

Light Generation

Quantum Dot LEDs

Chip Arrays

LED Signs

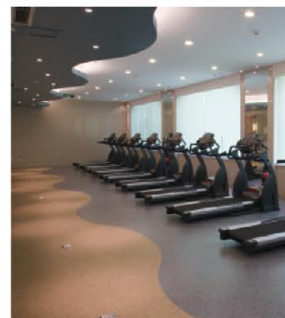
Interview with Citizen

Thermal Derating

Offline LED Driver



Edixeon® Federal Module

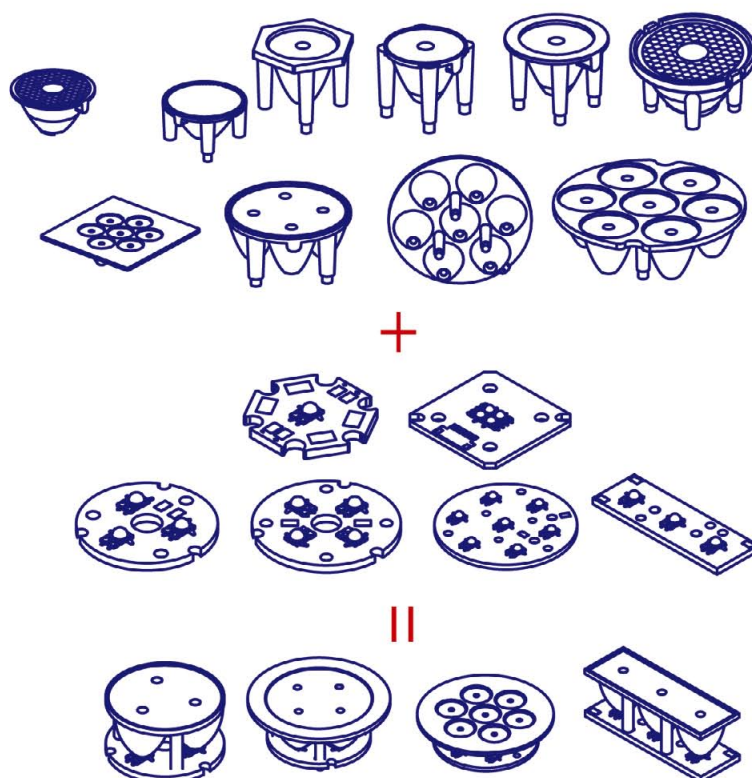
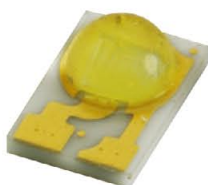


● Secondary Optics for Edixeon® Federal Modules

Standard 3-in-1 and 4-in-1 Edixeon® Federal modules can provide various color mixing choices for different scenarios. Edixeon® Federal module series can demonstrate exceptional performance through the **use of Khatod color mixing lens.**



EFEEx-xAE1



Quantum Dots – The NanoLight



"I think that, five years from now, LEDs will have a significant market share in lighting, and that quantum dots will play a big role in their rapid adoption by providing the warm color quality that consumers demand." These were the words of Seth Coe-Sullivan, the co-founder and CTO of QD Vision, in an interview last month. Coe-Sullivan continued by saying, "The focus on CFL technology will quickly turn to recycling and Mercury remediation, while incandescent bulbs will have been legislated out of existence." Together with Nexxus lighting QD Vision developed the first LED bulb based on the Quantum Dot technology, which will be available in the fourth quarter of 2009.

Quantum dots (QDs) refer to one of several promising materials niche sectors that have recently emerged from the burgeoning growth area of nanotechnology. QDs fall into the category of nanocrystals, which also includes quantum rods and nanowires. As a materials subset, QDs are characterized by particles fabricated to the smallest of dimensions from only a few atoms and upwards. At these tiny dimensions (diameter of 2-10 nanometers which are 10-50 atoms), they behave according to the rules of quantum physics, which describe the behavior of atoms and subatomic particles, in contrast to classical physics that describes the behavior of bulk materials, or in other words, objects consisting of many atoms.

The white-light quantum dots produce a smoother distribution of wavelengths in the visible spectrum with a slightly warmer, slightly more yellow tint, reports Michael Bowers, the graduate student at Vanderbilt University in Nashville who made the quantum dots and discovered their unusual property. As a result, the light produced by the quantum dots looks more nearly like the "full spectrum" reading lights now on the market which produce a light spectrum closer to that of sunlight than normal fluorescent tubes or light bulbs. Of course, quantum dots, like white LEDs, have the advantage of not giving off large amounts of invisible infrared radiation unlike the light bulb. This invisible radiation produces large amounts of heat and largely accounts for the light bulb's low energy efficiency.

In general, current and future applications of QDs impact a broad range of industrial markets. These include, for example, biology and biomedicine; computing and memory; electronics and displays; optoelectronic devices such as LEDs, lighting, and lasers; optical components used in telecommunications; and security applications such as covert identification tagging or biowarfare detection sensors.

The July/August 2009 *LED professional Review (LpR)* issue highlights the Light Generation topics and shows how to apply the latest light engine technologies into modern LED lighting systems.

We would be delighted to receive your feedback about *LpR* or tell us how we can improve our services. You are also welcome to contribute your own editorials.

Yours Sincerely,

A handwritten signature in blue ink, appearing to read 'S. Luger'.

Siegfried Luger

Publisher

PS: New! The *LED professional Review (LpR)* subscription was upgraded with the bi-monthly LED patent report and the "Hot News" information service. Have a look at the unique LED professional membership services on www.led-professional-review.com.

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- LED Primary & Secondary Optics

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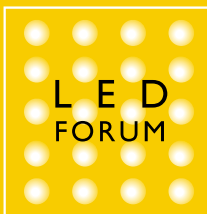
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3rd INTERNATIONAL LED FORUM MOSCOW LEDs IN LIGHTING TECHNOLOGIES

Time: November 11th – 12th, 2009
Venue: Expocentre Fairgrounds, Moscow



**Attend one of the biggest conferences on
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Project News

Perpignan Fountain Lighting: A Spectacular Display of Light, Sound and Movement

This summer the residents and tourists in Perpignan, located in the south of France, can enjoy a unique, dramatic fountain that uses computer controlled luminaires with LUXEON LEDs to create an incomparable light and water show without compare. The distinctive design of the fountain, built by Sacopa, occupies a space of 30m in diameter in the centre of the city, incorporates 217 separate water jets and 900 centrally-controlled LUXEON LED points of light.



The dramatic illumination of the Perpignan fountain is provided by computer controlled luminaires.

Perpignan's fountain is a festival for the eyes conjuring the spirit of ancient fountains that entertained and cooled city dwellers. However behind the mesmerizing visual dance of water and light lie very modern, highly technical LUXEON power LEDs whose size and stealth belie their power to manipulate a scene. With 900 separate points of light embedded in individual water jets, controlled centrally to provide routines that coordinate coloured light, water and music, the new Perpignan city centre fountains are a spectacular illustration of the novel effects made possible with the use of power LEDs.

The designers and engineers at Sacopa understood that the small size and the longevity of LEDs were the only solution that would allow the creation of a vast installation covering a wide floor area with an unusually large number of individual light sources. This would satisfy the requirement for a spectacular and novel effect, since fountain lighting is traditionally designed with small numbers of large spotlights illuminating a few water sources. The short relamping intervals of conventional lights would have caused rise to crippling replacement and maintenance costs.

Sacopa expects their lighting solutions for the Perpignan fountains to last approximately 27 years assuming five hours of use a day, 365 days a year. This extraordinarily long lifetime is made possible by the robustness of the LUXEON K2 LEDs and the associated components in the fixtures designed by Sacopa.



Sacopa's LED fixtures and the water jets bring the Perpignan Fountain to life.

So, with the fundamental idea in place, Sacopa was able to elaborate the detailed design. The scheme envisaged the detailed illumination under precise control of the hundreds of water jets. Sacopa thus designed a stainless steel fixture made in the shape of a flower, which contains a tri-colour LED luminaire and a water jet inside its 'stem.' While the diffuse beam of light from incandescent sources is hard to focus, the beam from the RGB LEDs is mixed and directed by a lens integrated into the fixture with almost no light loss.

Behind the aesthetics of the lighting routines, however, is some very practical engineering. The metal flower housing, together with an aluminium heatsink underneath the LEDs, provide a good thermal conduction path from the LEDs. This is important because controlling the operating heat at the LEDs below a certain threshold helps to maintain a high light output and extend operating lifetime. The LUXEON K2 LEDs in Sacopa's flowers operate at a typical junction temperature of 80 °C (in air) and 70 °C (when cooled by water) even though they are driven at a high 700 mA in order to produce a strong beam. Since the robust LUXEON K2 LEDs used in the installation have a high temperature tolerance (a maximum rating for junction temperature of 150 °C in the case of the red, and 185 °C for the green and blue versions), the Sacopa fixtures are comfortably inside Philips Lumileds' recommended operating conditions. Perpignan, located on the shores of the Mediterranean Sea, can enjoy daytime temperatures of up to 50 °C, but extensive product testing before installation showed that the luminaires' performance would be unimpaired, even on the hottest nights.

The excellent thermal performance of the flower fixtures and of the LUXEON K2 LEDs also enhances the efficiency of the lights: at full power, each LED consumes 3 W, and each RGB luminaire consumes 11 W in total. Thus the complete installation consumes 9900 W (maximum). Sacopa's calculations show that a halogen-powered equivalent installation, producing the same light intensity, would consume five times as much power. ■

Lediko: Spectacular RGB Fountain Illumination at the Wroclaw Continental Hall

On the 4th of June 2009 at the Wroclaw Continental Hall (Poland) there was an opening show of one of the greatest multimedia fountains in the world. In cooperation with the Polish fountain constructor – the company Gutkowski – LEDIKO designed and produced the majority of LED RGB modules which have been used for spectacular illuminations.



The spectacular RGB fountain illumination at the Wroclaw Continental Hall.

The project works with more than 6500 XLamp XR-E and XR-C LEDs, manufactured by the American company CREE, in the use of which LEDIKO specializes. The LEDs are characterized with extremely high quality, long lifetime and well-defined beams of light with an increased effectiveness due to the use of additional high-efficiency optics. An unquestionable advantage of LEDs in such applications is the easy control. Apart from the advantages of LEDs, the project also required a broad knowledge of LEDIKO in the scope of LED modules manufacturing as well as and many years of experience confirmed by the status of CREE LED Solution Provider. The Gutkowski company, which has implemented the project of the fountain, appreciated the skills of LEDIKO and entrusted the design and production of the modules to the company. As a result, the two companies together developed a modern and unique product, which was presented for the first time during the opening show of the fountain.

An unusual spectacle of water, music, fire and colourful LED light brought some 20 thousand people together. Nearly 800 points of light illuminated the multimedia show, water columns rose up to 40 meters and artistic animations were admired on a 700m² water screen. XLamp LEDs have proved to be the best choice, confirmed by the enthusiasm of the public. ■

Product News

Future Lighting Solutions: Wireless Reference Design

Future Lighting Solutions demonstrated a new IEEE 802.15.4-based Wireless Lighting & Control Reference Design jointly developed with Freescale Semiconductor on Thursday, July 16, in a 3:30 (EDT) webinar. The session discussed the benefits of using ZigBee® technology to build wireless control applications such as wireless colour mixing and light dimming for Solid-State Lighting applications.

The Future Lighting Solutions and Freescale reference design is intended to enable rapid development of wireless control applications in any industry. Components include Freescale's MC13213 System in Package (SIP), which integrates a low-power 2.4 GHz radio frequency transceiver and an 8-bit microcontroller in a compact 9 x 9 mm LGA package that can drive wireless sensing and control applications using the Simple MAC, IEEE 802.15.4 Compliant MAC or ZigBee protocols.

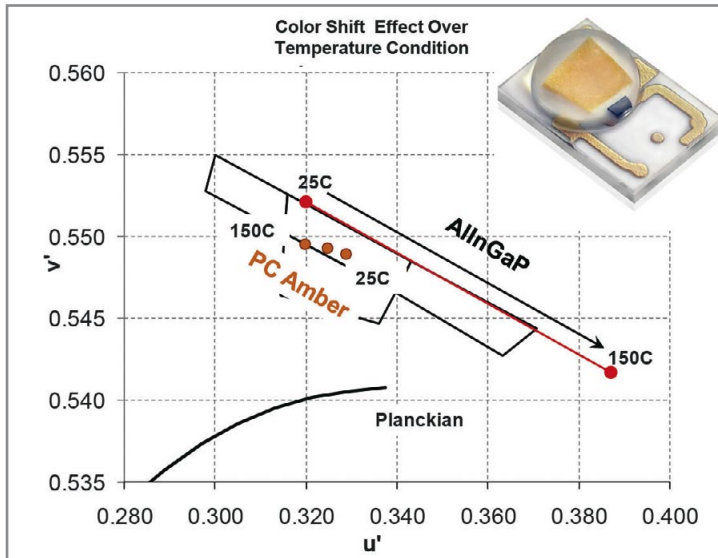
One recent use of ZigBee technology is in ultra-thin LED wayfinding signs built in a collaborative effort among Future Lighting Solutions and multiple third-party companies. The signs were designed to use a ZigBee-based wireless dimming control system that is capable of automatically adjusting sign brightness based on ambient light.

For that project, Future Lighting Solutions supplied minimum 100 lm LUXEON® Rebel LEDs from Philips Lumileds for custom LED light modules. Future's proprietary Usable Light Tool was used to calculate how many LEDs would be required to light the signs. Future engineers also assisted in identifying dimmable LED drivers and optics that fit the needs of the project. ■

Philips Lumileds Announces Breakthrough in Light Output and Temperature Stability

Philips Lumileds recently announced immediate availability of its breakthrough LUXEON Rebel phosphor converted amber (PC Amber) LED. The new LUXEON Rebel sets performance standards for colour stability and light output performance. Users will see two to five times more light output and dramatically less colour shift compared to typical amber LEDs. LUXEON Rebel PC Amber delivers a typical flux of 70 lm at 350 mA. This performance enables solution and application providers to reduce the number of LEDs used, the cost per lumen, overall system costs, and simplify the solution manufacturing process.

"The number and breadth of applications that require amber LEDs is tremendous," said Frank Harder, VP of Product Marketing at Philips Lumileds. "Markets including automotive, entertainment, roadway, signaling, and many others use amber LEDs. With better efficiency and more light output, LUXEON Rebel PC amber makes it that much easier to reduce energy consumption with an environmentally-friendly product."



The colour shift effect is dramatically reduced.

There are many applications that have not switched from conventional incandescent lamps to LEDs because they did not produce enough light and could not operate effectively at higher temperatures. With the advances provided by LUXEON Rebel PC Amber, yellow traffic signals will be converted, warning lights and beacons on vehicles and obstructions will be switched and entertainment applications will adopt the new LEDs.

Automotive applications, such as those for braking and signaling, use significant numbers of amber LEDs. With LUXEON Rebel PC Amber, manufacturers will be able to use fewer LEDs and lower other component costs because of the improved light output and particularly the stable colour over temperature; something that has been problematic for many auto manufacturers. Philips Lumileds expects full automotive qualification later this year.

Complete specifications and details are published in the LUXEON Rebel PC Amber Product Brief. ■

Edison Opto to Debut New Federal Module Series

Edison Opto, a Taiwan-based high-power LED packaging manufacturer, has presented the latest Federal module series at the 2009 Guangzhou International Lighting Exhibition.



Edixeon® Federal series from Edison and Optics from Khatod.

Edixeon® Federal, with the smallest high power LED footprint available by Edison Opto, has offered extended Solid-State Lighting design possibilities. For ease of use in applications such as spotlight, recessed downlight or vehicle lighting, Federal module series include multiple Federal emitters on a single FR4 PCB and are available in linear 3-in-1, and circular 3-in-1, 4-in-1 and 7-in-1. Complimented by Khatod's secondary optic solutions, the modules are available in choices of narrow, medium and wide beam angle. ■

Axiom NZ Introduces Low Cost LED T-Bar Ceiling Fixture

Axiom NZ recently announced that it has started shipping its AX24 line of LED T-Bar Ceiling fixtures for false grid ceiling applications. The AX2424 is 24" by 24" (2'x2') and the AX2448 is 24" by 48" (2'x4'). Both are designed to be direct replacements for commonly used fluorescent fixtures.

The Axiom NZ AX24 series uses high reliability Nichia of Japan LEDs and incorporates a simple maintenance friendly design that allows electricians to service and replace the modular LED and power supply system without having to go into the ceiling.



Axiom AX2424 LED fixture features indirect reflected lighting. The Low profile fixture drops in and easily replaces existing fluorescent fixtures. Mounting brackets are provided for securing the fixture as required. Axiom AXLE8 modules are easily replaceable with twist of the vinyl knurled mounting screw.

The UL listed fixture is developed by Axiom NZ in conjunction with other industry leading fixture manufacturers. The AX24 series uses Axiom NZ's UL Recognized removable and replaceable AXLE8 LED boards and UL Recognized PS60HS15 high reliability power supplies that feature 90-277VAC universal input. The fixture has a rated lifetime of 50,000 hours with less than 20% degradation over that time.

The AX24 uses indirect reflected lighting eliminating any glare and has comparable output to fluorescent fixtures they replace.

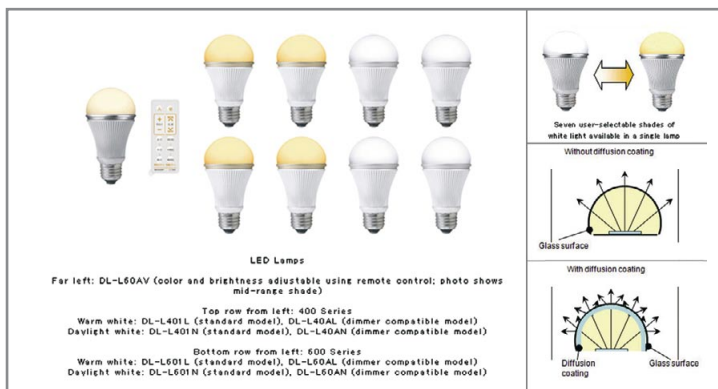
The AX24 fixture is made in the USA for customers there or in New Zealand for customers in the Southern Hemisphere to reduce transportation costs, shorten manufacturing cycle times, to provide customer customization, and to enhance the level of quality.

