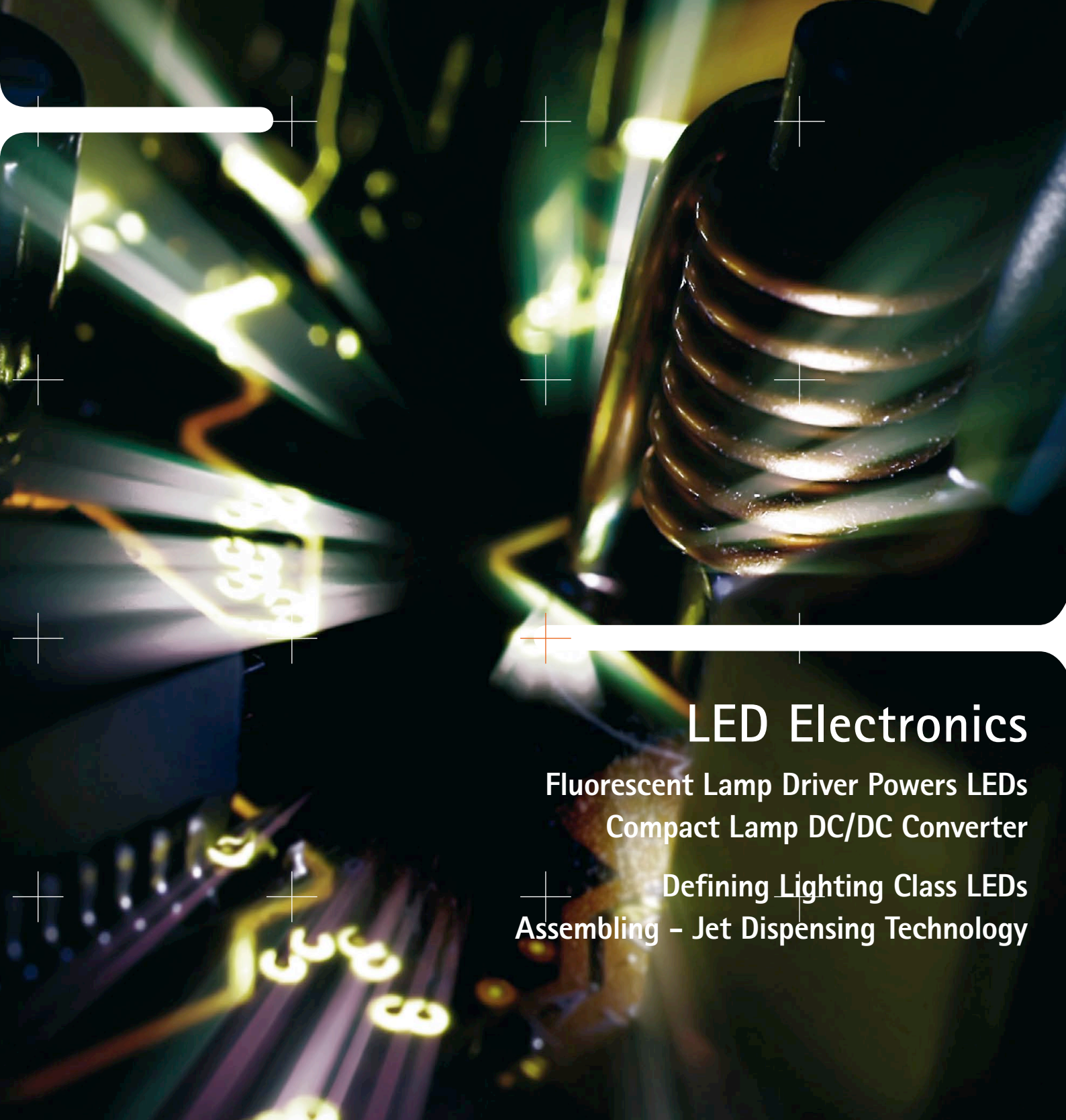


*The technology of tomorrow for general lighting applications.*

Jan/Feb 2009 | Issue

11



## LED Electronics

Fluorescent Lamp Driver Powers LEDs

Compact Lamp DC/DC Converter

Defining Lighting Class LEDs

Assembling - Jet Dispensing Technology

What would you see  
in 5 years ?



- Size : W 4.5 × D 3.0 × H 1.8 mm
- Reflow Compatible
- Moisture Sensitivity : JEDEC 1
- Color ○ ● ● ● ● ● ● ● ● ● ● ● ● ● ● ●

## Edixeon® Federal Series

Federal series is the latest high power LED product introduced by Edison Opto. Federal offers ***thirteen diverse range of color choices*** including: cool white, neutral white, warm white, red, cherry red, deep red, amber, green, cyan, blue, dental blue, royal blue and ultraviolet, enabling applications beyond illumination.

## A Need for Intelligent LED Drivers



This year, we start with a closer look at a more and more important topic in LED lighting - LED electronics - as professional LED lighting is strongly influenced by the future development in this field, such as LED drivers.

LED drivers require technical concepts with the direct control of currents, high efficiency values, PWM dimming options, overvoltage protections, load disconnect protection, small sizes, and ease of use. Nowadays, the preferred method to drive an LED is with a constant-current source. The constant current source eliminates the changes in the LED current due to variants in the LED forward voltage, basically depending on the LED junction temperature and component tolerances.

Efficiency values depend on the application, offline supply or battery drive. The losses vary according to the input to output voltage ratio. For example, the efficiency of photovoltaic, solar driven LED drivers are quite high, due to the fact, that the source and load voltages can be matched to similar ranges in this application. Two major types of LED driver dimming principles are commonly used nowadays: analog and PWM. Due to miniaturization and efficiency improvements, future designs will work in the MHz frequency range. Resonant driving mode is another approach to drive and dim LEDs and is highlighted in this issue also.

As a consequence of constant-current driving mode, LED electronics will need improved overvoltage protection if the load resistance increases or if the load is disconnected. The preferred method is to measure the voltage and shut down the driver in case of overvoltage: intelligent shutdown.

Small size is an important feature for an LED driver and supply. Several factors contribute to the size of the circuit components. One dominant factor is also the higher switching frequency, resulting in smaller passive components.

The further integration process into driver ICs will follow similar trends as seen in other technology areas like Microcontrollers, DSPs, etc. Intelligent LED drivers will support professional LED lighting and will be the key to having improved functionalities and operation-stability in future LED lighting designs.

The Jan/Feb 2009 LED professional Review (LpR) issue highlights LED electronic topics showing some aspects of professional LED driver approaches.

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 black ink, appearing to be 'S. Luger', written over a horizontal line.

Siegfried Luger

Publisher

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#### Next LpR Issue – Mar/Apr 2009

- LED Applications & Lighting Systems

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The logo for the 2009 LED Lighting Taiwan exhibition. It features the word "LED" in a stylized font where the 'L' is a vertical bar, the 'E' is a horizontal bar, and the 'D' is a vertical bar. To the right of "LED" is the year "2009" in a large, bold, sans-serif font. Below "LED" is the word "LIGHTING" in a smaller, bold, sans-serif font. Below "LIGHTING" is the word "Taiwan" in a large, bold, sans-serif font. The entire logo is set against a background of a blue and green gradient with a pattern of white dots and lines.

## LED Lighting Taiwan

The 5th Int'l LED Lighting Exposition

<http://www.optotaiwan.com>

**June 10-12, 2009**

Taipei World Trade Center, Hall 1

### Exhibits

- **LED Lighting Fixture**  
Indoor, Outdoor, Specialty  
Decorating, Landscape, Architecture, Garden  
Control System & Accessories
- **LED Applications**  
Automotive Lamps, Backlight, Display Board, Traffic Signal, IrDA, etc.
- **Package / Module**  
Lamp, Dot Matrix, Cluster, SMD, etc.
- **Epi Wafer, Chip**
- **Materials**  
Substrate, Ingot, Phosphor, Lead Frame, etc.
- **Processing Equipment**  
Wafer (MOCVD, Mask, Etching)  
Assembly (Dicing, Bonding, Packaging)  
Testing (Prober, Aging)

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## Product News

### Cree Announces High-Volume Availability of Brightest Lighting-Class LEDs

Cree, Inc. (Nasdaq: CREE), a market leader in LED lighting, announces the high-volume availability of lighting-class XLamp® XP-E LEDs with output of up to 122 lumens.

Cree continues to set the standard for innovation and availability of lighting-class LEDs through its broad family of XLamp LEDs. The volume availability of XLamp LEDs is aimed at further stimulating the LED lighting market, driving applications in outdoor and indoor general illumination as well as portable and retail display lighting

Cree now offers XLamp XP-E cool white (5,000K – 10,000K CCT) LEDs in a minimum R2 flux bin (114-122 lumens at 350 mA), which is the highest commercially available minimum-flux order code for a single-die LED, at 350 mA, in the industry today.

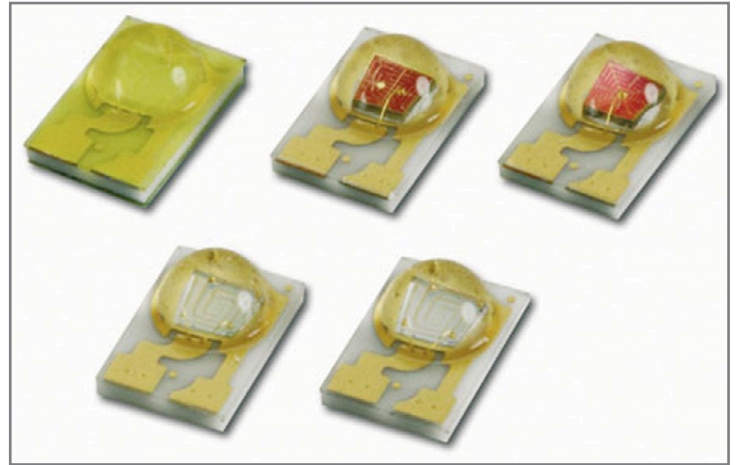


Cree XP-E LED

"LED product designers know they can depend on Cree to provide the industry's brightest commercially available LEDs," says Paul Thieken, Cree marketing director for LED components. ■

### Edison Opto Announced Compact, Powerful Edixeon® Federal Series

To stand out from the diversified range of LED products currently available on the market, an LED product now not only has to offer higher brightness, but also meet designers' needs for a reliable and flexible product. Edison Opto has introduced Federal series, an ultra-compact small sized high power LED offering efficient performance and design flexibility.



Edixeon® Federal series LEDs

Edixeon® Federal series offers thirteen (13) different choices of color from the White series (2,670K~10,000K), single color series as well as IR and UV series (395nm~740nm). The small footprint of Federal series is ideal for modular customization. Standard module comprises three Edixeon® Federals on a star-sized MCPCB.

Through its proprietary automated packaging process, Edixeon® Federal series conforms fully to the RoHS directive as with the rest of its Edixeon® family and offers accurate and stable manufacturing yields for a competitive edge over cost and delivery. ■

### Avago: 1-Watt HP LED Emitter for SSL Applications

Avago Technologies, a leading supplier of analog interface components for communications, industrial and consumer applications, announced a new competitively priced 1-Watt high power LED emitter for use in solid-state lighting applications. Avago's energy-efficient ASMT-Ax00 LED features a low-profile package design, wide 130-degree viewing angle, and the ability to handle high thermal and drive currents. Available in a variety of colors, this LED is ideal for use in architectural, contour, retail display, decorative and garden lighting applications.



Avago's new, energy-efficient ASMT-Ax00 LEDs

## Features:

- Available in red, amber, green, blue, cool white, neutral white and warm white colors
- Long operating life
- Energy efficient
- High reliability package due to enhanced silicone resin material
- Exposed metal slug for excellent heat transfer
- Suitable for reflow soldering processes
- Low thermal resistance
- Moisture sensitivity: MSL 2a
- Pb-Free and RoHS compliant
- ESD >16kV

Solid-state lighting equipment manufacturers are constantly in need of brighter, more reliable high power LED packages. Avago's ASMT-Ax00 is a high performance LED designed to handle high thermal and high drive currents. By delivering a high flux output of up to 76 lumens (lm) at 350mA, this LED features a maximum allowable junction temperature of 125 degrees-C and high ESD resistance of 16 kV. Moreover, the ASMT-Ax00 is compatible with standard SMT reflow soldering processes to provide lighting designers with more freedom and flexibility in designing their applications.

Avago's ASMT-Ax00 LED emitter is encapsulated in a heat and UV resistant silicone compound for high reliability and long life. The ASMT-Ax00 is ideal for use in lighting applications where height is a constraint and provides designers of solid-state lighting applications with a wide viewing angle, and superior heat dissipation. ■

## RGBA LED Assembly with Optimal Thermal Performance

Integrating four 1-W LED die into a single assembly for solid state lighting applications, TT electronics OPTEK Technology has developed a star-shaped red/green/blue/amber LED assembly with exceptional thermal performance. Designating the OV4Z Optimal IV Star series, the LEDs are offered in mono-color or RGBA packages and feature a recessed die design that houses four LED chips under a 5mm optical grade water clear lens. The assemblies achieve an extremely low thermal resistance of <math><2^{\circ}\text{C}/\text{W}</math> from junction to heat sink.

"The combination of red, green, blue and amber high-brightness LEDs provides solid state lighting designers with an extensive number of color combinations," said Alan Bennett, Vice President of Sales. "The star-shaped assembly results in a simplified mounting configuration, while the design of the part provides customers with optimal luminous intensity and transfer of heat generated due to increased current values."

The OV4Z series devices are exceptionally bright and ideally suited for applications including large signage; interior, exterior and landscape architectural lighting; recreational areas such as pools, spas and boats; and specialty lighting, display cases and stage lighting.



OV4Z Optimal IV Star series LEDs are offered in mono-color or RGBA packages

The Optimal IV Star series assemblies feature emitted colors of blue (455 - 460nm), green (530 - 535nm), red (620 - 630nm), amber (585 - 595nm), and daylight white. Typical forward voltage at 350mA ranges from 2.5V to 3.9V for the RGBA devices, and 8.6V to 13.1V for the mono-color assemblies, while luminous flux at 350mA ranges from 5 lm to 36 lm and 29 lm to 162 lm, depending on LED color. Viewing angle for both the RGBA and mono-color assemblies is 60°. Maximum allowable junction temperature is 130°C, with an operating temperature range of -50°C to +100°C.

The mono-color assembly is available with mounting pads, while the RGBA assembly is available with through-hole pins or mounting pads for surface mount electrical connections, along with six locating slots for mounting screws. The assemblies are 0.83 inches (21mm) in diameter on a 0.04 inch (1mm) thick star-shaped PC board. ■

## Mid-Power LED Light Source Features High Lumen Density

Sharp is introducing a new lighting-class, multi-chip LED (nicknamed the Flash Brick), featuring very high lumen density in a small package.

### Part Specifications:

P/N	Forward Voltage (V)	IF (mA)	Color Coordinates (x,y)	Luminous Intensity (lm)	Package (L x W x Thickness)
GM1BW78140A	3.5	150	(0.31,0.31)	40	2.64 x 1.64 x 0.7 mm

The GM1BW78140A is the 0.5 Watt Flash Brick. It features an electrically isolated, exposed pad design for excellent heat transfer from the package to the motherboard. The Flash Brick reduces the overall system cost by reducing the number of system components. It is an excellent solution for lighting and any other applications that require a high light output in a small space.



## CeramCool® GU10 LED Spot

The new CeramCool® GU10 LED spot works with any LED. Socket and reflector are made from a single material: a high-performance ceramic; thus its simple class II construction with safe insulation. A high voltage 4W LED only reaches a maximum temperature of 60°C, so both lifetime and light output are increased.



The CeramCool® GU10 LED spot has a fully ceramic construction

In all CeramCool® ceramic heat sinks the substrate becomes the heat sink. Here it acts as the lamp, or even the luminaire. The simplified construction delivers extremely high reliability. Conventional LED systems combine numerous layers with different expansion coefficients, typically introducing risks such as delamination and degradation. In addition, the mount and reflector of GU10 LED spots are usually made of different materials. With CeramCool® however, far fewer materials are used and ceramics are exploited for their electrical insulation, good EMC and high mechanical and chemical stability.

CeramTec AG develops individual designs and special technical solutions in consultation with manufacturers. The CeramCool® GU10 LED spot shown here delights the eye with its continuous ceramic construction and stunning indirect light from the ceramic reflector. ■

## Launch of Array™ Lighting Brand LED Light Bulbs

Nexus Lighting, Inc. (NASDAQ Capital Market: NEXS) began production and sale of its new Array™ Lighting brand of LED lamps early this year. The new Array™ Lighting Par 30, Par 16 and G4 LED are the first bulbs to begin production. The Array Lighting LED lamps feature its patent pending, Selective Heat Sink (SHS) technology, to achieve the highest efficacy levels of any LED replacement lamp in the industry. Array Lamps offer tremendous cost and energy savings by consuming only 5.5 and 7.8 watts for the Par 30 lamps, 2.6 watts for the Par 16 lamps and 1.2 watts for the G4 lamps which can amount to over 80% energy savings versus incandescent bulbs. Additional savings are gained in avoiding lamp replacement costs due to the lamp's 50,000 hour lamp life, making the Array lamps ideal for long burn hour, always on and 24/7 buildings.



Array™ lighting brand LED light bulbs linecard

"This marks a new era for Nexus Lighting. We are very excited to begin production and shipment of the first lamps in our Array™ Lighting line of products and we are very pleased with the market response since we originally announced the development of this product line," stated Mike Bauer, President & CEO of Nexus Lighting. "The product is ground breaking in its design and performance. It is lightweight, contains no mercury, reduces CO2 emissions and can achieve unmatched lumen per watt efficacies which are over 30% higher than other LED products on the market today."

Array Lighting's patent pending design, thermal management system and its manufacturing methodology reduces metal content to a minimum, reduces costs and at the same time maximizes luminous efficacies up to 95 lumens per watt. The Array™ bulbs are available in warm white (ANSI 3000K), natural white (ANSI 5000K) and cool white (ANSI 6500K) color temperatures and are fully dimmable on standard commercial dimmers.

The complete line of Array Lighting LED lamps, including the MR16 bi-pin and the MR 16 with a GU10 base, are scheduled to be rolled out through the balance of the first quarter of 2009. ■

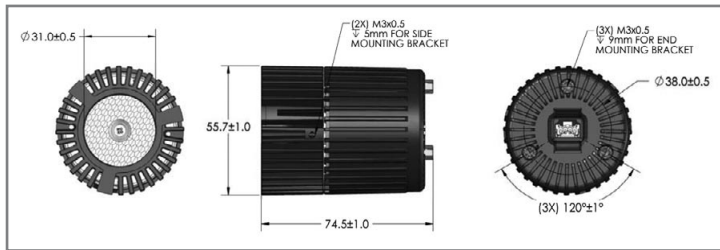
## LedEngin: Production Availability of LuxSpot™

LedEngin, Inc. has bridged the gap between LED technology and conventional lighting with the introduction of LuxSpot™, the first in a family of innovative, high brightness LED lighting modules. Ultra-compact LuxSpot is powered by LedEngin's industry leading multichip LED emitters, exceeding performance of 35W halogen equivalent. LuxSpot provides 60% savings in power consumption compared to a halogen source, and with a service life more than 10 times longer. By incorporating the industry's highest flux density LED emitter with the latest electrical, optical and thermal solutions, LedEngin is able to offer a truly leading-edge solid-state lighting system. LuxSpot is offered in warm, neutral, and daylight white, where CRI for warm white exceeds 90.

