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May 2010

PSDE Green Power
ENERGY EFFICIENCY

Special Report – Lighting Systems

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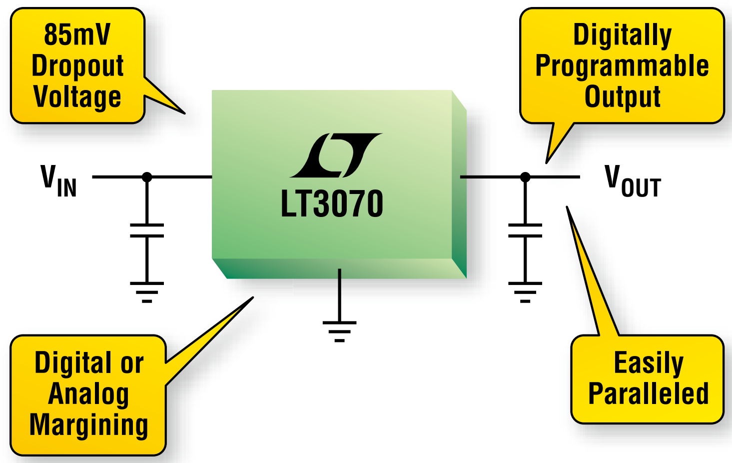

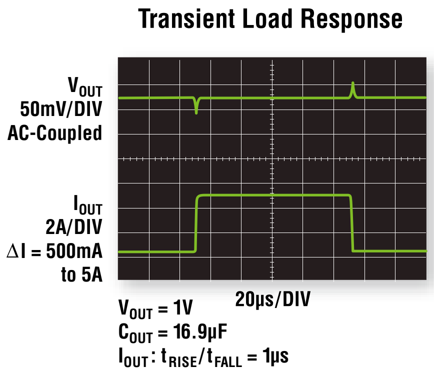

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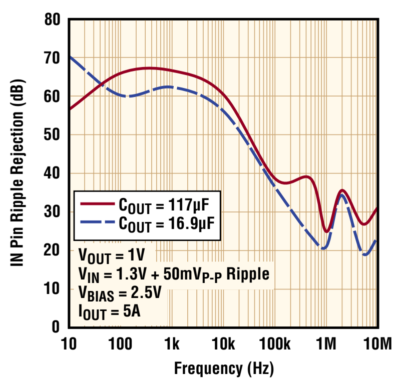

