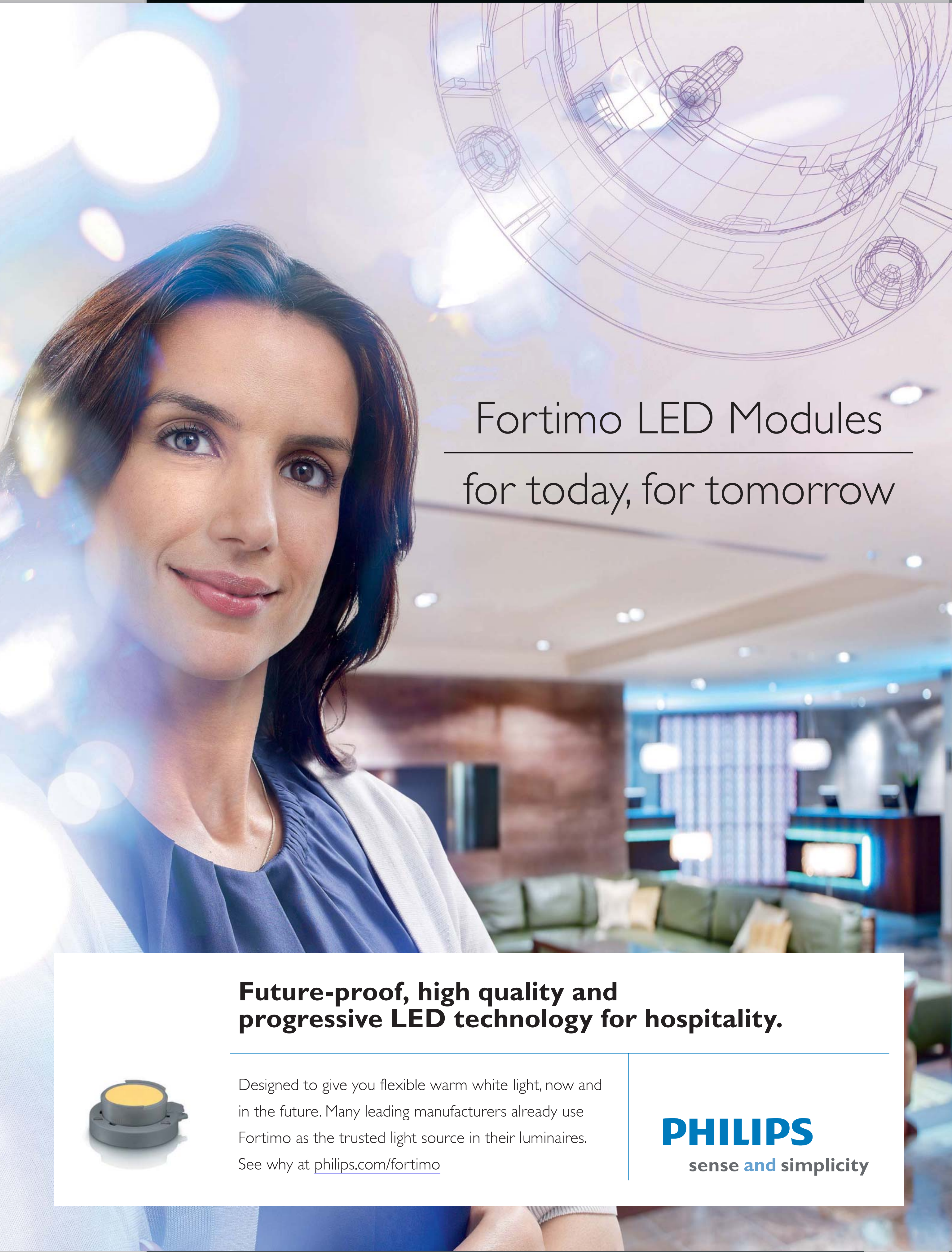
Meanwhile, Acuity Brands has acquired Alberta, Canada-based Pathway Connectivity, adding to its growing stable of adaptive-control technologies for SSL. Pathway is focused on control electronics for applications in architectural and entertainment lighting. "The Pathway team brings advanced networking products and engineering capabilities to Acuity Brands that fit into our strategy of expanding the opportunities associated with integrating lighting and controls solutions," said Vernon Nagel, CEO of Acuity Brands. Pathway's strengths lie in networking control systems, intelligent lighting systems and driver electronics, even when the products use disparate communication protocols. ◄

MORE: www.ledsmagazine.com/news/8/10/3

MANUFACTURING

Veeco, Aixtron report reduced bookings

Veeco Instruments Inc. (Nasdaq:VECO), based in Plainview, NY, and Aachen, Germany-based Aixtron SE (FSE:AIXA; Nasdaq:AIXG) have announced their financial results for the third quarter. Veeco's revenue was $268 million, with non-GAAP net income and earnings per share of $53 million and $1.33, respectively. The company reported a 7% sequential increase in LED and Solar revenues to $234 million, including $220 million in MOCVD system sales.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However, Veeco's third-quarter bookings were $133 million, a decline of 57% sequentially. LED & Solar orders declined 59% sequentially to $112 million, with MOCVD orders at $103 million. "Veeco's third-quarter orders were impacted by weak near-term LED industry demand, low MOCVD equipment utilization rates in Asia, and decreased business activity in China," commented John Peeler, Veeco's CEO.

Aixtron's equipment order intake was also down sequentially by 77% to EUR 51.5 million ($71 million) in Q3 of 2011, relative to EUR 222.2 million ($306.0 million) in Q2. Equipment order intake in the first 9 months of 2011 was down 11% year-over-year at EUR 484.1 million ($666.8 million).

Aixtron's quarterly revenues decreased by nearly half (49%) from EUR 175.6 million ($241.9 million) in Q2 to EUR89.8 million ($123.7 million) in Q3 2011. Revenues in the first 9 months of 2011 decreased 16% to EUR 470.8 million ($648.4 million) from EUR 558.1 million ($768.7 million) in the same period last year. The cause was customer delays in delivery dates and credit tightening in Asia, said the company.

Paul Hyland, president and CEO of Aixtron, described current market conditions as "difficult" but said: "There can be no doubt in anybody's mind that the LED lighting investment cycle will come and will be the biggest end-market opportunity this industry has ever seen. It is not a question of 'if' it is only a question of 'when'." ◄

MORE: www.ledsmagazine.com/news/8/11/3

OUTDOOR

Welland switches to LEDs

The City Council in Welland, Ontario, Canada, has voted unanimously to completely replace the city's street lights with LED fixtures. The Council approved an agreement with SSL Energy Solutions and Appalachian Lighting Systems Inc. (ALSI) to replace the existing street-lighting system throughout the city with ALSI's ALLED fixtures and ALLink control system.

The capital cost of CAN$2.74 million will be financed through a debenture, and paid back by utilizing the energy savings from the program. In year one, street-lighting energy costs should be reduced by $221,553 with a saving in maintenance costs of $159,250. Phase 1 of the project will include the replacement of 4300 cobrahead HPS fixtures by April 2012. Phase 2 will consist of replacement of 2410 decorative fixtures, scheduled for completion in December 2012.

Welland estimates that the total cost of operating its current HPS-based lighting system would amount to almost $18 million over 15 years, which is the "estimated true cost of doing nothing." By switching to LED lighting, the City will save $6.8 million in operating costs. After paying the various charges including debt repayments, the city will save $2.38 million in total over the 15-year term of the agreement. ◄

MORE: www.ledsmagazine.com/news/8/9/31

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LED FABRICATION

Optogan opens LED chip fab

Optogan GmbH has held an opening ceremony for its LED chip-production facility in the German city of Landshut. The site previously housed a Hitachi semiconductor factory, with a clean-room area of 4000 m². Optogan has invested tens of millions of euros in the site, which will employ up to 100 people. Initial capacity will be over one billion LED chips per year.

According to Optogan, the facility is Europe's second-largest LED chip-production site. The largest is also in Germany, namely Osram Opto Semiconductors' plant in Regensburg. The Optogan Group, headquartered in Russia, opened a large LED packaging facility in St. Petersburg last year (www.ledsmagazine.com/news/7/11/29).

"In Landshut, we have discovered the ideal infrastructure for our future high-volume production of LED chips," said Hans Peter Ehweiner, managing director of Optogan GmbH. "Our LED lamps and luminaires are on the way towards lighting up indoor, outdoor, and residential areas all over the world." ◂

MORE: www.ledsmagazine.com/news/8/10/14

LED MATERIALS

Rubicon ships 200,000th 6-inch wafer

Rubicon Technology, Inc. (Nasdaq:RBCN) has stated that it has shipped over 200,000 six-inch sapphire wafers to LED manufacturers worldwide. Rubicon had previously announced that it had upgraded the crystal-growth furnaces in its three manufacturing facilities to allow 8-inch sapphire wafer production. Rubicon has production facilities in Bensenville, IL, Batavia, IL and Penang, Malaysia.

Also, Rubicon says it has begun production of aluminum oxide, the starting material used to manufacture sapphire. On-site processing of aluminum oxide will allow better process control and the growth of higher-quality sapphire with larger crystals. Some analysts expect 8-in wafers to account for more than 50% of the LED market by 2016.

MORE: www.ledsmagazine.com/news/8/10/32


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EPA releases first draft of Energy Star Lamps spec

The US Environmental Protection Agency (EPA) has published the first draft of the Energy Star Lamps v1.0 specification at www.energystar.gov/lamps. This is intended to replace the existing Compact Fluorescent Lamps and Integral LED Lamps specifications. Comments or concerns about this first draft should be sent to lamps@energystar.gov by December 9.

The specification is described by the EPA as "technology-neutral" and includes a proposal to align lamp-life requirements across technologies by introducing a 10,000-hr minimum lifetime requirement (for LED lamps, this would be a 10,000-hr rated lumen maintenance life).

The specification is limited to lamps intended to be connected to the electric power grid. It includes photometric performance requirements, lumen maintenance and reliability requirements, luminous-intensity distribution requirements, electrical performance requirements, dimensional requirements, and lamp labeling and packaging requirements for all lamp types included in the specification.

In December 2009, the EPA laid out a plan to integrate the four existing Energy Star lighting specifications into two, new, technology-neutral specifications: Luminaires (light fixtures - www.ledsmagazine.com/news/8/5/23) and Lamps (light bulbs). EPA says that its goal was "to better serve the consumer interest in identifying energy-saving lighting products by ensuring that performance requirements and testing methods reward efficiency and quality, irrespective of technology." In doing so, the EPA is also seeking to remove any overlap or contradiction among specifications.

For lamps, the EPA initiated a consultation process in March 2011, feedback from which can be viewed on the Lamps website (www.energystar.gov/lamps). This feedback focused the EPA's attention on further improvements to quality-related requirements rather than increases to the already-high efficiency requirements.

The EPA has addressed consumer barriers to adoption by developing proposed improvements to lamp start time, run-up time, color consistency, and reliability in high-heat and frequent-switching applications. The EPA also re-evaluated the lamp labeling and packaging requirements in the existing specifications.

The first draft also includes a proposal to align lamp-life requirements across technologies, creating an "even playing field." Specifically, the draft includes a proposal for a 10,000-hr minimum lifetime requirement. The EPA says that product data shows this requirement to be readily attainable with CFLs. While the Integral LED Lamps specification has required a 15,000- to 25,000-hr minimum, "there are disadvantages to this approach which appear to be hindering adoption of LED lamps," said the EPA.

Several lamps are excluded from the specification including lamps that operate on an external ballast, driver or transformer; lamps powered by an internal power source, e.g. solar; lamps with other power-consuming features that do not provide useful illumination; lamp technologies without industry-standardized methods of measurement; lamps with bases not detailed in ANSI standards; and Zhaga-defined LED modules. ◄

China unveils plans for incandescent lamp phase-out

China has unveiled its three-step plan for phasing out energy-inefficient incandescent lamps. The announcement on Nov 4 caused a surge in the share price of several LED companies, including Cree. According to the Xinhua News Agency, the phase-out will ban imports and sales of incandescent lamps in the following categories, as follows:

- 100W and above: October 1, 2012
- 60W and above: October 1, 2014
- 15W and above: October 1, 2016

Xie Ji, deputy director of the environmental protection department with China's National Development and Reform Commission (NDRC), said that the plan shows China's determination to press ahead in its efforts to save energy, reduce emissions and curb climate change.

China is a major manufacturer and consumer of lighting products and is the world's largest producer of both energy-saving lamps (CFLs) and incandescent bulbs. In 2010, incandescent-lamp production totaled 3.85 billion units, and domestic sales stood at 1.07 billion units, said Ji.

Power consumption for lighting in China accounted for 12% percent of the country's total electricity use in 2010. The NRDC expects that the plan will enable China to save 48 billion kWh of power per year and reduce CO_2 emissions by 48 million tonnes annually.

China's phase-out ties in with legislation in other countries and regions to stop using these products. Europe's incandescent phase-out affected 60W-and-higher lamps from September 2011 (www.ledsmagazine.com/news/8/9/1), while the US begins its nationwide ban on 100W-and-above incandescent lamps from January 1, 2012. ◄

MORE: www.ledsmagazine.com/news/8/11/7

LUMEN coalition launches website

The LUMEN (Lighting Understanding for a More Efficient Nation) coalition has launched a website (www.lumennow.org) dedicated to informing US consumers regarding energy-efficient residential lighting options. The coalition is led by the Alliance to Save Energy, the American Lighting Association (ALA) and the National Electrical Manufacturers Association (NEMA) and includes participants from more than 40 nonprofit energy-efficiency advocacy groups, utilities, lighting manufacturers and trade associations.

The coalition has estimated an annual energy saving per household of up to $100 by replacing less-efficient bulbs with halogen, CFL or LED options. "Understanding which option is best for a specific application is where LUMEN members can help the homeowner," said Larry Lauck of the ALA.

The website includes a guide to selecting replacement bulbs, frequently-asked questions, and news regarding energy-efficient lighting options. The website also explains the new FTC Lighting Facts label, which will be required on all medium screw-base bulbs sold in the US as of January 1, 2012. ◄

MORE: www.ledsmagazine.com/news/8/10/23

DOE consortium publishes LED street-lighting guidelines

The DOE Municipal Solid-State Street Lighting Consortium has posted specification templates for use by utilities and municipalities that are evaluating or implementing LED street-lighting projects. The first draft of the Model Specification was posted in April and the revised specification takes into account feedback from consortium members and the wider community.

The Model Specification contains two guidelines and is available at www.ssl.energy.gov/specification.html. The System Specification option for municipalities (Appendix A), is designed to maximize application efficiency and incorporates site characteristics such as pole spacing and mounting height. Meanwhile, the Material Specification option for utilities (Appendix B), emphasizes luminaire efficiency and does not consider site characteristics. The flexible format of the guideline allows users to modify default values to fit their local design criteria, which typically vary from city to city, and even from application to application within a given city. ◄

MORE: www.ledsmagazine.com/news/8/10/29

The city of Stamford, CT, has installed over 1000 cobrahead LED fixtures from GE, leading to an annual saving in energy costs of $146,000. Initially, LED street lights did not fare well in comparison with other products, but the newer GE products offered improvements in terms of a color temperature of 4300K, better uniformity and reduced glare (www.ledsmagazine.com/news/8/10/33).

Competition begins for Next Generation Luminaires

The US DOE has announced that its Next Generation Luminaires (NGL) SSL competition has been separated into two competitions, for indoor and outdoor products, due to growth in participation. Each competition will have its own judging panel, and the dates are now staggered. The intent-to-submit deadline for indoor NGLs is December 16, while final online submissions are due by January 13, 2012. Physical product samples are due by January 18, and winners will be announced in May. The DOE will send out its call for entries for the outdoor NGL competition in March 2012, with awards being presented in August 2012.

The competition is jointly sponsored by the DOE, the Illumination Engineering Society of North America (IESNA), and the International Association of Lighting Designers (IALD). In the NGL SSL competition, the judges examine lighted samples in their intended applications, as well as photometric data and other documentation. Evaluation criteria include the quality and quantity of illumination, energy efficiency, and serviceability. ◄

MORE: www.ledsmagazine.com/news/8/2/27

DOE releases promising results from Round 13 Caliper testing

The US Department of Energy (DOE) has completed Round 13 of product testing through its SSL Caliper program. Round 13 included three types of products: LED and benchmark high-bay luminaires, LED wallpack luminaires, and LED and benchmark 2x2-foot troffers. The summary report provides an overview of photometric performance results, compares the results with respect to similar products that use conventional light sources, and can be downloaded at www.ssl.energy.gov/reports.html.

On average, the round 13 LED luminaires showed a significant improvement in efficacy over LED luminaires tested in 2009 and 2010, with a minimum efficacy close to the average observed in 2009-2010. In addition, the variation in performance across the Round 13 LED luminaires was less than in 2009-2010 products; that is, there were smaller differences between minimum and maximum efficacy. A similar trend was observed with other performance parameters including initial lumen output, CCT and CRI. ◄

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...or it's lights out.

Strategies in Light Europe focuses on LED lighting and market transformation

Europe-wide policies related to solid-state lighting, as well as standardization, lighting quality, product labels and global initiatives, were among the many subjects tackled at Strategies in Light Europe 2011. **TIM WHITAKER** reports.

With more than 900 registered participants, the second annual Strategies in Light Europe 2011 conference and exhibition took place in Milan, Italy, on October 4-6, 2011. One new feature of this year's event was the introduction of parallel tracks on Market Transformation and Technology: the latter is covered in a separate article on page 29.

The LED lighting market in Europe is expected to grow at a compound annual growth rate of 41% between 2010 and 2015, according to the Keynote presentation by Vrinda Bhandarkar, Strategies Unlimited's Director of LED Lighting Research (Fig. 1). The replacement-lamps sector will grow most rapidly, as the impact is felt of Europe-wide legislation to remove inefficient lamps from the market.

Bhandarkar said that the global LED lighting market had revenues of $5 billion in 2010, of which 21% was from replacement lamps and the remainder from luminaires. In general, performance is improving and prices are falling, but there are "huge issues with low-quality, under-performing LED products," said Bhandarkar. She also said that standards setting is moving rapidly, but needs consistency between regions. Product quality, labeling, and standardization were all themes taken up by other speakers at the conference. Module standards, for example, were discussed by Andy Davies of GE Lighting (see www.ledsmagazine.com/news/8/10/10 and page 43 of this issue).

Also in the Keynote session, Dominik Wee and Arthur Jaunich from McKinsey & Company covered the main points of their recent report entitled "Lighting the way: Perspectives on LEDs and the global lighting market" (www.ledsmagazine.com/features/8/9/13).

A different perspective was provided by Simon Fisher, general manager EMEA for Indoor Luminaire Solutions with GE Lighting. Fisher, formerly an independent lighting designer, gave a talk entitled "Designing with LEDs: Redefining the Lit Environment" but he was keen to stress that LEDs are not the only game in town. "This is the Strategies in Light conference," he said. "It's important to develop LED solutions but not ignore other technologies… this is GE's strategy going forward."

Fisher advocated a holistic approach to product design, encompassing not only the components and application design, but also system integration and quality and reliability. "We need to have a solution-orientated approach to customer needs," he said.

Focusing on modules, Fisher said that connectivity is the "design key." While electrical compatibility reduces losses, good thermal contact sustains the LED lifetime and a strong mechanical connection maintains system integrity.

From a client perspective, good optical quality is key, said Fisher. Clients require a choice of beam angles, high light-output ratio (LOR), and repeatable performance. He then discussed GE optics that are compatible with the company's module products, and also revealed that GE will introduce module-based luminaires for indoor use in Q3 2012.

Fisher said that the lighting industry has changed recently: "Five or six years ago the discussion was mainly on capital cost, now return-on-investment is part of the discussion," he said. "This is important, because we're going to be asking people to spend more on their lighting than they do at present."

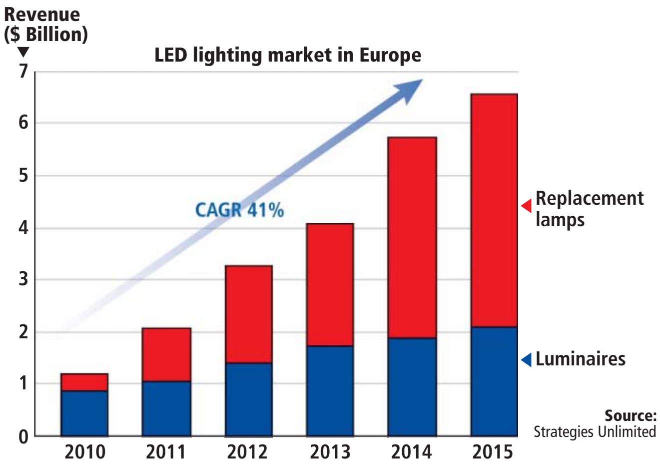

FIG. 1. Market forecast for LED lighting product sales in Europe.

European SSL policies and actions

EU policies for the promotion of SSL were discussed in detail by Paolo Bertoldi of the European Commission (EC) Joint Research Centre (http://re.jrc.ec.europa.eu/energyefficiency). Energy efficiency, including lighting, is a key component for reaching Europe's various climate and energy objectives by 2020. "Lighting is covered by many policies and actions, including the new strategy for SSL under the Digital Agenda for Europe," said Bertoldi. Among the activities are energy labeling, public procurement, the Eco-Design directive, and R&D programs in the current FP7 and future FP8 programs. The general aim is to support the most efficient technologies, and to introduce financial schemes that can overcome the barrier of high initial cost, a particular problem for SSL.

For many years, Europe has used the energy label, which grades appliances (including lamps) from A to G according to energy usage. This is now under review and is due to be revised by May 2012. Also, by setting minimum energy-efficiency requirements, the Eco-Design Directive has already had a major impact on the lamp market in Europe: 60W incandescent lamps were effectively outlawed from September 2011 (www.ledsmagazine.com/news/8/9/1). As Bertoldi explained, the second phase of the Directive, covering directional lamps, is due to be adopted by July 2012.

Lighting is also part of the Energy Performance for Building Directive, which is aiming to move towards "almost zero-energy buildings." However, feeling the need for a new impetus, the EC has put forward a proposal for a new Energy-Efficiency Directive (EED). One aspect would be to call on the public sector to lead by example, by purchasing products, services and buildings that have high energy-efficiency standards. Also, national energy-efficiency schemes could encourage utilities to distribute LED lamps to consumers, which Bertoldi described as a "great opportunity" for LEDs.

SSL is a central part of the Digital Agenda for Europe, which focuses on ways that information and communications technology (ICT) can stimulate the EU economy and benefit society. Specific SSL-related actions include a Green Paper, to be published later this year, and the large-scale SSL demonstration projects that should start at the beginning of 2012 (www.ledsmagazine.com/news/8/2/5).