"Our LED lighting system can replace the light fixtures used in any company office in the world at a price which is almost 50% less than competing technologies," commented Manuel Lynch, CEO of Axiom NZ. "We very proud that we have developed a way to manufacture this fixture in the country where it will be used, making it a truly green product."

The AX2424 system sells for \$275, and the AX2448 system sells for \$375. The typical payback cycles when including power savings, reduced maintenance, bulb replacement costs, and proper government regulated mercury disposal costs of fluorescent, are approximately 24 months. ■

Sharp Introduces Nine New LED Lamps for Home Use

Sharp Corporation will introduce nine models of LED lamps onto the Japanese market featuring outstanding environmental performance, including high energy efficiency, long service life, and free of hazardous mercury. Because these lamps have the same standard screw-in base and fit in the same sockets as ordinary incandescent lamps, they are simple and easy to use as replacements for ordinary lamps.



Sharp's new line of LED lamps for home use.

The model DL-L60AV LED Lamp features an Adjustable Colour Function that enables users to change the colour of the white light emitted from the lamp using an accessory remote control, an industry first for an LED lamp. Users can select from seven different shades of white ranging from a pleasing warm white to a cooler daylight white to match the weather, the season, time of day, purpose, or other preferences. This model also features a built-in dimmer function to adjust brightness. Together these features allow users to select the illumination they like best to complement a diverse range of interior settings by using a single remote control to change the colour and brightness of the light.

In addition, the model DL-L601N LED lamp delivers a brightness of 560 lumens, among the highest in the industry for LED lamps having nearly the same size and shape as ordinary incandescent lamps.

LED lamps consume a small amount of electricity and contribute to reducing CO₂ emissions by saving energy. The models DL-L401N/L LED lamps offer extremely economical operation, and can be run for approximately 11 hours at a cost of only one yen. All models feature a service life of 40,000 hours.

In the future, Sharp will be offering more such uniquely featured LED lamps with outstanding environmental performance to provide a diverse range of lighting options. ■

Innovations in Optics: New Sophisticated and Versatile LED Light Engines

Innovations in Optics is the first to develop a series of OEM light engines that incorporate ultra high brightness (UHB) LEDs, several available primary collection optics, and thermistor and photo-sensor options for real-time feedback loops of temperature and light intensity.

Standard Features:

- Highest brightness light engine
- UV thru near IR
- Single colour or broadband phosphors available
- High thermal conductivity metal core PCB
- Robust 8 pin SMT connector
- Thermistor option available
- Photosensor option available
- Non-imaging optics
- COB array technology
- High performance polymer optic/resistant to yellowing

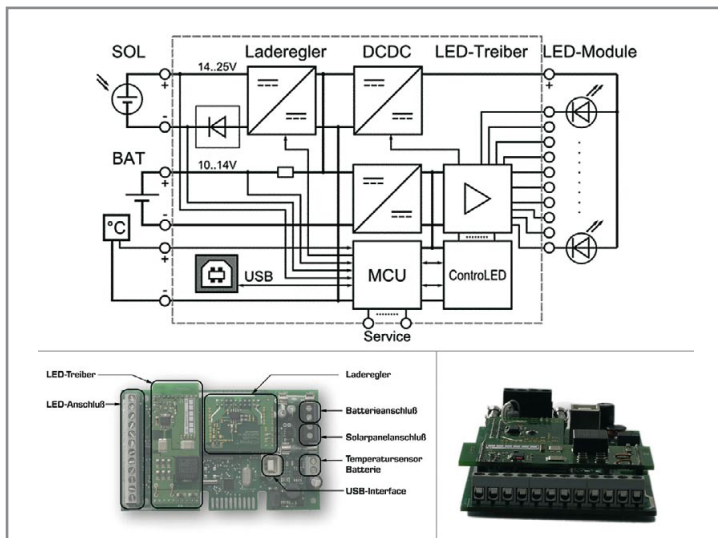


The five collection optics provide optimized output solutions specific to end-user applications.

The multi-configurable board can accommodate from one to fourteen LED die from UV to near IR and up to three colour combinations. The five collection optics provide optimized output solutions specific to end-user applications, such as light guide and fibre optic coupling, projection lighting and unrivaled uniform far field illumination. ■

Dilitronics Introduces Sophisticated Solar LED Controller

The high-tech company Dilitronics presents the Solar LED controller ESoLUX. This controller unit for solar-powered LED lamps provides the eco-friendly and efficient operation of off-grid lighting systems. The intelligent control of the components – solar panels, accumulators and LEDs – is the heart of the controller.



ESoLUX controller block diagram, layout and image.

In coming years, all the local luminaires will have to be changed to energy-efficient lights (EC regulation 2005/32/EC). Stephan Schulz, Managing Director of Dilitronics, explains: "Against this background, the demand for long-lasting lighting concepts is increasing. With ESoLUX we offer an innovative and competitively priced product that allows the reliable solar lighting based on LED technology."

ESoLUX can be programmed via USB interface and thus it can be adjusted to very different operating conditions. The integrated software offers a unique variety of controller configuration options. The capability of the components can be optimally used by programming. Mr Schulz adds, "The efficient use of the solar panel, battery and LED outputs allows to save energy by ten percent compared to conventional LED systems and thus guarantees a longer luminous period." A residual lifetime prediction and a low voltage disconnect for accumulator protection ensure the operating reliability of the system.

Apart from the advantage of an energy-independent and CO₂-neutral operation the controller maximizes the lifetime of the accumulators, panels and LEDs.

Moreover, the programmability allows the movement-, time- or weather-dependent control of the lighting systems. The ESoLUX controller enables a space-saving integration into the lighting units. Additional electronic components are not required for the operation of the light source. ■

Five New Constant Current LED Drivers with High Efficiency of 96%

Aimtec expands its AMLD-IZ series of step-down DC-DC LED drivers with five new models generating constant output currents reaching 1.2A.

With wide input ranges of 5-36 VDC that step-down to wide output ranges 2-32 VDC, the new models in the AMLD-IZ series generate constant output currents of 800 mA, 900 mA, 1,000 mA, 1,100 mA, 1,200mA with an accuracy of up to $\pm 2\%$, ensuring the constant colour and brightness that is required by today's most demanding LED applications.

Producing up to 38.4 watts of power in a compact DIP24 package (31.80 × 20.30 × 10.20 mm), the AMLD-IZ series features include remote ON/OFF control function as well as PWM and analogue voltage dimming control (0 - 100%).

Boasting efficiencies of 96%, Aimtec's LED drivers are designed to be as reliable as the LEDs they drive, allowing them to be used at an operating temperature of -40 °C to +85 °C at full load.

Compatible with a wide range of LEDs applications, all of Aimtec's LED drivers provide turn key solutions that require no external components, for easy integration into a multitude of LED lighting applications, including single unit or arrays of LEDs designs.

RoHS compliant, the entire AMLD-IZ series offers excellent quality/cost value and is competitively priced starting at \$19.36/1000+ pieces. Samples are available from stock and can be ordered immediately. ■

Announcements

LED FORUM MOSCOW 2009

Workshops with OSRAM OS and Italian lighting designer

The Russian lighting market has been growing constantly over the last few years. Now interest in LED lighting technologies is also skyrocketing in Russia, especially as energy-efficient lighting is becoming an issue. In addition, OSRAM Opto Semiconductors has emphasized the importance of the Russian LED market by becoming a premium sponsor of the LED FORUM MOSCOW.

The Russian LED market and technological developments – those are the headlines of the plenary session on November 11th, 2009. The second day (November 12th) of Russia's most important LED conference is dedicated to hands-on workshops. In the "Indoor and Outdoor Lighting" workshop, OSRAM OS will demonstrate a street lighting solution with a light fixture design based on OSRAM's outstanding high-power LEDs. The "Shop Lighting" workshop with Italian lighting designer Simone Mariotto from Liteq Design will feature trends in contemporary shop design.

LED FORUM MOSCOW is held in conjunction with INTERLIGHT MOSCOW, Russia's leading trade fair for lighting, light technologies and intelligent building technologies.

Further information: www.ledforum-moscow.com. ■

Upcoming Edition of LIGHT MIDDLE EAST: Re-Scheduled to Autumn 2010

Individual talks and strategic sessions with the key players in the lighting industry led to the conclusion that the timing for the upcoming Light Middle East edition, which was to be held at the Dubai International Convention & Exhibition Centre from September 27-29, 2009, would instead be preferred in autumn 2010. Light Middle East is the region's leading trade show and conference for urban, architectural, theatrical and retail lighting solutions.

According to Elisabeth Brehl, Managing Director of Epoc Messe Frankfurt GmbH, "Running Light Middle East in Autumn 2010 together with the ISH Kitchen and Bath Middle East exhibition, will enable key buyers in the real estate, architectural and design sectors to source new products and network within a specialized exhibition environment."

"While we regret any possible inconveniences caused to exhibitors signed up and already promoting their participation", commented Ms. Brehl, "we look forward to working with exhibitors and supporting organizations on the 2010 edition." ■

While the Middle East has witnessed a considerable slow-down in real estate development projects as an indirect result of the global crisis, a postponement of the exhibition to 2010 will benefit all involved participants. Many new projects needing lighting outfitting are on the horizon in the surrounding regions within the GCC (Gulf Cooperation Council) and wider Middle East, in particular Abu Dhabi, Qatar, and Saudi Arabia. ■

Correction

Additional Authors of Articles from *LpR13*

Methodology for Thermal and Electrical Characterization of Large Area OLEDs

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László Pohl, Ernő Kollár, Zsolt Kohári – Budapest University of Technology & Economics, Department of Electron Devices
Herbert Lifka, Cristina Tanase – Philips Research Laboratories

On the Standardization of Thermal Characterization of LEDs

> **Aandrás Poppe** – Budapest University of Technology & Economics, Department of Electron Devices and Mentor Graphics MicReD Division
Clemens J.M. Lasance – Philips Research Laboratories ■

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size as an XR-E.



XLamp XP-E
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the XR-E at 20%
the package size.

CREE 

Photos depict actual installations using Cree XLamp LEDs. Cree, the Cree logo and XLamp are registered trademarks of Cree, Inc.

Application

Using RGB LEDs for Multi-Color Sign Applications

> Andreas Pohl, Avago Technologies

Video walls utilizing multi-color LEDs are in demand, especially if the LED can be mounted using surface-mount technology. The following article deals with the latest red, green, and blue (RGB) LED package approaches for full-color indoor and outdoor displays, as well as technical considerations which designers should take into account when designing these large full color displays.

SMT Products for Full-Color LED Displays

There are different packages available in the market that can be used to build up a video wall using a surface mount approach. For instance, PLCC-2 LEDs can be used to build up a mono-chromatic display or full-color display where one pixel is made from multiple LEDs. On the other hand, due to the size of a PLCC-2 LED, the pixel pitch of such a screen can be quite large. This might be acceptable in screens with a distance to the viewer of at least 10-15 meters. In situations where the viewer is closer to the screen, like at a shopping mall, a finer resolution would be more favorable. 3-in-1 RGB packages enable smaller pixel sizes to be achieved. The most popular 3-in-1 RGB packages are based on either a PLCC-4 or PLCC-6 platform.

Recently, Avago released a new 3-in-1 RGB PLCC-4 LED (ASMT-QTB0). This PLCC-4 LED has highly reflective white package material which provides a high extraction of light. However a black surface is used on the upper side of the LED to achieve a high contrast ratio. The black surface needs to be non-reflective to absorb as much light as possible shining onto the screen from various sources, e.g. spot lights or the setting sun. The pixel pitch of the aforementioned PLCC-4 can go down to 8mm for high resolution video screens.



Figure 1: ASMT-QTB0-0AA02 (left), ASMT-QTC0-0AA02 (right).

A completely black package PLCC-4 leads to an even better contrast ratio, enabling enhanced visual performance and appearance of indoor full color screens. For example Avago's ASMT-QTC0 enables screens to be built with a similar visual appearance to an LCD display, but in much larger sizes.

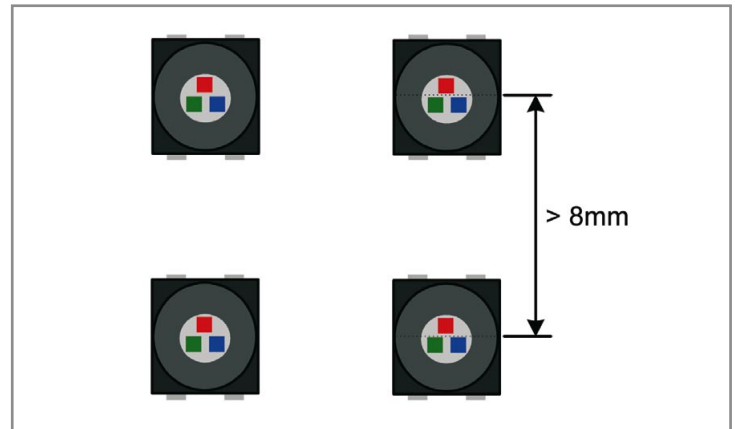


Figure 2: Pixel pitch example of a display using PLCC-4 packages.

Another popular package platform for full color video screens is a PLCC-6 LED which has 6 leads with an individual anode and cathode for each chip, like Avago's ASMT-YTB0. A highly reflective white package enables good color mixing and high brightness, making it suitable for outdoor applications. The black surface helps to achieve a high contrast ratio in indoor and outdoor video walls. Additionally, the small package design enables a pixel pitch down to 8mm. However, for optimum performance, the recommended pixel pitch is 10mm.

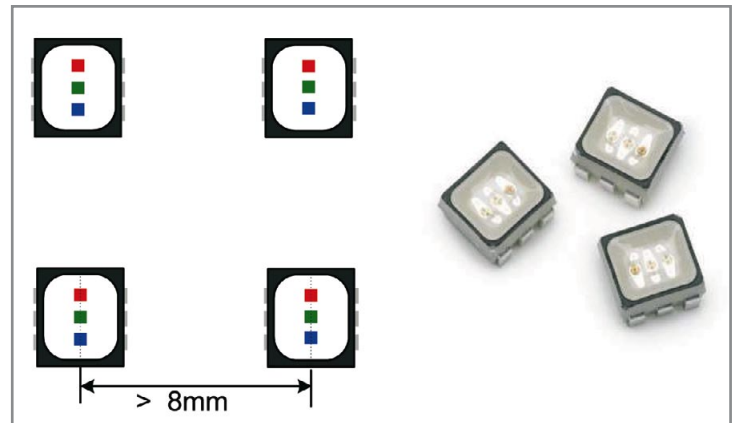


Figure 3: Pixel pitch example for a display using PLCC-6 packages (left) and ASMT-YTB0-0AA02 (right).

Considerations That Help to Further Improve Full-Color Screens

Thermal management and LED component behavior

Higher brightness is one easy way to boost the visual performance of full-color displays. The ASMT-QTB0 and ASMT-YTB0 for example, have a typical total brightness of 2.1cd @ 20mA for each chip; the fully black ASMT-QTC0 comes with typical total 925mcd @ 20mA for each chip. The LED chips are made of semiconductor materials, called AlInGaP and

InGaN. As it is taught in physics or electronics, semiconductors tend to be quite sensitive to heat. In the case of AlInGaP and InGaN LED chips, this heat leads to a significant decrease in brightness. For example, at 125°C, the light output of a green InGaN chip decreases by up to 40 percent compared to its performance at 25°C. Therefore, good heat conduction from the LED chip to the supporting PCB or heat sink is essential.

The thermal resistance between the junction of the chip and the pin of the package is about 280K/W in a conventional PLCC-2 and about 140K/W for a mono-color PLCC-4 LED. These values are quite high, especially in the case of a 3-in-1 LED with three chips heating up. Because of this the package of a multi-color LED has to be designed with the lowest possible thermal resistance. The PLCC-4 ASMT-QTBO or ASMT-QTCO has been designed with a typical thermal resistance junction to pin, $R_{\theta_{JP}}$ of <95°C/W.

RGB display panels are used to display a wide range of televised events such as soccer matches or rock concerts, and are not only run at night. In the afternoon, the LEDs and the sunlight combine to add heat to the display. Good visibility can be maintained by either increasing the contrast ratio with low-reflective potting material or by increasing the forward current. With the first solution being costly, driving the LED at a higher current seems to be an attractive alternative. A low thermal resistance enables the LED to be driven at a higher forward current in warm ambient conditions. For example, the ASMT-QTBO can be driven at the maximum current of 50mA for the red, and 30mA for green and blue at 70°C ambient temperature. A conventional RGB PLCC-4 LED can only be driven at 25mA (red) and 13mA (green and blue) under the same ambient conditions. If the ambient temperature around the LED increases to 85°C, the red chip can still be driven at 35mA, the green and blue at 22mA. By comparison, conventional RGB PLCC-4 LED's can only be driven at 15mA or 8mA respectively at such high ambient temperatures. This means that with a low thermal resistance LED, the brightness of the display will still be very high in warm environments. This also ensures good readability in sunlight or when a spotlight pointing towards the display.

Product stability

LEDs which will be used in outdoor full-color signs must use robust packaging materials. For example, epoxy encapsulation is more sensitive to near-UV or UV radiation. Moreover, the blue emission from the LED chip discolors the epoxy over time, which decreases the light output. A much better material to use for encapsulation is silicone. Silicone's strong siloxane bond results in superb stability under heat, or near-UV and UV radiation. This enables long life performance of multi-color or high-brightness LEDs with little intensity degradation. Additionally, silicone can be formulated with different hardness properties. For examples, silicone used in LEDs for full color signs should be formulated elastic to absorb potential thermal stress in the application. This relaxation also helps to prolong the lifetime expectancy of the LED.