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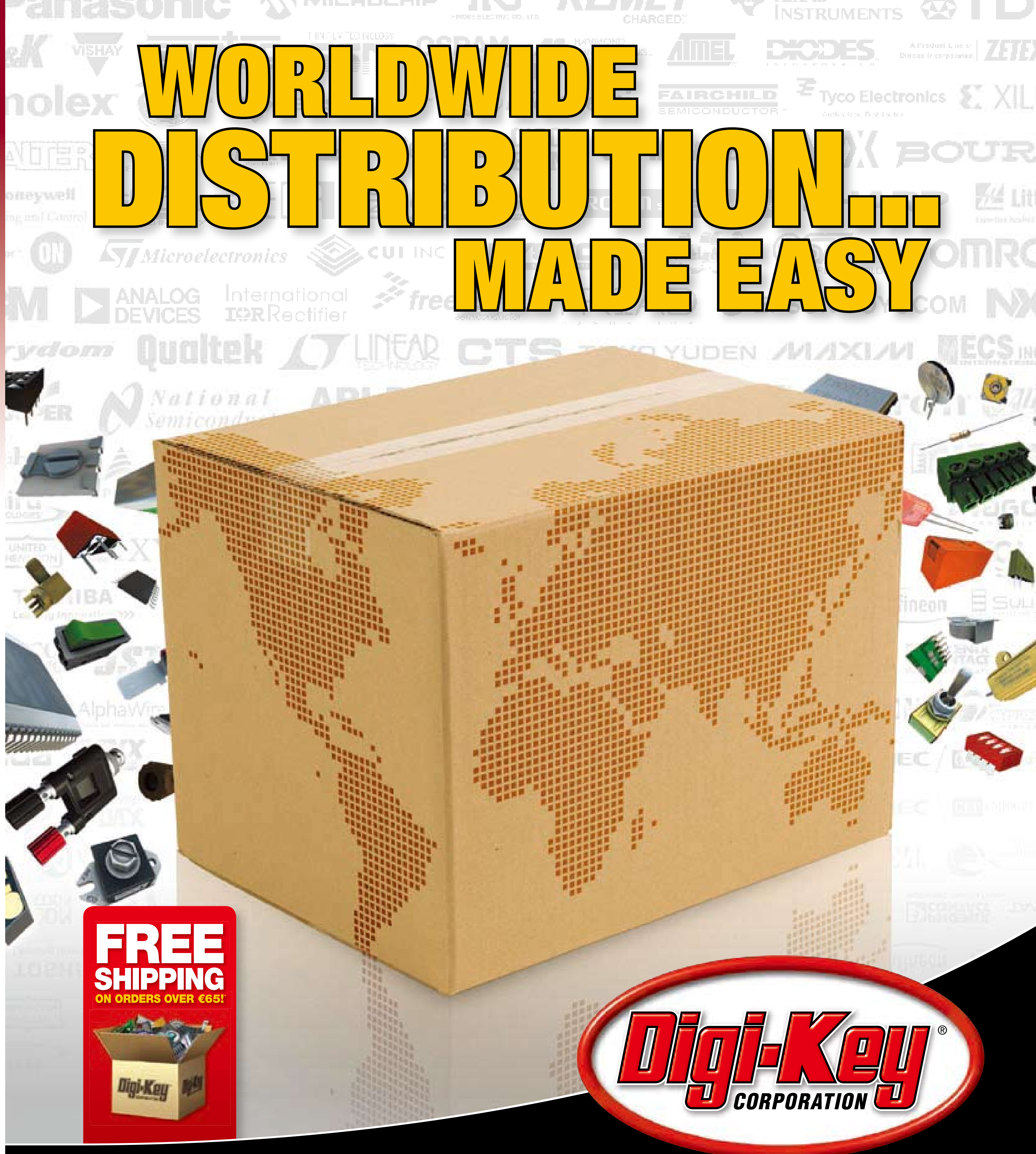

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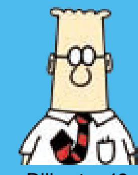

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PSDE Green Power
ENERGY EFFICIENCY

Longevity in Light

With the huge industry interest in Lighting as the topic themed in this issue, I have been amazed at the growth in the industry and hence the submission of a great deal of good quality content for this issue of our magazine since this time last year. Naturally the figure of Lumens per Watt figure for LEDs is getting ever better, but it's not just the LEDs themselves but also the circuits that drive them. We all were agog at the constantly specified lifetime of LEDs, usually in the order of 50,000 hours, but this assumes a well designed fixture with adequate heatsinking and a driver/controller circuit that can drive the device within its electrical and thermal specifications. Early fixtures proved disappointing to many users due to the less-than-perfect driving or mounting of the LED. As always, engineering came a long way in a very short time and solved the problem.

But the area of lighting is not merely confined to LEDs, although this does get the most in terms of media attention. Factories and offices as well as homes will not suddenly switch over to LED illumination overnight. Even though the traditional incandescent light bulb is being phased out by enforced legislation, there are other viable and hi-tech alternatives such as Compact Fluorescent (CFL) technologies to enable high efficiency operation, low cost and higher degree of control, particularly in dimming techniques, than available in the past. The other advantage is that CFL (and traditional incandescent) lighting fixtures throw a more evenly distributed light than their current LED counterparts. (See our MarketWatch report from IMS Research).

You should be able to get yourself updated on exactly what's happening in the area of lighting within the pages of this issue and naturally, if you have a compelling engineering story to tell, send it in to me.