LuxSpot has impressed lighting designers, architects and manufacturers with the quality and quantity of light delivered in a standard narrow flood beam, making it attractive for a broad range of applications such as track and down lights, spot and accent lighting. LuxSpot simplifies lighting fixture design with an easy-to-use, industry-standard interconnect, providing 24 VDC input with optional full dimming functionality. LuxSpot emits no UV or IR light in the beam. Ultra-quiet, fan-less cooling technology keeps LuxSpot cool to the touch all the time. Multiple mounting options provide maximum freedom for mechanical integration in any lighting fixture design.

**Optical Performance Data:**

LuxSpot™ Part Nr.	Color	CCT (K)	CRI	Beam Type	Beam Angle	Lux @ 1m	Lumen (lm)
LS17-002W14	Warm White	3200	80	Narrow Flood	23 °	1500	350
LS17-012W14	Warm White	3200	90	Narrow Flood	23 °	1400	325
LS17-002N14	Neutral White	4100	75	Narrow Flood	23 °	1900	420
LS17-002D14	Daylight White	5500	75	Narrow Flood	23 °	2200	500



LuxSpot mechanical dimensions in mm

"LuxSpot redefines the LED lighting horizon. In LuxSpot we merged longevity, reliability and efficiency of solid-state lighting with the performance, style and compact design of conventional lighting," said Leonard Livschitz, Vice President of Marketing and Business Development at LedEngin.

"LuxSpot delivers true "Lux on Target" meaningful surface brightness required for directional lighting," added Livschitz.

LuxSpot is available since the second half of December 2008. Projected lead-time for production quantities is currently 6 to 8 weeks ARO. ■

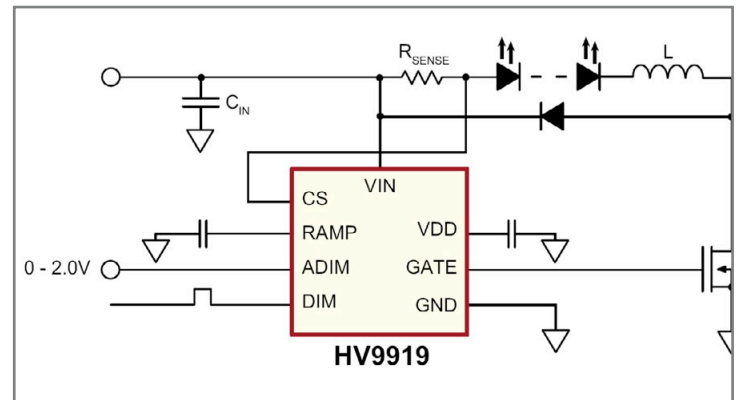
## Highly Efficient Hysteretic LED Driver from Supertex

Supertex, Inc. (NasdaqGS: SUPX) introduced the HV9919, a pulse-width managed (PWM) controller integrated circuit (IC) designed to drive LEDs using a buck topology. It is well suited for a variety of solidstate lighting applications, such as: industrial, architectural, signage, or decorative lighting; indicator or emergency lighting; and as a general purpose constant current source.

The HV9919's hysteretic control function maintains its output current between a fixed minimum and maximum level at all times, ensuring that the LED current will not change, despite surges in the input conditions. Built-in PWM circuitry in the IC provides true constant color and a high dimming range. Its dimming frequency can be programmed with a single capacitor.

"Supertex's HV9919 uses high-side current sensing and hysteretic control to accurately regulate output current, ensuring consistency and prolonging LED life," states Ahmed Masood, Vice President of Marketing at Supertex. "Switching frequency of up to 2.0 MHz permits the use of

only small inductors and capacitors in circuit design, thereby minimizing space and cost in the overall system and making it ideal for solidstate lighting applications with space constraints and lower voltage requirements."



Typical application circuit

**Applications:**

- Low voltage industrial and architectural lighting
- General purpose constant current source
- Signage and decorative LED lighting
- Indicator and emergency lighting

**Features:**

- Hysteretic control with high-side current sensing
- Wide input voltage range: 4.5 to 40V
- >90% Efficiency
- Typical  $\pm 5\%$  LED current accuracy
- Up to 2.0MHz switching frequency
- Adjustable constant LED current
- Analog or PWM control signal for PWM dimming
- Over-temperature protection
- $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  operating temperature range

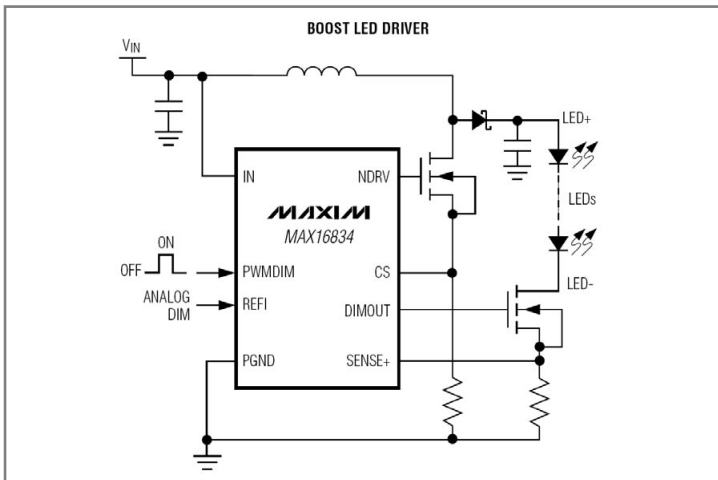
HV9919 is available in an 8-lead DFN package (HV9919K7-G). It is Green and RoHS compliant. Samples are available from stock. Lead-time for production quantities is 4-6 weeks ARO. Pricing is US\$0.55 each for HV9919K7-G in 1K quantities. ■

## Maxim's New Highly Efficient, HB LED Driver

Maxim Integrated Products (NASDAQ: MXIM) introduces the MAX16834, a current-mode, high-brightness LED (HB LED) driver for boost, buck-boost, SEPIC, and high-side buck topologies. This device is designed to reduce the size, complexity, and cost of solid-state lighting (SSL) designs such as MR16 spotlights, thus simplifying the implementation of green lighting technology. Towards this end, it integrates a high-side, current-sense amplifier; a PWM-dimming MOSFET driver; and robust protection circuitry. The MAX16834 is ideal for applications such as LED automotive exterior lighting, LCD backlighting, and architectural lighting.

**Main Features:**

- Wide input operating voltage range (4.75V to 28V)
- 3000:1 PWM dimming
- Analog dimming
- Integrated PWM dimming MOSFET driver
- Integrated high-side current-sense amplifier for LED current sense in buck-boost converter
- 100kHz to 1MHz programmable high-frequency operation
- External clock synchronization input
- Programmable UVLO
- Internal 7V low-dropout regulator
- Fault output (FLT) for overvoltage, overcurrent, thermal warning faults
- Programmable True Differential Overvoltage Protection



Typical simplified application circuit for a boost converter

The MAX16834's comprehensive feature set enables the implementation of boost or buck-boost DC-DC converters with minimal external components. In addition to driving an n-channel power MOSFET with the switching controller, the MAX16834 drives an n-channel PWM-dimming switch to achieve a wide, 3000:1 PWM-dimming range. To further enhance design flexibility, the device offers analog dimming that allows the LED current to be controlled by an external DC voltage. The built-in, high-voltage current-sense amplifier and up to 1MHz switching frequency allow designs to be optimized in terms of efficiency and size.

The MAX16834 integrates protection circuitry to ensure reliable operation in rugged environments. The driver provides analog thermal-foldback protection to allow the use of an external thermistor (NTC) to reduce the LED current when the temperature of the LED string exceeds a specified temperature point. Additionally, it includes a fault-output flag for overvoltage, overcurrent, and thermal warning faults, while its programmable, true-differential overvoltage protection meets stringent automotive requirements for LED lighting and display backlighting.

MAX16834 features a proprietary (patent pending) solution that provides excellent (> 92%) input power factor correction without the need for an additional PFC controller. This feature, together with thermal-foldback protection and low cost, makes this HB LED driver ideal for MR16 spotlights and similar applications powered from AC voltage sources.

This LED driver is fully specified over the -40 degrees Celsius to +125 degrees Celsius automotive temperature range and is available in a thermally enhanced, 4mm x 4mm, 20-pin TQFN package with exposed paddle. Prices start at \$1.24 (1000-up, FOB USA). ■

## NEC: 8-bit Microcontroller Lineup for Lighting

NEC Electronics Corporation (TSE:6723) began shipment of 14 new 8-bit All Flash® MCUs for energy-efficient lighting applications, in December 2008. Designed specifically for fluorescent and LED lighting devices requiring low cost, high efficiency and intelligent control, The extremely low-power-consuming 78K0/Ix2 devices stand apart from the competition by having two unique 16-bit timers with high-speed pulse-modulation (PWM) output, three channels of internal comparators, a one-channel operational amplifier with programmable gains and an extended operating temperature range of -40 to +105 degrees Celsius.

NEC Electronics' 78K0/Ix2 MCUs are well positioned to take on the challenges of controlling fluorescent and LED-based lighting systems by offering outstanding features in a single chip.

**Extended operating temperature range** - the new devices are qualified for an extended temperature range from -40 to +105 & 176;C, exceeding the extreme ambient temperatures demanded by lighting devices.

**Inverter and LED dimming control function** - two 16-bit PWM timers and a built-in high-speed oscillator that drives the timers at a maximum clock speed of 40 megahertz (MHz) enable fine-grained inverter control. These timers, each capable of two outputs, make it possible for the MCUs to drive four-channel LEDs with precise dimming and color control.

**Instantaneous control of PWM timer output** - built-in comparators with outputs linked to the PWM timer automatically detect abnormal conditions, such as over-current and over-voltage conditions, and immediately shut down PWM output—without CPU intervention—providing much faster protection against damage than an interrupt-based mechanism.

**Internal power factor correction (PFC) control** - an external interrupt and built-in comparators linked to the 16-bit timers along with the high-performance 78K0 core and hardware multiplier eliminate the need for a dedicated PFC control IC and thereby reduce system costs and space.

**Best-in-class low power consumption** - the new 8-bit devices consume only 0.3 micro-amps (µA) during standby operation and 260 µA during operation at 1 MHz, which helps reduce system standby power consumption to meet energy efficient regulations.

**Built-in inter-lighting communications peripheral** - a dedicated circuit, including a Manchester encoder/decoder in the digital addressable lighting interface (DALI)-compliant UART, enables lighting control for multiple networked lighting devices.

All in all, these new MCUs with dimming functionality are ideal for lighting equipment products, the market for which is growing as a result of increased awareness of the need for energy efficiency. ■

## Ultra Wide Angle LED Optic

Future Lighting Solutions announced the availability of Carclo Technical Plastics' Ultra Wide Angle Optic, the first off-the-shelf optic for LED lighting applications requiring uniform illumination over a wide area. The new optic will be available in both 120° and 130° beams and is suitable for low bay lighting, emergency lighting, parking facility illumination, street lighting and other applications with wide-beam and high uniformity needs.



Carclo's "bubble optic"

Carclo's 'bubble optic' – so-called because of its hemispherical outer shape – works by re-mapping the light output from the LED to spread the beam evenly across the entire field. The 120° optic, available now, will evenly illuminate an area 26 feet (8m) in diameter when mounted at a height of 8 feet (2.5m). The 130° optic, available in Q1 2009, mounted at the same height will evenly illuminate an area 33 feet (10m) in diameter.

Both models come in a one-piece design for the LUXEON® Rebel and add-on holders for LUXEON® K2 will be introduced Q1 2009. They operate at greater than 90% efficiency, are manufactured in optical grade polycarbonate with UL certification, and are suitable for continuous operation up to 120° C.

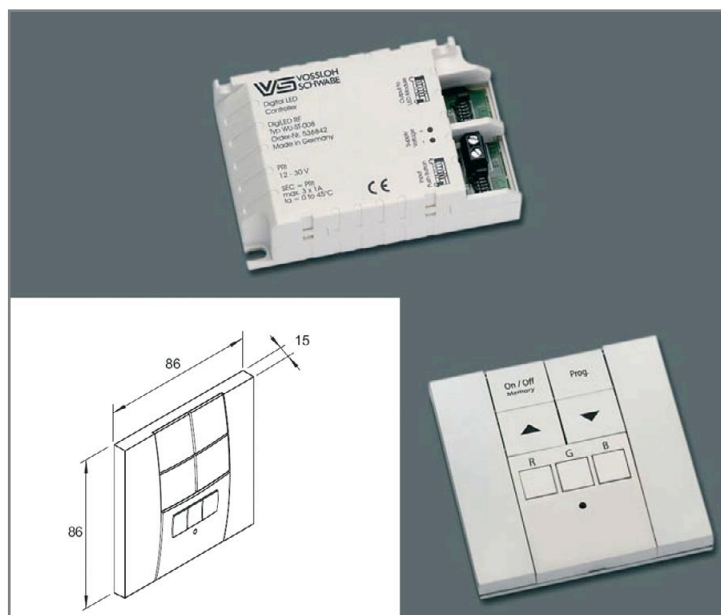
"Until now, LED luminaire designers who needed to illuminate a wide area had only two choices for optics: use standard collimators or reflectors and simply accept that light output would fall off at the edges of the field, or build a custom optic with associated time and tooling expenses," said François Mirand, European Technical Manager of Future Lighting Solutions. "Carclo's Ultra Wide Angle Optic fills the void and furthers our goal of simplifying LED application development through a combination of solutions and services."

"Our new Ultra Wide Angle Optic provides much-needed optical support for one of the fastest growing segments of the LED lighting market," said Jim O'Connor, Business Development Manager for Carclo USA. "Now designers can achieve uniform light distribution over a wide area with a standard optic for the first time."

Samples of Carclo's 120° Ultra Wide Angle Optic (part #10403) are available immediately from Future Lighting Solutions. ■

## Vossloh-Schwabe: New Colour Control Module DigiLED RF

Using a wireless remote control to address Vossloh-Schwabe DigiLED RF units opens up new opportunities for LED installations. Now, systems featuring DigiLED RF and transmitters can be operated without having to ensure direct 'line of sight' between the individual units. This highly convenient remote device comes with a 7-key control pad.



DigiLED RF system consisting of controller and wall transmitter

The following functions can be called up using DigiLED RF:

- Independent control of individual channel brightness (RGB),
- Retrieval and storage of individual colour values,
- Three different colour sequences (RGB colour sequence, colour sequence with shades of warm white, colour sequence with shades of cool white)
- Adjustment of colour sequence speeds. Should the DigiLED RF unit be disconnected from and then reconnected to the mains, the unit will restart with the last-stored colour.

DigiLED RF units are designed to enable pre-programmed colour sequence control of LED modules. Whether enabling independent brightness control of red, green and blue light is wanted, call up or storing an individual colour value, running one of three pre-programmed colour sequences, or adjusting the speed of a colour sequence, Vossloh-Schwabe's DigiLED RF unit offers outstanding ease of use for RGB applications. ■

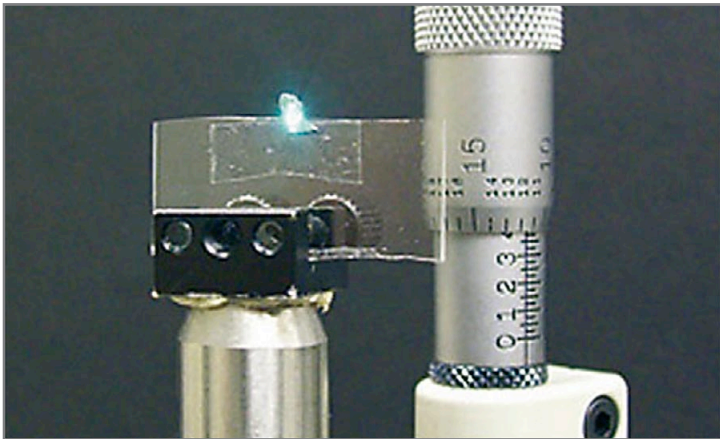
## Research News

### Bright White Light Coaxed from Unexpected Source

Duke University and United States Army scientists have found that a cheap and nontoxic sunburn and diaper rash preventative can be made to produce brilliant light best suited to the human eye.

Duke adjunct physics professor Henry Everitt, chemistry professor Jie Liu and their graduate student John Foreman have discovered that adding sulfur to ultra-fine powders of commonplace zinc oxide at about 1,000 degrees centigrade allows the preparation to convert invisible ultraviolet light into a remarkably bright and natural form of white light.

They are now probing the solid state chemistry and physics of various combinations of those ingredients to deduce an optimal design for a new kind of illumination. Everitt and Liu have applied for a patent on using the preparations as a light source. "Our target would be to help make solid state lighting with better characteristics than current fluorescent ones," said Everitt, who also works with Foreman at the Army's Redstone Arsenal in Huntsville, Ala.



*'Doped' zinc oxide 'phosphor' converts ultraviolet to visible white light*

The researchers said they are producing white light centered in the green part of the spectrum by forming the sulfur-doped preparation into a material called a phosphor. The phosphor converts the excited frequencies from an ultraviolet light emitting diode (LED) into glowing white light.

Nanometer-diameter zinc oxide powders are being prepared by Liu's research group, which focuses on the chemistry of nanomaterials. He is Duke's Jerry G. and Patricia Crawford Hubbard Professor of Chemistry. They are then being tested at the Aviation and Missile Research, Development and Engineering Center at Redstone Arsenal by Everitt, an Army senior research scientist, and Foreman, an Army research physicist.

The researchers are also exploring using electricity alone to trigger the visible emissions without need for an ultraviolet light trigger.

The Army has selected the project for priority funding through a competitive in-house Laboratory Independent Research program because of its potential advantages as an energy efficient and safe illumination source.

"One of the objectives is to give soldiers efficient lighting that doesn't run their batteries down," Everitt said. "They need efficiency, brightness, longevity and ruggedness, and this helps with all of those things."

Existing commercial LEDs are already rugged enough to be used in bumper-mounted brake lights, Everitt said.

"They are good enough for decoration and for use in traffic lights, but they don't make good reading lights because they are not of a white color that our eyes use best," Liu said. White LEDs on the market now are costly, short-lived and not truly white, the researchers added.

A compound that can be used on faces or babies' bottoms also has major safety advantages over fluorescent bulbs, which happen to contain toxic mercury. "If a fluorescent bulb gets broken in the course of battle, it exposes soldiers to that mercury in addition to its shattered glass," Everitt said.

"I think the biggest payoff for the general public will ultimately be in future energy crises we're certainly going to face," Everitt added. "If we can have more efficient lighting it will reduce our energy requirements."

Scientists have long known that zinc oxide can itself serve as a solid state ultraviolet light source. They have also known that adding sulfur allows it to emit some white light. But Liu, Everitt and Foreman are investigating how nanostructuring and doping improves its performance.

The introduced sulfur is thought to boost wavelength conversions from ultraviolet to visible wavelengths by serving as an "impurity" that changes the chemistry and physics of the zinc oxide in ways the Duke researchers are still probing.

Most scientists consider such impurities "defects" that interfere with zinc oxide's ability to produce a stronger ultraviolet light, they said. But "we love the defects that other people hate," Everitt said. "That's been the gift of nanostructured doped zinc oxide, emitting what your eye expects white light to look like."

In a report published May 10, 2006, in the research journal *Nano Letters*, Foreman, Everitt, Liu and co-researchers first disclosed they could induce a formulation of zinc oxide shaped into nanowires to absorb light from an ultraviolet laser and re-emit it as a "broadband visible emission of unprecedented brightness." The white light component was more than 1,000 times brighter than the ultraviolet component, they reported.

In a follow up report, published July 2, 2007, in the journal *Applied Physics Letters*, the Duke researchers initiated what they expect to be a series of published papers exploring how various alterations affect the white light emissions.

