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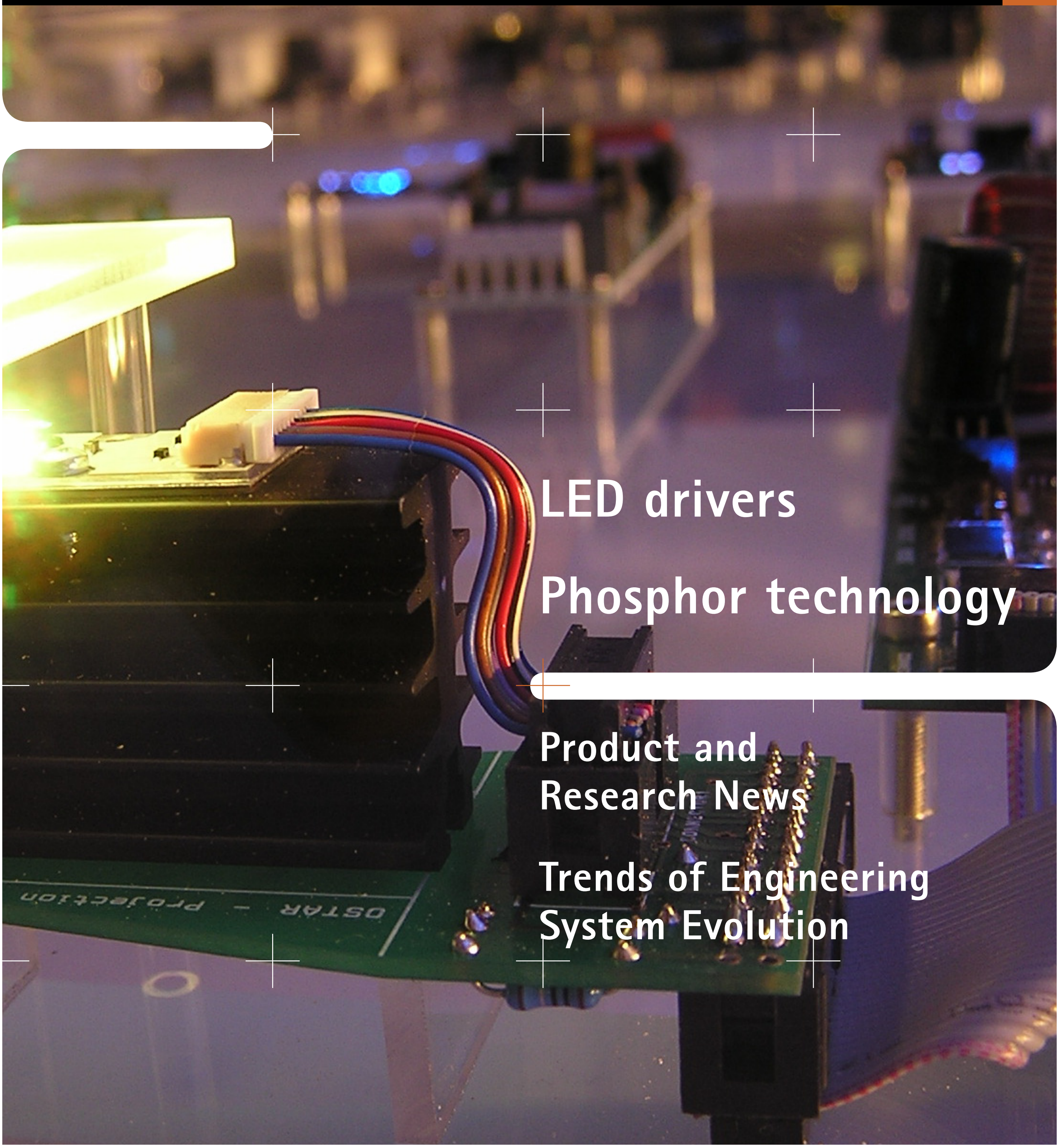
LED professional Review

LpR

The technology of tomorrow for general lighting applications.

June 2007 | Issue 02



LED drivers

Phosphor technology

Product and Research News

Trends of Engineering System Evolution

Entry to a big market

According to the EOS conference held in Munich in mid June 2007, the market volume for LED lighting will rise from ~500 Mio US$ in 2007 to ~900 Mio US$ in 2010 and will represent about 10% of the total global LED business volume.

With a growth rate of about 40% per year the commercial area (shops, offices, etc.) based on High-Brightness LED technologies is the fastest growing sector in which white LED systems make up 50% of the High-Brightness LED market. LED technology promotes new lighting systems on the basis of their aesthetic design potential, their robustness, their lack of radiated heat and UV-light, their easy driving functionality including dimming and colour changes and, last but not least, on the basis of the improved energy efficiency they offer.

What is driving the market growth? The improvement in LED energy efficiency is driving growth. Further developments over the next few years are expected to improve luminous efficacy by a factor of 2 from the latest efficacy figures of 80-100 lm/W to the region of 160-180 lm/W. The choice of LED for a system is more than just peak luminous efficacy values. The complete system needs to be considered as phosphor efficiency degrades by about 5% lumens per 20K increase in temperature and LED life time is strongly dependent on LED junction temperature, life time is reduced from 50,000 hours to only 100 hours at 180°C junction temperature.

For a LED system, the driver stage is a key for overall performance. Driver efficiencies vary between 80-95%, this means potentially up to 20% of energy could be lost in the supply / driver part. The core technology in LED drive modules is SMPS (switched mode power supplies). SMPS have been developed and optimized over years with specialist LED driver ICs providing the "intelligence" in the module. The new aspect of driving LEDs is the requirement for voltage to current converter technology. LED drive modules on the market range from simple systems (circuits) where only one external inductor is needed to complex drivers with interfaces for external control are available. The choice of the driving technique is mainly based on required functionalities such as dimming, colour control, closed loop feedback system, however simplicity and Intellectual Property (IP) rights also play an important role in selecting the most appropriate technique. Finally there is always the big issue of system cost; with LEDs costing about 100 lm/ US$, the driver stage, optics and thermal management have to be taken into consideration in order to develop new lighting solutions that will drive the market growth opportunity.

With the June issue of the LED professional Review (LpR), LED drivers are covered in depth with a summary on phosphor developments that links with the article on white LEDs in the last issue of LpR.

Please send us your feedback about the LpR content. We would like to get your opinion on how to continuously improve our services to you.

Yours Sincerely,

Siegfried Luger

Editor

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- New LED technologies
- LED drivers & sensors

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- Thermal Management

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LIGHTING

Solutions

One lamp or a thousand LEDs

Flashlight, general lighting, traffic lights or jumbo color displays.
The answer's always the same:
Total lighting control solutions from STMicroelectronics

Flash YOUR LEDs

Most advanced Flash Driver STCF03:

Dual mode buck-boost dc/dc converter
1.8 MHz PWM control scheme
Operating input voltage from 2.7 to 5.5V
Flash mode: up to 800mA
Torch mode: up to 200mA
Flash and torch exponential dimming
Flash intensity and duration programmable by I²C™

Part number	Topology	Iout	Efficiency
STCF03	Buck – Boost	800mA	92%
STCF02	Buck – Boost	600mA	90%
STCF01	Boost	300mA	90%

Part number	Description	Iout	VDD
L6902D	250kHz, Step-down with integrated current control	1A	8-36V
L5970D	250kHz, Step-down	1A	4.4-36V
L5970AD	500kHz, Step-down	1A	4.4-36V
L5973AD	500kHz, Step-down	1.5A	4-36V
L5973D	250kHz, Step-down	2A	4-36V

Display YOUR LEDs

Features of the STPxxCP/DP05 Power Logic family

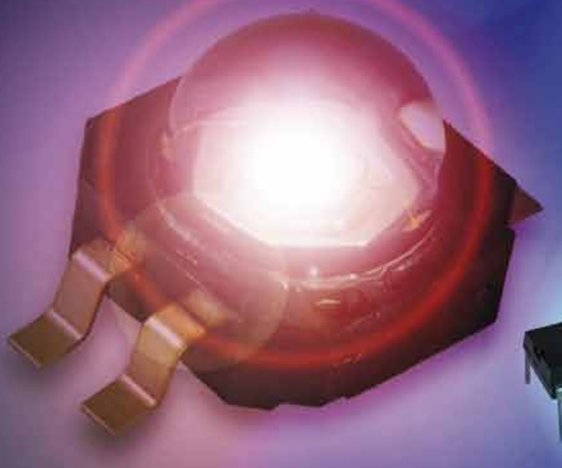
4, 8, 16 channels, output currents are set by only one resistor
Wide Current range from 5mA to 500mA per output channel
Serial data and clock re-synchronized device by device
VDD 3.3 or 5 V
Derivatives with error detection or auto power saving.

Part number	Description	Iout	Precision Channel/ Chip
STP04CM596	4 channels	500mA	±1% / ±6%
STP08/16CP05	8/16-channels	100mA	±1.5% / ±5%
STP08/16DP05	8/16-ch with error detection	100mA	±1.5% / ±5%
STP16CPS05	16-ch with auto power saving	100mA	±1.5% / ±5%

Power YOUR LEDs

Monolithic DC/DC converters

Operating input voltage from 4V to 36V
Up to 2A DC output current
Internal current limit
Inhibit for zero current consumption
Integrated current control (L6902D)



www.st.com/lighting

Product News

Cree Announces Breakthrough 100-Lumen XLamp LEDs

Cree, Inc., a market leader in LED solid-state lighting components, announced commercial availability of XLamp® LEDs with minimum luminous flux of 100 lumens at 350 mA. XLamp LEDs are the first LEDs to be available in volume with this level of performance. This advance sets a new standard in lighting-class LED brightness and efficiency.

XLamp LEDs have now achieved a 100% improvement in performance over the past 17 months. They can deliver either 25% greater brightness with improved efficacy, or they can deliver up to 55% greater brightness at the same efficacy when compared to the previous generation of XLamp LEDs. Moreover, the new XLamp LEDs retain the same footprint as previous XLamp LEDs, thereby protecting customers' design investments.

„Cree is to be congratulated on surpassing the 100-lumen level in its commercial white LED products," said Robert Steele, director of the optoelectronics practice at market research firm Strategies Unlimited. „The availability of such high-performance devices should certainly accelerate the conversion of the lighting market to solid-state sources."

"This is an announcement of volume availability, not an R&D result or availability of a few parts," stated Norbert Hiller, Cree vice president and general manager for lighting LEDs. "These LEDs can enable lighting manufactures to create fixtures using fewer LEDs than before, thereby lowering initial product cost and reducing energy consumption." ■

American Bright Opto-electronics Corporation announces new all metallic High Power LEDs

American Bright Optoelectronics announced the introduction of a full line high-power SMT LEDs that feature all metallic composition including a copper (Cu) circuit board and aluminum (Al) body/reflector. This new series features a wide range of standard attached optics and the options of being pre-mounted on industry standard star-style metal core printed circuit boards (MCPCB) or packaged in 250 piece reels. Stock viewing angles available range from the standard 110° degree discrete device with out a lens to 120°, 45° and 25° integrated lens versions and dual angle, or oval pattern lens versions in 90°/30° or 100°/50°.

The integration of optics reduces design time dramatically and allows the design engineer to focus on integration of fewer component level devices. The integration also reduces assembly costs by eliminating post-secondary assembly steps including application of adhesives, bonding agents and cleaners while assuring proper alignment of the optic and emitter.

The new series is available in the widest range of visible colors including 460nm Blue through 620nm Red. White bin groups, in both cool white and warm white, are binned according to McAdams Ellipses and clearly defined in the comprehensive, 25 page, American Bright Optoelectronics data sheets and application notes. The full spectrum possibilities give designers in the Architectural Lighting, Automotive, Decorative, Portable, Traffic, Signage and Signaling industries a viable alternative to costly multi-component solutions currently employed industry wide. ■

High-Power White LED Knocks Down General Illumination Barriers

The exclusive, new VIO™ high-power white LED from Lumination, LLC, GE Consumer & Industrial's LED business, uses proprietary violet-chip technology to produce less than a 100-Kelvin color shift over a 50,000-hour rated life. Its minimal color shift overcomes many of the inherent color control issues of standard blue or red-green-blue LED devices.

Lumination's VIO LED also provides high efficiency at warmer color temperatures, as well as flexible color temperature and color-rendering options.

Lumination scientists create VIO high-power white LEDs by combining 405 nanometer violet chips with a proprietary blend of phosphors. The VIO violet chip operates at a higher efficiency wavelength than blue LEDs. Phosphors applied to the hemispherical lens of the VIO LED convert its violet wavelength to white light. VIO LEDs are offered in 3500K and 4100K color temperatures that can be used in many standard fixtures designed for general illumination applications. „The availability of Lumination's VIO high-power white LED is a significant milestone on the path toward general illumination with GE-quality LEDs," comments Kraig Kasler, vice president of marketing, Lumination, LLC. „Our investment in this major new product underscores the commitment we made earlier this year to pursue global distinction in the general illumination market. We think our violet-chip technology offers the best available control of color shift in white LEDs."

Oftentimes, LEDs used in fixtures produce glare or bright spots. The use of multiple point sources in fixtures (e.g., several LEDs grouped together) has the potential to produce multiple shadows. VIO LEDs eliminate such distractions. High-power, 4-watt VIO LEDs distribute diffused light more evenly over a 180-degree beam angle.

The color of Lumination's VIO high-power white LED is so stable that its light can be used with confidence as a replacement for traditional general illumination light sources.

„With this new product, we're ushering in a new era for lighting fixture OEMs and designers," notes Kasler. „Incorporating LEDs in a lighting scheme is more than a novel approach or smart move from an energy standpoint. Based on its performance, our VIO LED is a real alternative light source that will maintain a consistent appearance over a period of years." Potential applications for VIO LEDs include general (pendant, sconce), commercial (task, display), landscape (pathway, in-ground) and architectural (wall wash, marker.) lighting. ■

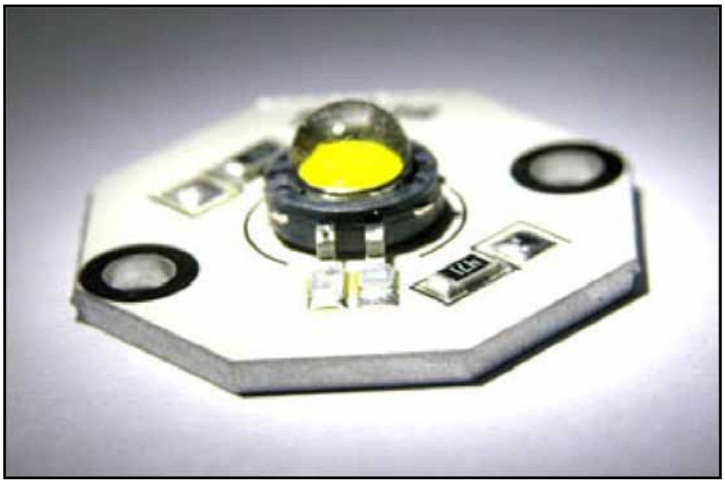
Seoul Semiconductor Unveils Warm White Acriche of 42 lm/W

Seoul Semiconductor announced that Acriche, the world's first semiconductor lighting source for AC power outlets, can now achieve warm white of near-daylight quality, making it suitable for general and indoor lighting applications. The warm white Acriche features 42 lm/W based on light source.

Actual System Efficiency – which takes into account luminous efficacy, ballast efficiency and luminaire efficiency – for the warm white Acriche is 39.9 lm/W. This is higher than 7.5 lm/W for incandescent lamps and 30.6 lm/W for compact fluorescents.

Warm white Acriche is a suitable replacement for DC-LED lighting. Compared to conventional warm white DC LED which has a luminous efficacy of nearly 35 lm/W, the warm white Acriche at 42lm/W is 20% more efficient. Warm white Acriche can also produce a brighter lighting environment without the need of a converter or ballast.

Seoul Semiconductor has also released warm white Acriche with a luminous efficacy of 33 lm/W which has a Color Rendering Index (CRI) rating of 90. The CRI measures the ability of a light source to produce vibrant colors in objects. A CRI rating of 100 suggests that the light source is equivalent to daylight, while a low CRI rating near 0 suggests that colors will appear unnatural under that particular light source.

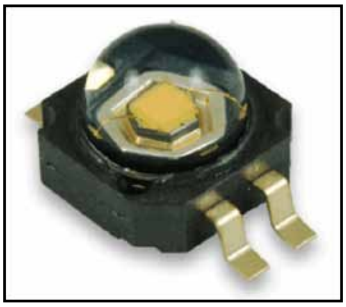


Acriche Warm White's high CRI ratings and superior color rendering capabilities make it an ideal solution for environments that demand vibrant and accurate lighting, such as museums, luxury hotels, art galleries, show rooms and displays.

For many years, the ability to produce a warm white semiconductor lighting source that can also offer a high quality CRI rating had appeared illusive. Today, that hurdle has been successfully negotiated.