In R&D, the EC is currently funding various programs in LEDs and OLEDs to the tune of around EUR 90 million, said Bertoldi. He also gave a number of project examples from the GreenLight program (www.eu-greenlight.org), an EC-lead voluntary initiative to reduce lighting energy use in commercial and industrial sectors and in street lighting.

FIG. 3. Dekra's certification mark for LED products.

Standards and CELMA guidelines

Standardization was a central discussion topic at SIL Europe, and was covered in detail by Kay Rauwerdink of CELMA, an organization that represents the European lighting industry for luminaires and components. CELMA has written a guidance paper on quality criteria for LED luminaire performance that focuses on two Public Available Specifications (PAS) documents that were recently published by IEC, the international standards body. IEC/PAS 62717 covers performance requirements for LED modules, while IEC/PAS 62722 covers LED luminaires, in both cases for general lighting.

Rauwerdink said the industry needs to transition from "comparing apples and pears" when it comes to commercial products, and instead make apples-to-apples comparisons. "Evaluating performance claims from different manufacturers cannot be done without using a standardized set of quality criteria that are measured in compliance with appropriate standards," he said. The CELMA guide suggests that users of LED luminaires should request LED luminaire specifications that are measured in compliance with the new IEC documents.

The documents were released simultaneously to ensure consistency between module- and luminaire-quality criteria. These criteria include a large selection of metrics, including input power, luminous flux and efficacy; luminous intensity distribution; CRI and chromaticity coordinate values, both initial and maintained; rated life (in hours) and associated rated lumen maintenance (in lux); and failure fraction (Fy), corresponding to the rated life of the LED module in the luminaire.

The CELMA guide explains the best methods for measuring these criteria, and why

FIG. 2. Module-based luminaires on the GE Lighting stand at SIL Europe.

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XLAMP ML-B & ML-E LEDs

OPTIMIZED FOR
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they are important. The document further explains the difference between lifetime claims based on lumen maintenance and luminaire lifetime claims that depend on component reliability.

LED Quality Charter

With the advent of the Eco-Design Directive to remove inefficient lamps from the European market, it was also deemed necessary to establish an EU LED Quality Charter (EU-QC), which was discussed at SIL Europe by Casper Kofod of Energy Piano. The EU-QC is a voluntary set of criteria that is intended to promote high-quality LED-based lamps, to raise consumer awareness and confidence, and to support promotion and procurement campaigns. Organizations can sign up to support the EU-QC, which is restricted only to LED lamps (not modules or luminaires), and to the residential, not commercial, sector.

Importantly, the EU-QC is not a quality label, although individual EU member countries can use the EU-QC to develop their own energy-efficiency labels, such as those introduced in the UK or in Kofod's home country of Denmark. The recommended criteria can by viewed by downloading the EU-QC document from the Residential Lighting section of the JRC website (http://re.jrc.ec.europa.eu/energyefficiency/).

Surprisingly, considering levels set by other similar programs, the EU-QC requirement for power factor (PF) is a minimum of 0.5. Kofod said that "the consumer has no advantages of high PF requirement, but disadvantages if an extra corrector-circuit is installed." The disadvantages come in terms of additional size, consumption, cost and other factors. He also said that lighting is currently 15-17% of domestic consumption, but in the future, when LEDs predominate, it will be only 2-4%. In this case, a high PF will only provide a marginal advantage: "We're talking about peanuts," said Kofod.

The Danish Energy Savings Trust (EST) has developed a quality label for lamps that meet EU regulations and the requirements of the EU-QC, explained Kofod. The lamps are self-certified, but the EST may perform random testing. Demark is at the forefront of green policy development, and recently announced that renewable energy sources would be required to cover all electricity and heat consumption by 2035, and all energy consumption by 2050. "There is a great future for LEDs to help slash energy consumption in Denmark," said Kofod.

However, not everyone agrees that EU member states should use the EU-QC to develop their own labels: one obvious potential consequence could be 27 different labeling schemes, one for each country. After Kofod's talk, Jürgen Sturm of the European Lamp Companies Federation (ELC) said that the European lighting industry "favors a Europe-wide approach, not fragmentation of labels on a country-wide basis."

Dekra performance mark

In his presentation, Jacob Neusink of Dekra, a quality and safety service-provider, asked: "Is there a need for an LED quality mark?" Not surprisingly, Neusink's answer was yes, given that Dekra has already issued its own LED performance mark (Fig. 3) to two Netherlands-based manufacturers, Lemnis Lighting and Ledned.

In explaining why the mark was introduced, Neusink quoted comments from Dekra's customers. He said that installers ask: "How can I be sure that the claims my supplier makes are true and how do I know that the products I buy will perform?" Meanwhile, manufacturers say: "I have a high-quality product with good performance, and my customer does not believe what I am saying." To address such comments, the Dekra mark sets performance levels for LED lamps, or modules, or luminaires.

Neusink pointed out that this is a "quality mark," where testing confirms that the performance reaches or exceeds the required levels set by Dekra, rather than a "truth mark," which simply confirms that the figures quoted by the manufacturer are accurate. It's important to note that Dekra offers its mark on a commercial basis, as distinct from government-sponsored programs such as the Danish EST label mentioned above (www.dekra-certification.com/en/led-performance-mark).

Global initiatives

The challenge of harmonizing SSL-related activities on a global basis has been taken up by at least two new organizations. The main aims of the International Energy Agency (IEA) Annex on SSL (http://ssl.iea-4e.org), as described at SIL Europe by Marc Fontoynont (Fig. 4), are to develop SSL quality assurance, to harmonize SSL performance testing, and to promote standards and develop

FIG. 4. Marc Fontoynont of Aalborg University discussed the IEA Annex on SSL, which aims to increase confidence in SSL, and to allow governments to prepare more ambitious policies for energy-efficient lighting products, for example relating to regulation and labels.

an accreditation infrastructure.

Meanwhile, the lighting industry is represented by the Global Lighting Forum (GLF), a gathering of lighting organizations from around the world representing over 5,000 lighting manufacturers and US$50 billion in annual sales. Jürgen Sturm, GLF general secretary, explained that the GLF aims to share knowledge of global lighting trends and legislative developments. It acts as a networking forum, developing joint industry positions and communicating these to government authorities and other stakeholders. One of its specific priorities is to "accelerate the uptake of LED and OLED lighting solutions," he said.

The benefits of SSL can be defined, said Sturm, in seven dimensions: energy, system, environmental, biological, business, design and quality. "The benefits over all other lighting technologies are unique, as only SSL combines all [these] dimensions," he said. In the biological dimension, Sturm said that "biological effective lighting" can influence our well-being and health, and that LED technology can help to manage the effects of demographic change, particularly for aging populations. However, he described the biological dimension as a "research topic" that often "raises a lot of tension."

In terms of business, Sturm said that "the characteristics and benefits of LED-lighting technology will lead to a change in business models in lighting." Models based on recurring revenues from replacement sales (i.e. lamps) will be superseded by models based on revenues over life including energy savings, but these will require innovative financing models. Sturm also said that LED lamp sales will peak in 2018 due to the growth in sales of integrated lamps and systems.

LED market in Russia

Evgeny Dolin, chairman of the Russian national association for manufacturers of LEDs and LED-based systems (www.nprpss.ru), said that the Russian LED market experienced very rapid growth of 50-60% in 2010. Even so, LED lighting fixtures were only about 5% of the total lighting market in 2010, with revenues of US $67 million. These figures are expected to increase to 15% and $333 million by 2015.

Dolin said that the Russian government is supporting energy efficiency and promoting the use of LEDs, while the biggest corporations are starting investment programs for LED lighting. One example is Russian Railways, which invested EUR 13 million in 2010, and EUR 24 million in 2011. Russia is trying to derive maximum benefit by switching directly from incandescent lamps to LED lamps, skipping the move to compact-fluorescent lamps (CFLs) that has been prevalent elsewhere in Europe.

Dolin's organization is of course involved in standards work, and he said that Russia has adopted the LED color-coordinates specified in the ANSI C78.377 standard. Also, October 2011 saw a national requirement come into play for a minimum efficacy of 50 lm/W for LED lighting. In the case of retrofit lamps, the minimum is between 50 lm/W and 70 lm/W depending on color temperature.

Dolin said that the organization is working to harmonize Russian measurement laboratories with international efforts. He pointed out that it is difficult for Russia to use US-developed standards without modifications, due to differences such as climate, and the nature of the electrical grid.

Business development

One member of the Russian LED manufacturers' association is Optogan, which has a major production facility in St. Petersburg and also recently opened an LED chip production facility in Landshut, Germany (page 14). Optogan's Markus Zeiler spoke about how the company has set about enabling fast adoption of LED lighting. One strategy is to set up a network of "technological and regional champions," he said, enabling each company to stay focused on its own technological areas of strength. One example is a technical cooperation on AC-LEDs between Optogan and Lynk Labs.

Another strategy is product modularity. "We need to reduce complexity and keep it simple for our customers," said Zeiler, offering a preview of a scalable chip-on-board (COB) concept which he said was analogous to Lego bricks. Finally, he discussed new sales channels and the value of franchising via remote business owners with regional know-how, as an alternative to setting up branch offices. "This keeps investment low, but enables global branding," he said.


M type New Products
MR16 4x1W
max.6W
270lm, 3000K CRI(RA)+80 (typcial)
Base Type / GU5.3, EZ10
Equivalent 50W Halogen
PAR16 4x1W
max.6W
Dimmable / Non-dimmable
300lm, 3000K CRI(RA)+80 (typcial 85)
Base Type / E11, E14, E26, E27, GU10, GU24
Equivalent 50W Halogen
PAR20 5x2W
max.9W
Dimmable / Non-dimmable
400lm, 3000K CRI(RA)+80 (typcial 85)
Base Type / E26, E27
Equivalent 60W Halogen
PAR30 8x2W
max.13.5W
Dimmable / Non-dimmable
600lm / 750lm,
2700K CRI(RA)+80 (typcial 85)
Base Type / E26, E27, GU24
Equivalent 75W Halogen
PAR38 12x1.5W
max.20W
Dimmable / Non-dimmable
1060lm / 1200lm,
2700K CRI(RA)+80 (typcial 85)
Base Type / E26, E27, GU24
Equivalent 100W Halogen
S type New Products
PAR16 4x1W
max.6.5W
Dimmable / Non-dimmable
315lm, 3000K CRI(RA)+80 (typcial 85)
Base Type / E11, GU10
Equivalent 50W Halogen
MR16 6x2W
max.15W
750lm, 3000K CRI(RA)+80 (typcial 85)
Base Type / GU5.3, EZ10
Equivalent 75W Halogen
LV G4
Ø:14mm
39
max.2W / 3W
Diameter(Ø) : 14mm / 20mm
90lm~100lm / 130~150lm
3000K CRI(RA)+80 (typcial 85)
Base Type / G4, T20, BA15S
Equivalent 60W Halogen
Candle Lamp
max.5W
Dimmable / Non-dimmable
250lm, 3000K CRI(RA)+80 (typcial 85)
Base Type / E12, E14, E17, BA15D, BA15S, B22, E26, E27
Equivalent 30W Incandescent Lamp
Classic P
Ø:50mm
92/94
E26 / E27
Outdoor IP65
max.5W
Non-dimmable
Base Type / E26, E27
Equivalent 20W Incandescent Lamp
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Sales : sales@bltc.com.tw
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Website : www.bltc.com.tw

SIL Europe technology track focuses on design, from optics to luminaires

The technology track at Strategies in Light Europe featured several presentations specifically aimed at selecting the right materials, optics, drivers and luminaire designs to best take advantage of LED technology, writes **LAURA PETERS.**

The Strategies in Light (SIL) Europe conference and exposition was held in Milan, Italy on October 4-6 and featured two days of discussion regarding the technological developments that go into solid-state lighting (SSL) products. A key message of these presentations rings true: LED lighting has matured to the point where luminaire design, whether it is for street lights, recessed downlights or integral replacement lamps, must bring together optimized drivers, optics and thermal design to best take advantage of all that LED technology has to offer. SIL Europe also featured parallel sessions in the Market Transformation track (page 21).

Luminaire design

Hans Laschefski, a consultant with Alanod Aluminium-Veredlung GmbH in Ennepetal, Germany, discussed a trend toward multiple reflectors as a means to control glare with high-power arrays of packaged LEDs. As the industry moves to smaller, denser arrays, glare increases and must be managed to provide an acceptable user experience. "When evaluating glare, people often talk about the average luminance, but since LEDs are spot-light sources, we should evaluate the spot illuminance, which is unfortunately difficult since the necessary measurement equipment is not typically available," he explained.

Laschefski showed several advanced reflector designs, all of which do not use lenses directly on the packaged LEDs but rather have the LEDs facing angled mirrors and reflectors. This helps to improve the light distribution, achieve better color mixing, and reduce glare. One of the advantages to having very-high reflectivity from aluminum-based alloys (95-98% reflectance with Alanod's Miro and Miro Silver reflectors) is that multiple reflections can eliminate the observation of a point-light-source by a person looking directly at the luminaire. For instance, in the Deflecto luminaire street light by AriannaLED of Padova, Italy (Fig. 1), the multiple reflections sufficiently scatter the light. "In these designs, you cannot even tell the light source is an LED," Laschefski said.

Laschefski stated that by separating the LEDs from the optics, the problem of lens aging can be controlled. He explained that when LEDs are closely coupled to optics in an air-tight environment, volatile organic compounds (VOCs) used in LED assembly

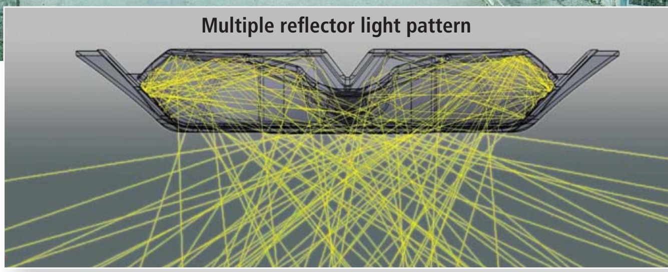

FIG. 1. Deflecto street lights utilize multiple reflections to eliminate point-light-source glare. Inset: Light distribution pattern from luminaire (source: AriannaLED).

LAURA PETERS *is a Senior Technical Editor with LEDs Magazine.*

may permeate the silicone dome. Light exposure causes the VOCs to oxidize, creating a discoloration of the silicone. If, instead, the LED emitters are not contained in an air-tight environment, VOCs have a chance to diffuse out and not interfere with the optical transmission.

The importance of visual comfort with LED luminaires was also emphasized by Giorgia Tordini, an optical designer with Philips Professional Lighting Solutions, who presented "The visual barrier: Designing the night appearance of an LED product." She defined night appearance as a person's visual perception when a light is first switched on in its application. Very high luminance from LED light (10^8 cd/m^2) can cause glare, which is an uncomfortable reaction to brightness. Tordini noted that glare is different from photobiological damage, which is caused mainly by light in the UV realm.

Tordini described the optical system of Philips' DayZone luminaire for office lighting, which has a task light in the middle and a separately-controlled outer ring-light for ambient lighting. The luminance of the outer ring is 3x smaller than that of the inner portion. The luminance limit for work spaces, according to British Standard EN-12464, is 1000 cd/m^2 at a 90-degree to 65-degree angle from the vertical axis.

Tordini explained that the optical design uses primary optics at the LED level (which is a multi-LED package) to convert the light distribution into a controlled beam. The plastic optics consists of a microlens array fabricated from polymethylmethacrylate (PMMA). This serves to minimize chromatic aberration due to first-order interference, while enhancing scattering to allow a uniform visual appearance of light. Transmittance through the PMMA film is 92%. This patterned film is available in roll-to-roll sheets and therefore is flexible to apply in different shapes and sizes. Beyond this primary optic, a secondary optic, consisting of a hollow prism ring, modifies the light distribution and controls the light level transmitted to the target surface.

Achieving omni-directionality

Markus Hofmann, a senior development engineer with Osram GmbH of Munich, Germany, presented the pros and cons of four different approaches to achieving omni-directionality with integral lamps for residential applications. He said that omni-directionality can be achieved using light guides, reflectors, a remote phosphor or a three-dimensional (3D) arrangement of LEDs.

The key advantage of using light guides is that an incandescent-like bulb in appearance can be achieved. However, there is great light loss and low efficiency associated with this approach, and meeting Energy Star specifications (Fig. 2) is very difficult. As a result, light-guide approaches are currently limited to low-lumen-output, design-driven applications.

Meeting Energy Star requirements is much more practical if reflectors are used inside the bulb to direct the light. Another advantage is that a classical bulb design is possible. Hofmann said that reflectors inside retrofit lamps currently work best for lamps with medium lumen output.

When it comes to achieving high lumen output, the remote phosphor approach is suitable because light losses are low and the phosphor is compatible with external aluminum fins that function as the heat sink. The downside, particularly in today's market according to Hofmann, is the high cost of remote phosphors that contain rare-earth materials. Assembly of the bulbs is also a more complex process, he said, but Energy Star requirements can be met.

Alternatively, a 3D arrangement of the LEDs can meet high-lumen-output needs and also meet Energy Star requirements. Hofmann stated that 60W-equivalent (850 lm) and 75W-equivalent (1060 lm) lamps that meet Energy Star requirements with good CRI, CCT and lifetime have been fabricated using 3D approaches. "Realization of 100W-equivalent lamps with 3D LED arrangements will be coming soon," he added.

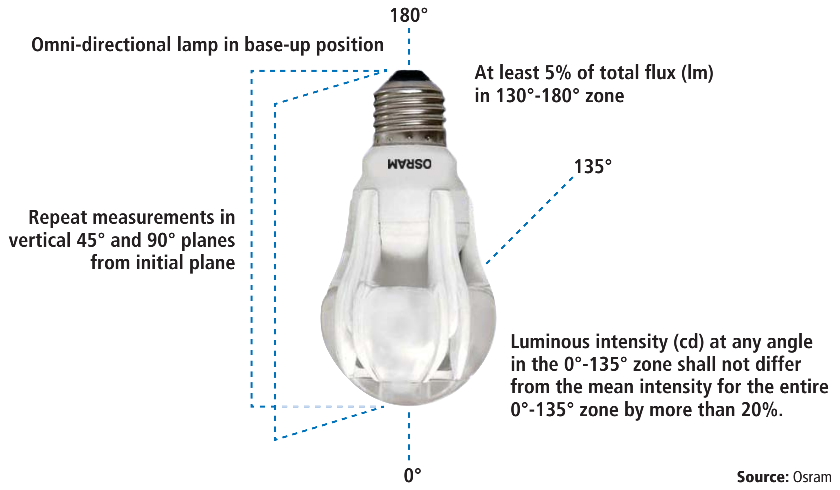

FIG. 2. Omnidirectionality is one of the more difficult requirements of Energy Star.

Another presentation in the same session revealed a less-traditional approach to fabricating and marketing retrofit lamps. Martijn Dekker, CTO of Lemnis Lighting, an LED lamp maker based in the Netherlands, announced that Lemnis has entered into a multiyear commitment with a large retailer to develop and market cost-effective LED lamps. The first products are 400-lm and 200-lm lamps, which will be introduced in European stores soon. Although not confirmed by Dekker, the retailer is thought to be Sweden-based Ikea. While Dekker noted that the lamps do not meet Energy Star requirements and have a shorter lifetime rating (20,000 hours) than most replacement lamps, the overriding goal in development was achieving acceptable consumer price points while delivering quality lamps.

"The price target for these lamps was less than €9.99 ($13.77) for the 45W-replacement lamp and €6.99 ($9.64) for the 25W-replacement," explained Dekker. The 400 lm lamp offers a CCT of 2700K and a CRI above 85. The LED design combines two red LEDs with four phosphor-converted blue LEDs, but the company plans to move to a phosphor-only array in 2012 products.

Dekker referred to the novel business agreement with Lemnis' partners as a virtual vertically-integrated company involving the retailer, the lighting manufacturer, an LED fabrication partner in India and other supply partners. These companies are sharing the project risk to achieve long-term volume sales of LED lamps priced at $8/klm at the lamp level. "A non-integrated supply chain leads to a stacking of profit margins through the supply chain," he said, which limits the industry's ability to hit low commercial price points.

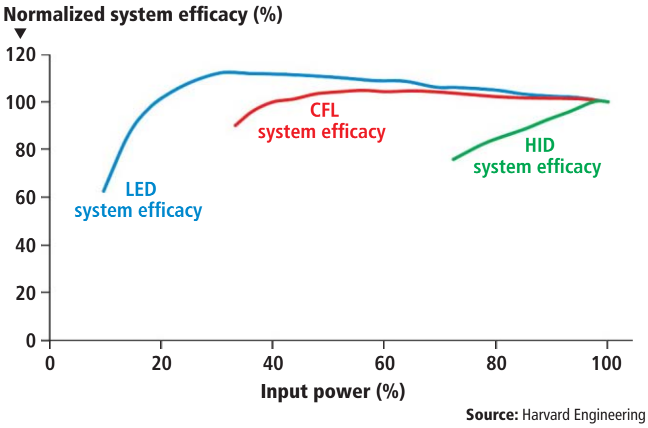

FIG. 3. System efficacy of various technologies when dimmed.

Optimizing optics

Among all retrofit lamps, perhaps the LED-based MR16, because of its small size, is one of the more difficult to design. Mike Bean, head of design and development at Carclo Technical Plastics (CTP), a designer and manufacturer of optical components based in London, UK, described the MR16 halogen lamp as a tough act to follow. "MR16 design using LEDs is quite a challenge…despite the fact that there are several commercially-available replacement lamps, most do not come close to the 50W halogen in performance," said Bean. According to the US Department of Energy's (DOE's) Caliper testing of LED-based MR16 lamps, while 50W-equivalent performance is the goal, typical measurements are closer to those of 25W- or 35W-equivalent lamps (Fig. 3).

To achieve the required center-beam intensity and a narrow overall beam angle, one key to the lamp design is to combine smaller LEDs with focusing optics. Smaller LEDs and total internal reflection (TIR) optics allow the beam angle to be reduced from 40 to 27°, while still delivering 2250 cd at 27°. In this design, the 30-mm-diameter optic was optimally placed 15 mm above the multi-chip LED source, allowing the reflector to fit within the specified geometry of the MR16 lamp (per ANSI C78.24 specification).

Bean said that in addition to helping with the beam angle, the multi-chip LED approach also affords more driver options, including serial or parallel operation. The reference design used a Diodes 1.5A driver, a Cree MT-G LED package and a Carclo TIR optic to deliver an initial output of 611 lm at 10.1W (61 lm/W).