For those who could not attend the PCIM show in Nuremberg, Germany, I covered the event and will prepare a report based on the industry meetings I had with engineering and management. I shall also report on the proceedings of my industry forum at the show titled "Designing for Energy Conservation and Performance". These will appear on our website. www.powersystemsdesign.com

As we work our way through another year and hopefully out of recession, into a period of sustainable growth, I hope we see more university places taken by students of engineering in all its forms. I would guess it depends who they see as role models for their future. It will hopefully be those firms who hunker down, lead and inspire their talented engineering resources to creatively innovate their way out of a recession into a bright future rather than those who hack their staffing to pieces merely to cut down on costs. It all depends on who pulls the strings.

Enjoy the issue, keep your guidance and feedback coming and check out our fun-site, Dilbert.

All the best!

Editor-in-Chief, PSDE
Cliff.Keys@powersystemsdesign.com

Everlight's New 3W Shuen LED Family

Slim package, high power and high luminosity for advanced lighting applications

With the increasing swing to LED lighting, the power industry is seeing a proliferation of new and more efficient devices hitting the market. Adding to the performance and popularity of Everlight's 1W Shuen series High Power LED, with a luminous flux up to 100 lm at 350mA, Everlight Electronics Co., Ltd. Has announced the new 3W Shuen High Power LED with up to 170 lm when driving at 700mA.

Both 1W and 3W Shuen packages are surface-mount high-power devices offering high brightness in a compact and slim form factor, making them suitable for different lighting applications including general illumination, flash, spot, signal, industrial and commercial lighting. The thermal pad of both the 1W and 3W Shuen Series are electrically isolated providing for improved thermal and electrical characteristics. It is well known that the benefits of LED devices are their environmentally friendly nature, energy savings, reliability and long life. All Shuen families exhibit these advantages while providing high efficiency luminous output.

The Shuen series not only offers slim size and high luminosity, but provides customers the flexibility of various CRI (Color Rendering Index) with 75 and 90 depending on their lighting applications. Within the global Solid-State Lighting market, Everlight strives to conform to all environmental initiatives. The Shuen series meets the European Union directives on the Restriction of Hazardous Substances in electronic equipment - namely the RoHS directive. All materials and processes of the Shuen series are free of form lead, mercury, cadmium, hexavalent, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).

Everlight is also promoting closer working relationships between its R&D, Sales and Marketing teams to better meet and exceed its customer's expectations in both product offering and technology perspectives. The Shuen LED series and its many technical features are a result of fostering a closer relationship between these teams.

Features

- Small package with high efficiency
- Typical view angle of 120°
- ESD protection up to 8kV
- Soldering method: SMT
- Binning Parameters: Brightness, Forward Voltage, Wavelength and Chromaticity
- Moisture Sensitivity Level: 1
- RoHS compliant
- Matches ANSI binning
- Electrically isolated thermal pad

Applications

- General Lighting
- Decorative and Entertainment Lighting
- Commercial Lighting
- Industrial Lighting
- Signal and Symbol Luminaries

Mass production is scheduled for the second quarter of 2010

www.everlight.com

The World Needs Higher Efficacy! But what else?

By Werner Berns, Manager PowerWise® Design Lab Europe, National Semiconductor

The energy consumption of general lighting represents a significant portion of the worldwide energy demand. It's about 8% of the total and thus has its related contribution to global warming. Well, assuming that the scientists are correct with the global warming forecast in general. But that's a different story. If there is a problem, we should work on it, now.

Solid State Lighting

In the not too distant future, solid state lighting (SSL) will become the predominant light source for general illumination. But why will this happen? There is no doubt that incandescent light has very poor efficacy vs. SSL, but is at very low cost. Legislation took the first steps to ban those lamps and one does not need to be a prophet to forecast the death of this old-fashioned light source.

With regard to fluorescent light, the situation is a little different. Today, the efficacy of SSL is about the same as that of a fluorescent light source. So where is the advantage? There are many: longer lifetime, better colour management, less toxic "ingredients", easier to dim, instantly to the desired brightness, just to mention a few. There is at least one more very important advantage that will outperform the fluorescent light by far: The amazing efficacy potential of SSL technology.

It took 40 years to increase the efficacy of fluorescent lamps, from less than 75 lm/W (lumens per Watt) to around 100 lm/W. SSL light source manufacturers are in a breathtaking race for ever higher efficacy limits. The race started just a few years ago and recently we heard the 200 lm/W barrier was breached. New records are seen every few months. How long will it take

to achieve 300 lm/W? When will we see 400?