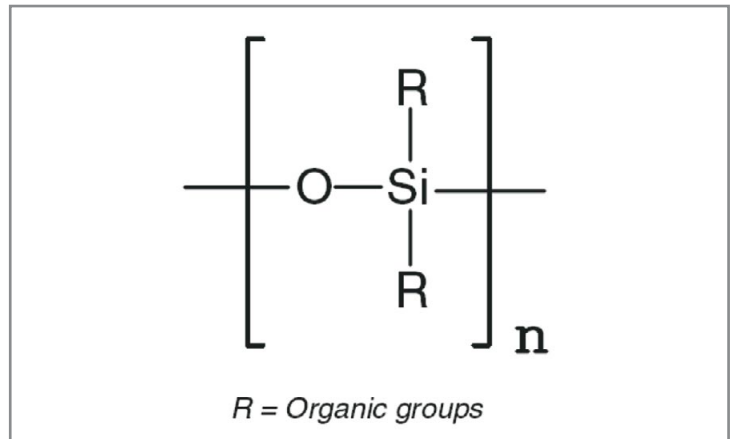


Figure 4: Silicone Bond group.

A lead frame dissipates a majority of the heat from the LED chip to the thermal pads on the PCB. Therefore, a highly thermally conductive material should be used as the base material used in the lead frame. Ideally, the lead frame is made from copper (Cu) which has the best thermal conductivity factor (min. 350 W/mK) among any metals that are the currently available. Additional silver plating makes the soldering easier and inhibits the growth of tin whiskers in the later product.

Colors and color mixing

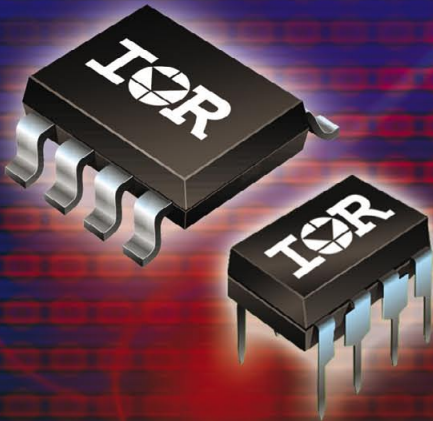
In a full color display, it is important to be able to display colors with high purity or saturation. This can only be achieved if the basic red, green and blue colors are highly saturated. For example, a very saturated blue (dominant wavelength ~465nm) enables good color mixing with green or red. This creates highly distinguished mixing colors with excellent saturation. Of course, the same approach also applies for red (dominant wavelength ~621nm) and green (dominant wavelength ~528nm). In order to achieve a D65 white color point, the ratio between red, green and blue is estimated to be approximately 3.5:8:1 for wavelengths of 621nm, 528nm and 470nm. Different wavelengths will determine a different ratio. This means, if you have 200mcd blue light, you need 700mcd red and 1600mcd green lights to generate a neutral white color from RGB multi-color LEDs. The LED manufacturer can help the display manufacturer by pre-selecting the appropriate wavelength and intensity chips for use in the LEDs' assembly.

Depending on the installation and size of the display it is important to choose the right internal dice arrangement. There are two types of arrangements available in the market: a triangular or "star" arrangement of the chips, and an in-line or linear chip arrangement.

The "Star" chips positioning is especially favorable for centered screens with a 4:3 or 16:9 ratio as this arrangement enables excellent light mixing and high color uniformity from a wide range of viewing angles. People watching or passing the display within an angle of 120° will perceive the screen to be very uniform. The "Star" chip arrangement also makes the screen suitable for vertical viewing as well.

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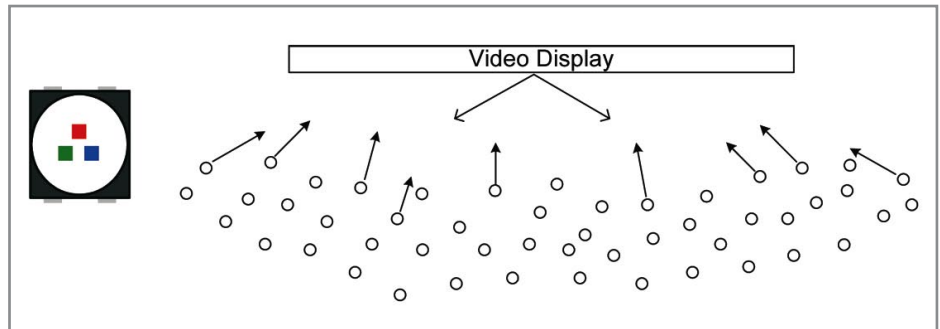


Figure 5: Example of centered screen with viewers in one direction within a 120° angle around the display.

In-line chip positioning is recommended for screens such as U-TVs which can be found in soccer stadium across the world. These exceed the ratio of a conventional screen. Because these displays are horizontally very wide, but relatively small in the vertical direction, they are being viewed from directions which can easily exceed 120°. The linear placement of LEDs helps to ensure a uniform perception of the display and good color mixing from wider horizontal viewing angles.

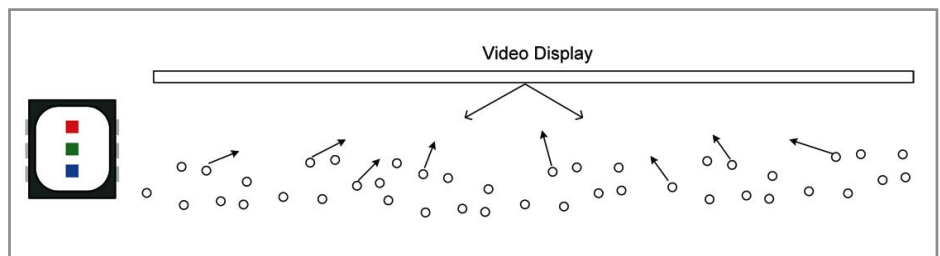


Figure 6: Example of a stretched screen with viewers at different locations but within a 120° angle around certain segments of the display.

Assembling a display and soldering the LED components

It is recommended that designers of large displays follow the JEDEC guidelines when using surface mount (SMT) LED components. Display manufactures that are used to using through-hole LEDs before switching to SMT need to be especially careful because SMT components are sensitive to moisture. The moisture sensitivity level (MSL) indicates how long the LEDs can be exposed to a factory controlled environment prior to soldering without the risk of moisture ingress. Moisture trapped inside the LED will vaporize immediately during the reflow soldering. This can cause the chip or the bond stitch to lift from the lead frame, leading to a broken mechanical or electrical connection. This effect is called "delamination" and can lead to field failures of an LED display.

For example Avago's PLCC-6 ASMT-YTB0 has an MSL rating of 2a. This means 4 weeks floor life with the ambient conditions maintained at a temperature below 30°C and a relative humidity below 60 percent. As outlined in JEDEC J-STD-033B, the floor life of SMT components with a thickness below 2.1mm will decrease from 4 weeks to 1 day if the relative humidity is increased by only 10 percent (to 70 percent) at a temperature of 30°C. Therefore, it is important to carefully control the ambient conditions of the production line during both day and night to avoid failures in the display. If the LED that has been exposed to unknown ambient conditions, it is recommended the LED are baked on the reel at 60°C +/-5°C for 20 hours. This will eliminate all moisture from the inside of the LED, and ensure that they can be soldered with the recommended soldering profile. ■

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Effective Illumination for Internally-lit LED Signs

> M. Nisa Khan, Ph.D., LED Lighting Technologies

LED-illuminated channel letters and cabinet signs are rapidly gaining popularity as supported by a signage industry survey, which revealed that in certain cases LEDs had overtaken the market share from neon¹. Despite being less mature than the long-established neon and fluorescent lighting, the on-going rapid advances in LED technologies are producing attractive alternative lighting sources for signs. Sign fabricators and end-users, therefore, have more choices to design their lit-signs.

For many sign makers and users, primary reasons for considering LEDs for illuminating channel letters are lower energy consumption, longer lifetime ratings, more flexible installation, higher durability (less breakage), lighter weight, and easier maintenance compared to neon lighting. Unlike neon tubes, LEDs are built to be easily-installable because they are more robust; and the smaller discrete modules can be connected via electrical wire strings in a parallel or serial fashion. This allows for more flexible spatial arrangements and higher fault tolerance because a failed module can be replaced without disturbing the entire sign or a leg.

LEDs are available in many single colors within the visible spectrum which includes red, amber, yellow, green, and blue; white LEDs are produced using various color mixing techniques, some of which include phosphors. Red LEDs perform quite well and is consequently a very popular color for channel letters; white-LEDs are still suffering from inadequate luminous efficacy, brightness, color-rendering, and color consistency – otherwise known as the 'color binning' problem. These factors make white LEDs more costly and sign makers do not find them as affordable as their red counterparts; they wind up selecting colors based on the sign size and how well the LEDs can illuminate it. Nonetheless, high-brightness white LEDs remain very desirable for sign makers because of retrofit possibilities and higher suitability for illuminating cabinet signs containing multi-colored graphics.

Retrofitting neon-illuminated channel letters with LED sources is feasible because LED systems are modular and can be cut to size in the shop or in the field to fit whatever shape and size is needed for illumination. Installers can easily attach the modules with some pre-applied, self-adhesive or screw them into the channel letter form. A low-voltage (e.g., 12V DC) accompanying power supply, connected with Class 2 power wires (e.g., 10-12 AWG), may be placed inside or outside the channel letters. Many companies are finding that replacing old neon signs with LED systems is cost effective because of lower maintenance cost and energy consumption.

Challenges

Despite these notable advantages, today's LEDs struggle with brightness, color quality, and illumination uniformity compared to neon. These disadvantages are more pronounced for white-LEDs than for a single-color-LED. While technological advances will overcome LEDs' disadvantages over time, there are some design tricks sign makers can

use today to achieve greater surface illuminance, improved uniformity, color quality, and longer lifespan for channel letters and cabinet signs. Illuminance is the amount of light that falls on a surface coming from a light source, which essentially tells us how well a channel-letter face is illuminated, for example.

How well LEDs can illuminate a channel letter or a cabinet sign also depends on obtaining an optimal design involving the brightness and size of the LED modules used, and the distance between these modules and the sign face. Bigger and brighter LEDs are not always better for sign illumination because sign viewers will not see these large, 'super bright' LEDs or even appreciate them; they will appreciate conspicuity and visibility – features that depend on the right amount of brightness, uniformity, and color quality of the sign face. A well-illuminated channel letter or a cabinet sign does not necessarily require excessively bright LED modules, which will result in energy waste and will also produce non-uniform illumination and glare.

Optimized LED Illumination

Illuminated channel letters and sign cabinets must achieve certain levels of brightness to satisfy customer expectations. To quantify that brightness, luminance, measured in nits or candela/square-meter (cd/m^2), is used; alternatively, a sign designer may measure illuminance at the viewer's eye plane and simply correlate this to the luminance value of the sign. Illuminance is measured in lux (lumen/square-meter) or footcandles. To properly illuminate a sign, each LED-lamp module used in the string must be bright enough to radiate the required amount of light to the sign surface.

In order to determine the luminance required of the LED modules to achieve a certain sign brightness level, this simple formula relating luminance and illuminance may be used:²

$$E_v = \frac{L \times S}{D^2} \quad \text{Eq.(1)}$$

where E_v is the illuminance at the sign surface, L is the luminance of the lamp module, S is the surface area of the lamp, and D is the normal or vertical distance from the center of the lamp to the illuminated surface. For simplicity, only the normal incident angle is considered, neglecting cross illumination from neighboring LEDs.

Applying this functional relationship, a designer can optimize LED sign illumination to produce bright and uniform channel letters that is more energy efficient and longer lasting than most designs of today.

Consider Figure 1 where Designs A and B are illustrated for the channel letter "B". The letters are shown faceless so that the LED modules connected via an electrical string can be seen. The analysis for these two designs below demonstrates the interplay of LED brightness and size to achieve the desired illuminance, while using less energy to produce more uniform illumination.

In Design A, each LED module's (labeled as A-LED) surface area is 4 a.u. where a.u. is the arbitrary unit of square area. There are 21 discrete A-LEDs with a total surface area of 84 a.u. In Design B, each LED

module's (labeled as B-LED) surface area is 1 a.u.; there are 84 B-LEDs with a total surface area of 84 a.u.

Distance D is the gap between the LED surface and the channel-letter face, which is the same in both designs.

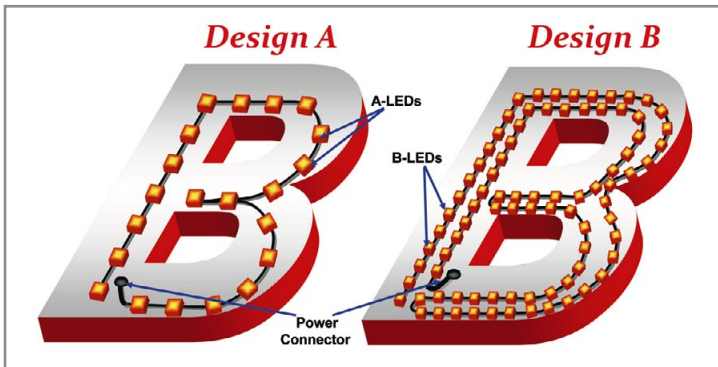


Figure 1: Two designs of the channel letter "B" without the face but showing the form inside where the LED modules connected via an electrical wire string are placed in each channel letter. Design A uses A-LEDs with 4 times the luminous area than Design B's B-LEDs. Both A-LEDs and B-LEDs have equal luminance per module.

In order to produce the same illuminance at the face (assuming only normal angle incidence), Eq. (1) yields:

$$E_{vA} = \frac{L_A \times S_A}{D^2} = E_{vB} = \frac{L_B \times S_B}{D^2} \quad \text{Eq.(2)}$$

where E_{vA} and E_{vB} are the center illuminance at the channel letter surfaces of the two designs; L_A and L_B are A-LED's and B-LED's luminance values and S_A and S_B are total surface areas of the two designs. Since S_A and S_B are both 84 a.u., Eq.(2) yields $L_B = L_A$, meaning that the luminance of B-LEDs and A-LEDs are the same. If the sign designer is unable to populate with exactly 4 times as many B-LED modules in Design B as there are A-LEDs in Design A, slightly fewer or more B-LEDs in Design B will still keep L_A and L_B within a few percent of each other and we can effectively say that both LED types will have about the same luminance.

However, it is important to note that the B-LEDs only need to produce 25% less luminous flux (i.e., lumen output) over a quarter of the area compared to A-LEDs, in order to produce the same level of illumination or have the same luminance. This means that the B-LEDs can be driven with 25% less current or even lower; even lower current is feasible because the efficacies (lumen/watt) are higher at lower drive currents. This makes Design B more energy efficient; further, driving with lower current will also increase the lifetime of the B-LEDs. The same power supply can be used for both designs.

There are other important benefits of Design B, which are more uniform illumination of channel letters and reduced color variation among different channel letter faces. Generally, a sign fabricator faces a frustrating amount of color variation that arises from a more economic color bin containing a broad range of colors. Design B's color variation is substantially reduced because more LEDs (i.e., 84 B-LEDs vs. 21 A-LEDs) provide a greater degree of color averaging.

Note that the calculations in this example ignore the cosine dependence of illuminance as well as the full integration over the channel letter surface in order to make straightforward arguments; nevertheless, comparisons made in the designs provide validity on an "average sum" approximation basis – this trend can be extended to the full integration case aggregating contributions from all LED modules.

I have reviewed a number of designs from several companies where most use designs similar to A and only a few similar to B. I have also been asked by many in the sign industry about solutions for the "annoying" binning problem causing unacceptable color variations. Design B should help with this concern.

Thermal Advantage

Design B also has an important advantage – lower operating junction temperature, T_j , due to at least 25% lower drive current. The junction temperature is the temperature of the diode active region and is the hottest point in the entire LED module and luminaire, if the module is integrated in a luminaire. A lower operating T_j will increase the lifetime significantly and will allow for simpler thermal management designs because Design B will generate less heat and hence there will be less heat to dissipate due to two factors: 1) the smaller active emitting area and 2) less applied current or electrical power consumption.

The solid state lighting industry is taking the thermal challenges seriously as LEDs are becoming brighter and consuming more power to generate much light from larger devices for numerous applications. Every LED module, due to its particular design and fabrication, has an inherent maximum T_j , which should not be exceeded under operation because doing such would lead to a catastrophic failure of the LED chip. The concept must also be applied to the entire luminaire because thermal management must extend to the entire fixture or enclosure. If the heat produced in the junction area is not effectively removed, the LED chip would continue to heat up over time and T_j will eventually exceed its maximum value, leading to a chip burn-out.

With sophisticated thermal designs and packaging material technology, higher T_j can be tolerated if an efficient thermal conduction path is created between the LED junction area and the substrate-circuit board assembly on which the LED is mounted. However, it will increase the cost of the modules and luminaires, and will likely increase the size of the luminaires as well. While luminaires are irrelevant in signage applications, higher cost of the modules is a big concern; so is the overall heat management for the channel letter or cabinet sign enclosure, which will be simpler if the individual LED modules themselves generate less heat. Higher operating temperature due to higher operating current also leads to greater degradation of the color quality due to wavelength shifting, which starts to become more pronounced over time.

Effective thermal management designs involve understanding how T_j rises with higher current and how much heat is generated from the LED chip, which is typically a chip design issue. It also depends on minimizing thermal resistance or increasing thermal conductance along the path from the junction to the die submount (the first heat sink), then to the

printed circuit board (PCB) – the second heat sink, on which the die submount is soldered. This constitutes the usage of appropriate thermally conductive materials (e.g. high thermally conductive substrates such as alumina and metal core PCBs, and good thermal epoxy or grease), packaging techniques (e.g. good solder joints), and substrate geometry that may include thermal via holes and flat mating surfaces.

Thermal resistance is defined by the resistance of a material to heat conduction, which depends on its inherent material conductivity property as well as the length and the cross-sectional area of the material.³ It also equals to the temperature difference between the two opposite surfaces where heat flows from one to the other along the path perpendicular to the surfaces, divided by the heat energy flow rate, as shown in Figure 2. Both of these definitions are analogous to electrical resistance.

