

**Digital Controlled Street-Lighting
TRIAC Dimming without Flicker
Thermal Foldback Design
Interview with ON Semiconductor**

Future Lighting Solutions

the company behind the spotlight



We are the market leader in LED based lighting solutions.

Accelerate your next project with our engineering expertise. From design to concept to production, Future Lighting Solutions works with customers across the globe to deliver superior, future-proof lighting solutions.

Through our partnership with Philips Lighting, we'll help you incorporate Philips Fortimo™ LED light modules, which have a 5-year warranty and are designed to ensure that form factor, color, and quality remain consistent and sustainable over time.

Future Lighting Solutions has the tools, knowledge and experience to help you make the right decisions in specifying your LED lighting system solutions.



Visit FutureLightingSolutions.com and start your next LED project with support from the experts

Impressions from electronica



Electronica 2010, the world's largest electronic fair, was hosted in Munich from November 9th to 12th. It was remarkable to see how diverse LEDs and related applications, as well as supplementary components were presented at the fair. The progress of LED components in parameters such as efficiency, CRI or thermal resistance is ongoing. There is now an LED with 160 lm/W in cool-white available on the market! Single LED packages derived from LED strings reach lumen output values of some 1,000 lumens. In addition, a range of package alternatives are available; optimized for explicit purposes like automotive headlamps, spot-lights etc.

Like at L&B, at electronica, component manufacturers offered system solutions such as bulbs, fluorescent replacement LED lamps or street-lighting headlamps, to name only a few. The rapid diversification of the lighting marketplace is a continuing process and a number of companies not only offer solutions, but have also formed their own planning services and distribution channels to penetrate the market.

Another trend could be seen as well. LED lighting systems are increasingly linked and integrated with intelligent controls. The strategy of many semiconductor IC manufacturers is to focus on LED lighting. The "new semiconductor load – LED" is much easier to manage than, for example, a discharge lamp with its complicated behavior. The field is therefore now ready for semiconductor specialists to bring their expertise into LED systems. These companies combine their vast experience in IC design with LED technology. Some examples shown at electronica were related to modern communication methodologies such as power-line and wireless communication while others presented intelligent LED controls to optimize thermal management. Some of the articles in this issue of *LpR* cover intelligent control schemes for improved performance.

All in all, it was fascinating to see the dynamics in the LED field. Here I have to mention the integration approach of discrete components on silicon. Working in the upper 100 MHz frequency band inductors, capacitors can be integrated into a complete driver on silicon – an LED system solution on a single chip!

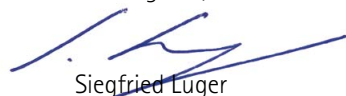
Today I'd also like to draw your attention to an event that we are organizing. The "LED professional Symposium + Exhibition 2011" will take place in Austria on Sept. 27-29 in the Festspielhaus (Festival House) in Bregenz, and it will focus on LED lighting technologies.

Technology is a key driver for innovation – that is the reason why we are bringing technology experts from the fields of LEDs, optics, drivers, ICs and thermal management together to present and discuss their "winning technologies". The LpS 2011 will be the ideal platform for you to gather information, get key contacts and meet the leaders. The "call-for-papers" ends on Feb 1, 2011. Exhibitors and sponsors are welcome to reserve their packages from today.

For detailed information please visit our symposium website: www.led-professional-symposium.com

We would very much appreciate your feedback about *LpR*. Let us know what you like or tell us how we can improve our services. Please keep in mind that you are also welcome to contribute your own editorials.

Best regards,



Siegfried Luger

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eldoLED L-dot LED driver
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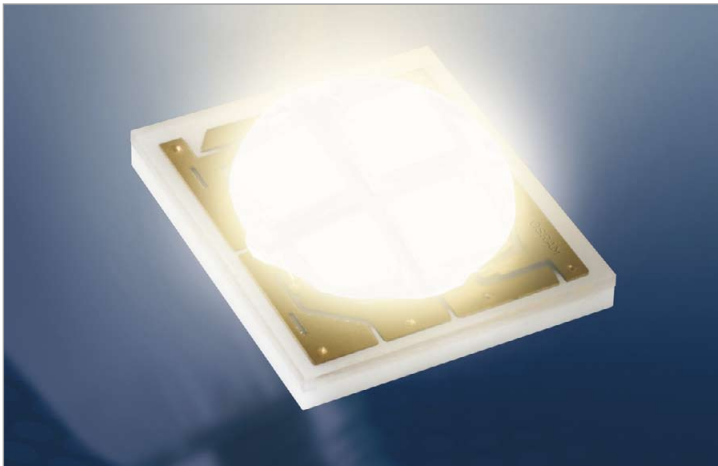
Product News

New OSTAR Lighting Plus and OSLOM LED

OSTAR Lighting Plus is the new power pack from OSRAM OS, providing a large amount of light from a small area and putting its predecessors firmly in the shade in terms of efficiency. Thanks to the new 150° beam angle of the OSRAM OSLOM SSL 150 LED luminaires can now be made simpler and more efficient.

OSTAR Lighting Plus

With its impressive brightness and color stability this high-power LED can be used without any problems in retrofits for incandescent lamps or halogen lamps. It contains four chips fabricated in state-of-the-art UX:3 chip technology and emits either cold white or warm white light.



An efficient replacement for incandescent lamps. The new OSTAR Lighting Plus offers impressive brightness and high color stability in different white tones.

The LED has an impressive brightness of 425 lm (5700 K to 6500 K) or 365 lm (2700 K to 4000 K) at an operating current of 350 mA. This corresponds to a typical efficiency of around 100 lm/W or 80 lm/W. "OSTAR Lighting Plus is also very efficient at higher currents and offers high light output thanks to the extremely uniform flux distribution over the entire chip surface," said Andreas Vogler, Marketing Manager General Illumination (SSL) at OSRAM OS. "The OSTAR Lighting Plus is ideal for applications where space is tight, such as LED luminaires and retrofits." Homogenous white light is ensured by an ANSI-compatible binning system with finely graded classes. The LED is easy to handle thanks to its SMT compatibility.

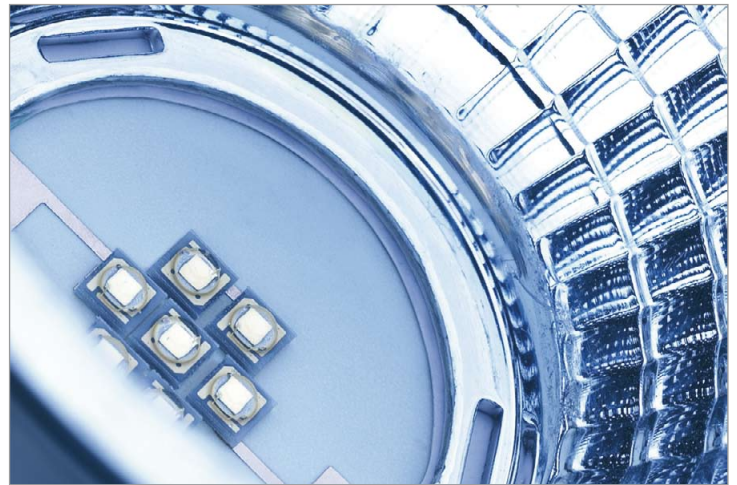
With a power draw of less than 5 W the warm white OSTAR version produces 365 lm – and from only four chips – which is much brighter than 25 W incandescent lamps which manage only 220 lm. Energy savings of more than 80% can therefore be made despite a luminous

flux that is 65% higher. Only four OSTAR Lighting Plus units are needed to replace a frosted 100 W incandescent lamp. And a color rendering index of 80 is no less impressive.

The applications for the new power LED cover interior lighting for shops, offices and homes, including many applications that require strong directional light from a small unit, such as spotlighting. The small dimensions of OSTAR Lighting Plus also make it ideal for applications that are currently being served mostly by halogen lamps.

OSLOM SSL 150

Retrofit and downlight designs in particular, will benefit from the even distribution of light from the new OSLOM SSL 150, which allows designers to better manage the light in external reflectors. Additionally OSLOM's small footprint can simplify the design of lamps and luminaires and facilitate low profile designs.



The tiny OSLOM SSL 150 LED can be closely placed in reflector systems for very low-profile designs.

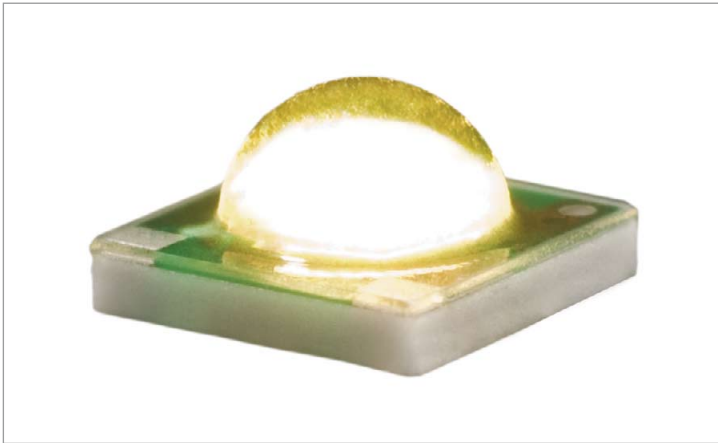
The wide beam characteristic of this new LED enables the light to be used in reflector systems with much lower light losses which means LED lamps and luminaires designed with OSLOM SSL 150 are more efficient. "With its low-profile and very compact design the new OSLOM SSL 150 can be closely clustered without creating shadow effects. In reflector applications for example, the luminaire efficiency can be increased by more than 5 percent. The reflectors can also be low-profile and the luminaire itself needs only a shallow mounting depth," said Martin Wittmann, Marketing Manager Solid State Lighting at OSRAM OS "Thanks to these properties the LED offers flexible design options for high-performance lighting solutions."

Color mixing is also easier than ever. If OSLOM SSL LEDs in different colors are used in a cluster the colors can be mixed at the reflector level. This is much less complex than mixing colors with secondary lenses.

The technical data of the new LED is also impressive. The LED is based on a 1 mm² chip, providing a typical brightness of 92 lm at 3000 K at an operating current of 350 mA and 156 lm at 700 mA. It is available in all white tones (2700-6500 K) and in different colors. ■

Cree Ups Performance for XLamp® XP-C, XP-E and XP-G White & Color LEDs

Cree, Inc. announces the addition of 80, 85 and 90 color rendering index (CRI) options to its XLamp® XP-G and XP-E warm-white LEDs and the commercial availability of new levels of performance for XLamp® XP-E & XP-C Color LEDs.



Cree XLamp® XP-E LEDs are available now in sample and production quantities with standard lead times.

XLamp® XP-G and XP-E

Many lighting applications, such as retail, medical and architectural, require high color accuracy to properly render object colors. With previous-generation high-CRI white LEDs, increasing color quality meant decreasing efficacy. Thanks to the new high-CRI XP-G and XP-E, luminaire and fixture designers can have both.

"High CRI is a must for certain applications that require a high quality of the light—but at the same time, we cannot forget about the system efficacy," said Massimo Santinon, brand manager i-Led, Linea Light s.r.l. "The new XLamps with high CRI are the perfect combination we were waiting for that will allow us to address new markets."

"Lighting applications require specific performance characteristics, and Cree's XLamp LED family delivers products optimized for these individual applications," said Paul Thieken, Cree director of marketing, LED components. "Our high-CRI XLamp LEDs can deliver light quality comparable to halogen with better efficacy than fluorescents. And Cree's lighting-class LEDs are proven to be one of the world's most-efficient light sources, which can enable more-economical designs and applications."

The new high-CRI XP-G is available with luminous flux of up to 107 lumens at 350 mA in warm white (3000 K), providing efficacy of 102 lumens per watt. Using this new XP-G, LED lamp designers can create systems that are 70 percent more efficient than a traditional halogen PAR38 lamp and deliver similar high color rendering.

High-CRI XP-G and XP-E LEDs are similar to standard XP-G and XP-E LEDs, respectively, and may work in existing systems without any redesign. Just as with the standard XP-G and XP-E, the new LEDs have LM-80 data approved by ENERGY STAR®, are UL-recognized components under UL 8750 (E326295), and feature excellent thermal-management properties.

XLamp® XP-E & XP-C Color

XLamp XP-E Color LEDs are now available delivering a minimum light output of 500 mW for Royal Blue, 39.8 lumens for Blue, 107 lumens for Green, 73.9 lumens for Red-Orange, and 62.0 lumens for Red, all at 350 mA. XLamp XP-C Color LEDs are now available delivering a minimum light output of 350 mW for Royal Blue, 23.5 lumens for Blue, 62 lumens for Red-Orange and 51.7 lumens for Red, all at 350 mA.

"Cree is extending our leadership with industry-best light output across the color spectrum in a common, small footprint," said Paul Thieken, Cree director of marketing, LED components. "These economical, high-performance options can provide designers additional flexibility for a broad set of applications including architectural, emergency vehicle, transportation and decorative lighting, all while leveraging the reliability of the XP package." ■

Nichia Announces a New Line of White High Power LEDs

Nichia announces the release of a new line of high power point source white LEDs that drives the cutting edge technology of power LEDs to a new level. Code named under Nichia part number "NVSx219A", or "Nichia 219", this line of high intensity point source LEDs offers unprecedented luminous efficacy, source brightness, a compact footprint, and superior color quality. It enables interior and exterior general illumination applications where directional, volumetric lighting is desired.

Nichia 219 white LED offers typical 140 lumen output at 1 W input power with 5,000 K color temperature. Using a uniformly phosphor coated chip; Nichia 219 has the industry leading source brightness and tightest optical footprint. The spatial color uniformity is also optimized with Nichia's leading phosphor technology. At 350 mA drive current, the typical forward voltage is only 3.0 V. Additionally, this package is capable of drive currents up to 1.5 A.

Nichia intends the 219 white LED to be Energy Star® compliant. This includes ANSI standard chromaticity binning, full color temperature selections, high CRI performance, LM-80 test data, and other relevant certifications. To enhance the delivered lumen output under thermally stabilized conditions, Nichia engineers have drastically improved the lumen maintenance at higher junction temperatures.

Powering the light of tomorrow

LightLine. The next generation of constant current LED drivers

✓ High Power AC input LED Driver

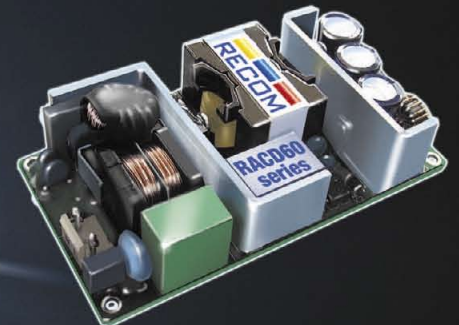
The RACD60 series - a high power AC input LED driver module. Designed to meet the requirements of the newest and brightest LEDs on the market. Output current from 700mA up to 4.2A, this series can drive almost any LED in the market. One of the smallest 60Watt AC LED driver in the industry.

✓ Low Power AC input LED Driver

Introducing the RACD series low power AC input LED driver. A low cost solution to the low power Solid State Lighting. This family includes of 3W, 6W, 12W and 20W modules with different configurations capable of driving up to 15 high brightness LEDs.

✓ DC input LED Driver

The RCD-24 family offers DC input LED driver modules with constant current output from 300mA up to 1.2A, high efficiency (up to 97%), wide input voltage range (5~36Vin), very low output dropout voltage, 2 independent dimming options (PWM and 0-10 analog) and a long lifetime up to 600,000 hrs.



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To make Nichia 219 user friendly, Nichia has incorporated an electrically isolated heat sink in the LED design, and lowered the junction to board thermal resistance, while minimizing the package size to a mere 3.5 mm x 3.5 mm. The symmetrical package shape with a dome lens makes it perfect for secondary optical and mechanical designs. ■

Philips Lumileds Expands its LUXEON Rebel White LED Portfolio

Philips Lumileds announced that it has added a new 4000 K CCT ANSI binned part to its award winning LUXEON Rebel product portfolio and raised the top flux bin for its cool and neutral white LUXEON Rebel by 20%. The new part delivers improved color rendering and tight binning to simplify luminaire designers' engineering efforts. In addition, flux bin increases for cool and neutral white LUXEON Rebel parts to a minimum 120 lumen flux bin at 350 mA demonstrates continued flux and efficacy improvements that are part of the company's technology development path. Coupled with the recent introduction of LUXEON Rebel ES, Philips Lumileds LEDs provide high performance options for a wide variety of applications.



LUMILED's new LUXEON Rebel white LED.

"As the market for solid-state lighting solutions takes hold, feedback from lighting engineers, designers, and end-users is playing a critical role in the development of the LUXEON LED portfolio," said Frank Harder, VP Marketing LUXEON Product Lines at Philips Lumileds. "The new 4000 K CCT part addresses specific needs in the office lighting segment where light output, efficacy and quality of light must meet certain levels. And our light output increases coupled with superior performance at application conditions means that our LUXEON Rebel LEDs will outperform virtually any similar product available today." ■

Avago Technologies Introduces New Tricolor LEDs

Avago Technologies announced a new family of high-brightness LEDs in ultra-small packages at the Combined Exhibition of Advanced Technologies (CEATEC) Japan 2010. The new ASMT-YTx2 tricolor surface-mount devices are available in 3.4- by 2.8- by 1.8-mm Plastic Leaded Chip Carrier (PLCC)-6 packages. The ultra small HSMF-C118 tricolor chip-type LED is designed in an ultra small package for miniaturization.



Avago's new ASMT-YTx multi color LED series (left) offer top performance on a small PLCC-6 footprint. Even smaller with excellent performance are the HSMF-C118 tricolor chip-type LEDs (right).

Chip-type Tricolor LED - HSMF- C118

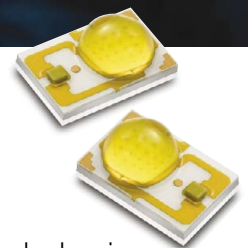
The HSMF-C118 tricolor chip-type LED is designed in an ultra small package for miniaturization. It is the first of its kind to achieve such small packaging for 3 dies. With the freedom to have any combination of colors from mixing of the 3 primary colors, this will yield a wide variety of colors to suit every application and product theme.

The small size, narrow footprint, and low profile make this LED excellent for back-lighting, status indication, and front panel illumination applications.

In order to facilitate pick and place operation, this ChipLED is shipped in tape and reel, with 3000 units per reel. The package is compatible with IR soldering and binned by both color and intensity.

ASMT-YTx2 Tricolor Surface-Mount (PLCC)-6 Devices

Avago Technologies announced a new family of high-brightness LEDs in ultra-small packages at the Combined Exhibition of Advanced Technologies (CEATEC) Japan 2010. The new ASMT-YTx2 tricolor surface-mount devices are available in 3.4- by 2.8- by 1.8-mm Plastic Leaded Chip Carrier (PLCC)-6 packages. The small footprint, high-brightness performance and robust contrast ratio of the devices all address demand for improved screen resolution in video screens and advertising signs used in transit malls, airports, stadium scoreboards and more, and also target gaming machines and decorative lighting.



Transforming Light

LUXEON LEDs are changing the way we light the spaces we live, shop and play in. With unparalleled efficiency, quality, and reliability, LUXEON LEDs are a simple way to transform lighting and improve the well being of our environment.

Whether you're lighting a restaurant, roadway or architectural masterpiece, you can count on LUXEON to deliver long life, high-quality white light while reducing energy consumption.

To learn how LUXEON can help you transform lighting, call our partner, Future Lighting Solutions U.S. +1-888 589 3662, Europe + 00 800 443 88 873 or visit www.philipslumileds.com

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Designers are choosing surface-mount LEDs because of their ease of assembly, compact footprint, and manufacturing flexibility, which reduce overall system development costs. The ASMT-YTx2 surface-mount devices are encapsulated in a heat-resistant silicone material, enabling them to operate in a wide range of environmental conditions with high reliability and long operating life. The LEDs have six leads that provide flexible color control for each chip to display a multitude of colors, including white. The devices are also water-resistant (compliance with IPx6), which reduces the cost and overall weight of signs by eliminating the need for protective covers.

"The market for indoor and outdoor displays presents a significant growth opportunity for LEDs over the coming years," said Francis Khor, director of marketing for the Optoelectronics Product Division at Avago. "Avago's ASMT-YTx2 LEDs are engineered to meet the display market's demand for reliable high-brightness, high-resolution performance, all at a competitive cost." ■

Bridgelux LED Array Portfolio Expands to Include High Efficacy Options

Bridgelux Inc. announced the expansion of its portfolio of award-winning LED Arrays to include new high efficacy products that meet the price and performance demands of the \$10 billion LED retrofit bulb market opportunity.



Bridgelux expands LED Array portfolio to include high efficacy options for the retrofit bulb market.

Featuring a broad product portfolio, industry leading light output performance, superior color quality and high efficacy across the white color spectrum; Bridgelux is now delivering high brightness, energy efficient light for both low and line (mains) voltage products to simplify system design and integration for lamp manufacturers.

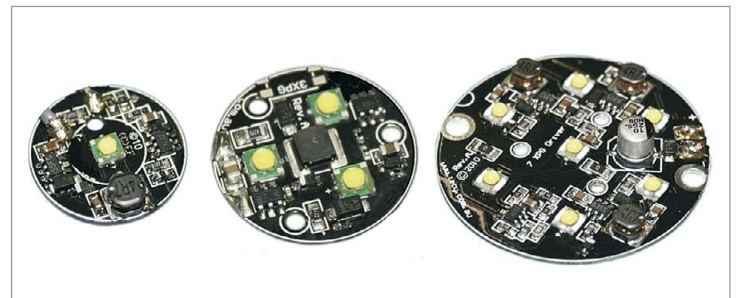
The Bridgelux LS Array Series now includes options designed specifically for low voltage lighting. The new miniaturized LS arrays enable both diffuse and directional light sources for applications including landscape lighting, residential lighting, track lighting, MR16 lamps and other 12 volt retrofit light bulbs. Delivering between 240 and 360 lumens in warm and cool white, these products are ideal replacement options for low wattage halogen and incandescent lamps.

The Bridgelux ES Array Series has also been expanded to include new voltage options for both cool white and warm white to better enable the A-line and decorative lamp markets. The new ES arrays take advantage of existing electronic drivers to facilitate rapid new lamp and luminaire product introductions.

"As governments around the world rapidly move to eliminate inefficient incandescent lamps the demand is growing for LED replacement lamps that can deliver the quality of light required by consumers," said Jason Posselt, Bridgelux vice president of marketing. "These new arrays deliver high quality light while simultaneously helping our customers reduce design complexity and product cost for this price sensitive market." ■

Cutter Release New Series on Integrated Light Engines

Lighting fixture designers can select from single, triple and 7 up designs with single Cree XP family LEDs or mix from Cree XPC, XPE or XPG, in all colours and colour temperatures, for the ultimate in Light Engine flexibility.



Cutter Electronics' Quiccpower program includes 1, 3 and 7 LED modules.

Cutter Electronics is pleased to announce the release of its QUICCPower series of Led Light Engines, offering the record breaking efficacy of the Cree XP family of LEDs in a series pf plug and play modules

The new range of Quiccpower engines will enable fixture makers with less experience in the Solid State arena to get products to market rapidly. The new Quiccpower family offers compatibility with leading optic vendors, products and user defined microcontroller based features such as dimming, colour mixing and thermal feedback all based on the customer's unique needs.

Future Lighting Solutions

the company behind the light

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with NXP dimmable LED driver technology

We are the market leader in LED based lighting solutions.

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Download the virtual catalog to start your next LED design at www.FutureLightingSolutions.com



The Quiccpower program includes round single, circular, modules with 1, 3 and 7 LEDs, in a variety of color temperatures. Managing Director Mark Riley noted, "We have stock available on the base boards and several standard engines, but can provide a wide range of options based on customer requests." The modules come with a three year warranty and feature ANSI-binned Cree XPC, XPE and XPG LEDs. ■

The New Philips Fortimo Light Engine Modules are Available Now

Future Lighting Solutions announced the availability of Philips Fortimo light engine module family of products with their associated drivers and cables.



Future Lighting Solutions offers new Philips Fortimo Light Engine Modules.

These Philips Fortimo light engine modules address the needs of many lighting applications, such as downlighting, accent lighting and spotlighting, while enabling energy savings. They are designed for ease of integration into new or existing luminaires and deliver high quality illumination with enough lumens to compete directly with conventional alternatives.

The Fortimo Module system is future-proof. The latest advances in LED efficacy can be easily implemented without changing the driver, the dimensions of the LED module or the lumen output. This means stability for the luminaire manufacturers and reassurance for lighting designers and specifies that the Fortimo module system will remain available for their projects in the years to come.

"Our enhanced portfolio offering comprised of Philips light engine modules, drivers and controls will assist our customers in accelerating time to market," said Gerry Duggan, Executive Vice President of Future Electronics, the parent company of Future Lighting Solutions. "It also advances our mission of simplifying and promoting solid-state lighting development." ■

AZ e-lite Showcases Sustainability Efforts in Clean Energy Expo Asia 2010

AZ e-lite Pte Ltd ("AZ e-lite"), a wholly-owned subsidiary of Aztech Group Ltd specialising in the design and development of quality LED lighting, showcased its range of eco-friendly LED lighting solutions as part of its sustainability efforts at Clean Energy Expo Asia (CEEA) 2010.



AZIS Spot is available in 2 power and 2 colour temperature versions.