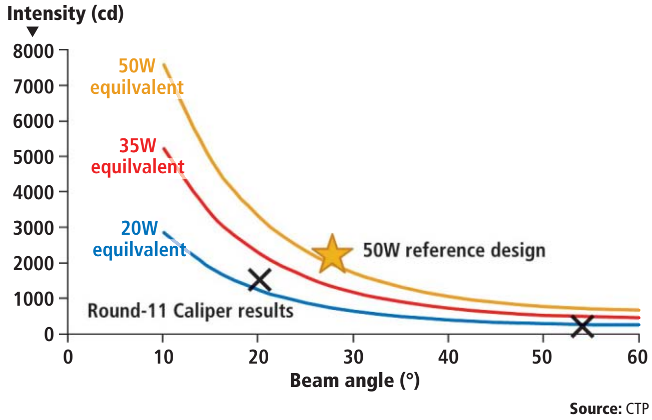

FIG. 4. Energy Star center-beam intensity targets for MR16 lamps, showing seleted Caliper results and reference design.

SIL presentations also addressed luminaire design elements related to product life. Klaus Reinartz, director of the global LED program at Bayer MaterialScience LLC (BMS) in Leverkusen, Germany, explained how advanced polycarbonate materials can offer increased transparency in a thinner optical lens with a much smaller yellowness index than previous-generation materials. The company's Makrolon products are stable against 90-degree LED light with an intensity of 46 lm/cm^2, and the company is currently performing trials at higher temperatures and light intensities.

Advanced polycarbonate materials can be injection-molded into a wide variety of shapes and sizes to meet LED light transmission, shaping and diffusing needs. One of the newer developments that Reinartz described is thermally conductive grades of polycarbonate (up to 40W/m·K), which can be custom-molded to act as a lighter, more flexible heat sink than aluminum options.

Driver and dimmer design

Rasib Khan, an engineering manager with Harvard Engineering plc, based in Wakefield, UK, presented a comparison of dimming system efficacy among LED,

CFL and high-pressure sodium (HPS) light sources. The greatest energy savings are associated with using LEDs and appropriate dimming levels. As a comparison, HPS sources can only be dimmed to approximately 40% of their maximum lumen output and system efficacy is compromised with all levels of dimming (Fig. 4). In other words, higher input power is required to produce the same lumen output. For example, a 60W Cosmo luminaire with Harvard DALI ballast at a 50% light-output level requires approximately 67% of input power.

System efficacy is better with CFLs, where high efficacy is maintained down to about 40% lumen output levels. For a typical fixture, 30% lumen output requires approximately 35% input power. However, below a 40% dimming level, CFLs suffers from cathode and driver inefficiencies.

LEDs are easier to dim and hypothetically can be dimmed readily to as low as 1%. System efficacy is excellent from 100% to around 20% of light output. For instance, a 50W-equivalent luminaire with Harvard 700 mA DALI driver at 50% light output only requires 44% input power. With current technology, system efficacy becomes impacted by driver efficiency below 20% of light output.

According to Khan, simple analog switch dimming (0-10V) works well on a small scale, but requires too much cable for large-scale implementations. More expensive control options such as DALI can provide greatwer flexibility for projects of all sizes and are re-configurable. However, DALI and other approaches require further work to fully maximize control efficiency and power factor over the control range. Ultimately, Khan expects the industry to move to wireless intelligent control systems capable of plug-and-play operation.

Also in the drivers session, Steve Roberts, technical manager at Recom, Austria, discussed the significant impact that high temperature can have on luminaire reliability. He made several design recommendations for minimizing temperature increases in LED luminaires including mounting the LEDs so that they have low thermal impedance to the heat sink and mounting the driver away from the LEDs and heat sink. The heat sink should be designed for the most efficient size/efficiency ratio. Thermal derating can be used to reduce the LED current if the junction temperature approaches specification limits. Roberts further recommends limiting thermal cycling and allowing for a single LED failure in multiple LED installations. Input-output voltage transients can be managed by using spike protection as well as short input cables with relatively-longer output cables.

Regarding triac dimmers, Roberts recommends that engineers consider the timing of triggers and the effect on the driver electronics. Rather than separate AC/DC ballasts, a centralized DC-power-distribution approach should be used with a large AC/DC power supply feeding multiple DC/DC LED drivers. Finally, Roberts recommends consideration of the reliability of every component in the luminaire system.

Designing power-distribution networks

A presentation by Marc Ottolini of iSotera Ltd of Hoddesdon, UK, considered the utility of DC-power-distribution networks for SSL. Ottolini compared four scenarios – the legacy architecture, a centralized DC Star approach where one AC/DC supply feeds DC/DC drivers, a DC grid where low-voltage DC leaves the AC/DC supply, or a centralized high-frequency AC (HFAC) bus approach. For each approach, he looked at simplicity of installation, cost, safety, reliability and controllability.

He concluded that there is no compelling benefit to implementing a full-DC-power-distribution system for LED lighting. However, a centralized (bulk) power processing approach can be advantageous if up and down (2-stage) conversion can be made efficient enough, which depends on the diversity of the LED load. He finalized with the statement that energy-efficiency benefits alone (2-5%) do not provide enough impetus to begin setting new standards.

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The elusive "life" of LEDs: How TM-21 contributes to the solution

The newly-introduced TM-21 document presents a method for lumen-depreciation projection based on LM-80 data, enabling LED lifetime extrapolations beyond 6000 hours, says **ERIC RICHMAN**.

In August 2011, the Illuminating Engineering Society (IES) published the TM-21 document entitled "Lumen degradation lifetime estimation method for LED light sources." TM-21 is the IES-recommended method for projecting lumen degradation of an LED package, array or module based on data collected according to LM-80.

The lighting community expects TM-21 to become the standard method for projecting useful LED lighting product life at realistic operating temperature. This article presents the development process behind TM-21, and clarifies how and when to apply the lifetime extrapolation method to arrive at reasonable and useful estimations.

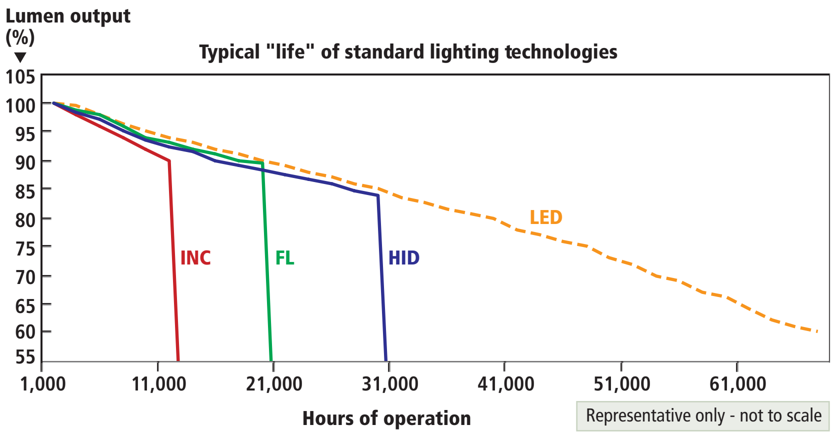

FIG. 1. Lumen degradation and failure behavior for incandescent (INC), fluorescent (FL), high-intensity discharge (HID), and LED lamps.

Why TM-21 and why now?

We are all familiar with the very real but sometimes exaggerated long-life attributes of LED technology. Not the least of these is the potential for very long life that helps make it an attractive design choice. The trick has been and continues to be how to measure or estimate this longevity to provide assurance to users of this technology's reliability (life) compared to other options. We also understand that the overall reliability of a complete LED lighting fixture can be affected by the reliability of individual product components (driver, lens, etc.) and should be accounted for in lifetime estimations.

The useful life of standard lighting technologies is defined as the time to filament or cathode failure. For most of these lamps, the time period prior to failure exhibits acceptable levels of light output, as shown with the solid lines in Fig. 1. This makes it easy to determine when to replace the lamp.

However, LEDs do not have filament burnout that conveniently announces the end of life (dashed line in Fig. 1). Further, the rapid development of the technology and the desire to bring products to market in a timely manner does not allow for actual testing verification of the long lives claimed (100,000 or even 35,000 hours). As a result, the industry has come to accept a definition of the end of the useful life of an LED as the point when it no longer provides a specified level of light output.

And finally, the life and performance of LED lighting products depends greatly on excess heat retained at the diode. This is why LEDs require testing at multiple temperatures such that when a source is installed in a luminaire, its actual operating temperature can be measured and lumen depreciation of the product can be derived.

Therefore, to serve the solid-state lighting industry, the Technical Procedures Committee (TPC) of the IES proceeded to develop appropriate tests for use in rating LED product longevity. The initial need was a measure of the basic lumen degradation of LED source components identified by a module, package, or array of diodes and this came in the form of LM-80. Importantly, LM-80 only specifies how to measure lumen depreciation to a minimum of 6000 hours (but recommends testing to 10,000 hours or longer). LM-80 stops short of using that data to estimate any depreciation after that, which is where TM-21 comes in.

The TM-21 working group (WG) as part of the IES TPC was formed to develop the lumen depreciation projection method and spent over three years exploring many options. The WG evaluated various projection options starting with an analysis of various mathematical, engineering-based models to provide effective depreciation fit and a useful projection method.

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Next, the WG analyzed LED lumen maintenance behavior using over 40 sets of LM-80-08 test data (20 sets with 10,000 hours or more) collected from four major LED manufacturers. The working group also examined the accuracy of proposed projections using various proposed models and LM-80 data that extended up to 15,000 hours.

Insight from LED manufacturers' data

This analysis showed that the LED lumen depreciation trends often change after 6000 hours in one way or another and there is no reliable and consistent approach to predict such trends from 6000-hour data points.

$T_{s,1}$, (°C)	55
$T_{s,1}$, (K)	328.15
a_1	1.684E-06
B_1	0.9639
$T_{s,2}$, (°C)	85
$T_{s,2}$, (K)	358.15
a_2	3.354E-06
B_2	0.9525
E_a/k_B	2699
A	6.283E-03
B_0	9.582E-01
$T_{s,i}$, (°C)	70
$T_{s,i}$, (K)	343.15
a_i	2.413E-06
Projected L_{70}(Dk)	130,131
Reported L_{70}(Dk)	>60,000

TABLE 1. Parameters of interpolation using 10,000 hours of LM-80 data for in-situ case temperature $T_{s,i}$ of 70˚C.

Even a 10,000 hour stream of data is often not sufficient to provide rigid statistical confidence in an extrapolation of a decay curve out to large numbers such as 35,000 hours.

In addition, the LED industry understands that degradation associated with effects other than the diode itself tends to manifest earlier in life rather than later. The WG concluded that the most reasonable approach to extrapolation of lumen degradation was to avoid using any initial variable data. This initial data variability is commonly associated with an early rise in output followed by the eventual decline, identified as a hump in the data. Instead, by utilizing a fit to the later data streams (Figs. 2 and 3), a more accurate representation of the product's lumen degradation curve is obtained.

What TM-21 is and is not!

First, TM-21 does not determine a traditional life or time-to-failure like we are used to for other lighting sources.

What TM-21 does provide is a projection of the lumen maintenance of an LED source (package/array/module) based on data collected according to LM-80. This projection information can then be used to project the expected lumen degradation of the light source as part of a complete system (fixture). It is important to note, however, that TM-21 is not a complete lifetime estimation tool.

TM-21 does make use of all data provided in an LM-80 test format. LM-80 requires 6000 hours of data at 1000-hour increments, but the TM-21 WG determined that longer streams of data and data taken at shorter intervals (less than 1000 hours) will provide for a better estimate. The methodology first normalizes the provided data to 1 (100%) at 0 hours and averages each point for all samples of the device for each test condition (temperature).

TM-21 also provides a suggested sample size of 20 LED packages, arrays or modules. Based on an evaluation of the uncertainty of measurement at various sample sizes, a larger sample size (30) does not significantly increase the uncertainty and smaller size (10) would significantly reduce the uncertainty of the degradation estimates.

How it works

As discussed previously, later data tends to exhibit the more characteristic decay curve that is of interest. So for 6000 hours of data (LM-80 minimum) and up to 10,000 hours, TM-21 applies curve fitting to the last 5000 hours of collected data. For collected data greater than 10,000 hours, TM-21 uses the last half of the data.

The method then applies an exponential least-squares-curve fit to the data:

$$\Phi(t) = B \exp(-\alpha t)$$

Where:

t = operating time in hours;

$\Phi(t)$ = averaged normalized luminous flux output at time t;

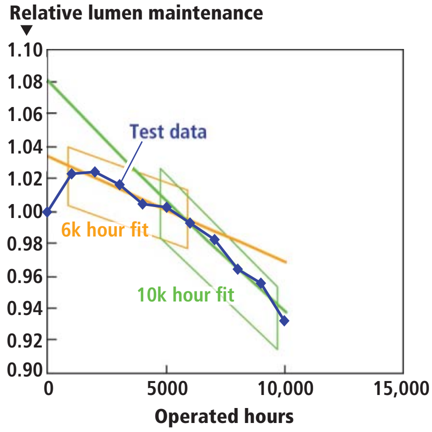

FIG. 2. Later TM-80 data points provide a better estimate of long-term lumen maintenance.

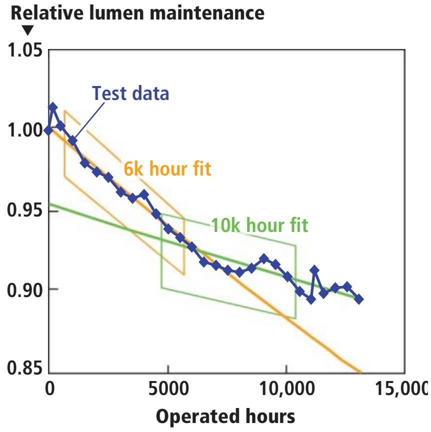

FIG. 3. As also shown in Fig. 2, a fit to LM-80 data collected later provides the best estimate of lumen maintenance for LEDs.

B = projected initial constant derived by the least-squares-curve fit;

α = decay rate constant derived by the least-squares-curve fit.

And a projected lumen maintenance value is derived using:

$$L_p = \ln(100 \cdot B/p)/\alpha$$

Where:

L_p= lumen maintenance life in hours where p is the maintained percentage of initial lumen output

This process can accommodate any user-identified level of light output (i.e. L_{70} or L_{50}). If the desired light output level is reached during the course of LM-80 testing, then that time value is reported.

During the development of the method, it

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became clear that limited 6000-hour data can produce mathematical results that are not necessarily rational or believable. For example, flat or increasing delay curves would be unreasonable for LED products. Clearly, reasonable limits on predictions are needed.

The WG analyzed 40 sets of data to determine model-fit uncertainty and its relationship to prediction limits. The recommended extrapolation limits are:

- For a sample size of 20 units, the maximum projection = 6× the test duration
- For a sample size of only 10 units, the maximum projection = 5.5× the test duration.

TM-21 also provides for interpolating between test data curves to determine the actual degradation characteristics the product will exhibit when installed in a fixture where heat conditions will change. When the in-fixture measured temperature is within the LM-80 test temperatures (55°C, 85°C, and manufacturer chosen), then TM-21 prescribes the use of the Arrhenius equation to interpolate between test temperatures. The Arrhenius relationship accounts for the temperature effect on decay rate constants, which is critical for temperature-dependent LEDs.

For instance, Table 1 presents an example of an extrapolation with an in-fixture temperature of 70˚C with the graphic

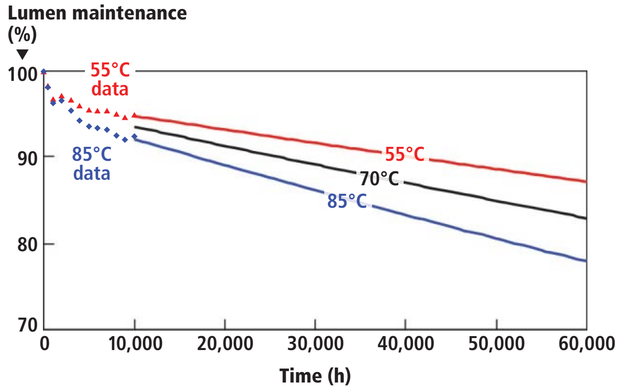


FIG. 4. Degradation curves from measured data and from in-fixture interpolation at 70˚C.

results in Figure 4. Extrapolation outside of LM-80 test temperatures is not recommended or supported.

The TM-21 document provides a nomenclature for results to provide uniform reporting between products. The general form is:

L_p (Dk)

Where:

p = the percentage of initial lumen output that is maintained

D = the total duration of the test in hours divided by 1000 and rounded

For example:

L_{70}(6k) = 34,000 hours represents results at 6000 hours of test data

L_{70}(10k) = 51,000 hours represents results at 10,000 hours of test data

L_{70}(6k) > 36,000 hours represents results with the 6 times rule applied

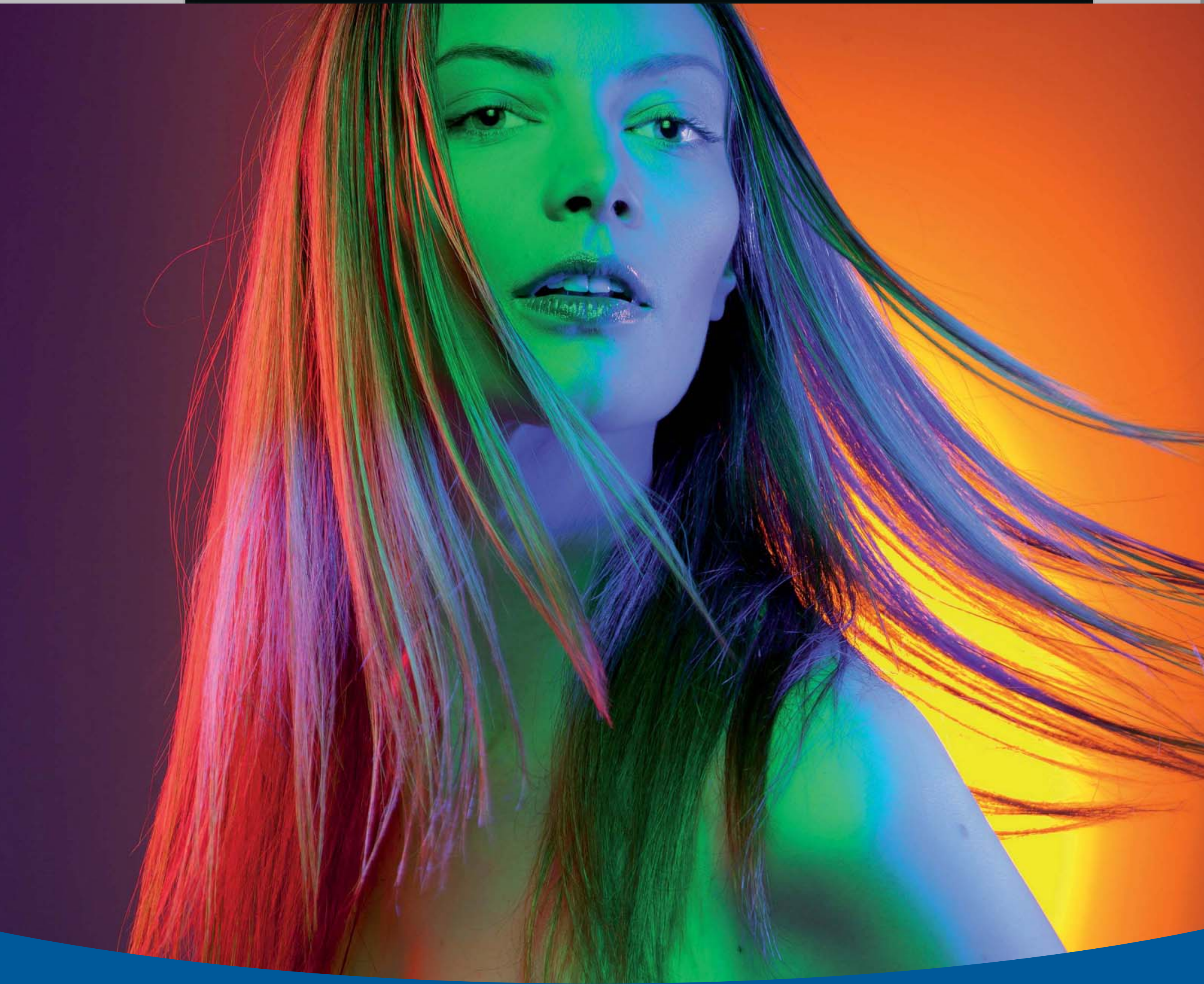
L_{70}(4k) = 4400 hours represents results at a value reached during testing.

The methodology is provided in the TM-21 document as formulas and procedure but can be developed into spreadsheets or other software-tool formats. The method can also be misapplied in software programs, so a set of examples is included for users to check the results.

Where does TM-21 fit in the industry's characterization of LED life?

TM-21 is the result of extensive analysis and it presents a realistic method of projecting lumen maintenance of LED packages, arrays and modules in actual operating conditions. However, diode lumen degradation over time is only one of many possible LED-product-degradation mechanisms. The industry is seeking to better understand component reliability metrics such as driver life, and the effect on lighting product performance.

The TM-21 document may be applied in various ways. It can be used by laboratories, manufacturers, or others as defined by the program or organization requiring its application. TM-21 data can be requested as part of LM-80 testing or applied by the manufacturer of an LED product. TM-21 is expected to achieve widespread use by organizations and program certifications (e.g. Energy Star) as part of their required documentation of performance.



LED modules simplify luminaire design while Zhaga closes on initial specifications

LED-based modules for SSL can simplify product design and even make products field-upgradeable, reports **MAURY WRIGHT.** Zhaga standards will yield interoperable modular products from multiple vendors.

Modular LED light engines can allow luminaire makers to develop solid-state-lighting (SSL) products without facing the technical details of electronic driver circuits, LED selection and configuration, thermal management, and optics design. Manufacturers should understand the basics and importance of these product-design disciplines, but a proven module vendor can ensure the details get proper attention. The modular approach can speed product development and enable upgradeable products. Today, the available modules are proprietary to each manufacturer, but standards such as those the Zhaga Consortium has under development will yield interoperable modules from multiple vendors.

Modular LED light engines are quickly gaining favor. A number of major LED manufacturers and LED-lighting companies including Cree, Osram, Philips, and GE Lighting have modules available for a variety of applications ranging from indoor downlights to outdoor street lights.

Philips Fortimo DLM modules in Hoffmeister luminaires light the parliament building in Dusseldorf.

Let's start by defining some terminology for the scope of this article because words such as light engine and module aren't used consistently in the SSL industry. Zhaga (see www.ledsmagazine.com/features/8/11/4 for background information and an update on Zhaga activity) defines a light engine as the combination of an LED module and its associated control gear or driver.