"We've learned something about what makes the white light conversion happen, and what makes it happen so efficiently," Everitt said. The Duke team has already achieved efficiencies as high as 80 percent. But there are still technical issues to resolve tied to the operating temperatures of the phosphors and the power from the underlying ultraviolet LED.

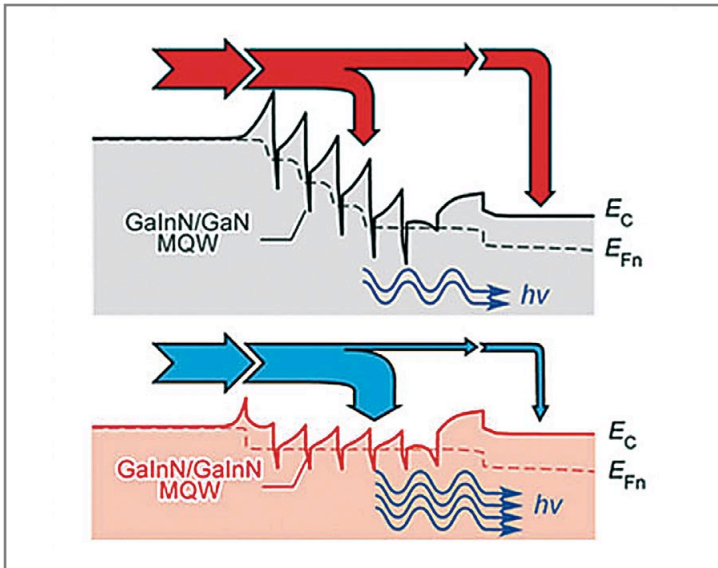
"Our challenge has been getting a foundational understanding so we can understand what is physically possible and how close we are to achieving it," Everitt said.

Zinc oxide would be both a less-toxic and cheaper light source than the combinations used in today's commercial LEDs - gallium nitride and cerium-doped yttrium oxide, they said. Cerium-doped yttrium oxide is also used in today's mercury-containing fluorescent bulbs, Everitt added.

Liu's lab originally stumbled on to the light emitting potential of sulfur-doped zinc oxide while studying its electronic conductivity. "We just lit it up with an ultraviolet laser and -- whammo -- there was a lot of white light coming out," Everitt said. ■

## Smart Lighting: New LED Drops the "Droop"

The new polarization-matched LED, developed in collaboration with Samsung Electro-Mechanics, exhibits an 18% increase in light output and a 22% increase in wall-plug efficiency, which essentially measures the amount of electricity the LED converts into light.



Band diagram of conventional GaInN/GaN active region and new polarization-matched GaInN/GaN active region of a light-emitting diode

The new device achieves a notable reduction in "efficiency droop," a well-known phenomenon that provokes LEDs to be most efficient when receiving low-density currents of electricity, but then to lose efficiency as higher density currents of electricity are fed into the device. The cause of this droop is not yet fully understood, but studies have shown that electron leakage is likely a large part of the problem.

"This droop is under the spotlight since today's high-brightness LEDs are operated at current densities far beyond where efficiency peaks," said project leader E. Fred Schubert, Wellfleet Senior Constellation Professor of Future Chips at Rensselaer, and head of the university's National Science Foundation-funded Smart Lighting Engineering Research Center.

"This challenge has been a stumbling block, because reducing the current densities to values where LEDs are more efficient is unacceptable. Our new LED, however, which has a radically re-designed active region, namely a polarization-matched active region, tackles this issue and brings LEDs closer to being able to operate efficiently at high current densities," Schubert said.

Results of the study are explained in a paper published online by Applied Physics Letters.

Focusing on the active region of LEDs where the light is generated, Schubert's team discovered the region contained materials with mismatched polarization. The polarization mismatch likely causes electron leakage, and therefore a loss of efficiency, Schubert said.

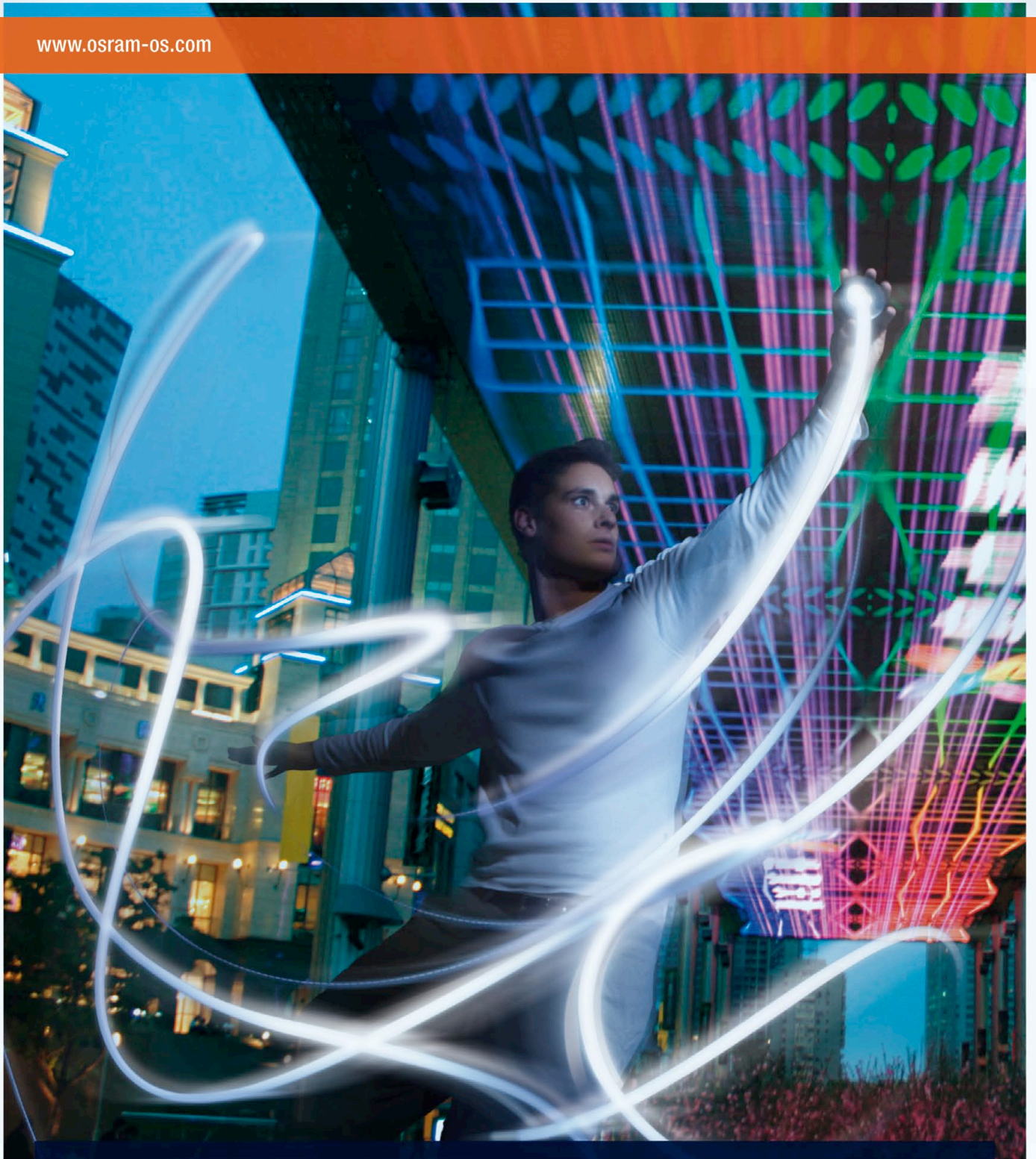
The researchers discovered that the polarization mismatch can be strongly reduced by introducing a new quantum-barrier design. They replaced the conventional Gallium Indium Nitride/Gallium Nitride (GaInN/GaN) layer of the LED active region, and replaced it with Gallium Indium Nitride/Gallium Indium Nitride (GaInN/GaN). This substitution allows the layers of the active region to have a better matched polarization and, in turn, reduce both electron leakage and efficiency droop.

The benefits seen by testing the new GaInN/GaN LED were consistent with theoretical simulations showing polarization matching reducing electron leakage and efficiency droop.

Schubert expects that a new wave of lighting devices based on LEDs and solid-state lighting will supplant the common light bulb in coming years, leading to vast environmental, energy, and cost benefits as well as innovations in healthcare, transportation systems, digital displays, and computer networking.

Along with Schubert, co-authors on the paper include Rensselaer physics, Future Chips, and electrical engineering graduate students Jiuru Xu, Martin F. Schubert, and Ahmed N. Noemaun; Rensselaer Future Chips research assistant Di Zhu; Jong Kyu Kim, research assistant professor of electrical, computer, and systems engineering at Rensselaer; along with Samsung Electro-Mechanics researchers Min Ho Kim, Hun Jae Chung, Sukho Yoon, Cheolsoo Sone, and Yongjo Park.

Funding for the project was contributed by Samsung Electro-Mechanics, the U.S. National Science Foundation, the Rensselaer Smart Lighting Engineering Research Center, Sandia National Laboratories, Rochester Institute of Technology, U.S. Department of Energy, U.S. Department of Defense, Magnolia Optics, Crystal IS, Troy Research Corporation, and New York State. ■



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# Characterization

## Defining Lighting Class LEDs

> Ralph Buehler, Vice President EMEA, Cree Inc.

Lighting is an integral part of human life. Seldom does anyone reflect on the lighting technology used in buildings, homes and open spaces, apart from the companies that are actually producing incandescent light bulbs, compact fluorescent lamps or LEDs. In general conversations about lighting, the first thing that springs into everybody's mind is incandescent light bulbs, which are still heavily used worldwide. However, not a lot of people realize that light bulb technology is more than 100 years old – for the technology industry as a whole this is an almost unbelievably long time span. Apart from the fact, that ancient technology is used to illuminate parking lots, office buildings and private homes, energy costs are rising at an ever-increasing speed. This entices people to look for energy-conserving solutions or at least those that do not use the majority of their power consumption for heating instead of lighting, as incandescent light bulbs do.

According to a study called "European Energy Efficient Lighting Market", conducted by Frost & Sullivan in February 2008, this aspect will continue to grow in years to come. Not only has the European Union just instituted a ban for incandescent light bulbs and stipulated the phasing them out of production from 2009 onwards, but more and more companies are implementing "Green IT" solutions elsewhere and are subsequently also changing their lighting to more environmentally friendly and energy-efficient solutions. One of these new lighting solutions is LEDs (Light Emitting Diodes). While the use of LEDs for indicators in consumer electronics is well known and their use in automotive lighting is gaining acceptance rapidly, the use of LEDs for general illumination is still relatively new. The rapid pace of innovation in LED technology is simply unprecedented in the lighting industry, enabling lighting-class LEDs to replace incumbent incandescent bulbs.

However, how can lighting installation companies and users be sure that they are getting a quality product that delivers on the promises of LED lighting in terms of brightness, longevity and energy efficiency? Since there are no industry standards for LEDs as yet, the US-based company Cree has developed some indicators which the LED specialist deems to be important when companies, government bodies or public institutions are investing in replacing their incandescent light bulbs by LED lighting. This categorization is called "lighting class LEDs" and emphasizes four factors which should be taken into consideration when deciding on a possible LED solution: luminous flux, efficacy, quality of light, and reliability.

## Lighting-Class LEDs in General Illumination

Today's LED light systems can save money through energy savings and maintenance avoidance. The growing supply of high quality LED lighting products, combined with increasing public awareness and demand for energy efficient products, has created a rapidly growing market for LED lighting in general illumination applications. The term "General Illumination" refers to any lighting application where light is needed to make an area useful. One common example of general illumination is the fluorescent troffer in an office building used to light up hallways, lobbies and work areas. Another everyday example is a roadway light that lights up a city road to increase driver safety. General illumination also refers to other less obvious applications, such as the lights that illuminate the meat display case in a grocery store or lights that mount onto mining helmets.

The possibilities of lighting-class LEDs at the moment are mainly in the public and commercial sectors. The reason for this is that the LEDs are still more expensive than conventional solutions and present a hurdle for general consumer adoption. However, as the technology becomes more prevalent and the usage in other areas of life grows, prices will fall and mass-market consumption will grow exponentially. Lighting-class LEDs are the first LEDs that make good on the promise of LEDs are the "light bulb of the future" with benefits of longevity, robustness, and low energy consumption.

## Lighting-Class LEDs

Lighting-Class LEDs are the high power LEDs that have fulfill given minimums of luminous flux (measured in lumens, lm), efficacy (lm/Watt), quality of light (currently identified with a Color Rendering Index, or CRI) and reliability (time in operation before reaching a percentage of original output) to enable the replacement of incumbent lighting sources with LED light. LED lighting has many advantages that are readily apparent, including efficiency by being directional (emitting light only within a certain solid angle, instead of nearly all directions uniformly, as with most light bulbs) without the use of additional optical reflectors or lenses. In addition, lighting-class LEDs can last for at least 50,000 hours under certain conditions and do not contain mercury, as most fluorescent and HID (High Density Discharge) light sources do. However, some benefits to LED light are unique among all light sources, such as reaching full brightness in nanoseconds and having better efficiency in cold temperatures. All of these advantages of LED light have started a revolution in the lighting industry – an industry that is still using technology that is over 100 years old.

The first uses of high power LEDs were primarily in niche applications where no other light source could offer the same combination of light output, durability, efficacy and quality, including decorative color mixing, personal and portable lighting as well as emergency vehicle lighting. The LEDs of this vintage had trouble creating a viable business case for lighting replacement. The main obstacle was the high initial cost of LED luminaires when compared to the traditional ones. An inflection point occurred in October 2006, with the launch of the XLamp



XR-E LED (Figure 1) in cool white (5,000K to 10,000K CCT), the first LED that had high enough performance and long enough lifetime to create total-cost-of-ownership (TCO) savings in outdoor lighting.

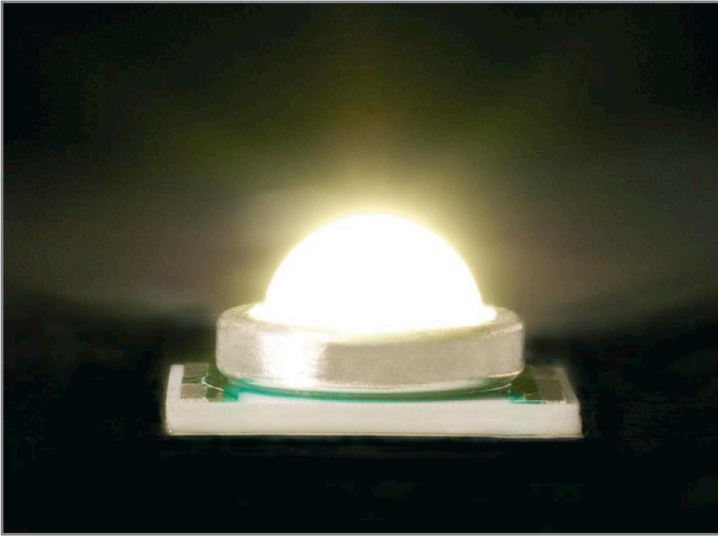


Figure 1: Lighting Class LED example: Cree XLamp XR-E

Six months later, the XLamp XR-E LED in neutral and warm white (2,600K to 5,000K CCT) was launched, a breakthrough enabling similar TCO savings and reduced energy efficiency in many more applications, including indoor lighting and retail display lighting. The area of application in which LEDs could be used not only broadened significantly, but LEDs finally became an alternative source of lighting for a larger audience. They also added social benefits above and

beyond brightness: municipalities lighting parking lots and streets (Figure 2), making people feel safer, restaurants using LEDs for indoor lighting with the added advantage of the food looking much more appetizing or architects and designers using bright LEDs to illuminate their work indoor and outside.

## Adoption of Lighting-Class LEDs

Despite all the advantages of LED light, there is a lingering perception that the high initial cost of LED lighting products will limit their adoption in mainstream lighting applications. While initial cost is an important factor in most consumer-level buying decisions, increasing numbers of lighting buyers are looking beyond initial cost. These include municipalities and power companies that own the majority of outdoor lighting fixtures, as well as business owners that construct factories and office buildings, who are much more likely to examine the total cost of a lighting solution. The total cost does include the initial cost of the fixture, but it also includes many other factors: the cost of the energy used to create light, maintenance costs associated with changing bulbs and cleaning the fixture, and the disposal costs for materials that need servicing over the life of the fixture.

Lighting-class LEDs enable reduction of all other life-cycle costs of lighting to the point where a higher initial cost for LED lighting is more than offset by the cost savings over time. While every lighting application and every LED solution is obviously different, there are three common ways that LED lighting creates value: energy savings, maintenance avoidance and quality of light.

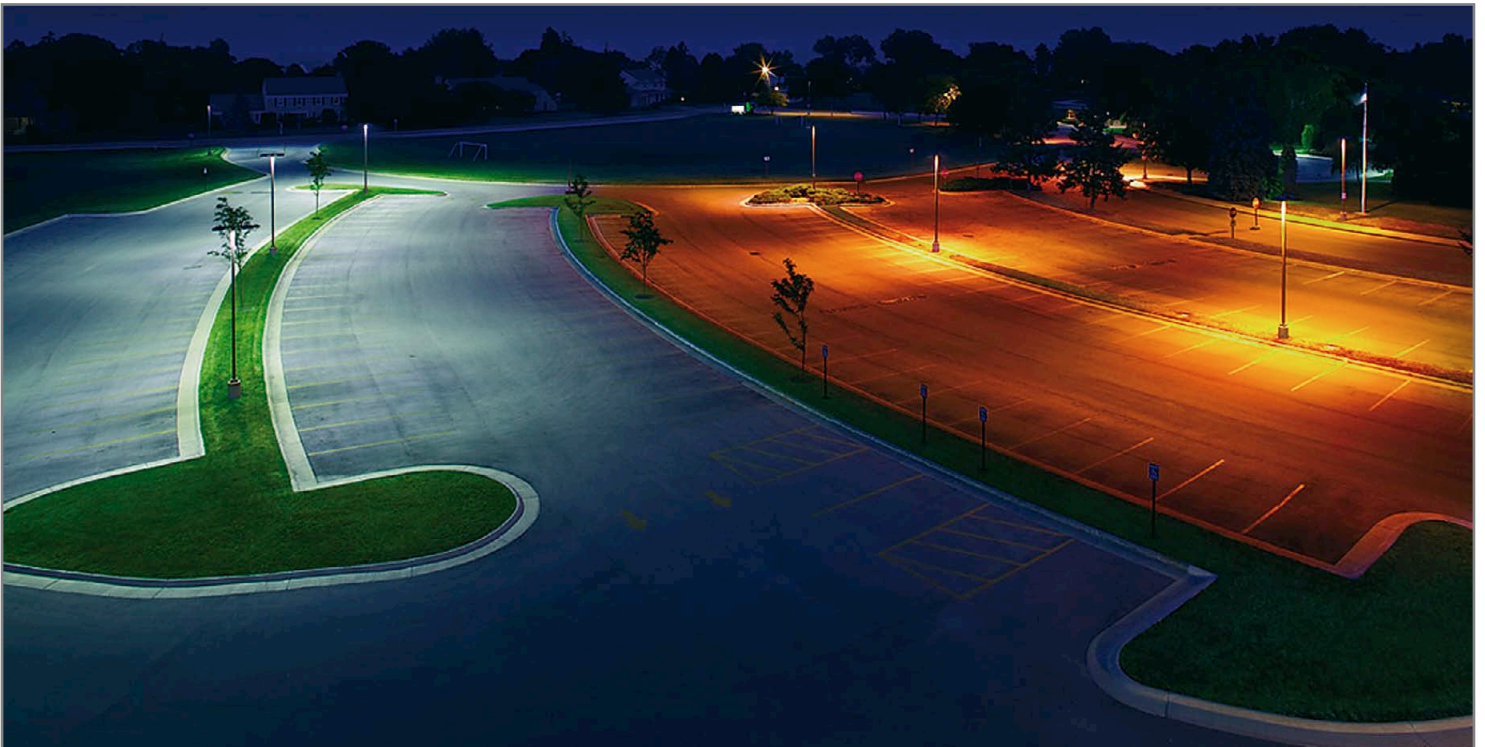


Figure 2: Parking lot with new LED lights (left) and original HPS lamps (right)