CEEA 2010, which is part of the Singapore International Energy Week 2010, is a premier exhibition cum conference to address key issues in the areas of renewable energy, energy efficiency and sustainable development in the Asia Pacific. Several innovative LED technologies from AZ e-lite will be demonstrated at the CEEA, including the newly launched AZIS Spot LED Spotlight which is a perfect replacement for MR16 base halogen lamp.

The AZIS Spot provides ambient level light and saves up to 80% energy compared to halogen spotlights. It can also be used with regular incandescent dimmers to provide dimming effect. With a long lifespan of 35,000 hours, users can expect savings in both electricity bills and replacement cost. AZIS Spot is available in 2 power (7-Watt & 10-Watt), 2 beam angles (24 & 36 degrees) and 2 colour temperatures (2700 K & 3000 K). ■

LedEngin adds PAR30 Lamps to LuxPAR™ Lamp Family

LedEngin, Inc. expands LuxPAR™ family of high quality, energy-efficient LED PAR lamps with the addition of PAR30 lamps. As with LuxPAR38 and LuxPAR20 lamps, the company's new LuxPAR30 lamps are available in a full range of color temperatures and beam distributions. The company's PAR lamps feature LedEngin proprietary LED components and optical designs that deliver highest Center Beam Candle Power (CBCP), superior light quality and uniformity across the light beam and color consistency over time that is 10 times better than demanded by Energy Star requirements. LuxPAR lamps offer significant energy savings as compared with traditional halogen lamps.



The PAR 30 LED lamp is the latest member of LedEngin's LuxPAR™ lamp family.

LedEngin LuxPAR 30 lamp key features include:

- Maximum "Lux on Target": Highest quality light where needed with well-controlled beams and minimal discomfort glare.
- Superior light intensity and color uniformity throughout beam with patented optical design.
- Crisp illumination without excess shadowing or fringes due to single package LED / single lens integration.
- Center Beam Candle Power (CBCP) of up to 3000 cd in narrow flood beam.
- 50 lm/W efficacy exceeds Energy Star requirements for PAR30 replacement lamps.
- Exceeds 80% energy reduction as compared with 60 W halogen lamps.
- Color point stability 10x the performance demanded by Energy Star.
- Color temperature options include 2700, 2900, 3100 & 4100 Kelvin.
- Optical distribution options include narrow flood and flood beams.
- Dimmable and non-dimmable options.

"With the introduction of LuxPAR30 lamps, we have now completed our PAR lamp product family. The PAR lamp series coupled with our MR-16 offering will enable our customers the flexibility to customize unique, high quality lighting creating a consistent look and quality of light throughout installations" said David Tahmassebi Chief Executive Officer, LedEngin, Inc. ■

First High-Efficiency Photolithography LED Light Tube for Clean Rooms

Lextar Electronics Corporation reveals a series of new lighting applications, including the world's first high-efficiency photolithography LED light tube for clean rooms, high-brightness LED light tubes of 2,600 lm, ultra light and bright LED bulbs of 1,000 lm, and CCT adjustable flat panel light. The products debuted at the 2010 Hong Kong International Lighting Fair (Autumn Edition) held at the Hong Kong Convention and Exhibition Center from Oct. 27 to 30. These innovative products will demonstrate the diversity of LED products and the technical strength of Lextar.



Lextar uses a technology that combines a special LED and a specially-made light tube lens with cut-off filters in LED light tubes, and extended the LED backlight technology to lighting products.

Lextar displayed four main series of products: LED light tubes, LED bulbs/downlights, LED panel lights and COB (Chip-on-Board) light engines.

LED Light Tube Series:

In LED light tubes, Lextar introduces the world's first high-efficiency photolithography LED light tube for clean rooms. The novel product uses a technology that combines a special LED and a specially-made light tube lens with cut-off filters. It can filter wavelengths of less than 500 nm and its efficiency is double that of similar tubes made with amber LED which are currently on the market. It is the ideal

lighting product for plants and clean rooms. It has a life-time of 40,000 hours, which is 7 to 10 times longer than that of traditional tubes. Another product, a high-brightness high-efficiency LED light tube of 2,600 lm, boasts the efficiency of 100 lm/W, and its high-brightness design extends its application to business environments with high ceilings, such as halls or factories. In addition, Lextar is introducing an ultra light plastic LED tube of 175 g, which is a breakthrough in LED lighting technology by the Lextar R&D team.

LED Bulb/Downlight Series:

In the bulb series, Lextar introduces an ultra light and bright LED bulb of 1,000 lm to replace the traditional 100 W incandescent bulb. Its power consumption of 12W saves up to 88% of energy compared to traditional bulbs. Its non-metallic heat sink reduces the weight to below 140 g. Lextar is also exhibiting a number of adjustable LED light sources, including a slim designed dimmable downlight module of a 2-cm thickness with a remote control, and a 4.5 W dimmable bulb.

LED Flat Panel Light Series:

With years of R&D technology in TFT-LCD backlights, Lextar extends the LED backlight technology to lighting products. Lextar is exhibiting a 60 x 60cm CCT adjustable LED flat panel light with a remote control which offers color temperatures ranging from warm white to cool white. The user can adjust the color temperature according to the occasion, time and mood to create different ambiances. LED panel lights emit a soft light produced by a secondary source. It creates a stable and soothing lighting effect which is suitable for offices, hospitals, schools and shopping centers.

COB Light Engine Series:

In addition to lighting applications, Lextar's COB (Chip-on-Board) light engine is a core component in lighting products. Lextar showcased its mega high brightness 70 W COB of 8,000 lm at the 2010 Hong Kong International. In addition, COB light engine series of 4 W, 6 W, 10 W, 70 W and 100 W were on display in the exhibition, and product application ranges from low-power bulbs to high-power bay lights, street lights, architectural light and more. The features include high stability, long lifespan and multiple applications. ■

Evluma's New 50W LED Clearlight Beacon Boosts Lumens

Evluma introduced the Clearlight Beacon, the powerful, new 50 W member of the Clearlight line of LED replacement luminaires for dusk-till-dawn fixtures. At 66 lumens per watt (LPW), the Beacon has the highest LPW of any Clearlight yet. The Beacon employs CREE XP-G Outdoor White LEDs and a new high-powered integral driver designed by Evluma's engineers.



Evluma's new clearlight beacon offers 66lm/W at 50W power and replaces HPS lamps up to 150W.

The 50W Clearlight Beacon is a mogul base, direct screw-in replacement for 50-175 W MV and 70-150 W HPS dusk-till-dawn fixtures. Light on the ground is delivered in a circular, Type V pattern. Prior to releasing the Beacon, Evluma spent months in the field with over 20 different electrical cooperatives and municipalities developing a product that would emit a wide angle of light while reducing the glare that frequently accompanies outdoor area lighting.

The Beacon uses highly efficient reflective optics and a diffused customized optical acrylic cover to help create a wide candela distribution. With a peak vertical angle just below 70°, the Beacon emits up to .01 footcandles (full moonlight) at four mounting heights per side. "Our customers asked for a replacement LED luminaire that would extend visibility over a great distance. Because LED lighting offers better color rendering and a more uniform surface illuminance than HPS or MV, it is possible to do more with less light," said Keith Miller, President and CEO of Evluma.

Evluma suggests pairing the Beacon with other members of the Clearlight family, such as the Dark Sky Friendly 40 W EcoSpot, to strategically control what is illuminated and how. Dusk-till-dawn fixtures previously limited to a single function can be customized. "For example, you could place a Beacon in a fixture near a parking lot, but then use an EcoSpot for the fixture next to an apartment building where light trespass might be an issue," said David Tanonis, VP of Sales & Marketing at Evluma. "At the same time, owners of Mercury Vapor fixtures can easily phase out environmentally hazardous bulbs and avoid an unnecessary maintenance burden. Energy efficiency, while key, doesn't have to be the only thing driving a change in lighting practice."

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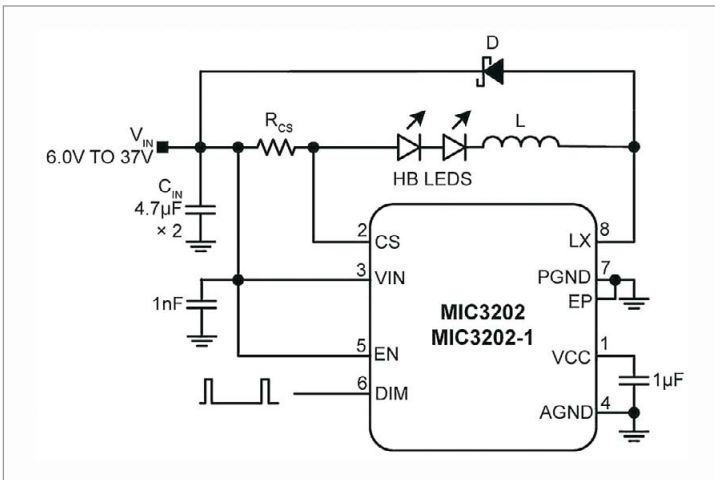
TLFEA

www.lighting.org.tw

The Clearlight Beacon has a 5 year warranty and is 50% more energy efficient than a 100W HPS bulb and 70% more energy efficient than a 175W MV bulb. As with all Clearlights, an active cooling system keeps the LED junction temperature low, resulting in long life and delivering an estimated L70 of 70,000 hours or longer. LM-79 data for the Clearlight is available at www.evlluma.com. NRTL (UL equivalent) testing is currently underway at MET Laboratories. All Clearlight products are manufactured in Seattle, WA from US and imported parts. ■

Micrel Expands Lighting Portfolio with New Step Down HBLED Driver IC

Micrel Inc. rolled out the MIC3202, a new Step-Down High Brightness LED (HBLED) driver with high-side current sense targeting MR-16 lamps and other general illumination applications. This device reduces the size, complexity and cost of the driver IC solutions for various lighting applications. The MIC3202 is currently available in volume quantities, with pricing starting at \$1.29 for 1K quantities.



MIC3202 step-down converter: The functional application diagram.

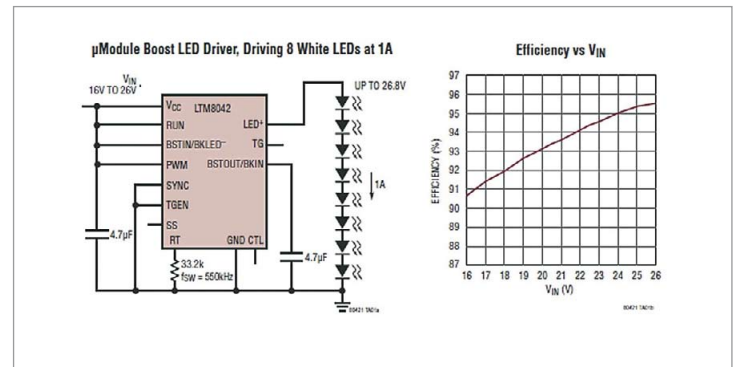
"With the ever increasing concern regarding carbon emissions and energy costs, high-efficiency lighting has become one of the highest growth segments of the electronics market," noted Doyle Slack, senior marketing director for Analog Power, Micrel. "Micrel's LED driver products provide the performance, flexibility and ease-of-use required by LED lighting system designers to meet these challenges."

The MIC3202 is capable of driving up to eight 1A HBLEDs in series at more than 90 percent efficiency with ± 5 percent current accuracy from input voltages of 6 V to 37 V. With its hysteretic control architecture and high-side current sense scheme, the MIC3202 is well positioned to provide constant current with changes in input

voltage and output load. The MIC3202 operating frequency is adjustable up to 1MHz to allow flexibility in the design. The MIC3202 features a dedicated PWM dimming pin allowing ultra wide contrast ratios, an enable pin for very low power shutdown, over temperature protection and UVLO. The MIC3202 has an internal power switch and requires no external compensation. In addition to enhanced power driving capability/reliability, the MIC3202 comes in an exposed pad SOIC-8L package. ■

LTM8042 and LTM8042-1: uModule LED String Drivers with Transient Protection

Linear Technology Corporation introduces the LTM8042 and LTM8042-1, DC/DC uModule® LED drivers for strings of up to 8 white LEDs or 9 red LEDs. Capable of operating as boost, buck or buck-boost with 3V to 30V input voltage range; each device is a complete LED driver solution in a 9 mm x 15 mm x 2.8 mm LGA (land grid array) package.



Linear's LTM8042 series boost LED drivers offer simplified LED string driver layout.

Features:

- True Color PWM™ with 3000:1 Dimming Ratio
- Operates in Boost, Buck Mode or Buck-Boost Mode
- Wide Input Voltage Range:
 - Operation from 3 V to 30 V
 - Transient Protection to 40 V
- Gate Driver for Optional PWM Dimming with P-channel MOSFET
- Adjustable Frequency: 250 kHz to 2.5 MHz
- Constant-Current and Constant-Voltage Regulation
- Low Shutdown Current: <math><1\mu\text{A}</math>
- RoHS Compliant Package with Gold Pad Finish
- Tiny, Low Profile (9 mm x 15 mm x 2.82 mm) Surface Mount LGA Package

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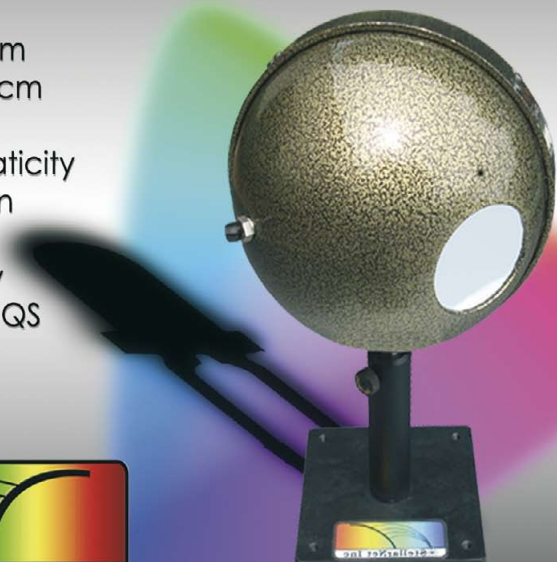


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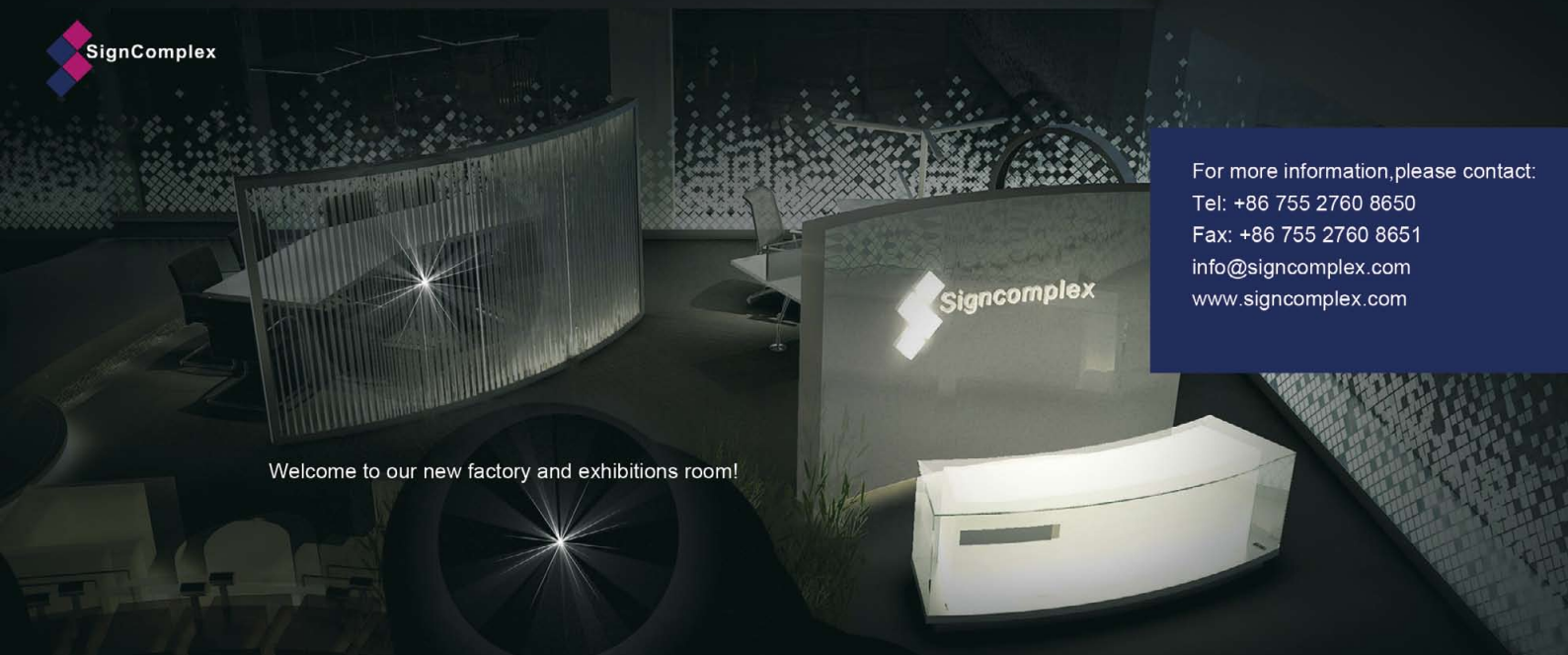
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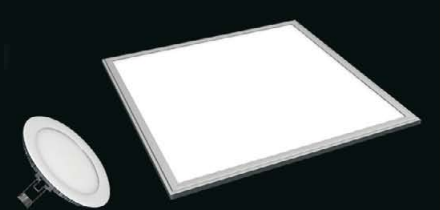
CONTROL SYSTEM



X-TUBETM fluorescent LED tube T10



ROUND/SQUARE PANEL LIGHT

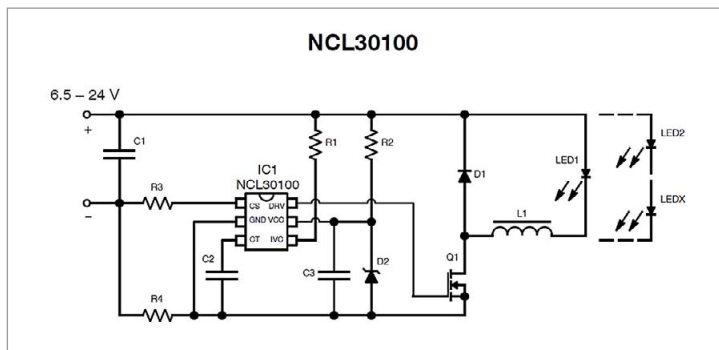


The LTM8042 and LTM8042-1 boast 0.5% output current line regulation accuracy and can withstand up to 40 V input transients. The LTM8042 sources up to 1A of current, whereas the LTM8042-1 sources up to 350mA. Each features True Color PWM™ dimming with 3,000:1 ratio or analog dimming with 10:1 ratio. Their compact, robust, and complete solution permit a quick design-to-fabrication of LED string driver circuits in applications such as industrial illumination, backlight displays, scanners, and automotive as well as avionics lighting.

The LTM8042 and LTM8042-1 are switching regulator LED drivers with very accurate output current line regulation, ideal for driving LEDs or for general purpose current sourcing. Inductors, capacitors, regulator IC and compensation circuitry are enclosed and protected in a plastic package resembling an IC. These devices are pin-compatible with each other. ■

ON Semiconductor Expands Its LED Lighting Solutions Portfolio

ON Semiconductor showcased its newest Light Emitting Diode (LED) lighting solutions at the Strategies in Light Europe conference Sept. 27-29 in Frankfurt, Germany.



ON Semiconductor NCL30100: Typical application example of the LED converter.

"Energy efficiency in a cost-effective design is critical to achieving high overall luminous efficacy in solid state lighting applications," said Laurent Jenck, director of ON Semiconductor's LED Lighting segment. "High Brightness LEDs (HBLED) are replacing incandescent lamps in a broad range of applications, and the overall popularity of solid state lighting is continuing to grow across many different industry sectors. ON Semiconductor has recognized the many needs and applications for efficient LED lighting and effective LED Lighting protection and is rapidly developing solutions targeted to address customers' needs ranging from backlighting in handheld electronics and LCD panels, to general lighting, architectural lighting and automotive lighting."

Buck LED Driver Controller for Efficient, Compact Lighting Designs: ON Semiconductor's NCL30100 is a new step-down (buck) LED driver controller that provides an ideal solution for high-brightness LED

driver applications where space is limited and high efficiency is important, such as low voltage MR-16 LED bulbs. The new controller helps designers optimize their solution for a wide range of LED drive currents and is ideal for low voltage halogen-to-LED replacement, LED track and landscape lighting, and solar LED products.

The NCL30100's ability to operate at high switching frequency and the flexibility it gives to select the most appropriate power MOSFETs, combine to support the customer in achieving an optimal solution for their design.

Based on a peak current, quasi fixed-off time control architecture optimized for continuous mode step-down operation that eliminates the need for an output filter capacitor, the NCL30100 saves both board space and cost. A switching frequency of up to 700 kHz enables designers to use smaller inductors and therefore achieve further valuable PCB real estate savings. The NCL30100 meets the energy saving demands of the latest designs by achieving up to 95 percent efficiency. For low voltage AC applications, the NCL30100 can be dimmed via a standard wall dimmer.

Next Generation ESD Protection for High Power HBLEDs:

ON Semiconductor's new CM1771 is a 100 V back-to-back electrostatic discharge (ESD) protection device that prolongs operation of HBLED lamp modules. It is the industry's first ESD protection solution for HBLED applications to feature a 100 V breakdown voltage. The CM1771 is a member of the innovative LuxGuard® family of turnkey solutions for ESD protection in high voltage circuits and is ideal for general illumination, signage, automotive and commercial lighting applications.

To ensure emerging opportunities for HBLED technology are realized, emitter manufacturers need to be sure their devices are not left vulnerable to damage from ESD strikes. Delivering protection at high breakdown voltages presents a new challenge in dissipating higher levels of power when an ESD strike occurs while maintaining acceptably low dynamic clamping voltages. The proprietary side mount arrangement featured in the CM1771 delivers robust, symmetrical ESD protection in a very small, cost-effective die that can be easily integrated into a wide selection of HBLED lamp modules.

Adjustable CCRs for LED Lighting Applications:

ON Semiconductor has expanded its portfolio of adjustable Constant Current Regulators (CCRs). The new CCRs, which provide voltage surge suppression to protect general lighting and automotive LEDs, are simple and highly robust devices designed to provide cost-effective current regulation to LEDs. They are based on the company's proprietary, patent-pending Self-Biased Transistor (SBT) technology and regulate current over a wide voltage range.

ON Semiconductor's new compact CCR devices eliminate the need for additional regulation within the system design. They offer engineers a highly effective LED protection solution that supports tight application budgets and development schedules.

The NSI45090JDT4G and NSI45060JDT4G are offered in D-PAK packages and priced at \$0.16 per unit in 10,000 unit quantities. The NSI45020JZT1G and NSI45035JZT1G are offered in SOT-223 packages and priced at \$0.10 per unit in 10,000 unit quantities. These devices are all AEC-Q101 qualified. All of the CCRs are offered in compact, thermally robust, RoHS-compliant packages, made using a halogen-free moulding compound and lead-free lead finish and have an operating temperature range of -55°C to $+150^{\circ}\text{C}$. ■

LED Driver from Diodes Inc. Simplifies Low Voltage Low Cost Lighting Design

Diodes Incorporated has announced an LED driver tailored to fit low voltage illumination products operating at between 6 V and 30 V. The AL8805, a 1 A rated buck mode constant current switching converter, will support up to ten 3 W LEDs connected in series, suiting a range of low cost 'safe electrical' designs including the ubiquitous MR16 lamp.



Diodes' AL8805 1A LED driver simplifies low voltage low cost lighting design.

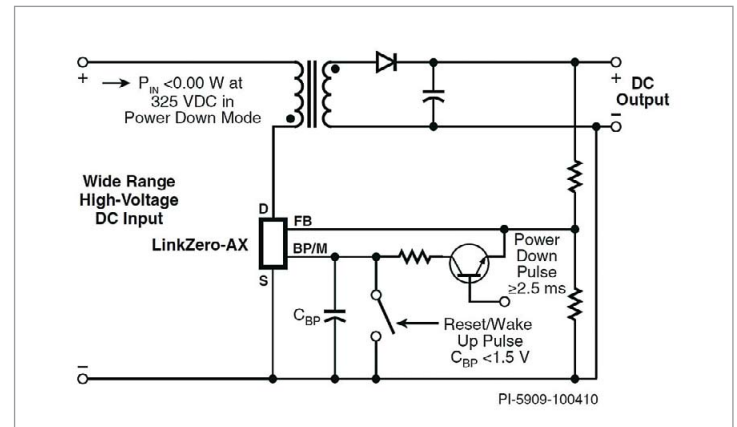
The driver's typical constant current output accuracy of 5%, irrespective of source voltage and LED chain length, is more than sufficient to meet the needs of low cost lighting products, ensuring uniform LED brightness and good inter-lamp matching without the need for ballast resistors.

With nominal output current determined by external resistor setting, LED dimming is simply achieved by either a DC voltage or PWM signal on the AL8805's control input. A DC voltage between 0.5V and 2.5V yields an output current between 25% and 100% of nominal, while a PWM signal between normal CMOS or TTL levels offers a highly flexible 1000:1 dynamic dimming range. On/off control is provided via a $<0.4\text{ V}$ signal applied to the same control input.