Beyond Efficacy

There is more than "just" efficacy. What else can we do? The answer is simpler than one may think: provide light, only when we need it, only where we need it, and only how much we need, not more.

So the overall light efficiency depends on these elements:

o Source efficacy (the SSL device itself)

o Power supply efficiency (LED drivers)

o Fixture efficacy (reflector, lens, etc.)

o Light distribution efficiency (where)

o 'Light provided' vs. 'light needed' efficiency (when and how much)

As a semiconductor supplier, National Semiconductor provides a wide range of energy-efficient PowerWise® LED drivers, and continuously strives to increase the efficiency of the SSL power supply. When, where, and how much are the additional questions we need to ask ourselves. By answering these questions and finding intelligent solutions to solve the challenges involved, we will discover huge additional possibilities for energy savings. These intelligent solutions are not very common today, but carry a great business potential.

Overall Efficiency

Let us look at the overall efficiency of a parking garage. What is the efficiency of its light sources on the 5th floor of a parking garage at 3AM with not a single person being around? What is the resulting efficiency if we provide x-times more light than necessary? And what's the light efficiency when there is so much ambient light that no one can tell that it is on? Of course, it's not a simple task to manage the light in such a complex environment. Furthermore, if a fluorescent light were to be switched on and off frequently, depending on the type of ballast, the lifetime would be negatively impacted. So, better that we leave it on all the time! SSL sources do not have this negative effect. Also, when they are off, their lifetime extends. This is a perfect example demonstrating the need for light management systems that keep our lives easy and comfortable but save energy as much as possible.

Conclusion

National Semiconductor continues to work on increasing efficiency/efficacy of SSL lighting solutions. The next step in front of us is to install wise (PowerWise ®) light management technologies everywhere. Remember the garage example above. Because a lamp that is not ON, saves the most energy.

www.national.com

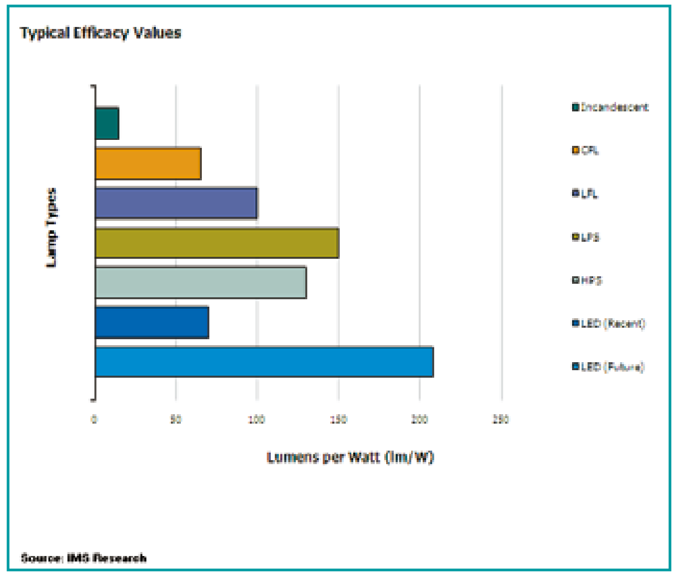
LEDs Are Straight Shooters (But That's Not Always Good)

By Kevin Furr, Senior Research Analyst, IMS Research

Lighting trade shows are shining a spotlight on the bright future of LEDs. Technology has now elevated LEDs to the point where they can take on the marquis role in light-emission – general illumination, lighting up our offices and streets and homes. Recent trade shows might lead an attendee to believe there is no other source of light, with supplier booths hawking almost nothing else but LED-based lamps and luminaires.

Like yesterday's cause célèbre – the compact fluorescent lamp – new LED-based lighting promises huge dividends in energy savings and longer life. But also as with CFLs, LED lighting leaves something to be desired in some lighting applications. For all its promise, LED may not be embraced in key everyday lighting applications we take for granted. The core problem is directionality – a filament bulb casts light in every direction, but an LED emitter projects light only in one.