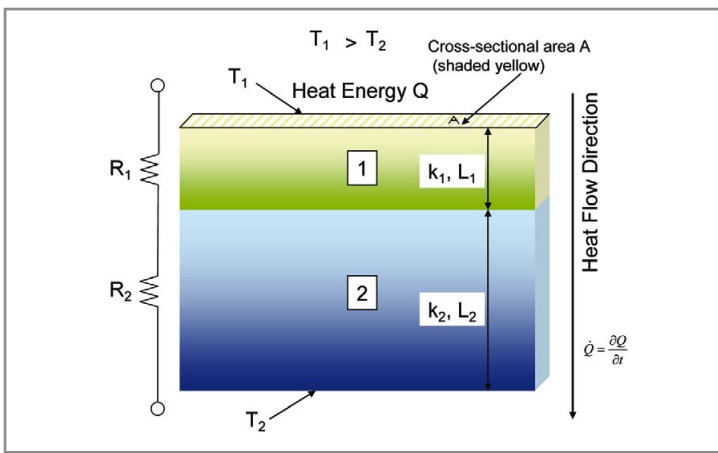


Figure 2: Heat transfer across a composite slab of two materials, 1 and 2, experiences a series thermal resistance $R = R_1 + R_2$. Temperatures T_1 and T_2 are at the outer surface of material 1 and 2 respectively where $T_1 > T_2$. Heat flows from the top of the composite slab where T_1 is present through material 1 and then 2, experiencing a thermal resistance R .

Thermal resistance R in Figure 2 is analogous to electrical resistance and is defined by

$$R = \frac{T_1 - T_2}{\dot{Q}} \quad \text{Eq.(3)}$$

where $\dot{Q} = \frac{\partial Q}{\partial t}$ is the heat flow rate of the heat energy Q that is present where the hotter temperature T_1 is defined.

In Figure 2,

$$R_1 = \frac{L_1}{k_1 A} \quad \text{and} \quad R_2 = \frac{L_2}{k_2 A} \quad \text{Eq.(4)}$$

where k_1 and k_2 are the conductivities of slab materials 1 and 2 respectively; and L_1 and L_2 are the lengths of slab materials 1 and 2 respectively; the cross sectional area A is the same for both slabs in this example. Note that R_1 , R_2 and therefore R can be calculated if the material properties k_1 and k_2 are known along with the geometric parameters L_1 , L_2 and A .

The unit of thermal resistance as defined by Eq.(3) is degree C per Watt ($^{\circ}\text{C}/\text{W}$), where W is thermal wattage or power. In the case of an LED, this is injected electrical power (i.e., voltage times current) into the LED minus the emitted optical power. This should not be mistaken for electrical power when one attempts to calculate the thermal resistance in an LED module using Eq.(3). In a more efficient LED, the generated thermal power is less than that of a less efficient LED even when the same amount of electrical current is injected into both.

In the SSL industry, it has become common to use a model similar to that shown in Figure 2 where material 1 is taken to be the LED chip, material 2 to be the chip submount (first heat sink), and sometimes adding a material 3 for the PCB (second heat sink). The junction temperature T_j is analogous to T_1 ; T_2 is analogous to the temperature of the first heat sink; similarly adding T_3 for the PCB, the bottom of which is usually the ambient temperature when a stand alone LED module is being tested. This model is used along with the measured values of forward voltage, T_1 , and T_2 (and perhaps T_3) to determine T_j of an LED; however, one must be careful not to mix thermal resistance with electrical resistance and thermal power with electrical power.

A more rigorous way of determining T_j would be to use a full 3-D finite element or finite difference method to model the thermal behavior (i.e., solving a heat wave equation) of an LED when a constant current is injected to it, with all of its surrounding components; it can make use of Eq.(3) and Eq.(4) for each material and boundaries, along with their geometry and k values. One must also be mindful that thermal resistance defined in Eq.(3) is a function of ambient temperature because k and the geometric parameters all change with temperature. The modeling results should be used in conjunction with as many measured parameters as possible under different ambient temperatures to determine the unknown parameter T_j using multiple iterations to ensure the convergence of a convincing T_j value.

Rigorous modeling as well as some straightforward temperature measurements will show that higher injected current into an LED chip will lead to higher thermal power that needs to be dissipated away from the junction. Thus, Design B in Figure 1 will have a thermal advantage over Design A, requiring less complicated thermal management.

While the above comparison shows that Design B is superior in terms of efficiency, color quality, and lifespan, the ideal design would be an extension of the concept where many, many minute LEDs would essentially cover the entire surface of the channel letter base or form, allowing the lumen output of each LED sources to be reduced even further; broad-area LEDs such as OLEDs would fit this description; OLEDs, however, are currently a much less mature technology than conventional LEDs. ■

References:

- [1] Wade Swormstedt, *Signs of the Times* magazine, April 2008, page 102.
- [2] IESNA Technical Memorandum TM-11-00.
- [3] *Thermodynamics: From Concepts to Applications*, Second Edition; authors: Arthur Shavit and Chaim Gutfinger, Haifa, Israel, December 09, 2008.



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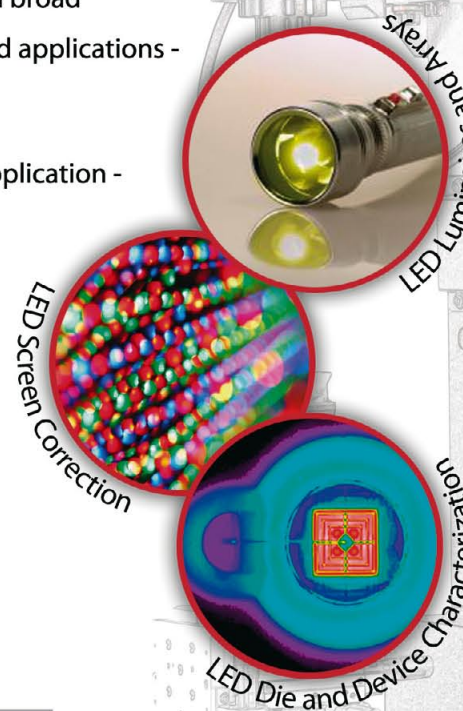
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Interview with Navid Delassae – Citizen Electronics Germany

> Siegfried Luger, LED professional

Citizen is a global LED player offering a broad range of products. How important is the LED business for Citizen?

LEDs and products with LEDs (e.g. Backlight units, switches with integrated LEDs, LED stripes) have a share of approx. 90% of our sales, Therefore we could say that LED is our most important product.

Nowadays we're globally facing a difficult economic situation. How do you see the market development for LEDs? Can you recognize regional differences?

We are in a global recession for sure, but, we think that the lighting market is not too much affected. Even now we can see some new opportunities to go further with new LED development. For example, new products with LEDs where each country can expect electrical power savings or CO₂ reduction, etc., which is a positive aspect for the market. We do recognize there are regional differences.

What are the key applications Citizen is focusing on with the LED technology?

In the general lighting market we focus on LED bulb applications, which will replace the current ordinary light sources. Also industrial light & street lighting are our main focus. In the cellular phone market, flash LED is one of our main forces. TVs with LED backlighting and the computer market are the next markets for our LEDs.

What are the key factors to get a faster and deeper market penetration?

Of course pricing and efficiency should be the main key factors. There are some technical challenges as well to realize market requirements. But we also think that being proactive to customers' requests is very important. To always have the customers' point of view in development is also a key factor for market growth.

In the cellular phone market, where changes happen very fast, we achieve constant success by responding to customers' demands more flexibly and more speedily. We consider that the similar responses are also important in the lighting market.

In many applications the colour quality including the spectral distribution is still not sufficient. Especially in the case of replacements it's not sure whether the customer will get the right light. How do you see this situation and what does Citizen offer to solve this problem?

Technically, it is possible to offer a high-quality colour. However, pursuing the quality may lead to the loss of efficiency. It is important to have customers understand the balance between the said two and then to find the valuable figures for customers. For example, Citizen has a colour rendering variation from Ra= 65 to 95, which provide the users different colour options.

Depending on the application, the costs for an LED system are quite high, leading to long amortization times. Where are the critical zones for cost reduction?

In view of the fact that the characteristics of LED improve every year and the movement towards using LEDs is growing massively, we have recognized that more reasonable prices can be offered and the amortization times could be shortened once manufacturer total volume is increased. In terms of price, the costs are added up by each supply chain to the finished product, so it is difficult to answer this question as our company only handles a single LED item.

Beside the phosphor-coated LEDs, the quantum-dot LED technology is available to produce white light. How do you appraise this technology? Will it replace the phosphor-coated technology?

We consider the quantum-dot LED technology as an attractive technology because it enables us to select the wavelength and to make spectrum shapes freely. However, there is still a major study being conducted in terms of reliability for the phase of "One Packaging" and "Mass Productivity". We look forward to the advancement of the quantum-dot LED technology.

Standardization is always an important aspect to increase market volumes. Will we see a breakthrough in this area or will the LED manufacturers keep their proprietary standards?

We think it is important that LED manufacturers and their affiliates firmly discuss the normalization or standardization that gives top priority to the future benefits customers could receive.

What kinds of new products will Citizen launch in the near future?

Nowadays, the customers' understanding of LED is becoming deeper and, along with that, the demands from the market are starting to vary and break into segments. To deal with these voices, we are planning to line up "array modules", "high CRI products with high-efficiency", and "ultra-high luminous flux in one package". ■

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Technology

Quantum Dots in LED Lighting: Improving Color Quality Without Sacrificing Efficiency

> Dr. Sridhar Sadasivan, Dr. Seth Coe-Sullivan, QD Vision, Inc.

Recent advances in the development and application of light-emitting quantum dot based materials are addressing color quality and efficiency concerns that have limited broad adoption of LED-based solid-state lighting systems. The article describes how quantum dot technology is being applied to deliver step-change improvements in power efficiency and color quality in LED lighting solutions.

Introduction

Despite their poor energy efficiency, incandescent bulbs have long dominated the lighting market, primarily because of their superior light quality. The relatively poor color quality of high-efficiency fluorescent and compact fluorescent bulb alternatives have prevented them from being widely accepted by consumers. The trade-off between color quality and efficiency has remained a significant challenge, and until recently, no lighting solution has yet provided an optimal solution.

The recent push toward energy efficient lighting along with measures to phase out incandescent lamps have created new opportunities for energy efficient lighting solutions that retain the superior color quality of incandescent lighting. LED-based solid state lighting (SSL) solutions have garnered much attention recently, due to dramatic improvements in performance in the past several years.

However, there are problems with current LED lighting technologies that must be overcome before they are widely adopted. While today's LED solutions produce very efficient 'cool' white light, delivering the kind of 'warm' white light preferred by consumers can require up to twice as much power. Second, the cost/lumen of LED lighting continues to remain high. While lower maintenance cost and increased efficiency can offset some of the high upfront investment in LED solutions, these costs limit widespread adoption.

Recent advances in the development and application of light-emitting quantum dot-based materials are addressing color quality and efficiency concerns limiting adoption of LED-based solid-state lighting solutions. Quantum dots (QDs) are tunable emitters with a very narrow band emission profile. The emission color of the QDs can be tuned throughout the visible and infrared spectrum by simply changing one or more aspects of the QD particle. The narrow emission band of QDs relative to conventional phosphors used in other lighting solutions translates into increased efficiency, since the emitted light can be tailored to provide the desired warmth and high Color Rendering Index (CRI), without

wasting energy where the human eye cannot perceive it. Quantum dot based optics can be used with LEDs to deliver higher efficiency lamps providing the warm white light that consumers desire.

What Makes LED-Based Lighting so Promising

There are many reasons to believe that LED technology will be the dominant lighting solution in the future. Concerns about global warming are driving demand for immediate solutions to replace the inefficient incandescent lighting that currently consumes over 7% of world energy output. Combined with the longer lifetime and potential lower cost of ownership, LED-based solid-state lighting solutions are too compelling to ignore:

- LED lamps last a long time – typically over 15 years. The long lifetime of LED lamps also translates into lower maintenance costs wherever it is difficult to replace bulbs.
- LED fixtures and lamps provide highly directional light, leading to higher fixture efficiency.
- The color of the LED lamps can be tuned with luminescent materials to meet the needs of the lighting environment.
- Efficiency of LED lighting continues to increase dramatically. The efficiency of LEDs has increased about 10-20 times over the last decade and is expected to continue to increase dramatically.

However, before LEDs can become the lighting solution of the future, a few key problems must be overcome. Today's products produce very efficient cool white light, but the efficiency of warm white light LED products lags that of cool lamps by 30-50%. Second, the cost/lumen of LED lighting continues to remain high. The lower maintenance cost and increased efficiency can offset some of the high upfront costs, but remains an issue for widespread adoption.

Key Challenge – Creating Efficient Warm White Light with High CRI

To meet consumer demand for light that has the same color quality as incandescent lamps, the challenge is to create an indoor light source that reproduces the colors of various objects faithfully while producing the "warm" white light that is familiar to consumers.

Two key metrics are used to describe the color quality of light. They are: Correlated Color Temperature (CCT) and Color Rendering Index (CRI). The temperature (in Kelvin) at which the heated black-body radiator closely matches the perceived color of the light is described as the Correlated Color Temperature of the source [1]. The color of the black body radiator for different color temperatures is shown in Figure 1. Light having a perceived color that falls close to this black body curve is defined as white light. White light that is blue-green in color (4000 – 6000K) is considered cool and is typical of fluorescent and LED lamps. White light that is yellow-red in color (2500 – 4000K) is considered warm and is typical of incandescent lamps. Warm white lighting is generally preferred for indoor lighting as it is most flattering for skin tones and clothing.

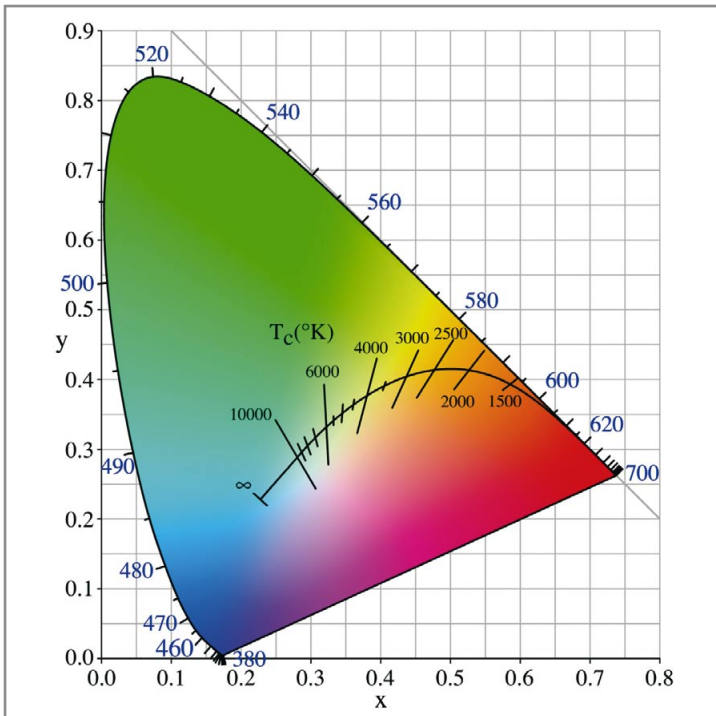


Figure 1: Black body radiator curve (also known as Planckian Locus) shown in the CIE x, y coordinate system [2].

The Color Rendering Index [3] (CRI) is a quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully. A black body radiator is defined as having the perfect light source with CRI of 100. Incandescent lamps being a black body radiator have very high CRI, while fluorescent and CFL lighting is typically in the 60-75 range.

Therefore, the white light source that is most preferred for indoor lighting has warm color temperature and high CRI.

Why Attempts to Create Efficient, High Quality White Light Using LEDs Have Failed

The white light from current LEDs most often is created using a combination of a blue LED chip and luminescent phosphors. This combination improves color quality but leads to inefficiencies that decrease lumen output to a point where the solutions do not meet the brightness requirement for many applications.

A yellow phosphor is used to absorb some of the blue light from the chip and emit a broad-spectrum yellow light ranging from the green end of the spectrum to the orange end of the spectrum. The CCT of the resultant white light is typically between 5000 – 6500 K, with low CRI (~ 70-75). Since this is too cool, a color for indoor lighting applications, an orange phosphor is added in addition to the yellow phosphor, shifting the CCT of the resultant light to between 2700 – 3500 K with low CRI (~70 – 75). The orange phosphors emit a broad spectrum light from orange to deep red light. However, the sensitivity of the human eye drops as the wavelength of the light extends into deep red. As a result, the orange phosphor creates light not perceived by the human eye and therefore lowers the overall efficiency of the light, typically by about 30%.

To create a warm white light with high CRI, a red phosphor is also used. The CCT of the resultant white light is between 2700 – 3500 K with high CRI (> 90). The red phosphor used in the LED emits broad spectrum light that extends all the way into near infrared that is not visible to the human eye at all. Most of the light emitted by the red phosphor falls in the range of low to no perception by the human eye. These inefficiencies result in warm white, high CRI LED packages that are as much as 50% less efficient than the cool white LED package

Quantum Dots: Superior Alternative to Phosphors

Quantum dots (QDs) are nano-scale tunable emitters with a very narrow band emission profile. The narrow light emissive properties of QDs come from their small size (typically 2 – 12 nm) and the resulting quantum confinement. The emission color of the QDs can be tuned throughout the visible and infrared spectrum by simply changing the particle size. Typical structure of a quantum dot and the function of different layers are shown in Figure 2.

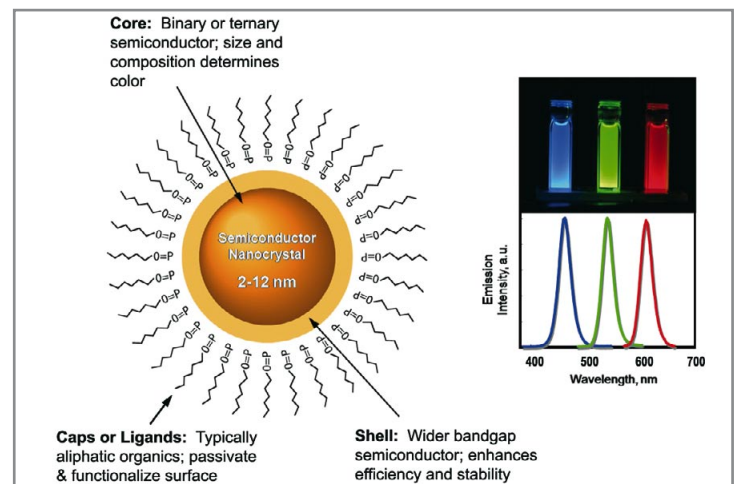


Figure 2: Structure of Quantum dots and their typical emission profiles.