The LED driver's enhanced switching speed and low on resistance provide 1MHz switching frequency capability which reduces the size of the external components required in thermally demanding environments. ■

Power Integrations Cuts Standby Waste to Zero with LinkZero™-AX

Power Integrations introduced LinkZero-AX, an integrated offline switching IC that enables designers to achieve 0.00 watts of standby energy consumption in auxiliary power supplies. Commonly used in such products as major appliances, TVs, and remotely-controlled electronic lighting ballasts, auxiliary power supplies continuously draw power as long as the product is plugged in, resulting in significant standby energy waste.



A schematic of a LinkZero-AX application to achieve 0.00 watts of standby energy consumption.

LinkZero-AX features an innovative power-down mode that effectively turns off the auxiliary power supply when the end product is idle. Power-down mode is triggered by a signal accessible to a microcontroller, completely shutting down switch-mode operation and internal switch control circuits, eliminating energy wasted by these unnecessary functions. While in power-down mode, the LinkZero-AX stays alive, allowing the IC to be awakened with a reset pulse or button press. The bypass pin on the LinkZero-AX IC can also provide up to 500 A of current for use by any system control or sensing circuit.

LinkZero-AX provides designers with flexibility to build ultra-low standby power supplies without mechanical AC mains switches. When used in tandem with Power Integrations' CAPZero™ X capacitor discharge IC and SENZero™ sense resistor disconnect device, LinkZero-AX reduces standby power waste in high-power consumer products and appliances to as low as 4 mW, or effectively zero. (IEC 62301 Clause 4.5 classifies power usage of less than 5 mW as zero.)

Delivering the industry's lowest component count for standby power supplies, LinkZero-AX is a simple upgrade for engineers targeting zero standby energy consumption. The IC allows appliance designs to easily exceed all global energy-efficiency regulations, including the European EcoDesign Directive and ENERGY STAR(R).

Comments Silvestro Fimiani, product marketing manager at Power Integrations: "Power Integrations first delivered a stake in the heart to energy vampires with our LinkSwitch™ ICs, the first cost-effective replacement for old-fashioned, energy-sucking linear transformers. Now we've put a nail in the coffin with LinkZero-AX, which eliminates the energy vampires lurking inside appliances, TVs, and other products that utilize low-power auxiliary power supplies. LinkZero-AX enables designers to achieve zero standby power consumption at the lowest system cost using the fewest parts. It is a simple solution to implement - in new designs or as a retrofit upgrade - and compliance with international efficiency regulations is assured." ■

Styron Introduces Customized Materials Solution for LED Applications

Styron announced the launch of a new customized material solution for durable LED (Light Emitting Diode) applications. Opalescent and tinted versions of CALIBRE™ 301-58LT tailored to customer needs are now available. In addition, UV protection can be provided on request depending on the requirements of the end-application.

High Performance Lighting Resin:

Styron's innovative CALIBRE™ 301-58 LT resin combines high light transmission comparable to acrylics with high melt flow, making it an ideal solution for LED lighting applications. The resin's high melt flow and excellent processing characteristics enable extra thin luminaire designs, providing product designers with a wider spectrum of design options to help shape the future of LED luminaires and lighting.

Now Available in Customized Versions:

In order to provide even more design flexibility to luminaire designers and manufacturers, Styron now offers CALIBRE™ 301-58 LT in customized versions with opalescence or tints like water white, a requirement for many modern luminaire designs. In addition, UV protection can be provided on request depending on the requirements of the end-application.

Opalescence for Open Space Lighting:

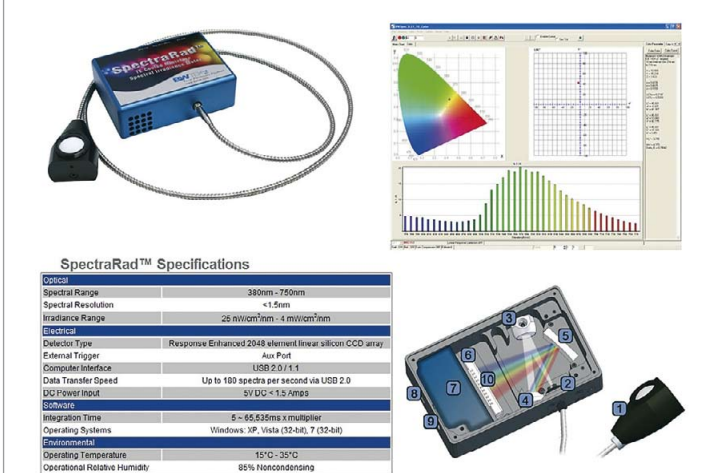
Because of its focused light source, the LED is not traditionally seen as a viable solution for open space lighting where a diffused, soft light is generally preferred. With its optional opalescent tint, CALIBRE™ 301-58 LT can overcome this challenge helping to manage light

transmission levels. The opalescent tint opens up the potential large area, energy efficient light sources for places such as offices or factory warehouses.

"LED's have the potential to become the mainstream solution for a wide range of sustainable lighting applications and our latest innovation is specifically designed for the LED lighting industry" says Tsuyoshi Okii, Global Marketing Manager for Electrical & Lighting at Styron. "With the customization of CALIBRE™ 301-58 LT, Styron now provides a materials solution for both focused and diffused lighting applications." ■

Konica Minolta Sensing Americas and B&W Tek Announce SpectraRad™ Irradiance Meter

Konica Minolta Sensing Americas, has partnered with B&W Tek, an advanced instrumentation company to introduce a new, lower cost option for LED characterization. Together, they announce the new thermoelectric (TE) cooled miniature spectral irradiance meter, the SpectraRad™, filling the need for a midrange irradiance meter in the Konica Minolta product line.



The image shows the SpectraRad™ irradiance meter, a small blue device with a fiber-optic cable and a probe. To the right is a screenshot of the BWSpec™ software interface, displaying a spectral power distribution graph with a color spectrum overlay and a bar chart below it. Below the meter and software is a table of specifications.

SpectraRad™ Specifications	
OSPCD	
Spectral Range	390nm - 750nm
Spectral Resolution	<1.5nm
Irradiance Range	28 mW/cm²nm - 4 mW/cm²nm
Detector	
Detection Type	Response Enhanced 2048 element linear silicon CCD array
External Trigger	Aux Port
Computer Interface	USB 2.0 / 1.1
Data Transfer Speed	Up to 100 spectra per second via USB 2.0
DC Power Input	5V DC < 1.2 A max
Software	
Integration Time	5 - 65,535ms x multiplier
Operating Systems	Windows XP, Vista (32-bit), 7 (32-bit)
Environmental	
Operating Temperature	15°C - 35°C
Operational Relative Humidity	85% Noncondensing

SpectraRad™ is a lower cost miniature TE cooled spectral irradiance meter for LED industrial and laboratory light measurement applications.

The SpectraRad™ is a miniature TE Cooled Spectral Irradiance Meter designed for industrial and laboratory light measurement applications with a USB 2.0 interface. It is equipped with a right angle, fiber-optically coupled cosine corrector and is irradiance calibrated against a NIST traceable tungsten light source. BWSpec™ software, included, provides for the characterization and measurement of many lighting devices and systems. The standard software features include time line

AAL406 LED Fault Monitor and Bypass

Features

- Open and Short LED Sensing
- Latching SCR 'Crowbar' for Open LED Bypass
- Architecture to Support Unlimited Cascade Connection of Individual AAL406s within Cascaded Connection of LEDs for an Individual String
- Ground Translated Fault Signal for Any String Open or Short
- Thermally Friendly Package, Low SCR Voltage Enable Use with String Currents of 50mA to 750mA
- Useable with 3 LEDs per AAL406
- Power Cycling Required to Properly Clear Fault

Application Examples

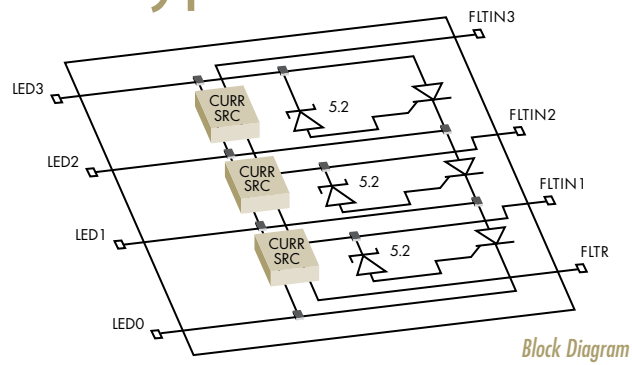
- Commercial and Industrial Lighting
- Residential Lighting
- Automotive Lighting
- Aircraft Lighting
- Street Lights



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Ordering Information

Ordering PN(1)	Subgroup	Description	Temp. Range	Package	Packing Type	Packing Qty
AAL406 A-S8B-G-LF	Monitoring and Interface	LED String Fault Monitoring	Automotive	8-Pin SOIC Thermal Pad	Tube	98
AAL406 A-S8B-G-LF-TR	Monitoring and Interface	LED String Fault Monitoring	Automotive	8-Pin SOIC Thermal Pad	13" T&R (2)	2500

(1) Only RoHS/Lead-Free Packaging is normally offered.

(2) T&R - Tape and Reel

*For samples and additional information,
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recording, data smoothing, illuminance (lux), chromaticity, color temperature, externally triggered pulsed light capturing, and other data-handling functions. The SpectraRad™ is ideal for lamp and LED characterization, color analysis, photo stability testing, photobiology and photochemistry.

"The advantage to users is that SpectraRad™ is a low cost, high resolution, high sensitivity, Thermoelectric Cooled CCD array spectral irradiance meter. This solution offers a high dynamic range with superior long term stability. It is ideal for various applications including low light level detection and long-term monitoring applications", said Randy Klimek, New Product Project Manager for KMSA.

The SpectraRad™ offers significant improvements over traditional filter based technology instruments. Filter based instruments have been desired for certain properties (cost, speed and portability) but lack the resolution to accurately describe the spectral characteristics of a light source. Filter based instruments only acquire average three data points across the entire spectrum of light to yield colorimetric values. This is accomplished by the use of filters corresponding to the normal human eye response. These filters can only be manufactured to a certain degree of accuracy. Due to these facts, filter based meters are susceptible to errors because of the deviation of the filter response from the ideal human eye response and the lack of resolution needed to accurately describe narrow bandwidth light sources.

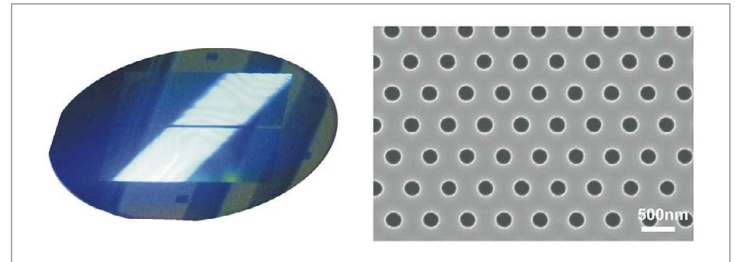
The SpectraRad™ avoids these problems at a comparable cost, higher speed and small footprint because it acquires hundreds of data points across the visible spectrum. The 2048 pixel linear CCD array provides the precision required to accurately measure narrow bandwidth light sources or LEDs. Having multiple sensors also enables the unit to report spectral data and display spectral graphs, making it the ideal instrument for evaluating LEDs, which is today's dominant light source. ■

Eulitha Unveils New Photolithography Technology for Photonics Patterning

Eulitha AG, a Swiss based nanolithography company, has developed a proprietary photolithography technology for low-cost and high-throughput fabrication of photonic nanostructures. This solves a major ongoing problem faced in the fabrication of high-resolution photonic structures since standard photolithography equipment either lacks the required resolution or its cost is prohibitively high. The patented technology enables the formation of periodic nanostructures over large areas for such applications as LEDs, solar cells and flat-screen displays.

The new technology, dubbed PHABLE (for Photonics Enabler), is a mask based UV lithography. Unlike currently available technologies, the PHABLE system forms an image that has practically unlimited

depth of focus. Therefore non-flat substrates, such as LED wafers, can be patterned uniformly and reproducibly. It also allows combinations of different patterns such as linear diffraction gratings and arrays of holes on hexagonal or square grids to be printed using a single exposure onto a chip or a wafer. The resolution of the printed features can be as small as one quarter of the illumination wavelength. The masks required by PHABLE can be produced inexpensively using standard chromium-on-quartz mask-writing technology. The technology was presented at the MNC 2010 conference in Fukuoka, Japan, from November 9-12, 2010.



Eulitha's PHABLE system forms an image that has practically unlimited depth of focus and therefore allows processing of non-flat substrates, such as LED wafers (left). Eulitha PHABLE allows processing of different pitch and hole diameters, for instance pitch 500nm / hole diameter 250nm (right).

Photonic crystals needed for enhancing the light extraction efficiency of LEDs is one of the major applications of the new technology. Unlike the Nanoimprint method that is commonly employed for this purpose, it avoids contact between the mask and the wafer, and it does not require consumable soft-stamps. Therefore an expensive two-step process is avoided. It is expected that other applications will also benefit greatly from this development, including nanowire-based LEDs and photovoltaic devices, heteroepitaxy on patterned silicon substrates and epitaxial lateral overgrowth (ELO) used in blue-ray lasers. Wire-grid polarizers, as required for both LCD displays and projectors, may also be produced with the PHABLE technology.

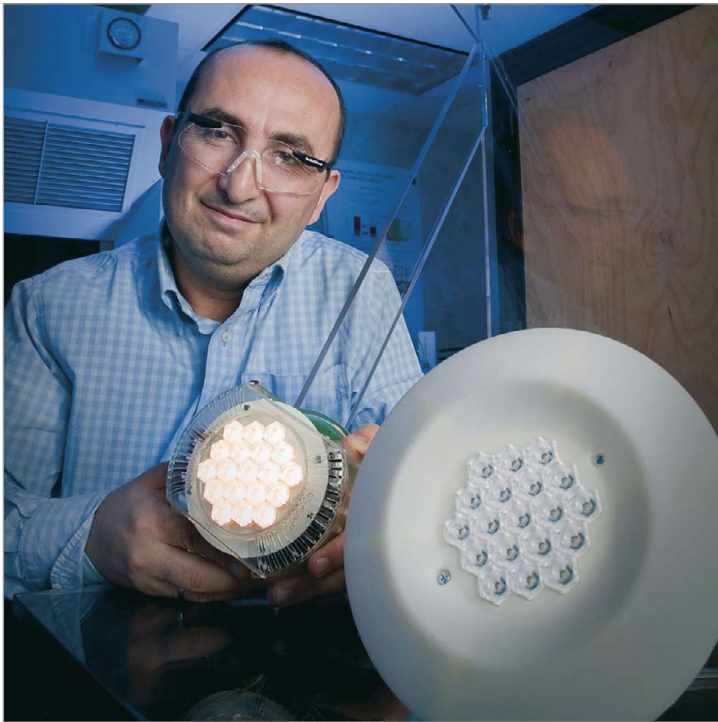
The compatibility of PHABLE with conventional masks and UV-exposure processing will ensure a smooth adoption of PHABLE by the industry. Standard photoresists with suitable resolution and etch properties are available from multiple vendors. Therefore, HB-LED and other device manufacturers will be able to rely on the usual, well-established sources for obtaining the required consumable materials so as to ensure a low-cost manufacturing process for their photonic nanostructures.

Eulitha now offers samples and wafer batch processing services to companies and researchers developing nanostructure-based products who are interested in taking advantage of this breakthrough technology. It is also currently offering laboratory lithography tools for 2"-4" wafers that are suitable for product development. High-volume production tools with throughput in excess of 100 wafers-per-hour will be made available to manufacturers in the near future. Eulitha expects many future photonic devices to shine even brighter with the introduction of the PHABLE technology. ■

Research News

GE Scientists Employ Jet Engine Cooling Technology in Prototype LED Bulb

A 1,500-lumen PAR 38 LED bulb prototype produces as much light as a 100-watt halogen bulb, using 1/3 the energy. GE's patented "dual cool jets" technology solves thermal challenges and enables a lamp design that is half the size and weight of a 600-lumen LED downlight available today.



As part of the DOE project, GE and the research team of Professors Bongtae Han and Avram Bar-Cohen have developed and demonstrated novel cooling technologies.

Scientists from GE Global Research, the technology development arm for the General Electric Company (NYSE: GE), GE Lighting, and the University of Maryland—as part of a two-year solid-state lighting program with the U.S. Department of Energy—have announced the successful demonstration of a 1,500-lumen LED bulb (a standard 100-watt halogen PAR38 bulb produces 1,500 lumens) that addresses key barriers to more widespread adoption of LED bulbs for general lighting.

The prototype provides a snapshot of the future: "The scientists and technology leaders involved in this collaboration are dissolving some major barriers to the commercialization of general lighting LED bulbs," says John Strainic, global product general manager for GE Lighting.

"We're taking swings at issues such as higher light output options, thermal management, and bulb size and weight. This kicks open the door to the solid-state age that is upon us."

This LED technology achievement was announced during a future of lighting symposium that GE hosted at its Global Research headquarters in Niskayuna, NY.

As part of the DOE project, GE and the research team of Professors Bongtae Han and Avram Bar-Cohen at the University of Maryland's A. James Clark School of Engineering have developed and demonstrated novel cooling technologies that effectively manage the heat and promote lower system costs by reducing the number of LED chips required, when compared to conventional cooling technologies.

Mehmet Arik, a mechanical engineer at GE Global Research and principal investigator on the LED project, says, "This is a revolutionary cooling technology with great promise. It has the potential to help us take LED lighting performance and efficiency to new heights. Through further research and improvements, we may be able to increase performance without compromising the efficiency or lifetime of an LED bulb."

Aviation and Energy roots:

GE's cooling solution is based on technology the company now uses in its Aviation and Energy businesses. GE Global Research has a world-class team of fluidics experts who specialize in technologies that manage flow. They are developing innovative ways to control airflow and combustion to dramatically reduce the amount of pressure losses and loading characteristics in aircraft engines and power generation in gas and wind turbines.

Arik adds, "Just one floor down in the same research building, I have colleagues using our dual cool jets technology to improve both the power and efficiency of GE's jet engines and power generation turbines. With wind turbines, for example, we're manipulating airflow to increase wind energy production. With LEDs, we're using dual cool jets to improve the heat transfer rate and reduce the number of chips in the lamp."

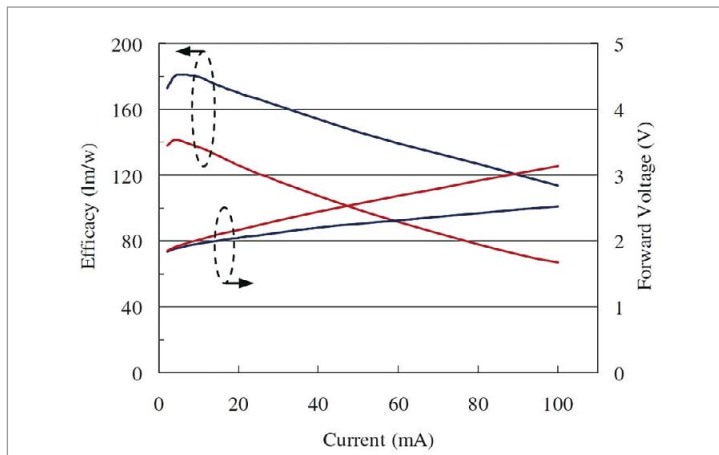
How GE's dual cool jets technology works:

GE dual cool jets are very small micro-fluidic bellows type devices that provide high-velocity jets of air, which impinge on the LED heat sink. These jets of air increase the heat transfer rate to more than ten times that of natural convection. The improved cooling enables LED operation at high drive currents without losses in efficiency or lifetime. For a given lumen output, the dual cool jets' improved thermal management reduces the necessary LED chip count. This, in turn, can dramatically lower the cost of the lamp. In addition to performance and cost advantages, this cooling technology enables reductions in LED lamp size and weight.

GE and the University of Maryland are in the final stages of the DOE project. The organizations are now studying ways to improve the reliability and lifetime of LED lighting systems. ■

Epistar Red-Orange LED Chips Set Efficacy Record in the Lab

Epistar announces the successful development of a new generation of Aquarius-series AlGaInP LEDs emitting at an efficacy 26 percent higher than the previously announced Mar. 15, 2010 record.



New generation of Aquarius-series chips have higher efficacy and lower forward voltage as compared to previously announced AX14.

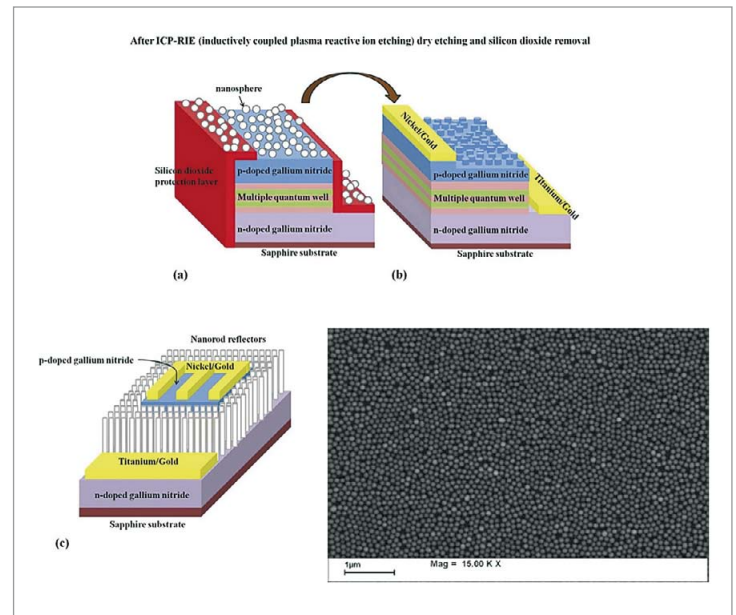
The record was set by the 14x14 mil² chip in the new generation of Aquarius-series chips. This chip reaches 168 lm/W at a dominant wavelength of 610 nm driven by 20mA current (180 lm/w at 6mA). Applying Epistar LabTM's novel light-extracting technology, the new Lambertian transmission has been demonstrated to increase the efficacy from 133 lm/w to 168 lm/w. Figure 1 shows the new generation of Aquarius-series chips with higher efficacy and lower forward voltage as compared to previously announced AX14. The horizontal chip structure was designed to satisfy chip-on-board packages for lighting applications which require multiple chips in series on nonconductive substrates.

This world-leading performance promises to make these small chips a preferred choice for outdoor display, and RGB BLU applications. Furthermore, this advance allows exceptional warm white LED solutions with higher efficacy and a better color rendering index to be provided via color mixing than can be achieved through conventional conversion of blue LEDs with phosphors.

So far, this new generation of Aquarius-series AlGaInP LED has been primarily demonstrated in Epistar LabTM itself, but plans are already in motion to transfer the technology to Epistar's product line. Moreover, Epistar LabTM continues to develop higher efficacy AlGaInP LEDs enabling lighting solutions with both high CRI and high efficacy warm white light for lighting applications as well as high performance in RGB BLU. This profound product portfolio and commitment to the future of LED technology has put Epistar in the leading position for AlGaInP LED market. ■

Using Nanostructures to Improve LED Light Emission

Application of nanosphere lithography to create uniform surface roughness on an optical device sample promotes light extraction and collection efficiency. In recent years, nanopattern definition has become a subject of extensive exploration owing to its ability to improve device performance in electronics and optoelectronics. The literature proposes a variety of techniques, including electron-beam lithography, which gives uniform nanopatterns but is expensive, and self-assembled metal nanomasks, which scatter non-uniformly on the sample. As an alternative, we have developed a technology called nanosphere lithography that creates nanopatterns by spin-coating a monolayer of nanospheres on top of the device surface. We have used the technology to fabricate nanopatterns on gallium nitride (GaN)-based LEDs to improve light extraction and collection efficiency.



Roughening of the p-doped GaN surface using nanosphere lithography. (a) The nanospheres are first spin-coated onto the sample, followed by dry etching to define patterns. (b) The silica spheres and protection layer are then removed. The device-fabrication process is completed following deposition of contact metal. (c) Structure of an LED equipped with nanorod reflectors. Scanning-electronic-microscope image of self-organized silica nanospheres. The diameter is 100nm.

Nanopatterns are defined by spin-coating nanospheres on the entire sample. The diameters of the nanospheres range from several nanometers to microns depending on the type. In our work, we chose silica particles. The particles were self-organized and firmly bound to the substrate surface by van der Waals (weak electronic) forces when the spin condition and nanosphere solvent are properly adjusted (see Figure 1). We then dry-etched the sample to form nanopatterns using the nanospheres as a hard mask, after which we removed them. Generally, nanorod distribution is determined by the spin speed and the silica nanosphere concentration in the solvent.

Nanosphere lithography can be applied to create uniform surface roughness on the LED samples, which improves light extraction. The large refractive index difference between air and semiconductor (for example, 2.5 for GaN) means that the critical angle for photons to escape from the LED is very small (23° for a GaN/air interface). Thus, external extraction efficiency is one of the major bottlenecks for LEDs. In nanosphere lithography, the photons are scattered, and consequently the chance of an electron falling within the escape cone is increased. In our experiment, we achieved surface roughness all over the 2-inch wafer with nanosphere spin casting and inductively coupled plasma dry etching. With nanopatterns on the p-doped GaN surface, we observed an $\sim 40\%$ increase of output power at 20mA injection current compared with conventional LEDs with a flat semiconductor-air interface, proving the effectiveness of light extraction. A similar approach can be used to roughen the transparent conducting layer, which leads to an $\sim 25\%$ output-power enhancement (see Figure 2).