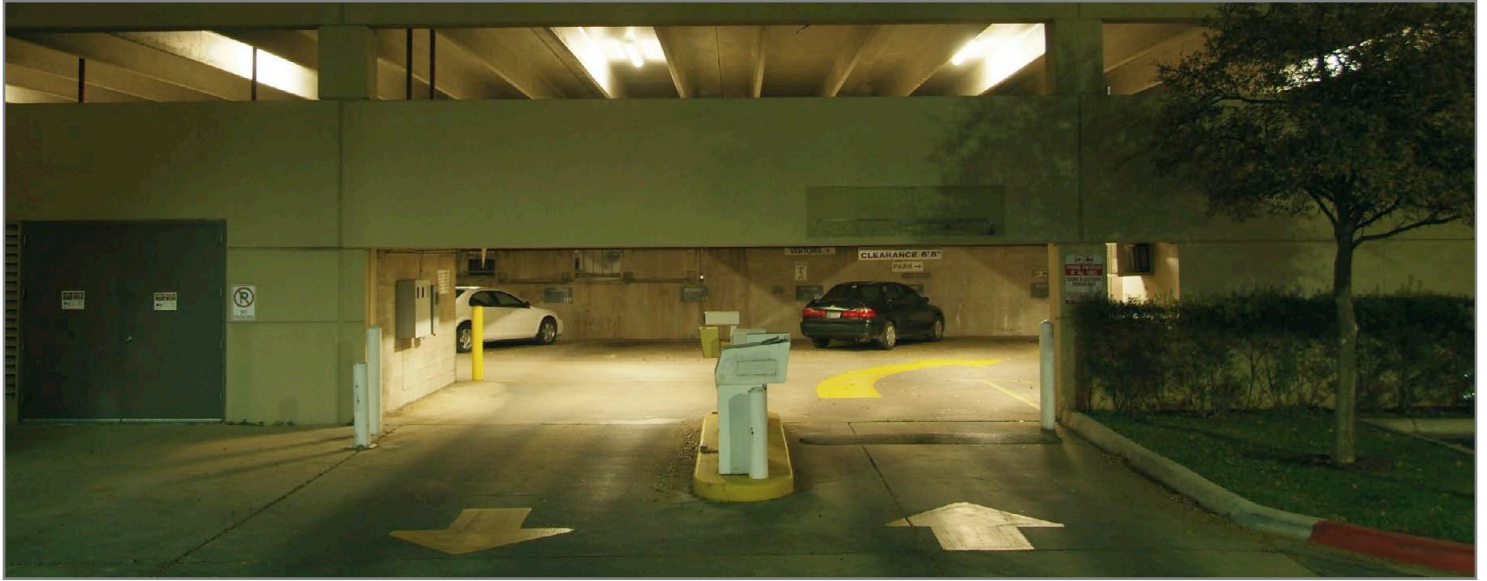


Figure 4: Appearance of Austing parking lot before the LED installation



Figure 5: Appearance of Austin parking lot with LED illumination

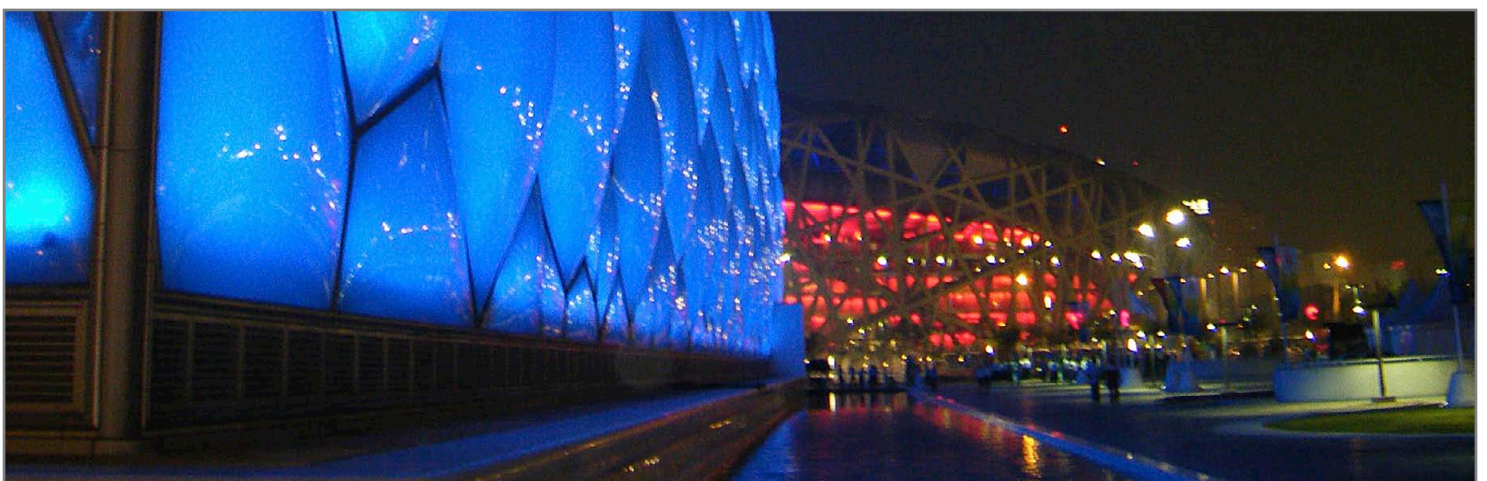


Figure 6: Spectacular coloured architectural illumination of the Beijing Water Cube

## Energy Savings

Lighting-class LEDs create energy savings relative to traditional lighting in two ways. First, LED light is already directional, so the losses associated with using an omni-directional light source with a reflector are greatly reduced. Second, LED light has quickly progressed to become one of the most efficient artificial light sources on the planet. LED lighting systems, like all lighting systems, have the same three basic parts: driver, LED or LED array and fixture. The efficiencies of the driver and fixture are high relative to the LED efficacy and are not likely to change much in the near future. Therefore, the brightness and efficacy of an LED lighting system is driven mainly by the LED itself, and what's more is that the rate at which these attributes of LEDs are changing is unprecedented for the lighting industry.

## Maintenance Avoidance

Maintenance avoidance refers to the TCO savings realized by not having to replace a light bulb. The exact amount saved depends on the application and installed location. While changing the light bulb in a bedroom lamp is relatively easy and inexpensive, the explicit and implicit costs associated with closing a lane of traffic in a tunnel to send a maintenance crew to change the light bulbs is clearly another matter. In many lighting applications, the maintenance costs can quickly become much larger and more important than the initial fixture cost. Lighting-class LEDs do not "burn out" like a traditional light bulb, continuing to produce light for an extremely long time as the amount of light output slowly decreases over operational life. The lumen maintenance of a lighting-class LED is complex and depends on several factors. Yet LED lumen maintenance is temperature dependent: the hotter the LED and its junction temperature are the shorter the lifetime until the LED will reach  $L_{70}$ , or 70 percent of its original output (Figure 3).

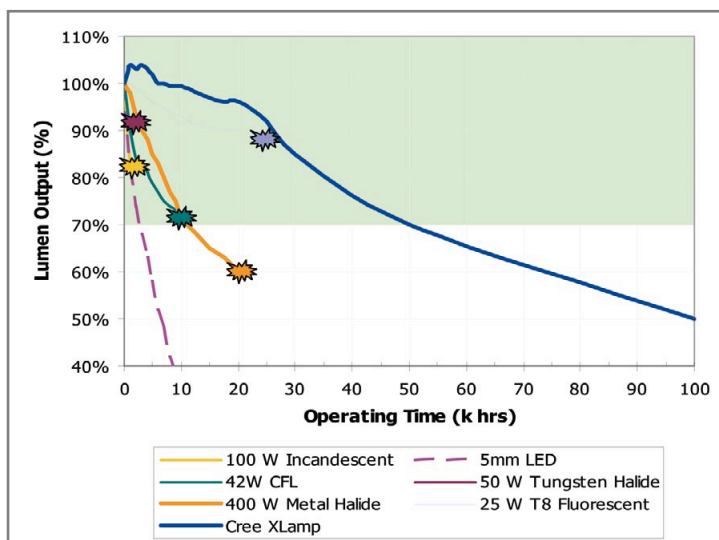


Figure 3: Lifetime  $L_{70}$  of lighting class LEDs in comparison to other light sources

## Quality of Light

In contrast to the semiconductor industry, where metrics and objective measures usually dominate buying decisions, buyers in the lighting industry tend to be more subjective. One concept from the lighting world, quality of light, is generally understood but tends to mean different things to different people. In general, quality of light refers to a combination of factors, including the specific color of light, the uniformity of intensity, the uniformity of color and the ability to properly illuminate specific colors.

In many lighting applications lighting-class LEDs offer another choice to the existing technology. Lighting-class LEDs come in a wide variety of color temperatures, render colors very well, are very small and generally use less power than traditional lights. Designers can use these attributes to create lighting systems in different color temperatures, sizes, light output levels, and power ratings than was possible with any other lighting technology.

## Conclusions

Several countries have either already decided to ban incandescent lighting or are on the verge of doing so – a global trend that cannot be reversed. LEDs are certainly not only there to stay, but the adoption of these lighting solutions will certainly accelerate in the future. With this in mind, LEDs will not only be implemented in a city, college or company environment, but also in private homes. In these surroundings, design-conscious home owners can use LEDs in a variety of creative ways. Still high pricing, which currently the biggest threshold, will continue to fall as implementation rates rise.

Using LED lighting – regardless if in a public or personal environment – has other benefits as well. The lighting is much more directed than incandescent light bulbs, thereby losing less brightness. While still a nascent technology, lighting-class LEDs are already a valid alternative to other lighting technologies as regards the so-called social factor: with parking lots looking brighter with LEDs than any other illumination, people are feeling safer at nights (Figure 4 & 5). In general, outdoor spaces have a more secure and clearer look. On the other hand, architects have more freedom designing spectacular buildings by using color LEDs for outside illumination, as the example of the Beijing Water Cube shows (Figure 6).

Last, but certainly not least, LED lighting can reduce the amount of energy needed to provide a given amount of light and reduces the amount of light bulb waste that must be captured and disposed of properly. All the pieces of the LED lighting puzzle, from the growing public awareness of the impending energy crisis to the rapid development of high quality LED products, come together to show that the LED is going to play a key role in the future of lighting and in the future of energy efficiency all around the world. ■

## Technology

# Jet Dispensing Technology for Capillary Underfiller

> Anton Knupfer, Product Manager, Essentec AG

In Electronic Assembly underfilling is defined as a process where under large and/or sensitive components a layer is inserted, that combines this component flat with the printed circuit board (PCB). Such a procedure is most common for BGA components (Ball Grid Array). The connections of these components, designated as a ball grid array structure, lie under the component (Figure 1). By this design the connections consist of solder balls that later on during the reflow process connects these leads with the PCB. So a high number of leads in a small area is possible.

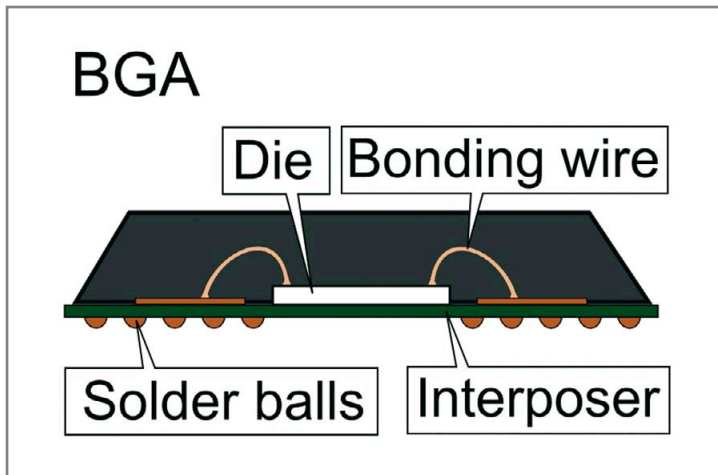


Figure 1: Schematic structure of a BGA with ball-shaped leads

To get a higher mechanical stability and to protect the component against environmental influences after the reflow process a material is inserted under the component. This non-conductive synthetic material furthermore has to show a permanent elasticity. Temperature changes and associated different heat expansions of PCB and component should not produce mechanical tensions that could destroy the component.

## Capillary Effect Produces High Tensile Forces

Nowadays there are three types of underfilling systems. Capillary underfills, no-flow underfills and corner-bond underfills. All three have special fields of operations, but capillary underfills record the largest market share. This system uses the so-called capillary force, drawing the underfiller under the component by itself. This capillary effect for example draws up water a little bit into a straw against gravity. It also enables the writing with a fountain pen. This effect is caused by an adhesion force in the boundary layer between fluid and solid surface.

Many have experienced how strong these forces are with wet microscope glass slides that could not be separated again. One can calculate that a liquid film of 1  $\mu\text{m}$  between two windowpanes causes a pressure of 2.8 bar (28 m water depth).

The capillary effect is used to fill completely the thin space under the BGA component with an underfiller after soldering. The tensile force of the capillary and the flow characteristics depend on many factors. If all parameters are correct, it is enough to apply the underfill material along at one of the two sides of the component. The rest will be done by the capillary force. Simultaneously the material flowing in, displaces all air out of the cavity.

## Dispensing Technology for Underfill

There are different possibilities for depositing a fluid. The mostly used method is dispensing with a dosing needle. The underfill medium was led to the edge of the component (Figure 2). Then the capillary effect draws the fluid into the gap between component and PCB. Precondition is a very small distance between needle and component. The fluid must completely wet the gap to start the capillary effect.

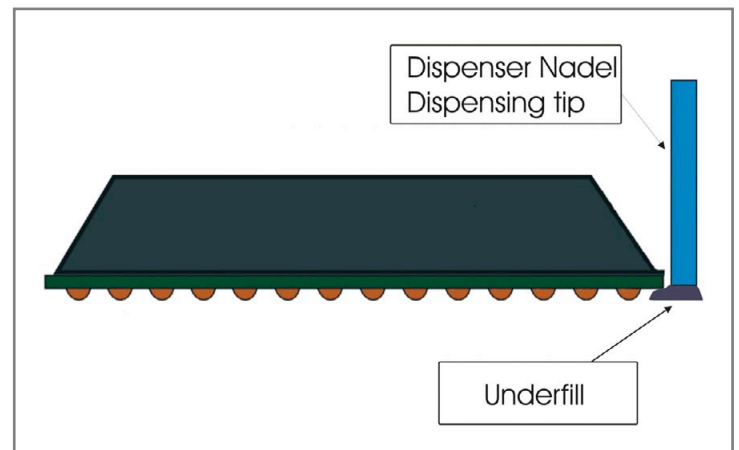


Figure 2: Dispensing underfill material along the edge of a component with a dispensing needle

Getting more and more common and widely spread is dispensing without a dosing needle with the contactless JET technology (Figure 3). Here the liquid medium is ejected as small drops by a pestle that is moving with high speed into a specially formed cylinder. These drops fly with relatively high speed to the PCB surface.

Also a small lateral distance between component and flying drops are very important to initiate the capillary effect that draws the underfill medium under the component. The advantages of this method are obvious. Because there is no dispensing needle the system becomes insensitive against height changes of the components. In this way possible damages of components by the needle are prevented.

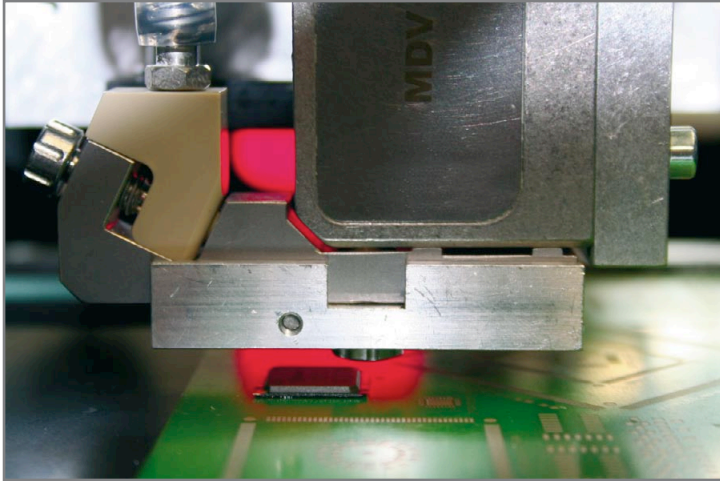


Figure 3: Touch-less Jet dispensing becomes more common

A further advantage of JET technology is that the underfiller can be shot into small gaps. Regarding high integration density this is the only possibility for dispensing the material secure and precise between two components (Figure 4)

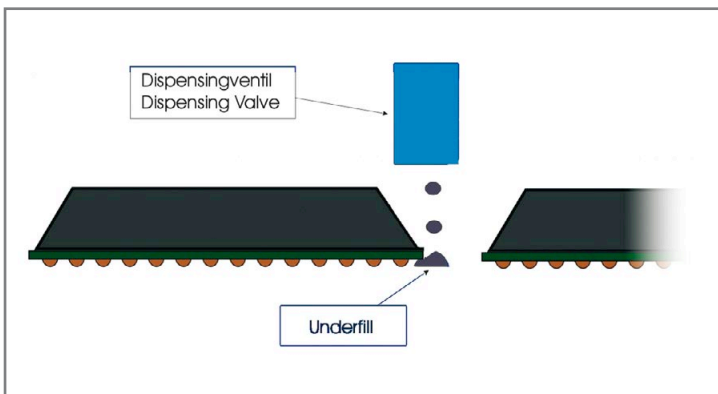


Figure 4: Die Jet dispensing provides high reliability especially for high integrated circuits

## Process Control by Controlling Temperature

The properties of many commercial underfill materials can be controlled via temperature. In production this is used optimizing processes. During the process the PCB is heated up. By controlling the temperature flow characteristics can be accelerated and improved.

To reach a shorter process duration the component will be heated up one step before the dispense position. This is called pre-heating zone. Also after dispensing one finds usually a heating zone, which supports finally the flow characteristics of the underfilling. This heating zone is called post-heating zone.

The simplest form is the contact heating: a heated up metal plate will be pressed at the bottom side of the PCB. Work pieces with components on both sides cannot be heated up by this method. In this case a convection heating with hot circulating air can be used. A third possibility is an infrared heater to warm up complex forms.

## The Positioning

As mentioned above the accuracy of positioning the needle, respectively the landing zone of the drops plays an important role dispensing underfill materials. Especially with products where several components are placed in small distances.