"The need for alternative lighting sources has never been more pressing," said Seoul Semiconductor CEO Cheong Hoon Lee. "Environmental pollution and oil prices are rising, and the effects of mercury and lead continue to take a toll on our ecosystems. We hope to accelerate the move towards energy efficient and environmentally friendly lighting by producing alternative lighting sources such as warm white Acriche that can match the capabilities of conventional lighting sources, but with less harm to the environment and at a lower cost in terms of energy consumption." ■

Philips Lumileds LUXEON K2 Warm and Neutral White LEDs



Philips Lumileds announced immediate availability of warm-white and neutral-white LUXEON K2 emitters as well as a LUXEON K2 Star part that can be specified with any standard white emitter. The new white colors have typical correlated color temperatures (CCT) of 3000K and 4100K and a color rendering index (CRI) of 80 and 75 respectively. The CCT range for LUXEON K2 now extends from 2670K to 10,000K and a new finer color bin structure allows for better overall selection. Unlike most power LEDs that are limited to 700mA, LUXEON K2 warm white and neutral white LEDs can be run up to 1500mA and a junction temperature of 150°C. The new warm-white and neutral white can deliver more than 130lm and 140lm respectively. LUXEON K2 delivers more usable light at virtually any drive current and junction temperature condition.

"With the increases in light output performance and efficacy, there is expanding demand for power LEDs that deliver the quality of light required for general lighting applications," said Steve Landau, Director of Marketing Communications. "Designers of residential applications, such as recessed can lights need uniformity, high color rendering and a warm white color temperature at 3000K. In many retail and commercial applications, a cooler temperature of 4100K is desired. With the new binning and phosphor technologies in LUXEON K2, the needs of lighting designers in both markets can be addressed."

Lighting designers consider several critical "quality of light" factors when evaluating white LEDs: color temperature (CCT), color rendering (CRI) and color uniformity are three of the most important. The new LUXEON K2 parts address CCT and CRI and Philips Lumileds phosphor expertise and technologies ensure the highest degree of color uniformity resulting in white LEDs that are as much as 7 times more uniform that other white power LEDs. ■

Introducing Fairchild Semiconductor's TinyBuck™

Fairchild Semiconductor introduces the FAN2106, the first product in a new family of TinyBuck™ DC-DC buck regulators that integrate an advanced analog IC, MOSFETs and a boot diode into an ultra-compact molded leadless package (MLP). Measuring only 5mm x 6mm, the FAN2106 is the industry's smallest 6A, 24V-input integrated synchronous buck regulator on the market today. This highly integrated low-profile, small-footprint device consumes approximately 50 percent less board space than discrete solutions and facilitates greater design flexibility. Furthermore, the FAN2106 achieves up to 95 percent power efficiency by converting input of 3V through 24V input voltages to output voltages as low as 0.8V while delivering up to 6A output current. This compact, easy-to-use, high-efficiency regulator is ideal in a broad range of point-of-load (POL) applications. These include set-top boxes, cable modems, in-cabin GPSs, portable medical equipment, LED lighting, industrial instrumentation as well as ultra-mobile PCs, notebooks and blade servers.

"Fairchild's TinyBuck all-in-one module offers superior features that enable engineers to meet their primary design challenges: saving board space, simplifying designs and increasing power efficiency," said Justin Chiang, vice president of Fairchild's System Power Group. "As the first product in this new family, the FAN2106 integrates our latest DC-DC PWM controller with gate drivers, advanced MOSFETs and a boot diode into a tiny MLP package. ■

PWM Dimming

Linear Technology Corporation announces the LT3496, a 2MHz DC/DC converter designed to operate as a three-channel constant current LED driver. Each of the LT3496's three channels can drive up to eight 500mA LEDs in series, enabling it to drive up to 24 x 500mA LEDs at efficiencies up to 96%. All three channels are operated by an independent True Color PWM™ signal, enabling each to be dimmed independently to ratios as high as 3,000:1. A fixed frequency, current mode architecture ensures stable operation over a wide range of supply and output voltages. A frequency adjust pin enables the user to program the frequency between 330kHz and 2.1MHz to optimize efficiency while minimizing external component size. The LT3496's thermally enhanced 4mm x 5mm QFN package provides a highly compact solution footprint for 50W LED applications.

The LT3496 senses output current at the high side of the LED, enabling buck, buck-boost or boost configurations. With an external sense resistor, the user programs the output current range of each channel. Each of the three independent driver channels utilizes an internal 750mA, 45V NPN switch and has a built in gate driver for PMOS disconnect. Other features include open LED protection and thermal limiting. ■

STMicroelectronics Introduces First Auto-Shutdown LED Driver to Address Energy-Saving Programs

STMicroelectronics, a leader in ICs for driving high-brightness (HB) LEDs, introduced the first LED driver to include auto-power-saving features. The STP16CPS05, an innovative member of ST's Power Logic (STP**CP/DP05, where ** is the number of bits 4, 8 or 16) family, allows manufacturers to meet the high power-efficiency requirements of industrial lighting, signage and transport applications, especially battery-powered LED panels by guaranteeing savings of 80% compared to existing solutions.

An evolutionary advantage of this new Power Logic device is the new constant-current LED drivers allow the individual ICs to go into a shutdown mode when no active inputs are detected. As a result, the STP16CPS05 can save power without external intervention, making it the ideal solution to support all worldwide energy-saving programs which encourage power efficiency in lighting applications

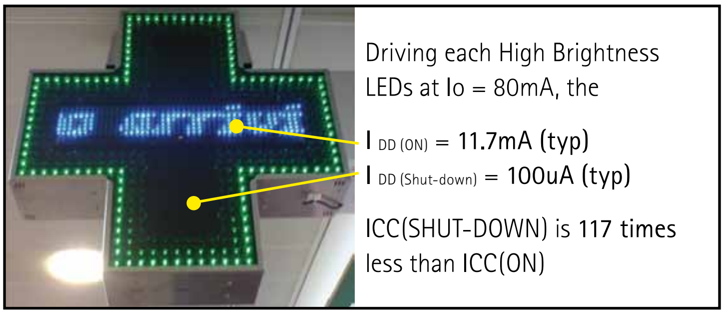


Fig. 1 A Pharmacy LED Display Crossoften found outside Pharmacies. Usually, these LED Displays drive monochrome LEDs and RGB LEDs in some applications. An example follows for the power-saving possibilities using the STP16CPS05.

Estimated number of LED Drivers: 80 units LED drivers active at any one time: ~ 20%

- Using standard LED driver, all 80 drivers will consume high current (approx. 1A)
- Using STP16CPS05, only 16 will consumer high current (approx. 0.2A)
- This hypothesis gives an possible power-saving rating of 80%.

The STP16CPS05 Power Logic series features a clock and data re-synchronization function, which is useful when the devices are connected in cascade. the STP16CPS05 can work with a power supply from 3.3V up to 5V; its output current is programmable from 5mA to 100mA to suit applications requiring mid-current range. This high-precision LED control guarantees an industry-best's output precision of ±1.5% Bit-to-Bit and ±5% Chip-to-Chip over the output current range from 20mA to 100mA and covers the full wide temperature range of -40°C to +125°C.

The IC also has the market-highest Vout of 20V. This IC is available in three package types, of which one, the thermally efficient exposed-pad TSSOP, comes with outstanding heat dissipation features of RthJC = 37.5°C/W. When it comes to protection, this IC is ESD protected at 2.5kV(HBM) and 200V(MM). And it is thermally-protected by an in-built Automatic Thermal-shutdown circuitry. ■

Virtuoso dimming in a dual package

Top-class dimming is the watchword of the K350 DALI RGB LED converter and the C350 PWM 4-channel LED dimmer. Both control gear units by TridonicAtco GmbH & Co. KG, Dornbirn/Austria demonstrate their unique selling proposition with a dimming range of 0.1% to 100%, continuous dimming and load-independent control. These features are especially vital for colour mixing or for coloured effects using high-light output powerLED RGB modules.

The K350 DALI RGB LED converter has a built-in power supply unit and three LED output channels with a constant current of 350 mA and PWM modulation, each of which can be used to dim up to five RGB light emitting diodes. Because of its compact design, this control gear offers plenty of scope for luminaire design and integrates particularly well into spotlights. Because its housing is equivalent to those of the TE one4all digitally dimmable transformer and the powerControl PCI ballast, a luminaire manufacturer can easily create a spotlight family for various light sources such as RGB LED modules, low-voltage halogen lamps or metal halide lamps. The result - a consistent stylistic idiom at less expense.

Up to ten high-power LEDs can be controlled on each of the four output channels of the LED C350 PWM 4-channel dimmer. This makes it possible to implement applications involving long lengths such as wallwashing lighting effects among others. The fourth channel extends RGB colour mixing possibilities; for example, an additional amber LED improves colour rendition considerably.

With its slim-line design, the 4-channel dimmer is extremely suitable for installation in sections and luminaires. Its universal PWM input is ideal for easy integration into control systems, using the DMX protocol for instance. The 4-channel dimmer can also be combined with the LED K211 DALI converter very easily.

The K350 DALI RGB LED converter and the C350 PWM 4-channel LED dimmer set new standards when it comes to RGB colour mixing. Here, TridonicAtco's emphasis is on perfect dimming. ■

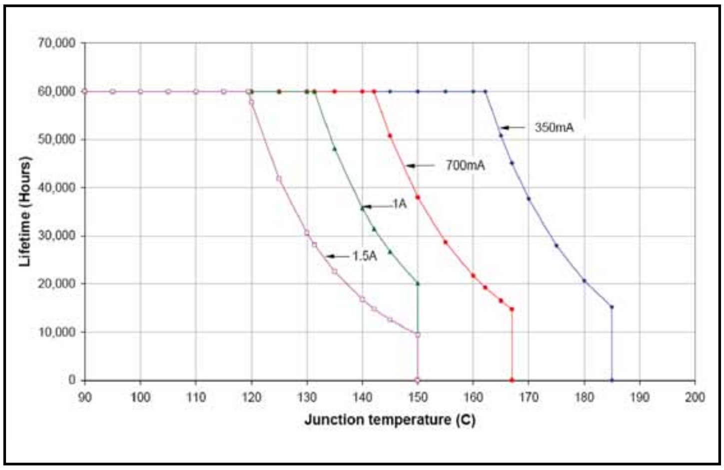
Research News

Philips Lumileds Leads Re-sponse to Lighting Industry Needs with New Reliability Analysis Tools

Philips Lumileds has introduced a new reliability analysis tool that for the first time enables lighting designers to confidently determine lifetime performance of LEDs under different operating conditions. Philips Lumileds graphical representation of reliability allows designers to understand and evaluate the impact of temperature and drive current on lumen maintenance and failure rates of LEDs. Historically, only simple lumen maintenance data (x% lumen maintenance at y-hours) has been available and that single piece of information has been limited in scope. Details of the new analysis are available in a white paper published today, Understanding power LED lifetime analysis. Providing comprehensive and statistically-relevant reliability performance data is a step towards bridging the communication gap between the LED semiconductor world and the lighting community.

Graphical representation clearly shows dramatic reliability performance differences between LEDs from different manufacturers and allows designers and engineers to make a more fully informed decision.

Simple lumen maintenance statements not enough to make intelligent lighting design decisions. When designing LED-based lighting systems, engineers need to understand LED reliability in similar terms to those used when designing with conventional light sources. In addition, designers need extra information to predict the lifetime of LEDs under a variety of operating conditions. Although a number of techniques to predict LED lifetimes have been proposed, none has generated sufficiently clear and unambiguous data for lighting engineers. Philips Lumileds graphical tool provides designers with information required to make decisions about product lifetimes, driver constraints, number of LEDs required, and thermal management. ■



The Right White: Recent developments in white phosphors

> Prof. R. J. Artley, ETeCH Management GmbH

There has been recent interest concerning the announcements by various governments that incandescent light bulbs are to be phased out as hugely energy-inefficient (typically <10%). Transforming to more efficient forms of lighting (80%+) will save considerable amounts of energy - worldwide about 20% of electricity is used for lighting - and hence money and carbon emissions.

What is less clear is what could or should replace incandescent lamps. What is clear is that nearly all solutions will probably involve white phosphors. Many press reports and recent literature have talked about compact fluorescent lamps (CFL). These are sealed glass tubes, containing gases, which ionize creating ultraviolet (UV) light when a high voltage is placed across the tube. The UV excites an inner coating of phosphor, creating visible light. However, CFLs are not an ideal solution. For one thing, they use mercury, which nearly all governments now wish to ban (it is a toxic metal and poisons the land when the lamps are incorrectly disposed of), and secondly, they may not be the best solution on cost grounds either, as we shall shortly see. Last, and by no means least, their light is 'cold', and can be harsh – which point we will also explore.

The actual solution may well be white light-emitting diodes (LEDs), which have come a long way in the last few years, and will probably – and soon – become even better yet.

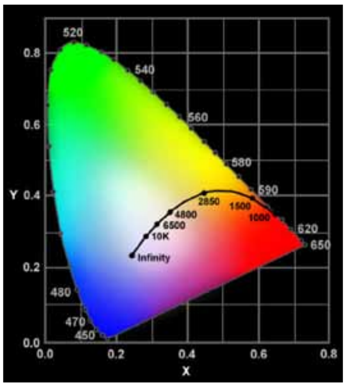
This table shows what lamp bulbs you would need for 1000 lumen (lm) – equal to a 100W incandescent light bulb, for 100,000 hours (11.4 years) continuous running[1]. Efficiencies are measured in lumens/Watt (electrical power consumed); where for LEDs the theoretical limit of luminous efficiency is probably 275 lm/W.

This table allows one to calculate that, provided the upfront cost is affordable, white LEDs need only to be 100 lm and 100 lm/W to be economically superior to incandescent lamps and CFLs by a considerable margin, on the grounds of electricity consumption alone (not even taking into account savings in maintenance costs, as many government and other large organisations – e.g., hospitals, factories, schools – have to do) – and also to be economically equivalent to standard 'tube' fluorescent lamps also.

According to 'Haitz's Law' of improvements in brightness of LEDs, this was usually expected around 2010. The good news is this is already possible. In the last few weeks (March 2007) Siemens' subsidiary Osram has announced a 1000 lm (six chip package), 75 lm/W white lamp, Philips Lumileds has one similar at 160 lm (one chip), 70 lm/W, and Seoul Semiconductor (SSC) has announced 240 lm (off one chip) at 100 lm/W. As can be seen from the calculations above these are already cost-effective – and the purchase prices are not expected to be disadvantageous as well. Other manufacturers have similar products. White LEDs have now 'made the grade'.

		Incandescent (best)	CFL (best)	Fluorescent (best)	LED (target)	LED (Osram)	LED (SSC)
Brightness	Lm	1000	1000	3400	100	1000	240
Bulbs for 1000 lm		1	1	0.29	10	1	4
Lifetime	hrs	1000	15000	10000	100000	50000	50000
Bulbs for 100000 hours		100	6	10	1	2	2
Energy efficiency	Lm/W	15	60	85	100	75	100
Bulb cost	$	1	3	5	3.5	10*	4*
Electricity cost 1000 lm, 1000 hrs ($0.1/kWh)	$	6.67	1.66	1.18	1	1.25	1
Bulbs for 1000 lm, 100000 hrs		100	6	2.94	10	2	8
Cost of bulbs	$	100	18	14.71	35	20	32
Electricity for 100000 hours	$	667	166	117.65	100	125	100
Upfront cost for bulbs	$	1	3	5	35	10	16
TOTAL LIFETIME COST	$	767	184	132.35	135	145	132
CRI		95	80	75	95	80	80

** Will be commercially available summer 2007: prices are not yet available: costs used here are estimates by the author based on known other products in company ranges*



The above calculation is on a like-for-like basis, but there is another significant difference between LEDs and incandescent- and CFL-lamps: with LEDs it is easy to direct the light where needed, and not in any other direction. This limits light pollution, but more importantly it means that lighting can be 'designed down' to what is actually needed – and hence save even more energy and cost.

The commercial prospects look good. By 2010, semiconductor-based light-emitting diodes (LEDs), especially high-brightness (HB) versions, are expected to have made significant inroads into general illumination, to be a market worth $15 billion from $5.73bn in 2006 (CAGR 22%). Total unit shipment of LED devices is expected to reach 64 billion in 2010 from 27.4 billion in 2005 (IC Insights).

So what happens next? Improvements in quality are what are needed.

The major drawback of most conventional 'white' LEDs is that they are not truly white, but are phosphor-coated (PCLEDs), made from blue LEDs (450-470nm, InGaN) with a coating of a yellow phosphor (chiefly yttrium aluminium garnet activated with cerium, Y3(Al,Si)5O12:Ce (YAG:Ce), which is a saturated colour with a peak at 570-573nm). These look white, but do not provide true white light across the visible spectrum. They provide 'cold' white light (colour coordinated temperature (CCT) 6000K), which most people do not favour for domestic lighting, and in particular they have very poor colour rendition in the red region of the spectrum. When this is measured by the standard full colour rendering index (CRI) which uses the full set of 14 or 15 colours (not just the 'short set' of 8 colours), some current 'white' LEDs actually negatively score (out of 100) on measurements with Plate 9 – the strong red. The graph below illustrates this (CIE coordinates) – the mixture of a blue LED and a white phosphor can look white, and can illuminate any colour between them (in the triangle towards the top of the diagram, although the more saturated colours, especially the greens, are also weak) – but not, properly, ones which are more orange or red (those below the line).

Improvements to such LEDs are needed to provide the full colour gamut (range of colours), and the most obvious way is to add a pinch of red phosphor (usually a nitride). Unfortunately since this is likely to be a different material, it is likely to age and change colour over time at a different rate from the yellow phosphor (or the blue LED) and so the light shifts colour over time.