The key property that is of interest to lighting is the narrow band emission of quantum dots. The spectral width of emission is usually one half to one third that of a conventional phosphor.

Figure 3 compares the spectral width of a typical phosphor and a typical quantum dot.

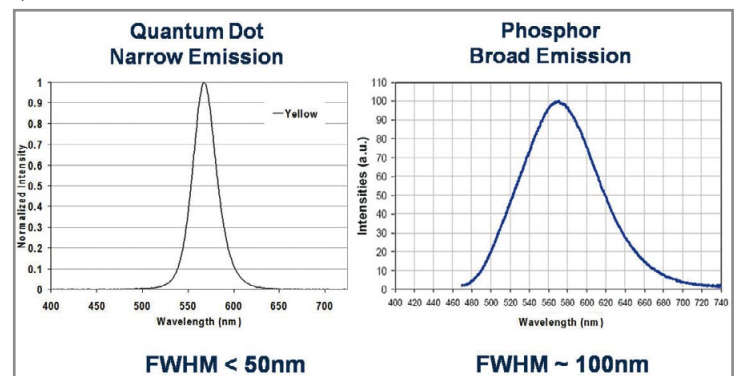


Figure 3: Comparison of emission spectra of quantum dots and conventional phosphors.

The narrow emission of QDs relative to conventional phosphors translates into increased efficiency, since the emitted light can be tailored to provide the desired warmth and high CRI, without "wasting" light where the human eye cannot perceive it. A quantum dot with peak wavelength around 600 nm can be used to shift color temperature to 2700K. The quantum dots absorb higher energy blue and yellow light and emit orange light, without emitting anything in the deep red. Similarly, a quantum dot with peak wavelength around 630 nm can be used to shift color temperature to 2700K and increase CRI, without emitting any light in the infrared. In both these cases, it is the narrow emission profile of the quantum dots that enables this significant improvement.

Quantum Light™ Breakthrough is First to Create High Efficiency Warm White Light

The first lighting products taking advantage of the color quality and power efficiency possible with quantum dots are being introduced in 2009. The products include an optic with a thin film of quantum dot ink. The quantum dot ink is coated over the diffusive cover plate of LED lamps, or in other geometries between the LEDs and the environment to be illuminated. The quantum dots efficiently add red light to the white light from the LED. The result is a pleasing incandescent-like light with significantly higher efficiency than what can be achieved by any other technology today.

The implementation of quantum dot technology in Nexxus Lighting, Inc.'s, Array™ LED lamp is shown in Figure 4. The Array™ LED lamp shown here with Quantum Light™ optic produces 2700K light with a CRI of 90 and is 500% more efficient than an incandescent lamp. This product has 40% better efficiency than would be possible with an LED lamp that uses red phosphor.

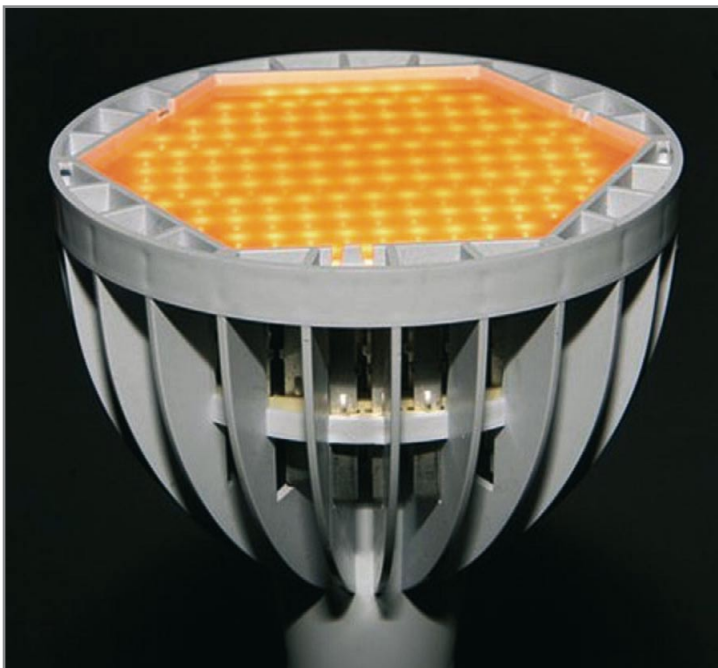


Figure 4: Quantum Light™ Optic on a Nexxus LED Array™ PAR lamp.

Previous LED solutions and lighting solutions in general have traded warm white light with high CRI for efficiency, slowing adoption of these otherwise compelling lighting products. The QD Vision Quantum Light™ optic provides the first technology to overcome the previous limitations imposed by this trade-off, enabling warm white light with high efficiency. High efficiency translates into lower overall cost, as less LED chips are required to reach a desired brightness. Finally, because the QDs are extremely stable, the warm white light product will qualify to be rated at 50,000 hours. The combination of color quality, efficiency, and life make LED lighting products that incorporate Quantum Light™ optics a clear choice for lighting designers, architects, and consumers.

A Quantum Dot Future

Optics improving the efficiency and color quality of current-generation white-light LEDs are only the initial applications for quantum dot technologies. Because of their tunable, emissive qualities, QDs can be used as foundation materials for LEDs capable of producing a full spectrum of colors. These QD based LEDs will enable higher luminance and better power efficiency than current-generation LEDs, paving the way not only for additional lighting applications but also the next generation of very high resolution flat panel displays. ■

References:

- [1] http://en.wikipedia.org/wiki/Correlated_color_temperature
- [2] <http://commons.wikimedia.org/wiki/File:PlanckianLocus.png>
- [3] http://en.wikipedia.org/wiki/Color_Rendering_Index



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Chip-Array-on-Ceramic LED: A Versatile Solution to High Performance LED Luminaires

>Dr. Gang Wang, Dr. Ian Collier, Dr. Ilkan Cokgor, Harik Su and Dr. Yi-Qun Li, Inteamtix Corp.

Chip-array-on-ceramic LEDs are a special LED design developed by Inteamtix Corp. Cetus™ is a brand name of a family of LEDs based on this design concept that employ a unique cavity design in which each cavity is electrically connected through a circuit processed in a LTCC (low temperature co-fired ceramic) substrate, allowing the creation of a desired array configuration that delivers an emission product with a pleasant, smooth and natural looking light.

Features

Compared with a single chip LED solution an array LED has several advantages and can provide the features lighting companies are looking for: ease of design, tight binning, excellent color quality, robust thermal management and a simplified and scalable power and area size.

The main advantage of an array LED is versatility, in particular, flexibility of array size. As shown in Figure 1 the C3535 (Figure 1(a)) is a 2 x 2 LED array consisting of 4 LED chips; the C5050 (Figure 1(b)) is a 3 x 3 LED array consisting of 9 LED chips; the C6060 (Figure 1(c)) is a 4 x 4 LED array consisting of 16 chips; and the C1109 (Figure 1(d)) is a 3 x 4 LED array consisting of 12 LED chips. Due to the flexible nature of an array LED, it is easy to develop LED products with different input powers based on the same LED chip. As a result, the performance of an entire family of LEDs can be improved with a single superior LED chip.

In addition to versatility in array size, a chip-array-on-ceramic LED also allows versatile electrical connection. The connection between LED chips can be serial, parallel or a combination. Figure 2 are circuit diagrams for C3535, C6060, C5050, C7676 and ACC6565 LEDs. The

C3535 (Figure 2(a)) and C6060 (Figure 2(b)) each comprise parallel connected LED chips and respectively have a rated current (I_F) of 80mA and 350mA at a drive voltage of 3.3V. The C5050 (Figure 2(c)) comprises 3 parallel strings of serially connected LEDs. Its rated current is 60mA for a drive voltage of 10V. The C7676 (Figure 1(d)) has 16 LED chips connected in series with a rated current of 20mA and 50V drive voltage. In the ACC6565 the LED chips are connected in a bridge (self rectifying) configuration allowing the device to be directly driven from an AC power source without additional rectifying circuitry. The rated current for such a device is 80mA for 12V drive voltage. By changing the LED array size and the electrical connection, the LED can be readily adapted to operate from different power supply sources. This feature makes it more competitive in applications where the power supply source is predefined.

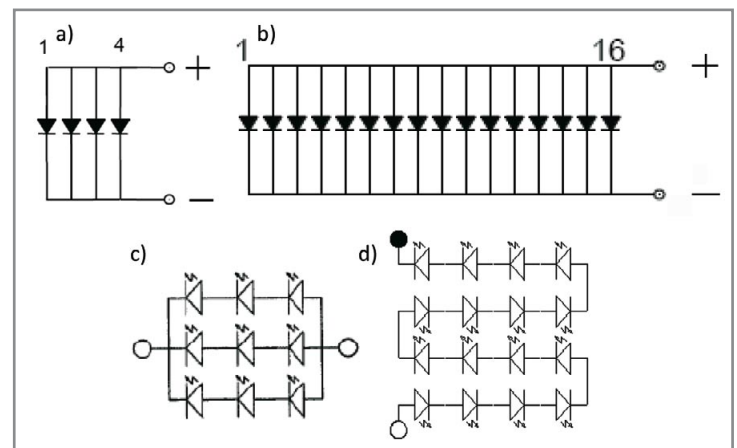


Figure 2: Internal circuit diagrams for a) C3535; b) C6060; c) C5050; d) C7676.

Since each cell in the LED array is a fully functional LED, this enables the function of each cell of the array to be individually set. For example by using different phosphors in the various cells, the cells can be separated into different color groups. By providing independent electrical control to different group, it is possible to tune the color and/or CCT of the LED within the chromaticity ranges of the different groups.

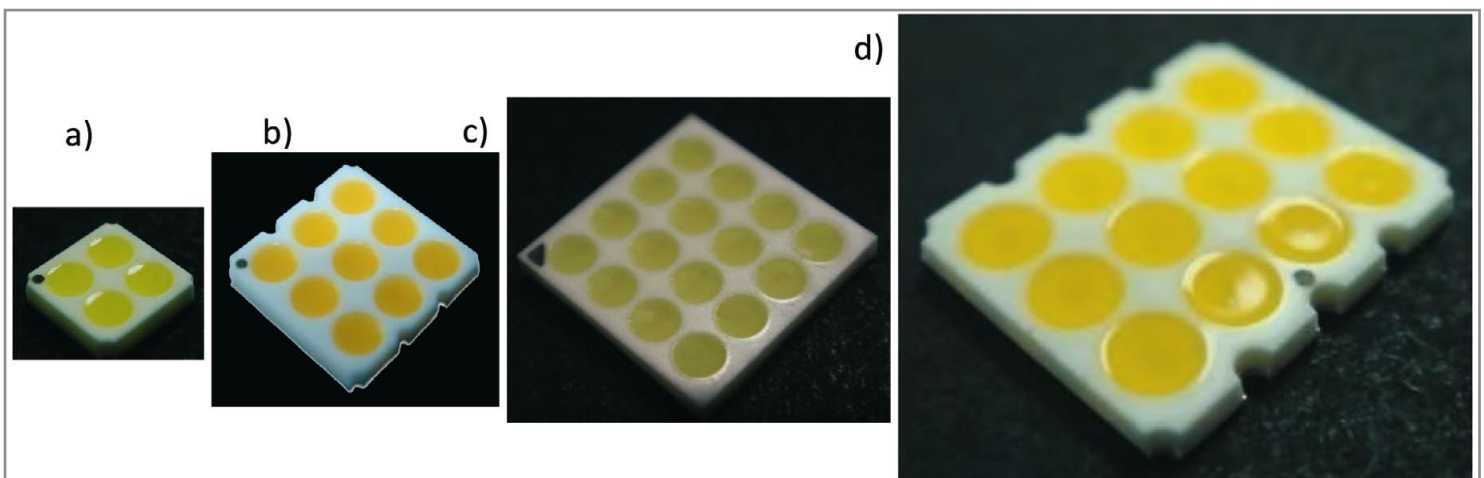


Figure 1: Cetus LEDs with different array size. a) C3535; b) C5050; c) C6060; d) C1109.

Cetus E	CRI	CCT (K)	Flux(lm)		Efficacy		Cetus	CRI	Flux(lm)		Efficacy	
			@2x rated If	Flux (lm) @rated If	(lm/W) @ rated If				@2x rated If	Flux (lm) @rated If	(lm/W) @ rated If	
C6060E	CRI<70	2700-3500	185	103	95		C6060	CRI<70	NA	90	78	
		5000-6500	190	106	97				NA	95	82	
	CRI>80	2700-3500	135	75	69			CRI~75	NA	60	52	
		5000-6500	150	83	77				NA	70	61	
C5050E	CRI<70	2700-3500	95	53	95		C3535	CRI<70	NA	18	70	
		5000-6500	100	56	100				NA	20	78	
	CRI>80	2700-3500	70	39	70		C1109	CRI<70	NA	250	53	
		5000-6500	80	44	80				NA	320	67	
C7676E	CRI<70	2700-3500	178	99	97							
		5000-6500	183	102	100							
	CRI>80	2700-3500	130	72								
		5000-6500	145	81	79							

Table 1. Performance comparison of Cetus E versus Cetus LEDs.

A further advantage of a chip-array-on-ceramic LED is the potential to achieve a higher luminous efficacy. LED arrays use multiple smaller chips to achieve the same emission intensity as a single high power chip LED that has larger chip size. Due to the strong absorption, the extraction efficiency is a key factor that affects the external quantum efficiency of the LEDs. Compared with the larger size chip, a smaller size chip has a higher extraction efficiency since light has less distance to travel before being emitted from the chip. In addition, a multi chip structure dissipates the heat generated by the LED chips into a relatively larger area, which helps keep LED junction temperature low as well as improve performance.

Moreover, since the substrate material is an LTCC, this ensures a high thermal conductivity, a good matching of the thermal expansion coefficient with the LED chips and zero water absorption. Together these features result in a superior thermal characteristics, which are essential for LED lifetime and the luminous performance at high power ratings.

Finally, an array LED has an improved emission uniformity as their output is the sum of contributions from each of the many LED cells in the array. It's a simple statistical fact that the effect of variation of individual LED chips can be reduced through averaging. For example, the performance is the average of between 4 (C3535) and 16 (C6060) LED chips. As a result, tight binning, superior color uniformity and high production yield become possible.

Improved Luminous Efficacy

In order to become well-recognized in the LED industry, a key parameter is luminous efficacy. Indeed generating more light using less power is the key reason for the rapid growth of the LED lighting industry. The luminous efficacy of the Cetus LEDs have been continuously improved. Launched in May 2008, they initially had a luminous efficacy of 80lm/W. One year later, a luminous efficacy of 100lm/W is achieved with the new E-series.

As shown in Table 1, the E series LEDs have several improvements, namely increased emitted luminous flux and luminous efficacy. Comparing the E series C6060E and precursor series C6060, there is a 10-30% improvement of luminous flux and luminous efficacy. The improvement for the "high" (>80) color rendering index (CRI) LEDs is more significant than the "low" (<70) CRI LEDs. Generally, all low CRI E series LEDs can achieve an efficacy of 95lm/W for warm white light and ~100lm/W for cool white light whilst the high CRI E series LEDs can achieve an efficacy of ~70lm/W for warm white light and ~80lm/W for cool white light versions.

The second improvement is in the CRI. The CRI>80 module is available for all type LEDs to comply with emerging Energy Star requirements for integral lamps. Before the development of the E series the CRI was typically ~75 (C6060). However, the luminous efficacy was not high enough and this limited its application.

Finally, all E series LEDs are capable of being safely overdriven at up to double their rated forward current (IF). This feature allows to deliver almost double the light. Since cost issue is still one of main concerns that limit the application of LEDs in the general lighting industry, an increase of flux output for the same cost is a highly desirable feature.

What contributes to these improvements? The continuous effort to improve the LED package design is a key factor. Various ceramic materials and different thermal conduction schemes on the base of each cavity have been used to optimize the luminous efficacy and lifetime of the device. Although a chip-array-on-ceramic LED has many advantages, the electrical connection between LED chips can increase the challenge of thermal management of the device. The thermal management design has to be optimized for each type of LED. Since the release of the new E series, the cavity design has been through several runs of optimization and a thermal resistance of 10°C/W or less has been achieved on all devices.

Besides the package design, the use of higher performance LED chips is a reason for the improvement. Since phosphor converted white LED has become one of the dominant solid state light sources for general lighting, the blue LED performance has rapidly improved in the past years. The higher power rating, higher rated current and lower forward voltage of the blue LED chip have contributed to LED component improvement.

As one of the essential elements for white light generation, the phosphor plays the most significant role on the flux output and CRI improvement. The high luminous efficacy is achieved by well-recognized patent-backed phosphor compositions. As shown in Figure 3, more than 20 different kinds of LED phosphors that are categorized in four color groups have been developed: green, yellow, orange and red. The emission peak wavelength of these phosphors covers a broad range from 500nm to 670nm. The abundant phosphor choice provides more opportunity to improve the efficiency once a new phosphor is developed or an existing phosphor is improved.

The high efficiency of the standard CRI module relies on the high brightness yellow phosphors, whilst the high CRI module relies on the development of red phosphors (Figure 4).

The dichotomy between CRI and luminous efficacy is a common issue for phosphor converted white LEDs. On the one hand, a high efficacy requires the LEDs spectrum to be more concentrated around 555nm, where the eye's response function reaches its maximum. Conversely a high CRI requires the spectrum to closely resemble that of blackbody radiation. A high CRI light source does not necessarily have to have the same spectral distribution as a black body radiator, but it should have a similar color distribution ratio between red, blue and yellow green regions. For example, a typical white LED, employing a blue chip and yellow phosphor, can have a good luminous efficacy since the emission peak of the yellow phosphor is very close to 555nm, however the CRI value will be poor due to the lack of red light.