Tolerances in placement and reflow process are normal practice. A dispensing system for the underfill process must be equipped with all kinds of high tech to fit the required accuracy. An exemplary system is the automatic dispensing machine CDS6200 from Essemtec (Figure 5)



Figure 5: An automatic dispensing system with high accuracy and versatile flexibility

The dosing head has an integrated vision system that can exactly determine position and angular position of components. The movement of the dosing head will be adjusted in the way that the underfill material is dispensed perfectly along the edge of the component. Furthermore the dispenser has an integrated surface scanner. This device scans the topography of the PCB in advance and corrects strong height differences automatically. ■



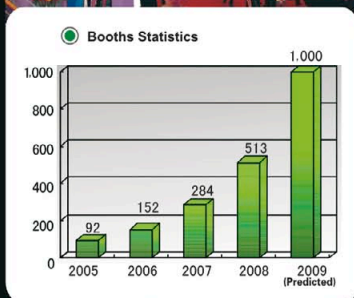
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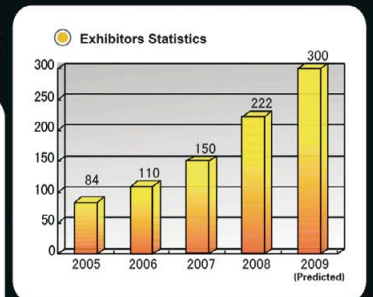
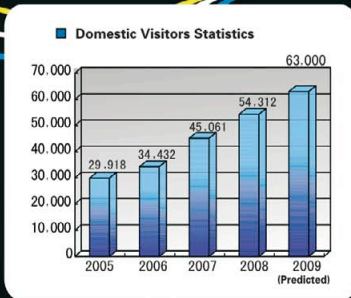
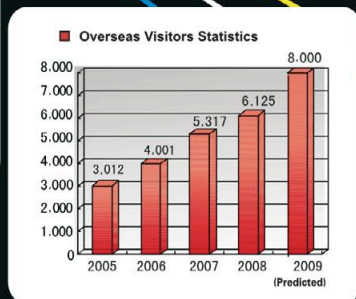
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## Driver

### Off-Line LED Control Circuit

> Tom Ribarich, Director of Lighting Systems and Applications, International Rectifier

Resonant mode topologies offer many benefits over traditional buck, boost and flyback solutions. These include soft-switching, higher operating frequencies, higher power density and higher efficiency. Electronic ballast designs for fluorescent lighting applications have already been taking advantage of these benefits for many decades. Much can be learned from electronic ballast circuits and applied to LED driver circuits. This article compares the load requirements for fluorescent lamps and LEDs, explains the functionality of a new dimming electronic ballast control IC, and describes a new resonant mode control circuit for LEDs that uses the new IC. Experimental results of the new circuit are also presented and summarized to show final performance.

#### Fluorescent vs. LEDs

Fluorescence is the conversion of UV light to visible light. Electrons flow through the fluorescent lamp and collide with mercury atoms causing photons of UV light to be released. The UV light is then converted into visible light as it passes through the phosphor coating on the inside of the glass tube wall. This two-stage conversion process results in about 25% of the total energy consumed by the lamp being used to generate light. A typical fluorescent lamp also has a low lamp running temperature (40degC) and a lifetime of about 10,000 hours. To control a fluorescent lamp, the lamp requires a voltage or current to preheat the filaments, a high-voltage for ignition, and a high-frequency AC current during running.

LEDs work on a completely different principle than fluorescent lamps. Individual electrons jump across a p-n junction (from the n-type region to the p-type) of a semiconductor material. The 'band-gap' in certain semiconductors such as gallium is very wide and requires appreciable energy to make electrons jump across the junction. When each electron recombines with an atom, it emits a particle of light known as a photon. Because all of the light is being produced in a very small space down at the junction, the resulting light source is a point source and requires many LEDs to light a large area. Also, the heat inside an LED cannot be thermally dissipated by the LED itself resulting in high LED working temperatures and therefore requires heatsinking.

LEDs are much simpler to control but still have their own set of requirements and challenges. They do not need to be ignited or preheated but the current should be constant and matched in each LED. Also, depending on the application, the electrical connection to the LEDs may or may not need to be galvanically isolated. The circuit requirements for fluorescent and LED have been summarized for comparison (Table 1).

Load Requirement	Fluorescent	LED
Filament Preheating	Current or Voltage Control	No
Ignition Voltage	1kV	No
Running Control	High-Frequency AC Current	Constant Current
Current Crest Factor (peak/r.m.s.)	1.7	1.42*
Dimming Control	Current Control	PWM On/Off
Isolation	No	Yes/No

Table 1: Load requirement summary for fluorescent and LED

#### IRS2530D "DIM8™" Control IC

Existing ballast non-dimming circuits include (Figure 1) an input filter for blocking ballast generated noise, a rectifier and smoothing capacitor for converting the AC line input into a DC bus voltage, a control IC and half-bridge for producing a high-frequency square-wave voltage, and a resonant output stage for preheating, igniting and running the fluorescent lamp. The additional circuitry needed for dimming includes (Figure 1) an isolated 0-to-10VDC dimming interface, a current-sensing circuit to measure the lamp current, and a closed-loop feedback circuit to keep the lamp current regulated to the user setting by continuously adjusting the output frequency. A closed-loop system is needed to regulate the lamp current due to the non-linear electrical characteristics of the fluorescent lamp.

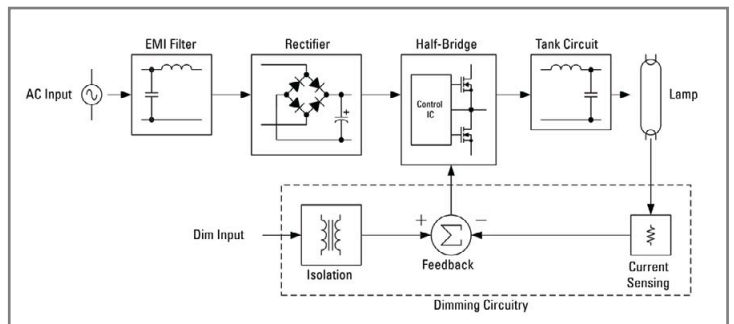


Figure 1: Fluorescent dimming ballast block diagram

The IRS2530D (Figure 2) is a 600V, 8-pin fluorescent dimming control IC that provides the high- and low-side gate drive for the half-bridge, includes all of the dimming ballast functions, and protects the circuit against line and load fault conditions. The IC already uses 6 pins for very basic but necessary functions: IC supply and ground (VCC, COM), and, half-bridge high- and low-side gate drive (VB, HO, VS, LO). The challenge is then to realize the other functions -- preheat, ignition and dimming - with only two remaining pins (VCO, DIM).

#### Annotation:

\*Philips LumiLeds 700mA Luxeon V Emitter, green/cyan/blue/royal blue, Absolute Maximum Ratings, (peak pulsed forward current)/(average forward current).

IRS2530D or reference design kits: [www.irf.com](http://www.irf.com).

Name	No.	Description
VCC	1	IC supply voltage input
COM	2	IC supply ground return
DIM	3	AC + DC dimming input
VCO	4	Voltage-controlled oscillator (VCO) input
LO	5	Half-bridge low-side gate driver output
VS	6	High voltage floating supply return
HO	7	High-side gate driver output
VB	8	High-side gate driver floating supply

Figure 2: IRS2530D pin assignments and functions

When a voltage is first applied to VCC (14V, typical) the IC exits UVLO mode and enters Preheat/Ignition mode. The half-bridge begins oscillating at the maximum frequency and the internal current source at the VCO pin begins charging up an external capacitor (CVCO) linearly from COM (Figure 3). The output frequency decreases as the VCO voltage increases and the lamp filaments are preheated by secondary windings from the resonant tank inductor. As the VCO voltage charges up, the frequency decreases towards the resonance frequency of the resonant tank circuit and the output voltage across the lamp increases. The lamp ignites when the output voltage exceeds the lamp ignition threshold voltage, lamp current begins to flow, and the IC enters Dim mode.

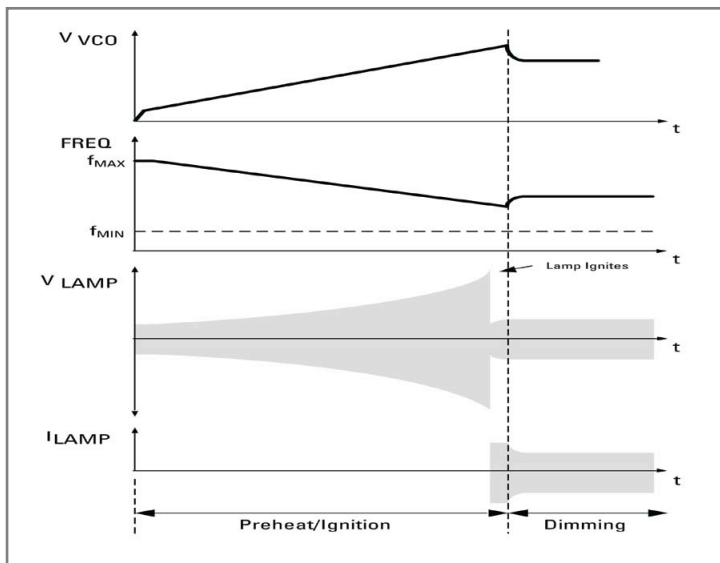


Figure 3: Preheat, ignition and dimming timing diagram

During Dim mode, a current sense resistor (RCS) is used to measure the AC lamp current. This AC measurement is then coupled to the DC reference at the DIM pin through a feedback capacitor (C2). The AC + DC signal at the DIM pin is then compared to COM internally to the IC and the frequency is controlled such that the valleys of the AC component are held at COM continuously (Figure 4). As the DC reference is increased or decreased while the AC valleys are held at COM, the AC lamp current amplitude will then increase or decrease as well. By combining the DC reference with the AC lamp current, a single pin can then be used for both reference and feedback functions to achieve closed-loop dimming control.

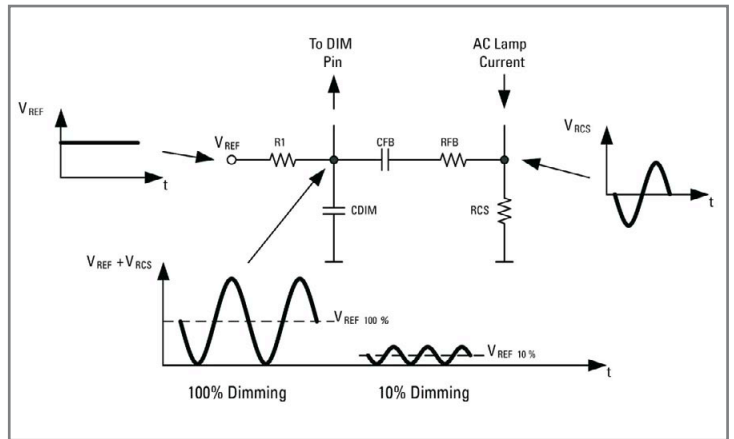


Figure 4: AC + DC dimming control method

## New LED Control Circuit

Typical LED control circuits are designed around a buck, boost or flyback topology, and they are used to generate a constant DC current through a string of a given number of LEDs. Each of these topologies has advantages and disadvantages depending on the input voltage range, the number of LEDs being driven in series, the number of parallel LED strings, the LED output current, if isolation is required, if dimming is required, efficiency, size and cost. For this reason, many circuit variations exist to satisfy the many different LED applications. The new circuit is a resonant mode circuit that has been slightly modified from dimming fluorescent applications. It is for non-isolated, off-line applications, and can drive one or many LEDs in series, can be easily scaled for different LED current levels, and utilizes soft-switching for good efficiency. The new circuit (Figure 5) is designed around the existing IRS2530D Dimming Control IC, and the output stage has been modified to drive LEDs instead of a fluorescent lamp. It is no longer necessary to preheat and ignite the load so the resonant tank has been changed to a series L-C-LED type (instead of a series L, parallel R-C for fluorescent). Since the output current is AC, a full-wave bridge rectifier has been added to the output so that current is always flowing through the LEDs during each high-frequency switching cycle.

The AC current sensing is still performed using a resistor (RCS) that is placed in between the bottom of the rectifier and COM, and gives a direct AC measurement of the full-wave rectified LED current amplitude. This AC measurement is then coupled onto the DIM pin through resistor RFB and capacitor CFB. The dimming control loop of the IRS2530D then keeps the amplitude of the LED current regulated by continuously adjusting the frequency of the half-bridge switching circuit such that the nominal r.m.s. LED current is maintained within the manufacturer's specifications. If the LED current decreases, then the loop decreases the frequency. This will increase the gain of the resonant tank circuit and increase the LED current. If the LED current increases, then the loop increases the frequency. This will decrease the gain of the resonant tank circuit and decrease the LED current. The dimming control loop keeps the LED current constant over line, load and temperature variations, and will work for a single LED or many LEDs in series.



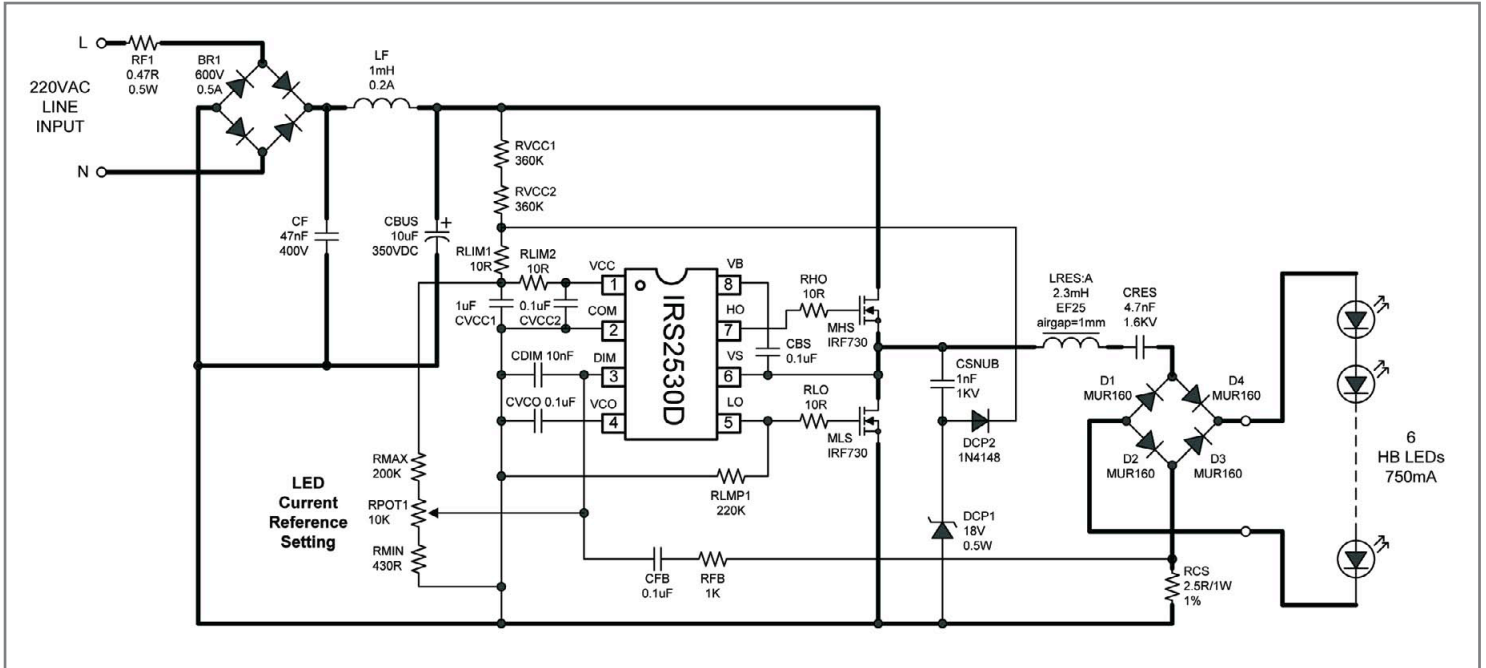


Figure 5: New IRS2530D off-line LED control circuit

## Experimental Results

The experimental results show the waveforms during normal start-up and running conditions (Figures 6 and 7). When the AC line voltage is first applied, VCC charges up and the IC turns on. The output frequency starts at the maximum frequency of the IC and sweeps down towards the resonant frequency of the series L-C-LED resonant circuit. The frequency sweep is performed by the capacitor CVCO at the VCO pin. The LED current (sensed through resistor RCS) increases as the frequency decreases. This causes the amplitude of the AC signal at the DIM pin to

also increase until the valley of the AC signal reaches COM (Figure 6). The IC then enters Dim mode and enables the dimming loop. The dimming loop continuously adjusts the output frequency to keep valley of the AC signal at the DIM pin maintained at COM and therefore maintains a constant LED current amplitude. The LED current (Figure 7) is full-wave rectified and operates at twice the frequency of the half-bridge switching node (VS pin). The shape of the LED current waveform is sinusoidal due to the resonant behavior of the circuit. This helps keep the current crest factor low so that the nominal LED r.m.s. current is achieved without excessive peak currents.

## Housing machine RAH

This machine is designed as a fully automatic assembly process for mounting LED's into a plastic housing. The housing and LED's are conveyed as bulk material via a hopper system into bowl feeders.

Handling systems positioned around an index table take care of such operations as bending, cutting, electrical check and measuring of the component via a camera system. The index table is driven by a servo motor which ensures precision by every step of the index table.

Before LED's can be assembled with the housing they are singulated into a comb conveyor, which carries out a polarity test and in accordance with customer specifications the LED's are turned within the comb conveyor so all LED's are in the correct position or is rejected as non-suitable part, the polarity can be switched over. Te completely mounted and testet components are ejected into a bin box.

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The IRS2530D also includes additional circuitry for protection against all line and load fault conditions. These include AC mains brown-out, open circuit (no load or LED failure) and short circuit fault conditions.

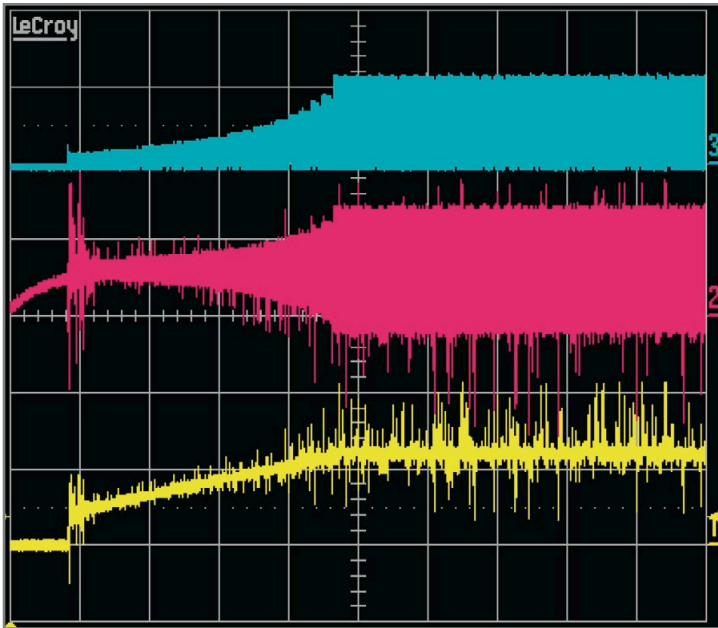


Figure 6: LED current (upper, 1A/div), DIM pin voltage (middle, 1V/div), and VCO pin voltage (lower, 2V/div) during start-up. Time scale = 50msec/div

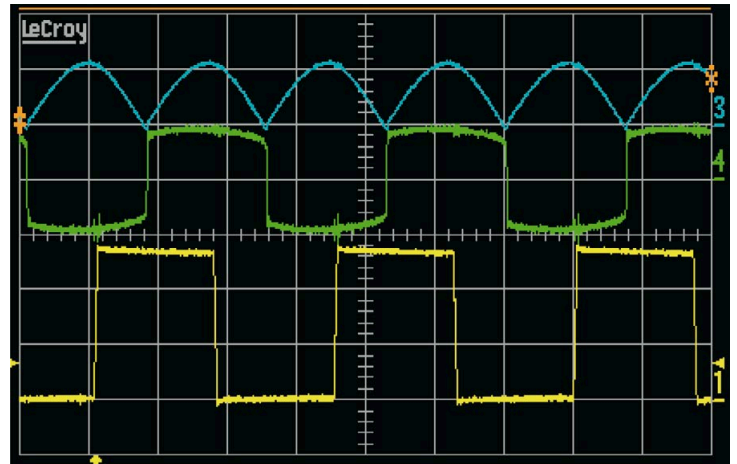


Figure 7: LED current (upper, 1A/div), D4:A - D3:A bridge rectifier voltage (middle, 25V/div), and VS pin voltage (lower, 100V/div) during running. Time scale = 5usec/div

### Conclusion

The new off-line LED control circuit is simple and provides good constant current regulation for the LEDs. It is easily scalable for different input voltage ranges and LED current levels, and is flexible to the number of LEDs connected at the output. The IRS2530D successfully drives circuit for both fluorescent and LED applications. The IC integrates the complete control in a low-cost, 8-pin solution, and the control loop delivers good constant current performance over all line and load conditions, and the IC detects all fault conditions and deactivates the circuit safely. Additional circuit improvements to be considered include PWM on/off dimming of the LEDs. ■



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# Current Uniformity for LED Display Drivers

> Frank Shih, Technical Marketing Engineer, Macroblock

LED panels can be seen almost everywhere from shopping malls, stadiums, to highways. With a variety of applications, LED display manufacturers are facing severe competition and challenges on the image quality of LED panels. The fundamental problem that influences the image quality of LED panels is the uniformity of LED panels. This article will address more in details on how to select the right LED drivers to improve the uniformity of LED panels.