There are other approaches, of course. Combining red, green and blue LEDs is one, although expensive. Sometimes these can be combined in the same chip – when Nichia Corp. of Japan first created white LEDs (using augmented light from blue chips) in 1993 it used gallium nitride and indium gallium nitride, but almost no LEDs are produced using this method today; although the University of California at San Diego is researching phosphorless heterostructures based on InGaAlN:Ce; Georgia Tech is working on similar lines. Another method used to produce white light LEDs also uses no phosphors and is based on homoepitaxially grown zinc selenide (ZnSe) on a ZnSe substrate which simultaneously emits blue light from its active region and yellow light from the substrate. This is also rather red-deficient. There is also interest in organic light-emitting diodes (OLEDs), noting in particular the efficiency improvements made using these with white phosphors, by Prof. Stephen Forrest (ex Princeton, now University of Michigan in Ann Arbor) together with Prof. Mark Thompson (University of Southern California in Los Angeles).

A better solution than all the above would thus be a single, truly 'white' phosphor, which would give true representation of all colours. This would probably be activated not by a blue LED (because of the difficulties of balancing the direct and indirect light, especially over time – one tends to end up with better reds but poorer greens), but by UV light (just as in the CFLs) from a UV LED. There is fundamentally a greater loss in conversion of UV to white light than blue light to white light (this is called the 'Stokes shift'), but on the other hand UV LEDs are much more energy-efficient than blue LEDs, so they tend to be slightly better overall. They are also being rapidly improved - the first UV LEDs (under 380nm) were demonstrated as recently as April 2002 – less than five years ago - by Nitride Semiconductors and (separately) PARC (Xerox, Palo Alto) and Crystal IS (AlGaN): such UV LEDs have only been commercial since 2004 (Nichia) and 2005 (Nitride Semiconductors, others). This is important since there is a great deal of experience in the fluorescent lamp industry in converting from the mercury lines at 366nm.

There is thus a race to create a good, 'warm white' (5000K, similar to solar) single-material phosphor, in which several dozen companies and academic establishments are competing. A single phosphor, it is expected, would not have the problems of different aging cycles of mixed systems, but any candidate needs to be highly luminescent, highly energy-effective, and highly stable to be considered commercially viable.

It's probably appropriate here to give a short background to phosphors, to illustrate the enormous possibilities being explored. Phosphors fundamentally consist of 'hosts' (inorganic crystalline materials) and 'activators' (transition metals (TM) and rare earth metals (REM)), and, optionally, 'sensitizers' (similar). The 'hosts', conventionally, are usually oxides although nitrides, silicates, aluminates and sulphides are also used: other systems such as halides (fluorides, chlorides), yttrates, gallates etc. have been either largely unexplored or have historically been considered 'difficult' to work with. However this is where some of the most exciting new discoveries are being made. With so many possible combinations – some hundreds if not thousands of phosphors (of varying effectiveness and colour) are known - this is still a rich field of exploration.

Light emission from phosphors happens by energy absorption by the host, sensitizer, or activator directly, transfer of energy to the activator, and emission, any spare energy showing up as heat. Normally, for light stimulation, 'down-conversion' of more energetic light (UV, blue) to less (yellow, red), occurs. The choice of activator determines the range of colours of light which is emitted: for lighting, 'broad band' is desirable, which is achieved by using the lower oxidation states of TM or REM, e.g., Eu2+ or Sn2+.

Probably the first publicly announced single white phosphor (July, 2005) was that from the group of Prof. Sue-Lein Wang at the National Tsing Hua University, Hsinchu, Taiwan. This was zinc gallophosphate, laced with nanoscale pores, where the white light seems to stem from blue fluorescence in highly ordered regions of the material, combined with yellow emission where it is more disordered. Unfortunately it does not appear that any quantitative data has yet been published on this, so the questions of its luminance, efficiency and stability as yet remain open.

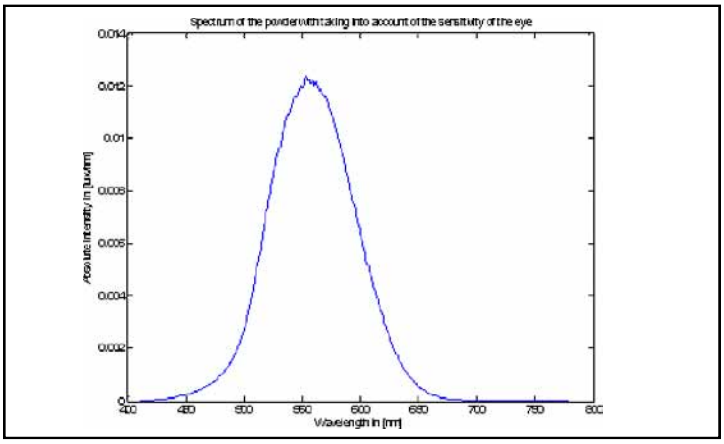
Many centres are looking at the possibilities of zinc oxide, amongst others the Universities of Bristol, California-Riverside, Florida, Gothenburg (nanowires), Hanoi, Hsinchu (Industrial Technology Research Institute), and Tohoku. Zinc oxide can be a white-emitting material, but it is proving very difficult to gain suitably high energy efficiencies from it (remember 100 lm/W is the target).

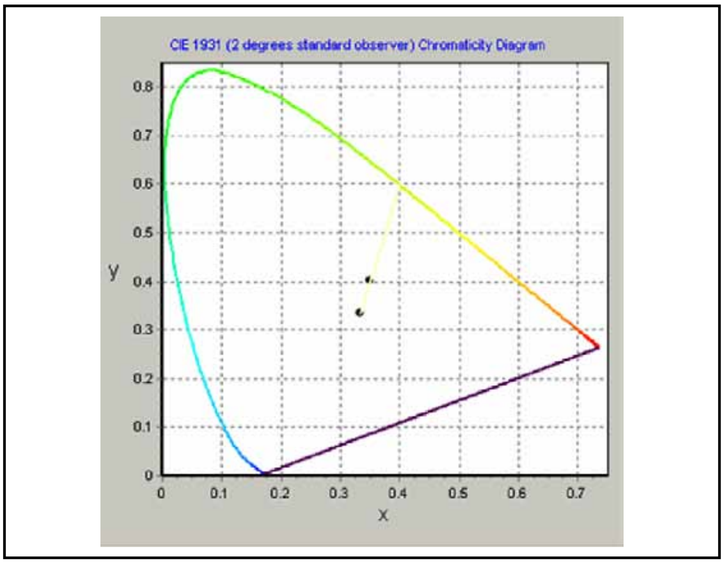
Some of the latest research has centered on 'quantum dots', or nanocrystals of phosphors or semiconductors (usually III-V types), where 'tuneable' changes in their physical size adjust the light frequencies output. Each size emits one colour, but of course a mixture of sizes can emit white or near to it. Centres of research into this phenomenon include Cranfield University (UK), the Naval Research Laboratory (USA), and Vanderbilt University (USA), which is looking at CdSe nanocrystals: these are also the subject of a cooperation between the University of Chicago, Corning and NYSTAR. The University of Texas (in cooperation with Innovalight) is looking at silicon nanocrystals as high energy white phosphors.

In more conventional phosphors, the silicates are attracting attention. Niigata University (Japan), in cooperation with Sumitomo Chemical Co. Ltd., is researching europium-doped silicate phosphors for white LEDs: Li2SrSiO4:Eu(2+), Ba9Sc2Si6O24:Eu(2+), Ca3Si2O7:Eu(2+), and Ba2MgSi2O7:Eu(2+). Unfortunately again little quantitative data has yet been published. The University of Georgia is likewise looking at strontium silicates Sr2SiO4:Eu2+, (normally a yellow phosphor) in cooperation with GE, and NIMS (the National Institute for Materials Science, Japan) is considering Li-SiAlON (used with InGaN sources) in cooperation with Fujikura Ltd / Sharp Corp. Litec-LLL GmbH, (Griefswald Germany) is also looking at advanced silicate phosphors for improved white LEDs, chiefly Ba2-x-y-zSrxCaySiO4:Eu2+z (BOSE).

ETeCH[2] has its own development programme for white phosphors, in cooperation with the Vienna University of Technology, the University of Geneva, the West Switzerland University of Applied Sciences, Yverdon, and EPFL Lausanne, which has generated a number of interesting novel phosphors, including two single-material white phosphors. The lead compound, Ba7F12Cl2:Eu(II), is already showing 45 lm/W in unoptimised samples (CCT 5000k), and 100lm/W is confidently expected: the second material, a specially co-doped form of strontium orthosilicate, Sr2SiO4 [Eu(II),La(III)], is also showing good performance when stimulated by 350-400nm ultra-violet (UV) light-emitting diodes (LEDs). The novel materials convert the UV into visible light with a broad spectrum, thus enabling compact, highly efficient, low-cost lighting. There have also been various two-component white systems developed, and also various novel coloured materials have also been discovered and are being tested. The ongoing work (in collaboration with various industry partners) is to improve the reproduction of materials on larger scales, and optimization of particle size / coating thickness / match to LED sources. The materials and their use in lighting systems have been patented and filed for patent worldwide: the patents concerning Ba7F12Cl2, Eu(II) (BA7) are already granted for major territories worldwide.

BA7 light output





Spectrum and cromaticity diagram of BA7

[1] *http://www.blackenergy.com/store/images/specs/light_levels_lumens.html and other sources*

[2] *http://www.etech.ch*

Driving LEDs – A Real Challenge

> Arno Grabher-Meyer, LED professional

Selecting the right design to drive a LED system is easy, isn't it? – Choose a LED, take a voltage source and limit current with a resistor. For several years it was done in that way. Can that be so wrong?

Yet modern, efficient and high quality LED systems are far more complex and challenging than former applications, when LEDs were mostly used as indicator lights. We have to imagine, that there are a lot of different applications with many conceptual paths. LEDs can be used as replacement for low voltage halogen light or high voltage halogen light, but also to design revolutionary new luminaries for office lighting or residential lighting, a wall washer or floodlight, etc.

For the electronic designer the differentiation starts with the chosen LEDs for the particular application. To achieve an optimum result individual solutions are necessary, e.g. arrays of mid power LEDs require other electronics than a single or a few high power LEDs. A lot of additional questions have to be answered before the design process can be started:

Will the LEDs be driven in series or in parallel? Is the design based on LEDs of the similar colour and type, or is it a multicolour design for adaptation of CCT, CRI or colour effects? What are the real requirements for the light quality, the dimming range, the colour stability over time, the light output? How to take in account degradation over time or thermal issues?

Besides application specific questions there are some really basic problems that engineers are confronted with. These are the real challenges that are partly new in the field of lighting electronics:

Improve electrical efficiency

At the International „Workshop on Status, Prospects and Strategies for LEDs in General Lighting 2007" Dr. Geoff Archenhold from SSLRC stated "A LED fixture is more than just a LED, it's a system!" Improvement of driver efficiency from 80% to 88% results in a 5% increase of system efficacy. Considering the struggle of the European Community for CO2 reduction this 5% improvement is not negligible.

There are numerous contradictions that can hinder or constrict optimization of efficiency:

- A big difference between Mains voltage and secondary output voltage.
- Needs for a specific driving mode, because light quality would suffer.

DRIVER MODULE MANUFACTURERS	
AbstractAvr	http://www.abstractavr.com
Acro Engineering Inc.	http://acro-powers.com
Advance	http://www.advancetransformer.com
Aurora Ltd	http://www.aurora.eu.com
CML Innovative Technologies	http://www.cml-it.com
Erea nv	http://www.erea.be
Insta Elektro GmbH	http://www.insta.de
L.C. Relco S.p.A	http://www.relco.it
Lightech Electronic Industries	http://www.lightech.co.il
Lumotech Holland BV	http://www.lumotech.com
LEDdynamics	http://www.leddynamics.com
Magtech Industries Corp.	http://www.magtechind.com
Mean Well Enterprises Co.	http://www.meanwell.com
Nobilé AG	http://www.nobile.de
OSRAM GmbH	http://www.osram.de
Paulmann	http://www.paulmann.de
Permlight Corporation	http://www.permlight.com
Power Vector	http://www.powervector.com
Prism Audio Ltd	http://www.prismaudio.co.uk
Tridonic.Atco	http://www.tridonicatco.com

Reliability of electronics

The quality of driver electronics has to be on a very high level to compete with lifetime of the LEDs. Especially for embedded systems when the driver and LEDs are mounted on the same circuit board this is necessary:

- Passive electronic components sometimes don't have the lifetime or robustness of LEDs.

Save system operation

The driver electronics should prevent damage of the LEDs because of thermal issues under all circumstances.

- Closed loop feedback systems, with voltage and current control and thermal sensors are necessary.

Dimming capability

Dimming opportunities are desirable for white LED lighting and in particular for RGB, RGBW or RGBA LED clusters to adjust colour, CCT and CRI. The free choice of colour or CCT is one of the most interesting features of LED lighting.

- Analogue dimming leads to colour drift.
- For 1% dimming a RGB system covering the full colour range PWM duty cycle must have a range of about 1:10.000.
- Switching losses of a PWM system stay almost constant at low dimming levels, hence system efficacy decreases.
- For highly accurate lighting systems costly closed loop feedback systems with optical sensors are necessary.

Costs

Depending on the application costs are very critical, especially for replacement of today's low voltage halogen systems high quality low cost solutions are necessary.

- Replacement: AC/DC 12V systems with magnetic transformers and switch mode power supplies must be served.
- Replacement: Dimming should be possible anyways.

Patent infringement

Lots of patent applications for LED systems were published during the last decade. Many are really basic that some technician wonders that they were granted, others are really ingenious and it is hard not to use the presented solution:

- For many applications PWM would be the first choice, but for some applications this technology is blocked by the CK patent US6016038.
- Calculation and transformation algorithms for fast and accurate colour settings are also blocked by different granted patents.

DRIVER IC MANUFACTURES	
Allegro MicroSystems, Inc.	http://www.allegromicro.com
Austriamicrosystems	http://www.austriamicrosystems.com
Clare Micronix	http://www.claremicronix.com
Dialog Imaging Systems GmbH	http://www.diasemi.com
FAIRCHILD Semiconductor GmbH	http://www.fairchildsemi.com
International Rectifier	http://www.irf.com
Linear Technology Corporate	http://www.linear.com
Maxim Integrated Products, Inc.	http://www.maxim-ic.com
Micrel Inc.	http://www.micrel.com
Microchip Technology Inc.	http://www.microchip.com
Monolithic Power Systems	http://www.monolithicpower.com
National Semiconductor	http://www.national.com
NXP Semiconductors	http://www.nxp.com
ON Semiconductor	http://www.onsemi.com
Power Integrations	http://www.powerint.com
Sipex Corporation	http://www.sipex.com
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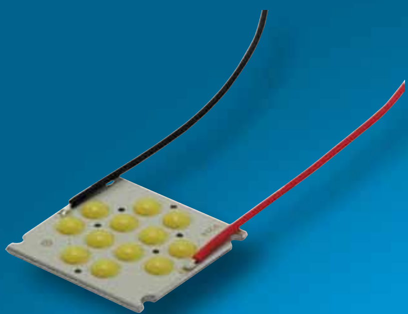
Ster Century Thessaloniki, Grecia



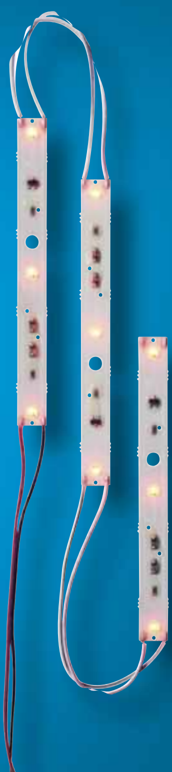
powerLED EOS P216

powerLED EOS P211

LED Converter

LED Controls

Accessories



LED Chain P515

Colour compensation: LED technology for colour constant RGB colour mixing luminaires

> Thomas Schielke, ERCO Leuchten

Lighting designers have always used coloured light to add emphasis or provide atmospheric effects. This was done using coloured lamps or luminaires with colour filters, but thanks to electronically controlled RGB colour mixing luminaires it is now possible to produce any colour of light with LEDs. Using colour compensation, the luminaire manufacturer is able to compensate for the deviations in luminous flux and hue due to the manufacturing tolerances of LEDs, and thus to satisfy the highest demands of designers for uniformity, e.g. for coloured wall-washing.

LEDs and deviations in manufacture

High colour saturation is one of the characteristic properties of LEDs. However, the actual colour of the individual LEDs is determined by two factors that are subject to certain manufacturing fluctuations: the luminous flux and the dominant wavelength. In practice this means that the colours of light from two identical LED luminaires can in fact deviate from one other. Semiconductor manufacturers classify every LED according to these two criteria, sorting them into different categories called "binnings". Some luminaire manufacturers demand that their suppliers provide binnings that are particularly stringently selected with respect to the dominant wavelength. This is because the greater the accuracy with which an individual light source emits a certain wavelength from the outset, the more exact the match between light colours of several luminaires. But even with the most stringent selection, deviations in both the luminous flux and the dominant wavelength between individual LEDs of one colour still have to be accepted.

Colour mixing and perception of differences in colour

The problem of the manufacturing deviations of LEDs is aggravated when mixed colours of light are used. In RGB colour mixing, the tolerances of two of three LEDs are compounded together. On the one hand, the dominant wavelength can deviate by 5nm or more within one binning, depending on the manufacturer; on the other, fluctuations of 20 to 30% can arise for one luminous flux binning. This means that the mixed colour of two LED luminaires can differ by more than 10nm in a worst-case scenario. The eye, however, can detect differences starting from 1-3nm, depending on the wavelength and the background. Therefore, high-quality colour mixing for architectural lighting with several luminaires cannot be reliably implemented on this basis. Achieving colour constancy between several luminaires when washlighting a white wall – especially with an amber or cyan hue – is one of the most demanding challenges facing lighting engineering. The eye has a very high sensitivity for these wavelengths and therefore detects even fine differences in colour.