Before red phosphor was developed this LED was only available as standard CRI modules. High CRI modules were developed when blue excitable red phosphors were discovered. However, the efficiency became a concern as the red light made a very poor contribution to the LED brightness. The big breakthrough happened when a high brightness shorter wavelength red phosphor was developed. The E-series high CRI LED achieves over 70lm/W efficiency using a 630nm red phosphor and will continue growing with further improvements of red phosphors.

Conclusion

The E-series LEDs inherit all the advantages from the Cetus LEDs. Their versatile array size, electrical connection, function setting and their high uniform color binning enable them to be used in many kinds of LED lighting applications. More importantly, they deliver superior luminous performance through improvements of all the key elements—package design, LED chip and phosphor solutions. These improvements make them one of the top choices in developing high performance luminaries. ■

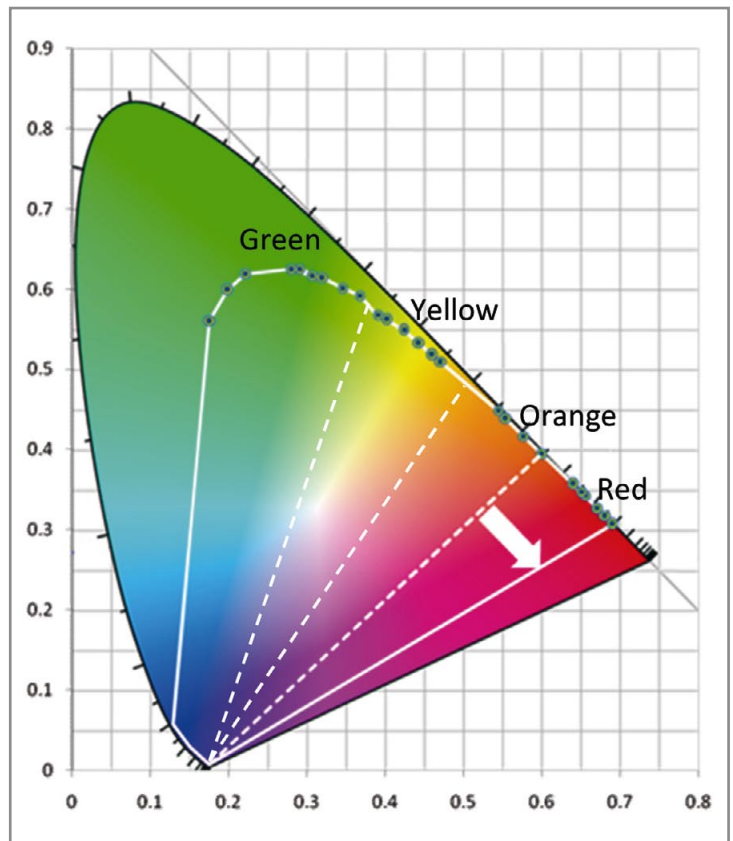


Figure 3: CIE chart of the phosphors.

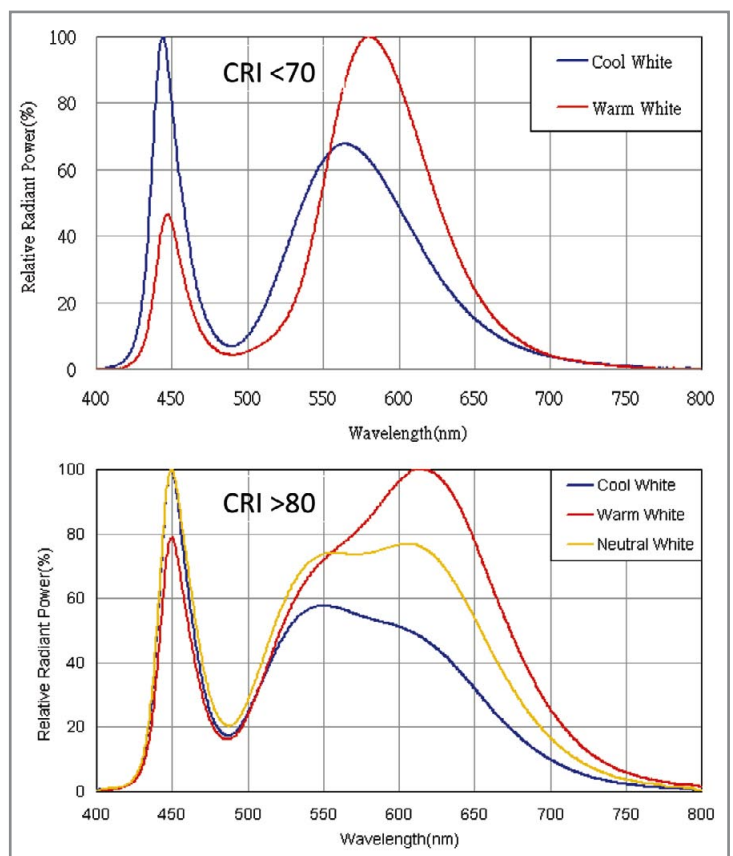
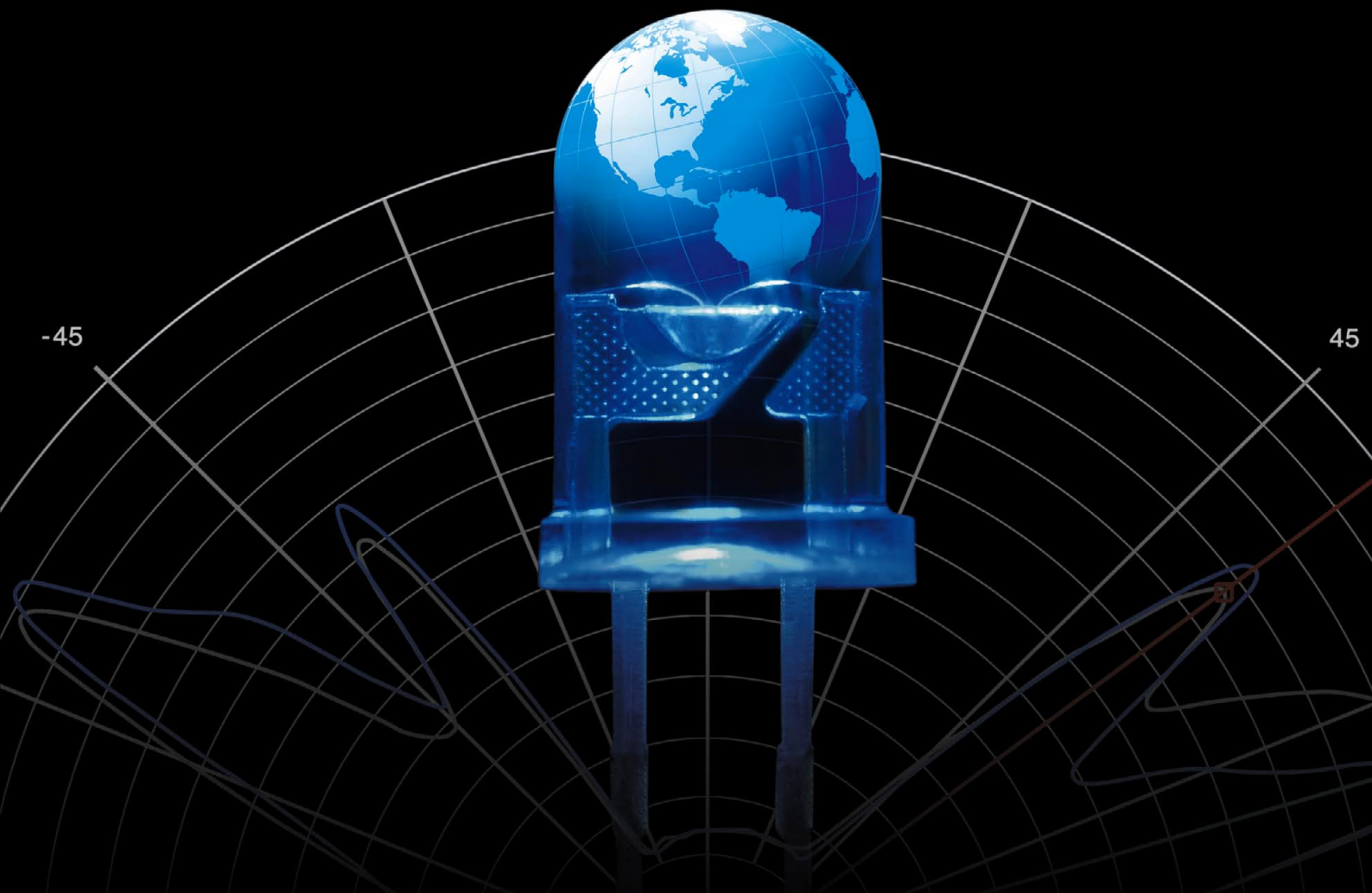


Figure 4: Typical standard CRI and high CRI spectra.



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- Spatial radiation pattern

Driver

Primary Side Regulation: Low Cost and High Efficiency Offline LED Driver

> Hangseok Choi, Fairchild Semiconductor

With the rapid innovations and developments in the lighting industry, coupled with the importance of energy savings and environmental friendliness, high brightness (HB) LEDs have evolved from a simple indicator light to a prominent source of light over conventional light sources. HB LEDs offer several compelling advantages over other lighting solutions, such as less energy consumption, longer life time and enhanced light quality. However, for HB LED to successfully replace standard incandescent bulbs for high volume markets, the cost of the electronics required to drive the LEDs must be minimized.

When it comes to traditional lighting source – incandescent bulb, driving is easy since all we had to do is just connecting voltage source directly to a bulb. Most of energy sources already exist as a form of constant voltage, which results in a simple low cost driving for incandescent bulbs. However, LEDs have an optical output intensity which is proportional to the current flowing through them and the forward voltage drop changes with temperature. Therefore LEDs need to be driven by a constant current and requires additional circuitry. Traditionally, offline constant current driver for LEDs is implemented using an isolated flyback converter with output current regulation circuit as shown in Figure 1. The actual LED current is measured using a sense resistor and then compared with a reference to generate error voltage. The error voltage is transferred to the primary side through opto-coupler and used to control the duty cycle of the primary side switching device. Although this allows excellent LED current regulation, output regulation circuitry requires an opto-coupler, reference voltage, and sense resistor, which increase system cost and deteriorate overall efficiency.

Primary side regulation (PSR) technique can be an optimal solution to minimize the cost for offline LED drivers. This technique precisely controls LED current in the secondary side with the information in the primary side of the driver only, not only removing the output current sensing loss but also eliminating all secondary feedback circuitry. This facilitates a higher efficiency offline LED driver design without incurring tremendous costs. This technique also regulates the LED driver output voltage without secondary feedback circuitry, which acts an open lamp over-voltage protection guaranteeing better reliability of the driver. This article describes the basic operation principle behind primary side regulation and introduces a highly integrated primary side regulation PWM controller that offers distinct advantages over conventional secondary side regulation methods.

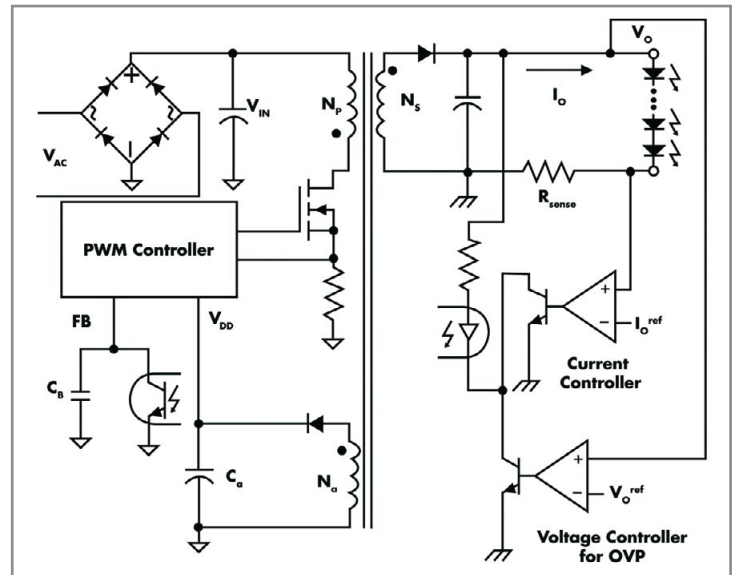


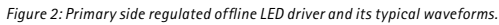
Figure 1: Conventional secondary side regulated offline LED driver.

Basic Idea of Primary Side Regulation

Figure 2 shows the basic circuit diagram of primary side regulated flyback converter and its typical waveforms. Generally, discontinuous conduction mode (DCM) operation is preferred for primary side regulation due to better output regulation. The key of primary side regulation is how to obtain output voltage and current information without directly sensing them. Once these values are obtained, the control can be easily done by the conventional PI control.

During the MOSFET ON time (T_{ON}), input voltage (V_{IN}) is applied across the primary side inductor (L_m). Then, MOSFET current (I_{ds}) increases linearly from zero to the peak value (I_{pk}). During this time, the energy is drawn from the input and stored in the inductor. When the MOSFET is turned off, the energy stored in the inductor forces the rectifier diode (D) to be turned on. During the diode ON time (T_D), the output voltage (V_o) is applied across the secondary side inductor ($L_m \times N_s^2 / N_p^2$) and the diode current (I_D) decreases linearly from the peak value ($I_{pk} \times N_p / N_s$) to zero. At the end of T_D , all the energy stored in the inductor has been delivered to the output. During this period, the sum of output voltage and diode forward voltage drop is reflected to the auxiliary winding side as $(V_o + V_f) \times N_a / N_s$. Since the diode forward voltage drop decreases as current decreases, the auxiliary winding voltage reflects the output voltage best at the end of diode conduction time where the diode current diminishes to zero. Thus, by simply sampling the winding voltage at the end of the diode conduction time, the output voltage information can be obtained. The diode conduction time can be obtained by monitoring the auxiliary winding voltage.

Meanwhile, the output current estimation requires some multiplying calculations. Assuming that output current is same as average of the diode current in steady state, the output current can be estimated as $I_o = I_{pk} \times (N_p / N_s) \times (T_D / 2T_s)$. The output current estimator picks up the peak value of the drain current with a peak detection circuit and calculates the output current using the diode conduction time (T_D).



An Integrated Primary Side Regulation Controller

One technology that specifically addresses primary side regulated offline LED driver designs is the primary side regulation PWM controller FAN102, introduced by Fairchild Semiconductor. This technology significantly simplifies meeting tighter efficiency requirements while eliminating external components that add both cost and reliability issues, such as opto-couplers and KA431.

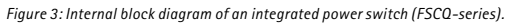
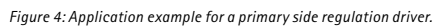


Figure 3 shows the internal block diagram of FAN102. It has an internal reference voltage with $\pm 1\%$ tolerance for error amplifier, which minimizes the output current/voltage variation according to tolerance of external components. It also has an integrated external component temperature variation compensation circuit, which allows high accuracy regardless of temperature variation. The internal oscillator is frequency hopped to reduce EMI, which allows small line filter in the input side.



Conclusion

As HB LEDs are becoming prominent source of light, there has been increasing demand on low cost off-line LED drivers. Fairchild primary side regulation controller promises to dramatically improve the overall cost and performance of future offline LED driver solutions.

A proprietary combination of sampling and output estimation techniques provides a tight regulation and less expensive implementation for offline LED driver everywhere – from street lighting to medical applications and consumer electronics such as cabinet lighting and table lamps. These LED drivers can now be smaller, less expensive, and more efficient. ■

Thermal Derating of LEDs

> Steve Roberts, Recom

In the last few years, the high-brightness LEDs have developed enormously from a niche existence as a high-priced designer spotlight to a useful general purpose illumination source with efficiencies of up to 160 Lumens/Watt and lifetimes measured in decades. As high power LEDs have become more popular as an alternative to wasteful incandescent bulbs or un-recyclable CFL lamps, the economies of scale have caused the price of LEDs to fall to a level where they can now compete in mass markets rather than just the cutting edge applications.

However, the introduction of high power LED Technology has pushed the issue of thermal management back to the forefront of lighting design. Like all semiconductors, LEDs must not overheat otherwise their celebrated long lifetimes will be adversely affected. Although the efficiency of a standard high power LED is around six times better than a standard incandescent light bulb and around twice as good as a fluorescent, a significant amount of the electrical energy flowing through the device is still converted into heat. Therefore, it is essential that thermal management and the consideration of the effects of high environmental temperatures are addressed right at the start of the design phase.

Figure 1a shows how the lifetime of power LEDs drops rapidly once the high ambient temperature causes the internal junction temperature to exceed 130°C. The maximum ambient operating temperature is dependent on the internal thermal design of the LED, its efficiency and its power dissipation, so it varies from manufacturer to manufacturer. However, setting the derating point to 55°C ambient is a reasonable compromise.

Figure 1b therefore shows an ideal LED current versus temperature relationship. Up to the maximum operating temperature, the LED current remains constant. As the LED temperature exceeds the limit, the current is reduced and the LED dimmed to protect it from overheating. This curve is called a "Derating Curve" and keeps the LED working within its safe power dissipation limits.

Adding Automatic Thermal Derating to an LED Driver

LED constant current drivers are circuits that maintain a constant LED light output even if the input voltage changes or the LED characteristics change overtime or from production batch to production batch.

If the LED driver has a dimming input, then we can easily add an external temperature sensor and some external circuitry to recreate the desired derating characteristic as shown in Figure 1b. The RCD-xxB series LED driver from RECOM has three different dimming inputs and so is an ideal candidate to explain the three different ways in which over-temperature protection can be added to an LED driver circuit. In addition, it also has a useful 3.3V Vref output that can deliver up to 5mA to power external circuits.

Over-temperature protection using a PTC thermistor

A thermistor is a resistor that changes its value with temperature. If the resistance increases with increasing temperature, it has a positive temperature coefficient (PTC). It is possible to obtain PTC thermistors with very non-linear characteristics (Figure 2).

As long as the temperature stays below a given threshold, in this case 70°C, the PTC thermistor has a relatively stable low resistance in the order of a few hundred ohms. Above this threshold, the resistance increases very rapidly: at 80°C the resistance is 1k0hm; at 90°C it is 10k0hm and at 100°C, it is 100k0hm.