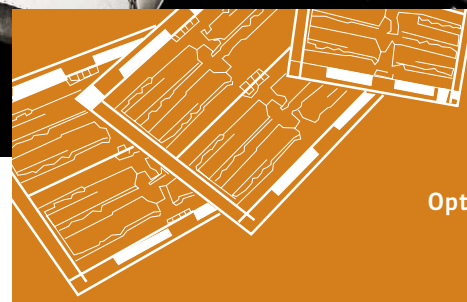
In addition, nanosphere lithography can be used to fabricate nanorods by etching the sample further through the p-i-n structure using nanospheres as the etch mask. Applying this approach, we demonstrated a new device whose LEDs were embedded with nanorod reflectors. In the past, most work on LED power enhancement focused on extracting light vertically. Even though lateral guided modes fall within the critical angle of total internal reflection when propagating toward the mesa sidewall, they are unfavorable since only a small amount of extracted light contributes to the designated radiation angle through sidewall scattering. The use of lateral guided modes (i.e., horizontally propagated light) that are extracted from the mesa sidewalls has rarely been addressed. We fabricated such a reflector structure and found that it enhances power output. A device equipped with nanorod arrays $20\ \mu\text{m}$ wide showed an $\sim 25\%$ increase in light collection compared with conventional LEDs (i.e., without nanorod sidewall reflectors). The results establish that this configuration enables emission to be scattered, reflected, or diffracted to the surface normal.

In summary, using the nanosphere approach, we have been able to realize nanopatterns on optical devices at very low cost. Moreover, nanopatterns improve device performance. As a next step, we plan to fabricate GaN nanorod LED arrays with a diameter smaller than the average distance between defects. By reducing contact resistance, we expect the device to show high emission density for potential next-generation lighting.

The research work was conducted by Min-Yung Ke and Yun-Wei Cheng under the supervision of JianJang Huang at the Graduate Institute of Photonics and Optoelectronics, National Taiwan University. JianJang Huang's group focuses on applying nanotechnology to optoelectronics and electronics. ■



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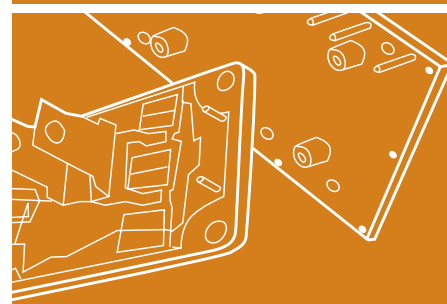


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Application

Intelligent Lighting (Part1): From Definition to Implementation

> Osama Mannan, Technical Marketing Engineer,
Future Lighting Solutions

The increasing interest in solid state lighting and the improvement in LED technology have not only created a need for more reliable and high quality LEDs, but also created a demand for cost effective and interactive LED systems. Such demands are influencing lighting designers to develop more efficient and robust products for the market. The goal of such developments is to decrease energy consumption. While there are different methods in meeting that goal, having an intelligent lighting system that incorporates monitoring, control, and a communication network can greatly help in achieving that goal more effectively.

LEDs are recognized for their extended operating lifetime compared to traditional bulbs. They also offer flexibility in design, due to their small form factor, which enables the implementation of diverse and more sophisticated designs. Furthermore LEDs have better luminous efficacy (lumens per watt) than many light sources presently available. Therefore, this makes LEDs a favorable choice when it comes to savings in maintenance and energy costs. All these advantages have led to the emergence of numerous LED products with varying specifications to meet the needs of the lighting market. Whether indoor or outdoor, applications such as downlights, street lights, display signs, and parking lights, are all starting to incorporate LEDs and make use of their value proposition. Figure 1 shows some applications where LEDs are used.

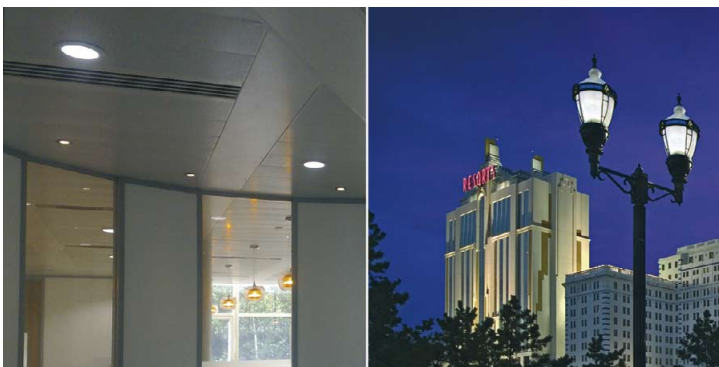


Figure 1: Indoor downlights and outdoor post top lights using LEDs.

Intelligent Control

The flexibility that LEDs bring to lighting applications does not stop at efficacy and quality of light. Solid State Lighting enabled various innovative methods of control. While the conventional operation of light fixtures has been achieved by means of simple switches to turn them ON and OFF, a more interactive lighting system is becoming a requirement rather than just an appealing addition. Functionalities such as dimming, sensor interaction, and the ability to control fixtures collectively or separately are quickly becoming standard specifications in many lighting applications. This is where an intelligent lighting system comes into play.

While this type of control and interaction was more prominent in entertainment lighting, through the DMX 512 protocol, designers in the general illumination space want to take that control ability to general lighting applications, for both indoor and outdoor. In the same manner that LEDs are being slowly incorporated into most lighting applications to replace conventional bulbs, the idea of disruptive technology is applied to intelligent control.

In order to accelerate adoption of disruptive intelligent lighting control technology for general lighting applications, the path of least resistance is to leverage the current infrastructure and established lighting control protocols. In the general lighting world, depending on the region, control is typically done by means of 0-10V control (Americas), DALI control (Europe), and 12V Pulse Width Modulation (Japan and Korea). The goal is to work with current lighting infrastructures and their existing controls and gradually introduce more innovative and effective ways to implement intelligent control of luminaires.

Make vs. Buy

Despite the multiple benefits that intelligent control provides, only a few have ventured into implementing such systems. This has mainly been due to the varying level of knowledge about this technology. While the sophistication involved in assembling all the components that make up an intelligent lighting system is quite daunting, companies who provide such intelligent solutions have approached this in different ways. However, the main challenges they have to tackle are knowledge, cost, and time to market.

One approach is to start from the basic semiconductor IC level and progressively build a solution that is tailored to the exact needs of the application. This approach is intended for customers who have a sound knowledge in the different components involved in a control system and also have the luxury of time to design and go to market. These customers have typically a large engineering team with detailed knowledge of components such as microcontrollers, radios, power amplifiers, sensors, and development software.

Another approach is to offer an off-the-shelf solution. This may come in the form of a "black-box" that includes all the components and is ready to be used instantly. This solution can be an intelligent LED

driver, a multi-functional remote control, or any device that can be easily integrated with existing luminaires. This can alleviate the need to know the intricate details of the intelligent system components and trying to incorporate them into the design. Therefore, it can be a very attractive option for customers who lack that knowledge and need to market their products as soon as possible.

An intermediate option is leveraging sub-systems that are not entirely a finished product but are also flexible enough to build a customized control system around. With this solution, components can be either inside the fixture or even inside the black-box. They can be configured through software to initiate actions and perform tasks as required. For example, an RF module can be integrated with an LED driver module to control light fixtures using a remote control. Alternatively, this same RF module can be integrated in the luminaire fixture to be able to control it wirelessly.

Figure 2 shows an example of how different intelligent control components can be leveraged to manage light fixtures using different methods. In this figure, a computer can be connected to the Internet and communicate to gateways to wirelessly control multiple fixtures in different locations. The computer can also be linked to the wireless nodes through a wired or wireless connection and execute control actions in light fixtures.

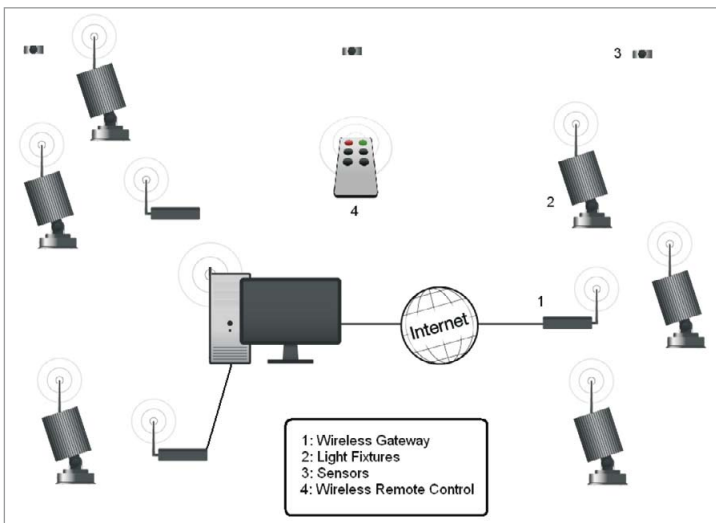


Figure 2: Intelligent lighting control components and methods.

Communication

Exchanging data between intelligent control components and light fixtures can take place using different topologies. These topologies define how the nodes in the intelligent lighting system are linked to each other and how they communicate to deliver commands and data.

Examples of topologies are Point-to-Point, Ring, Star, Tree, or Mesh topologies. Let's look at some of these topologies closely. The point-to-point topology creates a permanent link between the nodes, providing a non-complex and direct communication between nodes. A star topology consists of a central hub that connects to each node

using a point-to-point link. An advantage of this topology is in the simplicity of adding more nodes to the central control node. However a failure in the central hub will create a failure in all the nodes connected to it.

Finally, the most important topology for lighting control is the mesh topology. In this topology, all nodes are inter-connected to each other to provide flexibility and redundancy for linking the nodes. The main advantage of this topology is that all nodes are equal peers. This gives them the ability to coordinate tasks amongst themselves and offer a self healing capability to the entire network. As a result, if one node fails, another node route the data to the intended end node. Figure 3 shows an example of a mesh network. Figure 3a shows that the preferred path of communicating between node 1 and node 4 is through node 2. However, Figure 3b shows that node 2 fails and disconnects from the network. In this case, node 1 attempts to find other paths to maintain communication between node 4 and establishes a route through node 3.

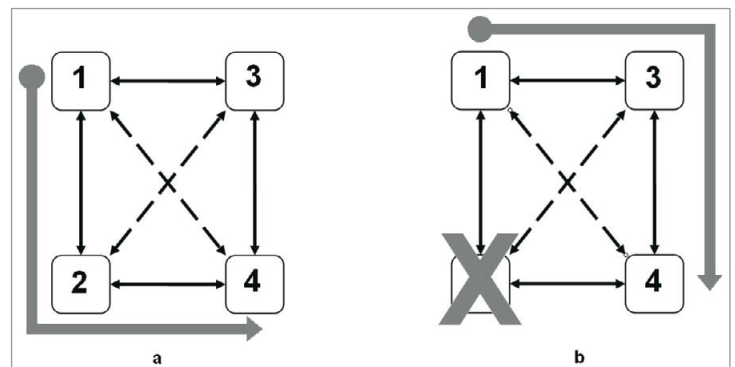


Figure 3: Example of self-healing mesh network.

Regardless of the implementation approach or topology used, an intelligent lighting solution can be used with different communication methods. One method is wireless communication. While it is commonly believed that wireless communication always involves complicated networks and protocols, many solution providers offer simple, and easily integrated systems that can make use of wireless control without having to manage the complexity associated with it.

One important factor of wireless communication is the frequency band used. Wireless technologies generally operate at either the unlicensed 2.4GHz frequency band or the sub-GHz band. Looking closely at the 2.4GHz band, different standards operate within that frequency range. One is the IEEE 802.11 standard. This standard forms the basis of the WiFi technology. Publicly available everywhere and used by numerous devices, the 802.11 standard has the advantage of frequency hopping, a process by which different protocols of the 802.11 standard transmit data over different channels of the frequency band without interfering with each other. However, one downfall of that standard is that it's designed for medium range data transfer. That limits the distance that the data can travel before experiencing quality deterioration.

Another 2.4GHz wireless standard is the IEEE 802.15.4. One of the most popular technologies based on this standard is ZigBee. It can be configured to support large and complex systems for remote wireless device control and monitoring. The frequency band of 2.4GHz that ZigBee uses is popular amongst most of the wireless devices. However, it is prone to interference from other technologies that share the same band, such as Bluetooth and WiFi. A ZigBee network uses a pseudo-mesh network topology, which means that it is not a true mesh network. The nodes in the network have specialized functions. For instance, end devices (or wireless light fixtures) are connected to router nodes that are linked to a coordinator node that governs the functions of the network. This arrangement is shown in Figure 4, where only the router nodes behave like a mesh network. The single coordinator node has the ability to manage all the end device nodes and coordinate with other networks. However, because the coordinator node is unique and the most capable, if this node fails, the entire network will also fail. For lighting applications that require a true mesh network for flexibility, scalability, robustness and redundancy reasons, there are several existing proprietary protocols based on 802.15.4 that enable mesh networks.

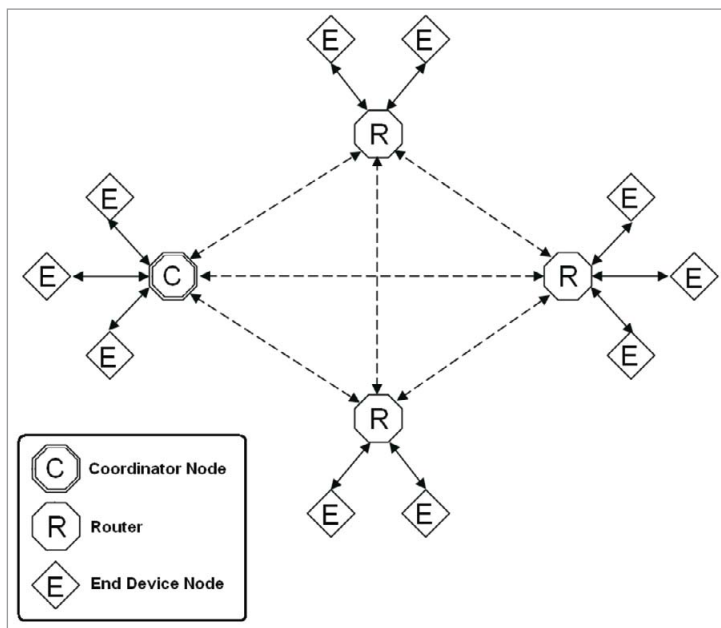


Figure 4: ZigBee network example.

A different frequency band that can be used for wireless communication is the sub-GHz band. This band offers several advantages over the 2.4GHz band, including less interference and lower power consumption. Sub-GHz devices also allow for transmitting over longer ranges, eliminating the need to hop from one node to another to reach the destination hub. This is attributed to their lower attenuation rate as they pass through obstacles while travelling to distant hubs. This helps in retaining the quality of the signal, thus making it a better choice for outdoor applications. Unlike the typical 2.4 GHz band, which is used globally, the sub-GHz band is regional. This makes it difficult for the manufacturers of wireless

lighting solutions to build an all-purpose product that could work anywhere. Different regions of the world use different frequencies to communicate between devices. For example, 915MHz is heavily used in North America, 868MHz across Europe, and various other frequencies are leveraged across Asia.

Another communication method is Power Line Communication. In this method, the data commands that are used to control or provide feedback to and from the light fixtures are sent through the same lines that provide the power to those fixtures. The same network topologies used for wireless networks can apply to powerline communication. One implementation of a powerline system is to control the light fixtures in a house, take readings of power consumption, and send feedback to the utilities for analysis, via GPRS for example. Figure 5 illustrates this powerline communication implementation.

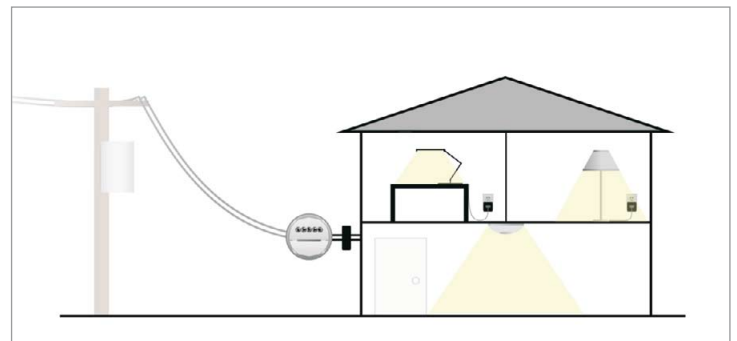


Figure 5: Powerline communication setup.

All communication methods (wireless and powerline) can be bridged together to form a complete system that relays commands and information to different nodes as required. This can be for redundancy purposes or to extend the range of the network. It also helps in bypassing obstacles that may get in the way of the communication link.

Features

Intelligent control offers a range of features depending on the need and the capability of the lighting system. One key feature is dimming. Although there have been advancements in enabling dimming in conventional bulbs such as fluorescent and HID lamps, it's not common and most often not precisely achieved. This limits the possibility of enabling a dimming feature in applications that leverage these bulbs. On the other hand, LEDs offer flexible dimming capability in all the applications they are incorporated into. Accordingly, regardless if the application is an indoor downlight or an outdoor street light, dimming can be easily realized using LEDs. By dimming the LEDs, considerable power savings can be achieved since they are not operating at full brightness.

Dimming control signals can be sent using any of the communication methods mentioned previously. A direct way of dimming light fixture is by manually controlling a wall dimmer, software via a PC or the Internet, or a wireless remote control as shown in Figure 6.

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Figure 6: Wireless dimming using a remote control.

Additionally, dimming can be triggered using various automated methods. One is by leveraging sensors. Sensors can either be installed inside the light fixtures or outside in different locations. Placing them inside the fixture provides the convenience in having integrated components in a complete system. With this approach, the fixtures can all be designed similarly but in order to save cost, only a fraction of them will include the sensors. This approach then allows for the grouping of several light fixtures that do not contain the integrated sensors, where they will be dimmed and controlled in a synchronized way by the fixture that contains the integrated sensor. Alternatively, the sensors can be placed outside the fixtures on a wall or ceiling, providing more flexibility in their installation in key locations to interact with each other and with the light fixtures.

One type of sensor used is motion detectors. These sense presence at specific locations and then trigger the light fixtures to perform an action. For example, the fixtures can be set to be in stand by OFF mode by default, and when the sensor is triggered they would turn ON for a certain amount of time, or as long as motion is being detected. The sensors can also be configured to avoid triggering an action due to false detection, eliminating the possibility of power wasting.

Ambient light sensors can also be installed in the lighting system. The actions triggered by these sensors can be implemented in the same way as the motion detector when there is a change in the ambient light at their location.

Other sensors that can be leveraged in an intelligent lighting system are light output sensors, lightning detectors, or even temperature sensors that can be used to keep track of temperature changes inside the fixture and send feedback to the controller. This feedback can be used for observing the behavior of the fixture in addition to providing protection to the LEDs from thermal overstress by prompting actions such as derating the current or shutting down the driver.

The sensors used are chosen according to the application requirements. Those requirements will define where those sensors will be placed to interact and cause the light fixtures to perform an action.

A schedule can also be implemented to manage the behavior of the light fixtures depending on certain criteria. For instance, whether indoor or outdoor, the lights can be set to turn ON and OFF, by default, at specific times depending on the season and when daylight is actually present. This can also be linked to interact with ambient and motion sensors to perform non-default actions based on change in the surroundings.

Another intelligent lighting feature is monitoring. A metering device can monitor certain parameters of the lighting system and send feedback for analysis. As examples, it is possible to monitor energy consumption or failures within the lighting system. Measuring energy can be executed at the input or output of the system. At the output, it can be used for simply measuring the voltage and current of the LEDs. Although it is much simpler and cost effective to measure energy on the output, it is on the input where energy metering is most important. A more detailed analysis of the system performance can be obtained from installing the metering device at the input to the lighting system. At that location, readings of the driver efficiency, wire losses, and power factor can be analyzed as power comes from the Utility. Metering can also be useful in detecting failures in the system and sending feedback to inform stakeholders of such failures. As a result, instead of investing in a dedicated person to constantly verify if certain luminaires have failed, a failure detection system can alert the appropriate individual to take action once a failure occurs. This is critical for applications such as street and tunnel lighting where failures can cause accidents and lead to significant legal ramifications.

From Theory to Practice

Lighting contributes greatly to the overall energy consumption. As such, implementing a lighting system that is more efficient will play a big role in energy savings. Considering all the benefits mentioned previously on intelligent lighting, a recessed downlight scenario will be covered in detail on how energy savings can be achieved by implementing intelligent control to LED luminaires.

Recessed downlights are one of the most common applications in indoor lighting. Therefore, developing an efficient downlight system can lead to a significant amount of savings. Traditionally, downlights used incandescent bulbs. These were later replaced by compact fluorescent lamps, which are more efficient. Today, manufacturers are moving towards LEDs for downlight fixtures due to the benefits they bring, namely efficacy, longevity, and reliability.

Considering a downlight fixture where the light source is a compact fluorescent lamp and one that uses LEDs, the following comparison demonstrates the power costs incurred by each system. Additionally, the performance of the LED system is evaluated after adding intelligent control.

The intelligent lighting solution is implementing the following rules to control the lights by optimally turning the lights ON/OFF and dimming them while leveraging sensors and a pre-programmed scheduling system:

- 24 hrs per day, 7 days per week:
 - If the motion detector detects presence in a room, the light will be turned ON.
 - The light levels from the luminaires will be adjusted to take into account the ambient light to deliver a constant illumination level.
 - During very sunny days, for the target illuminations levels, some lights may be turned OFF if the sunlight generates the required illumination level.
- From 6 P.M to 6 A.M. and weekends:
 - The schedule will set the lights to be OFF for all unoccupied rooms and by extension, the entire building.
 - The OFF state during this time is defined as the luminaires being completely turned off.
- From 6 A.M to 6 P.M.:
 - For meeting rooms or all rooms with a closed door, if presence is not detected, the lights will be completely turned off.
 - For open rooms or hallways, if presence is not detected, lights will be dimmed to 60%.

Table 1 summarizes how each of these rules affects the utilization of the LED fixtures for the described scenario, and illustrates that intelligent control system and the implemented rules can reduce the total energy consumption from the luminaires by 40%. As a result, on average, the luminaires for an intelligent lighting system, based on the described scenario and rules, will effectively consume 60% of the power compared to the traditional and non-optimized LED luminaire system.

Table 2 explains the power costs incurred by the Fluorescent lamp system, the LED system, and the LED system with intelligent control. From the table, it's shown that in addition to the savings that LEDs bring to the downlight fixtures, which are about 61.4% when compared to compact fluorescent, an additional 15.4% cost savings are realized when these LEDs are optimally controlled based on the scenario above. These savings can be enhanced when implemented on a larger scale or on fixtures that have a large number of LEDs in them. From an end user's stand point, achieving the energy savings, in addition to the LED payback, may justify the overall initial cost of implementing the intelligent system in addition to the other value added features.

Conclusion

From controlling light systems via wireless or power line communication, to initiating functions via sensor interaction, adding an intelligent system into light fixtures goes beyond simply making the product more appealing with impressive functionality. It provides the means to making lighting systems more interactive, more adaptable, and, most importantly, more energy efficient. In the scenario presented previously, it can be noticed how adding intelligent lighting control to an LED lighting system increased the cost savings by almost 15% for only one room. Extending that to include more applications, indoor and outdoor, will lead to achieving more savings and also help in complying with regulations that require luminaires to bring about a required level of energy savings. ■

Trigger	Action	Energy Saving Contribution
Schedule	ON/OFF	15%
Ambient sensor	ON/OFF	2%
	Dimming	8%
Motion selector	ON/OFF	10%
	Dimming	5%
Total Reduction in energy consumption		40%

Table 1: Energy consumption reduction from intelligent control.

Item	FLUORESCENT (CFL)	LED	LED with Intelligent control
Number of lamps/LEDs	1	9	9
Average power per lamp/LED	24.00	1.03	0.62
Average power per fixture	24.00	9.26	5.56
Ballast or LED driver power losses		15%	
Watts per fixture with losses	24.00	9.26	5.56
Average lifetime (hours)	2,000	60,000	60,000
Energy consumption (KWh of electricity used over 60k hours)	1,440.00	555.66	333.72
Electricity rate		0.12	
Energy costs	\$172.80	\$66.68	\$40.05
Expected number of CFL or LED failures per luminaire over 60k hours	3	0	0
Total power costs of one fixture over 60k hours	\$172.80	\$66.68	\$40.05

Number of fixtures in one room	25		
Total energy costs of all fixtures	\$4,320.00	\$1,666.98	\$1,001.16
Energy savings in \$	-->	\$2,653.02	\$3,318.84
Energy savings in %	-->	61.4%	76.8%

Table 2: Power consumption and cost comparison.



ILD 4035 Step-down LED Driver with internal switch for 1W LEDs



The new ILD 4035 from Infineon Technologies is a LED driver tailored for driving 1W LEDs. The flexible dimming concept in combination with the small footprint and the protection features make this LED driver a perfect match for Indoor and Outdoor lighting applications.

- 40V input voltage
- 350mA typical LED output current
- PWM or analog voltage dimming capability
- Overvoltage, overcurrent and thermal protection
- Small SC-74 package

To learn more about the LED driver portfolio for General Lighting, please visit www.infineon.com/lowcostledrivers

Technology

"Status Quo and Perspectives of LED driver ICs – Market and Technology"

> Interview with Laurent Jenck, Lighting & Smart Grid Segment Director, and Marc Barboni, CCPG EMEA Marketing Manager from ON Semiconductor, by Arno Grabher-Meyer, LED professional

LED professional: ONSemi has a broad portfolio of ICs. LED drivers make up just a fraction of it. How important is this part of the business and what do you expect in the future?