From the technical side, fluctuations in luminous flux are more serious than fluctuations in dominant wavelength for the perception of the colour differences. Without colour compensation technology, this could cause the light colours produced by RGB colour mixing to visibly deviate from one luminaire to the next for the same DALI (Digital Addressable Lighting Interface) control values. Conversely, lighting users require lighting products that will always reproduce exactly the same light colour from a given DALI control value – even in difficult applications such as strip lighting or a row of LED luminaires acting as wallwashers. To ensure reliable colour precision, a colour compensation technology, is introduced whereby LED luminaires with RGB colour mixing capability (also known as varychrome luminaires) are individually measured and calibrated at the factory.

Fig. 5: Coloured wallwashing without colour compensation

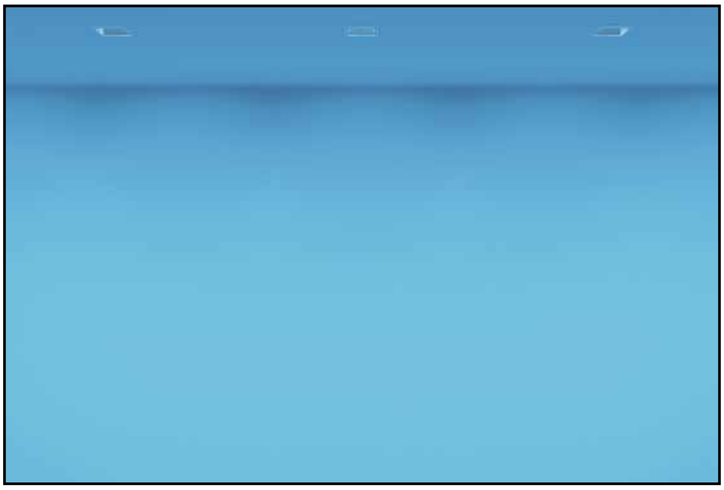


Fig. 6: Coloured wallwashing with colour compensated Quadra varychrome LED luminaire

Colour compensation process

The colour compensation is performed in four steps: i) the luminaires are operated for a certain time period; ii) their actual values are recorded; iii) compensation values are entered and iv) the compensation is checked. To achieve a reliable and constant value for the measurement, the luminaires are operated continuously for about two hours under reproducible temperature conditions until the luminaire reaches thermal saturation. Following this, a computer-aided measuring instrument records the luminous flux and the dominant wavelength for each of the luminaire's RGB channels. In the third step, the measured values are compared with the set values. The software then calculates the compensation factors from these figures and permanently stores the result in the control gear. The set values are adjusted at certain production cycles to keep them up to date with technological progress. This will enable adjustment to suit the increasing luminous flux of future LEDs. The resulting product versions are identified on the label of the luminaire to ensure that it can be reordered or reproduced as and when required. Colour compensation technology comes into play on luminaires featuring their own control gear where the compensation factors can be individually stored. Colour compensation, control gear and LED module are seen here as a single unit and can be replaced as a single unit in a luminaire as and when necessary. Colour compensation is used, for instance, for spotlights or wallwashers in the indoor area or for outdoor luminaires such as projectors, in-ground luminaires or facade luminaires.

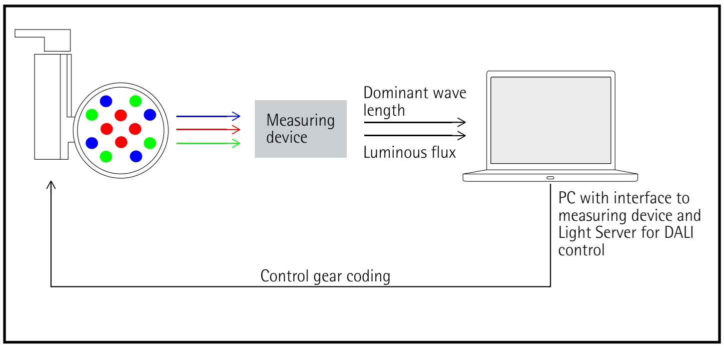


Fig. 7: Colour compensation process diagram

Encoded DALI control gear

The Light System DALI uses encoded DALI control gear, using which the central DALI controller automatically identifies the luminaires and their properties and enables the user-friendly functions. Various data (including the article number, a unique luminaire ID and an index for identifying the lamp type and lamp colour) is saved in the 16-byte memory of the DALI control gear to provide unique identification within the system. The advantage of the encoded DALI control gear is particularly apparent when implementing coloured lighting installations with luminaires featuring RGB colour mixing technology. These luminaires have three addresses with which the light colours red, green and blue are already assigned to the respective control gear. Compared with conventional DALI systems, this does away with the time consuming task, performed on site, of assigning the addresses to the luminaires with their respective colour channels and control gear. A light colour can now be selected and assigned to several luminaires via the software. The LED compensation factors stored in the control gear are used to compensate for the deviations in the LEDs, due to their manufacturing process, so that the user always receives a uniform colour of light.

Output comparison of RGB colour mixing luminaires

The prerequisite for colour mixing luminaires is to have lighting tools with individually dimmable light sources in the primary colours of red, green and blue as components of additive colour mixing. Coloured fluorescent lamps but also LEDs in particular are suitable for this task. The saturation of the individual primary colours will determine the usable colour space. Due to their operating principle, LEDS have one advantage over colour mixing luminaires with fluorescent lamps: their very high colour saturation produces a large colour space, which also includes highly saturated mixed colours. A quantitative output comparison of LED colour mixing luminaires should therefore not be based on the maximum luminous flux for white mixed light but on the entire spectrum and the saturation. Colour compensation allows the luminaire manufacturer to ensure that the user obtains the same hue on several adjacent luminaires; however, the trade off for this is that, in practice, the luminous flux can be slightly below the LED module's maximum possible level.

Summary

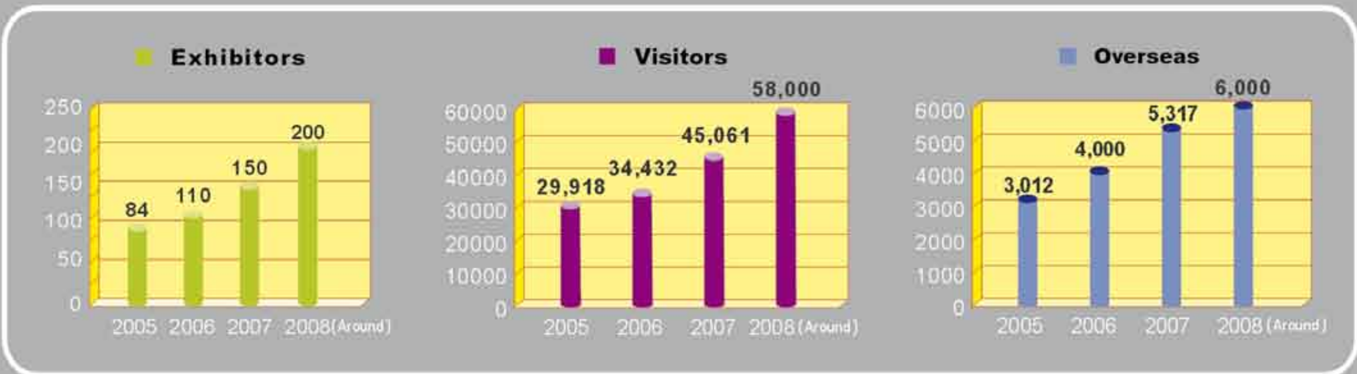
Colour compensation technology for colour mixing luminaires with LEDs makes it possible to compensate for the luminaire's manufacturing tolerances and to achieve optimum lighting quality for the user. Even when LED binnings of the highest grade are sourced, the variation of both the maximum luminous flux and the dominant wavelength still represents a real problem for discerning architectural lighting solutions. Compensation factors stored in each luminaire's own control gear ensure a uniform colour of light for luminaires of the same type during operation. In addition, the version control also takes the technical progress of the increasing luminous flux into account and improves the reordering process for subsequent deliveries.

LED CHINA 2008

— The Toppest Global Event for LED Application

Time: March 4–6, 2008

Venue: Chinese (Guangzhou) Import and Export Fair Pazhou Complex



Preview of LED CHINA 2008

In 2008, LED CHINA, SIGN CHINA and NEON SHOW will be held under the same roof again. The total exhibition area will be up to 50,000 square meters, and LED CHINA area will be more than 10,000 square meters with around 450 standard booths.

Concurrent Activities

- SIGN CHINA 2008
- NEON SHOW 2008

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Adding Intelligence to LED Lighting Systems

> Steve Bowling, Microchip Technology Inc.

The latest generations of small, low-cost microcontrollers (MCUs) can be used to implement various types of electronic control in lighting power supply systems. They can improve control and efficiency, as well as providing intelligence for closed-loop monitoring and communication.

For example, LED technology has now evolved to a point where it provides a durable source of light with efficiencies exceeding those of incandescent bulbs. An MCU added to an LED lighting system provides the ability to efficiently control brightness over the entire operating range. It also provides additional benefits such as active power factor correction (PFC) to further increase efficiency, battery charging for portable lighting applications and the opportunity to integrate popular communication protocols, such as DALI or DMX512

The California Energy Commission has performed a comprehensive study to document lighting energy usage. This shows that residential lighting consumes 8 percent of all energy used by the state, while commercial lighting consumes 14 percent.

The efficiency of a light source, or efficacy, is defined as the amount of light output divided by the electrical input power. The light output is measured in lumens. The efficacy of several types of light sources is shown in Figure 1.

Luminous Efficiency (1m/W)				
Candle 1400's	Incandescent 1800's	Fluorescent 1920's	HID 1950's	LED 2000's
				
1	10 - 15	70 - 100	80 - 120	80 - 100

Figure 1: Efficacy of various light sources

The incandescent light bulb is still widely used in residential applications. The California data shows that 59 percent of all residential lighting energy and 13 percent of all commercial lighting energy is consumed by incandescent sources. However, the incandescent bulb offers the lowest efficacy of all electrically-powered sources.

The high-power LED

The LED has been widely used in indicator applications for many years. These are low-current, low-power devices that are not very suitable for lighting applications. Recent advances in semiconductor manufacturing, silicon structures and phosphor coatings have made the high-power LED a possibility.

Today's power LED has an efficacy that approaches or exceeds other efficient light sources. However, it also has other benefits, including long lifetime and resistance to shock and vibration. These make it useful for applications such as traffic signs, automotive lighting, military applications and any place where safety, reliability or the cost of maintenance is an issue.

A power LED is manufactured with a silicon-carbide or sapphire substrate. The sapphire substrate offers a lower manufacturing cost, but has a higher thermal resistance. The lower thermal resistance of silicon carbide is attractive for power LED applications. The substrate can then be doped with AlInGaP to make LEDs in the red, orange or yellow colour ranges, or with AlInGaN to make green, blue or white devices.

The ability to make a white light source with an LED is very important for lighting applications. Two common methods are used. The first is to use a blue LED with a phosphor coating that creates a white light. The other is to use an LED that emits light in the ultra-violet range. A mix of red, green and blue phosphors is then used to turn this into visible white light.

The blue-LED + phosphor approach provides a very efficient light source. However, it is harder to control the exact colour of the light output because of variations in the blue LED. The UV LED + RGB phosphor construction provides a more predictable colour because the properties of the phosphor determine the colour of the light output. A disadvantage of this technique is that the red phosphor will degrade faster than the other phosphors, causing a shift towards cool white.

Another way to produce white light with LEDs is to use three emitters for red, green, and blue. If the LEDs are driven in the right proportions, white light is produced. Similar to the UV + RGB phosphor type of LED, the colour of the three-LED solution will drift as each LED ages differently. In critical applications, active sensing and control can be used to correct the system over time.

Thermal issues

Heat dissipation and thermal resistance can be significant issues with power LEDs. These devices do not radiate heat, so the heat generated must be mechanically conducted away from the junction.

A power LED would not be viable without the same assembly techniques used to make power semiconductors. Indicator LEDs have a junction that is encapsulated by an insulating epoxy lens. This leaves only the leads to conduct heat away from the junction. In contrast, the power

LED Driving Solutions for Efficient Lighting Applications

Efficient LED Control from Microchip

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- **Intelligent control for additional functions**
- **Off-the-shelf reference designs**
- **Range of options to drive LED current**
- **Solutions for lighting control standards – 0-10V, DMX512, DALI**

Energy-saving LED lighting requires highly efficient solutions to drive the LED current. Using a switch-mode power supply (SMPS) minimises energy wasted in the control circuitry.

Microchip offers a broad range of SMPS solutions for LED driving, with a selection of reference designs that lets you decide the trade-offs between circuit complexity; component count; input and output voltages; and other factors.

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For more information on LED Driving Solutions, go to the Microchip Lighting Applications Design Center at www.microchip.com/lighting or contact us at lighting@microchip.com

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LED is manufactured on a chip like other semiconductor devices. This is then fixed to a heat slug that penetrates through the package, and the connections are made to external terminals by bonding wires. The slug is then encapsulated with a silicone gel and covered with a hard plastic lens that is coated with a phosphor. This avoids stress on the bonding wires. An epoxy lens would not be practicable, because of thermal expansion.

Heat is the biggest enemy of power LEDs. A major advantage of the power LED is lifetime, which can exceed 50,000 hours. In comparison, a typical fluorescent lamp has a lifetime of 8,000 hours and a typical incandescent bulb has a lifetime of 2,000 hours. To achieve this long lifetime, the junction temperature of the LED must be kept low. The actual temperature limit is a subject of debate among the major LED manufacturers, but in general, the junction temperature must be kept at 80 degrees Celsius or less to achieve a long lifetime. When run continuously above this temperature, the LED can fail in less than 10,000 hours. At temperatures near 80 degrees, the light output will fall off rapidly in the first 10,000 hours, but the LED will continue to generate a reduced light output for long after that. At more moderate temperature levels, the LED will produce a relatively consistent light output over its lifetime.

Although LEDs have evolved to be very efficient sources of light, every design is a trade-off between light output, efficacy and heat-sink design. It may be necessary to drive a power LED at a reduced power level to meet temperature and heat-sink design requirements. Furthermore, the packaging requirements of the lighting fixture can limit the ability to provide good heat sinking.

Power LEDs with power levels exceeding 3W have become widely available. However, it is still easier to meet thermal design requirements using multiple smaller LEDs in the 1-2W power range. Greater efficacy can be obtained when the LED is driven at a lower current. LED systems will become easier to design as the efficacy of LEDs increases.

The LED requires a source of constant current, rather than constant voltage. For indicator and lower-power types, a resistor will be adequate. For LEDs above 1W, this becomes impractical. Standard switch-mode power supply (SMPS) topologies and controllers can be used to drive the LED at these higher power levels, using LED current as the feedback to the controller instead of voltage. The choice of topology depends on the system input voltage, LED forward voltage and the number of LEDs connected in series.

It is also important to consider how current is drawn from the AC line. A typical bridge rectifier circuit with filter capacitors will only consume current from the AC line at the peaks of the AC input voltage. The result is a current waveform with high harmonic content and a poor power factor. An active PFC circuit can improve the conversion of AC power to DC power, by forcing the current consumption of the circuit to track the envelope of the incoming AC line voltage. Power factor correction helps to meet energy-efficiency requirements and helps customers to achieve a faster payback for electronic lighting controls.

Active PFC is most easily implemented using a voltage-boost circuit with an outer voltage-feedback loop and an inner-current control loop. The voltage-feedback control loop provides the demand for the inner-current control loop and determines whether more or less current is required to achieve the desired bus voltage. The current loop demand is then used to scale a sinusoidal reference signal.

This signal can be derived in one of two ways. It can be measured directly from the rectified AC input voltage, but a simpler solution uses a sinusoidal reference stored in the memory of the MCU. A PWM channel on the MCU can be used as a simple digital-to-analogue converter, to generate the sinusoidal reference. An RC filter is connected to the PWM output pin to convert the PWM signal into a voltage.

The values in the sinusoidal table are scaled up or down by the current demand from the voltage control loop. The sinusoidal reference signal stored in memory is synchronised to the zero crossings of the incoming AC voltage, using an interrupt on the MCU.

The use of a sinusoidal reference table assumes that the incoming AC voltage is purely sinusoidal and does not have any distortion. This assumption is practical for many applications. The method is known as indirect PFC (Figure 2).

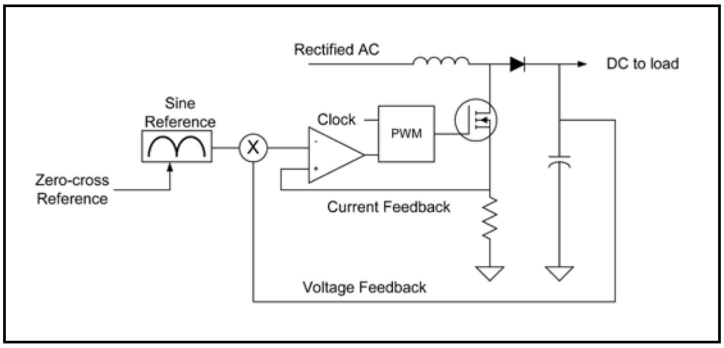

Figure 2: Indirect PFC block diagram

Microcontrollers allow communication to be integrated into lighting applications. This is especially important for commercial applications where regulations and energy pricing incentives may dictate the use of daylight harvesting, occupancy sensors and other automatic control methods.

The most common method of dimming in large installations is analogue 0-10 VDC control. This can be incorporated into the design using an analogue-to-digital converter channel.