Zhaga sticks with the term light engine whether or not the driver is integrated into a modular package along with the LEDs. Zhaga is developing specifications for light engines with integrated control gear and light engines with separate control gear. In the latter case the driver is also essentially a packaged module or subsystem.

For this article, we will use the terms LED module and LED light engine interchangeably and simply specify whether a driver is integrated in the module. Indeed the module makers mentioned above use the term module whether or not a driver is included. We will include discussion of modules that fasten into a luminaire using screws or other fasteners, and modules that use some form of snap-in or twist-lock mounting mechanism. The latter are sometimes referred to as tool-less or tool-free designs, and Zhaga uses the term socketable if the module can be installed without tools.

The modular advantage

Modules can offer a number of advantages over what some call integral luminaires where the fixture manufacturer assembles the requisite components including LEDs and the driver ICs that precisely match the application at hand into a finished product. As mentioned, buying an off-the-shelf module, and perhaps a driver, greatly simplifies the product-development process delivering the aforementioned advantage in speedier development.

Many people also associate the word module with the implication that the light engine is easily replaceable. In contrast, many integral luminaires on the market require a complete fixture replacement if the light engine fails of if an upgrade to greater lumen output or perhaps a different color temperature is desired. Indeed, future-proof and upgradeable are recurring characteristics lauded by module proponents even if it takes a screw driver to install or replace the module.

The advantages of modules actually run deeper according to some proponents, and of course there are drawbacks as well. Bridgelux and Molex were among the first companies to offer a socketable module with the jointly-developed Helieon product introduced last year (http://www.ledsmagazine.com/news/7/3/21). A press-and-turn action locks the Helieon module into a receptacle socket mounted in the luminaire. The mating action both secures the module in place and makes the electrical contact.

Supply chain benefits

Bridgelux vice president of marketing Jason Posselt said that the modular approach can offer manufacturers great benefits in the supply chain. He said that a single module form factor can be used across a wide range of fixtures. Moreover Posselt said, "There is no need for the luminaire maker to inventory large numbers of modules." Instead the luminaire manufacturer can build various fixtures that are customizable in terms of light output, color temperature, beam pattern, and other characteristics based on the particular modular light engine mated to the fixture. Posselt said, "The manufacturer can deliver the fixture and module separately."

According to Posselt, the typical bill of materials for an SSL luminaire is about a third attributable to the LED assembly, a third to the driver, and a third to the remainder of the fixture. Eliminating the need to buy and stock an inventory of components that are needed to build the LED assembly can reduce the investment in inventory significantly.

The first generation of Helieon modules did not include a driver. At Lightfair 2011 in May, Bridgelux and Molex introduced the second-generation of Helieon with an integrated driver. Posselt said, "The DC version didn't completely solve the problem we were trying to address." That problem was fully simplifying the SSL design process. Posselt added, "The driver is a big issue for luminaire makers."

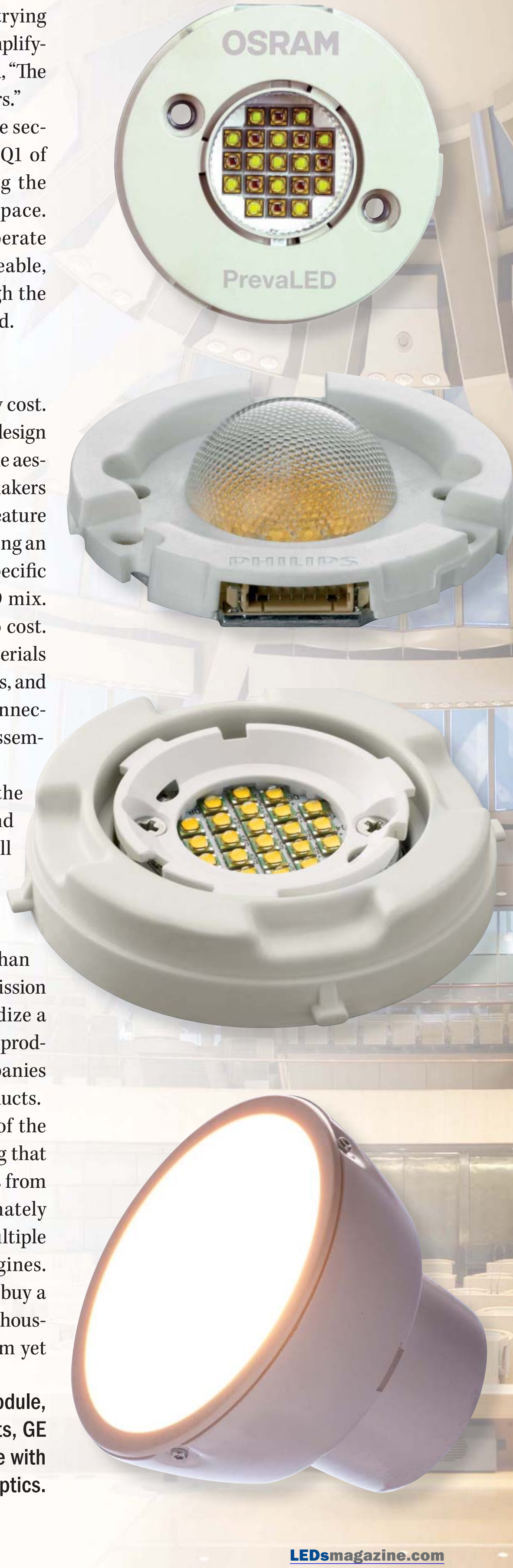
Bridgelux and Molex plan to ship the second-generation Helieon products in Q1 of 2012. The companies are fine tuning the driver design to fit a very confined space. And because the new version will operate from line voltage and be user replaceable, the companies are proceeding through the process of getting the module UL listed.

The tradeoffs

The downside to modules is principally cost. A module may also restrict some of the design elements in a luminaire and therefore the aesthetics. And with modules, luminaire makers will never have complete photometric feature freedom, for instance in terms of choosing an exact lumen output or generating a specific color temperature with a custom LED mix. But the biggest tradeoff comes back to cost. Modules invariably introduce extra materials such as plastic or metal module housings, and complex electrical and mechanical connectors. Moreover the cost of separately assembling the module is an adder.

Module proponents believe that the technology will ramp SSL uptake and the greater manufacturing volumes will reduce the cost premium. Moreover the modular approach will likely resonate with consumers that are accustomed to changing light bulbs rather than replacing fixtures. And that's Zhaga's mission to develop specifications that standardize a modular approach to interoperable SSL products rather than having multiple companies building similar but incompatible products.

Menno Treffers, secretary general of the Zhaga Consortium, said "The key thing that we want to achieve is that the products from multiple vendors fit together." Ultimately Zhaga specifications should allow multiple vendors to make compatible light engines. Luminaire makers will also be able to buy a driver from one company, a mechanical housing from another, an LED module from yet



From top: Osram PrevaLED module, Philips Fortimo SLM for spot lights, GE Infusion module, Cree LMR4 module with integrated driver and optics.

another, and optics such as a reflector from still another.

Zhaga's process and progress

Zhaga's approach is based on defining what it calls the mechanical, thermal, electrical, and photometric interfaces of a light engine. The mechanical elements include shape, dimensions and mounting scheme or socket. The electrical interface includes the connector and AC- or DC-voltage specification. The thermal interface defines how cooling elements in the luminaire housing mate to a thermal surface on the module. The photometric interface includes elements such as the size of the light emitting surface, lambertian or shaped-beam pattern, and uniformity of light on the task plane.

The Zhaga process includes proposal, merger, specification-development, and published-specification stages. Members of the consortium that are interested in a particular type of module submit proposals based on their own R&D. Elements of the proposals are merged by task forces and then converted into specifications by working groups.

Zhaga has approved three light engine specifications thus far:

- A socketable LED downlight engine with integrated control gear
- An LED spotlight engine with separate control gear
- A socketable LED light engine with separate control gear.

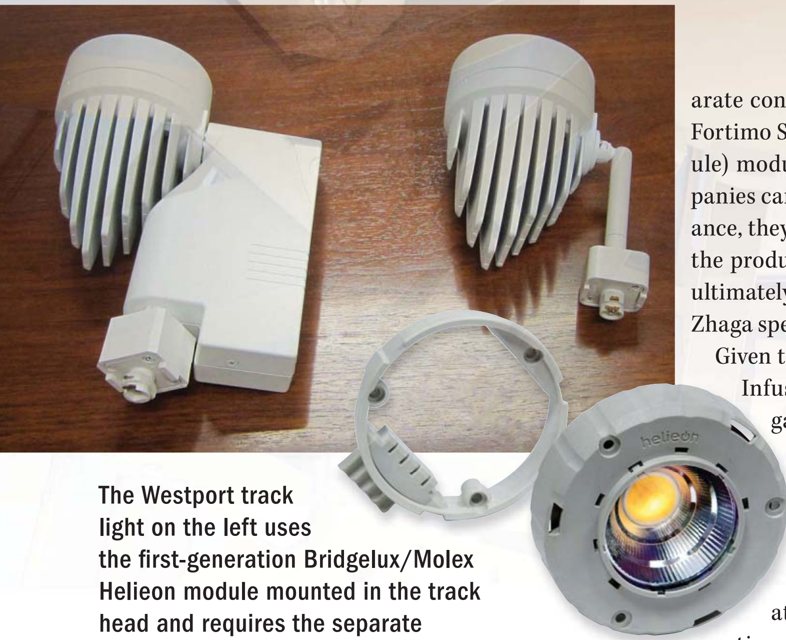
The specifications have not been made available to the public although members of the consortium have free access. At this time no company can claim official Zhaga compliance for a product because the consortium is still working on compliance testing procedures. Treffers says that the first products to carry the official Zhaga logo are months away from the market as opposed to a year, but he can't offer a more specific projection.

Zhaga has four other specifications in development including a street light module, and a rectangular module – a number of which may be connected together for indoor linear lighting. There are other proposals at earlier stages of the Zhaga process.

Designed for Zhaga

In reality, there are already modules on the market that are based on Zhaga standards, or more correctly that were the basis for a couple of the completed Zhaga specifications. Remember that Zhaga's process is based on merging proposals from multiple companies. When asked if individual companies were behind any of the Zhaga specifications, Treffers said, "In all cases there were multiple companies involved." Still it's pretty clear that in some cases a single company has provided the majority of the technical input.

For example, photos that Zhaga has published make it clear that the socketable LED light engine with separate control gear is essentially GE's Infusion module. And the LED spotlight engine with sep-



The Westport track light on the left uses the first-generation Bridgelux/Molex Helieon module mounted in the track head and requires the separate rectangular driver mounted on the track arm. The reference design on the right uses the new AC-powered Helieon module that's installed in the track head and eliminates the need for the external driver.

arate control gear is Phillips' Fortimo SLM (spot light module) module. While the companies can't yet claim compliance, they have both said that the products are designed to ultimately be compatible with Zhaga specifications.

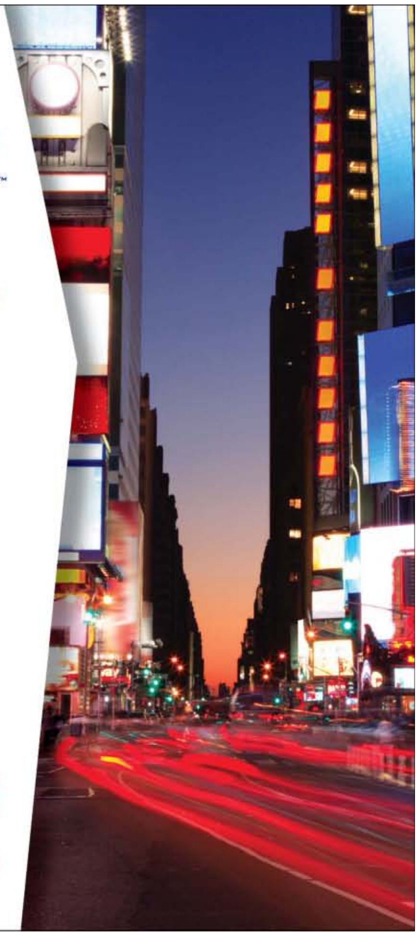
Given the clear tie between Infusion and one of Zhaga's completed specifications, we asked Steve Briggs, vice president of marketing and product management at GE Lighting Solutions (the LED-focused business within GE Lighting) about the collaboration in the Zhaga process. Briggs said that multiple companies were involved in proposing concepts and added "Our Infusion module has been shaped and changed by the Zhaga process."

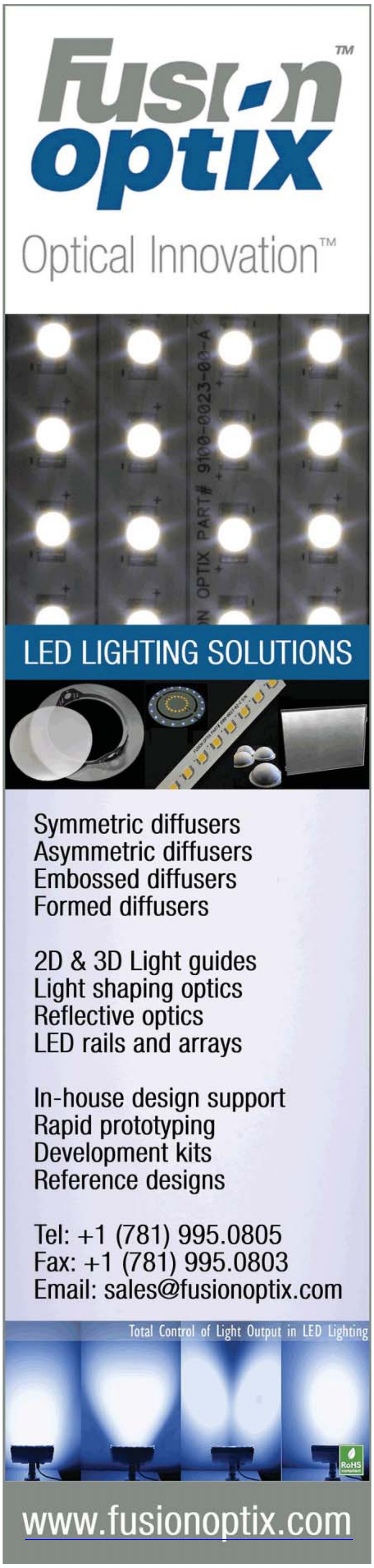
As an example Briggs pointed out a design change that happened between the announcement of the second-generation Infusion back at Lightfair in May and the production modules that just commenced shipping in Q3. The mechanical design now includes mechanical mounting tabs on the front of the module that allow easy connection of reflectors or other optics.

So in some cases the multiple parties that participate in the Zhaga proposal-merger process may have interest in different elements of a luminaire design as opposed to being companies with competing module concepts. For example, Posselt said that while Bridgelux is a Zhaga member, that the company's primary goal in the endeavor is to "make sure our core product, the LED array, is not precluded from use in Zhaga-compliant products."

Too many or just right?

The question that arises with the Zhaga





progress to date is one of how many standards do we need. In lighting, there are clearly different requirements for modules in different applications. For example street lights will need larger modules with space for more LEDs. Downlights and spot lights will need small circular modules and linear fixtures long and slim modules. Still it's already evident that Zhaga will publish specifications that overlap and that may be bad for an industry looking for standardization to ramp production volumes of interchangeable products.

The opposite pull of the desire for standardization and the need for optimum luminaire design for a specific application is a tough conundrum. Companies have vastly different philosophies and that is surely playing out within Zhaga. To understand the philosophical extremes, let's take a closer look at the existing module products available from GE and Philips.

Philips' approach is a module for every application or maybe more than one. Andrew Lindstrom, director of SSL at Philips Lighting, said, "We have competing lines across the board." Consider street lighting where we have published numerous stories about applications that use Philips' LEDgine module (http://www.ledsmagazine.com/news/8/9/10). That module uses LEDs in an array with TIR (total internal reflection) optics on each LED to form a beam.

Philips also offers the Fortimo LLM (linear light module) that is based on remote-phosphor technology (www.ledsmagazine.com/news/8/5/2) and that targets outdoor applications with output ranging from 1100-4500 lm. And the company has the Fortimo HBM (high brightness module) that uses phosphor-converted LEDs and delivers 4000-6000 lm, and that Philips business development manager Dan Sullivan said is designed to be compatible with a Zhaga standard currently under development.

In the indoor space the Philips line is equally if not more crowded. The Fortimo DLM (down light module) uses remote phosphor technology. Philips' Sullivan said in a recent presentation that the remote-phosphor approach could provide a 30-40% efficiency advantage. Philips' Lindstrom adds that the remote phosphor provides more consistent color and said "For the near term, 12-18 months, remote phosphor is definitely going to be the way to go."

It's worth noting that Zhaga doesn't weigh in on the choice of remote phosphor or direct lighting using phosphor converted LEDs. Either is allowed although some mechanical designs may lack the depth and size for an efficient mixing chamber needed for the remote approach.

Moreover some applications aren't compatible with remote phosphor even if it does offer an efficiency advantage. Philips for instance, uses phosphor-converted LEDs in the aforementioned Fortimo SLM. Lindstrom said the need for a tight beam pattern dictated the choice.

One module, many uses

GE, conversely is planning to use Infusion across applications. That usage certainly won't include street lights. Briggs said that the company is investigating linear modules for such applications. But Infusion will span downlights, spot lights and many other indoor products. GE has announced Infusion modules ranging in output from 850-3500 lm and plans to go to 5000 lm.

Briggs said that luminaire makers will be able to choose a module with an LED package that's optimum for any specific application. They will add an optics package that's matched to the LED package and application. GE already has a broad portfolio of optics and third parties will offer products as well.

The migration to modules is in the early stages. It's too soon to know if modules will become the dominant choice for SSL implementations or remain a niche. Much may depend on how well Zhaga is accepted. Even if Zhaga yields overlapping specifications, the standardization effort does accomplish something else – it opens technology developed within companies to others. No one has rights to the intellectual property within a GE Infusion module, for example, but others can build compatible products once Zhaga publishes the specification.

And modules are being successfully – and spectacularly – deployed today. Our cover photo for this issue, and another nearby photo, are of the Dusseldorf parliament hall lit by Hoffmeister Leuchten LED downlights that are based on 2000-lm Philips Fortimo DLM modules.


Let There Be NEW Lighting
Greeble

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LED revolution advances in China with government backing

Despite some quality issues, China now leads the world in the deployment of LED street lights, and the country's next Five-Year Plan is expected to drive further advancements, writes **PHILIP JESSUP.**

China is the epicenter of the LED revolution, accounting globally for 46% of the consumption of high-brightness LEDs in 2009, followed by North America at 30% and Europe at 17%, according to Strategies Unlimited. With over 2,200 manufacturers making LED devices, packages and luminaires today, China is advancing rapidly to the forefront of Asia's LED market.

Although much of the country's LED industry makes contract products for western companies, the central and provincial governments, especially Guangdong Province, are aggressively developing their own internal markets for high-quality, high-brightness, white-lighting applications.

Photo courtesy of Ryan Pyle.

This very long street on the Tianjin Polytechnical University campus in China is lit with hundreds of LED luminaires as part of a demonstration project.

21 City, 10,000 LED Lights program

In 2009, the Ministry of Science and Technology launched its "21 City, 10,000 LED Lights" program, the first phase of a much larger national demonstration project to install two million LED lamps in 50 cities.

A key aim of the project is to enable LED companies to deploy their LED products in the cities where they are located, using large installations as platforms for demonstration, for local investment, and to attract utility orders. As a result, the Ministry provided subsidies directly to the LED manufacturers – a 10% subsidy has been the norm – which then partnered with their local municipal governments. Here are some typical projects:

Tianjin: A variety of outdoor LED demonstration projects were undertaken in 2010 on the Tianjin Polytechnic University campus (see photo) and on the city's streets, as well as many indoor installations, totaling 110,000 lighting fixtures.

Hangzhou, Zhejiang province: An outdoor demonstration was undertaken of LED luminaires along 21 km of the Jinghang or Grand Canal and in the vicinity of West Lake. A total of 65,000 outdoor and indoor LED lamps were installed.

Dongguan, Guangdong province: Demonstration of 20,000 LED street lights on a variety of streets, supplied by local firm Kingsun Optoelectronic, one of China's oldest LED product manufacturers.

Shanghai: Support for LED street-light demonstrations at the Shanghai World Expo site, including the China Pavilion and a wide variety of streets near the Expo, as well as public spaces and landscape applications.

Shenzhen, Guangdong province: Installation of 10,000 LED luminaires along 130 km of expressway and tunnels, one of the largest highway LED retrofit projects in China (www.ledsmagazine.com/news/8/10/13).

The "21 City, 10,000 LED Lights" project was reportedly hampered by LED product-quality issues. Failure rates of 70% and annual lumen depreciation as high as 30% in some locales have been reported anecdotally. Hence, the project slowed in 2011 to allow time for evaluation by the China Solid-State Lighting Alliance (CSA). Key problems identified by the CSA's study were:

- Municipal governments found it difficult

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to implement the programs. Financial subsidies from central government were low, and restricted to the LED companies.

- Technical assessment of the products offered by local companies and site applications was often insufficient, leading to a mismatch between the product and its application.
- Quality standards, LED procurement specifications, and project management processes were lacking. National LED lighting standards were still in development when the program unfolded.
- Business modeling was challenging, due to underestimated maintenance costs associated with non-standardized products and extensive product failures.
- Low electricity prices and high LED costs extended payback periods under ideal conditions to eight years or more in many cities.
- A dearth of energy-service companies in China with strong financial expertise in energy-efficiency technologies made it difficult for municipal governments to raise adequate funding.
- Regional trade-protection barriers within China prevented quality products from being used in many cities.

Major recommendations coming out of CSA's review included creating national LED evaluation criteria; setting up quality-control systems; providing central-government subsidies to local governments; implementing better coordination among central government's agencies; improving LED manufacturing processes; and supporting further R&D. After the review, the Ministry expanded the program to a second group of 16 cities in 2011.

Guangdong leadership

Despite the early problems encountered, demonstration projects undertaken by cities in Guangdong province proved very successful. This was due to the implementation of rigorous technical requirements and standards associated with the energy management contract (EMC) business model pioneered in China by these cities.

Under the EMC model, banks provide project financing to the cities to cover third-party testing data, feasibility analysis, street reconstruction, and light sources. The loans are repaid from energy savings over a six-year period, which involves periodic field monitoring. Typically, 10% of the project cost is subsidized by Guangdong province, 15% by the municipal government, and the remaining 75% financed through the EMC with an energy-service company.

Guangdong's leadership in LEDs is driven by the importance of the technology to the province's economy. Companies located in the province supplied 70% of China's LED packages in 2010, with foreign investment approaching $1.5 billion in local LED firms, much of it centered in Shenzhen's Special Economic Zone.