Marc Barboni: The LED Lighting business is so important for ON Semi that we have started a company-wide initiative on LED Lighting. This initiative encompasses virtually every application such as: Automotive Lighting (interior and exterior lighting), Mobile Lighting (backlight of small color screens, camera flash), Architecture Lighting, Signage, Backlight of medium and large LCD panels (notebook, LCD TV, netbooks, tablet PCs), General Lighting (replacement of incandescent light bulbs and fluorescent tubes, street and parking lights). We believe that LED lighting will have a CAGR (Compound Annual Growth Rate) of over 50% over the next 3 years.

LED professional: What is the relation between general SSL, LED backlighting products, and automotive LED products?

Laurent Jenck: These 3 applications are going to exhibit the highest CAGR over the next 3 years with LED backlighting products at 120% growth rate, followed by General Lighting at 18% and Automotive LED lighting at 15%.

LED professional: For a long time, the general lighting market seemed to be ignored by driver IC manufacturers. For instance, it took some time until the industry offered the first products that allow simplified design of TRIAC dimmable solutions. It looks like they waited for the worldwide ban of incandescent bulbs. Is this perception correct, or what are the reasons for the relatively late reaction of the IC industry?

Marc Barboni: I think the General Lighting market can be divided into two categories: Residential and Commercial/Industrial. LED drivers have been shipping into Commercial/Industrial applications such as down lights, spot lights, architectural lighting, area (parking and street) lighting for several years because commercial/industrial customers understand the concept of Total Cost of Ownership (TCO) and are ready to accept a payback of 3 to 5 years. These customers

understand the operating expenses that are associated with the maintenance of lighting fixtures and have quickly realized the benefits that LED Lighting could bring in reducing these operating expenses.

On the other hand, customers in the residential category behave just like the average consumers, just like all of us who go buy light bulbs at the local hardware store. The average consumer does not understand the concept of Total Cost of Ownership and wants something inexpensive with an immediate payback.

Laurent Jenck: So, we believe that driver IC manufacturers have been focusing mostly on the Commercial/Industrial part of General Lighting because that market was ready for LED Lighting earlier than the residential one.

Regarding the TRIAC dimming of LED Lighting applications, it is an extremely complicated technical domain, this may explain why driver IC manufacturers have taken some time to introduce LED Lighting TRIAC dimmable solutions that are reliable and can operate with a large number of TRIACs all around the world. The lack of TRIAC dimmers standardization is also creating extra complexity, thus slowing down its market penetration.

LED professional: OnSemi has ICs for almost every LED application. The most advanced and recent products are the NCL 30000 and the NCL 30001. Both are designed for single stage PFC LED drivers and use an extra current source driver, usually the NCS1002, on the secondary side. This concept differs from most competitor designs. Why did ONSemi choose this concept? And where do you see the main advantages?

Marc Barboni: By using a single stage PFC LED driver and an extra current source driver (NCS1002) on the secondary side, we only use one conversion stage and improve the efficiency.

Laurent Jenck: Let me show you two figures. One figure shows the efficiency of an LED driver from our competition in a 2-stage configuration. Maximum efficiency is 76% (figure 1). In the other figure you can see the efficiency of a single stage driver using the NCL30000 (figure 2). In any case the efficiency is much higher.

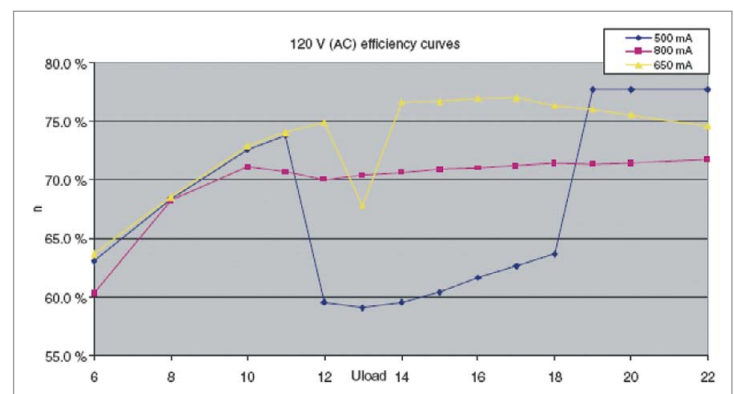


Figure 1: Efficiency curve of a standard 2-stage PFC LED driver based on the load.

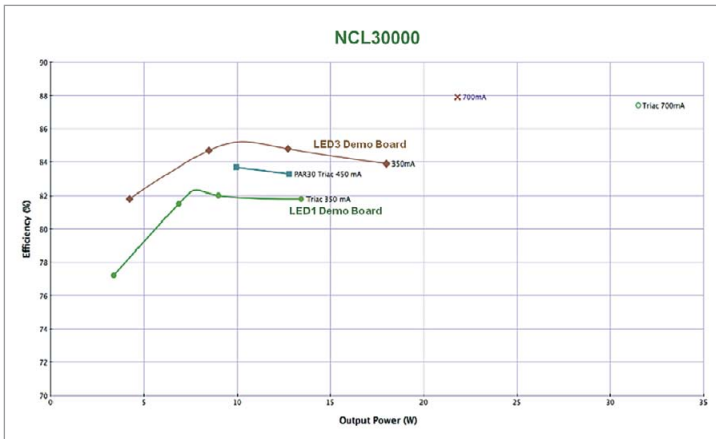


Figure 2: Efficiency curve of a 1-stage PFC LED driver using the NCL30000 based on the load.

Marc Barboni: The single stage topology also eliminates the need for a separate boost stage followed by a flyback or LLC DC-DC conversion stage thus reducing the overall parts count as well as total BOM cost.

LED professional: These drivers are designed for different applications. While the NCL 30000 is recommended for TRIAC dimming replacement products, the NCL 30001 is advised for applications that need higher power – up to 150W – like commercial lighting applications. What are the main differences between these products?

Marc Barboni: Both NCL30000 and NCL30001 are single stage PFC LED drivers. The NCL30000 implements a critical conduction mode whereas the NCL30001 implements a continuous conduction mode. Only the NCL30000 complies with TRIAC dimming. The NCL30001 can implement several dimming options on the secondary side such as: PWM dimming control, two-step bi-level digital dimming and 1-10V analog voltage input dimming.

Finally, NCL30001 continuous conduction mode naturally offers benefits when the power budget increases. Its higher efficiency also offers commercial lighting applications a payback period reduction by cutting the electricity bill.

LED professional: The fast changing LED market shows new developments almost every day. Bernie Weir indicated that due to new classes of LEDs coming on the market in the near future, new driver concepts with simplified conversion architecture can be expected. Are there new SSL products in the pipeline?

Laurent Jenck: Yes, there is a variety.

LED professional: Can you tell us something about these products and concepts?

Marc Barboni: We are working on multiple parallel fronts: DC-DC LED drivers, AC-DC LED drivers and Linear LED Drivers. DC-DC LED drivers are going to be used more and more in solar applications, for example. You will see a real implementation of a DC-DC LED Driver in

a solar system at Electronica. In AC-DC, we are working on different power levels: for power levels above 150 W for street lighting and parking lighting. At this power level, we are going to use a topology different from that used in NCL30000 and NCL30001. We are also working in low power applications for the replacement of conventional light bulbs where more and more solutions are going to use non-isolated topologies. As a tangible sign of our relentless efforts in these domains, we've recently launched a new Fixed Off-Time Buck LED Driver Controller - NCL30100 - intended for space constrained constant current high brightness LED driver applications such as MR16 standard bulb replacement.

LED professional: It isn't only LED technology that is changing rapidly. There are also ideas regarding DC grids, centralized power supplies, smart grids, etc. SSL technology would be a perfect fit for such concepts, especially if intelligent controls are added. Is this also a topic of interest for your business?

Laurent Jenck: Absolutely. We would like to illustrate your question with the example of LED street lights. These street lights are going to implement intelligent control such as two-step bi-level dimming and are going to be controlled through power line communication. This will enable to turn these lights on and off and have a remote diagnostic. At ON Semi, we have products such as PLC (Power Line Communication) modems which are designed into some LED lighting street lights along with other products such as temperature sensors, ambient light sensors.

LED professional: Marc, Laurent, thank you very much for talking to LED professional and giving us some interesting insights into LED driver technology and the business plans of On Semiconductor.

Laurent Jenck & Marc Barboni: Thank you. ■

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Thermal Management

Thermal Foldback LED Design

> James Patterson, Senior Applications Engineer, National Semiconductor Corporation

With the increasing demand for solid state lighting solutions comes the need for better thermal management techniques. Beyond the standard mechanical solutions, there are also electrical techniques to monitor thermal behavior and adjust the control to thermally stabilize a system.

Specifically, as high-brightness LEDs increase in forward current and decrease in package size, the potential for thermal runaway and catastrophic failure increases. The extreme high-temperature environments in many LED applications demand another level of protection.

Thermal foldback is a common approach for mitigation of LED failures and reduced lifetime due to excessive heat. This control approach takes a signal that is inversely proportional to temperature and uses it to reduce the LED current after a set temperature breakpoint.

This approach can be implemented in many ways. Two examples will be presented: a 100 W streetlight application and a 12 W military flashlight application. These two examples will highlight both the design procedure as well as the differences between a more complex implementation and a simple one

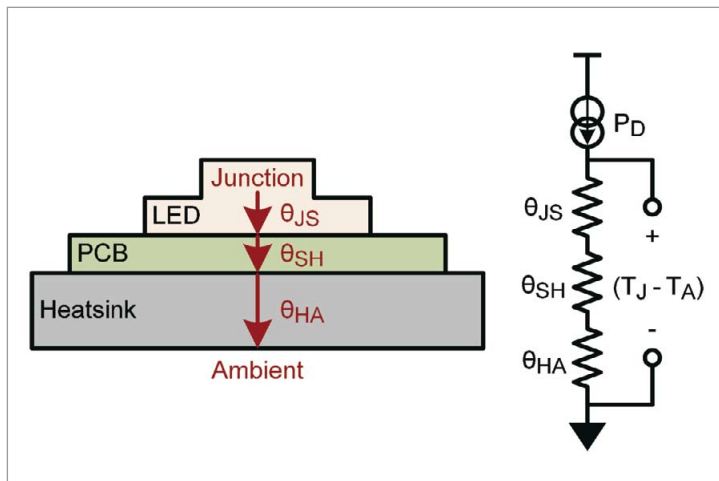


Figure 1: Thermal model of LED.

Background

Traditional lighting applications employing high power LEDs require large heat sinks to dissipate heat generated by the LEDs. LEDs do not radiate heat; instead, they conduct heat through the semiconductor junction. This conducted power (P_D) is equal to the product of the forward voltage (V_F) and the regulated forward current (I_F):

$$P_D = V_F \times I_F$$

This power has to be dissipated in order to maintain a safe LED junction temperature. Sizing a heat sink to maintain desired thermal performance for a given power requires an analysis of the thermal impedances in the system.

A typical high power LED will dissipate most of its power through the device, the solder point connection, the PCB and the heat sink as shown in figure 1. Using this simplistic model, the calculation is fairly simple. The power dissipation (P_D) across the junction of the LED must be distributed through the total junction-to-ambient thermal resistance (θ_{JA}) much like a current flows through an electrical resistance.

The resulting temperature difference ($T_J - T_A$) between the junction temperature (T_J) and the ambient temperature (T_A) is equivalent to an electrical voltage (the thermal equivalent of Ohms law):

$$T_J - T_A = P_D \times \theta_{JA}$$

θ_{JA} is defined as the sum of the following:

θ_{JS} ... junction to solder point resistance

θ_{SH} ... solder point to heat sink resistance

θ_{HA} ... heatsink to ambient resistance

θ_{JS} represents the internal LED thermal resistance, while θ_{SH} represents the PCB dielectric and connection thermal resistance. Finally, θ_{HA} represents the heat sink thermal resistance. θ_{JS} is specified by the LED manufacturer's datasheet and is simply a function of the LED package. This can vary from 2-15°C/W. θ_{SH} can basically be neglected provided a good connection is made from the solder point to the heat sink including: multiple thermal vias, adequate copper, good soldering and possibly thermal adhesive. This will yield a very low θ_{SH} of less than 2°C/W.

That leaves θ_{HA} , which is mostly dependent on the surface area and conductive properties of the heat sink. With no external heat sink and only the bottom copper plane on a standard FR4 PCB (approximately the size of the LED), θ_{HA} can be very large, in excess of 100°C/W. With an external heat sink as shown in figure 1, the thermal resistance can be reduced to maintain the desired temperature differential ($T_J - T_A$). Thermal design requires solving the equation for θ_{HA} and picking the appropriate heat sink:

$$\theta_{HA} = \frac{(T_J - T_A)}{P_D} - \theta_{JS} - \theta_{SH}$$

Looking at the calculation, it is easy to see that if the power is increased or the allowable temperature differential is decreased, the necessary thermal impedance will decrease. This equates to needing a larger heat sink.

Calculating for realistic applications, the output LED power is usually

increased by 5% to 10% to account for forward voltage and other electronics variation over the system lifetime. The allowable temperature rise also has to be calculated at the worst-case expected T_A . In addition, the maximum allowable T_J is usually de-rated from the manufacturer's specification to ensure the LED lifetime and efficacy is not compromised. These tolerances combine to force a worst-case heat sink design that can be 25 to 50% larger than what is nominally necessary.

LED Driver

The LEDs are only a part of a dynamic system with the main control mechanism being the LED driver. The LED driver for high-brightness LEDs is usually implemented with a switching converter. The converter regulates the system to provide a near constant luminous flux output from the LED. The driver adapts to the ever-changing dynamics to continuously provide regulation, electrically stabilizing the system. In most common LED drivers, output current is regulated due to its close correlation with output flux and the ease of implementation.

Though electrical stability is inherent in the control method, thermal equilibrium is a function of both the controlled variables (LED current) and the uncontrolled variables (the environment). As the ambient temperature increases from room temperature (25°C), the forward voltage of the LED decreases. Since current is being regulated, the power decreases ensuring thermal equilibrium of the junction is ultimately reached. However, eventually the ambient temperature increase can cause the junction temperature to exceed the safe operating area of the LED. At this point, different mechanisms within the LED begin to deteriorate eventually causing thermal runaway and catastrophic LED failure.

Every LED manufacturer provides a characteristic plot of maximum forward current vs. ambient temperature. An example from the Cree XRE series is shown in figure 2. This plot indicates the recommended safe operating area (SOA) of the LED over temperature. This is a quick reference which gives profiles for multiple θ_{JA} . Since θ_{JS} is specified on the datasheet, and θ_{SH} can be neglected in a well implemented system, θ_{HA} is the control variable. Maintaining the LED drive current within the limits for a given θ_{HA} will prevent thermal runaway and/or excessive life degradation from unsafe LED operation.

Looking at figure 2, it is easy to see how a larger heat sink will extend the usable range of the LED. Unfortunately, the added heat sink cost and size can be prohibitive in some LED applications. To reduce the thermal requirements for prohibitive applications, a complimentary solution is necessary.

Rather than design the thermal solution with a large tolerance band on each specification, the designer would like to design more aggressively. This becomes a possibility with the LED driver. Since the driver regulates the current and consequently the power, unsafe operation need only be detected and the driver can be designed to react accordingly.

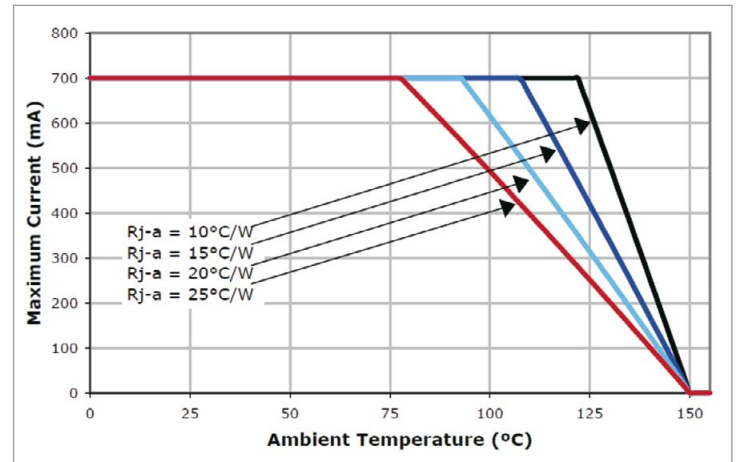


Figure 2: LED safe operating area.

Thermal Foldback

With the manufacturers' forward current de-ratings in mind, the designer can now look to the LED driver to provide some helpful control mechanisms to thermally protect the LED. Since most new LED drivers have a dimming input, there is almost always an easy way to decrease the output current to the LEDs. Given this, a circuit can be constructed to sense the temperature in close proximity to the LED. If the system is well characterized in terms of thermal impedances, then the junction temperature of the LED can be interpolated from the measurement.

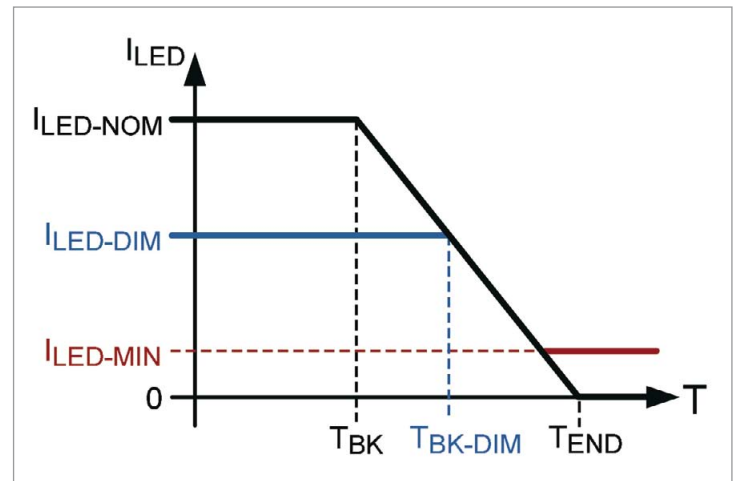


Figure 3: Basic thermal foldback profiles.

Consequently, the LED driver can then maintain or reduce the regulated current according to the desired profile as shown in figure 3. This profile can be very aggressive and basically match the manufacturer's datasheet specification or it can be constructed more conservatively. Either way, the LEDs are protected from excessive drive current and temperature. Specifically, the heat sink requirements can be reduced as desired because worst-case conditions causing thermal runaway can be eliminated.

Thermal foldback can be implemented in many ways. The most common and simplest approach is to use an NTC thermistor to measure the temperature near the LEDs as shown in figure 4. An NTC thermistor is a resistor whose value is large at colder temperatures and decreases as the temperature increases. If a resistor divider is placed off a reference voltage and the bottom resistor is a thermistor, then the divided voltage will decrease as a function of increasing temperature. If this voltage is then clamped at a set maximum voltage below the reference voltage, then for some range of temperatures up to a maximum temperature breakpoint (T_{BK}), the voltage will be fixed at the clamp voltage. Then for temperatures above T_{BK} , the voltage will decrease according to figure 3. This voltage can then be used to control the analog dimming input of an LED driver to perform basic thermal foldback.

A variant of the foldback profile can be implemented when dimming the LEDs. Since the nominal LED current level ($I_{LED-NOM}$) is reduced to the dimmed level ($I_{LED-DIM}$), the foldback profile can be adapted to match the new temperature breakpoint (T_{BK-DIM}). This extends the usable temperature range of the LED as shown in figure 3. This can be accomplished in discrete steps or continuously depending on the implementation.

Another variant is the addition of a minimum LED current ($I_{LED-MIN}$) clamp to prevent the LED current from ever reaching zero; also shown in figure 3. There are many applications where the end user would not want complete thermal foldback for safety reasons. Using this feature, the minimum desired current clamp may allow the system to violate the safe operating area restrictions. However, at that point the user is willing to sacrifice long-term life for short-term functionality.

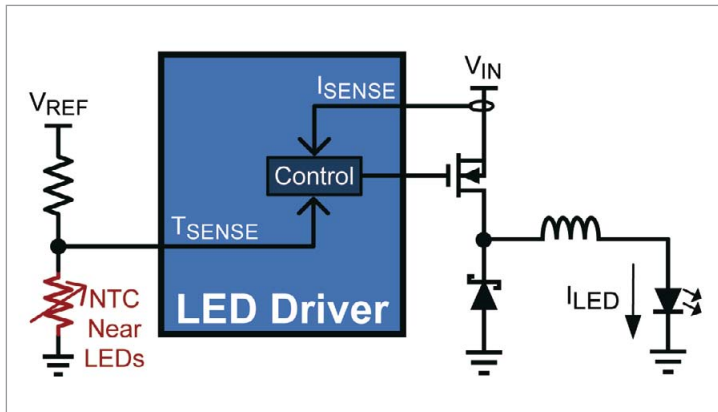


Figure 4: Basic thermal foldback circuit.

Streetlight Example

A standard streetlight is subject to harsh environmental conditions and over a lifetime the mechanical heat sink connection can degrade for various reasons. This degradation effectively increases the total thermal impedance θ_{JA} and ultimately causes higher LED junction temperatures reducing lifetime. Thermal foldback is almost always necessary in streetlights to ensure municipality lifetime specifications are met.

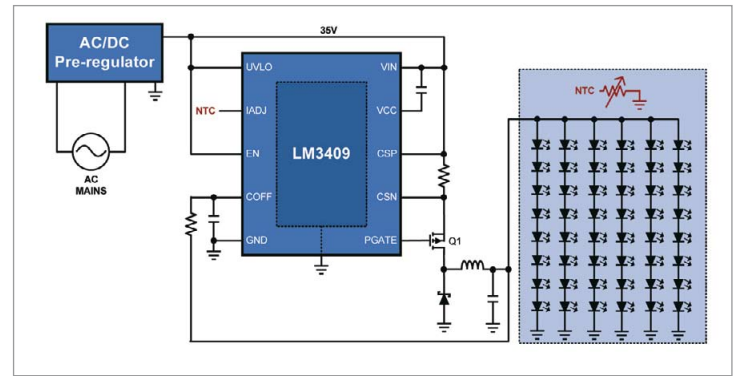


Figure 5: 100W streetlight with thermal foldback using LM3409.

A 100 W streetlight application is shown in figure 5. The front-end AC-DC converter takes the 120 VAC mains input and converts it to a 35 VDC output. The secondary stage is a LM3409 constant current buck LED driver. The load is 6 parallel strings of 8 series LEDs driven at 700 mA per string.

The LM3409 regulates current with a very simple hysteretic control method. During the main switch (Q1) on-time the inductor current ramps up to a peak current threshold set by the I_{ADJ} pin. Once the threshold is reached, Q1 is turned off and the inductor current ramps down until a programmed off-timer expires. The off-timer is programmed with an RC from the output voltage. This makes the timer directly proportional to the output voltage, resulting in an inductor current ripple and consequent LED current ripple that is constant over the operating range.

Continuous analog dimming of the average LED current can be implemented easily by reducing the voltage on I_{ADJ} from 1.24 V to 0 V. If the voltage at I_{ADJ} is at or above 1.24 V, the maximum nominal LED current is regulated. When the I_{ADJ} pin voltage falls below 1.24 V, the current begins to dim, providing an excellent means for implementing thermal foldback.

The thermal foldback circuit for this application is even more basic than the one described previously, utilizing only one NTC thermistor attached from I_{ADJ} . The NTC thermistor is sized to be above 250k Ω (I_{ADJ} above 1.24 V) until the temperature reaches the desired breakpoint. Then the resistance decreases as a function of the NTC, decreasing the I_{ADJ} voltage and LED current respectively.

It should be noted that the NTC transfer function from resistance to temperature is fairly non-linear. This nonlinearity extends the endpoint temperature (T_{END}) where true zero current will occur. In a streetlight application, foldback linearity is not paramount. In fact, the end of life for a streetlight is usually specified at 70% initial light; therefore, the exact foldback profile is fairly insignificant to the streetlight designer. That being said, a precision temperature sensor can just as easily be used for a more linear foldback profile if desired.

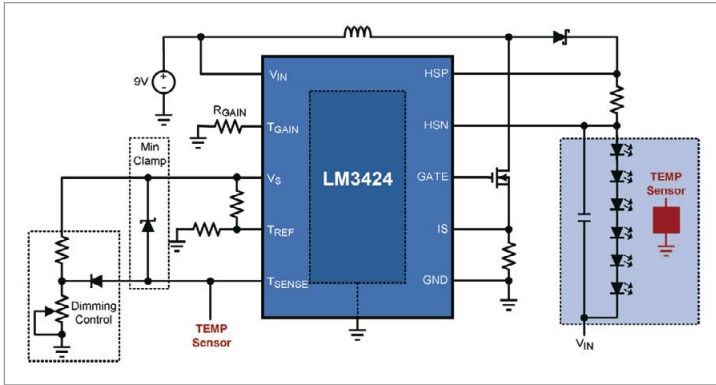


Figure 6: 15W flashlight with thermal foldback using LM3424.

Flashlight Example

A more complex thermal foldback implementation using the LM3424 is shown in figure 6. The intended application is a 15 W dimmable military flashlight comprised of an LM3424 controlling 6 series LEDs driven at 700 mA from a 9 V battery. The multi-topology LM3424 is implemented as a buck-boost controller since the string voltage can vary from 24 V to less than 9 V during dimming. The LEDs are analog dimmed for simplicity, size and cost.