The more sophisticated digital communication solutions, such as Digital Addressable Lighting Interface (DALI) and DMX-512, rely on an MCU-based design. DALI is a bidirectional protocol for controlling multiple lighting fixtures on a two-wire bus. It uses a 1200 baud, bi-phase signal that is easily generated by an MCU, and can address one of 64 lighting fixtures individually, one of 16 groups, or broadcast to an entire network. Advanced features such as fading, logarithmic profiles and scene control can be implemented. Since the protocol is bidirectional, fault information can be sent to a host controller.

As the name suggests, DMX-512 allows dimming signals for 512 lighting channels to be multiplexed onto a single wire. The protocol evolved from analogue multiplexing protocols used in the theatre and entertainment industries. It can be implemented with a standard UART operating at 250 Kbaud and uses an RS-485 differential driver to allow transmission over long distances. One disadvantage is that it only provides unidirectional communication. A new extension to DMX-512, called Remote Device Management, has recently been proposed as a means to offer bidirectional communication. It would also allow the remote setting of node addresses.

One of the disadvantages of DALI, 0-10V and other control schemes is that separate wiring needs to be run to each fixture. With an MCU, other control schemes, such as power-line modems and infrared communication, are possible.

The ZigBee™ wireless protocol provides a cost-effective solution for low data rate control networks and could have potential for use in lighting-control applications. The protocol provides self-commissioning of network nodes and security features.

The use of an MCU in an LED driver application facilitates PWM dimming methods. The easiest way to dim a LED is to adjust the current-output level of the switch-mode or linear driver. However, linear dimming is not preferred for two reasons. Firstly, the LED is not operating at its optimum efficiency point over the brightness range. Secondly, linear dimming can produce a colour shift in the light output of the LED. PWM dimming solves both of these issues by modulating the LED output with a low-frequency PWM signal. The LED is turned on at a single current drive level. Its brightness is adjusted by

changing the average amount of time that the LED is active. The PWM control and LED drive functions can be integrated into a single chip solution, or a low cost MCU with as few as six pins can be used to generate the PWM dimming signals for a separate driver circuit.

At first, you might not consider the use of an MCU for a lighting application. However, they can be integrated into the design at any level to create efficient lighting applications. An MCU can handle both communication and power-control functions. Furthermore, it provides a versatile platform that can be easily programmed to create new features and functions. ■

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What's your favourite colour?

> Simon Bramble – austriamicrosystems Applications

RGB LED lighting system design made easy

There is little doubt that lighting, quite literally, changes the way we look at things. Not so long ago White Light Emitting Diodes (LEDs) were seen as being the cutting edge of lighting technology with these devices being fitted into everything from mobile phones and children's toys to architectural lighting. Now the world of illumination is changing and Red Green Blue (RGB) LED lighting is stealing more attention.

RGB LEDs allow the user to modulate the colour spectrum. This can be used to paint a more appealing picture of the subject being lit as well as to produce stunning 'mood' lighting for rooms, displays or even whole buildings. Fluorescent lights, although cheap to run, give out a colour high in blue wavelength so can look cold. RGB LEDs allow the user to change the lighting colour dynamically, depending on what is being lit, as frequently as desired. Simply choose your favourite colour!

RGB LED driving

The mobile phone industry has caused many manufacturers to design solutions for driving white LEDs, but there are very few suppliers providing an adequate solution for driving RGB LEDs.

Many solutions for driving RGB LEDs have well known shortcomings:

- Current control is inaccurate. Current variations greater than 2% cause a noticeable change in colour, therefore the current accuracy of the driver must be at least +/- 1%. Most LED drivers and discrete solutions can't reach this required accuracy.
- Many external components required and therefore a less attractive Bill of Material
- Problems with thermal management
- Difficulties in building large systems with high colour uniformity
- EMC issues due to limited speed of DCDC converter loops

The solution shown below resolves all of these issues and is suitable for both portable and non portable applications. It can be used for tiny RGB solutions up to large scale lighting systems controlling several thousands LEDs. The chip itself occupies only 16mm2 of board space.

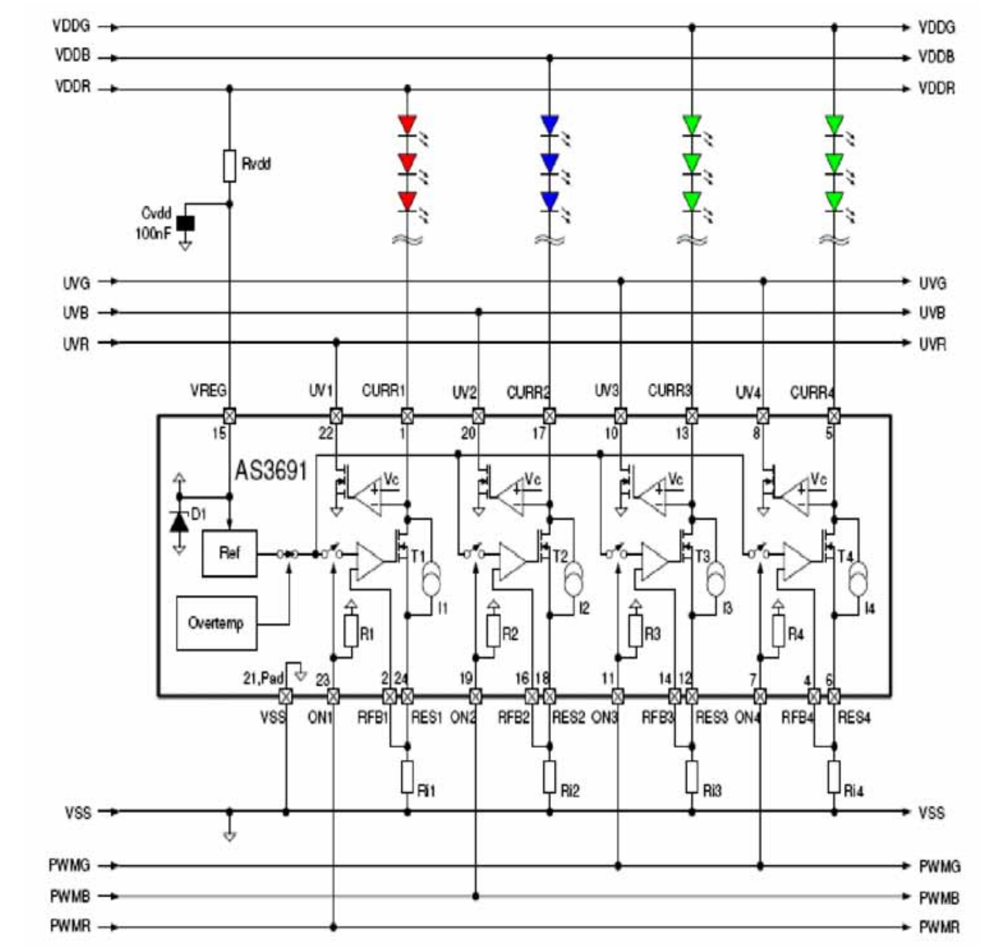


FIG 1 – AS3691 block diagram

The AS3691 is a tiny 4 channel, 400mA low side RGB LED driver. In addition, each of the four channels can be combined, to give an LED current of up to 1.6A. A typical setup would be to use four LED strings with 350mA (FIG1) or just two strings with 700mA. Both configurations align very well with the latest state of the art LED technology.

Because it is a low side driver, the AS3691 is never exposed to the high voltage needed to drive a string of LEDs which keeps the geometry of the AS3691 small and its cost low. Despite this, it has very accurate LED current matching (0.5%) both from channel to channel and device to device ensuring the brightness of adjacent strings of LEDs is very closely matched.

FIG 1 shows the AS3691 block diagram. The LED current is monitored by resistors Ri1 to Ri4. The current flows through the LEDs into the CURR pins and current sense resistors Ri1-Ri4.

In addition, a PWM signal can be applied to the ONx pins to enable dimming of each LED chain individually.

The AS3691 has over temperature protection and the rise and fall time of the switches is accurately controlled within the AS3691, therefore enhancing EMC performance.

Patented power regulation

The AS3691 can be used to control any power supply that uses an external feedback network. The AS3691 can either be used to regulate one power supply for all LED colours or control separate power supplies for each colour for maximum efficiency (as shown in Fig4). To reduce the power dissipation of the AS3691 and therefore increase the power efficiency of a complete lighting solution, the AS3691 regulates the voltage of the supplies as follows:

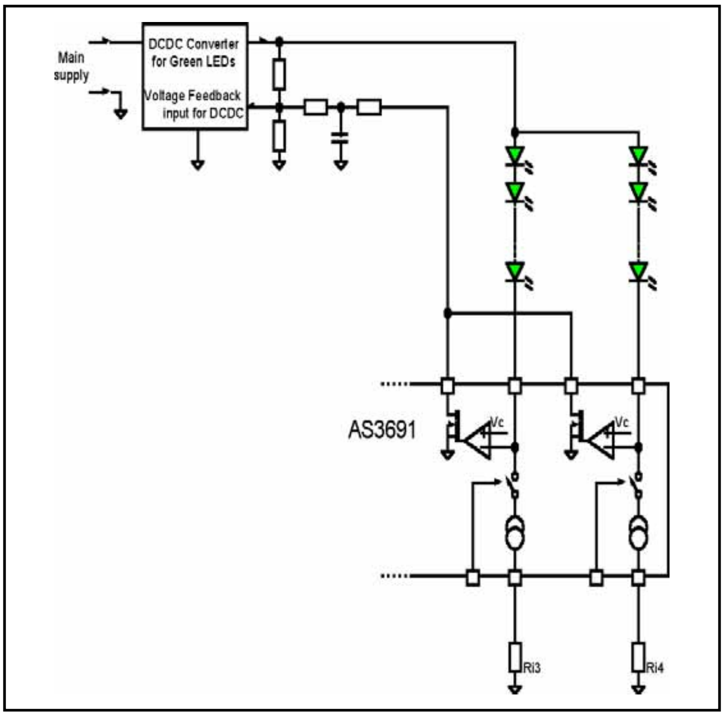


FIG 2 –AS3691 Power Supply Regulation Loop shown for all green LEDs

The supply is dynamically adjusted to meet the forward voltage of the LEDs by modulating the feedback regulation loop. FIG 2 illustrates multiple chains of LEDs connected to one adjustable power supply whose feedback voltage is modulated by the common connection of pins UV3 and UV4 of the AS3691. The current sinks do not even need to be on the same AS3691 and the number of parallel strings is unlimited.

UV3 and UV4 adjust the voltage of the DCDC converter output to minimize the remaining voltage across the current sources but nevertheless ensuring that all current sources will be within their correct operating range.

Use of high LED supply voltages

If a higher voltage is required (to adequately bias the blue LEDs or indeed drive a larger LED stack) the AS3691 can be used with external cascode transistors. A suitable circuit is shown in FIG 3. The AS3691 provides the current regulation and the feedback voltage modulation, but the external cascode transistor, T1, buffers the high voltage. The power supply feedback resistors need to be changed to give a higher output voltage on the power supply. The gate of the transistor T1 was tied to the input voltage (5V). If a local 5V is not available, the AS3691 has an on chip Zener diode that can act as a shunt regulator to power the AS3691 and bias the transistor's gate.

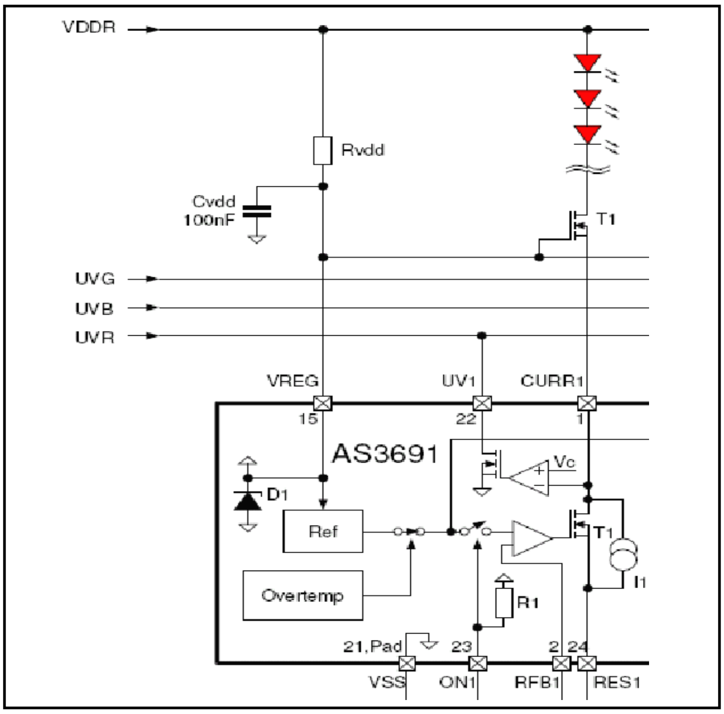
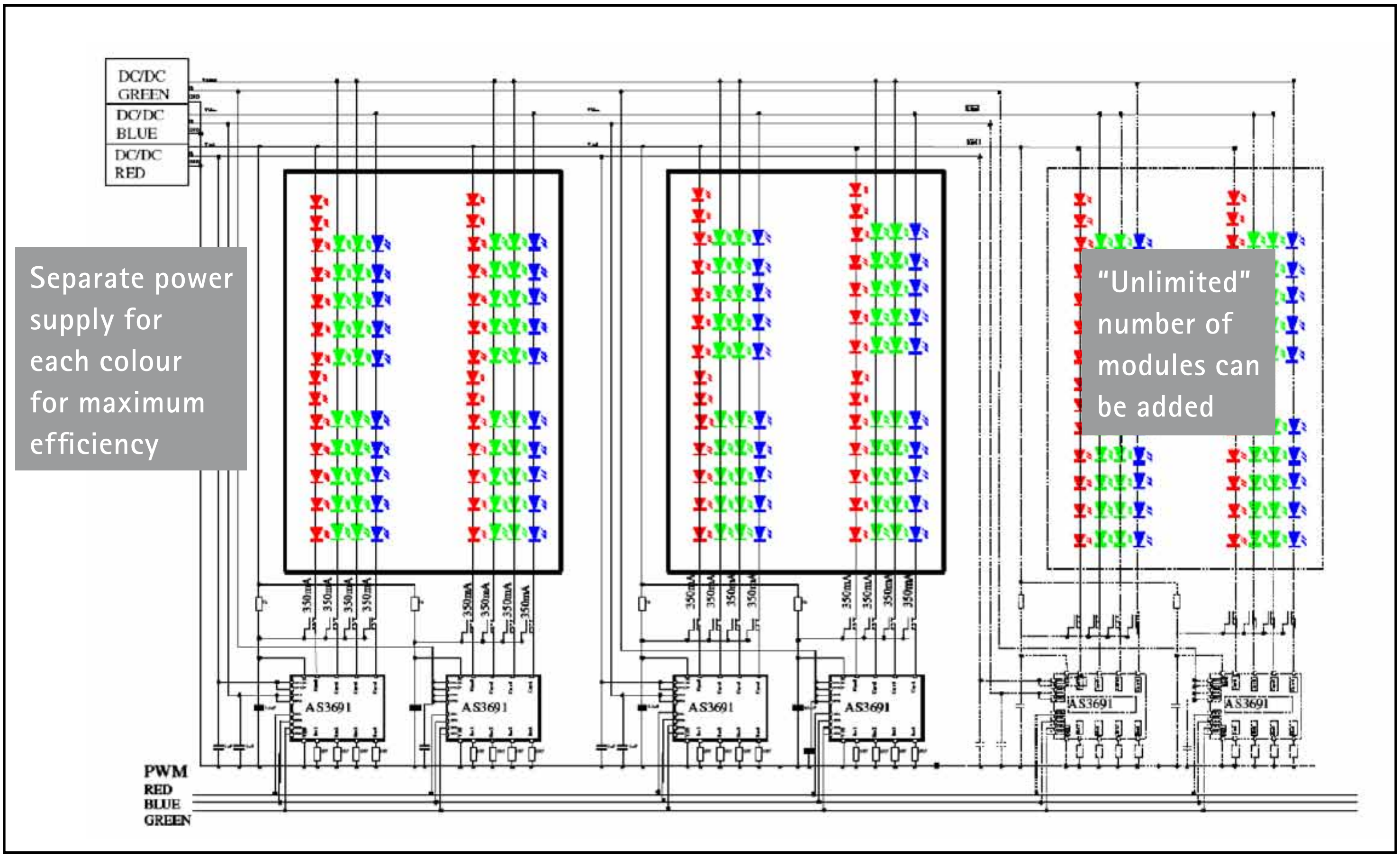


FIG 3 – AS3691 with High Voltage

Large lighting systems with high colour uniformity

With the AS3691 it is easy to build large lighting systems with thousands of LEDs. The solution can be designed with a modular approach and can be extended according to the requirements of the application (see Fig 4). Because the AS3691 has such good channel to channel matching, colour uniformity of the highest accuracy can be achieved across all the modules. Universal brightness control for each colour can be achieved by connecting all the PWM inputs together. Each colour group (Red, Green or Blue) can be individually controlled by connecting together the feedback lines for the corresponding power supplies, making the system very energy efficient and good in terms of thermal design. The solution is easy to design, scaleable, and low in cost. Figure 4 shows a large lighting system. This kind of system design is used today in large screen LCD backlights well as in large lighting systems.