## Selecting LED Drivers with Good Output Current Uniformity

One of the most important factors that may influence the image quality of LED panels is the uniformity of the LED panels. However, the uniformity of LED panels is decided by two factors:

- the brightness uniformity of LEDs
- the output current uniformity of LED drivers

The most common way to get a better brightness uniformity of LEDs is to pick LEDs from tighter bins to reduce the variations during LED manufacturing process. However, binning is a time consuming and costly process, and the tighter bins the more expensive it is to do the binning. By choosing LED drivers with good current uniformity, users are more flexible to select LEDs from more bins to save the cost of LEDs. For example, the total cost of a 100m<sup>2</sup>, P20 display will be reduced by US\$12,500 if the LED cost could be saved up to 10%.

Display Size (m2)	Pitch (mm)	Numbers of LED (pcs)	Cost of LED (SMD 3 in 1) (USD)	Cost Saving (USD)	Cost Saving Percentage (%)
100	20	250,000	0.5	\$12,500	10%

Table 1: Cost reduction by a clever LED driver design

Therefore, a cost effective way to achieve better uniformity of LED panels is to select LED drivers with good output current uniformity.

For LEDs are current dependant devices, the output current ( $I_{OUT}$ ) uniformity of LED drivers is regarded as a key factor to calibrate the brightness of LED and to achieve better uniformity of LED panels. This is why LED driver vendors are dedicated to the continuous improvement on the output current uniformity.

Four characteristics determine the output current uniformity, including the well-known "channel skew", "chip skew", the supply voltage regulation (also called "line regulation"), and the output voltage regulation (also called "load regulation"). The following paragraphs detail the importance of these characteristics.

## Channel Skew and Chip Skew

Channel skew is the percentage of output current variation between different channels of the same LED driver, and chip skew is the percentage of output current variation between two LED drivers.

The channel skew can be calculated by the equation below:

$$\text{Channel Skew (\%)} = (\text{Max. } I_{OUT} - \text{Min. } I_{OUT}) / (\text{Avg. } I_{OUT}) / 2 \times 100\%$$

where  $I_{OUT}$  means the output current of an LED driver.

The chip skew can be calculated by the equation below:

$$\text{Chip Skew (\%)} = (\text{Max. } I_{OUT} - \text{Min. } I_{OUT}) / (\text{Avg. } I_{OUT}) / 2 * 100\%$$

where  $I_{OUT}$  means the output current of two LED drivers.

In 2007, the maximum channel skew and chip skew of many LED drivers on the market can be achieved to  $\pm 3\%$  and  $\pm 6\%$  separately. However, human eyes can distinguish 6% brightness difference, and may be even sensitive to 1% difference when an LED panel is in a low-brightness configuration due to the inconsistent brightness within LED modules. To minimize the variations during the manufacturing process and keep the stability and consistency from each LED module to each LED panel, there is a trend of continuous improvement on the channel skew and chip skew of LED drivers. Macroblock first achieves the maximum channel skew and chip skew to  $\pm 2.5\%$  and  $\pm 3\%$  separately in 2008 by its advanced circuit design skills and well-controlled fabrication process. The ultra-concentrative distributions of the output current of LED drivers help reduce the manufacturing costs and improve the video quality of LED panels at the same time.

Figure 1 and Figure 2 are examples of the constant current LED driver-MBI5025, which show the ultra-concentrative distribution results of channel skew and chip skew according to a mass test result.

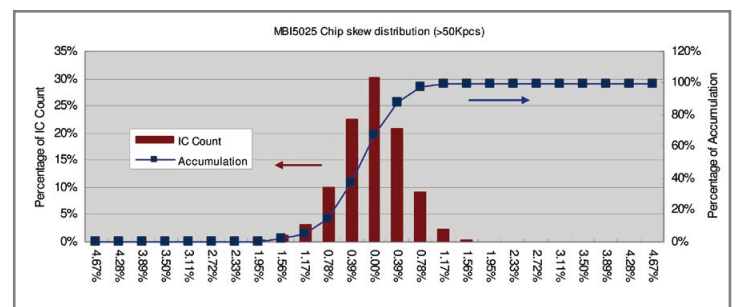


Figure 1: Channel Skew Distribution of MBI5025

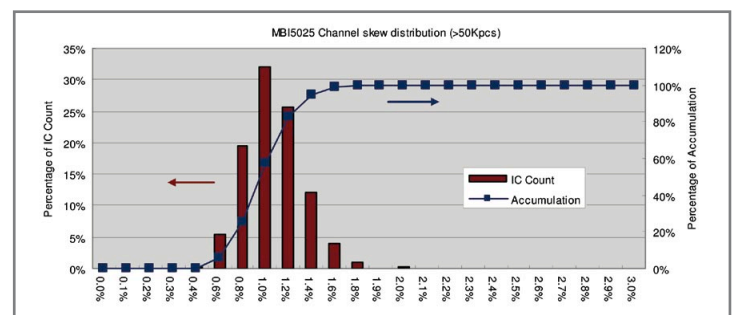


Figure 2: Chip Skew Distribution of MBI5025

## Supply Voltage Regulation (Line Regulation)

If the output current variation causes the supply voltage to vary, the power supply will have poor voltage regulation.

The supply voltage regulation can be calculated from the equation below:

Supply Voltage Regulation ( $\%/dV_{DD}$ ) = ( $I_{OUT}$  variation in percentage) / ( $V_{DD}$  variation in voltage)

where  $I_{OUT}$  is the output current of different LED drivers, and  $V_{DD}$  is the supply voltage.

Therefore, a smaller supply voltage regulation helps minimize the output current variation of LED drivers. However, the supply voltage drop is unavoidable on the power traces of PCB due to the parasitic resistance. Take Figure 3 for example, the  $V_{DD\_A}$  close to the power source is usually larger than  $V_{DD\_B}$ .

According to the above equation, if: the voltage drop on the power trace is 0.5V, and the maximum supply voltage regulation of the LED driver is  $\pm 5\%$ , there will be  $\pm 2.5\%$  output current variation between different LED drivers. This is why the supply voltage regulation is important to the performance of output current uniformity of an LED driver.

From the above example, there are two approaches that may help improve the image quality of LED panels.

One is to design with a good PCB placement and routing. As in Figure 4, it is recommended to place the input power socket at the center of the PCB to minimize the power trace length and internal resistance. Manufacturers can also separate the  $V_{DD}$  trace and  $V_{LED}$  trace at the power source or by a ferrite bead to reduce the current and noise on  $V_{DD}$  trace. Adding small capacitors distributed on the whole PCB is also better than adding one or two large capacitors near by the power socket for reducing the voltage drop. Based on the equation  $V_{drop} = I \times R_{trace}$ , the voltage drop through PCB will be therefore reduced, including both  $V_{DD}$  and  $V_{LED}$ .

The other approach is to select LED drivers with smaller supply voltage regulation. For example, if manufacturers select LED drivers with 1% supply voltage regulation, the output current variation will be greatly reduced to 0.5%. The image quality will be apparently improved due to the output current uniformity improvement.

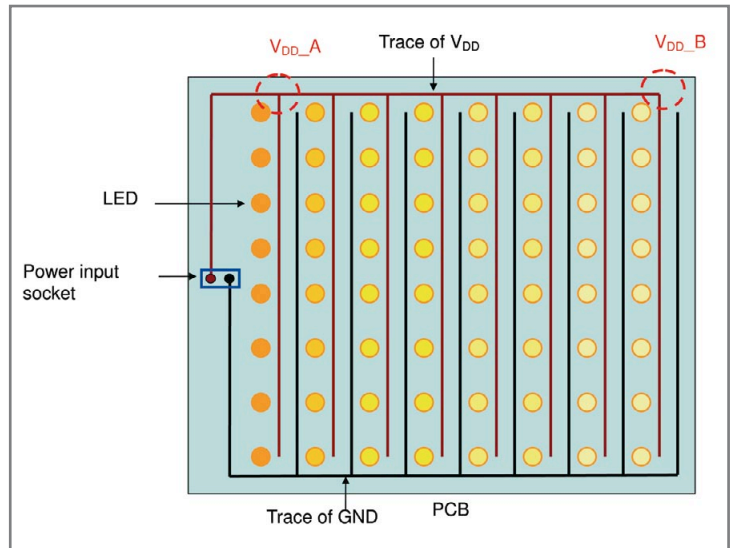


Figure 3: Supply voltage drop on PCB

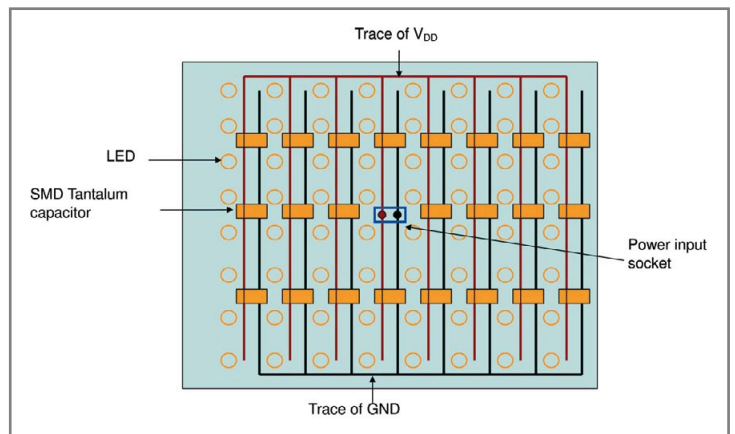


Figure 4: Recommended PCB placement and routing

## Output Voltage Regulation (Load Regulation)

Ideally, the load regulation should be zero percent, which means the output voltage should be constant under all load conditions. However, the load resistance may affect the output voltage to vary. The equation below indicates how to define the output voltage regulation:

Output Voltage Regulation ( $\%/dV_{DS}$ ) = ( $I_{OUT}$  variation in percentage) / ( $V_{DS}$  variation in voltage)

where  $V_{DS}$  is the output voltage of the output channel of an LED driver.

In addition, according to the following equation:

$$V_{DS} = V_{LED} - V_{drop} - V_F$$

where  $V_{LED}$  is the supply voltage of LEDs,  $V_{drop}$  is the voltage drop on the resistor (if any), and  $V_F$  is the forward voltage of the LEDs.

Figure 5 shows the relationships of  $V_{DS}$ ,  $V_{LED}$ ,  $V_{drop}$ ,  $V_F$  and since  $V_{LED}$ ,  $V_{Drop}$ ,  $V_F$  are all different for different output channels,  $V_{DS}$  may differ within output channels.



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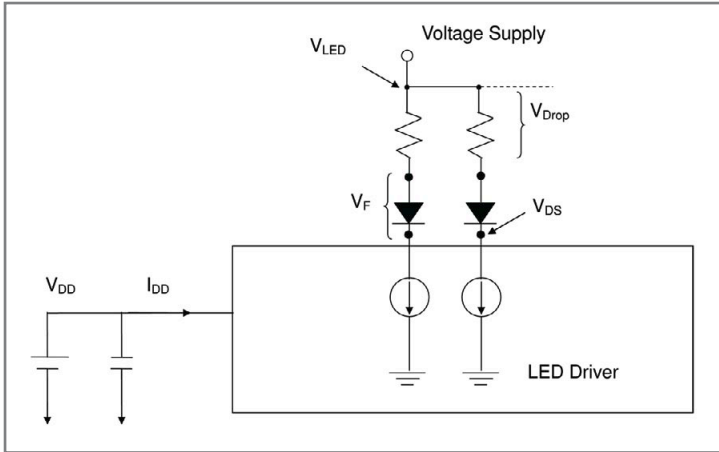


Figure 5: The relationships of  $V_{DS}$ ,  $V_{LED}$ ,  $V_{drop}$ , and  $V_F$

Figure 6 and Figure 7 show different output current performance with different output voltage regulation. The output current performance is apparently different when  $V_{DS}$  is from 0.5V to 2V. Figure 6 indicates that MBI5039 has a better output current uniformity with a smaller output voltage regulation ( $\pm 0.3\%$ ), while Figure 7 shows a worse output current uniformity with  $\pm 3\%$  output voltage regulation. For an LED driver with  $\pm 3\%$  output voltage regulation, the output current uniformity degrades by  $\pm 1.5\%$  if the  $V_{DS}$  difference is 0.5V, according to the output voltage regulation equation.

To maintain good output current uniformity, the above-mentioned PCB routing may reduce the  $V_{LED}$  variation, but it is difficult to keep consistent  $V_F$  of LEDs, and it costs a lot for more consistent LEDs since LED cost accounts for the major cost of the overall LED panels. Therefore, a better way is to select LED drivers with good output voltage regulation.

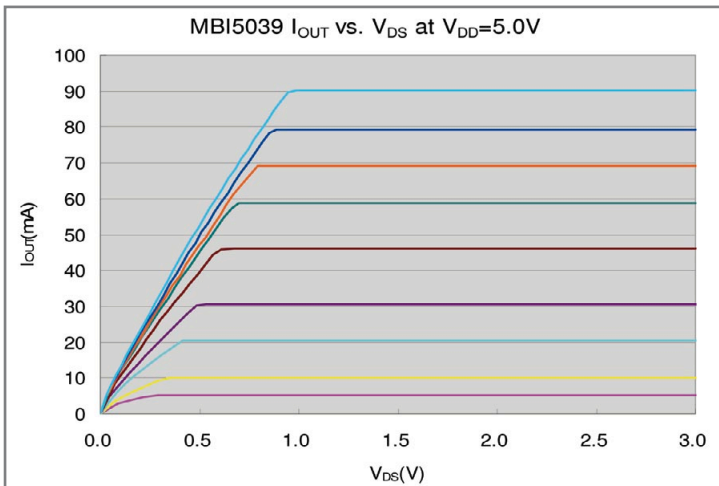


Figure 6: The  $I_{out}$  vs.  $V_{DS}$  curve of MBI5039 with  $\pm 0.3\%$  maximum output voltage regulation

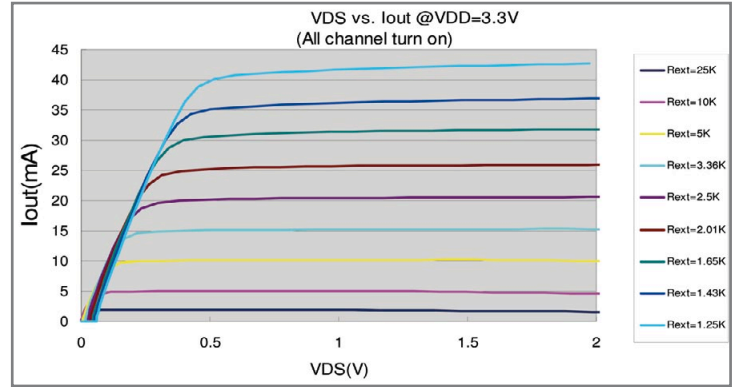


Figure 7: The  $I_{out}$  vs.  $V_{DS}$  curve of an LED driver with  $\pm 3\%$  maximum output voltage regulation

## Conclusion

The easier and cost-effective way to achieve uniformity of LED panels is to choose good LED drivers which can meet the above-mentioned 4 criteria including channel skew, chip skew, line regulation, and load regulation. By this way, LED panel manufacturers save the time and money on LED sorting while making uniformed LED panels. ■

# Driving Compact Lamps Having High-Brightness LEDs

> Rafael A. Pinto et al., Federal University of Santa Marial

Approximately 20% of electrical energy consumed in the world is used by lighting systems. With the increase of the energy consumption in various segments, developing more efficient systems is really important. The incandescent lamps, widely used in residential lighting, are being abolished in many countries due its low efficiency. So, the replacement of these bulbs for compact fluorescent lamps (CFL) has become an efficient way to reduce the energy consumption.

However, lighting systems using LEDs (Light Emitting Diode) have greater efficiency with long useful life compared to fluorescent lamps [1]. The goal of this work is to develop a compact lighting system in order to replace incandescent lamps and CFL. The use of standard E-27 socket (the same used in incandescent bulbs) in the LED lamp makes easy the replacement of other bulbs without any change in the installed electric system.

## Features and Applications of LEDs

The use of LEDs on lighting systems is due to its high luminous efficacy and long useful life. Today this efficacy can reach 100 lm/W, this is greater than incandescent (15 lm/W) and fluorescent lamps (80 lm/W) [2], and it tends to increase due to the novel researches in this technology. The LED's lifespan is very long, its can reach 60.000 hours of operation, while CFL and incandescent lamps can reach 6.000 hours and 1.000 hours [2], respectively. Another advantage is the small size of LEDs compared to fluorescent and incandescent bulbs, which provides better aesthetics to the ambient. Furthermore, LEDs have lower maintenance cost due to they do not present gas or filament for light generation, resulting in a low heat.

## Connection Types for Several LEDs

There are three ways to connect a group of LEDs in a circuit: series, parallel or series-parallel. The advantage of series connection is that all LEDs produce the same brightness since its luminous intensity is proportional to forward current. In the parallel connection, the output converter voltage is smaller. However, it becomes more difficult to ensure the same current to all branches. Moreover, to supply the system in  $220V_{RMS}$  it must work with a very small duty cycle, if the buck converter is employed. This condition do not give a large range to control LED's current being one of the disadvantage of this systems. In parallel connection with branches of LEDs in series (series-parallel connection) the voltage applied is not as high as in the series connection or as low as in the parallel one. However, the forward voltage on high brightness LED can change between 3.5V to 4.0V. So, it becomes more complex to control the voltage and current applied to each LED with this connection type. Analyzing the three alternatives presented, it is concluded that the best one is the series connection because the facility of providing the same brightness at all LEDs through the converter output current control and a high output converter voltage [3].

However, the LED's damage can results in an open-circuit or short-circuit in the device. For the series connection, a short-circuit just causes the no operation of this LED, keeping the others LEDs working. But in the case of an open-circuit, the entire group is disconnected. This is the main disadvantage that leads many authors do not use this connection type [4].

## Protection to Failure of LEDs

The proposed idea to fix the failure problem of an LED is to put Diacs in parallel connection with LED groups. So, if one LED burns and the circuit opens, the converter output voltage is applied to the Diac's terminals.