The LM3424 regulates the output current in a closed loop fashion with a traditional error amplifier. The average LED current is sensed differentially at the top of the LED stack. The duty cycle of the main switch (Q1) is then changed dynamically to ensure regulation at all times.

The LM3424 has a fully programmable thermal foldback circuit integrated on chip. The foldback breakpoint is set at T_{REF} by a resistor divider off the internal 3 V reference (V_S). The temperature sensing is accomplished using a sensor or NTC divider at T_{SENSE} . When the T_{SENSE} voltage falls below the preset T_{REF} voltage, the circuit begins to dim the LEDs according to the profile shown in figure 7. The slope of the foldback can be set with a resistor (R_{GAIN}), placed from T_{GAIN} to GND. If a precision temperature sensor, such as the LM94022, is used, a highly linear profile can be established.

An external Zener clamp from the reference voltage V_S can be added to set a minimum desired current as shown in figure 3. This highly controllable thermal foldback allows the flashlight to maximum its useful lifetime while maximizing the light output for a given LED at a given temperature.

Another useful feature implemented in the flashlight application is the combination of dimming and thermal foldback. Since both utilize the thermal foldback circuitry, they can be combined in several ways. Figure 6 shows the NTC divider directly connected to T_{SENSE} while the dimming divider is diode connected. This connection ensures that the T_{BK} moves with the dimming level, thus maximizing the useful temperature range at any dimming level.

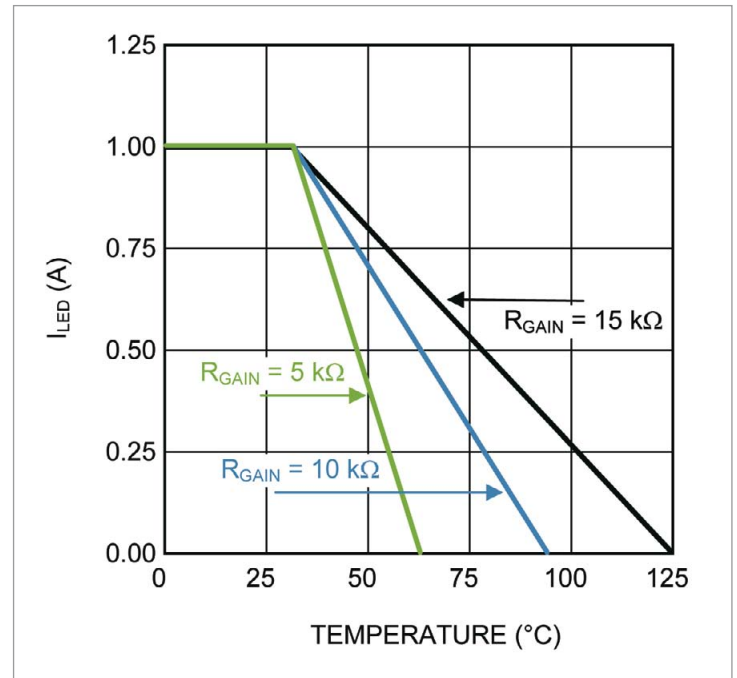


Figure 7: LM3424 foldback profiles.

Heat Sink Comparison

Finally, a thermal comparison will be made with and without thermal foldback in the flashlight application. The LEDs are close enough together in a flashlight application to model as one LED, and assuming θ_{SH} and θ_{JS} are small compared to θ_{HA} , the calculation simplifies to:

$$\theta_{HA} = \frac{(T_J - T_A)}{P_D}$$

Without thermal foldback, the output power has to be increased by 5% to allow for regulation variance over time. Also, the temperature difference is decreased by 25% to account for the worst-case ambient temperature and to allow for a healthy SOA margin. Therefore, θ_{HA} will have to be almost 70% smaller than the application with thermal foldback. This translates into a 30% increase in heat sink size and cost. Considering the heat sink can be one of the largest costs in an LED application, the thermal foldback is a valuable addition to the flashlight application.

Conclusion

The use of thermal foldback protects the LEDs from catastrophic failure while reducing the mechanical thermal requirements for a given system. LED technologies tout long lifetimes, high reliability, and superior performance to other lighting technologies. These endorsements require the use of thermal control to ensure unforeseen circumstances do not impede the development of this technology. ■

Drivers

Dimming without Flicker for LED Lighting Applications

> Bill Weiss, Lighting Applications Business Development Manager, Power Integrations, Inc.

LED lighting is now firmly established as a mainstream technology. The technology is maturing and one aspect of maturity is the emergence of standards and regulations governing LED lighting. Stringent requirements for efficiency have been in place for a while now and are tightening, but the job of the LED lighting designer has been made that much harder recently with the combination of two requirements: the capability of dimming control using dimmers made for incandescent bulbs, together with high-power-factor performance.

Dimming is a very common feature of lighting systems. With incandescent bulbs, it is cheap and simple to implement. With LED lamps, dimming is difficult, but architects and residential users are simply not willing to forego the benefits of dimming control in order to switch over to LED lighting.

Power factor is important because a high power factor decreases losses in the power distribution network. The most effective way to reduce the environmental impact of electricity use is to minimize waste, so standards authorities throughout the world are forcing up their power factor specifications. One example is ENERGY STAR® 09/12/07 for SSL luminaires where PF >0.7 is required for residential and PF >0.9 is required for commercial applications.

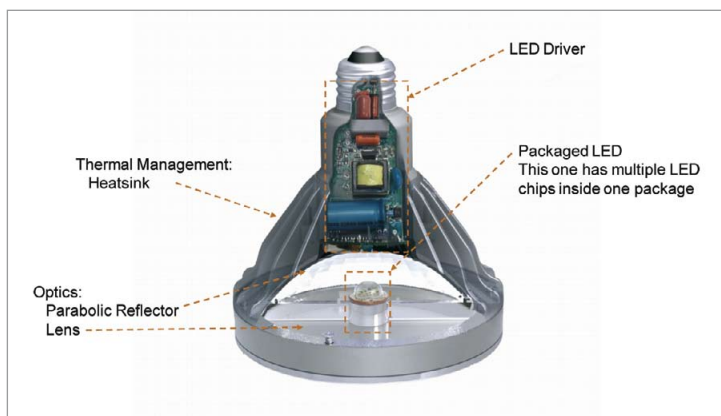


Figure 1: Anatomy of an LED light.

The manufacturers of LED lamps and luminaires are responding to these demands and naturally want their products to be as universal in application as possible. So they are calling for the LED driver circuits to perform with all types of dimmer units at high efficiency and PF >0.9.

Dimming Controllers

Lighting controllers operate by either line dimming or secondary-side dimming. The simplest form of line dimming is the leading-edge TRIAC controller. This is by far the most common form of lighting control, which is unfortunate because TRIAC controllers cause considerable problems when attempting to dim LED lamps. More sophisticated line dimmers are electronic leading-edge or trailing-edge dimmers. Secondary-side electronic control dimmers are used in professional lighting installations.

TRIAC controllers, which perform flawlessly with incandescent lamps, have been found to cause a variety of effects when connected to LED lamps, including flickering, uneven lighting, audible noise, and flashing. To understand why, the operation of a TRIAC controller must be considered.

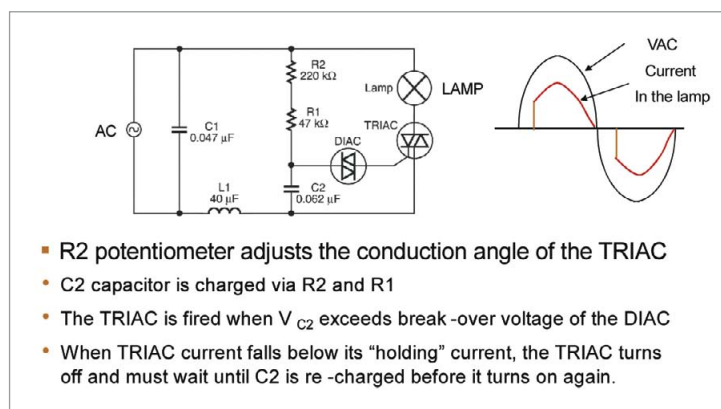


Figure 2: Leading edge TRIAC dimmer.

Dimming control is achieved by altering the phase angle over which the TRIAC conducts each half cycle. The current through a lamp filament is a function of the phase angle of the dimming signal, which can vary from almost zero to 180°. An important parameter for a TRIAC is the holding current (I_H). This is the minimum load that must flow for the TRIAC to continue firing in the absence of a gate drive. This cannot be zero for stable operation of the TRIAC and typical values for I_H are 8 to 40 mA. When driving incandescent lamps, the holding current is not an issue. However, with the high efficiency of LED lamps, conditions can occur when the holding current is not maintained and the lamp goes out. Such conditions can easily occur if any oscillation takes place.

An incandescent lamp presents a TRIAC controller with a simple low impedance load, so oscillation is unlikely. An LED driver, on the contrary, presents a high impedance load and has at its input EMI filtering circuitry consisting of capacitors and inductors. At each half cycle, a current inrush occurs when the TRIAC fires, with the worst case at a firing angle of 90° when the input voltage is at maximum. Because of the line/filter impedance, the bus voltage can overshoot and ringing can occur. If the ringing causes the current to fall below I_H , the TRIAC turns off (Figure 3).



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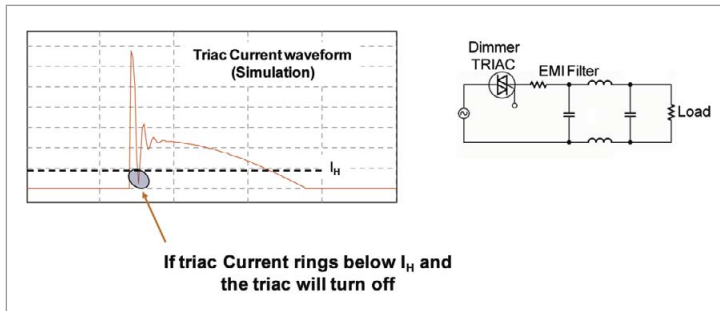


Figure 3: Current ringing due to input EMI filter.

When the TRIAC turns off, R1 and R2 recharge the DIAC (Figure 2) up to the breakover threshold. The DIAC then fires the TRIAC and the cycle repeats. The result is multiple restarts of the TRIAC during an input line cycle (Figure 4).

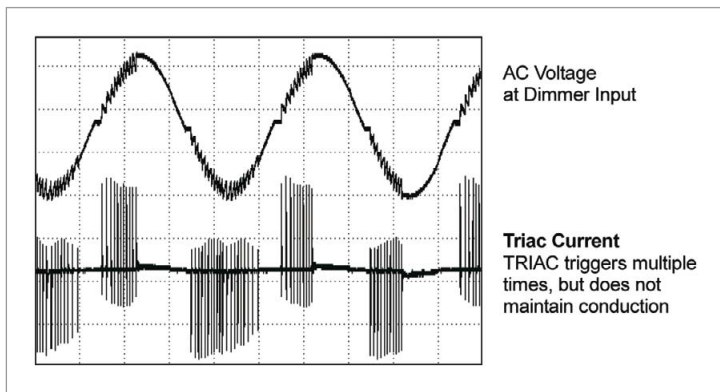


Figure 4: TRIAC multiple restarts due to ringing.

To avoid the problems associated with TRIAC dimming, an LED driver must deliver the very different requirements of the LED load while interfacing with dimming circuitry designed for the incandescent world. An LED lamp intended to replace a standard incandescent bulb will typically contain several LEDs arranged to provide an even spread of light. The LEDs are connected in a series string. The brightness of each LED is a function of the current through it. The LEDs have a forward voltage drop of approximately 3.4 V, but can vary from 2.8 V to 4.2 V ($\pm 20\%$). Despite this wide load variance, the LED string must be driven by a constant current supply, which must be tightly controlled to ensure matching between adjacent lights.

For an LED lamp to be dimmable, the lamp's power supply must detect the variable phase angle output from the TRIAC controller and use this information to change the constant current drive to the LEDs. The circuit must inherently produce the minimum of conducted EMI to enable the input filter to be as small as possible. In addition, the drive circuit must control the power factor.

LED Driver Control

It is clear that a standard flyback configuration for an LED driver simply will not do, and a controller optimized specifically for driving LEDs is required. Figures 5 and 6 illustrate this point.

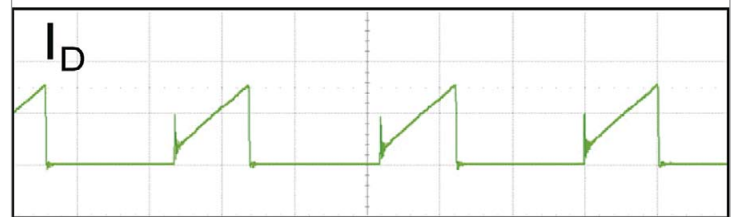
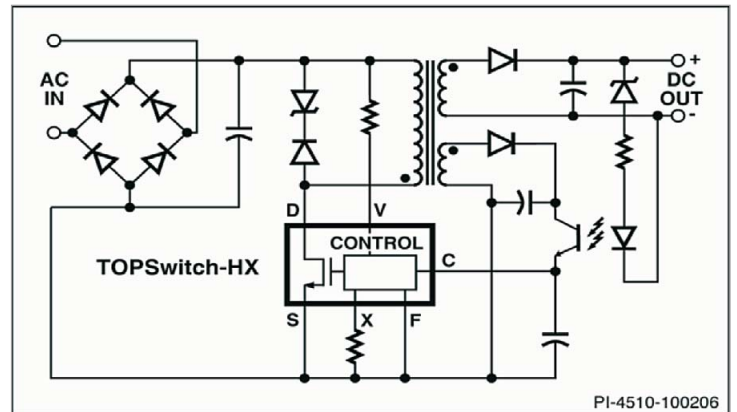


Figure 5: Standard flyback circuit using TOPSwitch-HX.

Figure 5 is a constant current output flyback power supply using a TOPSwitch™-HX controller from Power Integrations (PI). The output voltage is determined by the Zener diode at the output. This provides a feedback signal to the controller via the optocoupler. The controller responds to the voltage feedback signal at input C by adjusting the duty cycle of the integrated high-voltage power MOSFET switch to maintain the required output. For a given load and input voltage, the circuit will operate at a fixed frequency and duty cycle.

The circuit can be configured to provide a constant current output which will successfully drive an LED lamp. However, there is no TRIAC phase angle detection and no power factor control.

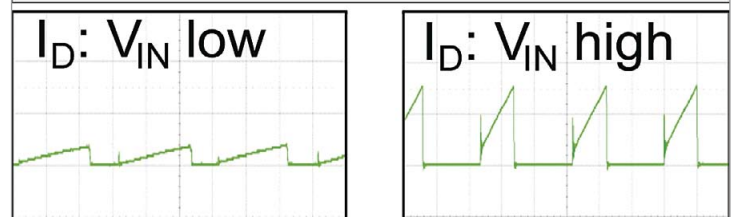
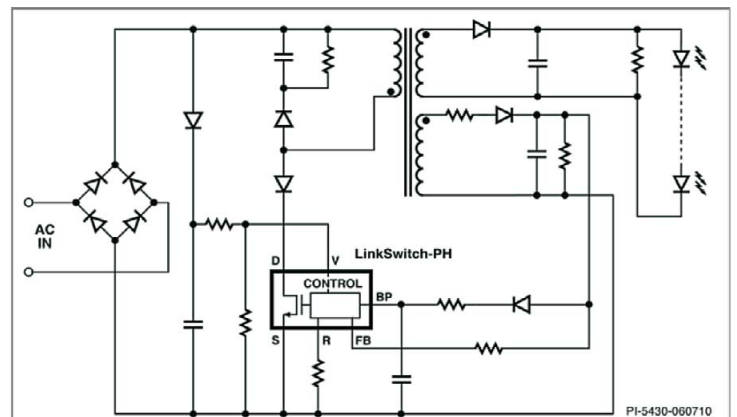


Figure 6: Flyback power supply optimized for constant current LED load.

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Figure 6 shows a flyback power supply implemented using the new LinkSwitch™-PH. The controller incorporates several new features designed specifically for driving LEDs. The circuit differs from Figure 5 in that it employs primary-side regulation. This eliminates the optocoupler and secondary-side control circuitry. The second-secondary winding (bias winding) on the transformer performs two functions: it provides power to the controller via the BP pin and current feedback via the FB pin. The two secondary windings are closely coupled, with the result that the voltage developed across the bias winding is proportional to the current through the LED load. The controller responds to current feedback at the FB pin by adjusting the duty cycle of the integrated high voltage power MOSFET to maintain current regulation.

The circuit is designed to operate with a limited amount of smoothing of the rectified AC mains input. The controller continually adjusts the duty cycle of the high-voltage power MOSFET as the mains input rises and falls throughout each half cycle with the average charge over each half cycle being controlled to maintain output current regulation as shown in Figure 7.

At close to the zero crossing, the instantaneous input voltage is low and the duty cycle is large. At the peak of the rectified AC input, the voltage is at its maximum and the duty cycle is smallest. For each switching cycle, the MOSFET current is integrated to give the charge per cycle. The charge per cycle is compared to a reference, which when met terminates the switching cycle. The input at the V pin sets the input voltage gain term, providing line compensation.

Dimming Control

The driver can be set to either dimming or non-dimming mode via the programming resistor linking input R to 0 V. In non-dimming mode, the circuit delivers a constant current output over the full AC input range with power factor close to 1. In dimming mode, the zero crossing and phase angle of the rectified input are used to set the level of the output current, hence providing a dimming function. It can be used to build an LED driver that will operate over the universal input voltage range yet provides a 1000:1 dimming range from low-cost TRIAC dimmers without flickering or blinking. Figure 8 illustrates how this is achieved.

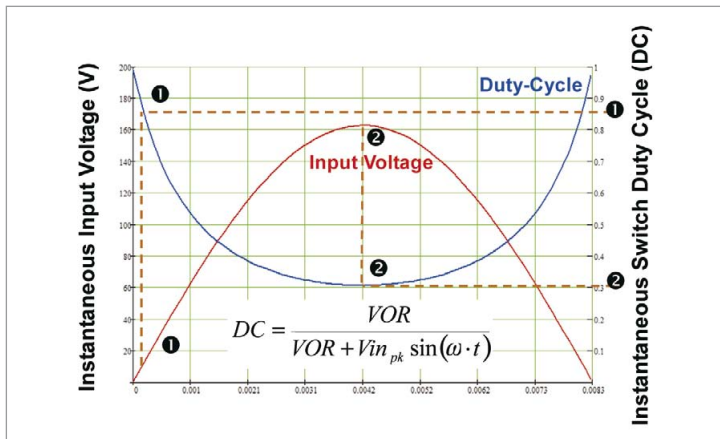


Figure 7: LinkSwitch-PH duty cycle variation over half AC cycle.

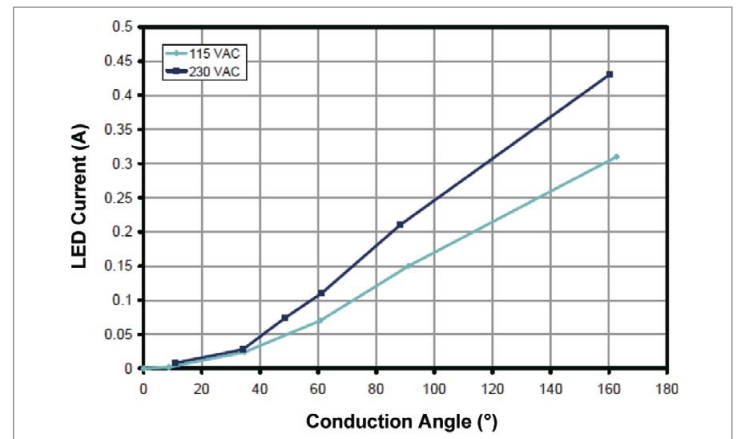


Figure 9: Input phase vs. output current.

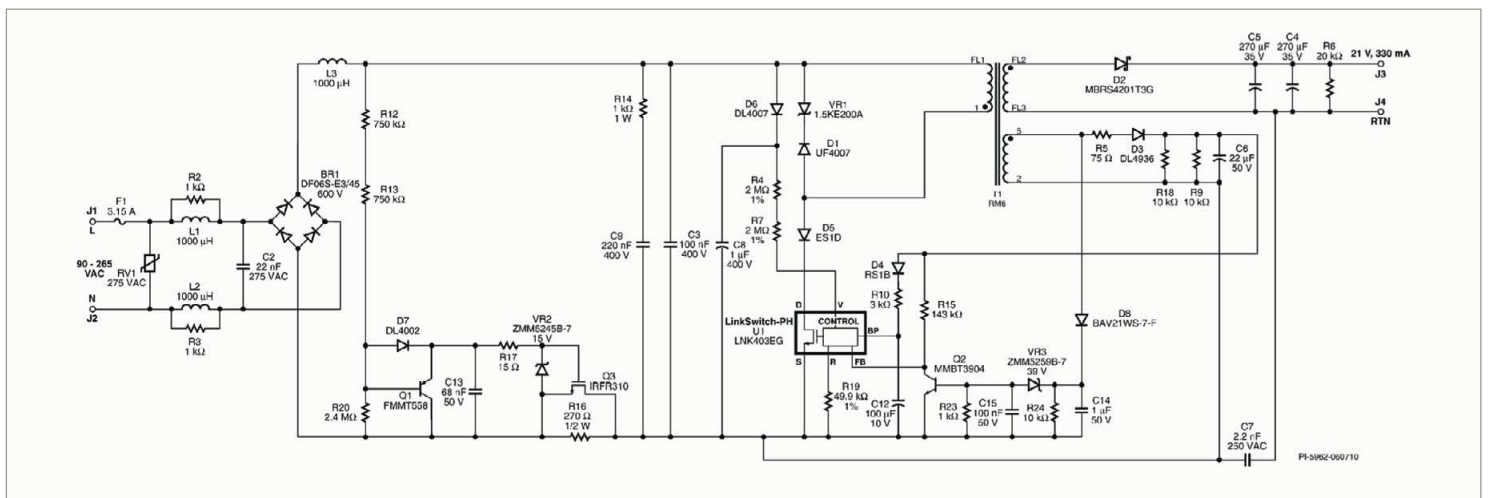


Figure 8: Schematic for a 7 W dimmable LED driver.

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Figure 8 is the schematic for a 7 W TRIAC dimmable LED driver using LinkSwitch-PH (U1)^(Ref 1.). The circuit achieves 1000:1 dimming range from low-cost, leading-edge TRIAC dimmers with no output flicker or blinking, a fast start-up (<100 ms), and consistent dimming unit-to-unit performance. The design is highly energy efficient ($\geq 81\%$) with a high power factor (>0.9). Figure 9 shows the linearity of the dimming control over an exceptionally wide range.

One key to consistent dimming performance is a small EMI filter at the input. Two features of this driver contribute to simplifying input filtering, continuous conduction mode, and frequency jitter. Continuous conduction mode provides two key benefits, reduced conduction loss, hence better efficiency and a lower EMI signature. This enables EMI standards to be met with a smaller and lower cost input EMI filter. One X capacitor can be eliminated and the common mode choke reduced in size or also eliminated. The controller also applies a jitter to the switching of the high-voltage power MOSFET. This creates a spread to the switching frequency and further reduces the filtering requirement.

The smaller input EMI filter presents lower impedance to the driving circuit, with the key benefit of significantly reduced input current ringing. Stability is further enhanced by being powered from its own internal reference supply. To ensure compatibility with all types of dimmer control, two optional simple additional elements are included in the design, a damper and a bleeder. The damper circuit consists of R12, R13, R20, R17, D7, Q1, C13, VR2, and Q3 in conjunction with R16. The purpose of the circuit is to reduce the inrush current when the TRIAC dimmer turns on. The circuit routes the inrush current through R16 for the first 2.4 ms at 115 VAC (1.2 ms at 230 VAC) of the TRIAC conduction. After approximately 2.4 ms, Q3 turns on and shorts R16.

This eliminates the power loss due to the current flow through R16 for the remainder of the half cycle. The bleeder circuit consists of C9 and R14. The purpose of the bleeder circuit is to ensure that in deep dimming conditions when very little current is being supplied to the LED load, the TRIAC current is maintained above the holding threshold, thus preventing premature TRIAC turn-off.

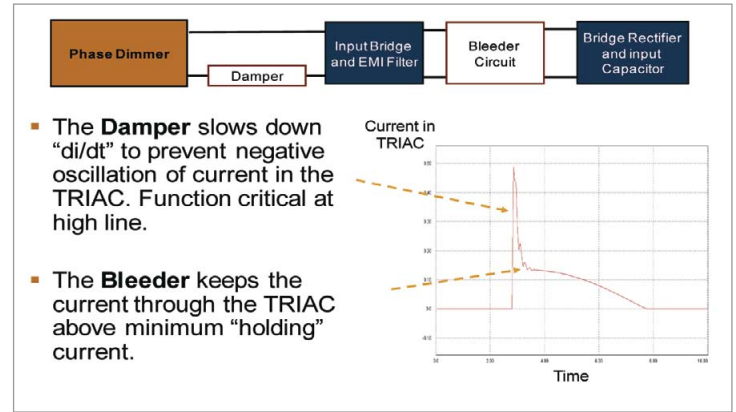


Figure 10: Damper and bleeder circuits help to ensure 1000:1 dimming range.

The addition of active damper and bleeder circuits ensures robust, flicker-free operation over an exceptionally wide dimming range.