Safety Features

A number of safety features are incorporated onto the AS3691. Over temperature protection is built in that switches off the LED current when the die temperature reaches 140 degrees C. On the AS3691A, the LED current never falls to zero, always maintaining 5% of the maximum current through the LEDs. This is to keep the LEDs conducting so there is always a voltage drop across them in order to keep the voltage seen by the CURR pins within specification. If it is desired to have the LED current decreasing to less than 100uA, the AS3691B has this feature.

Conclusions

The AS3691 provides a small, low cost solution for driving small or large LED networks – and it guarantees by design that the exact colour is achieved within the whole system. Because it regulates the current and the voltage on the low side, it can control both low and high voltage systems and does not limit the designer to a particular LED architecture. It is suitable for small RGB lighting applications, backlighting large LED displays, automotive dashboard illumination and architectural lighting. ■

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Low Cost Power Supply for High Power LED Applications

> Dr. Michael Weirich, Fairchild Semiconductor GmbH

Dr. Michael Weirich

Is the head of Fairchild Semiconductor's 'The Global Power Resource™' Centre Europe. After finishing his Ph.D. thesis in solid state physics at the University des Saarlandes, Germany he started as a designer for analog and power electronics at the Siems & Becker GMBH, Bonn. Before he joined Fairchild in 2003, he worked several years as engineering manager in the design of fluorescent lamp ballasts at the OSRAM GmbH, Munich.

Since high power LEDs are more and more used in general lighting there is an increasing demand for off-line power supplies to drive these. Due to the V-I characteristic of LED such a power supply must have a constant current output. The following article describes a PSU based on a Fairchild Power Switch (FPS™) that realizes constant secondary current with primary-side regulation. The absence of operational amplifiers and an optocoupler for the stabilization of the output current makes this PSU extremely cost effective in case safety isolation is needed.

Conventional constant current output PSU

The traditional approach for a constant output current offline power supply (PSU) is shown in Fig. 1. This PSU is based on flyback topology and can deliver a current of 700mA and a maximum output voltage of 5.1V from a input voltage from 85 VRMS to 265 VRMS. As the technical data imply, the PSU is mentioned to drive a 3W high power LED. The circuit is quite straightforward: After rectification (BD1 - BD4) and filtering (C2, C3 and L1) of the mains input, a flyback with the FPS™ FSQ510 follows.

The FSQ510 is the 'smallest' member of a family of integrated circuits that contain all necessary functions to implement a state of the art switched mode power supply. While the FSQ510 is a monolithic device with integrated 700V Sense-FET, the higher power members of the family are two chip devices consisting of a controller and a separate Sense-FET with a VDS of 650V. Basic functions and behavior are almost identical for all members of the family, thus the description of operation of the PSU with FSQ510 may stand for the complete family.

After connecting the PSU to the mains, operation starts via the internal start-up path of the device i.e. an internal high voltage JFET charges C8 to the start voltage of 13V typical. As soon as this voltage level is reached, the internal Power-MOSFET starts to switch and normal operation of the PSU begins. The internal JFET is switched off now to reduce consumption of the power supply. The power for the FPS™ is now supplied from a separate winding of the transformer, rectified with D2 and filtered by R7 and C8.

RS2 and RS3 together with DS1 and C82 form a clamping or 'snubber' network that takes the energy stored in the leakage inductance of the transformer. This is necessary to limit the drain voltage to a save level.

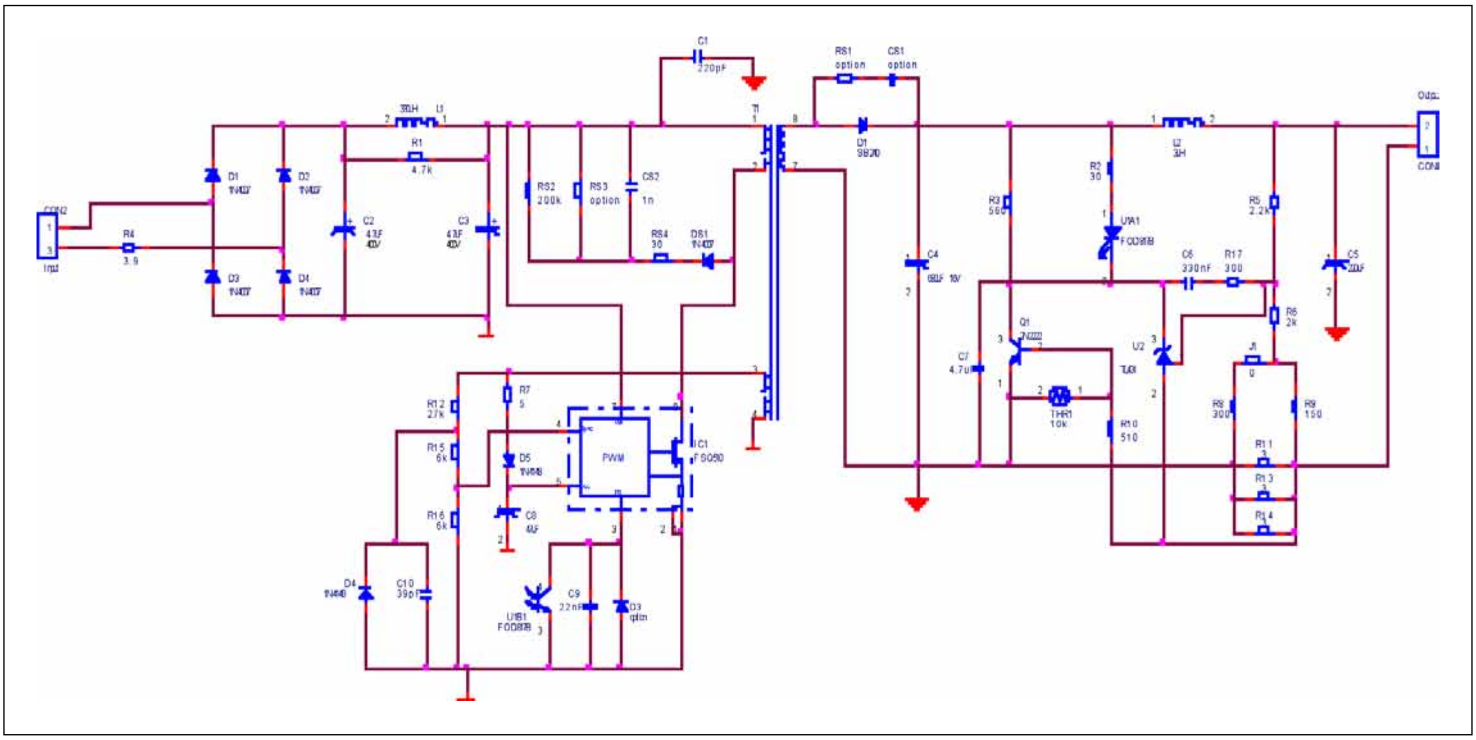


Fig. 1: Conventional constant current output power supply

The transformed voltage is rectified by D1 and filtered by C4 with post filtering by L2 and C5. The output voltage is regulated with the network consisting of R2, R3, R5, R6, U1 and U2. U1 couples the feedback signal to the primary side and C6 and R17 form a frequency compensation network in order to get stable close loop operation.

The actual output current in this application is sensed with the shunt R11|R13|R14 and regulated with the help of Q1 and U1. When the voltage drop across the shunt exceeds the VBE of Q1, a current starts to flow through the LED of U1 and in turn the voltage at the feedback pin of the FPS™ is lowered. In sequence the duty cycle of the Power-MOSFET is reduced and at last the output voltage respective current. Since the VBE of a BJT is strongly temperature dependant, a compensation network consisting of R10 and the NTC THR1 is added. Purpose of R8 and R9 is to disable U2 in order the voltage loop doesn't spoil operation of the current regulation loop.

The network R12, R15, R16, D4 and C10 form a network that enables Quasi-Resonant-Switching of the Power-MOSFET inside the FPS™. QR-Switching means that the drain voltage is monitored and the actual turn-on of the MOSFET happens when the drain voltage is at minimum. This uses the fact that after the energy stored in the transformer has been transferred completely to the secondary, an oscillation of the drain voltage occurs. This oscillation is due to the resonant network formed by the magnetizing inductance of the transformer and the drain-source capacitance of the MOSFET. By switch-on at minimum drain voltage the switching losses are considerably reduced and EMI performance is improved. The synchronization network is actually not connected to the drain of the MOSFET but to the VCC winding of the transformer, that has identical waveform but lower amplitude.

Primary Side Regulated Constant Current PSU

In a flyback converter it is possible to get a fair regulation of the output voltages without explicitly regulating these. That is due to the fact that – if parasitic effects are neglected - the ratio of two output voltages is equal to the winding ratio of the respective transformer windings. Consequently it is possible to regulate e.g. the voltage of the VCC winding and get quite stable isolated outputs without using an optocoupler. Fig. 2 shows the schematic of a primary side regulated power supply – still without the constant current feature.

Most blocks are identical to the secondary side regulated PSU, but the feedback loop is completely different.

As mentioned before, feedback is taken from the same transformer winding that supplies the FPS™. D3 rectifies this voltage and feds the network R2/C7 that generates the VCC of the chip and R4/C4 that filters the feedback voltage. In general the feedback could be taken from C7 as well. But since the FPS™ needs quite a big capacitor to support start-up current consumption it is better to have the additional path with a different time constant. The Zener-Diode D7 delivers base current to Q1 which acts as error amplifier. If VCC and at the same time the output voltages rise, this transistor gets more base current and in turn lowers the potential at the feedback pin of the FPS™, similar to the PSU with optocoupler feedback.

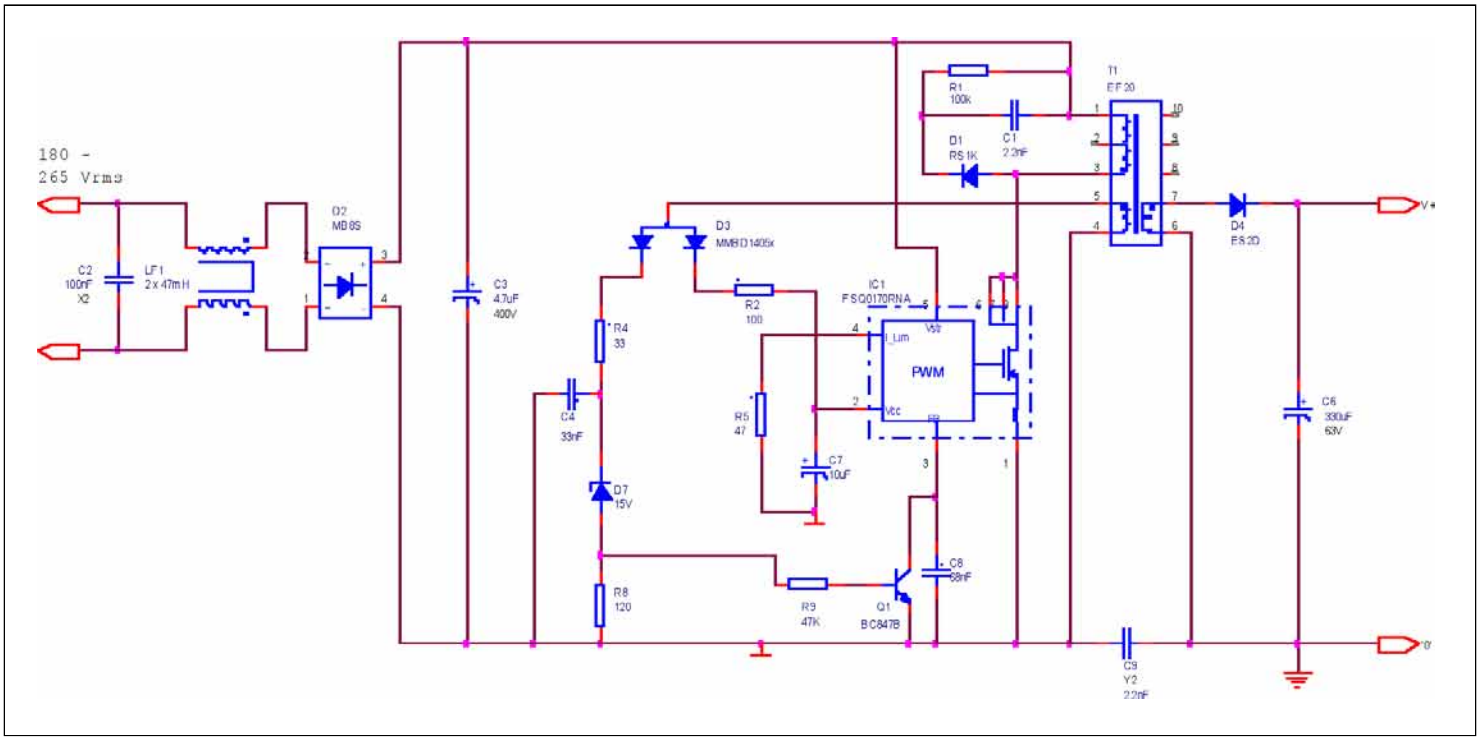


Fig. 2 Primary side regulated power supply with constant output voltage.

So far the PSU works in constant voltage mode, how can it be turned into a current source? If one analyzes the relationship between output current of a flyback in continuous conduction mode and the peak MOSFET current one will find that, in order to get a constant output current, the peak MOSFET one has to be directly proportional to the output voltage VOut and inversely proportional to the input voltage VIn. In discontinuous conduction mode drain current must be proportional to the square root of VOut and the dependence on Vin disappears in theory.

One thing that helps creating a primary side regulated current source is that the used FPS™ FSQ0170RNA has an input 'ILim' instead of the sync input, that allows setting the maximum peak drain current of the MOSFET. This can be done by attaching a resistor to the pin or drawing a current from it. If a resistor is attached to this pin, the peak drain current can't rise behind a certain value

At last, the principle of the current source can be explained with the help of Fig. 3, that makes clear that only a few lowest cost passive components have to be added to the constant voltage PSR PSU to turn it into a current source.

D5 rectifies both polarities of the voltage across the VCC winding. Both are filtered with an R/C network, namely R3/C5 and R4/C4 respective. The positive portion across C4 is proportional to the output voltage while the negative across C5 is relative to the input voltage of the power supply and negative compared to primary side ground. The regulation loop consisting of D7, R8, R9 and Q1 operates in the same way as the one in Fig. 2 as long as the load current is low. The only difference to Fig. 2 is that R8 is not connected to primary ground but to the negative voltage across C5. As long as the PSU works in voltage mode, the voltage of the node that includes the cathode of D7 is almost identical to VBE of Q1 and only little current is flowing through R7 out of pin 4. When the load current increases, the peak current on the primary side increases as well. When the primary side peak current limit determined mainly by R5 is reached, the output voltage starts to drop. In turn the voltage at the cathode of D7 drops as well and the current through R7 is increased with the result that the peak current of the MOSFET is lowered further. With a well chosen value of R7, the peak current shows the right dependence on the output voltage and the output current is almost constant. R6 is used to compensate for changes in the output current with increasing input voltage. When in constant current mode, Q1 is negative biased and therefore completely switched off. In a constant voltage power supply this wpould indicate a failure condition, the voltage at the VFB pin would rise to a 6V and the device would shut down. To prevent this, R10 has been added.

Since the output voltage of a current source varies significantly with the load, so does the voltage of the VCC winding. Therefore, the winding ratio has to be chosen such that the supply voltage of the chip is higher than the undervoltage lock-out level of the FPS™ at minimum output voltage. Due to the maybe wide range of the VCC voltage the Zener D6 has to be added in order not to drive the chip into overvoltage shutdown.

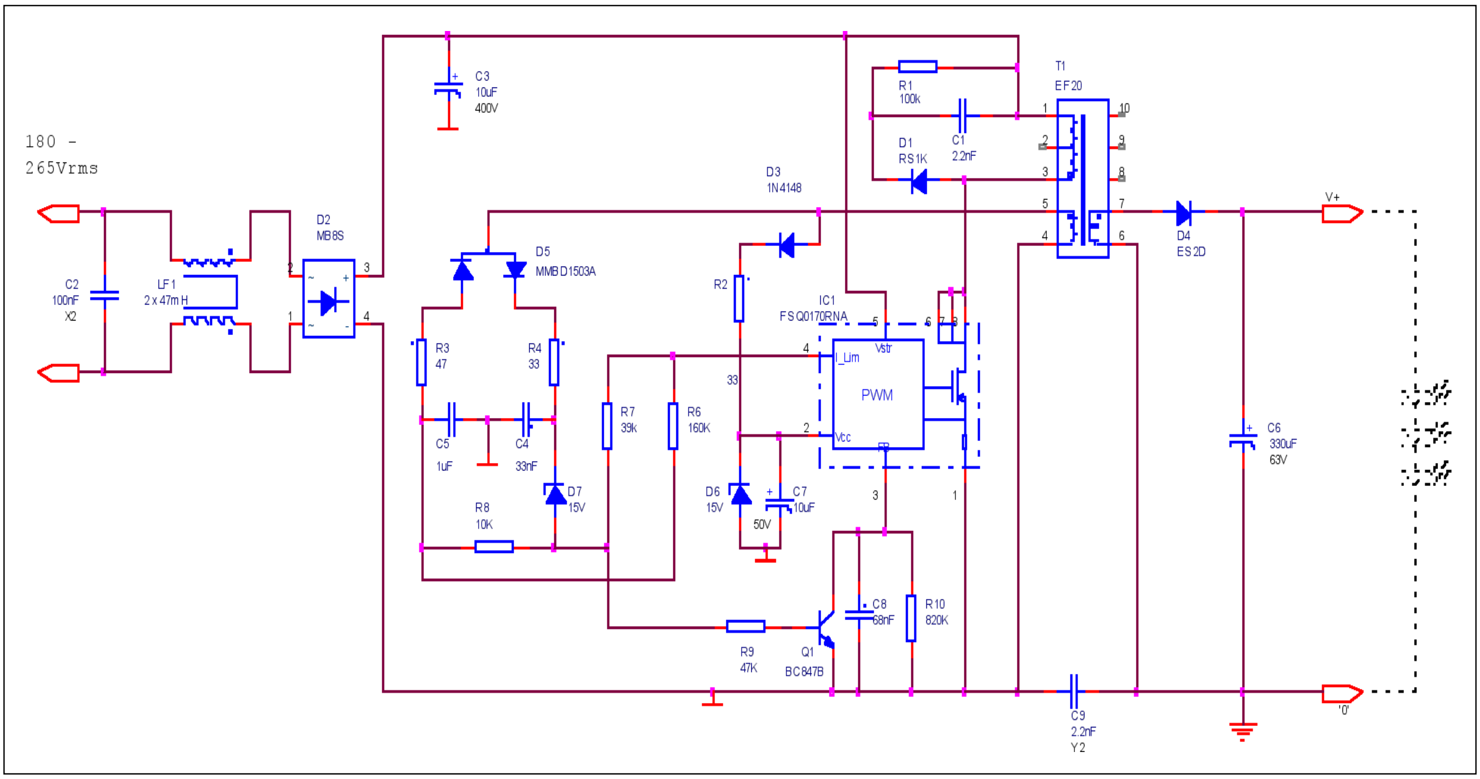


Fig. 3 Primary side regulated power supply with constant output current.