In order to maintain this momentum, Guangdong relies on aggregating local procurement to expand the provincial market for locally-produced LED luminaire products. As of the end of 2011, 200,000 streetlight luminaires had been installed on 2,000 km of provincial streets and roads, including 100,000 units in the capital, Guangzhou (see also page 8). Installation of another three million LED street lights is planned soon.

In part due to the "21 City, 10,000 LED Lights" project and Guangdong's leadership, China now leads the world in the deployment of LED street lights. In 2010, approximately 350,000 LED street lights were installed in Chinese cities, 74% of the global total, according to Strategies Unlimited. A temporary contraction is expected in 2011.

12th Five-Year Plan (2012-2016)

China will continue its ambitious LED lighting program in the next Five-Year Plan, which ambitiously aims for LEDs to achieve 30% market share of China's general lighting market by 2015. Guangdong province has adopted probably the most ambitious provincial goal: the installation of 30 million indoor LED lights by 2015. Key elements of the national plan include:

- Continued R&D, industry promotion, and scale-up of niche applications such as street lighting, tunnel lighting, and indoor uses.
- Establishment of national photonic testing labs in various regions, including Guangdong.
- Development of Chinese technology in the field of metal-organic vapor-phase epitaxy (MOCVD).
- Inclusion of LED domestic lamps in the central government's Green Lights program, which offers substantial subsidies in the A-lamp mass market.

While quality issues have dogged China's HB-LED efforts to date, these are not likely to dampen the country's long-term ambition to become one of the top three leaders in manufacturing LED products. It is expected that Chinese governments will effectively address LED product quality problems all along the supply chain through home-grown R&D and procurement initiatives, and joint ventures with western LED companies such as Cree, while deploying a mix of well-coordinated policies, subsidies, and market aggregation initiatives that capitalize on the large size of China's market to gain comparative advantage globally.

Strategies in Light 2012 to highlight LED market dynamics

With the theme of "Navigating the Dynamic LED and Lighting Markets," the 13th annual Strategies in Light conference will be held in Santa Clara, California, on February 7-9, 2012 writes **BOB STEELE**.

It can be said with some certainty that 2011 is shaping up as one of the most challenging years in the history of the HB-LED industry. After an astounding 108% market growth in 2010, driven largely by the adoption of LED backlights in LCD TVs, computer monitors and notebook computers, the market is expected to grow at a rate of less than 10% in 2011 (ledsmagazine.com/news/8/10/9). Demand for LCD TVs has slowed, and the oversupply of LEDs caused by widespread capacity expansion has put strong downward pressure on prices. Helping conference attendees to understand the dynamics of this rapidly changing and complex market is a key goal of Strategies in Light 2012.

To address the wide range of issues and growing pains facing the LED industry, Strategies in Light 2012 has assembled a roster of distinguished speakers from all levels of the LED and lighting supply chain, and from all parts of the globe. As usual, the conference will be kicked off by a presentation of Strategies Unlimited's most recent research update and forecast for the worldwide HB-LED market, delivered by Ella Shum, Director of LED Market Research.

Headlining the conference's Plenary Session will be Ling Wu, General Secretary of the China Solid-State Lighting Association. With the expansion of the LED industry in China much in the news this year, Ms. Wu will shed light on the future development strategies of China's SSL industry. Korea has been a key player in the recent growth of the LED market, and C.H. Lee, CEO of Seoul Semiconductor, Korea's largest independent LED supplier, will provide his company's perspective on the LED industry's trajectory. The final Keynote Speaker, Eric Kim, is CEO of Soraa, Inc., the start-up co-founded by LED industry legend Shuji Nakamura. After many months of being in "stealth mode" regarding its technology, Mr. Kim will discuss Soraa's holistic approach to LED lighting.

Following the opening Plenary Session, SIL 2012 will split into three parallel tracks – the traditional HB-LED Market and LEDs in Lighting tracks, plus an LED Manufacturing track, new for 2012. Leading off the LEDs in Lighting track, Strategies Unlimited's Director of LED Lighting Research, Vrinda Bhandarkar, will provide an update and forecast of the LED luminaire and replacement lamp markets. The first keynote speaker will be veteran lighting designer Ted Ferreira, Principal at CD+M Lighting Design Group, who will address the issue of sustainable design as it relates to the SSL industry. Dave Ranieri, VP and General Manager of the Commercial Indoor Business Unit, Lithonia Lighting, will discuss the advent of intelligent digital lighting.

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The lead keynote speaker for the LED Manufacturing track will be Iain Black, VP of Worldwide Manufacturing, Engineering and Innovation for Philips Lumileds Lighting, who will address the manufacturing challenges of dealing with complexity in an evolving market. He will be followed by Tom Morrow, Executive VP of SEMI, who will discuss the issues associated with the recent unprecedented expansion of LED manufacturing capacity around the world. Jacob Tarn, President of TSMC Solid-State Lighting Ltd., will provide insight on whether a major semiconductor company can help to accelerate the LED cost-reduction curve.

Other speakers in the HB-LED Market track will address topics ranging from providing LED-based lighting to the rural poor, to the market for LED backlights in displays, automotive headlamps, LED lighting, and strategies for dealing with the current tumultuous LED market. Two panel sessions will be offered – one on new developments in phosphors (including quantum dots) and one on drivers, controls and dimming.

In the LEDs in Lighting track, presentations will address lighting in the retail industry, utility energy-efficiency programs, the results of DOE's Caliper testing of LED replacement lamps, museum lighting, "smart" street lighting, and the digital control of lighting, among many other topics.

The LEDs in Manufacturing track will focus on the issues faced by the LED industry as it scales up to unprecedented levels of high-volume production. Topics to be addressed will include the development and application of new equipment and techniques to move to larger substrate sizes, increase automation, improve yield and throughput, and provide lower cost and more robust packaging.

In addition to the three main conference tracks, Strategies in Light 2012 will continue its tradition of offering a full-day Solid-State Lighting Investor Forum, featuring presentations by a wide range of advanced technology start-ups. Moreover, five in-depth workshops and two lighting tutorials will be offered on the day before the main conference, along with numerous informative free presentations in the LED Light and Design Pavilion on the exhibit floor.

strategically speaking™

LED drivers represent a critical but confusing market

The LED driver market is characterized by complex and dynamic design issues, volatile pricing, varying degrees of integration and customization, and confusing terminology. **TOM HAUSKEN** makes sense of it all.

With all the attention devoted to LEDs and LED lighting, you hear surprisingly little about the rest of the electronics in LED products — what is known as the driver. Yet, the driver design determines such things as whether the product is properly loaded or inefficient, or whether the LEDs have to be tightly selected or can be loosely binned. And if you think that driver design is well understood and mature, you are wrong, for reasons that this article will discuss. Driver design is evolving rapidly to keep up with new applications and new requirements, such as improved power factor correction and sophisticated dimming for improved uniformity and reliability.

Driver IC market scales with LEDs

Let's make one thing clear: the market for LED driver ICs – an important component of most LED drivers – is significant, at $2 billion. Also, it's growing at about the same rate as the LED market, about 13% per year (Fig. 1).

Most LED driver ICs are used in backlights for LCD displays, such as in mobile phones and TVs. These are dynamic consumer end products, with short product cycles and tight control on performance, size, and cost. That makes the driver-IC segment dynamic too.

The next big opportunity in LED drivers is in LED lighting. There have been LED lighting products in the market for many years, but in niche categories like architectural lighting, exit signs, and flashlights. Now, LED replacement bulbs are being sold in hardware stores, with the promise of large-volume sales but extreme demands are being made on size, efficiency, and cost. After that will come growth in general commercial and industrial luminaires, as building owners choose LED lighting for the lower-life-cycle cost compared to legacy lighting. The residential segment will take longer because private homeowners donate their labor for bulb replacement and do not strictly rationalize their life-cycle costs.

The driver is important, but it's under-appreciated by the industry and difficult to forecast. Why is that? The following sections explain.

1. Confusing terminology

One reason is that the terminology is absurdly confusing, although it can be mastered with a few pointers. Most important, the driver is the entire circuit, minus the LEDs. A driver IC is one or more ICs dedicated to controlling the current, and sometimes also the voltage, in the driver circuit. Fig. 2 shows an example of each. Nearly every LED-based light has a driver, even a simple one, but not every driver has a driver IC.

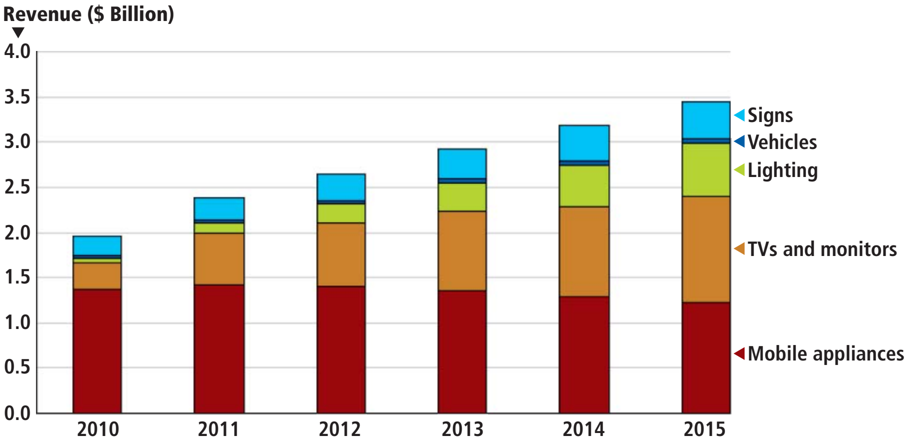


FIG. 1. Revenue growth for LED driver ICs tracks the growth in the HB-LED market. The strongest sales today are in backlights for displays in mobile appliances and TVs, but LED lighting is becoming the next big thing (source: Strategies Unlimited).

The term controller refers to a circuit within the driver that controls the LED current. We use microcontroller to refer to programmable boxes added by the lighting designer or customer to manage the system (for example, a timer or dimmer switch). This is shown in Fig. 3, in which the current controller is a key part of the driver, but the programmable microcontroller is entirely separate.

2. Complex, unique, dynamic design

Driver design is not simple and standardized as many people assume. First, LEDs require

TOM HAUSKEN *is Director of the Components Practice at Strategies Unlimited, a market research firm based in Mountain View, California (www.strategies-u.com). The company's most recent market-research report on LED Driver ICs was published in June 2011.*

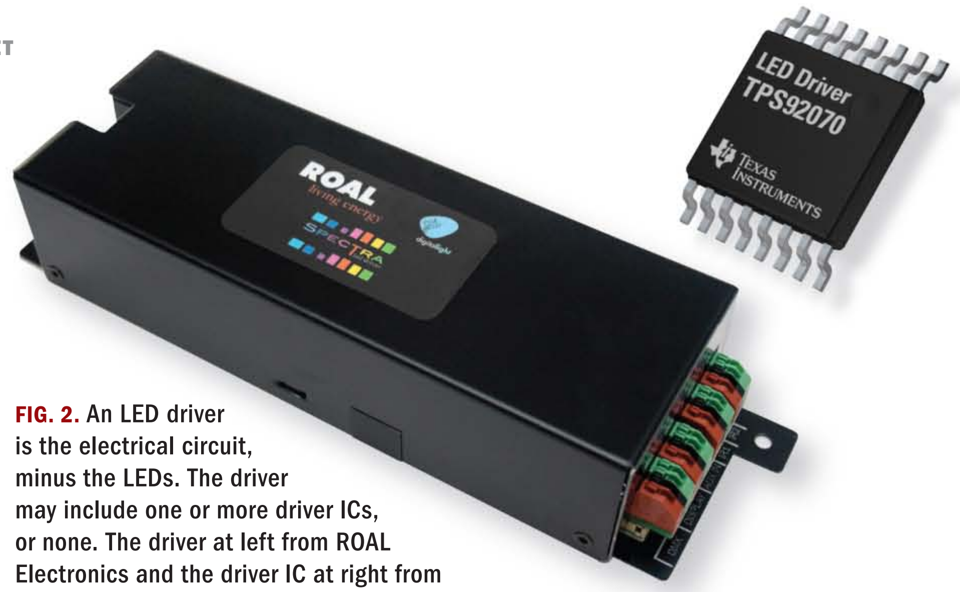


FIG. 2. An LED driver is the electrical circuit, minus the LEDs. The driver may include one or more driver ICs, or none. The driver at left from ROAL Electronics and the driver IC at right from TI both serve LED lighting.

constant, high-current sources, which are unusual in electronics and create unusual challenges for product engineers. Moreover, the designs are complex and unique to every LED product. The end-product features are constantly evolving: from keypads to touch-screens, from one type of edge-lighting to another, and so forth. And, there is a wide variety of supply arrangements that obscure the landscape for observers: from conventional suppliers to contract manufacturers to wide-spread use of chip foundries to manufacturers of custom ICs for specialized driver designs.

Fig. 4 shows some examples of LED driver circuits driven from a DC voltage. The strings of LEDs, shown in the figure as single diodes, require at least some current control. A common design uses only a resistor to limit the current (Fig. 4a). This approach is simple and inexpensive, and is common in vehicle lighting, but is inadequate for applications demanding precise control and uniformity, such as backlights or signs. Substituting a linear regulator (not shown) for the current-limiting resistor improves the current control. Ganging multiple regulators in parallel into an IC can reduce the component count and improve reliability (Fig. 4b).

Controlling the input rail voltage is normally considered the task of the system's power supply, but many LED applications require a voltage conversion to match the LED load. An IC may be dedicated for that purpose (Fig. 4c). For example, LED backlights can operate with strings of up to 10 or more LEDs in series, with a total string voltage of 60V or more.

3. IC integration and customization

Voltage conversion creates another option: the converter IC may be combined with a current-regulating function on the same chip (Fig. 4d). The choice to integrate voltage conversion and current regulation depends on many factors, such as the need for reduced component count, current requirements, and so forth.

LED driver ICs are especially vexing because of the ways that multiple functions or components can be integrated onto one chip. For example, in a handset the LED flash and backlight functions can be managed with multiple ICs, or they can be integrated into a single IC, or they can be managed with yet other handset functions in a general-purpose-power-management IC (PMIC). We consider a PMIC to be in a category apart, not an LED driver IC, if it includes management of battery recharging and voltage regulation for other functions. The trend toward PMICs therefore shifts some of the sales of LED driver ICs to suppliers of PMICs.

The trend toward integration also offers an opportunity for chipmakers that use BCD (bipolar-CMOS-DMOS) processes to fabricate LED driver ICs that enable high-voltage operation. BCD allows for integration of diverse circuit elements – such as low-voltage analog and high-voltage power transistors – on the same chip. It is a high-margin growth opportunity for the foundries and chip suppliers that can do it.

Customers must also choose between custom ASICs (application-specific ICs) that form a perfect fit for their application versus off-the-shelf products that leverage non-recurring engineering costs. Customers commonly veer between custom and standard products depending on many changing demands in their product cycles.

4. Potentially disruptive AC-LEDs

Novel AC-LED products have the potential to complicate the driver market. In its purest form, the AC-LED eliminates the driver, using the diode features of the LED to replace conventional diodes. Other designs use some basic components to limit the current, but sparingly. If highly successful, the AC-LED could make some LED lighting products – such as replacement bulbs – more competitive and greatly expand the LED-lighting market. Such a move could be good for both the LED industry and the end users, but would displace potential driver sales for those products.

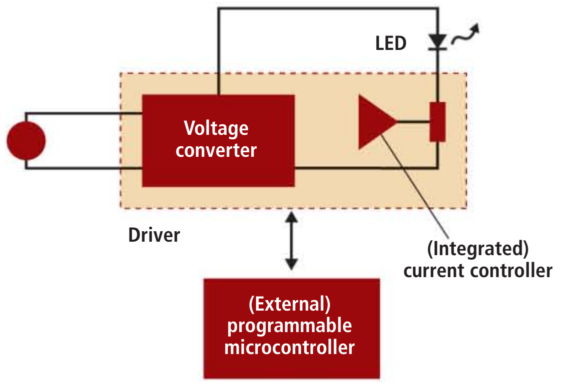


FIG. 3. The driver (dotted rectangle) in this simplified circuit includes a voltage converter and a current-controlling element. The programmable microcontroller is not part of the driver. It is external to the LED product, and may include such features as timing, dimming, and color control.

However, we expect that AC-LEDs will have an impact only in certain product segments. In replacement bulbs, the pressure to innovate is so high that the AC-LED is just one of several novel solutions, and there is no room for older, less-innovative designs. Consequently,

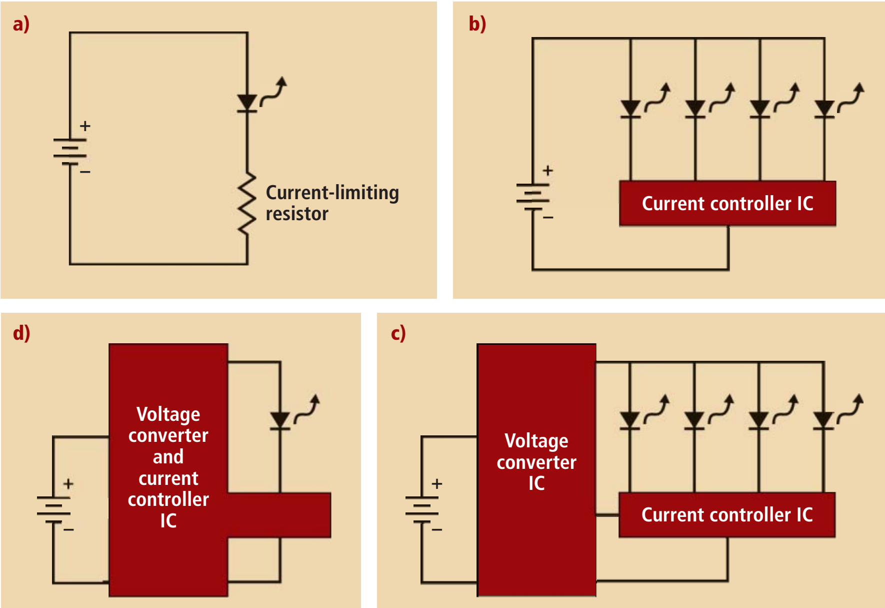


FIG. 4. LED driver design ranges from minimal (the current-limiting resistor) to monolithic integration of multiple channels and even voltage conversion onto a single driver IC, with the specific design unique to each product and application. Strings of LEDs are represented in the figures as single diodes.

there are plenty of opportunities for everyone.

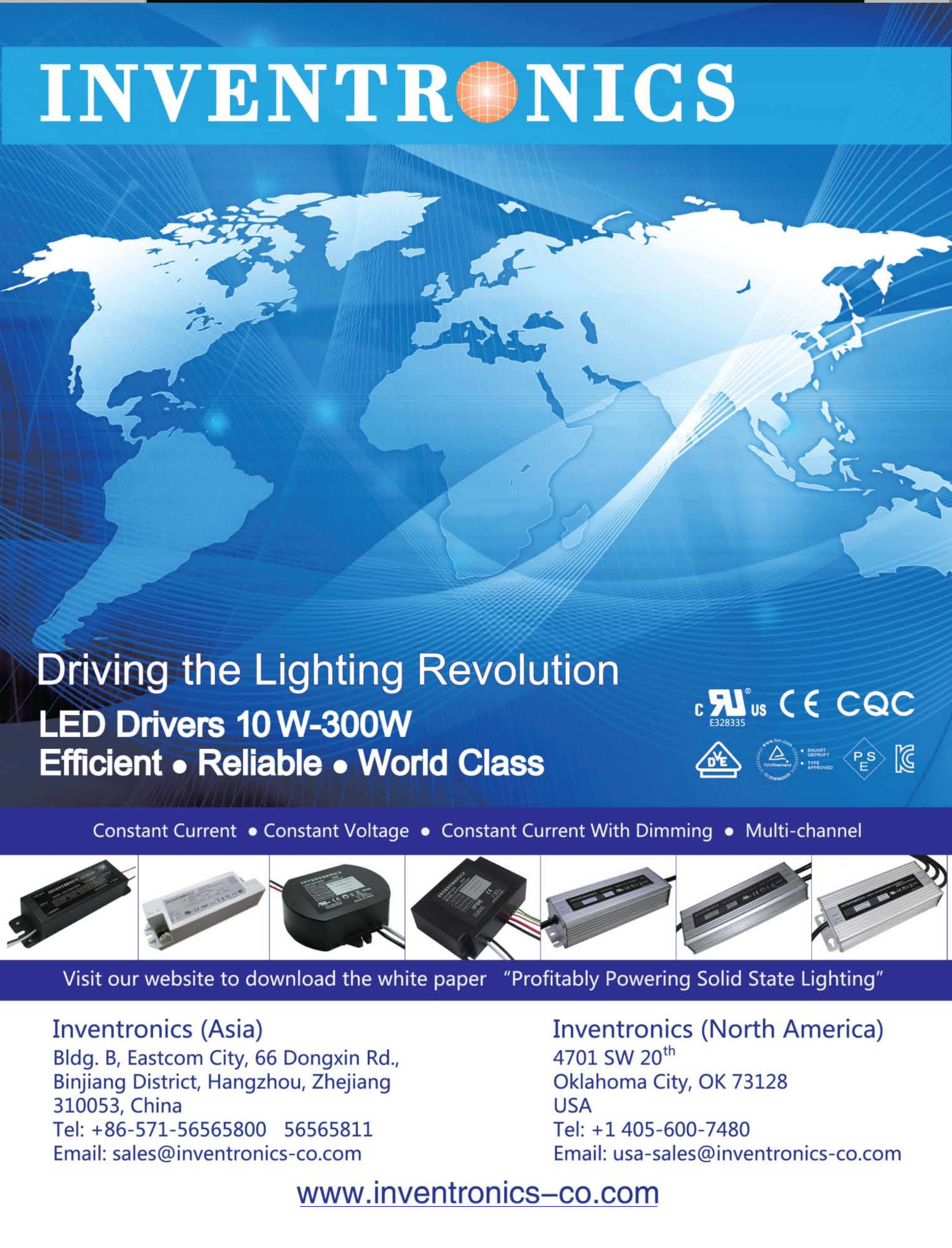
The high-voltage LED (HV-LED) is another buzz word but it will have minimal impact on the driver market. LED-based products commonly use long strings of LEDs in series. Until recently, the LEDs have been packaged in discrete packages and assembled together in the luminaire or lamp. An HV-LED integrates the LED string onto the same chip or within the same package, gaining some advantages for the customer. It means little to the driver design, other than the usual considerations for the LED load that impacts every product design.