Non-Isolated LED Driver

The circuit in figure 8 is an isolated design. This provides complete safety for lighting systems where the driver can be separated from the LED lamps. This is common in higher power commercial and industrial lighting systems. For applications where the driver and LED lamps are incorporated within the same envelope, as is the case with retrofit

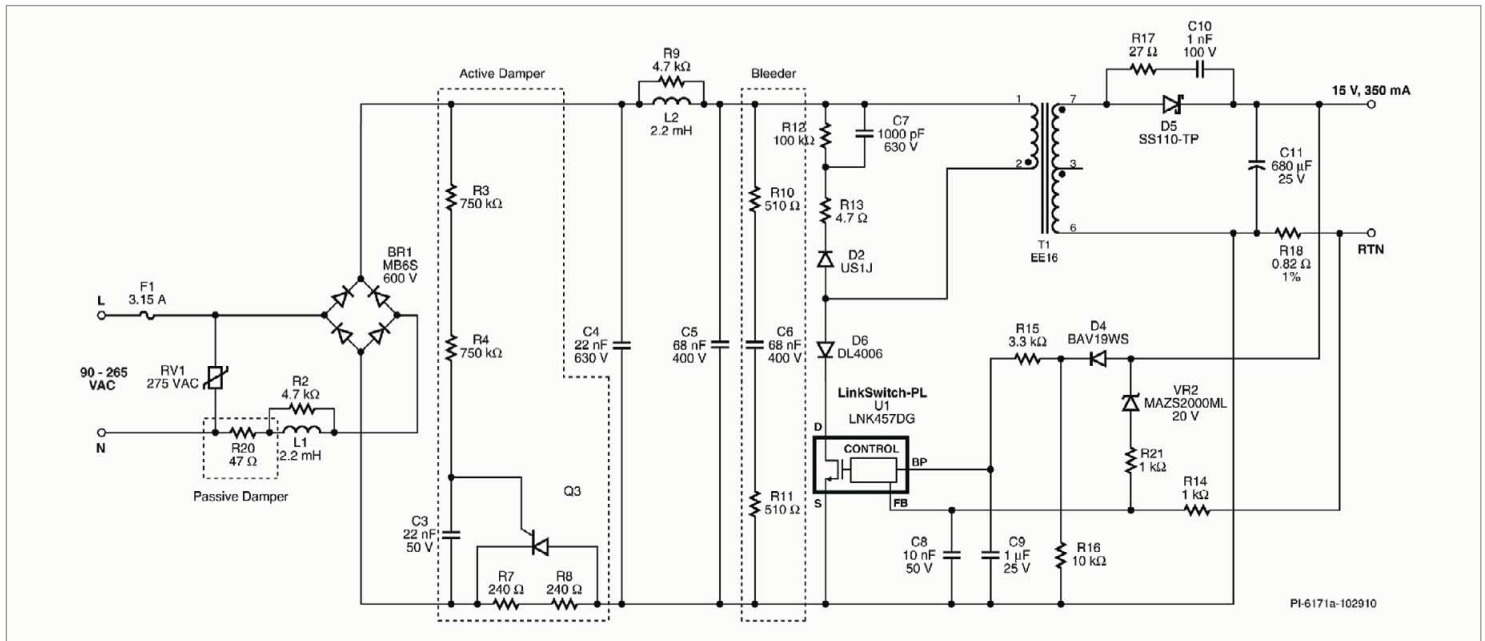


Figure 11: Schematic – highlighted blocks may be removed for non-dimming applications.

bulbs, isolated and non-isolated designs are employed. A significant reduction in component count and cost is achieved with a non-isolated design. The LinkSwitch™-PL family provides single-stage power factor correction and constant current control combined with a 725 V MOSFET optimized for non-isolated applications. Figure 11 is the schematic for a 5 W dimmable, power factor corrected LED driver^(Ref2).

This design is intended for incandescent lamp replacement, with a low-cost, low component count, and small PCB footprint solution. A dimming range of 100:1 without flickering or blinking is achieved with all dimmer types, including leading-edge TRIAC dimmers. Startup is <300 ms with consistent dimming performance unit to unit. Efficiency is >73% at 115/230 VAC in the dimmable configuration and >78% at 115/230 VAC in the non-dimmable configuration with power factor >0.9.



Figure 12: Driver incorporated in an A19 LED replacement lamp (board removed from housing).

In the design, no bias winding is required on the transformer and the constant current mode set-point is determined by the voltage drop that appears across R18. The voltage is then fed to the FB pin of U1. Output over-voltage protection is provided by VR2 and R14.

Figure 13 illustrates how the FB voltage is used to implement dimming with leading-edge dimmers.

The output LED current is controlled by the FB pin voltage which changes proportionally to the TRIAC dimmer conduction angle. When the conduction angle decreases, the FB pin reference voltage decreases and causes the average LED current to decrease. The FB pin voltage adjustment is initiated at approximately 25% of the main half-cycle duration (θ_{OS}). Between θ_{OS} and θ_{OL} , a linear relationship exists between phase angle and V_{FB} . Beyond θ_{OL} , with the TRIAC conduction angle being very limited, the IC runs open loop at constant frequency and duty cycle and the integrated high-voltage power MOSFET processes as much power as the heavily chopped input voltage will allow, creating a light output that is deeply dimmed. To help maintain the holding current of the TRIAC in the dimmer, the driver extends the MOSFET on-time towards the zero crossings of the AC input voltage providing an active bleed or holding current function.

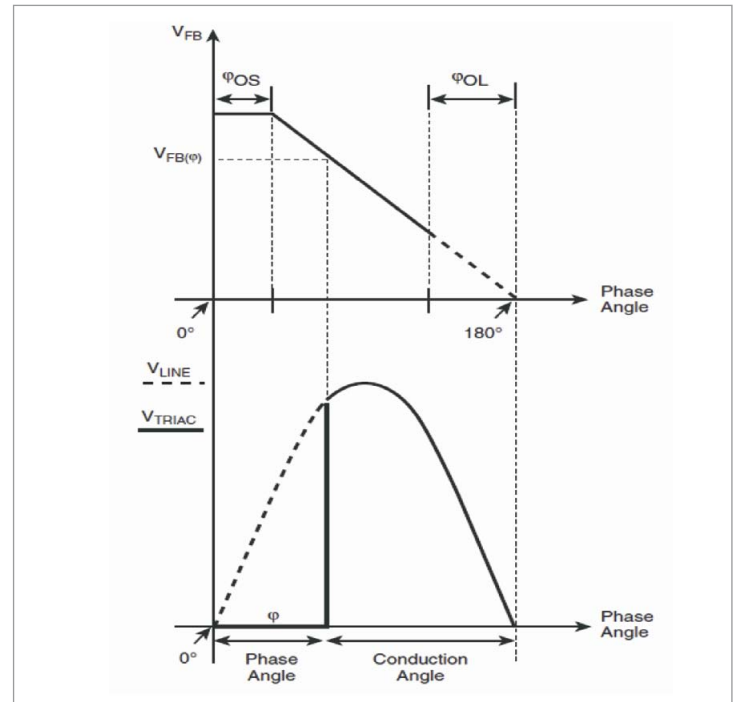


Figure 13: FB pin reference as a function of TRIAC phase angle.

Active damper and bleeder blocks are incorporated in the design to ensure flicker-free operation under worst-case conditions with all types of dimmer control. For non-dimming applications, these components can be simply omitted.

The two applications described show that, given a controller that implements power factor correction together with constant current drive and phase angle detection, it is possible to build isolated and non-isolated LED drivers that will operate reliably with all types of dimming controllers. Furthermore, the circuits meet all international standards for efficiency, power factor, harmonics, and EMI. In the past, incandescent light bulbs had to be manufactured for specific supply voltages. It is now possible to go beyond this and manufacture a dimmable LED lamp that can be used without modification anywhere in the world. ■

References:

RDR-193: Reference Design Report for a High Efficiency ($\geq 81\%$), High Power Factor (>0.9) TRIAC Dimmable 7 WTYTP LED Driver Using LinkSwitch-PH LNK403EG. Power Integrations Inc.

RDR-251: Reference Design Report for a 5 W Dimmable Power Factor Corrected LED Driver (Non-Isolated) Using LinkSwitch-PL LNK457DG. Power Integrations Inc..

Optimization of LED Control Powered from Line Voltage

> Erhard Muesch, Chief Standard Products System Architect, ZMDI

It has become common knowledge that the incandescent lamp produces over 95% heat and less than 5% visible light, and since ecological awareness has significantly grown during the last years, alternative illuminants such as compact fluorescent lamps lend themselves as a higher efficiency alternative. But these devices need a warm-up phase before reaching their nominal brightness, and frequent switching has a great impact on their life time. The magic word is now "white LED", featuring quite a number of advantages: high luminous efficiency, instantaneous brightness, very long life time, mechanical robustness, no sensitivity to switching, low operating temperature, and small dimensions which give a maximum degree of freedom to the lamp designer.

High temperatures (in the order of 100°C) reduce the LED's life time significantly, and therefore the low operating temperature is also a technical challenge. Driving LEDs with some noteworthy power from the line voltage requires an electronic ballast, and the first measure to avoid unnecessary thermal load is to achieve high efficiency of this ballast.

There is a variety of solutions existing to realize efficient LED control, but there is not a single one that meets the requirement of all different applications. This article shows two examples of how to minimize power dissipation of the LED driver: a Buck converter with an "auxiliary converter" for the IC supply, and a Boost converter for long LED chains which controls the LED power while featuring power factor correction from a single controller. Both solutions make use of the same universal switched mode power supply IC.

Switched Mode Power Supplies for LED Control

Current changes rapidly with forward voltage across an LED in its operating region, therefore constant current control is recommended rather than constant voltage. Linear current sources may be used, but power dissipation becomes excessive when the supply voltage is significantly higher than the forward voltage of the LED (chain). A switched mode power supply with constant current output is the best choice to achieve highest system efficiency. Still, it is necessary to match the converter topology and selected components to the specific requirements of the application.

Example 1: Buck Converter with "Auxiliary Supply Converter"

The simplest solution for a constant current switched mode LED control is the step-down or Buck converter as shown in figure 1. The only basic requirement is that the supply voltage is higher than the LED chain's forward voltage. Besides simplicity, the buck converter features a few more advantages:

- constant current control without the necessity for a control loop by peak current switching and constant off-time
- average current and current ripple are widely independent from supply voltage
- no open load protection is required

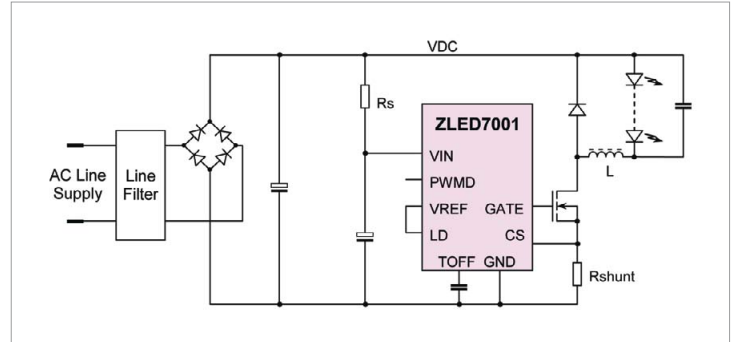


Figure 1: Basic constant current Buck converter topology.

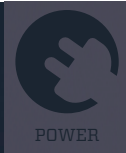
The basic buck converter application contains a supply line filter on the input for EMC reasons, a rectifier with bypass capacitor, the series inductance L, a switching transistor plus free wheel diode, a shunt resistor for current sensing, and the control IC with supply voltage generation. Each component shown in figure 1 dissipates power:

- Line filter, power dissipation is mainly determined by the resistance of inductance(s): $P_{diss} = \int (i^2 R_{dc}) dt$
- Bridge rectifier: $P_{diss} = 2 * V_d * I_{av}$
- Inductance: $P_{diss} \approx I_{LED}^2 * R_{dc}$
- DC supply cap.: $P_{diss} = I_{sw,eff}^2 * R_{ESR}$
- Free wheel diode: $P_{diss} = V_d * I_{LED} * (1 - d_{av})$
- Power transistor: $P_{diss,stat} \approx I_{LED}^2 * R_{ds,on} * d_{av}$
 $P_{diss,dyn} \approx Q_d * V_{dc,av} * f_s$
- Shunt resistor: $P_{diss} \approx V_{sense} * I_{LED} * d_{av}$
- Control IC: $P_{diss} \approx V_{dc,av} * I_{crl,av}$
including supply series resistor

with

P_{diss} : power dissipation, $P_{diss,stat}$: static P_{diss} , $P_{diss,dyn}$: dynamic (transient) $P_{diss,dc}$: DC resistance, R_{ESR} : equivalent series resistance, V_d : diode forward voltage, I_{LED} : average LED current, d_{av} : average switching duty cycle, I_{av} : average DC supply current $\approx I_{LED} * d_{av}$, $R_{ds,on}$: drain source on-resistance, Q_d : drain charge, f_s : switching frequency, V_{sense} : current sense reference voltage, $V_{dc,av}$: average DC supply voltage, $I_{crl,av}$: average supply current for the control circuit

This overview contains a few simplifications, such as constant diode forward voltage, or consideration of average rather than effective currents where current ripple occurs, and also neglects some smaller parasitic capacitances. But it should be sufficient as a starting point. So where are the "knobs to turn" in our optimization process?



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The biggest impact comes from the topology of the LEDs themselves. For a given output power a long chain of LEDs with high forward voltage and low current leads to a better efficiency than a low voltage, high current solution (e.g. by paralleling LEDs). This is mainly caused by the free wheel diode and the switching transistor. One may assume that the inductance with its DC resistance also contributes in the same direction, but higher current allows higher current ripple and thus lower inductance, and that scales nicely with the DC resistance. Reducing the inductor losses can only be achieved by improved core material or bigger size.

The AC current load of the DC supply capacitor will also be reduced when switching current and thus current ripple is lower, leading to lower dissipation on its ESR.

Regarding the transistor there are different parameters to be considered: A low $R_{ds,on}$ reduces conduction losses during on-time, but unfortunately comes along with higher gate and drain charge. Assuming that the transient drain current capability of the transistor is significantly higher than the LED current, and the gate drive current of the control IC is at least somewhat higher than the LED current, the transistor's dynamic power dissipation is mainly determined by the discharge of its drain capacitance and the switching frequency. Drain capacitance is a non-linear function of drain voltage, and what can be found in data sheets is normally a value for the drain charge at a given drain-source voltage. This value is not quite satisfactory, since it does not contain any information about voltage dependency, but for a first estimation it may be sufficient. Dynamic power dissipation can then be calculated as the product of drain charge, average DC voltage and average switching frequency. As long as the LED chain's forward voltage is low compared to the DC supply (e.g. 10 LEDs with 35 V) the switching duty cycle is small and the average static power dissipation of the transistor stays low even with a relatively high $R_{ds,on}$. Since the target should be to minimize the total (static plus dynamic) power dissipation, this may easily lead to a small transistor which could also save cost.

The second aspect of power dissipation caused by the transistor is the gate drive circuit. Average current is given by the product of its gate charge and the switching frequency. If the supply current for the control including gate drive current is derived linearly from the DC supply voltage, the total power dissipation is the product of this current and voltage. Especially in 230 VAC applications it can be pretty high.

There are proposals existing to reduce this power by using a transformer instead of a series inductance, and have the control IC powered from the secondary winding. Transformers are normally application specific devices, and thus more expensive than standard components. Fig. 2 shows an alternative solution, employing a second, but very small inductance that is used to supply the IC, once it has started operation.

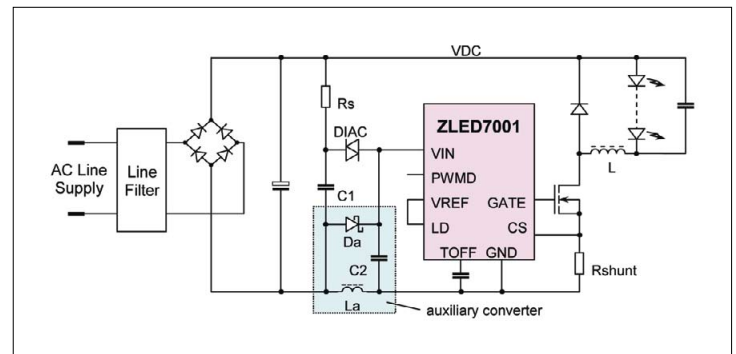


Figure 2: Constant current Buck converter with "auxiliary converter" for IC supply (principle).

In contrast to the "main" converter this "auxiliary converter" operates in "discontinuous conduction mode", i.e. during the transistor's off-time the inductor's energy is completely discharged into the IC's supply capacitor. The energy provided is given by

$$W = \frac{1}{2} I_{peak} * L_a * f_s,$$

with I_{peak} : switching current, L_a : auxiliary inductance.

A few μH are typically sufficient to provide several mA for the control circuit.

Before the auxiliary converter can start operating the IC needs to be powered up. The start-up circuit is realized with a DIAC (normally used in TRIAC dimmers) that turns on when the voltage on capacitor C1 exceeds its trigger level of 30 ~ 35 V. C1 is then discharged into C2, providing a voltage according to the capacitor ratio, high enough to start the converter's operation. Power dissipation in the series resistor R_s can be kept very low, and still the circuit operates in a wide supply voltage range with low turn-on delay.

Example 2: Boost Converter with Power Factor Correction

Power Factor Correction (PFC) is required by legislation for lighting equipment with a power consumption of 25 W or more. But even at lower power it makes sense to employ at least a basic kind of current wave shape improvement, considering that in the future the number of electronically controlled illuminants will increase dramatically. "Valley Fill", as shown in figure 3, is the most basic passive kind of PFC. The current shape does not at all look like a sine wave, but the rectifier's conduction time is significantly increased, and the harmonic content is reduced accordingly. Even though the additional three diodes cause extra power dissipation, system efficiency may be improved for two reasons:

- Average VDC is lower causing reduces switching losses in the power transistor
- Losses in the line filter are reduced due to lower harmonic current content

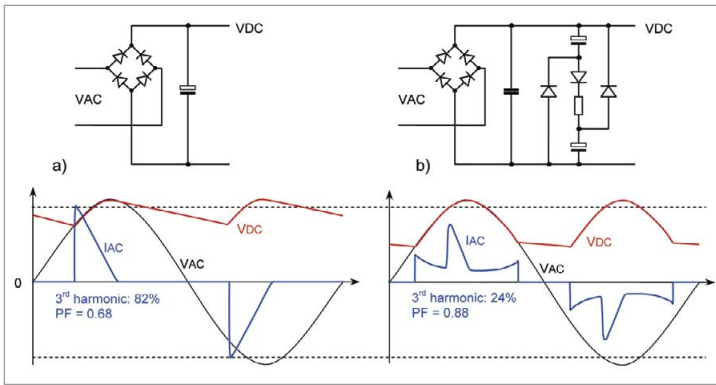


Figure 3: Power line current IAC a) without b) with "Valley Fill".

Figure 3 a) and b) show the line current of an LED load with a single bypass capacitor and a Valley Fill circuit, respectively. For higher power ratings this approach is not sufficient. In order to avoid bulky passive components an active PFC is recommended. A good approximation of sinusoidal current can be achieved operating a Boost converter with constant on-time in critical conduction mode. Peak switching current is proportional to the momentary supply voltage, and the transistor is turned on again after zero crossing of the inductor current has been detected. Current shape is triangular, and average current of a switching period is $\frac{1}{2}$ of the peak current. As a consequence average output power is constant regardless of the output voltage.

Usually a second converter that drives the LEDs is supplied from the PFC converter's output. A different approach is possible when the forward voltage of a long LED chain is always higher than the maximum peak line voltage. For an AC voltage of $230\text{ V} \pm 15\%$ the highest peak is 374 V. 120 LEDs in series are required as minimum, which are quite a few, but for uniform illumination of large areas it certainly makes sense. Using multiple chip LEDs reduces this number, e.g. 4 chips in series lead to 30 LEDs, which could be used in fluorescent tube replacement. In such cases the output of the PFC converter can directly drive the LED chain, and the second converter is saved. The output has to be constant current or power rather than constant voltage.

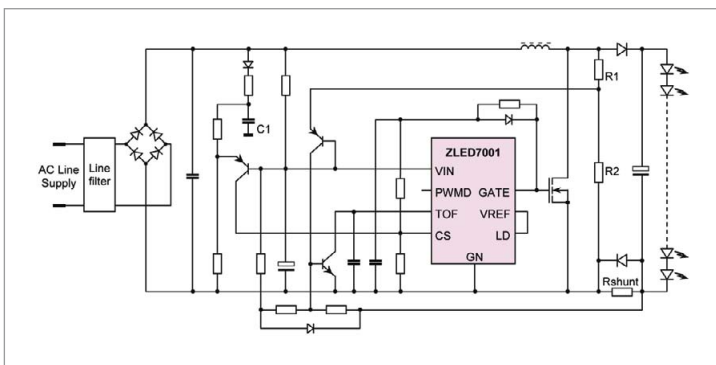


Figure 4: PFC converter for long LED chains with $V_f > V_{AC,peak}$.

The circuit shown in figure 4 features open loop control which results in excellent stability. The peak supply voltage is stored on C1 and is fed forward to keep the LED current constant. Voltage dependency is non-linear, but with proper dimensioning of this linear compensation $< 1\%$ variation can be achieved for a line voltage tolerance of $\pm 15\%$.

Zero crossing of inductance current is detected as voltage across Rshunt, thus no transformer is required. A parallel diode limits power dissipation to $< 100\text{ mW}$.

Every Boost converter needs over voltage protection, since in case of open load the output voltage increases until a component fails. The divider R1/R2 feeds back the output voltage to turn the converter off when typically 500 V are exceeded.

The single converter approach offers PFC in combination with excellent efficiency at low cost. A few numbers may serve as an example:

- 120 (30 x 4) LEDs operated at typically $400\text{ V} / 80\text{ mA} = 32\text{ W}$
- Power consumption: $P_{in} = 34.5\text{ W}$, efficiency $\approx 93\%$, power factor $PF = 0.998$
- 3rd harmonic amplitude $< 3\%$

Conclusion

LED topology and choice of the best suitable switched mode power supply define system efficiency of a line driven LED illuminant. With a universal DC-DC controller many different architectures can be realized in order to achieve low cost at optimum performance for the individual application. The two examples presented in this article show solutions for simple incandescent bulb replacement on the low end and control of long LED strings including power factor correction for large area illumination or fluorescent lamp replacement on the high end of the scale. The same device can be used to address many other requirements as well. ■

Street-Lighting Solution Based on a Digital Current Control

> N. Aiello, G. Macina, ST Microelectronics – IMS Systems Lab

The brightness of an LED is proportional to the forward current; thus the best way to supply LEDs is to control the forward current to satisfy the LED manufacturer's characteristics such as lumens and color temperature.

An important key feature must be taken into account for lighting applications, especially with high-power LEDs. Forward voltage and output power are strictly dependent on the junction temperature of an LED, which drastically affect quality and lifetime.

To put it precisely: As the junction temperature increases, forward voltage and output decrease, generating a critical current rise as a consequence of a thermal drift.

Advanced LED drivers are required more and more by lighting applications in order to solve the thermal runaway effect, depending on forward voltage reduction and getting some advantages in terms of efficiency, brightness control with PWM and/or analog dimming, fault management and over-temperature control. A remote control function may also be required to provide added value in some applications, such as architectural lighting and street-lighting.

The majority of LED drivers for general lighting are based mainly on Buck topology due to higher DC voltage input coming from AC mains by means of a high power factor AC/DC stage. The analog architecture based on the monolithic solution with integrated power switch and for output current up to 350mA is generally preferred but has some limitations in the case of voltage higher than 50/60V.

The need to design multi-channel systems requires several output channels to cover a complete lighting platform, with a huge quantity of drivers increasing complexity in system architecture, lay-out design with the consequence of higher costs.

The main limitation of the standard solution is related to the sensing methodology based on a shunt resistor and on an internal comparator. The current feedback coming from the voltage across the sense resistor is compared to an internal reference by the comparator providing an output signal which controls the gate driving stage.

This analog approach, commonly used, implements a peak current control which is not ideal for lighting quality due to an LED color shift which is not acceptable in many demanding application fields.

A New Solution in LED Driving

STMicroelectronics proposes a cost-effective street-lighting platform that can guarantee lighting requirements, offering high-end performance, very high efficiency (overall efficiency at full load >91%) with a complete fault management (over-current, over-voltage and load short circuit).

Two main sections can be identified: the power supply section and the current controller managed by a digital current control.

The power supply circuit provides up to 130W (48V at 2.7A) and is composed of two stages: a front-end PFC using the L6562AT and an LLC resonant converter based on the L6599AT.

The peculiarities of this design are: Extended European input mains range (177 ÷ 277 VAC - frequency 45 ÷ 55 Hz), no heat sink needed due to very high efficiency (93.85% at full load), long term reliability due to lack of electrolytic capacitors and compliant with EN61000-3-2 Class-C (main harmonics), EN55022-Class-B(EMI) and EN60950 with double insulation (SELV).

The current controller section is based on an inverse Buck topology and is fully digitally controlled by a general purpose microcontroller with a special key feature for a ground referred current sensing methodology that does not require either differential or error amplifier or network filtering and further external passive components.

An inverse Buck topology, operating in Continuous Conduction Mode (CCM), was chosen because the power switch is connected to ground rather than the high side switch, as in a standard buck topology. Thus with this solution, Logic Level (5 V) or even Super Logic Level (3.3 V) power switch can be driven directly by the microcontroller without any gate driving stage, rendering the overall solution simple and cost-effective. In Figure 1 the complete lighting solution is shown.