The schematic in Fig. 3 shows a LED ballast that is capable to drive three to five high power LED with a nominal current of 700mA from an European mains input. The output characteristic is shown in Fig. 4. The voltage at very small load currents rises quite high, as is normal in a PSR power supply, and pretty constant in the medium to higher current range. But this region is not of interest for an LED ballast. More important, the load current in constant current mode is fairly constant over a wide range of output voltages.

Different versions with e.g. 350mA output current or universal mains input together with transformer specifications and PCB data are available from Fairchild Semiconductor.

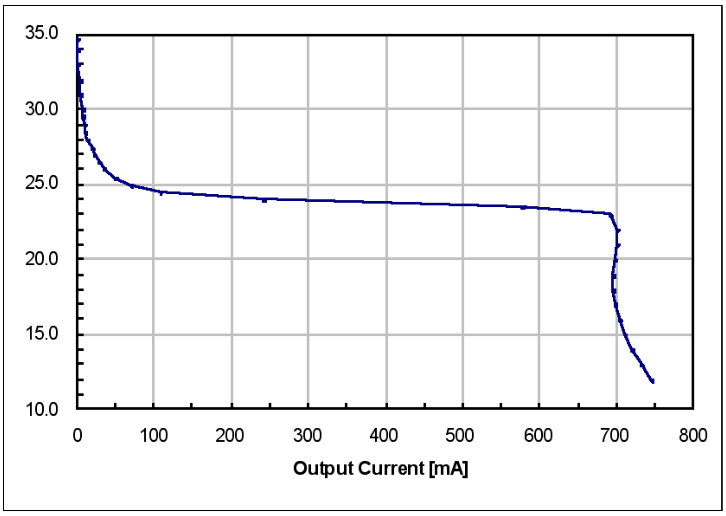


Fig. 3 Primary side regulated power supply with constant output current.

Next Generation MR16 LED Lamps Powered by the MAX16820 Driver IC

> Da Feng Weng, Product Definer, and Mehmet Nalbant, Director, Application Engineering Maxim Integrated Products Inc., Sunnyvale, Calif.

Halogen MR16 lamps are widely used in professional store and home decorative lighting applications. The power dissipation of the most commonly used halogen based MR16s ranges from 10W to 50W and their light output ranges from 150 to 800 lumens. That equates to an efficacy of about 15lm/W. The life time of a typical halogen bulb is limited to about 2000hrs. In addition the filament should not be exposed to high levels of vibration to prevent the bulb from failing prematurely.

Today's LED technologies offer a cost effective alternative. For example the latest generation of 5W (one chip 4x4mm package) and 10W (four chip 7x7mm package) high power LEDs from LedEngin generate typical efficacies of 45lm/W@1000mA/Tj=120'C. That equates to typical lumen output levels of 155lm (@1000mA/Tj=120'C) for the 5W package and 345lm (@700mA/Tj=120'C) for the 10W package in actual use conditions. It can be shown that when these LEDs perform at the same brightness level as halogen bulbs, that then the power dissipation can be reduced by about 50%. In addition LedEngin predicts a remarkable lumen maintenance of 90% @100k hrs/Tj=120'C thus eliminating the need for bulb replacement throughout the life of the product.

For the MR16 reference design Maxim selected the LedEngin 5W product to demonstrate the 1000mA drive capabilities of the MAX16820 IC circuit. In most MR16 applications, the input voltage is 12VAC±10%.

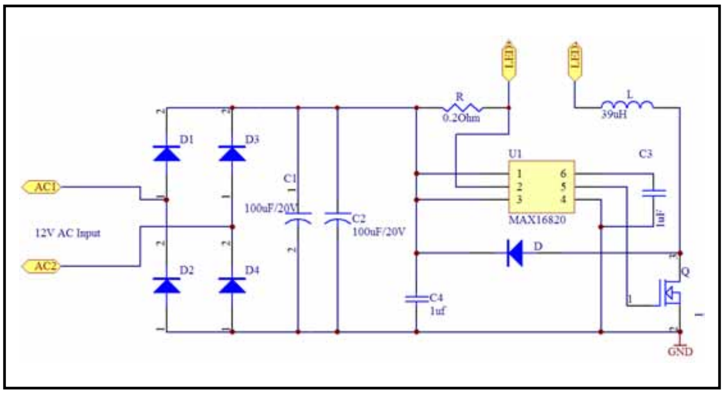


Figure 1. 5W MR16 LED Lamp Circuit with MAX16820

The MAX16820 has been specifically designed for LED driver applications targeting among others LED based MR16s, and it is available in a very small 6-pin TDFN package. A 4.5V to 28V input voltage range along with the ability to drive an external cost effective MOSFETs give the MAX16820 based driver circuits a broad range of LED current drive capabilities. In addition its wide operating temperature range extended to 125oC allows the MAX16820 to be safely operated in the high temperature environment of the MR16 light fixture. While the MAX16820 can control power levels up to 25W or even higher, a 2MHz switching frequency results in small inductor and capacitors which allow the driver circuit to be placed in the MR16 fixture.

Figure 1, shows a 5W MR16 LED lamp driver composed of rectifier bridge D1~D4, 100uF filter capacitors C1&C2 and Buck converter circuit. The Buck LED converter is composed of MAX16820, buck inductor L, power MOSFET Q, freewheeling diode D and sense resistor R.

5W HBLEDs require 1A of drive current. The Buck LED driver is designed to output 1A DC current. The hysteretic control method is used to control the buck inductor current which is also the LED current. The hysteretic control implemented in MAX16820 results in a simple and very robust driver resulting in 5% LED current accuracy.

In order to make a 5W LED run in constant 1A current for the entire line frequency period, DC bus filter capacitors are added to limit the DC bus voltage ripple. The total capacitance should be at least 200uf. DC capacitors can be tantalum capacitors or electrolytic types of 220uF/25V rating for low cost.

In order to keep enough high output current accuracy, the maximum di/dt of the inductor current should be limited to less than 0.4A/us. As shown in Fig.1, the maximum voltage drop on the inductor is V_{LMAX}. The following can be used to calculate the value of the inductor L:

$$V_{LMAX} = V_{AC\_IN} \cdot (1 + \delta) \cdot \sqrt{2} - V_O$$

$$L = \frac{V_{LMAX}}{di/dt}$$

For V_{AC_IN}=12V, δ=10% and V_O=3.6, L>37uH and 39uH standard value is chosen for L.

Where: δ is the allowed input AC variation percentage, and the V_O is LED forward voltage.

The bench test waveforms are shown in Figures 2 through 5. The output current ripple is about 10%.

A 5W white LED based MR16 light fixture from LedEngin has been used for the above tests, Figure 7 shows a picture of the setup. As shown in Fig.4, with 200uF DC filter cap, the DC bus voltage ripple is 8.5V. The MAX16820 based hysteretic mode control is shown to have very good line regulation performance. The output LED current has minimal variation as result of the input bus voltage. The bench tests show that for the 5W MR16 LED lamp driver, the input AC ripple and variation can be more that 8.5V, while the output LED current is regulated to 1A constant current.

Designation	Description	Designation	Descrition
D1~D4	Rectifier Diode 1N4001	Q	MOSFET FDN359BN
C1, C12	Tantalum Cap 100uF/20V or one Electrolytic Cap 220uF/25F	D	Freewheeling Diode FBR130
C4	Ceramic Cap 1 uF/25V	U1	MAX16820
R	Sense Resistor 0.2Ω±1% IRC LRC-LR1206LF-01-R200-F	L	BUCK Inductor 39uH/1.2A CDRH6D38NP-390NC Sumida
C3	Ceramic Cap 1uF/6.3 V		

Table 1: Parts List for the circuit of Figure 1.

Vin(min)	10.8 VAC
Vin(max)	13.2VAC
VLED(min)	5V
VLED(max)	3.1V
ILED	1A
ILED Tolerance	+/-15%
Open LED Protection	Yes
Shorted LED Protection	Yes

Table 2: Electrical Specification of the circuit of Figure 1.

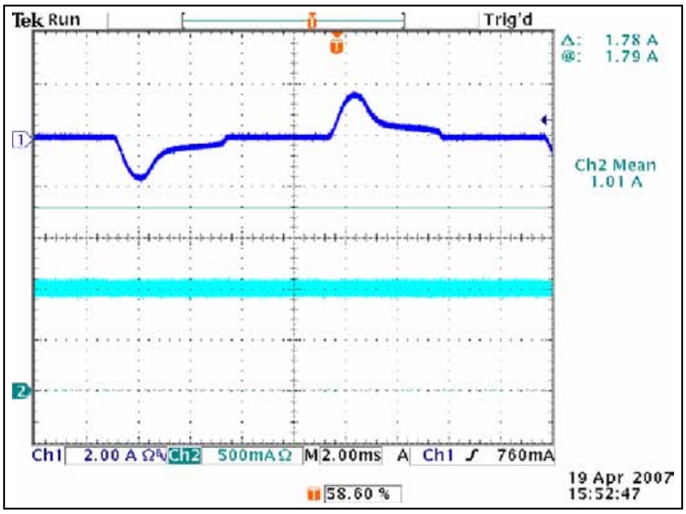


Figure 2. CH1=Input AC Current; CH2=Output DC Current

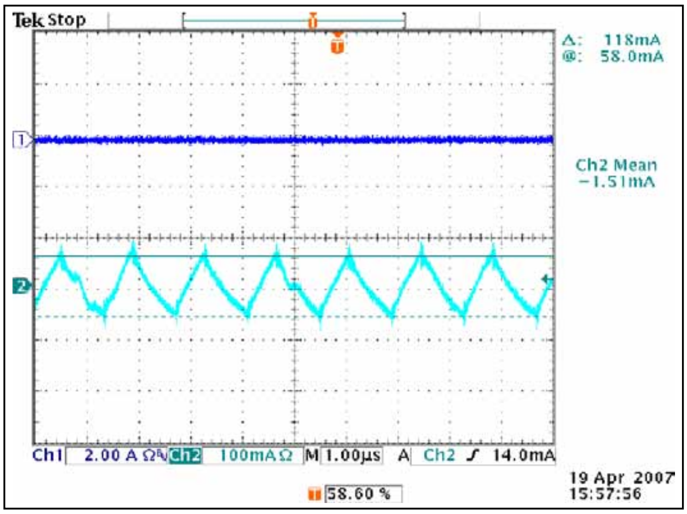


Figure 3. Detailed waveform CH2= Output Current ripple.

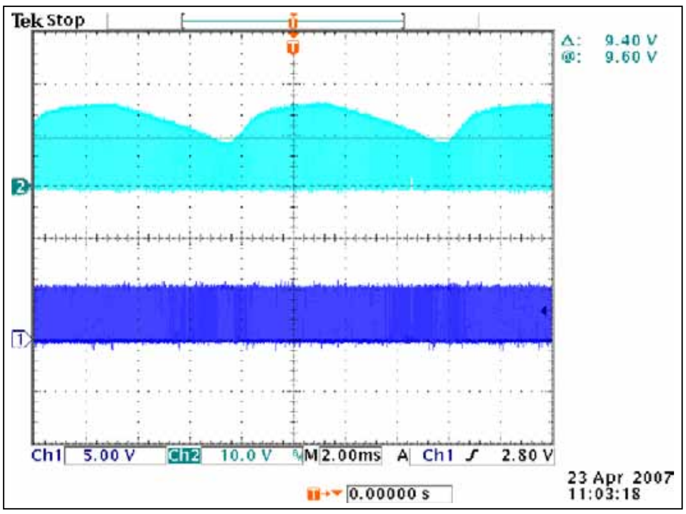


Figure 4. CH1=MOSFET gate drive voltage envelope; CH2=Drain-Source voltage envelope

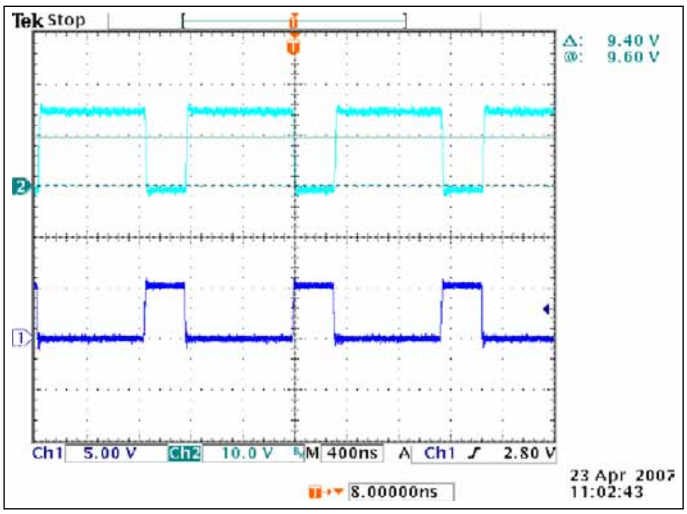


Figure 5. Detailed waveforms: CH1=MOSFET gate driver; CH2= Drain-Source voltage

The MR16 PCB shown in Figure 6 consists of two layers. All components are on the top layer. The bottom layer is just for ground connection. In the board, there are two AC input connection pads and two DC current output connection labeled LED+ and LED- pads.

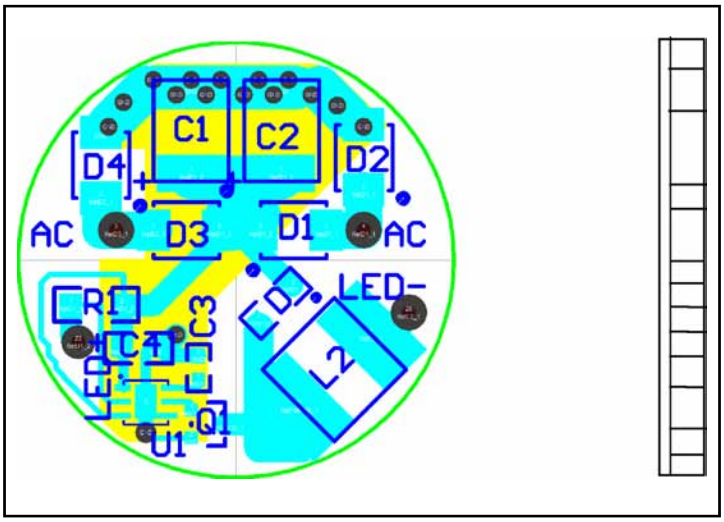


Figure 6. 5W MR16 LED Lamp Driver PCB Board.

In high brightness LED applications, it is recommended to limit the junction temperature of the 5W LedEngin LED to less than 120oC when long term lumen maintenance performances of 90% after 100k hrs is a requirement.. Heat-sinking is a low cost solution to transfer the heat generated in the LED junction to the air. The 5W MR16 LED lamp has a heat-sink to transfer 5W LED power dissipation. 5W MR16 LED lamp driver PCB board is mounted on the back side of the heat-sink of 5W LED.

Noteworthy is the unique MR16 shape like heat sink design of the lamp assembly. Unlike in halogen based assemblies where the lamp heat is primarily radiated to the environment, in LED based designs the heat is conducted to the heat sink (such as the one shown in Figure 7) and then transferred to the surrounding air through convection.

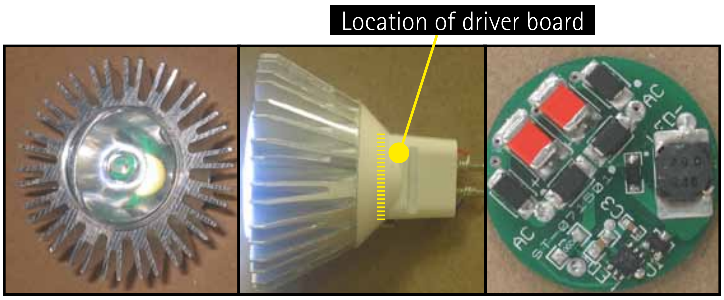


Figure 7. MR16 Lamp and MAX16820 based driver board.