5. Volatile pricing

Estimates for IC pricing also complicate the forecast. It's obvious that IC prices decline over time as volumes increase and margins shrink. What's not as clear is the effect on the average price of changes in the product mix. New products can appear at much higher prices than more-mature products in the same category, but can earn the difference via savings in component count or improved LED performance. The new products may be priced higher because they use a larger chip that takes up more wafer area, because they use a more expensive foundry process, or simply because they deliver more value, and can earn greater margin for the chip supplier.

Temporary oversupply or shortages of products within the supply chain – such as driver ICs, LEDs, or the end products – also create fluctuations in prices. We ignore these short-term fluctuations; in our studies we focus on the underlying medium-term trends in demand and technology.

LEDs are relatively uniform and easy to understand – compared to drivers. As one supplier said, explaining drivers requires a deep dive, but few customers have the patience or expertise to listen for very long. Yet, with some patience, LED drivers can be appreciated as a critical partner to LEDs, which garner so much attention.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lighting | **PLANAR FIXTURES**

LED backlight technology offers promising choice for lighting

Edge-lit light guides with embedded optics can provide precise light control and high optical efficiency in general-lighting applications, say **JOHN LANGEVIN** and **KENDRA DE BERTI**.

Planar light fixtures offer aesthetic advantages in many applications and the inherently-diffused concept can efficiently deliver the required light to a task plane. The potential market for such fixtures has driven the solid-state lighting (SSL) industry to pursue several approaches to planar lighting including OLEDs and panels that are edge- or back-lit by LEDs. Technology with an LCD-panel backlight unit (BLU) heritage can enable planar fixtures and may prove the best option in such luminaires in terms of light control and application efficiency.

In general, the introduction of LEDs to the application of general lighting presents lighting architects and fixture designers with unprecedented flexibility that can't be achieved with the constraints of bulbs and tubes. LEDs can slash energy use and offer greater control and directionality of light. Moreover, the light source can now become an integrated part of the fixture itself rather than a replaceable object to be designed around.

In the BLU segment, meanwhile, the growing popularity of LEDs has driven innovations in the LEDs themselves, and has yielded new LED subsystems in the BLU that control and distribute the light. These subsystems include advanced optics that enable precise control of the uniformity and emission angle of light out of the BLU, while helping maximize the amount of light delivered through the LCD panel.

With shared needs for lower power and cost, longer lifetimes, improved color quality and the desire to eliminate light sources that contain hazardous materials, the lighting industry can benefit from the advances of LED backlighting in the display industry. The proven technologies originally implemented in display backlights can be leveraged to accelerate the time-to-market and adoption of LED-based light fixtures.

JOHN LANGEVIN *is the director of strategic development and* KENDRA DE BERTI *is a senior marketing manager with Rambus (www.rambus.com/lighting).*

Thin is in

BLUs can be edge- or direct-lit, with LEDs placed on the sides or directly behind an optical light guide. The lighting market has similar options for illumination. Today's LED light fixtures can be direct- or indirect-view, or edge-lit (Fig. 1). In a direct architecture, as the name would imply, the light source is in view and aimed directly at the illumination target. Though seemingly the most efficient, the aesthetics of direct-lit fixtures can be unpleasant. Because of their luminous intensity, the LEDs in these direct-lit architectures create bright spots that are uncomfortable to look at, so diffusers are often included to reduce glare. However, these diffusers reduce the optical efficiency of the fixture.

Indirect fixtures offer a softer aesthetic by bouncing the light off a surface, such as a back reflector or a ceiling, before illuminating the desired area. While indirect fixtures avoid the glare drawbacks of direct-lit architectures, they do so at the cost of efficiency. A portion of the light is lost through absorption by the surfaces used to reflect it, as well as that lost when propagated in undesired directions.

A third alternative is the edge-lit architecture that places LEDs along one or more edges of a light guide whose principal function is to direct and distribute light as desired. Light guides are typically made of thermoplastics such as acrylic or polymethylmethacrylate (PMMA). Light emitted from the LEDs is directed into the edge of the light guide and distributed throughout using the properties of total internal reflection (TIR). Different types of optical elements that are printed, etched or embedded into the light guide are then used to extract the light via the properties of refraction (Fig. 2).

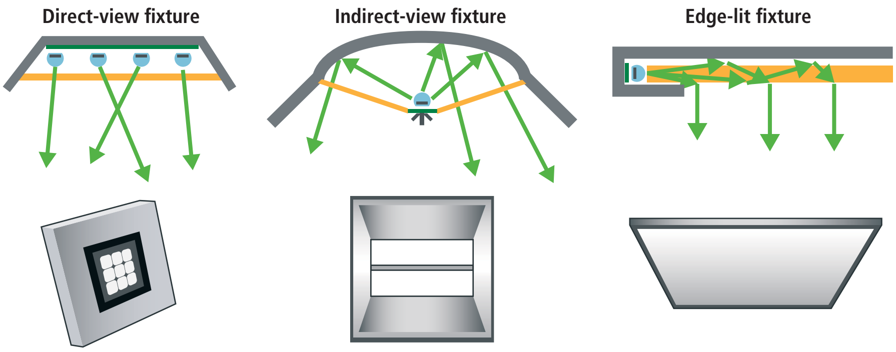


FIG. 1. LED fixtures can be direct- or indirect-view, or edge-lit.

Forming optical elements

All of these various patterning techniques for edge-lit fixtures can produce good uniformity, but they have a wide range of optical efficiencies, tooling costs, manufacturing costs, and optical characteristics. Printed and chemically-etched dots offer low-cost manufacturability, but produce diffused light outputs that offer virtually no control of the beam pattern. Laser-etched optical features provide improved optical efficiency, but require long manufacturing cycle times. Light guides with embedded optics combine specular reflection with fast and highly-repeatable manufacturing to deliver the highest level of ray-angle control and lowest overall cost.

In many ways, edge-lit architectures combine the benefits of direct and indirect fixtures while also providing unique benefits.

One example of embedded optics is Rambus' MicroLens light-distribution technology. MicroLens optics are 3-dimensional elements embedded directly into the light guide using injection molding, extrusion, or hot-embossing processes. They produce a highly-directed light output, provide ray-angle control, and maximize the amount of light delivered on target. In addition, the distribution pattern can be customized to meet specific application needs by varying the shape, size, location and density of the optics.

In many ways, edge-lit architectures combine the benefits of direct and indirect fixtures while also providing unique benefits. They offer high optical efficiency, control of the light distribution, reduced number of LEDs, and superior aesthetics. The adoption of edge-lit BLUs has enabled sleek, ultra-thin notebook computers, tablets, monitors and HDTVs that are less than 0.3 inch thick at a lower cost than direct-lit counter parts. Those same benefits can be leveraged for lighting. Light guides with embedded optics can be implemented in countless shapes and sizes with a wide variation of light distribution patterns. Edge-lit fixtures will usher in a new era of efficient, flexible and beautiful products. But with these new capabilities and flexibility of form factor, what is the best method for comparing relative performance and efficiency?

Introducing a new metric

With the introduction of energy-efficient light sources, such as fluorescents and LEDs, the reference to the wattage of a bulb is no longer an acceptable means of expressing the light output. In an effort to ease the transition, the term "watt equivalent" has been used to provide a reference. For example, a typical 60W incandescent bulb generates about 800 lm. But a 60W-equivalent LED bulb uses less than 12W to produce the same amount of light. The use of lumens has also been incorporated to describe the luminous flux or light output of a light source. Luminous efficacy, measured in lumens-per-watt (lm/W), is an important metric when describing the efficiency of a light fixture, but it doesn't tell the whole story.

Lumen output provides an accurate representation of traditional light sources as it is an averaged value used to measure total light output from an omnidirectional light source. However, LEDs are directional, so these metrics fail to accurately depict the true benefits of LEDs as general light sources. By using lumen output as a measurement for LED-based fixtures, the actual amount of light the luminaire is capable of delivering to a specific surface can be misrepresented.

Where all of these metrics miss the mark is that they measure the amount of light emitted from a light fixture rather than the actual amount delivered to the desired application area. The end goal of any lighting design is to create beautiful, functional spaces as efficiently as possible. This is achieved through the uniform distribution of light to a desired surface, minimizing light lost in undesired directions, and improving lighting ergonomics through reduced glare.

Application efficiency

In order to truly maximize the amount of light delivered to a desired area with the least amount of energy required, designers must focus on the application efficiency of the fixture. Application efficiency is the percentage of light delivered to the targeted area as it relates to the total light output of the fixture. In other words, the amount of light emitted from a fixture and directed to a specific surface. In order to achieve high application efficiency, a fixture must combine high luminous efficacy with the ability to direct as much of the emitted light to the desired surface, or area, as possible (Fig. 3.).

Application efficiency depends on three

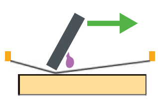
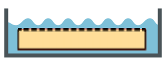
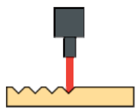
Patterning technology	Printed dot	Chemical etch	Laser etch	Embedded optics
Method				
Optics	• Diffuse	• Diffuse	• Diffuse	• Specular (ray angle control) ✓
Optical efficiency	• Good	• Good	• Better	• Best ✓
Uniformity	• Good	• Good	• Better	• Best ✓
Manufacturability	• Fast ✓	• Fast ✓	• Slow	• Fast ✓

FIG. 2. Optical elements can be formed in several ways.

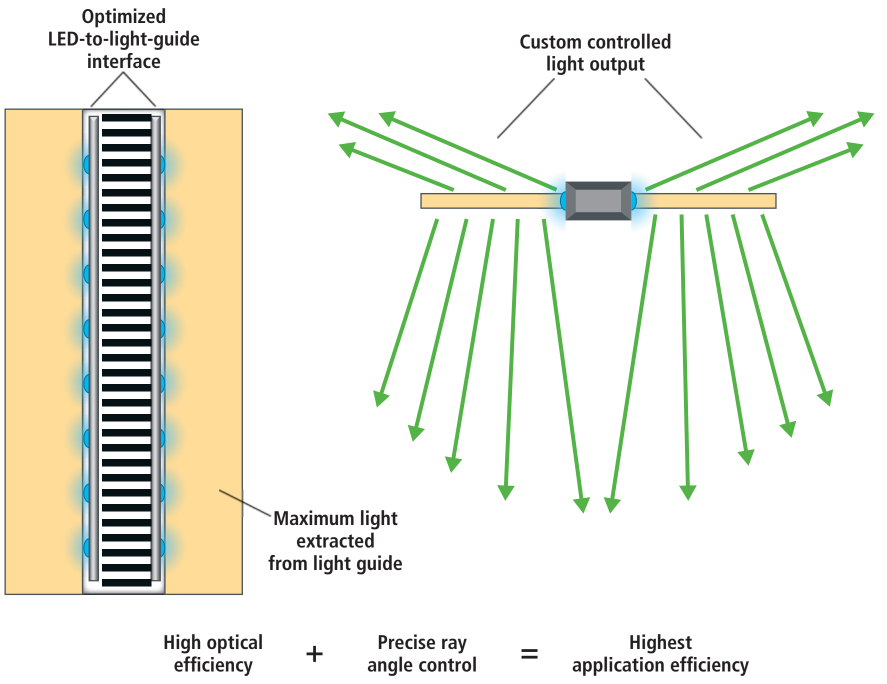


FIG. 3. LEDs and ray control yield high application efficiency.

elements: the efficacy of the LEDs, the optical efficiency of the total fixture, and the degree of ray-angle control provided by the fixture's optics. Today's high-brightness LEDs deliver upwards of 140 lm/W, but not all of the light emitted from the LEDs is effectively delivered to the fixture. Special design techniques are required in order to maximize the efficiency of the interface between the LED light source and the light guide.

There are additional losses introduced by the fixture inherent in the LED driver used to condition the power supplied to the LEDs, the thermal-management system used to cool the fixture, and the optics used to extract light out of the fixture. A system-design approach which takes all of these elements into account is required to maximize the overall efficiency of the light fixture.

Finally, light emitted by the fixture in undesired directions is effectively lost. The ability to control the light delivered from the fixture to the desired area depends on the nature of the optics used in the light guide. While diffuse optics cannot direct the light in a specific direction, specular optics embedded in the light guide, such as MicroLens optics, can. As a result, more light can be directed to the desired surface, with less light straying to an unneeded area.

A system approach

By optimizing the LED efficacy, optical efficiency, and driver design, and then providing ray-angle control, fixture designers can achieve maximum application efficiency to reach their end goal of creating a productive, functional space with the least amount energy.

In the display market, edge-lit architectures are the leading way to employ LEDs for BLUs. They deliver efficiency, thin displays, and low cost. Ultimately, these same benefits will translate to edge-lit architectures becoming the preferred solutions for lighting. The added benefit of form-factor flexibility means edge-lit solutions offer tremendous freedom of design. Lighting designers no longer need be constrained by the limitations of legacy bulb and tube-based fixtures. Nor should they evaluate lighting solutions only in terms of legacy measures. By designing with maximum application efficiency in mind, they can create beautiful, functional spaces with fewer fixtures and lower energy consumption.

LED-based products must meet photobiological safety standards: part 2

The potentially complex procedure of evaluating LED photobiological safety is now a legal requirement in Europe, but few countries have yet followed the European mandatory-testing lead. **LESLIE LYONS** discusses the implementation of the IEC62471 standard after an in-depth look at the measurement of radiance and irradiance.

Part one of this three-part series provided an overview of the potential hazards to the human body posed by exposure to optical radiation, and the development of international standards to evaluate the photobiological safety of non-laser sources (see *LEDs Magazine* October 2011, p31; ledsmagazine.com/features/8/10/8). Here, a more practical approach is adopted, in considering the finer details of source evaluation and the implementation of safety standards in Europe and the rest of the world.

Scope of IEC62471:2006

The IEC62471:2006 standard "Photobiological Safety of Lamps and Lamp Systems" provides guidance for the evaluation of the photobiological safety of all electrically-powered, non-laser sources of optical radiation emitting in the spectral range 200-3000 nm, whether or not the emission of light is the primary purpose of the product. The inclusion of LEDs in the scope of this standard is specifically mentioned to highlight the removal of LEDs from the scope of the laser standard, IEC60825.

The potential hazards of exposure to the skin, the front surfaces of the eye (cornea, conjunctiva and lens) and the retina are evaluated through consideration of six specific hazards with respect to exposure limits (ELs) provided for an exposure duration of eight hours, taken as a working day. The standard does not consider the potential effects of long-term exposure, nor of abnormal photosensitivity.

In the case of hazards to the skin and front surfaces of the eye, it is sufficient to take into account the amount of light incident on the surface in question. However, to consider hazards to the retina, one must take account of the imaging properties of the eye. It follows that two distinct measurements are required: irradiance and radiance.

The standard provides specific guidance on the geometrical conditions under which these measurements should be made to take into account biophysical phenomena, such as the effect of eye movements on retinal irradiation. The spectral range over which radiance should be considered is reduced to 300-1400 nm, since the retina is essentially protected outside this range due to the transmission characteristics of the lens. Table 1 indicates the required measurement (radiance or irradiance) for different hazards.

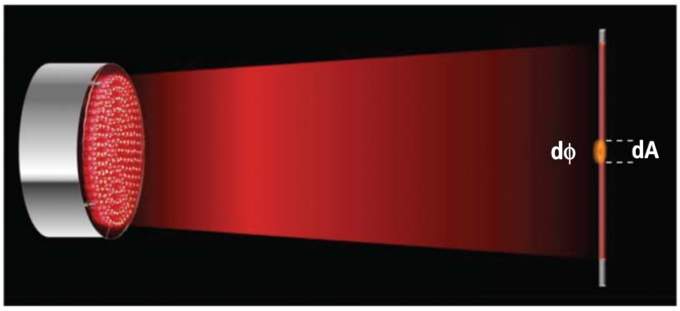


FIG. 1. Definition of irradiance.

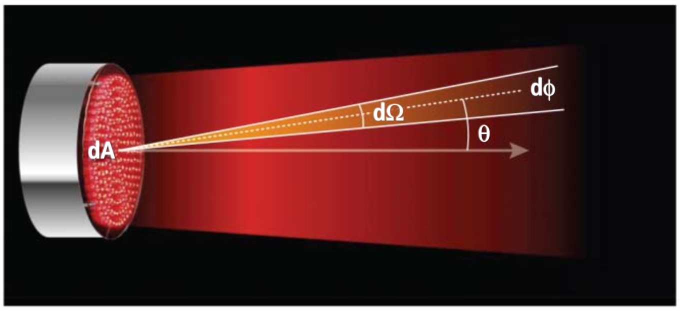


FIG. 2. Definition of radiance.

Measurement of irradiance

Irradiance permits the evaluation of hazards to the skin and front surfaces of the eye. Irradiance is defined as the ratio of radiant power ($d\Phi$) incident on an element of a surface, to the area (dA) of that element (Fig. 1). Its symbol is E and its units are W/m^2.

Irradiance accounts for light arriving at a surface from the entire hemisphere above. However, due to its position with respect to the bridge and nose, the eye is shielded from wide-angle radiation. Within the scope of this standard, the measurement of irradiance in all but the case of the thermal skin hazard is performed over a 1.4-radian acceptance angle. Light emitted from a source outside this acceptance angle need not be measured.

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In measuring irradiance, the measurement optic, typically a diffuser or an integrating sphere, should have a cosine angular response to correctly account for off-axis contributions. At a given angle from the surface normal, the projected area on the surface is increased by the cosine of the said angle, resulting in reduced irradiance.

Knowledge of source irradiance does not however give any information about the quantity of light coupled by the eye and imaged on the retina, for which a measurement of radiance is required.

Measurement of radiance

Radiance permits the evaluation of hazards to the retina. Radiance is defined as the ratio of radiant power (dΦ) emitted by area dA into solid angle dΩ at angle θ to the source normal, to the product of solid angle dΩ and the projected area dA·cos θ (Fig. 2). The symbol is L and the units are W/m^2sr.

In viewing a source, the eye collects light within a given solid angle set by the diameter of the pupil, and projects an image of the source onto the retina. As the pupil dilates (or contracts) according to the level of visual stimulus, or luminance, of the source, the retinal irradiance of the image increases (or decreases).

The law of conservation of radiance states that radiance cannot be increased by passive optical systems such as the lens of the eye. The retinal irradiance is therefore determined from the source radiance and the solid angle subtended by the pupil (2-7-mm diameter) at the retina (17-mm distant) in the reverse of the determination of radiance from irradiance, given below.

	Hazard	Wavelength range (nm)	Quantity measured
Skin & Eye	Actinic UV	200-400†	Irradiance
	Near UV	315-400	Irradiance
	IR Radiation Eye	780-3000	Irradiance
	Thermal Skin	380-3000	Irradiance
Retina	Blue Light Small Source	300-700†	Irradiance
	Blue Light	300-700†	Radiance
	Retinal Thermal	380-1400†	Radiance
	Retinal Thermal Weak Visual	780-1400†	Radiance

TABLE 1. Different hazards require the measurement of either irradiance or radiance. († Weighting function required.)

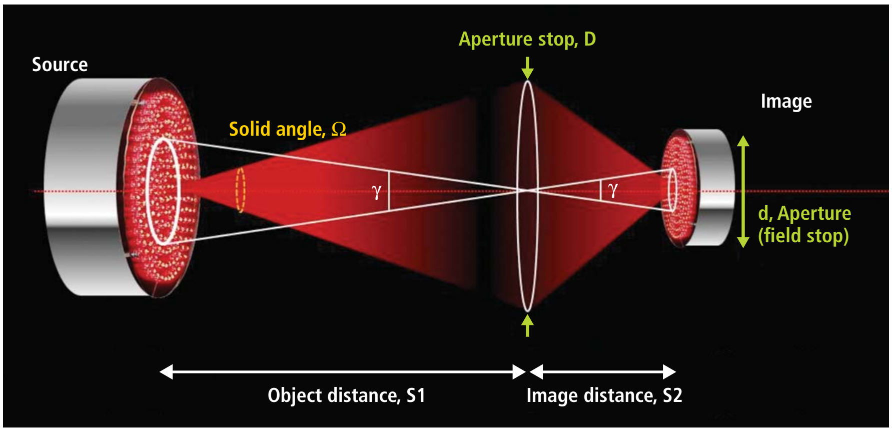

FIG. 3. Measurement of radiance: imaging technique.

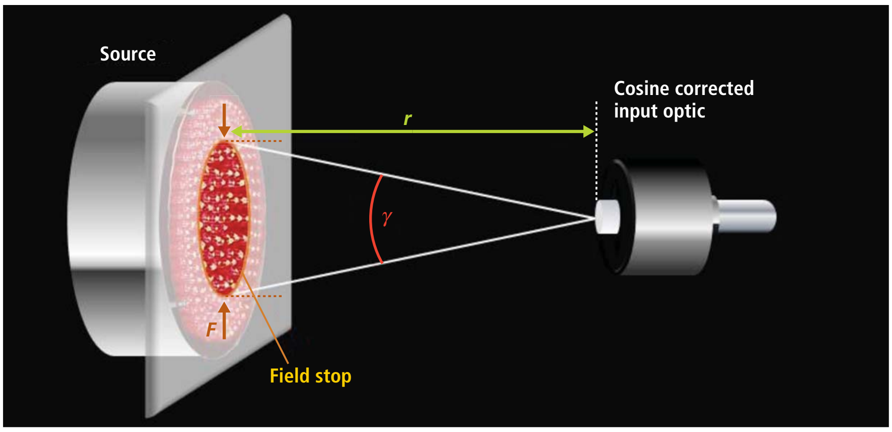

FIG. 4. Measurement of radiance: indirect technique.

Radiance may be measured by two manners, either using an imaging technique or indirectly through an irradiance measurement. In both cases, the measurement is performed in a specific field of view (FOV) or solid angle of acceptance (often described by a planar angle, θ) that defines the area of the source measured.

The imaging technique (Fig. 3) replicates the imaging of the eye. A telescope images the source under test onto a plane at which may be placed apertures of varying diameter to select the required FOV of measurement.

Alternatively, a measurement of irradiance with a cosine-corrected input optic may be performed (Fig. 4). An aperture is placed directly at the source to define the measurement FOV. The radiance is computed from the ratio of irradiance to the solid angle of the FOV in steradians.

Physiological radiance

For momentary viewing , the retinal image of a source subtends the same angle as does the source. The smallest image formed on the retina, according to IEC62471, has an angular extent of 1.7 mrad, given the imperfect imaging performance of the eye.

With increasing exposure time, due to eye movement (saccades) and task-determined movement, the retinal image is smeared over a larger area of the retina, resulting in a corresponding reduction in retinal irradiance. A time-dependent function is defined to represent the spread of the retinal image in the range from 1.7 to 100 mrad. This covers the range from 0.25s (aversion response time) to 10,000s exposure.

In the context of photobiological safety, the measurement of radiance is performed in a manner that reflects this phenomenon i.e. the FOV of measurement is chosen to account for the light falling within a given area of the retina. The measurement FOV follows therefore the same time dependence, from 1.7 to 100 mrad, regardless of the size of the source measured.