When the Diac's breakdown voltage is reached the device conduces maintaining the current to the others LEDs. Then, even if some LEDs burn the other groups in series remain the normal operation. The use of Diacs in parallel with each device would increase the cost of the circuit. For this reason it is desirable to use the Diacs with groups of LEDs, however the operation voltage in this group must be lower than the breakdown voltage of the Diac.

This is a simple and low cost alternative which increases the useful life of the lamp, with a reducing in the total luminous intensity, which is proportional to the number of LEDs disabled.

## Proposed Circuit

The buck (step-down), boost (step-up), buck-boost and flyback converters are very popular in the literature and fairly used to supply LEDs [5]. In this work the buck converter is employed due to the needed of an output voltage lower than the input one, associated with the simplicity and low cost of the circuit. Besides, there is no need for insulation.

The circuit is designed to supply the LEDs with a DC current about 23mA. The load can be composed of 36 to 52 LEDs of 5mm connected in series for a input voltage of  $220V_{RMS}$ , resulting in a converter output voltage between 90V and 187V. Among the studied modulation techniques, used to supply LEDs, which gives better luminous efficiency is the forward current mode [6] and [7]. That is the reason why this technique has been chosen for this work. The proposed circuit supplying 49 LEDs is presented in Figure 1.

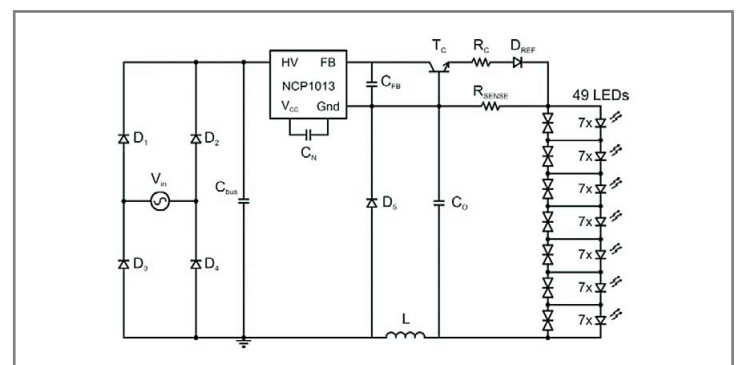


Figure 1: Proposed Circuit

In this circuit, the mains voltage ( $220V_{RMS}$ ) is rectified by diodes ( $D_1$ - $D_4$ ) and filtered by the bus capacitor ( $C_{bus}$ ). The switch is employed by the integrated circuit NCP1013. This IC is used because it works as a switch without the need of an external driver. Therefore it has a feedback pin (FB) to control the output power.

The NCP1013 operates in high frequency (100kHz), avoiding acoustic noise. It requires low power consumption and has low cost. Besides it has protection for short-circuit or feedback failure [8]. The IC's power supply is done through the capacitor  $C_N$ .

When the switch is turned on, the input source provides energy for the inductor (L), capacitor ( $C_0$ ) and also supplies the load. When it is turned off the diode  $D_5$  conducts and the energy stored in L is transferred to the capacitor and to the load. The maximum voltage applied to the switch and the diode is equal to the voltage on the bus capacitor ( $V_{C_{bus}}$ ).

The current control in the LEDs is done through a shunt resistor ( $R_{SENSE}$ ) connected in series with the load [5]. In case that  $R_{SENSE}$ 's voltage changes, and consequently its current, the internal controller of NCP1013 changes the duty cycle to maintain the reference voltage.

The reference voltage should be as small as possible to guarantee the high efficiency of the system. So, when the  $R_{SENSE}$ 's voltage increases until the diode breakdown voltage ( $V_{D_{REF}}$ ) plus base-emitter voltage of transistor ( $V_{T_{BE}}$ ), approximately 1.3 V, this device conducts and changes the voltage of the FB pin. The FB pin voltage variation changes the duty cycle. The CFB capacitor is recommended by the manufacturer to reduce a possible noise in this pin.

The current in the LEDs is designed to be 23mA. The reference voltage is 1.3 V. So the value of  $R_{SENSE}$  is equal to  $56\Omega$ , determined by (1).

$$R_{SENSE} = \frac{V_{D_{REF}} + V_{T_{BE}}}{I_{LEDs}} \quad (1)$$

The dissipated power into the resistor is only 30mW. And the total power in LEDs is about 3.6W.

If the current through the NCP1013 is less than 25% of the nominal value (350mA), the device enters standby mode. This feature reduces the consumption of the IC turning off it in low frequency. However, it causes an audible noise in the inductor, which is not desirable. So the buck converter must be designed to operate in the discontinuous conduction mode.

The inductor is designed to reach 25% of the NCP1013 nominal current. The value is determined by (2) [9].

$$L = \frac{E_{min} - V_{0max}}{I_{pk}} \times \frac{D_{max}}{f_s} \quad (2)$$

Where:

$E_{min}$ :	Minimum input voltage (worst case);
$V_{0max}$ :	Maximum output voltage;
$D_{max}$ :	Maximum duty cycle;
$I_{pk}$ :	Peak current on NCP1013;
$f_s$ :	Switching frequency.

For the appropriate converter design the minimum and maximum input voltage must be specified considering the capacitor ( $C_{bus}$ ) ripple and a possible changing of the mains voltage. The chosen value for  $E_{min}$  was 215V, due to the capacitor ripple of 10% and a changing of the mains voltage of 25% below the nominal value. The considered value for  $E_{max}$  was 389V (25% above the nominal value of the mains voltage).

The LED voltage can change between 2.5V and 3.6V for the model used on this work. As the load can also be composed by 36 to 52 LEDs, the converter output voltage ( $V_0$ ) should be specified for values between 90V and 187V plus 1.3V due to the reference voltage. The minimum current peak should reach at least 25% of the switch nominal value (equal to 88mA). The switching frequency is 100kHz and the duty cycle is the variable to be set by the internal controller of the NCP1013.

Thus, specifying a design value to  $D_{max}$  of 50% and making use of (2), the inductor value to the Buck converter used is 1.6mH. The minimum duty cycle happens when the input voltage is maximal and the output voltage is minimal, and can be obtained by (3). The minimum duty cycle will be 8.6%.

$$D_{min} = \sqrt{\frac{8 \times L \times f_s \times I_o}{V_{0min}}} \div \sqrt{\left(\frac{2 \times E_{max}}{V_{0min}} - 2\right)^2} \quad (3)$$

Where:

$D_{min}$ :	Minimum duty cycle;
L:	Inductor value of the Buck converter;
$I_o$ :	LED average current;
$V_{0min}$ :	Minimum output voltage;
$E_{max}$ :	Maximum input voltage;

The maximum current in the switch occurs in the same situation and may be obtained by (4). The maximum current value is designed to reach about 160mA and it is below the maximum value of the NCP1013.

$$I_{pk} = \frac{E_{max} - V_{0min}}{L} \times \frac{D_{min}}{f_s} \quad (4)$$

The capacitor  $C_0$  is designed to limit the output voltage ripple in small values, without compromising the size of the circuit. The value is determined by (5) [9]. The output voltage ripple ( $\Delta V$ ) was specified at 350mV. The value used for  $C_0$  is 2.2uF.

$$C_0 = \frac{V_0 \times (1 - D)}{8 \times \Delta V \times L \times f_s^2} \quad (5)$$

The circuit can be designed to operate with bivolt input detecting automatically the input voltage ( $110V_{AC}$  or  $220V_{AC}$ ) if 28 LEDs are used. This number is determined by the output voltage of the Buck converter which must be compatible with the minimum and maximum limits of the NCP 1013's duty-cycle.



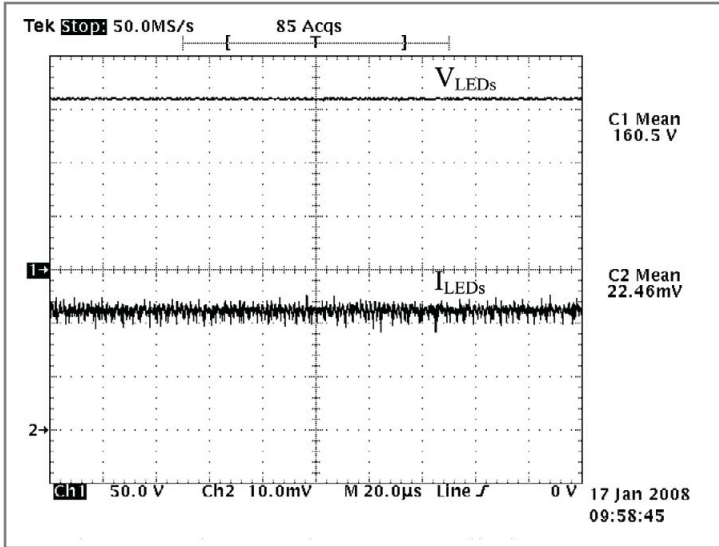


Figure 3. Voltage and current applied to 49 LEDs (50V/div, 10mA/div, 20us)

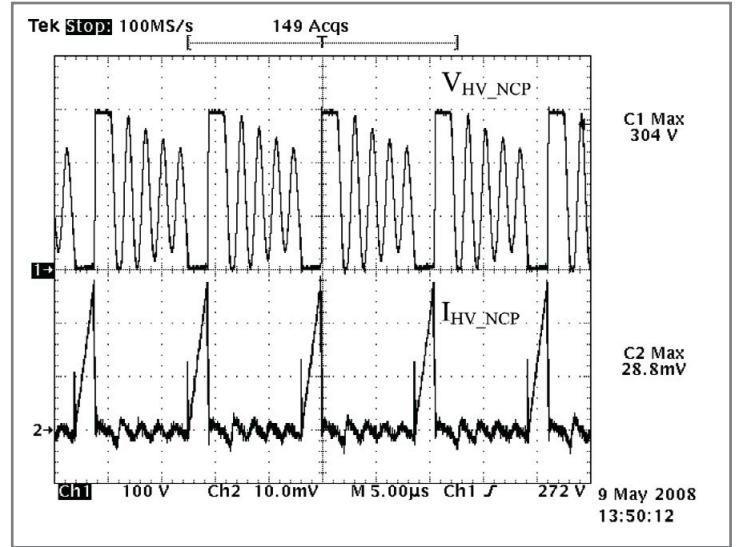


Figure 4. Voltage and current in the switch to 49 LEDs (100V/div, 50mA/div, 5µs)

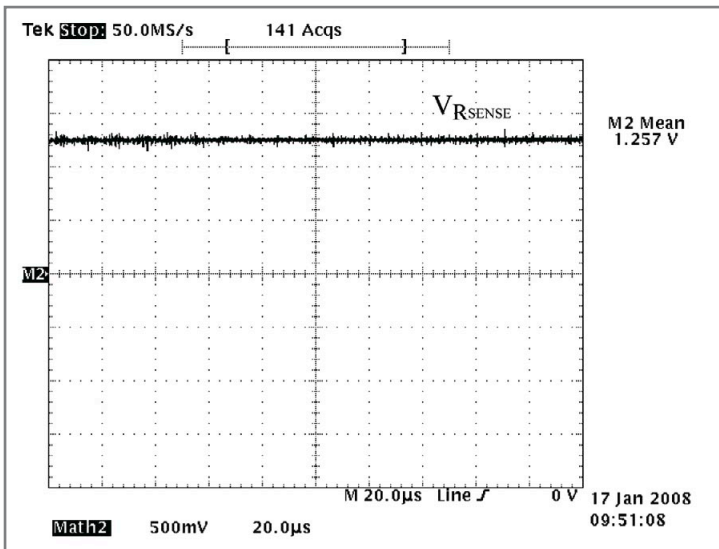


Figure 5. Voltage in resistor RSENSE for 35 LEDs (2 Diacs on) (500mV/div, 20ns)

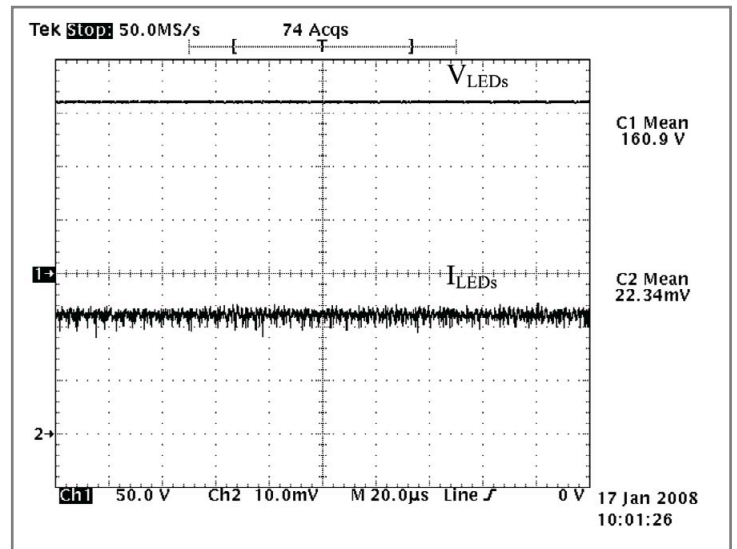


Figure 6. Voltage and current applied to 35 LEDs (2 Diacs on) (50V/div, 10mA/div, 20ns)

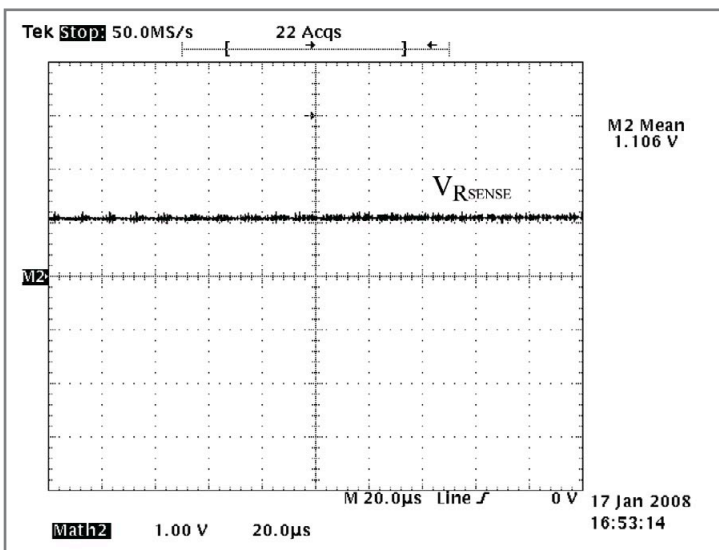


Figure 7. Voltage in resistor RSENSE for 36 LEDs (1V/div, 20ns)

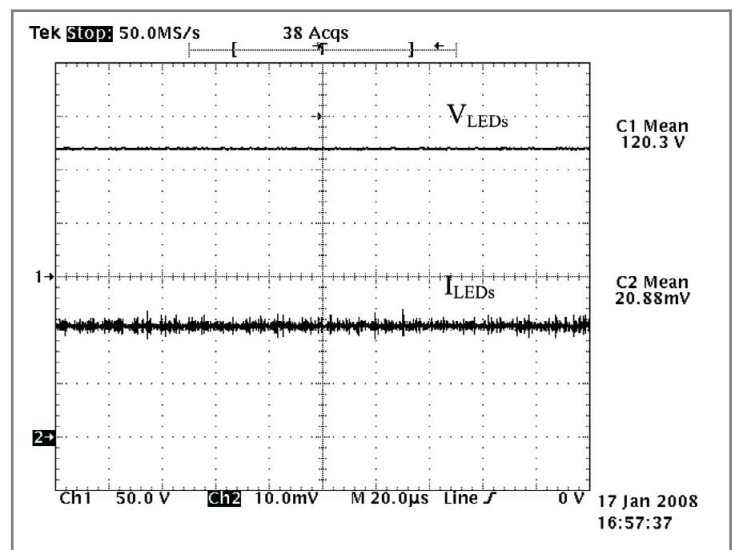


Figure 8. Voltage and current applied to 36 LEDs (50V/div, 10mA/div, 20ns)

## Experimental Results

For a uniform lighting with similar characteristics to the CFL and incandescent lamps, a circuit with 49 LEDs was implemented on a semispherical surface. The voltage waveform of R<sub>SENSE</sub> is presented in Figure 2, which shows that the control maintain the reference voltage. Thus, as can be seen in Figure 3, the current in the LEDs remain constant in the designed value of 22.46mA.

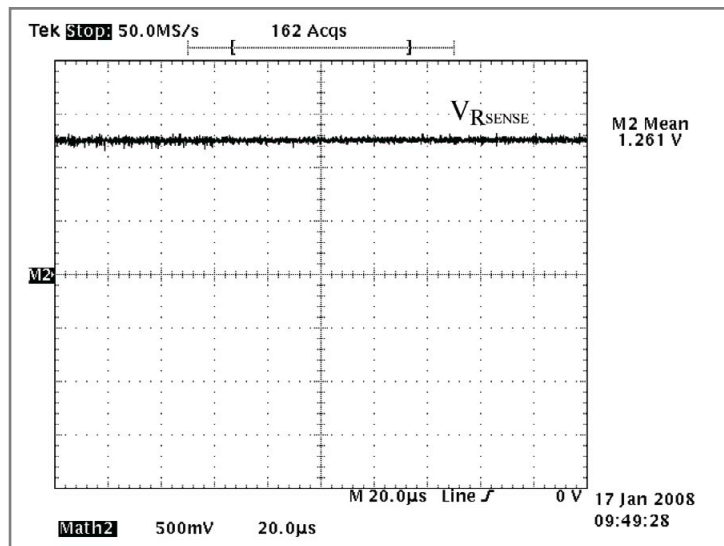


Figure 2. Voltage in resistor R<sub>SENSE</sub> for 49 LEDs (500mV/div, 20ns)

The switch voltage and current waveforms are shown in Figure 4. The switching is done with a duty cycle of approximately 16%, resulting in an output voltage of 160.5V. The peak current in the switch reaches 144mA avoiding that NCP 1013 enters into standby mode. The average value of current can be used to calculate the circuit input power (12mA). The consumption of the lamp was 3.8W. The converter efficiency was approximately 95%.

In order to simulate the damage of a LED, two devices were removed from the circuit. So, the Diacs connected in parallel with the groups that contains the removed devices become a short-circuit and the voltage in R<sub>SENSE</sub> and consequently the current of LEDs (35 LEDs), remain constant as shown in Figures 5 and 6, respectively.

To analyze the lamp behavior with the minimum load, a circuit with 36 LEDs was implemented, on a flat surface, resulting in a directional lighting, similar to dichroic lamps. The Figure 7 shows the voltage waveform of R<sub>SENSE</sub> and Figures 8 the LED's voltage and current waveforms. The resistor's voltage followed the reference voltage, limiting the current in the LEDs in 20mA.

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The lamp had the luminous intensity measured and it reached 60 LUX one meter away from the luximeter, with 49 LEDs, approximately the same value found for a compact fluorescent lamp of 8W and 900 LUX for the circuit of 36 LEDs with directional lighting. The Figures 9 and 10 show the photos of the prototypes.



Figure 9. Prototype of the circuit



Figure 10. Prototype of the lamps in operation

## Conclusions

This work presents a compact lamp design using high-brightness LEDs, with the goal to provide directly replacement to incandescent and compact fluorescent lamps by LEDs. The proposed circuit is simple and has low cost. The use of LEDs allows high efficiency and high lifetime to the lamp.

A prototype has been built and the experimental results show that a continuous current is maintained on LEDs, what validates the proposed idea. The system ensures the circuit operation even if some LEDs burn, reducing the maintenance cost of the system. ■

## Basic Topologies for Driving LEDs

> Steve Winder, Field Application Engineer, Supertex Inc.

When considering a driver design for an LED, it is natural to think about a voltage source and a current limiting device in series (usually a resistor). This works in most cases for standard 20mA LEDs if the supply voltage variation is small, or a 20mA constant current device like CL2 (Figure 1) can be used otherwise.