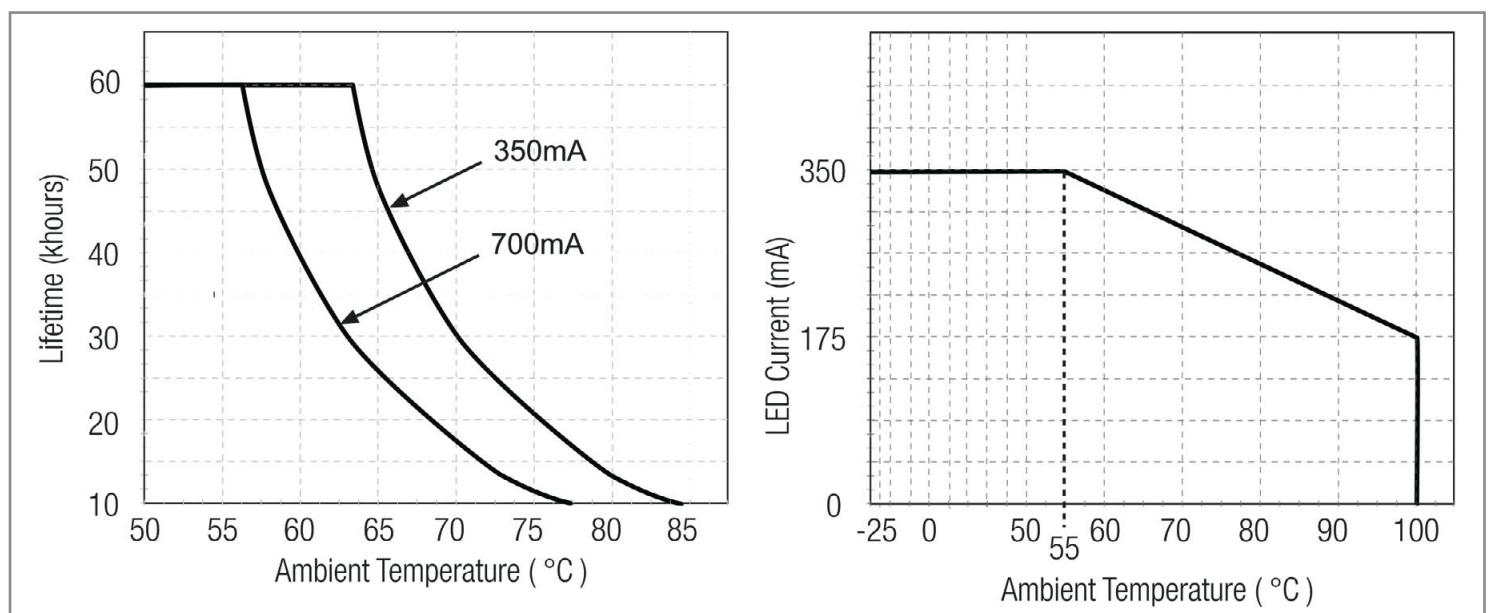


Figure 1: (a) Effect of ambient temperature on lifetime; (b) typical LED temperature derating curve.

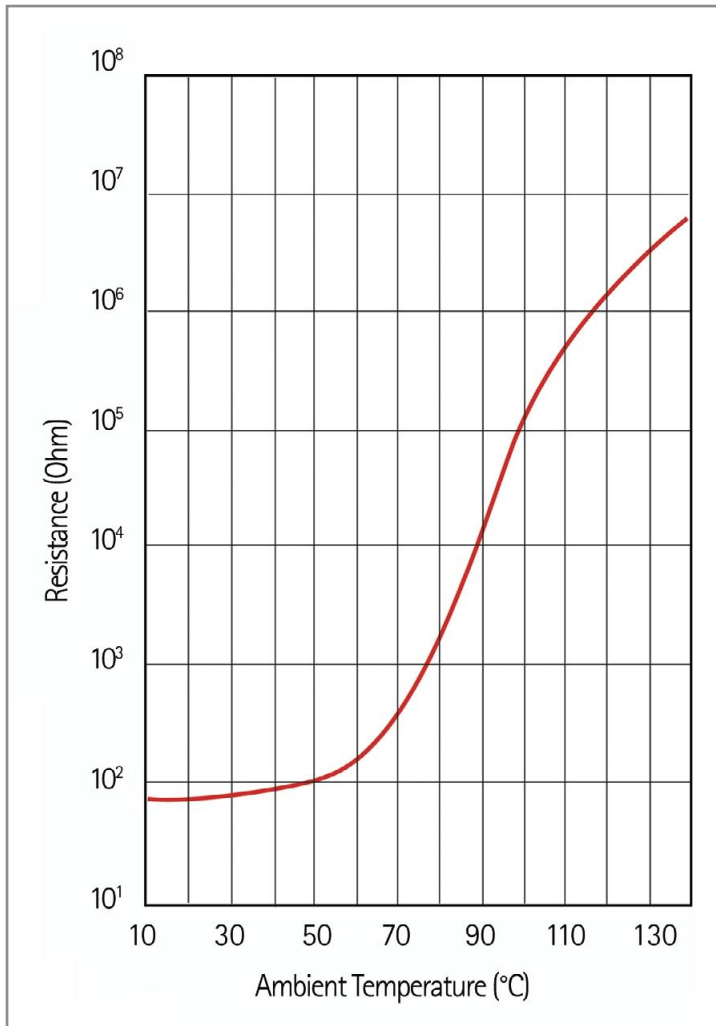


Figure 2: Typical PTC thermistor resistance / temperature curve.

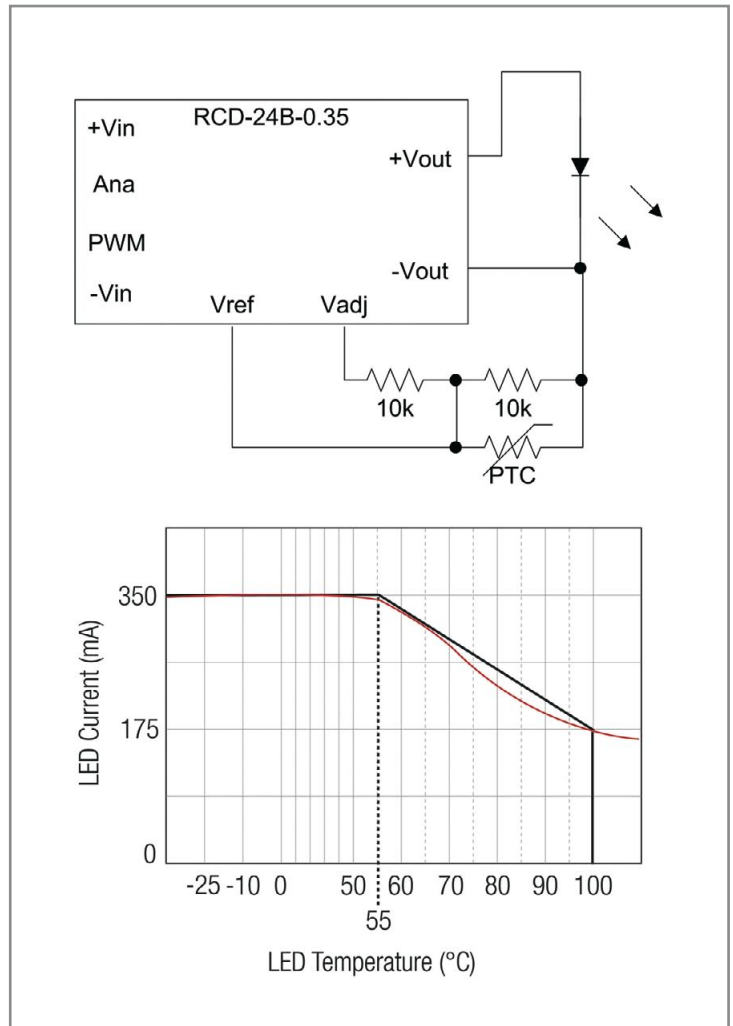


Figure 3: PTC Thermistor circuit and resulting LED derating curve (red line).

Conveniently, PTC thermistors are also available pre-assembled to a mounting lug that can be very easily attached to the heat-sink casing of a LED lamp fixture.

We can use this response to make a very simple, low cost and reliable over-temperature protection circuit using the resistive analogue dimming input of the RCD-xxB series LED drivers (Figure 3). This dimming input is controlled by a variable external resistance and so a PTC thermistor plus bias resistors are the only additional components required. If different derating temperature points are required, PTC thermistors are available with different threshold temperatures in 10°C steps from 60°C to 130°C, so it is simply a matter of selecting the right part to match the specification of the LED.

Over-temperature protection using an analogue temperature sensor IC

There are many IC temperature sensors available that provide a linear output with temperature. They do not cost much more than PTC thermistors and have the advantage that the linearity and offsets are

very accurate, so temperature monitoring with 1°C resolution is possible. The output needs to be amplified in order to generate a useful control signal voltage, so they are most often used in conjunction with an operational amplifier.

The circuit suggestion below (Figure 4) uses a common temperature sensor IC and dual operation amplifier. Similar products are available from a wide range of manufacturers. The output of the temperature sensing circuit is fed into the analogue voltage dimming input of the RSD-xxB series. This control input linearly dims the LED brightness according to the voltage present on the pin.

In the circuit below, the LM61 temperature sensor delivers a linear output voltage depending on its temperature. The output is pre-calibrated to give 10mV/°C + 600mV, so at 55°C the output voltage will be 1.15V. The LM10 device contains two low power op-amps and a precision 200mV voltage reference. The 10kOhm offset adjustment preset adjusts the offset to 1.15V and the gain is set so that at 100°C, the LED is running at 50% nominal current.

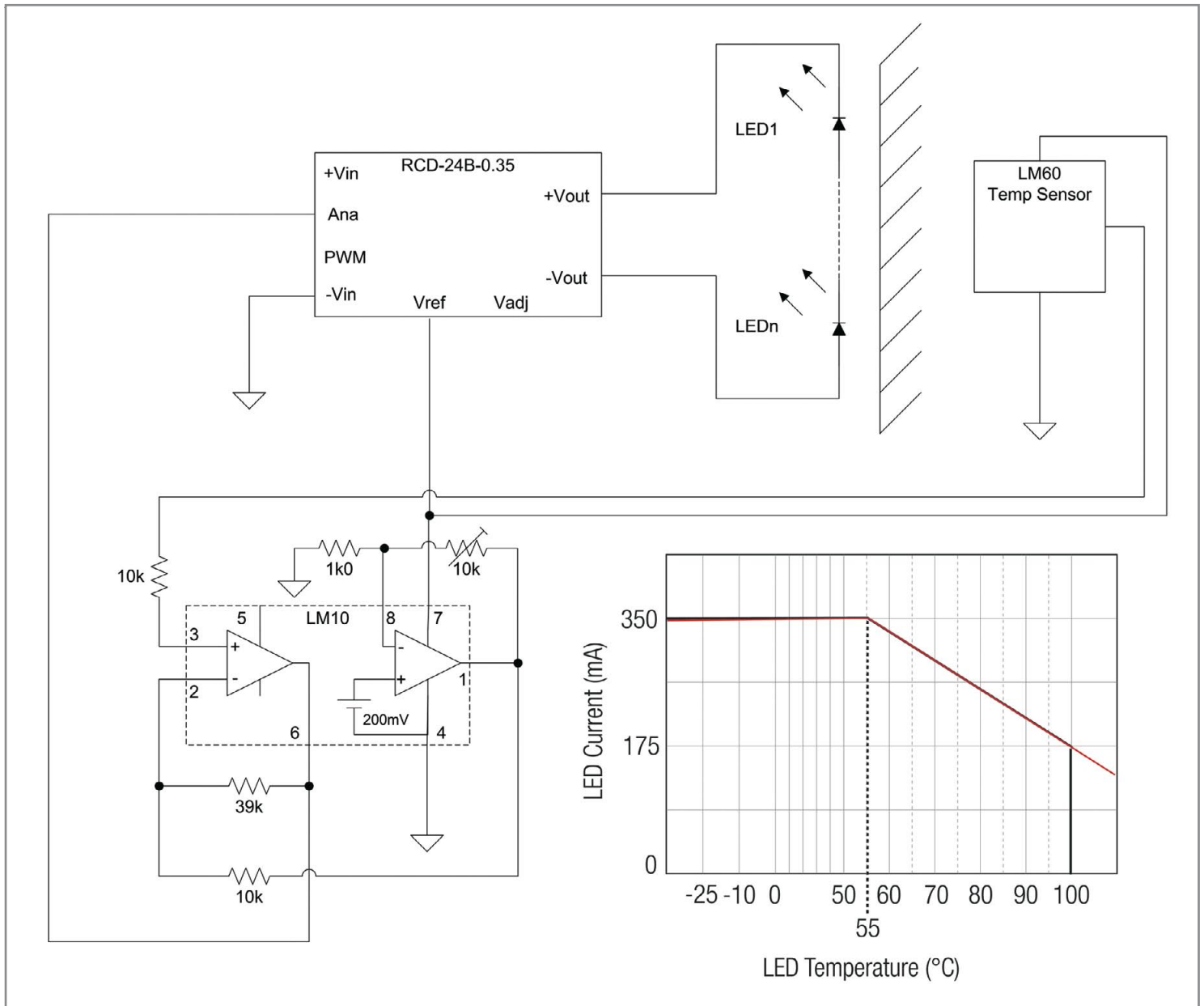


Figure 4: Analogue over-temperature circuit and resulting LED derating curve (red line).

Over-temperature protection using a PWM controller

The third dimming input possibility of the RCD-xxB series is the PWM input. Pulse width modulation uses a digital control signal to alter the brightness of the LED by switching it on and off too rapidly for the eye to see. If the LED spends more time off than on, it will appear dim. If the LED spends more time on than off, it will appear bright. The PWM input responds to logic level signals, so is ideal for interfacing to digital controllers.

The circuit suggestion below (Figure 5) uses a microprocessor to monitor and control up to eight LED drivers. As only 5 I/O pins are used, the circuit could be easily expanded to control more LED drivers or an additional remote over-temperature alert could be added.

Temperature sensing is realized via MAX6575L/H devices which are low cost, low current temperature sensors. There are other manufacturers offering equivalent temperature sensors with digital interfaces, but these parts have the advantage that up to eight temperature sensors can share a single control line. Temperatures are sensed by measuring the time delay between the microprocessor initiated trigger pulse and the falling edge of the subsequent pulses reported from the devices. On the output side, a low power addressable latch is reset with each trigger pulse, so turning all LED drivers on. The microprocessor then can individually set each output after an appropriate time delay to generate eight PWM signals to independently control each LED driver.



Conclusion

up to 85°C, it is recommended that the LED driver is not placed too close to the LED to avoid thermal stress. ■

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Thermal Management

Thermal Management of High Power LEDs

> Norbert P. Engelberts, Advanced Thermal Solutions

Light-emitting diodes (LEDs) have long been used in instruments and computers as visual indicators for signal integrity and operations status., LEDs are ideal choices due to their high reliability, low power use and little to no maintenance needs. More recent market interest in LEDs is in their use, not only as indicators, but also as lighting devices. However, as illumination becomes the focus, the power consumption of LEDs has risen dramatically. Device heat fluxes are rivaling those of CPUs and other semiconductor packages. As a result, thermal management of LEDs has taken center stage for successful implementation.

It is important to remember that an LED is not a high temperature, filament-type lighting device. While a single LED is a cold and efficient light source, high-power LED applications, including arrays of LEDs, need thermal management similar to other semiconductor devices. High temperatures not only degrade an LED's lifetime, but also result in lower or non-uniform light output, which can significantly affect their application.

Most LEDs are designed in SMT (surface mount technology) or COB (chip-on-board) packages. In the new 1 to 8W range of surface mount power LED packages, the heat flux at the device's thermal interface can range from 5 to 20W/cm². These AlInGaP and InGaN semiconductors have physical properties and limits similar to other transistors or ASICs (application specific integrated circuit). While the heat of filament lights can be removed by infrared radiation, LEDs rely on conductive heat transfer for effective cooling.

As higher powers are dissipated from LED leads and central thermal slugs, boards have changed to move this heat appropriately. Standard FR-4 technology boards can still be used for LEDs with up to 0.5W of dissipation, but metallic substrates are required for higher levels. A metal core printed circuit board (MCPCB), also known as an insulated metal substrate (IMS) board, is often used underneath 1W and larger devices. These boards typically have a 1,6mm (1/16 inch) base layer of aluminum with a dielectric layer attached. Copper traces and solder masks are added subsequently. The aluminum base allows the heat to move efficiently away from the LED to the system [1].

Thermally dissipating PCBs are not always adequate or suitable for LED applications. Other cooling design choices are available, and it can be challenging to select the most appropriate and cost effective solution for a given application. In this article, we show the required approach for the thermal management of LEDs. This method enables the designer to select the appropriate cooling solution based on the LED's junction temperature and not on the total power dissipation.

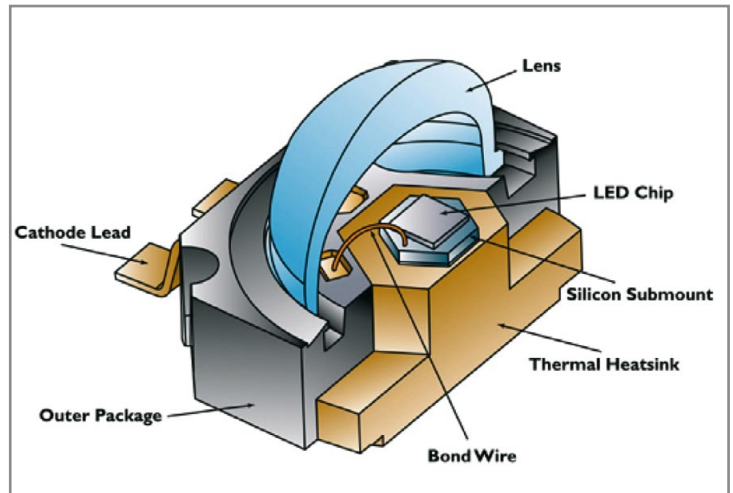


Figure 1: Luxeon K2 Power LED (courtesy of Lumileds).