The measured quantity is more accurately termed physiological radiance as opposed to true radiance, which by definition samples only the emitting area of the source (Fig. 5). Where the physiological radiance is measured in a FOV greater than the angle subtended by the source, the resultant radiance is an average of the true source radiance and the dark background. Furthermore, since the angular subtense of a source varies with distance, physiological radiance, unlike true radiance, is a function of measurement distance.

Spectral influence

In the above, reference was made to irradiance and physiological radiance with no consideration for the spectrum of the source, which is clearly very important within the context of this standard. These quantities should, in practice, be evaluated at each wavelength with a monochromator. This yields spectral irradiance and spectral physiological radiance. The resultant spectra should be weighted, where required, against hazard weighting functions to take account of the strong wavelength dependence of three of the hazards considered (Fig. 6). The result should be integrated over the required wavelength range prior to comparison with ELs.

Measurement distance

The distance at which a source should be evaluated depends upon its intended application. Two exposure scenarios are considered; general lighting service (GLS) and all other applications (non-GLS).

The present definition of GLS is ambiguous, but relates to finished products that emit white light and are intended for illuminating spaces. Evaluation should be reported, not necessarily measured, at a distance at which the source produces an illuminance of 500 lux. This distance may be less than one meter for household luminaires, but many meters for street lighting, for example.

Irradiance measurements may be performed at a convenient distance and scaled to 500 lux. However, physiological radiance, which depends on the source subtense with respect to the applicable FOV, should be performed at the correct distance.

The rationale for the 500-lux condition is arbitrary and a bone of contention within the lighting industry since this in many cases does not represent a realistic exposure scenario. In the next part of this article, we shall consider how this issue is currently being addressed.

Non-GLS sources should be measured at a distance of 200 mm from the (apparent) source. This distance represents the near point of the human eye. At shorter distances than 200 mm, the retinal image is out of focus, resulting in lower retinal irradiance.

Here, the concept of apparent source is important. Where a lens is used to collimate the output of an LED, a magnified virtual image is produced behind the chip. The 200-mm measurement distance should be taken with respect to this apparent source, since it is this which the eye images.

The measurement at 200 mm may represent a worst-case exposure condition for the retina. However, this is not the case for the skin and front surfaces of the eye where the exposure distance may be closer. This latter eventuality has not yet been taken into account in this standard, for which the primary concern is acute retinal damage.

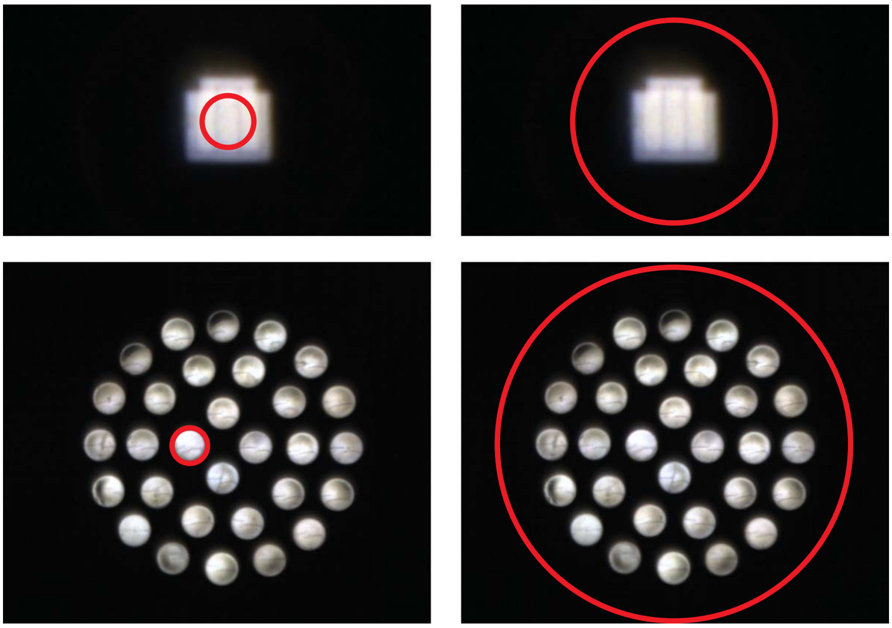

FIG. 5. In each pair of images, the red circles show the measurement fields of view for true (left) and physiological (right) radiance. For true radiance measurements, the circle encompasses only the light-emitting area, while the physiological radiance is an average of the true source radiance and the dark background.

Comparison with ELs

ELs are provided in terms of radiant flux for thermal hazards or energy (radiant flux multiplied by time) for photochemical hazards: a measured irradiance result can be directly compared with the former, and an exposure time obtained for the latter. This procedure does not apply to the measurement of radiance, for which the FOV of measurement is time dependent.

A pass/fail test is therefore applied to the retinal hazards based on measurements at FOVs corresponding to the minimum exposure times of the classification system in turn, starting from the exempt risk group. Where the resultant radiance exceeds the maximum-permissible radiance for a given risk group, the next risk group is tested.

The detailed evaluation of retinal hazards is rather more convoluted since source size and level of visual stimulus should be taken into account in determining which ELs to apply.

Classification

As outlined in part 1 of this article series, a classification system, based on the minimum exposure time before the EL is exceeded, is defined ranging from exempt (no risk) to risk group 3 (RG3; high risk). The limit irradiance (radiance) of each risk group can then be determined, and the measured irradiance (radiance) may be compared against these limits.

Labeling

IEC62471 is intended as a horizontal standard, and as such does not include manufacturing or user-safety requirements that may be required as a result of a product being assigned to a particular risk group. Such safety requirements vary according to application, and should be dealt with in vertical, product-based standards. However, IEC TR 62471-2 does provide some further guidance on the measurement and provides a recommendation of labeling for each hazard and risk group (Fig. 7).

Implementation of IEC62471 in Europe

In the European Union, CE marking demonstrates product safety by compliance with the relevant applicable EU directive, such as the low-voltage directive (LVD), through application of European Norme (EN) standards harmonized to the directive under consideration. While compliance with these EN standards is not mandatory, it does provide presumption of compliance with the essential health and safety requirements of the directive considered.

Optical radiation is specifically considered under the terms of the LVD. This is applicable to electrical products operating at voltages of 50-1000V AC. The European adoption of IEC62471, namely EN62471:2008, is harmonized to the LVD.

From September 1, 2011, evaluation of LEDs against the laser standard (IEC60825) no longer allows presumption of conformity with the essential health and safety requirements of the LVD.

From April 2010, the EU artificial optical radiation directive (AORD), 2006/25/EC, came into force. This adopts exposure limits slightly different to those of IEC62471. For consistency, EN62471 adopts the exposure limits of the AORD and is the standard to be used to evaluate worker exposure to non-laser sources of optical radiation.

Also relevant to LEDs is the EU Toy Safety directive, to which is harmonized EN62115 "Safety of electric toys." This standard has in the past referenced the laser standard (EN60825) for the classification of LEDs. It is currently under review, but it is expected that reference will be made to EN 62471 where measurements are required.

Finally, where products are not covered by the LVD or toy directives, consideration should also be made of the general product-safety directive to which few standards are specifically harmonized, yet for the evaluation of non-laser sources of light, EN62471 is the relevant EN standard.

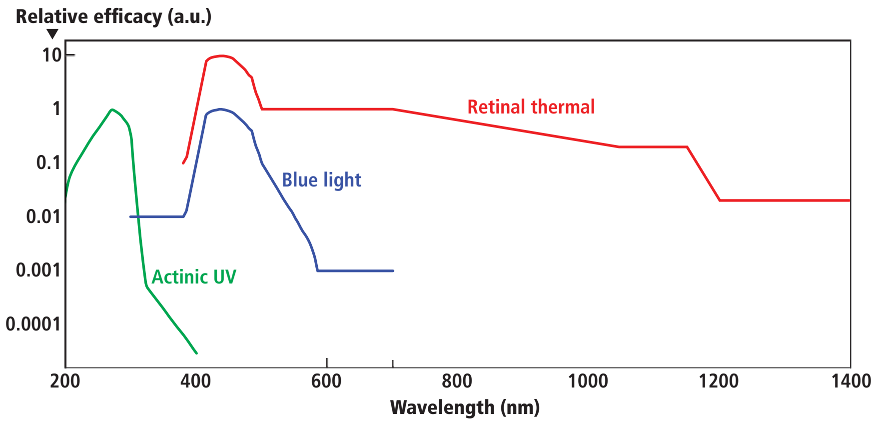

FIG. 6. Hazard weighting functions used by IEC62471.

Implementation of IEC62471 in ROW

While many standardization bodies around the world are considering the adoption of IEC62471, few have yet issued national standards let alone a legal framework to render testing mandatory. Of the activity

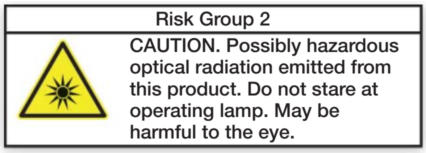

FIG. 7. Ex Close ding to IEC TR 62471-2

seen, much is related to the lighting industry, for which a well-defined standardization framework is in place and under active development to accommodate solid-state lighting.

To the knowledge of the author, China is presently alone in having formally implemented a voluntary standard – GB/T 20145-2006 – with Japan expected to publish JIS C 7550 in November 2011.

Some countries, such as Australia and New Zealand, are currently working on the adoption of IEC62471 as a voluntary standard. Another group (e.g. Hong Kong, Republic of Korea) are presently content to reference IEC62471 on a voluntary basis, while others (e.g. Canada) are at the stage of considering implementation and potential regulations.

Finally, in the US, where ANSI RP27.1 exists as a voluntary standard, there is currently no mandatory requirement for the evaluation of non-laser sources. However, following a meeting in August 2011 of the standards technical panel of UL/ANSI 8750 "Light Emitting Diode (LED) Equipment for Use in Lighting Products," a task group has been formed to consider the implementation of photobiological safety standards for those lighting products covered by this UL standard.

Part 3 of this series of articles will discuss the implementation of IEC62471 to the LED devices of today, and its potential future development. Also, it will be shown that IEC62471 does not remain unknown to the world, principally through the implementation of international IECEE CB and numerous other certification schemes.

Production testing of HB-LEDs and LED modules demands the right hardware and techniques

Cost-effective testing of LEDs and LED modules in a production environment can have a strong influence on manufacturing efficiency, as **MARK CEJER** explains.

The latest high-brightness LEDs (HB-LEDs) offer ever-higher luminous flux, longer lifetimes, greater chromaticity, and more lumens per watt. To reduce the cost of LEDs to consumers, manufacturers are working to improve their yields and their manufacturing-efficiency levels. This requires cost-effective testing of LEDs and modules in a production environment. The key is to find the right combination of test equipment and the knowledge of how to use it effectively.

HB-LED testing fundamentals

A typical diode's electrical I-V (current-voltage) curve is shown in Fig. 1. Although a complete test sequence could include hundreds of points, a limited sample is generally sufficient to probe for the figures of merit. Many HB-LED tests involve supplying a known current and measuring the resulting voltage, or vice-versa, so a single piece of hardware that synchronizes both functions can result in quicker system setup and enhanced throughput.

Testing can be done at the die level (both wafer and package) or the module/subassembly level. In the latter case, HB-LEDs are connected in series and/or parallel; therefore, higher currents are typically involved, sometimes up to 50A or more, depending on the application. Some die-level testing can require 5-10A, depending on die size.

Forward-voltage (V_F) test: A forward-voltage test verifies the device's forward operating voltage. When a forward current is applied to the diode, it begins to conduct. During the initial low-current values, the voltage drop across the diode increases rapidly but levels off as the drive current increases. The region of relatively-constant voltage is where the diode normally operates. Results are often used in binning devices because an HB-LED's V_F is related to its chromaticity.

Optical tests: Forward current biasing is also used for optical tests because current flow is closely related to the amount of light emitted by an HB-LED. A photodiode or integrating sphere can be used to capture the emitted photons to measure optical power. This light is converted to a current that's measured using an ammeter or one channel of a source-measure unit (SMU).

Reverse breakdown voltage (V_R) test: A negative bias current applied to an HB-LED allows probing for its reverse breakdown voltage. The test current should be set to a level where the measured voltage value no longer increases significantly when current is increased slightly. At voltages higher in magnitude than the breakdown voltage, large increases in reverse-bias current produce insignificant changes in reverse voltage. The V_R test is performed by sourcing a low-level reverse-bias current for a specified time, then measuring the voltage drop across the HB-LED. Results are typically in the tens of volts.

Leakage current testing: Moderate voltages are normally used to measure the current that leaks (I_L) across an HB-LED when a reverse voltage less than breakdown is applied. In production testing, it is common practice to ensure only that leakage doesn't exceed a specified threshold.

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Boosting test throughput in production

At one time, manufacturers used an external PC to control all aspects of HB-LED production testing; in each element of a test sequence, the sources and instruments had to be configured for each test, perform the desired action, and then return the data to the PC, which evaluated the pass/fail criteria and determined where to bin the DUT (device under test). Transferring commands from the PC and results back to it ate up a lot of test time.

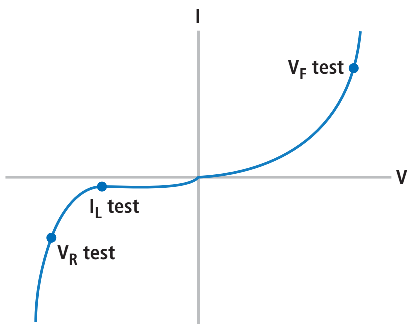

FIG. 1. Typical DC current-voltage (I-V) curve for an HB-LED, showing test points (not to scale).

The latest generation of smart instruments, including Keithley's new Model 2651A High Power System SourceMeter instrument (Fig. 2), is optimized to boost throughput substantially by minimizing communication traffic. The majority of the test sequence is embedded in the test instrumentation within a script and is executed by a microprocessor that allows control of the test sequence, with internal pass/fail criteria, calculations, and control of digital I/O. The microprocessor stores a user-defined test sequence in memory and executes it on command to all SourceMeter instruments in the test configuration, reducing set-up and configuration time. Communication between units takes place via TSP-Link technology, a high-speed trigger-synchronization/inter-unit communication bus, which connects multiple instruments in a master/slave configuration. This eliminates time-consuming GPIB (general purpose interface bus) traffic, and greatly enhances system throughput.

LED test system for a single device

A system configuration for testing one HB-LED at a time is shown in Fig. 3. The component handler transports the individual HB-LED to a test fixture, which is shielded from ambient light and houses a photodetector (PD) for light measurements. Two SMUs are used: SMU #1 supplies the test signal to the HB-LED and measures its electrical response, while SMU #2 monitors the photodiode during optical measurements.

The test sequence is programmed to begin using a digital line from the component handler that serves as a start-of-test (SOT) signal. After the instrument detects this signal, the test sequence begins. Once completed, a digital line signals measurement-complete status to the component handler. In addition, the instrument's built-in intelligence performs all pass/fail operations and sends a digital command through the instrument's digital I/O port to the component handler to bin the HB-LED based on the pass/fail criteria. Then, two actions can be programmed to take place simultaneously: data is transferred to the

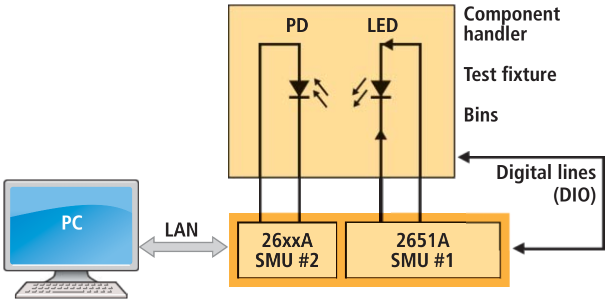

FIG. 3. A test system for a single HB-LED, which uses two source-measure units (SMU).

PC for statistical process control, and a new DUT moves into the test fixture.

Production testing of HB-LEDs

To achieve acceptable throughput, production test systems measure multiple parts simultaneously. Fig. 4 illustrates a device test system for three HB-LEDs that has one photodiode (PD) channel.

Junction self-heating can contribute significant measurement error in HB-LED production testing. As the junction heats over time, for a constant forward-bias current, the forward voltage drops, so it's crucial to manage device self-heating to ensure accurate, repeatable measurements. Self-heating can be minimized by reducing the amount of time the test will take, which in turn reduces the amount of time necessary for the test current to be applied to the device. Smart instruments can simplify configuration of the device soak time (which allows any circuit capacitance to settle before the measurement begins), as well as the integration time (which defines how long it takes the analog-to-digital (ADC) to acquire the input signal), because both factor into how long the test will take. New SMU instruments, including Keithley's 2651A, have digitizing ADCs, which can sample at speeds up to one microsecond per point or up to 50 times faster than high-performance integrated ADCs. These higher measurement speeds further improve overall test times.

The use of pulsed measurements minimizes test times and junction self-heating. Modern SMUs with high pulse-width resolution ensure precise control over how long power is applied to the device. Pulsed operation also allows these instruments to output current levels well beyond their DC capabilities.

High-power LED module testing

The demand for a lot of light in a small package has led lighting manufacturers to develop

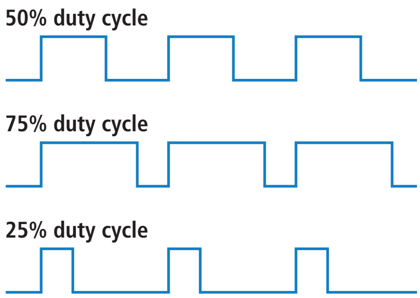

FIG. 5. In pulse-width modulation, the pulse level and frequency remain constant, but the duty cycle is varied.

high-power LED modules, which often consist of one or more large-die LEDs. When multiple die are present, they're either wired in parallel or in series, depending on the application and the available power source. The die of these LEDs can be much larger than those of typical HB-LEDs and can handle much higher currents. In fact, it's common for a single die to be required to withstand current levels as high as 10A.

Obviously, testing high power HB-LED modules demands hardware that can deliver a lot of power to the DUT. Although SMUs' ability to handle both sourcing and measurement normally makes them the

FIG. 2. Model 2651A High Power System SourceMeter instrument.

best solution for testing LEDs, most SMUs on the market simply can't deliver the level of power that testing high power HB-LED modules requires. Most instrument-based SMUs are capable of delivering only 20W of power or less, but this application often requires 100W or more. Keithley's 2651A instrument is capable of delivering up to 200W of continuous DC power and up to 2000W of pulsed power.

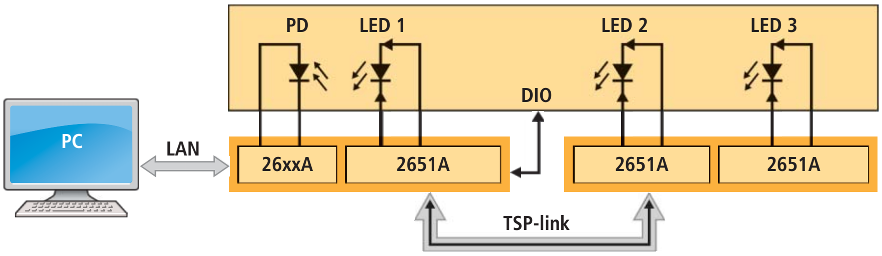

FIG. 4. Production setup for testing three HB-LEDs.

Pulse-width modulation and HB-LEDs

Pulse-width modulation (PWM) offers a way to control the brightness of LEDs. Although it's also possible to control an LED's brightness simply by lowering the forward drive current, this method is undesirable because the color of the light produced will change slightly with current level. PWM is the preferred technique because it uses a constant current level for each pulse and therefore offers greater consistency in the color of the light produced. PWM also offers more-linear control over brightness, and greater power-conversion efficiency.

In this technique, the current through the LED is pulsed at a constant frequency with a constant pulse level, but the width of the pulse is varied (Fig. 5), which changes the amount of time the LED is in the ON state, as well as the perceived level of brightness. The LED is actually flashing but at such a high frequency that the human eye can't distinguish it from a constant light level.

Given that LEDs are often used with PWM, it's only appropriate that they be tested with PWM techniques. As part of PWM testing, an LED is usually tested by running a series of pulses through it while using a spectrometer to take an integrated measurement of the light output over the course of many pulses. This measurement may take tens or hundreds of milliseconds to complete. During the pulsed output, the forward voltage is measured on every pulse to look for changes as the temperature of the LED rises.

Matching driver design with LED backlight scheme optimizes energy savings

LED backlighting is a requisite for TVs to meet more demanding Energy Star requirements, explains **GYAN TIWARY**, and matching the driver design to the backlight implementation delivers maximum energy savings.

Energy Star requirements for flat-panel televisions have become more stringent in recent years. If the Energy Star 6.0 proposal is accepted, it mandates that all TVs larger than 50 inches must consume no more than 85W of power by the fall of 2012. Two years ago, such TVs consumed close to 200W. These strict standards that attempt to curb power consumption worldwide have led to significant innovations in LCD TVs, especially in the backlight unit (BLU) which is a major source of power consumption. LED-based BLU can offer significant power reduction although the driver design must be optimized for the different direct- and edge-backlit schemes.

Active power consumption in an LCD TV consists of two main components: display power and baseline power. Baseline power encompasses the video-processing aspects of the TV and the main power supply, and typically accounts for about a third of the total power. Various components and scenarios will impact baseline power consumption, such as frame rate and power supply efficiency. In a 3D TV scenario, for example, additional image processing, a faster refresh rate and increased brightness can increase baseline power by 50-100% relative to standard TVs. Similarly, smart Internet-connected TVs require a higher performance processor, additional memory, and other elements adding a few watts of power. Still, the baseline power adders are a small fraction of the overall TV power consumption.

Display power refers to the power consumed by the LCD screen, BLU, and associated circuitry, and accounts for about two thirds of the total power consumed by a TV. Therefore, it would be logical for the industry to focus on reducing power consumption in this area.

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	Direct dimming*	Segment-edge/ hybrid dimming*	Edge dimming**
Picture quality	Best	Medium	Worse
Energy consumption	Lowest	Medium	Highest
Form factor	Thicker (by <0.5")	Thin	Thin
Cost	Highest	Medium	Lowest
Driver & TV system complexity	Complex	Medium	Easy
LED count	Large (~1k+)	Medium (100~200)	Small (~100)
LED current rating	30~60 mA	70~120 mA	150~250 mA
Number of LEDs per string	8~12	~20~30	~50+
Typical channel count	100+	12~48	1~2
Driving cost	$$	$+	$

* Also known as local dimming **Also known as global dimming

TABLE 1. Characteristics of LED backlight types.