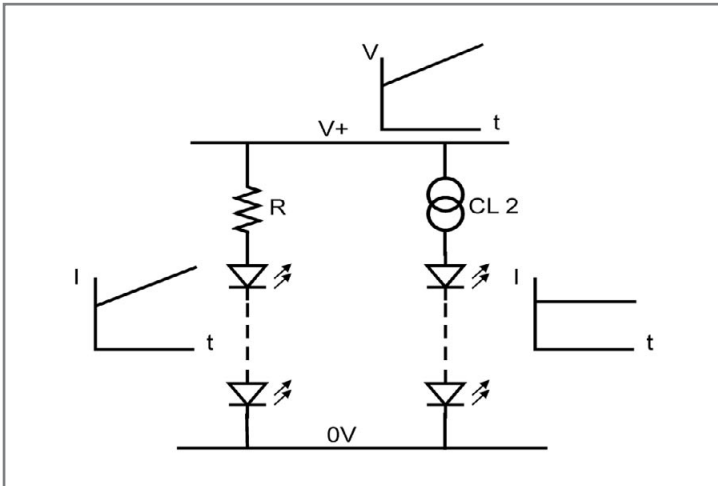


Figure 1: Simple Current Regulator

However, in the case of a high bright LED (1W) or an Ultra bright LED (3W - 5W) a resistor or constant current regulator gives poor results. Why? Because these high power LEDs need 350mA, 750mA, or higher current levels, and the heat dissipation in a resistor will be too great. Also, if we make the voltage drop across the resistor low, to keep the power dissipation to a minimum, any change in the supply voltage or the LED forward voltage drop will result in a large change in the current. Note the LED forward voltage varies from device to device and also varies with temperature. Since high power LEDs can get very hot, this voltage change is significant.

Linear current regulators can be used to overcome the supply voltage variation. Using a LM317 type regulator configured as a constant current generator can work. However, we still have the power dissipation problem if the supply voltage is very different from the LED forward voltage drop ( $V_f$ ). This is where switching regulators are necessary.

Systems using high or ultra-bright LEDs often have many connected in series. A series connection has several advantages: only one driver is needed; all the LEDs have the same current flowing through them, to give a relatively constant brightness; and this arrangement gives the highest efficiency since no current mirror circuit is needed.

## Buck, Boost or Buck-Boost

There are three general categories of switching driver. Buck is used when the supply voltage is higher than the load voltage. Buck-boost is used when the supply voltage changes and can be higher or lower than the load voltage. Boost is used when the load voltage is always higher than the supply voltage. Each can be realised with a circuit using a single inductor, although a buck-boost circuit using two inductors give far better results.

In each circuit there is a "flywheel" diode to create a path for the LED current when the MOSFET is off. This is necessary because the inductor current cannot just stop – the energy stored need to go somewhere – and damaging high voltages would be created if there were no diode in circuit. Like a flywheel in a mechanical rotating system, the diode keeps the current flowing around the circuit. Note that the flywheel diode in each type of converter must be very fast – a Schottky type is good for low voltage applications, or an ultra-fast diode for high voltage applications. The diode switches from forward conduction to reverse blocking, so some reverse current can flow before the diode has time to stop conduction and this can lead to switching losses (heat in the MOSFET). A good, but not cheap, ultra-fast 600V 1A diode is STTH1R06 (STTA106U in surface mount).

Switching takes place at a high frequency, typically in the 50kHz to 250kHz range, so EMI must be considered. A low impedance capacitor, made from ceramic or plastic film, should be connected across the supply rails, close to the inductor and MOSFET. A ceramic capacitor is more expensive, but gives better performance. Because the inductor is never perfect and has some capacitance across the windings, it is also a good idea to place a small capacitor across the LED string, typically 10nF - 100nF. This capacitor will conduct the initial current surge due to the inductor winding's capacitance and thus keep EMI on the output side of the LED driver to a minimum.

### Buck converter

If the supply voltage is always greater than the total LED voltage drop, a buck converter can be used. This is a simple circuit, as shown in Figure 2.

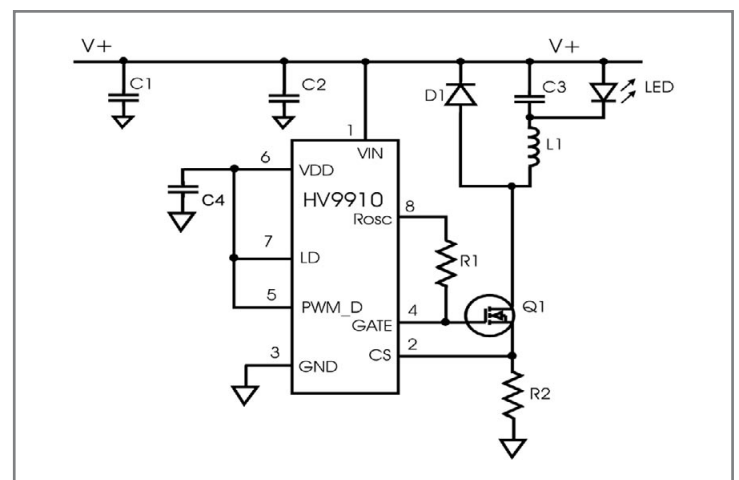


Figure 2: Buck Converter

Energy is stored in the magnetic field of the inductor when the MOSFET M1 is on. This energy is used to maintain current in the LED when the MOSFET is off. Put another way, the inductor opposes any change in current, so when the MOSFET turns off it finds a path through the flywheel diode D1. Since the LED string is in series with the inductor, the current through them both is kept fairly constant during switching.

The output voltage should be greater than 5% and less than 85% of the supply voltage to keep a simple design. If the output voltage is less than 5% of the supply voltage, the MOSFET on time will be very short and some loss of current regulation could occur. A solution around this is to have a low switching speed, say 25kHz, but this results in a large inductor. If the output voltage is greater than 85% of the supply voltage, there may be stability problems with the controller. Indeed, if the output voltage is more than 50% of the supply voltage this can occur, unless a constant off-time is used when switching.

**Buck-boost converter**

If the LED string voltage can be higher or lower than the supply voltage, for example in automotive applications where the battery voltage varies from 9V to 16V, but the LED string voltage may be 12V. In this case a buck-boost circuit can be used.

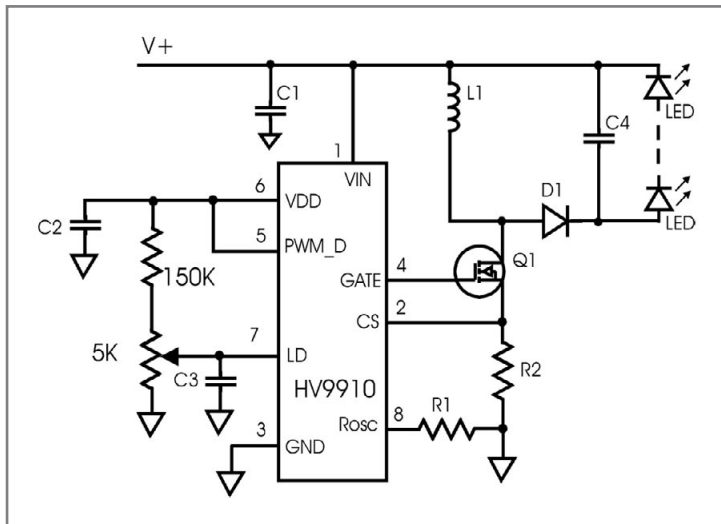


Figure 3: Buck-boost (single inductor)

A single inductor buck-boost, as shown in Figure 3 has the problem of regulation; if the supply voltage changes, or the LED string voltage changes, the output current can change. External circuits can be added to improve this situation, but this is not ideal. A Cuk converter (Figure 4) can be used to give a buck-boost function without being sensitive to the supply voltage or load voltage.

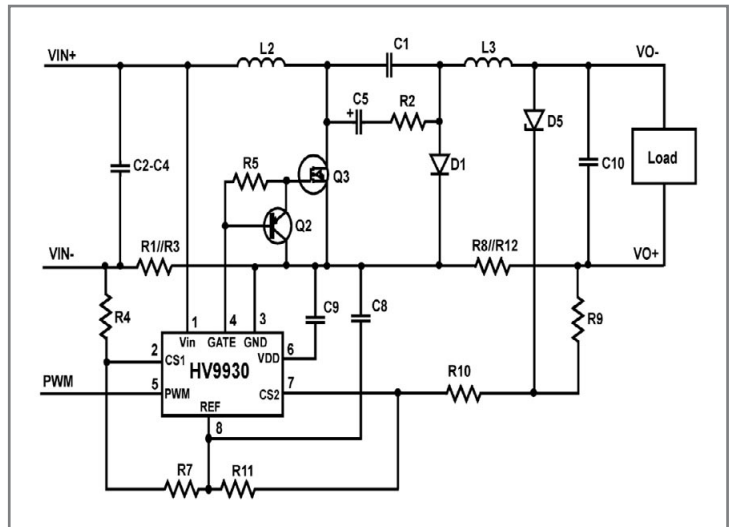


Figure 4: Buck-boost (Cuk Converter)

The Cuk circuit has an advantage in that EMI is minimal. There is an inductor in series with the input and in series with the output, so filtering takes place automatically. Typically, the input to output voltage step-up or step-down ratio should be limited to 4:1 to make the design straightforward.

**Boost converter**

The boost circuit is quite simple and is used when the load voltage is always higher than the supply voltage. Generally, it is recommended that the load voltage is at least twice the supply voltage. A boost converter circuit is shown in Figure 5.

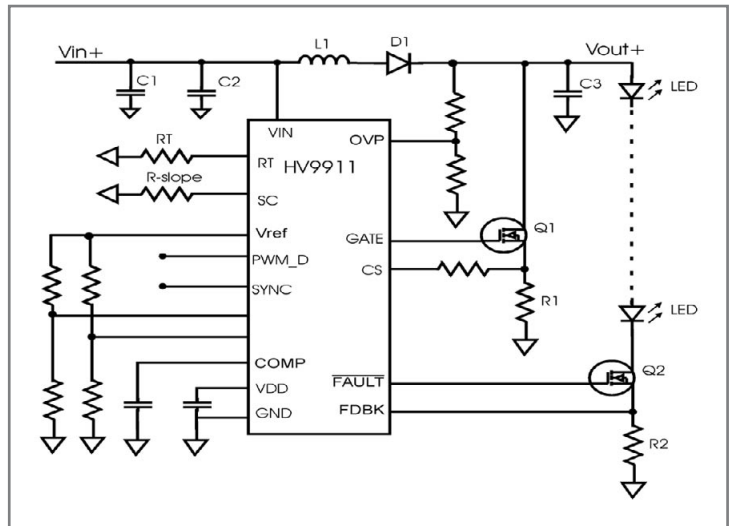


Figure 5: Boost Converter

For a constant current boost converter, the driver circuit needs to control the inductor current when the MOSFET is on, such that the output current is kept constant. It does this by adjusting the peak inductor current dynamically, using feedback from a current sensing resistor that is in series with the LED string. As the feedback voltage

risers, the internal comparator that controls the inductor current has its reference voltage lowered, so that the comparator triggers at a lower current and turns off the MOSFET.

## Other Converters

The converters shown here have been the basic types. Converters for Power Factor Correction (PFC) may be necessary in some high power AC applications. These can be a PFC converter and a LED driver in series, or a combined circuit that can provide both functions (Multi-converter).

## Pulse Width Modulation

Pulse width modulation (PWM) is often used to dim LEDs. Some use it to combine red, green and blue for colour mixing (this technique is the subject of a disputed patent by Color Kinetics).

The frequency of PWM signals is usually in the range 100Hz to 1kHz. Lower frequencies give a dimming range with finer steps, but can cause flicker. Dimming a buck or Cuk converter is simple because when the MOSFET is off, any LED current quickly reduces to zero. A single-inductor buck-boost circuit and a boost converter both have quite large energy storage capacitors across the LED string, to keep the current flowing through the LEDs when the MOSFET is on, so these have a problem with PWM dimming. There is a solution for the boost converter, to have an additional switching MOSFET in series with the LED string to cut its current.

## Power Dissipation

There are two power dissipation issues to consider.

Power in the converter could be 5% – 20% of the total power, mostly dissipated in the MOSFET but also the inductor and flywheel diode.

Power in the LED: this is  $V_f \times I_f$  and can be 1W to 5W per device. For some reason many people think that LEDs are cold, this is not true, although some white LEDs are called 'cold white' because they have a large blue light content. Most of the power into the LED comes out as heat, not light. Whichever way you look at it, LEDs need a lot of heat sinking!

If an enclosure contains the LED string and the driver circuit, such as in a traffic light head, the ambient temperature can get quite high. Circuits that do not need electrolytic capacitors should be used to give a long life. In high temperatures, electrolytic capacitors dry out and no longer work properly.

## Supply Voltage Transients

In AC line powered circuits and automotive circuits, consider any transients. A transient suppressor helps, but make sure that the driver will not be damaged under worst-case conditions. A 275VAC varistor limits the voltage to about 700V but, with a smoothing capacitor across the bridge rectifier, the voltage is no more than 450V. Many automotive systems have a transient suppressor than limits to about 42V, but the driver should be rated higher than this for reliable operation.

## Testing LED Drivers

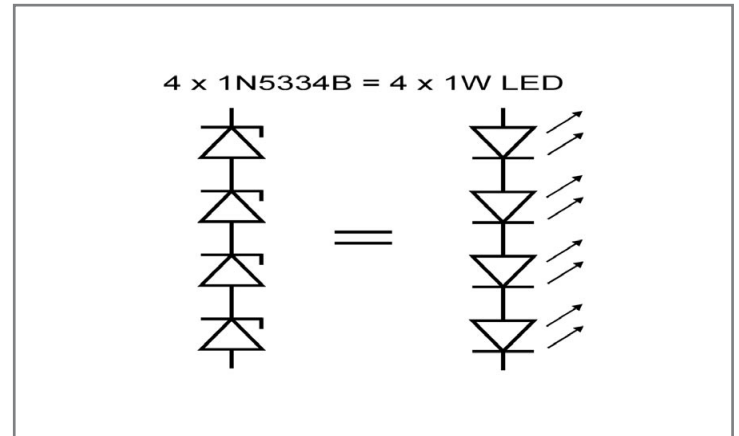


Figure 6: Testing LED drivers

Never test an LED driver using LEDs! High bright LEDs are very expensive. Since they behave like a Zener diode in breakdown, using 5W Zener diodes instead (such as 1N5334B [3,6V] or 1N5335B [3,9V]), see Figure 6. ■

### Annotation:

The HV9910 has been replaced by the improved HV9910B

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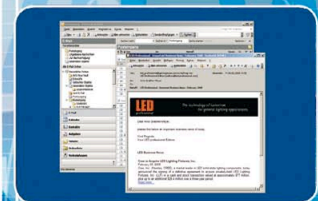
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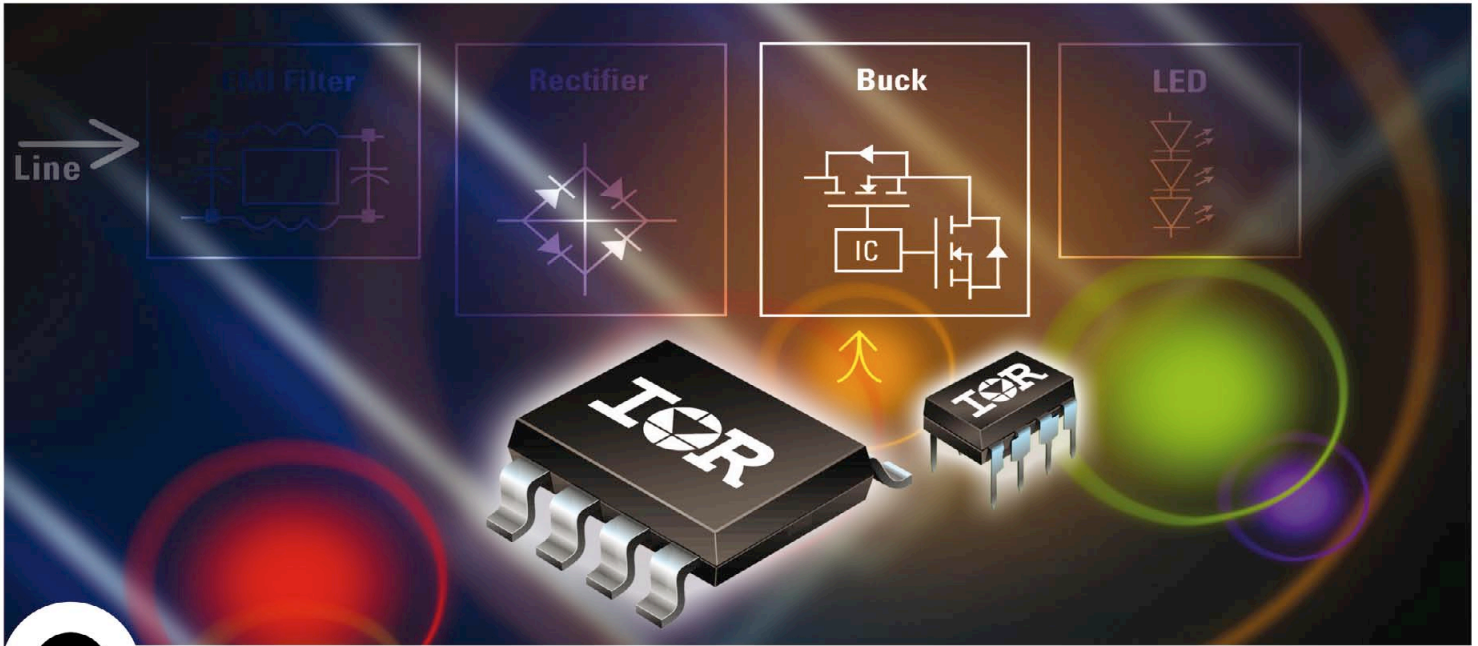
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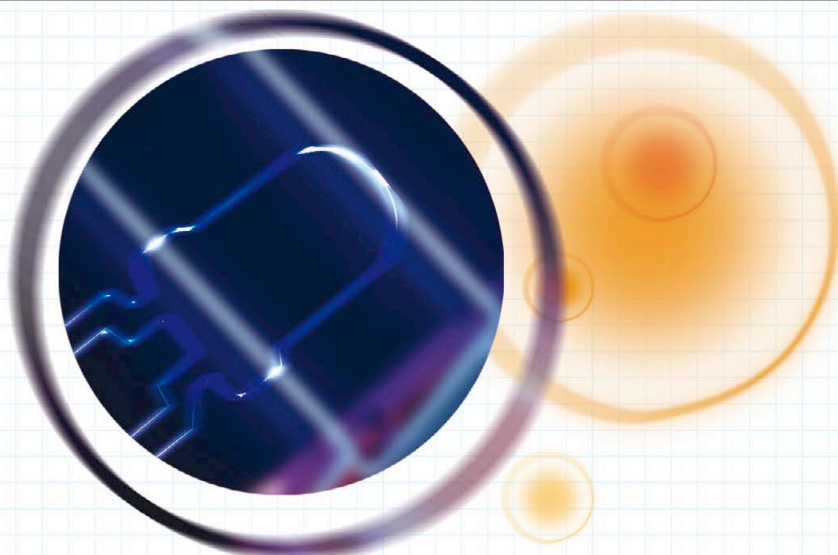
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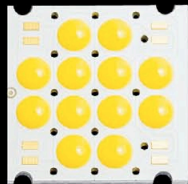
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