When compared to other lower power LED (1W and 3W LEDs) solutions, the high power MR16 solution with a 5W LedEngin LED in combination with the MAX16820 IC circuit significantly increases the amount of usable light and therefore eliminates the need for multiple emitter solutions to meet the performance levels of a 10W halogen solution. ■

LED Lamps Require Integrated Power Conversion ICs To Meet EMC and Quality Standards

> By Silvestro Fimiani, Power Integrations

Regulatory standards in Europe and America are forcing the replacement of incandescent lamps with by more efficient lighting technologies such as compact fluorescent and LED bulbs. The recent introduction of more efficient high brightness white LEDs (HB LED) has made this approach increasingly attractive. The most meaningful metric when comparing lighting technologies is luminous efficiency, which specifies the amount of light generated in the visible spectrum in lumens per watt of power supplied to the lamp. Incandescent and halogen bulbs are particularly poor in this regard, with efficiency ratings in the 15 to 20 Lm/W range. Compact fluorescent lamps are much better, with a typical value of 50 Lm/W. However, within the past year, HB LEDs have surpassed even this figure and are expected to reach values of up to 150 Lm/W by 2012. In addition to its greater energy efficiency the LED lamp has other significant advantages, including longer operating lifetime and lower operating and maintenance costs. Because of these factors the HB LED lamp is expected to be a significant product for both residential and commercial usage for years to come.

The fastest and easiest way to take advantage of this new lighting technology is through the retrofit market – replacing existing incandescent and halogen bulbs with HB LED lamps. The goal is to integrate both the HB LEDs and their required drive electronics into a standard lamp housing such that it can be installed in an existing socket powered from the AC mains. The drive circuitry, or electronic ballast, provides the functions of line rectification, voltage reduction and generation of a regulated constant current to optimally power the LEDs. Needless to say, the physical space constraints within the confines of the lamp housing create some difficult design challenges.

Incandescent-replacement, retrofit LED lightbulbs have just recently started to be introduced, however they have suffered from several problems. Because it is tricky to fit the LED power driver circuitry into a standard bulb housing, some of these early LED lightbulbs have no internal filtering, so they will not pass EMC standards. Moreover, many of them use an inefficient capacitor dropper power supply rather than a switched-mode regulated ballast. This approach can cause a current unbalance on the AC mains which can create power quality problems in some installations. Both compliance with EMC regulations and power quality are important issues and must be considered.

Recently, Power Integrations introduced its LinkSwitch TN family of power supply ICs in the tiny SO-8 package. This article describes a design for a high performance yet inexpensive electronic ballast for HB LED lamps using this chip that meets EN55022A EMI standards within the space limitations of standard lamp housings.

Design Objectives

This design is intended to power a string of three HB LEDs (the equivalent of a 10W standard incandescent lightbulb) with a nominal current of 300 mA. In normal operation, the output voltage is clamped at about 9.5 Vdc by the forward drop of the series LEDs, but this circuit has a compliance of up to 12 Vdc to allow for variations in diode performance. The topology is a switched-mode constant current offline buck regulator, and is capable of operation over the entire 85 to 265 Vac universal input range and at line frequencies from 47 to 64 Hz. Other objectives include high efficiency, low cost, and compliance to EN55022A EMI requirements. The design can be integrated into a standard lamp housing - either screw-in Edison or bayonet halogen configurations - to allow for convenient retrofit within existing lamps. The design (Reference Design Kit 131), is fully supported with design tools and applications assistance in order to minimize time-to-market for new HB LED lamp products.

EMI Considerations

Power Integrations has found that many LED lightbulb designs on the market do not comply with conducted EMI specifications, due to both space and cost constraints. However, the design in this article takes advantage of the frequency jitter feature integrated into PI's LinkSwitch-TN power conversion IC, which means that a smaller EMI filter can be used. .

Design Details

Power Integrations' LinkSwitch®-TN LNK306DN integrated power conversion IC includes a fully integrated 700 V power MOSFET so that no external power device is required. The offline non-isolated buck topology operates at a maximum frequency of 66 KHz in continuous conduction mode. This frequency is modulated with a 4 kHz peak to peak frequency jitter to simplify the design requirements for the EMI filter. Although in this design a buck topology is used, this IC is also configurable as a buck-boost converter. Crucially, the LinkSwitch®-TN LNK306DN is in the compact SO-8 package - a major benefit to the mechanical design for this application.

The schematic for both converter and EMI filter is shown in Figure 1. The current control loop is set to the desired constant current value based on the voltage drop across the current sensing resistors R8 and R10. While the nominal design is for a current of 300 mA, it can easily accommodate output currents of up to 360 mA. Q1 and Q2 amplify the sensed voltage drop such that a lower resistance current sensing resistor can be used for purposes of minimizing power dissipation. The EMI filter utilizes a pi topology and includes a fusible flameproof resistor, RF1, for overload protection.

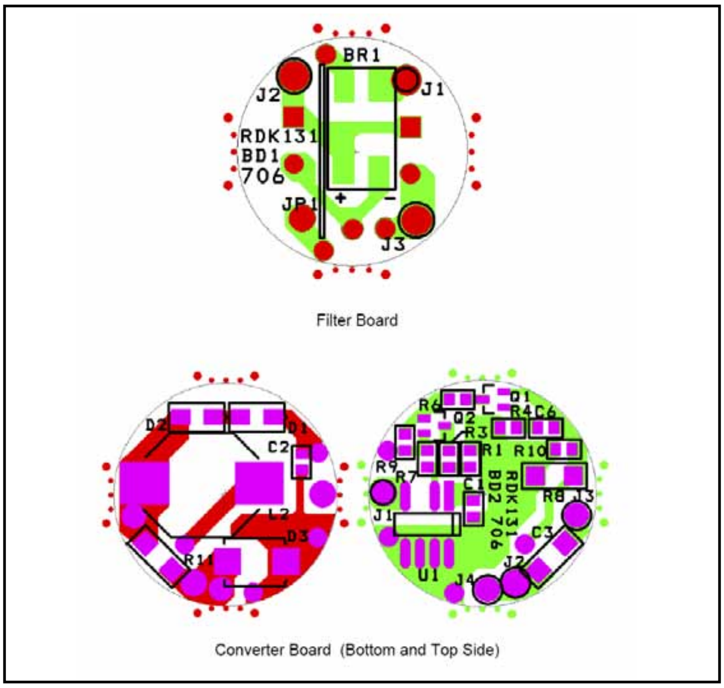


Figure 1. Converter and EMI Filter Schematic.

Only 25 components are required for the design for both converter and EMI filter, exclusive of PCBs and interconnects. A complete parts list for the design can be found in the referenced material.

The electrical design for this application is fairly conventional for this proven power conversion IC. The biggest challenge was the mechanical design, specifically integrating both the converter and the EMI filter into standard lamp housings. However, this design fits comfortably into either a screw-in Edison base (E27) or the bayonet halogen socket (GU 10). (Dimensions for the halogen bayonet socket are shown in Figure 2.)

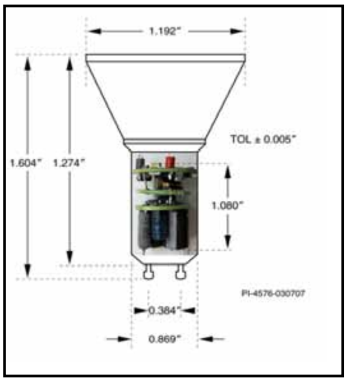


Figure 2. Mechanical Packaging Challenge.

Early on in the design process it became clear that a circular PCB large enough to house all the components for both the converter and the EMI filter would not fit into the lamp socket base. So a decision was made to partition the design onto two circular PCBs, one for the converter circuitry and another for the EMI filter. The final diameter of the converter board is 19.66 mm while the diameter of the EMI filter board is 16.91 mm. These boards were then stacked and interconnected with discrete wires to complete the assembly.

Although this design was functional, there was still a problem with conducted emissions. Because of the proximity of the two PCBs, there was coupling of switching currents from the converter board into the EMI filter board, compromising the performance of the EMI filter. This situation was solved by the inclusion of a 'shielding' PCB between the other two boards. This third board is simply a layer of copper with no circuitry. It is electrically connected to the junction of the negative output of the EMI filter and the negative input to the converter board. The final assembly then consists of a stack of three circular boards. This simple and inexpensive addition solves the coupling problem and results in the EMI performance demanded.

Performance

The reference design meets all of the design objectives. When used with 120 Vac nominal input voltages, the circuit efficiency is over 62 percent. The efficiency is over 56 percent with 220/240 Vac input voltages. Conducted EMI characterization was performed at both 115 Vac and 230 Vac inputs using both quasi-peak and average readings based on the EN55022A limits. The worst case configuration was at 230 Vac input, where the circuit passed with a margin of 7 dB. Margins were higher at 115 Vac input. Additional EMI plots along with waveforms of operation during both normal operation and start-up are included in the referenced test report.

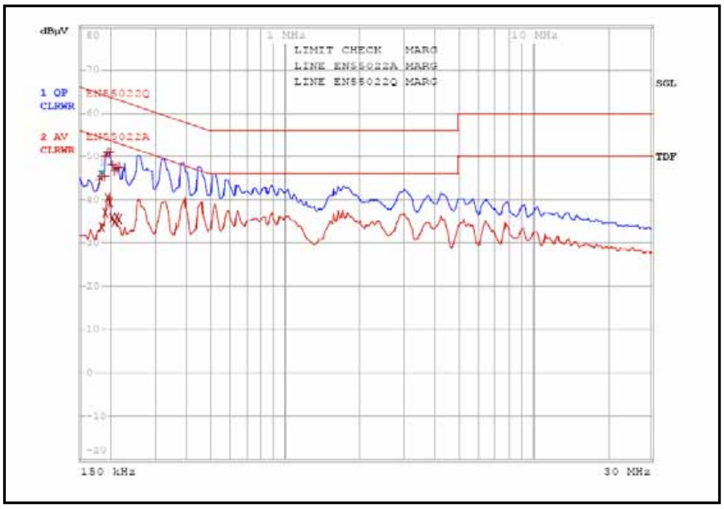


Figure 3. Compliance to EN55022A at Worst Case Input of 230 Vac.

Conclusion

In spite of the physical constraints, therefore, it is perfectly possible to integrate a high performance electronic ballast for a HB LED bulb into a standard lamp housing cost-effectively and still meet EMI and power quality standards. The design is extensively supported with application notes, design tools, and a new LED lighting microsite. The availability of the RDK-131 reference design will allow new HB LED lighting products to be introduced with a fast time-to-market and alleviate the current scarcity of offerings that address important EMI questions. ■

Trends of Engineering System Evolution: S-Curve Analysis

> Siegfried Luger, LED professional

Products at the infancy stage often don't need sophisticated performance analysis, level of inventiveness, number of inventions or profitability to show that they are infants. Similarly, the strategic R&D decisions available to organisations at the infant stage are also usually straightforward; get the product to market and start paying back the R&D expenditure or go out of business. On the other hand, mature products are less easy to categorise and strategic decisions on where to take the business next can be anything but clear-cut. A major strategic decision for companies in relation to a mature product is the perennial optimization versus innovation dilemma.

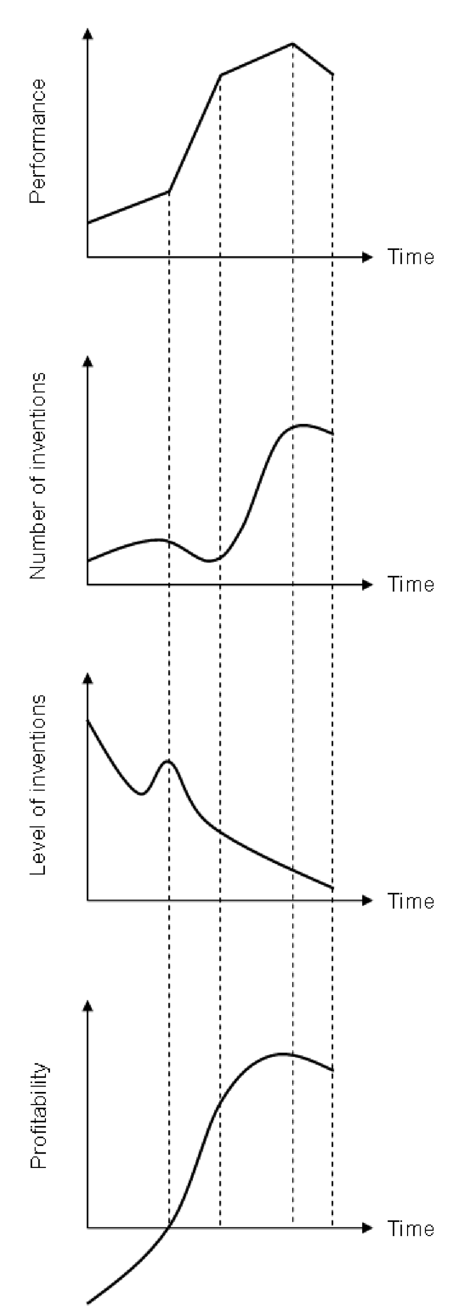
Performance

Performance is often the easiest of the four metrics to obtain data for. Quantified performance data is the main output of R&D programs; the world in which engineers live. The trick in terms of using performance data to establish product maturity is knowing which performance parameters to use in the analysis. The difficulty here lies in the fact that relative importance of different parameters often changes as the product matures. This in turn results from the fact that engineers are usually required to focus on different parameters at different stages in product evolution. Thus a parameter like temperature dependencies was an irrelevance on former low current LED components (where the emphasis was very much on getting increased light-output were considered much more important) and is now, for High-Power Light Emitting Diodes, a predominant performance measure. Parameters related to product efficiency (efficacy) are commonly found to be the most appropriate measures upon which to base performance s-curve analyses. Particular care should be taken when using parameters which hit externally constrained limits. Example – LED development uses 'efficacy values' as one of the most important performance parameters. This is a good metric when the technology is in its infancy and there are difficulties in achieving adequate values. But as soon as the capability reaches the ceiling at which the system is getting inapplicable due to application temperature barriers, the parameter ceases to become relevant.

Number of Inventions

Usually number of inventions is the next easiest s-curve metric to obtain data for. Particularly from on-line patent databases and increasingly effective search engines. The main problem here, however, relates to the eventual relevance of the patents emerging from the search. A search from the US patent database using the word 'LED' will produce several thousand patents, but only a proportion of which will have anything to do with e.g. general lighting. Defining the appropriate key word query is one of the most important issues here but will definitively end up in proper results for the s-curve analysis.

Technology Maturity determination tools



"Lifelines" of Technological Systems

Level of Invention

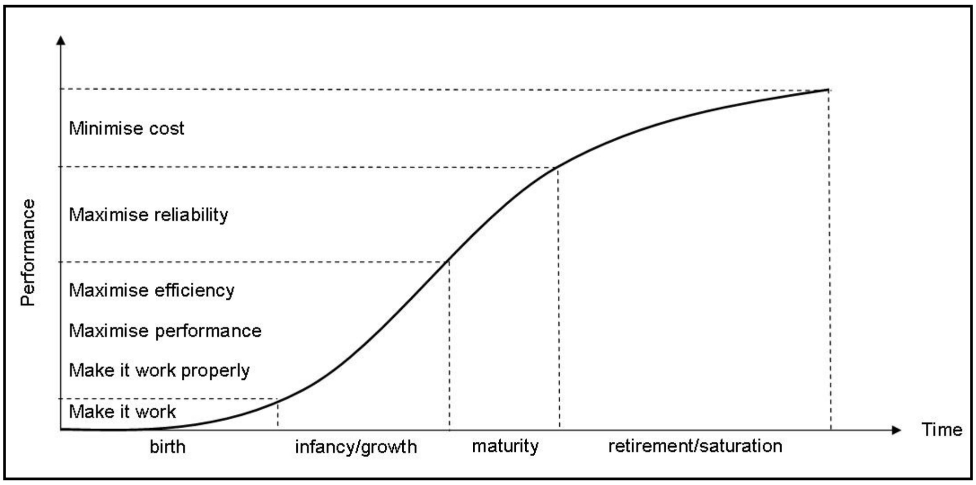
Determination of level of invention using the definitions devised by Altshuller very much relies on a case by case evaluation of patents. It often entails analysis of the detailed patent description (i.e. the abstract is usually inadequate to make the assessment). A level of invention analysis on a product with considerable history and high numbers within the last decade like the LED can be an extremely time consuming process. Every patent is classified into 5 levels of invention ranging from no-invention (level 1) until new-physical-principle (level 5).

Profitability

Probably the most difficult of the four metrics to obtain useful, reliable data for. For a sub-system of a bigger product which in turn forms only a part of a large industry dominated by companies which produce a diverse range of other products – as is the case for a LED system component. Beyond the four metrics discovered by Altshuller, are a number of other methods which may be used to determine the maturity of a given product family. Here is one quick indicator method:

Cost Reduction Related Inventions

Examination of patents relating to product cost reductions can be an effective means of determining the maturity of a product. By 'cost reductions', we mean inventions that relate to make the product cheaper – such as manufacturing technology or method of assembly. Such inventions are relatively easy to spot from examination of patent abstracts and their preponderance increases as product maturity increases.



Performance is saturating over time, passing through well defined quality stages.

FACT BOX

Improve your products with the 40 inventive principles explained for Light Emitting Diodes.

No. 2: Taking Out

A. Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.

- Use fiber optics or a light pipe to separate the hot light source from the location where the light is needed.
- Separate the phosphor from the LED die to reduce the temperature influence.