Display power usage is high largely because the luminous efficiency of LCD TVs is very poor. An LCD panel has an extremely low transmittance level, in the 4-6% range, as the light travels from the BLU through the light guide, diffuser, optical film, and color filter. For example, if the BLU generates 8000-10000 cd/m^2 of luminance, then the final, visible-to-the-eye output might typically be between 380-450 cd/m^2.

The BLU must therefore generate considerable light and consumes the largest amount of power inside an LCD TV. Any improvement in BLU efficacy will lead to dramatic power savings for the TV.

Not too many years ago, cold cathode fluorescent light (CCFL)-backlit LCD displays were the biggest power guzzlers inside LCD TVs. Much of the power consumed in CCFL BLUs is wasted because it is difficult to dim CCFL bulbs appropriately when the picture itself is dark. As a result, LCD TVs are rapidly transitioning to LED BLUs. LEDs inherently consume less power and also have significantly faster switching speeds. These characteristics make LEDs an ideal replacement for CCFL, enabling dimming to both improve picture quality and save energy.

LED backlight configurations

There are varying opinions about the best way to deploy LEDs for optimal cost, efficiency and picture quality. The various backlight configurations and their current and voltage requirements vary widely and result in different architectures and driver requirements. Fig. 1 shows the relative current and voltage characteristics of the three most common types of LED BLUs.

In edge-lit designs, LED light bars are placed on the sides or edges of the screen.

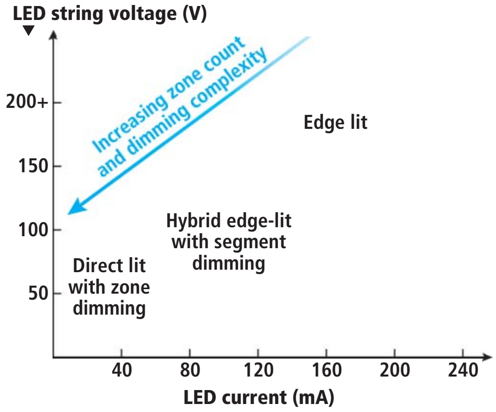

FIG. 1. Characteristics of different LED BLUs.

Edge-lit BLUs were the initial configuration of choice for notebook computer screens and LCD TVs. As edge-lit BLUs were deployed over the past several years in larger displays, most people considered the picture quality from these devices to be inferior to traditional CCFL-backlit TVs.

To improve picture quality and to benefit from the switching capability of the LEDs themselves, two other BLU schemes emerged with a heavy emphasis on dimming select portions of a screen. Direct-lit designs place LEDs directly behind the screen. Such designs can dim LEDs with fine granularity in small zones. Hybrid edge-lit designs place the LEDs on the side of the screen, but still support dimming of individual rectangular segments that extend horizontally across the screen. Both direct and hybrid schemes utilize dimming to significantly improve black levels, uniformity, and viewing angles, and reduce motion blur. Table 1 summarizes the BLU types and their characteristics.

Driving requirements and challenges

The different BLU schemes require significantly different driver architectures. Edge-type drivers typically require very high output voltages (a few hundred volts) that in most cases drive a single string of LEDs. Challenges related to driving multiple parallel strings such as matching current and forward voltages are a non-issue. However, this BLU style keeps all of the LEDs illuminated at all times, which wastes power. The only energy savings come from the baseline efficiency advantage of LEDs. The LEDs can be dimmed globally – the technique is sometimes called global dimming – but the dimming capability does not enhance the picture quality.

A driver for an edge-lit TV must utilize a high-voltage, boost topology. Typical voltage output from a TV power supply is 12-14V so this is used as an input supply to the driver circuit, which then boosts the voltage by a factor of 10-20 while still keeping the efficiency high.

The driver itself can be a discrete DC-to-DC design or, in certain instances, the main power supply can generate the high voltage directly from the AC input. Efficiency requirements for such drivers are between 90-95%. Typically over a hundred LEDs are strung together in series. Some designs do use multiple strings, typically 2-4, lowering the requisite string voltages.

The majority of LED-backlit TVs in the market today use the basic edge-lit design. The key challenge for edge-type drivers is to maintain high efficiency at the high voltage while keeping the overall component count low. Fig. 2 shows the typical driver architecture for edge-lit TVs.

Direct BLU driver issues

In direct backlighting, LEDs are positioned right behind the LCD panel and controlled in small zones. Each zone contains a few LEDs that can be locally controlled. The type and number of zones are manufacturer specific and based on screen size, picture quality and other factors. Picture quality improves with an increase in the number of local-dimming zones, but this also increases LED and driver count and hence, the cost.

Fig. 3 shows the typical driver configuration for direct- and segment-edge-backlit TVs. The drive voltage is much lower than edge-lit designs, simplifying the issue of designing an efficient driver. A direct-backlit design would typically have a greater number of strings with fewer LEDs per string relative to a segment-edge design.

The main driver challenge in a direct-lit design is one of scale. Some such TVs have more than 100 strings or channels of LEDs. Typical drivers can handle 8-16 channels. So a TV can require many drivers.

In a typical direct-lit TV, LEDs chalk up about 40% of the total cost of the BLU bill of material, while the drivers make up another 20%. The cost of the LEDs, the power they consume, and the system complexity are all disadvantages.

Consider the issue of the varying forward voltages (Vf) of the LEDs. Even after sorting the LEDs, the varying forward voltages amongst the many strings causes a significant amount of power to be wasted inside the TV, producing heat and increasing the chance of thermal-stress-related LED failures.

Segment-edge drivers

The sheer number of LEDs and drivers required for direct BLUs, and the cost of those components, has been a key reason for the growing popularity of the segment-edge approach. Moreover picture quality is not the only purchase criteria consumers consider. In some cases thinner form factors are key selling points and the edge-segment scheme enables thinner TVs. More than 60 segment-edge-backlit TVs were announced in 2011 and this number is expected to grow rapidly in 2012.

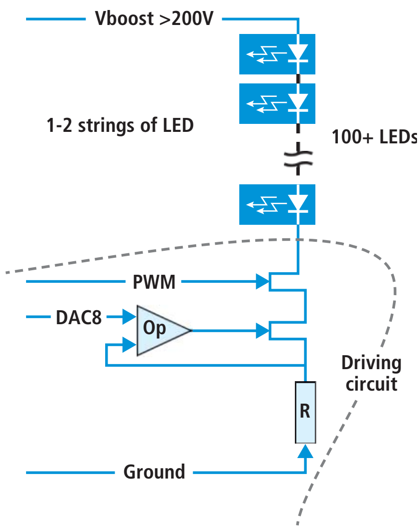

FIG. 2. Typical edge-lit driver configuration.

Segment-edge dimmed TVs require anywhere from 12-48 channels of LEDs depending on the size of the TV and number of segments desired by the maker. Given the high channel counts, all of the challenges associated with drivers in direct-lit designs also apply here, albeit to a lesser degree. The aforementioned thermal problem persists and forces the TV maker to utilize several additional discrete

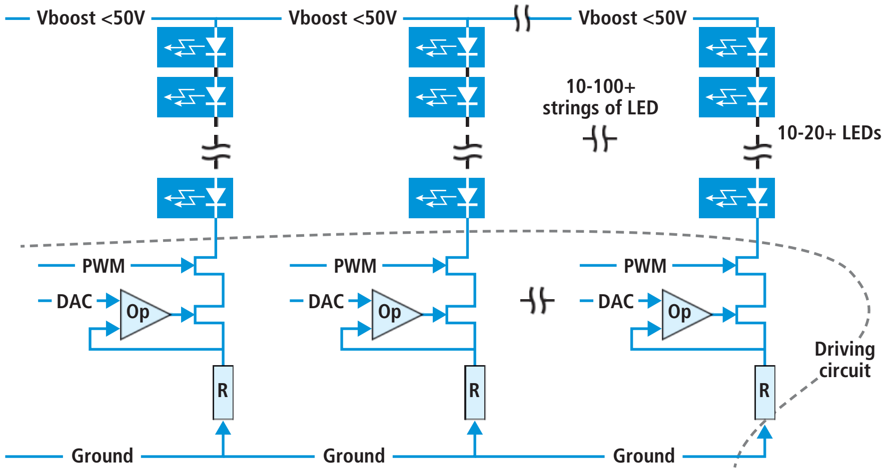

FIG. 3. Typical LED driver configuration for direct or segment-edge dimming.

components that add significant costs to the bottom line.

Evolving driver-IC technology helps overcome the thermal and cost problems. For example, iWatt developed an adaptive switching technology that senses the Vf mismatch and makes the appropriate adjustments on each LED channel, thereby reducing overall wasted power by up to 90%. The technique minimizes the generated heat, thus enabling a driver to handle more strings with integrated MOSFETs. The iW7032 driver IC, for instance, can power up to 32 parallel strings of LEDs.

LED driver ICs have become a key disruptive technology that is enabling widespread adoption of LED-backlit TVs, especially considering their cost-savings potential. The types of drivers and the related BLU architectures will have to evolve with the innovations in LCD displays and TVs.

Segment-edge designs appear be the sweet spot of BLU architectures since they best satisfy the consumer's dueling requirements for a quality picture and low cost. Still there may be increased demand for direct-backlit LCD TVs led by aggressive energy consumption mandates and demand for better video quality. New advancements in direct backlighting, such as multiple-zone sizes, fewer zones and super-selective current control will challenge traditional driver implementations to reduce costs even further.

LED DESIGN FORUM

Analog technique simplifies LED dimming in portable applications

Products ranging from mobile handsets to LED flashlights require SSL dimming control, explains **CHRISTOPHER JAMES GLASER**, and analog implementations can offer better efficiency than PWM dimming in such products.

Portable equipment that uses LED-based solid-state lighting (SSL) requires an efficient drive circuit that prolongs battery life, as well as dimming options to adjust the light output for the ambient lighting conditions. LED dimming is necessary in applications such as the backlight for smart phones or portable GPS navigation systems to ensure an easily readable display in both bright sunlight and the dark of night. In flashlights, a user may deem longer battery life more important than delivering the most light possible. Either analog dimming or pulse-width-modulation (PWM) dimming can be used in such applications. By using an innovative approach to creating a reference voltage, an analog design can prove more efficient than PWM-based designs.

Both analog and PWM dimming techniques control the LED drive current, which is proportional to the light output. Analog dimming is simple, requires the least control overhead, and generally is more efficient than PWM dimming due to the lower forward voltage of the LEDs at lower drive currents.

Analog dimming, however, requires an analog voltage to be generated by a separate voltage reference – perhaps using the output of an RC filter on a square wave input signal, or from an expensive digital-to-analog converter (DAC). The circuit in Fig. 1 eliminates the complexity of these techniques to provide simple, cost-effective analog dimming based on varying a potentiometer. The total solution is an efficient, low-cost, low-component-count LED driver for a single high-current LED, such as Osram's Golden Dragon, for use in small, battery-powered devices.

CHRISTOPHER JAMES GLASER *is an applications engineer in TI's battery power group (www.ti.com).*

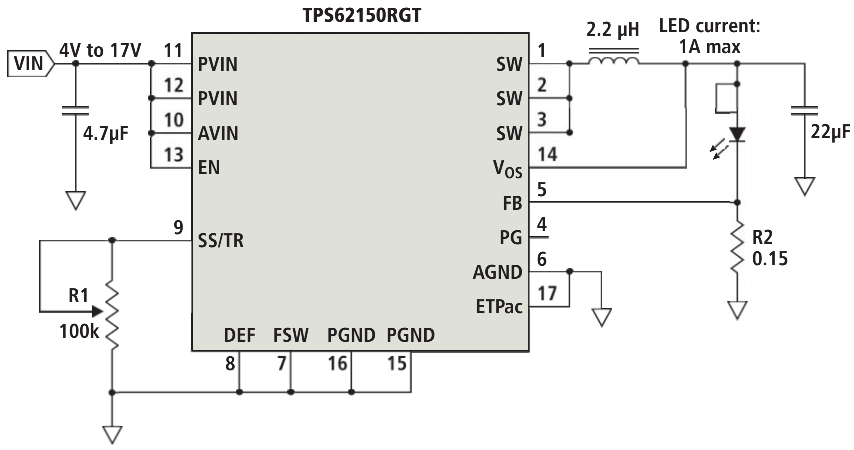

FIG. 1. LED driver with analog dimming enabled by the potentiometer R1.

Circuit operation

The circuit requires a voltage-regulating, synchronous, buck converter that provides output currents of up to 1A from up to a 17V source, such as the TPS62150. In Fig. 1, this buck converter regulates the current in the LED by using the feedback (FB) pin to control the voltage across the sense resistor R2. The FB voltage is controlled by a combination of a precision internal reference voltage, which typically is 0.8V, and an external input on the SS/TR (slow start and tracking) pin.

When the voltage on the SS/TR pin is below 1.25V, the FB pin voltage tracks the SS/TR pin voltage by a factor of 0.64 as expressed by this equation $-V_{FB} = 0.64 * V_{SS/TR}$. By controlling the FB voltage and therefore the voltage across R2, the IC varies the current that drives the LED.

The SS/TR pin has a built-in current source of typically 2.5 μA. This is commonly used to charge a capacitor and create a smooth, linear ramp-up of the SS/TR pin voltage. In a typical buck converter, this then creates a linear and well-controlled ramp-up of the output voltage while reducing inrush current from the input supply. For this design, a resistor to ground produces a constant voltage at the SS/TR pin instead.

A potentiometer is placed on the SS/TR pin to keep the voltage at that pin between 250 mV (potentiometer = 100 kΩ) and 0V (potentiometer = 0Ω). Recalling the equation above, that means the voltage on the FB pin varies between 160 mV and 0V. With a 0.15Ω resistor for R2, the LED current varies between 1.07A and 0A. Since the FB pin voltage is linearly related to the SS/TR pin voltage, the potentiometer provides linear

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analog dimming as shown in Fig. 2.

This circuit has very good efficiency, since the FB pin voltage is a relatively low value. That low voltage reduces the losses in the sense resistor, R2. In addition, the TPS62150 employs a power-save mode at light load currents to keep the efficiency high for the majority of the load range. Fig. 3 shows the efficiency of the circuit in Fig. 1 operating from a 12V input, and using TDK's VLF3012ST-2R2 inductor in the switching output.

The efficiency of this circuit can be improved, but at the cost of circuit size. For example you could connect the FSW (switching frequency) control pin to the output voltage, which reduces the operating frequency, and/or select a different inductor with lower DCR (DC resistance) and/or better AC loss characteristics. Efficiencies in excess of 90 percent are possible, although these two methods would likely take more circuit board area to realize. The design presented in Fig. 1 delivers a small solution size with good, albeit not the greatest, efficiency.

Circuit limitations

Since this circuit uses an imprecise analog input (a manually adjustable potentiometer) for regulating the LED current, the tolerances of the sense resistor, potentiometer resistance, and SS/TR pin current and how they affect the LED brightness do not matter. If the LED is too bright, the user simply turns the potentiometer resistance down. If it is too dim, simply turn the potentiometer resistance up. With a multi-turn potentiometer, the LED brightness can be sufficiently controlled for ordinary applications, such as flashlights and backlights.

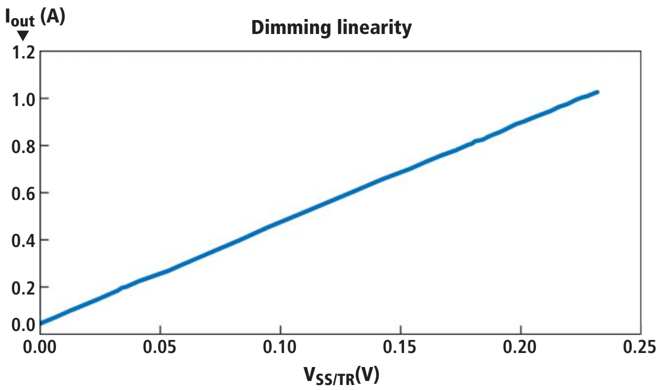

FIG. 2. Dimming linearity of the circuit in Fig. 1, in which dimming is achieved using a potentiometer.

One drawback of this design is the offset between the SS/TR pin and FB pin voltages. When the SS/TR pin is pulled all the way down to 0V, by decreasing the potentiometer resistance, there is still about 50 mA of current flowing through the LED. Thus, the LED cannot be turned off completely unless you add a switch to ground with a pull-up resistor connected to the EN (enable) pin.

Other analog dimming methods

The advantage of using the potentiometer circuit described in this article is its simplicity and cost-effectiveness. The required analog voltage for analog dimming is generated by a precise current source already in the IC which is then translated to a corresponding light output by a user-adjustable resistor. Besides this potentiometer, no other components are required. The input for the dimming, the potentiometer, is the only needed component.

If this precise current source were not present, other methods of generating the required analog voltage for analog dimming would have to be considered. Some traditional options include: using a separate reference voltage IC that creates a precise analog voltage; varying the duty cycle of the PWM output of a microcontroller through an RC filter to generate the precise analog voltage; or using a microcontroller with a DAC to generate the precise analog voltage.

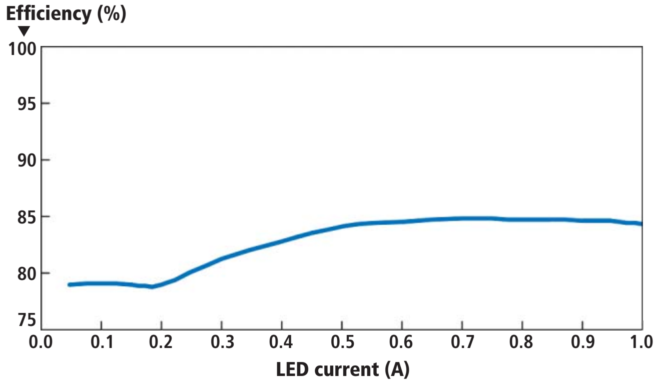

FIG. 3. Efficiency of the circuit in Fig. 1 over the dimming range.

Each of these three options requires an input from the user to vary the light. With the reference voltage IC, a potentiometer is still required as an input to the IC to adjust the voltage and control light output. The reference IC alternative is more costly than the simple option focused on in this article.

The final two alternatives require a microcontroller and again add cost. While smart phones and GPS systems include a microcontroller, the typical flashlight does not. The decision on pursuing such methods depends on the application at hand as some products would benefit from a more elegant user interface, perhaps with touch-screen control.

Option three replaces the potentiometer with a larger and more expensive DAC. The DAC could offer better granularity in the output analog voltage, and therefore more-precise light control than does the potentiometer. The application should dictate whether the expense is justified.

Using a potentiometer on the SS/TR pin of the buck converter is a simple, small, and low-cost method to provide linear analog dimming to a high-current LED in applications such as backlights and flashlights. With analog dimming, the efficiency over most of the dimming range remains near 85 percent from a 12V input supply. The complete circuit requires only six components, plus the high-power LED.

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LED industry tales from Taiwan

A recent visit to Taiwan highlighted a number of issues in the local LED industry, writes **ELLA SHUM**, Director of HB-LED Research with **STRATEGIES UNLIMITED**.

On a recent trip to Taiwan, it became clear that the overall feeling among LED industry players is pretty gloomy. I came across a variety of issues relating to LED pricing, personnel, and subsidies. However, one company, Lextar, managed to go public in September (www.ledsmagazine.com/news/8/9/35), so the news is not all bad.

Concerning pricing, the industry was shocked by rumors of a quote of $0.08 given by a large Korean vendor for a 5630-type packaged LED for lighting. Such packages are often used in retrofit lamps that do not require high lumen output. The price is equivalent to approximately 400 lm/$. Even in Taiwan, where the art of cost-cutting is most refined, this price is looked upon as below cost. A curious observer would note that a similar package from the same vendor designated for backlight applications is more expensive. The conclusion varies, but most people feel this may be an attempt to buy the lighting market, or that it is another tactic to put downward pressure on prices for the whole industry and to force weaker players out. Whatever it is, once the prices go down, they don't usually go back up.

Retaining personnel is a challenge for Taiwanese companies: whole teams of engineers have moved from Taiwan to China, and with a 4-5-fold increase in salary, the temptation can be irresistible. Teams frequently move together, but this is essentially a one-way street since no Taiwanese companies will ever hire them again. When there were many start-ups in China buying MOCVD systems last year, bidding wars were frequent for these teams. What's interesting is that quite a few of these relocated personnel have totally changed their identity. The suspicion is that these people took valuable IP with them. Due to the political situation between the two regions, there is no legal way to pursue or extradite suspected criminals from China to Taiwan. In a Confucian society, where ancestry worship is core to the cultural identity, changing one's name means denying one's ancestors. I only hope the money is worth it.

I met someone from Taiwan whose company sold energy-saving electronic ballasts for florescent lights. He secured a contract to supply 2700 ballasts to a major US retail chainstore. The product performed as specified, saving 25-30% energy, and payback was 1.5 years based on 24/7 usage. My friend called every 6 months to check on the products and see if follow-on orders were going to come. After a couple of years, he gave up calling. Four years after the initial installation, he received an order for 775,000 units. Similarly, after Walmart tested LED lights from GE in their refrigerator displays, it took them 3 years to decide to roll out LEDs in all stores. This illustrates the chasm between the early adopters and the early majority. Time has passed since these stories happened, and the chasm is probably shorter now. However, if you are a start-up in the LED lighting market, what is your strategy for crossing the chasm?

A new kind of net profit

The mainstream semiconductor industry is used to feast and famine. During down-cycles, weaker players leave the scene, while stronger ones survive to reap the profit in the next upturn. In this particular down-cycle, we have noticed something interesting when comparing the net profits of two LED chip companies; Epistar from Taiwan and SanAn from China.

Epistar's net profit for the first half of 2011 was NT 1.1 billion ($35.7 million), with a margin of 11%. In the same period in 2010, the margin was 29% on NT 2.7 billion ($88.6 million) net profit. In contrast, SanAn's net profit margin for the first half of 2011 was RMB 459 million ($72.3 million) with 64% margin. In the same period in 2010, the margin was 56% on RMB 202 million ($31.8 million) net profit. Why the huge difference in profit margin between the two companies? Why did SanAn's margin and net profit go up in 2011 when the overall market crashed?

Upon further analysis, SanAn received RMB 583 million ($91.8 million) in subsidies for the first 6 months of 2011 from the government, and that is counted towards its net profit. If you take out the subsidies, it lost RMB 124 million ($19.5 million). For the rest of 2011, SanAn still has RMB 928 million ($146.2 million) in subsidies to add to its balance sheet.

Another new player in the China LED world is ETI (Elec-Tech International), which received subsidies totaling RMB 534 million ($84.1 million) in 2011. This is an amount higher than the net profit of the company's LED business.

I think we will have to invent a new term for this type of "net profit," to distinguish it from the hard earned "net profit" we are used to.

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