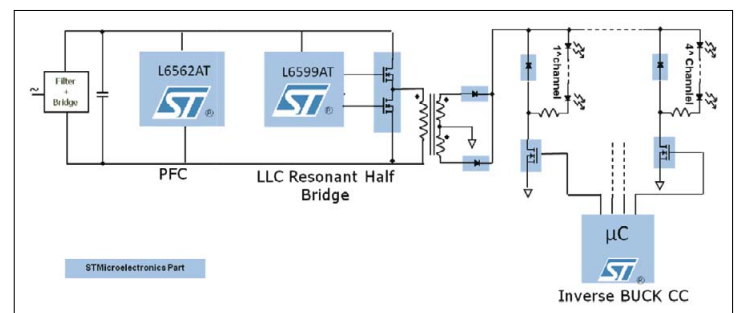


Figure 1: LED Street-lighting solution.

The flexibility concept which is the aim of this solution, allows driving up to 16 output channels from low power and low voltage to high power and high voltage independently, offering designers the possibility of covering a wide range of different LED driving systems using a single topology - thanks to a dedicated product portfolio.

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Lens height = 0,7 mm

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Constant Current Regulation: Digitally Controlled Sensing Methodology

The main peculiarity is related to the current control which is managed by microcontroller's peripherals (High-resolution Timers and Fast ADC).

The ADC triggering is a special feature embedded into the Trigger/Clock controller that is one of the timer's architecture sections. Four triggering source events (Reset, Enable, Up/Down, Count) can be managed for the ADC by means of the TRGO signal.

In the proposed methodology a triangular carrier with center aligned PWM triggers, by TRGO, the ADC at the crest of counting that coincides with the middle of the conduction time ($T_{on}/2$).

This triggering and consequential conversion points out the average value, if the CCM operations is guaranteed, not estimated by software processing during the current growth as shown in figure 2b.

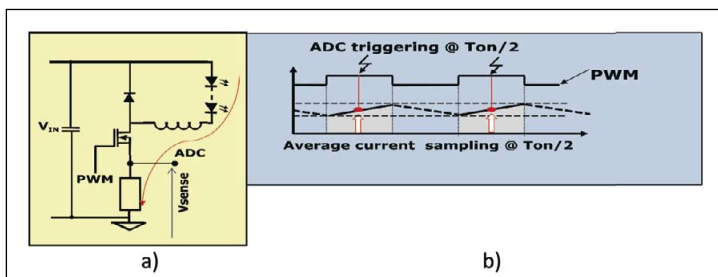


Figure 2: a) LED current during the conduction time (T_{on}); b) ADC triggering during the $T_{on}/2$.

This feature, embedded into the timer's architecture, does not overload the CPU with a start of conversion managed by software until the converted data is available for the current loop regulation by means of a standard PI controller.

Moreover, a $T_{on}/2$ current reading is not influenced by switching activities (figure 3a), having an advantage in terms of accuracy that has to be guaranteed as high as possible, thanks to no delay time introduced by RC filtering. The current regulation is pointed out in figure 3b.

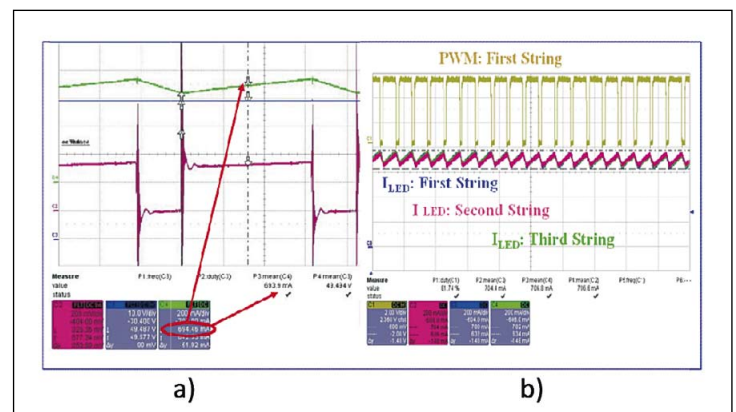


Figure 3: a) LED Current (green waveform) and voltage across the shunt resistor (violet waveform); b) Average current control on LED strings.

As soon as the conversion is completed the current control is implemented into the End Of Conversion Interrupt Service Routine (EOC ISR) channel by channel every 3 PWM periods -guaranteeing a suitable control bandwidth. In order to minimize the channel by channel current mismatch due to the conversion time, the control converts and regulates one of the possible output channels while the remaining are controlled in different sampling times.

The Dimming function is then applied on the LED current in order to vary the output lumen and regulating total brightness throughout the entire day.

An over-voltage, over-current and LED string short-circuit protection (in case of maintenance by operator) complete the street lighting platform and make it competitive in terms of performance. The advantages for architecture are that it can be easily achieved from 1 up to 16 output channels with 1W, 3W or even Power LED modules using the software and the digital control flexibility and offering the best solution in dimmable high efficiency systems with multi-string architecture. ■

The Multi-Stage Off Line LED Driver

> Peter B. Green, LED Group Manager, International Rectifier

Although it is relatively straightforward to design a basic LED driver for a general lighting application, it becomes far more complex when additional functionality such as phase cut dimming and power factor correction are also required.

A non-dimming LED driver with no power factor correction generally consists of an off line switching power supply configured to regulate the output at a constant current. This is not much different from a standard off line switching power supply such as the types commonly used in AC-DC adaptors. Such designs can be based on standard SMPS circuit topologies like the Buck, Boost or Flyback converter.

On December 3rd 2009 the US Department of Energy (DOE) released the final version of ENERGY STAR Program requirements for Integral LED lamps, which mandates that power factor must be better than 0.7 for domestic applications for LED drivers. The requirement for industrial applications is expected to be better than 0.9. Many products currently on the market fail to meet these requirements and therefore more advanced designs are needed to replace them in the future. There are two basic approaches to power factor correction, each of which requires some additional circuitry at the front end of the converter; the simple low cost passive PFC and the more complex active PFC. Before exploring these methods in greater depth it should be mentioned that in order to gain Energy Star rating the LED driver must also be dimmable.

This generally means dimmable from existing wall dimmers based on the phase cut principle of operation originally designed to work with purely resistive incandescent lamps. Although other dimming methods such as linear 0-10 V dimming or DALI would presumably also qualify, they are likely to be limited to high end industrial type LED drivers. Phase cut dimmers are by far the most widely used and it is clear that there would be a significant advantage for LED lamps to able to be dimmed effectively by them. Since many low cost triac based dimmers exist in the market it is not practically possible for LED drivers to guarantee to compatibility with all types, especially since many dimmers are of very basic design and limited performance. For this reason the energy star program requires only that the LED driver manufacturer specify in a web page, which dimmers are compatible with their product.

Another energy star requirement worth mentioning is that the LED operating frequency has to be greater than 150 Hz in order to eliminate the possibility of visible flicker. This means that the output current supplying the LEDs may not include any significant amount of ripple at twice the line frequency of 50 or 60 Hz.

The adoption of LED lighting in off line applications such as office lighting, public buildings and street lighting is increasing and is

predicted to continue to do so for the next few years. In these applications high power LEDs replace linear or high power CFL fluorescent lamps, HID (metal halide and high pressure sodium) lamps as well as incandescent lamps. These applications require an LED driver, which will typically range from 25 W to 150 W. In many cases the LED load is comprised of an array of high brightness white LEDs often packaged in multiple die form. The DC current required to drive these loads is often at least one Amp. AC current driven LED systems also exist but DC systems are generally considered to provide more optimal driving conditions for LEDs.

In LED light fixtures galvanic isolation is required to prevent electric shock risk where LEDs are accessible, which is in most cases unless a mechanical system of isolation is employed. This is because unlike for example fluorescent light fixtures which do not need to be isolated for safety, the LED die need to be connected to a metal heatsink. For good thermal conductivity it is necessary for the thermal barrier between the LED die and the heatsink, which precludes the possibility of adding insulating material in between that would be thick enough to satisfy isolation requirements. It is therefore the best option to provide isolation within the LED driver itself and this dictates the power converter topologies that are suitable. The two possibilities are the Flyback converter or a multi stage converter that includes a PFC stage, followed by an isolation and step down stage and finally a back end current regulation stage. Of the two the Flyback is the more popular due to its relative simplicity and low cost. The Flyback converter offers a good solution for many applications, however it has the following limitations:

- Limited power factor correction ability.
- Limited efficiency over wide input voltage range.
- Output ripple at twice the line frequency (<150 Hz) cannot be easily eliminated.
- Additional circuitry required for dimming.

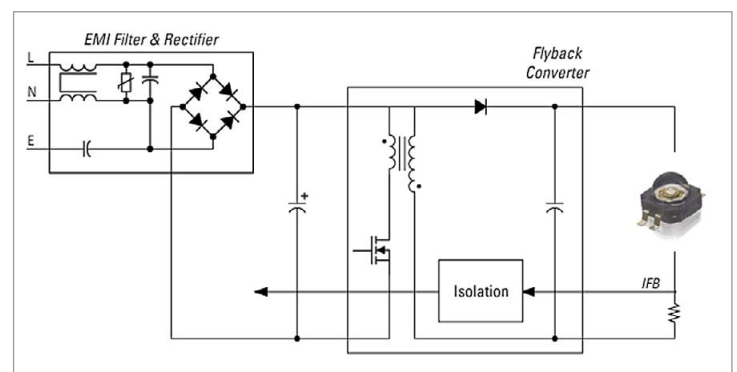


Figure 1: Flyback converter – simple diagram.

The multi stage design can overcome some of these problems, although its additional cost limits its adoption to higher end products. High power factor and low total harmonic distortion (THD) can be achieved over a wide AC input voltage range allowing the same LED driver to operate from a 110 V, 120 V, 220 V, 240 V or 277 V mains supply. Efficiency can be maintained over this range rather than peak

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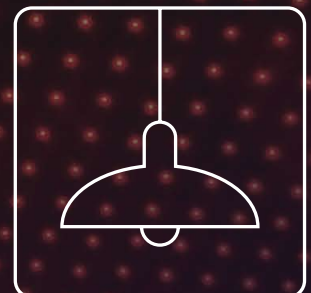
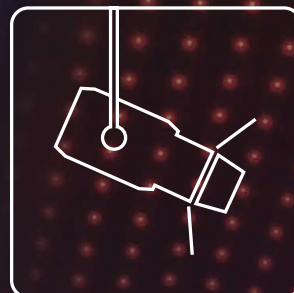
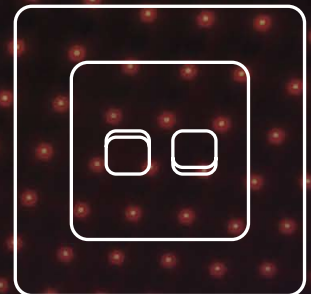
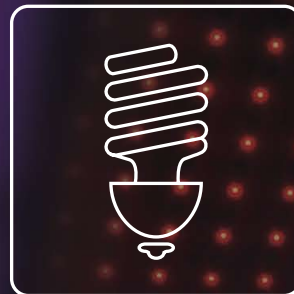
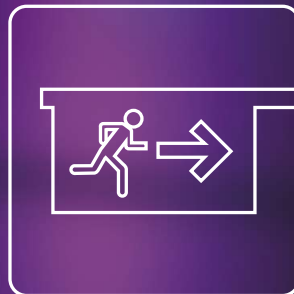
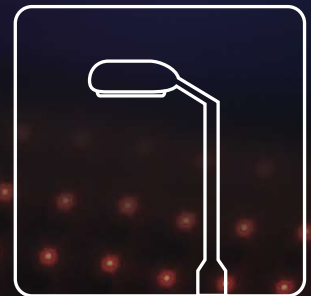
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at a specific line load point and drop off significantly under different conditions. It is also much easier to minimize output ripple under 150 Hz and the multi stage system lends itself more effectively to the different methods of dimming.

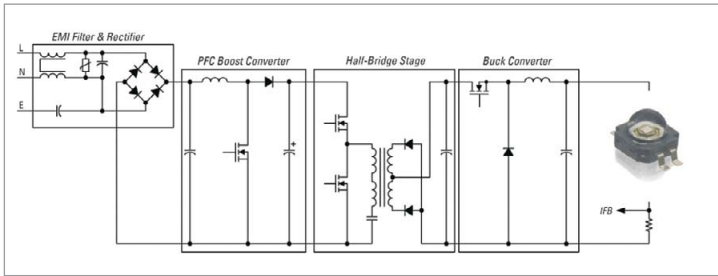


Figure 2: Multistage converter – simple diagram.

The remainder of this article will discuss in detail the design of a wide input voltage range, isolated, dimmable, regulated DC output multi stage LED driver design concept intended for applications in the 25 W to 150 W range.

The multi stage LED driver in this example will be broken down into three sections:

- The front end, power factor correction (PFC) section.
- The isolation and step down section.
- The back end, current regulation section.

The front end section consists of a Boost converter configured as a power factor correcting pre-regulator that delivers a high voltage DC bus at the output regulated to a fixed voltage over variations in line or load. Since the regulating control loop response is slow and takes many cycles of AC line frequency to react to line load changes, it draws an essentially sinusoidal line input current. This circuit typically operates in critical conduction mode otherwise known as transition mode. In this mode the PWM off period and therefore the switching frequency is variable such that the new switching cycle begins at the point when all of the energy stored in the Boost inductor has been transferred to the output. This resonant mode of operation is widely used and offers high efficiency due to minimal switching losses. It is the best approach to use in the power range required.

The middle stage converts the high voltage DC bus voltage (typically around 475 V) to a low voltage output suitable for driving LED loads. For safety reasons LED loads are normally driven from low voltage and therefore drive current is often at least 1 Amp.

The configuration of the isolation and step down stage recommended here is a resonant half bridge consisting of a pair of switching MOSFETs driven in anti-phase with each other. The mid point of these switches supplies one end of the primary winding of a high frequency step down transformer and the other end is connected to a capacitive divider network from the DC bus to the zero volt return. In this way the transformer primary sees a square wave voltage of equal positive and negative amplitude. The secondary winding will be center tapped in order that a two diode rectifier can be used to convert the output

back to DC. Where the output current is sufficiently high the rectifying diodes can be replaced with MOSFETs operating as a synchronous rectification system. In a typical application running at 3 Amps, the surface temperature of synchronous MOSFETs was measured at 30 degrees C lower than Schottky diodes having the same package. It can be seen that as the current requirement increases the thermal benefits of synchronous rectification become very significant. Finally a smoothing capacitor is required to produce an isolated DC voltage with low ripple. This can be in the order of tens of micro-Farads and therefore ceramic capacitors can be used.

In order for the half bridge stage to operate efficiently it should be designed to operate in resonant mode where the MOSFETs switch at zero voltage (ZVS). This is accomplished by ensuring that there is a short delay between the time when one MOSFET switches off and its counterpart switches on and that during this time the voltage at the mid point commutates from one rail to the other. This happens due to the release of energy stored in the inductor conducting through the integral body diodes of the MOSFETs. It is necessary for the primary of the transformer to possess sufficient leakage inductance in order for sufficient energy to be stored to allow commutation to take place. This makes the transformer design rather more complicated and one easy way to get around this difficulty is to use a standard high frequency transformer design without additional leakage inductance added into its design and to simply add another inductor in parallel with the primary solely to facilitate commutation. This extra inductor can also be used to aid dimming operation from triac based dimmers, therefore adding justification for the extra cost and space. This will be further discussed later. Such an inductor can be built around a gapped or open core to facilitate energy storage.

The back end stage of the LED driver consists of a current regulating circuit with short circuit protection. This can be realized with a linear regulating circuit, however such an approach is inherently inefficient and therefore only suitable for low output currents, which will not generally apply in a multi stage system. The alternative is a simple Buck regulator circuit with a current feedback to limit the output current from ever exceeding the intended LED drive current. This compensates for variations in total LED forward voltage over temperature and device tolerance and also limits the current in the event of a short circuit or other fault condition thereby protecting the driver against damage.

A multi channel approach is also possible where several output stages are connected to a single isolated DC voltage supplied by the previous stage. This is advantageous because with such an arrangement a short circuit at the output of one of the channels would not prevent the other channels from working normally. Furthermore it allows several channels of regulated current to supply different LED arrays and avoids the need for connecting LED arrays in parallel. It is well known that connecting LEDs in parallel is problematic unless the LEDs are of similar forward voltage drop operating at similar temperature, therefore the advantage of a driver with multiple independent outputs is apparent.

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Drawbacks of Using Triac Based Dimmers

Most dimmers commonly available operate by means of leading edge phase cutting using a very simple circuit based around a triac. These dimmers were originally designed to work with incandescent light bulbs which are purely resistive loads. The triac device is a semiconductor switch that conducts current in either direction between its two main terminals only after it has been fired by a pulse applied to the third gate terminal. This pulse can be of either polarity and is therefore simple to create with a basic RC timing circuit. The principle of operation consists of firing the triac at a point in the AC line cycle so that it conducts until the end of the cycle at which point the line voltage drops to zero and consequently so does the current flowing through the triac, which causes it to switch off again. Triac devices have a minimum rated holding current below which will switch off. Adjusting a potentiometer in the circuit controls the firing point of the triac in the dimmer circuit and changes the overall average AC current passed through enabling dimming.

LED converters and other power supplies or electronic ballasts however, do not represent a purely resistive load to the dimmer even when they include a power factor correcting front end. The triac in the dimmer therefore tends to fire erratically and miss cycles when the dimming level is lowered. The factors that influence this behavior are quite complicated and it is not necessary to go into a deep analysis since a simple solution has been found which can overcome the problem to a large extent in the multi stage system.

Instead of returning the commutating inductor from the primary side of the step down transformer to the mid point of the capacitive divider the current can be fed through a DC blocking capacitor back to the line input. This provides a small amount of additional current which will keep the triac from switching off before the end of the AC line cycle and allow it to operate as required over the range of dimming. This solution uses current that would otherwise be wasted to facilitate dimming using triac based dimmers.

Dimming in this way works because as the dimmer level is reduced the output bus voltage from the front end stage also falls. This results in the secondary voltage also dropping and since LED loads have a fixed total voltage drop a small variation in voltage causes a large variation in current and therefore light output. In this way linear dimming of LEDs is realized, which circumvents the need for more complicated PWM dimming circuitry as well as avoiding possible patent infringement.

Although dimmer compatibility necessitates some loss in efficiency, the multi stage configuration remains a good option for LED driver designs where higher performance is required. ■

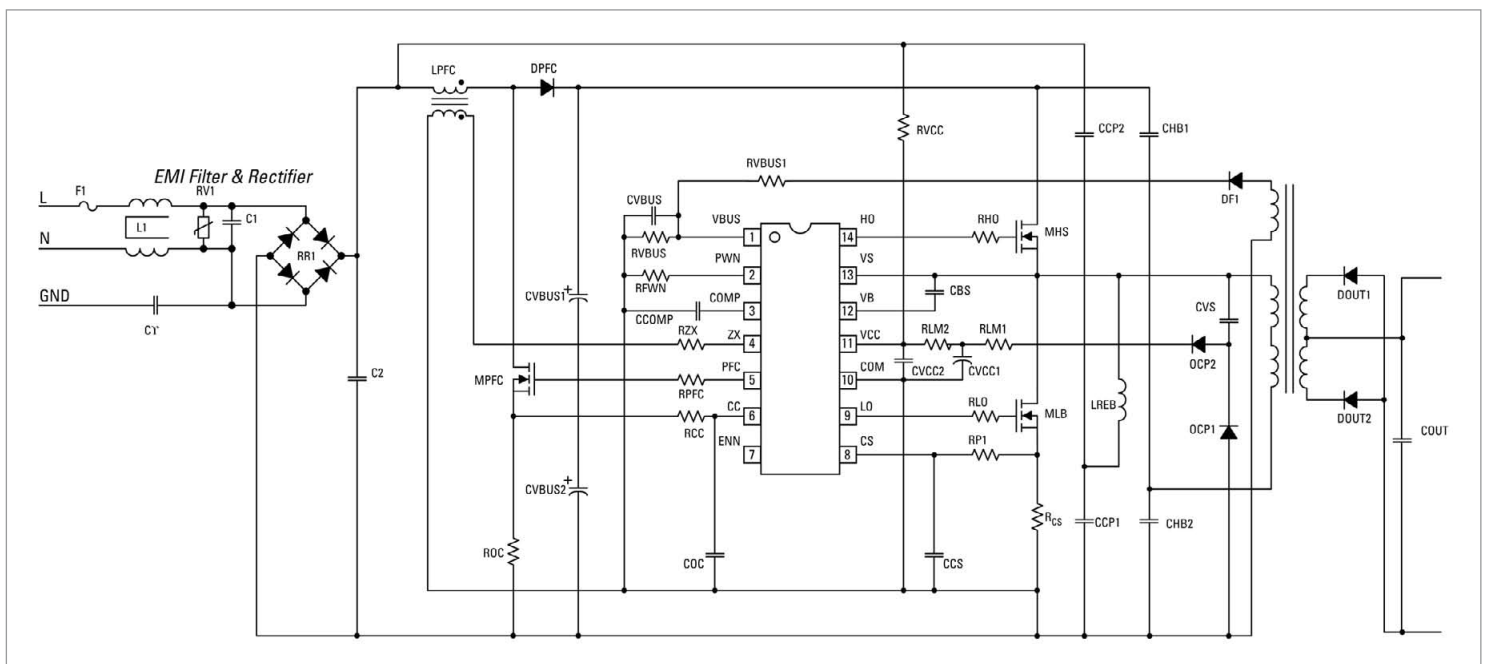
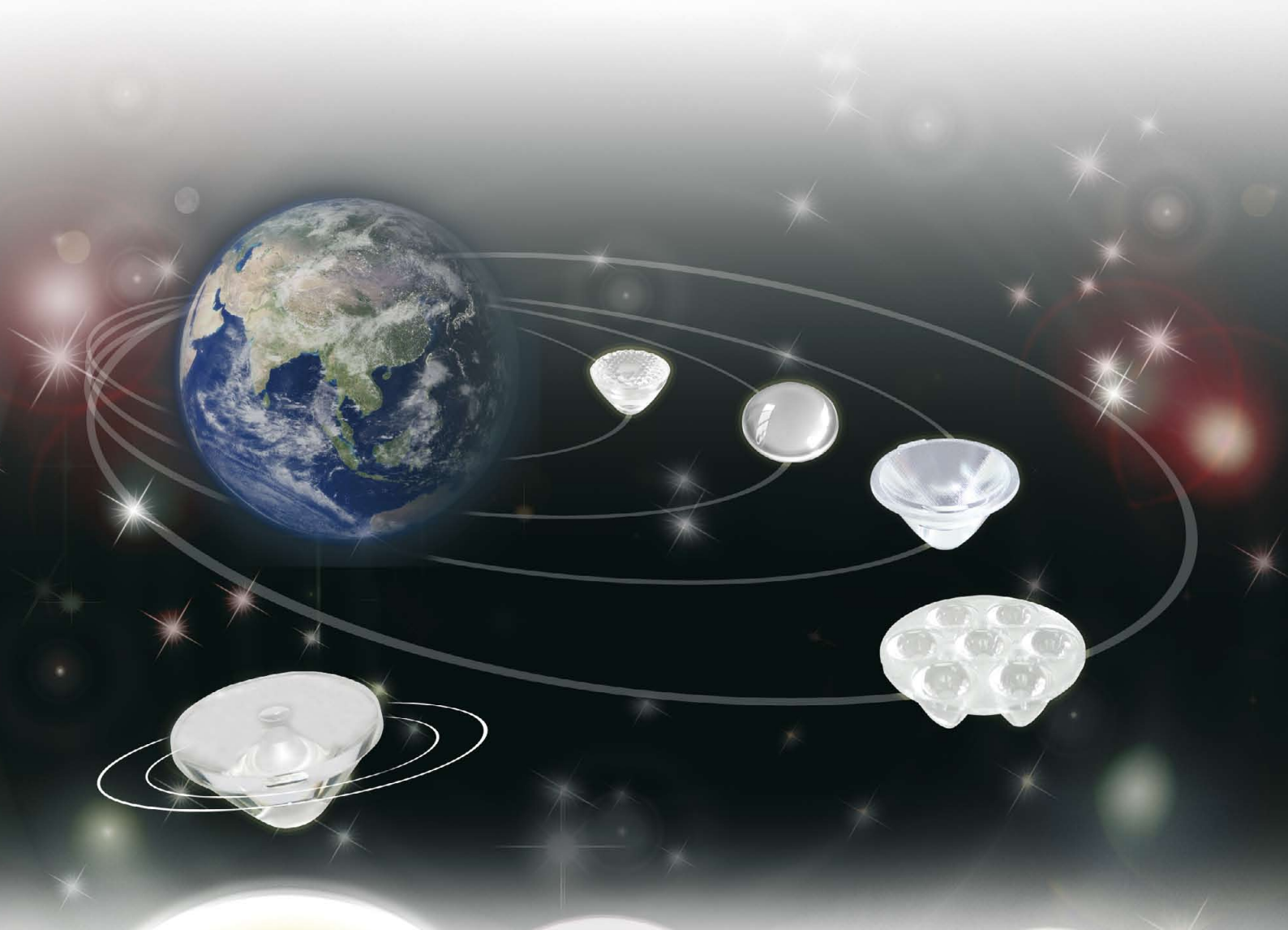


Figure 3: Front end and half bridge with dimming charge pump.



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