Two parameters play a pivotal role in the success of an LED. These are the cooling method and the optical lens. These factors affect the shape, size and construction of the luminaire that comprises the overall lighting unit. Because long life and fail safe operation are essential for any LED, the cooling process is uniquely critical. An LED's plastic body is not thermally conductive and the device does not radiate heat. The only effective cooling method is to conduct the heat away through the bottom of the device. Therefore, highly thermally conductive materials are commonly used to take the heat from the LED's back side (Figure 1). Depending on power dissipation and light emission uniformity, the method of cooling can be passive (heat sink in natural convection) to active (fan-sinks) or can use liquid cooling.

With their basic, robust construction, LEDs can be used in environments ranging from ornamental to such critical illumination needs as automotive headlamps. Therefore, their cooling systems must be designed with the ambient temperature and the specific end use in mind. For example, a car's headlamp with an under-the-hood temperature of 85-100°C and power dissipation values of 42-90W requires unique consideration for cooling and reliability. In other applications, to get the same light output as an incandescent lamp, the LED lamp will often run on comparable power dissipation values. However, the LED device's maximum allowable junction temperature is limited to 120-135°C (up to 185°C in recent developments). If we compare these limits to an incandescent lamp, which allows filament operating temperatures of 1500-3000°C, the thermal challenge for LEDs, especially in harsh environments, is the major obstacle to their successful implementation.

These thermal constraints typically need to be considered:

- Tjunction LED max < 120-185°C
- Tjunction LED lifetime < 100-110°C
- PLED = 1-8 W
- Light output is strongly dependent on temperature

Cooling Options

The cooling options for LEDs range from simple natural convection in air to liquid cooling, where a cold plate and liquid loop form the required cooling system. Because most market applications for LEDs shy away from liquid cooling, the focus of this section will be on air cooling of LEDs.

Most LED lamps employ familiar heat sinking techniques. In some cases, the metal fixture of a luminaire can act as a heat sink, but the thermal requirements of its LEDs must be considered when designing the unit. Increasing power density, a higher demand for light output and space constraints are leading to more advanced cooling solutions. High-efficiency heat sinks, optimized for convection and radiation within a specific application, will become more and more important.

As with any semiconductor package, thermal resistance plays a significant role in the thermal management of LEDs. The highest thermal resistance in the heat transfer path is the junction-to-board thermal resistance (R_{j-b}) of the package [2]. Spreading resistance is also an important issue. Thermally enhanced spreader materials, such as metal core PCBs, cold plates and vapor chambers for very high heat flux applications are viable systems to reduce spreading resistance [3].

Linear heat sinks are available specifically for LED strips, such as OSRAM SYLVANIA's DRAGONstick® linear LED strips, which are widely used in architectural lighting. For example, the maxiFLOW™ linear heat sink from Advanced Thermal Solutions has a patented spread fin array that maximizes surface area for more effective convection (air) cooling, particularly when air flow is limited, such as inside display cases.

Round heat sinks are available specifically for round LED boards, which are used to replace halogen light bulbs in applications such as spotlights and down lighting. A typical LED spotlight is shown in Figure 2 [5]. Here, a round QooLED® heat sink from Advanced Thermal Solutions is used for cooling three LEDs. The round heat sink has a special star-shaped profile fin design that maximizes surface area for more effective convection (air) and radiation cooling in the vertical mounting orientation, e.g., inside ceilings.

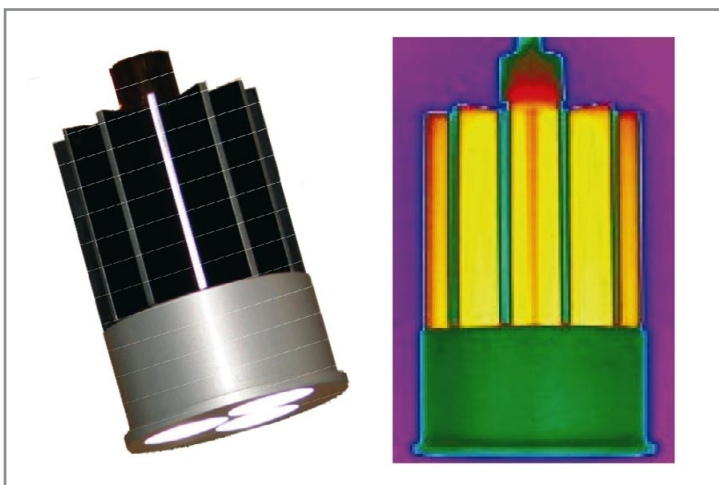


Figure 2: An LED-based spotlight with a round, finned heat sink, visible and IR views [5].

Active thermal management systems can be used for high-flux power LED applications. These include water cooling, two-phase cooling and fans. Although active cooling methods may not be energy-justifiable for LEDs, reasons for using them include ensuring lumen output, or maintenance-free operation, or to meet specific wavelength requirements.

The LED Thermal Design and Cooling Solution Selection Process

The thermal design of any electronic component, including an LED, consists of three steps [4].

- Analytical (Integral) Analysis
- Computational (Numerical) Analysis
- Experimental Analysis/Verification

Thermal Design – Analytical Analysis

Analytical analysis is used to develop a first-order solution. This approach identifies the problem areas (components and system layout) and ascertains the magnitude of the problem (device junction temperature and required level of cooling). Some analyses can be performed quickly to evaluate the scope of the problem – the so-called "what if" scenario.

Computational Analysis

Computational analyses are used to develop second-order solutions to verify results from step 1. The problem must be well understood in order to develop a model that accurately represents the problem.

CFD (computational fluid dynamics) gives a total 3D picture of the problem. Both heat transfer and flow will be calculated. CFD is typically used to characterize the effect of spreading resistance within the PCB, the flow around the LED lamp and the thermal performance and optimization of a heat sink. Figure 3 shows some results from a CFD study of the LED-based spotlight discussed earlier.

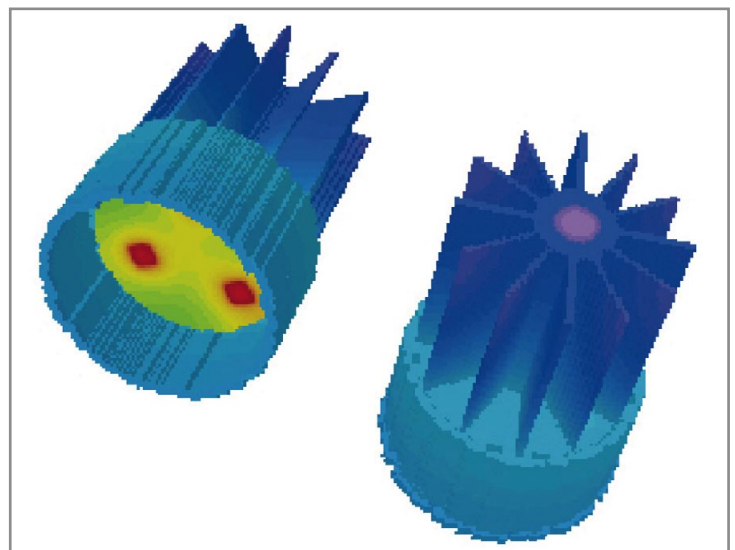


Figure 3: Results of a CFD study on an LED-based spotlight.

Experimental Analysis/Verification

The final product must be tested experimentally, whether for compliance or effective operation. For an LED-based application, the junction temperature is measured by the forward voltage characteristic. The LED has to be calibrated first with a 10 mA constant current source. During the operational test, the current measurement source is on all the time, then, after stabilization, the operational current is switched off. After turning off the current, the drop in the forward voltage is measured. The thermal mass of the junction is small, which results in a fast cool-down time. This temperature change occurs in less than 1 msec, so the forward voltage has to be measured in microseconds after the event. More information can be found in Farkas, et al. [6].

The forward voltage together with the calibration curve will give the junction temperature under operational conditions. This junction temperature must be within specifications for both maximum and typical ambient conditions.

Conclusion

This article highlights the importance of thermal management to the successful use of LEDs. Selecting a cooling solution based on device (LED) junction temperature ensures that the most critical parameter, one that can adversely impact its reliability and performance, is identified and thermally managed. More importantly, developing a cooling solution based on an independent analysis approach, i.e., analytical, experimental and computational, provides a high degree of confidence for identifying the most effective cooling solution for high power LEDs. ■

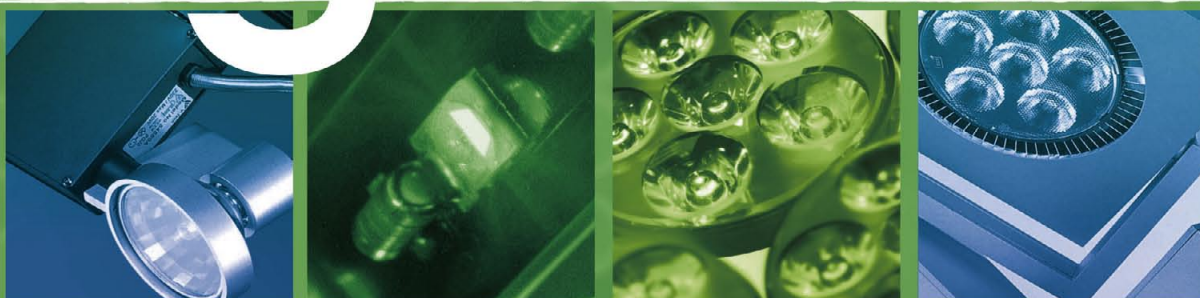
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LED professional – Patent Report

> Siegfried Luger and Arno Grabher-Meyer, Editors, LED professional

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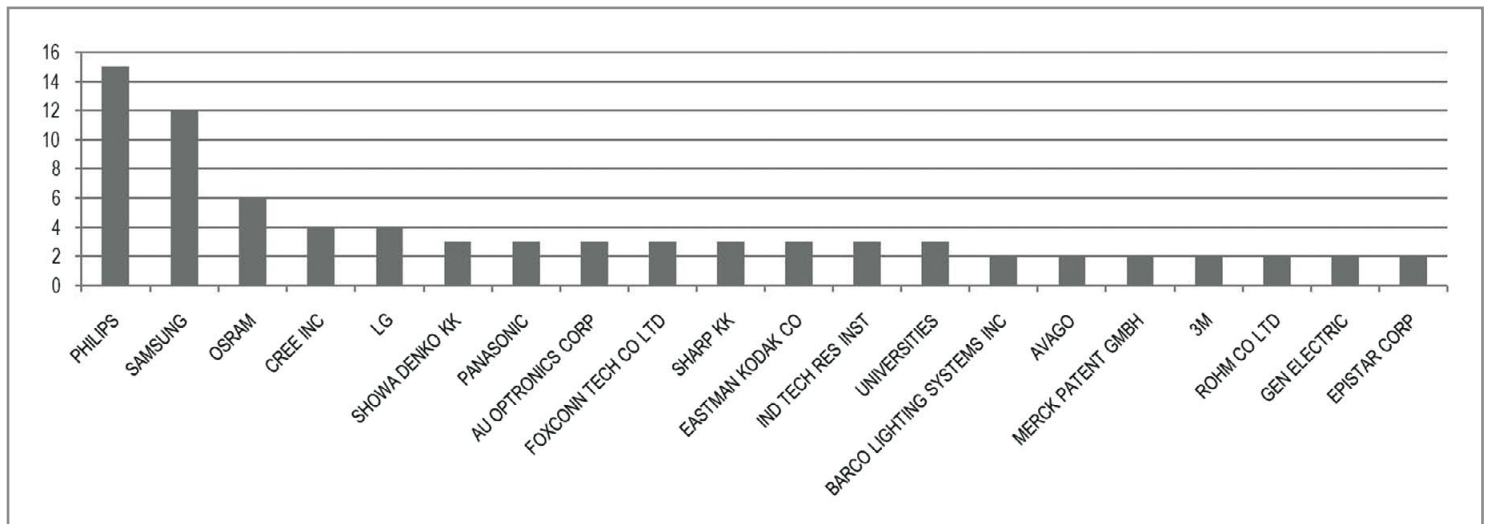
Application: General Lighting

Granted Patents: 147

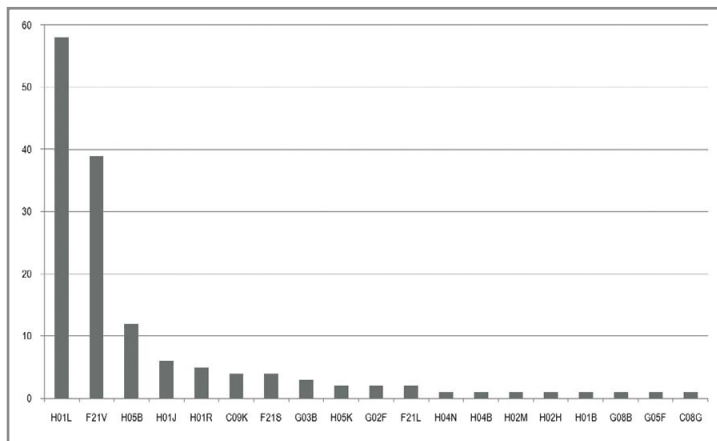
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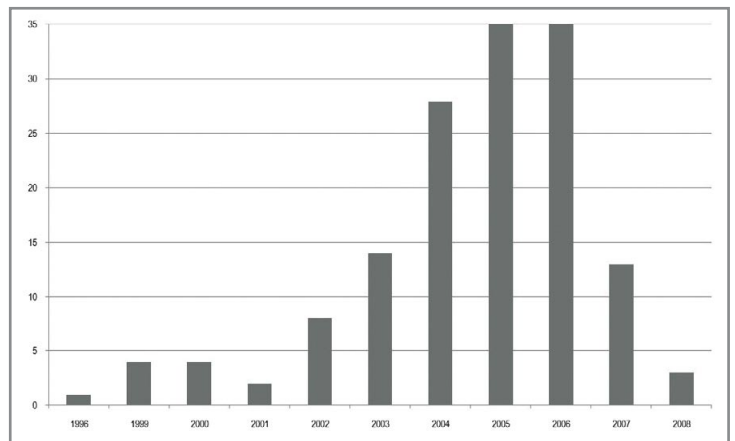
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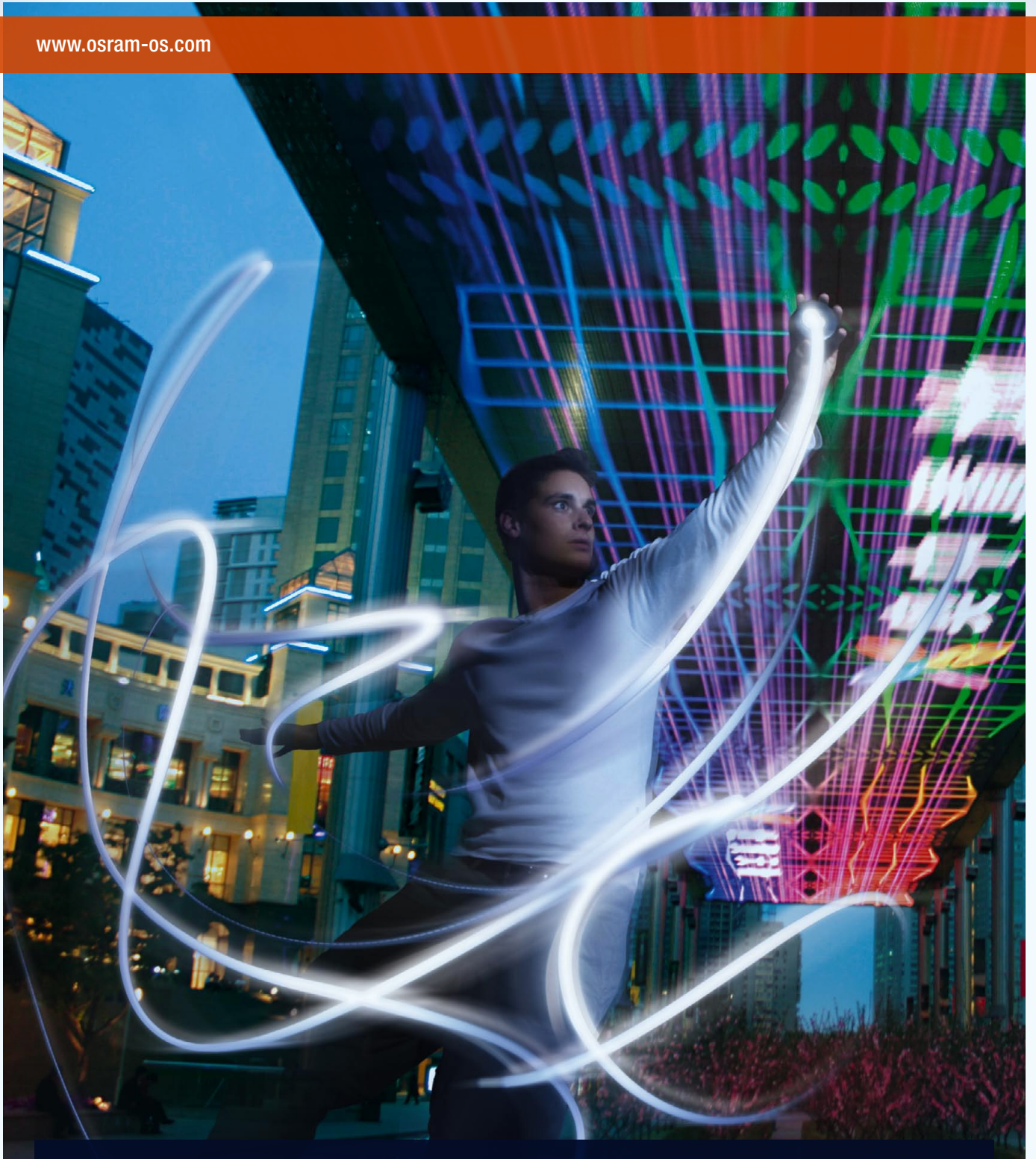
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