That trait makes LED-based lamps a good fit for highly directional applications – recessed lighting, accent lighting, retail downlighting, street lighting. Indeed roadway lighting has proved to be an early target for LED conversion, with LEDs putting out no stray lumens above the horizon – and so not polluting the night skies. In terms of indoor products, the first against the wall in the LED revolution are likely halogen MR and PAR lamps.



But LED lighting is a more debatable replacement for common A-19 bulbs and linear fluorescent tubes. A public accustomed to omnidirectional output lighting up all corners of a room may find the directionality of an LED device limiting and off-putting. Lamps designed with an array of emitters facing a variety of directions are not yet satisfying replacements for the incumbent technologies – and packing so many emitters into such a small space challenges the device's thermal management.

Not so debatable is the potential energy savings from LEDs, a technology that's rapidly improving. A key metric in the lighting world is efficacy, or lumens-per-Watt. Current LED lamps have been clocking in about 70 lm/W, but the emitter efficacy record in the lab has reached 208 lm/W – recently announced by Cree. We may not see that number for a few years in LED-based lamps on the market, but LED products should soon pass the 100 lm/W we see with T-8 or T-5 fluorescent tubes.

Bringing that kind of efficiency to as wide a market as possible may require us to solve the problem of diffusion: clever advancements may yet enable a pleasing and useful omnidirectional diffusion of LED emission.

A second approach is to rethink lighting design, tapping LEDs to put light where needed but with a design users can accept. Omnidirectional filament-bulbs, after all, cast lumens where they are not really needed – in the end, designing replacement LED bulbs for the installed based of sockets may not be the most effective use of LED technology.

www.imsresearch.com

DESIGN TIPS

Power Supply Development Diary Part III

Introduction

This article continues the series in which Dr. Ridley documents the processes involved in getting a power supply from the initial design to the full-power prototype. In part III, initial power is applied to the circuit with a resistive load to verify proper operation of the primary circuitry.

Power Supply Testing with Analog Controller

In the previous article of this series, several problems were found on the control board prior to applying power to the input. The first important lesson was that trying to debug a digital controller at the same time as trying to debug a power stage was not a reasonable approach. The digital controller was replaced with a standard analog controller in order to debug the power stage while minimizing the number of variables.

After several years of power supply design, you become quickly aware that you cannot "breadboard" designs with proto-boards and long wires. Critical noise-sensitive areas MUST be laid out on a PCB to provide minimal path lengths for high frequency connections, and ground planes for shielding. In all projects, you want to minimize the development times. Decisions must be made about whether to stop testing and return to board layout, or provide compromise interim solutions in order to collect data as quickly as possible. One trick I have used frequently is to build power supply test circuits from a collection of previously-designed printed-circuit boards. For this project, a control circuit containing a 3825 controller was cut out of a large PC

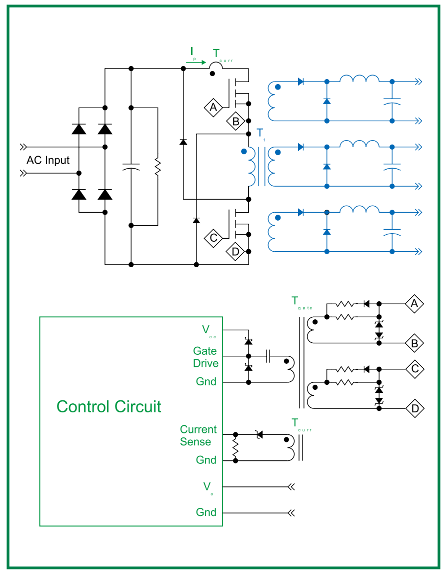


Figure 1: Power stage and control interface schematic. Snubbers are omitted for clarity. The power transformer and secondary circuits are highlighted in blue – these will be removed for initial power stage testing.

board, and connected to the power circuit after removing the digital controller parts. This allowed testing to continue after just a few hours work.

Applying Bulk Power to the Circuit

The schematic of the power stage is shown in Figure 1, together with the signals for interfacing with the control circuit. Snubbers are omitted from Figure 1 for clarity. (This circuit was shown in full in the previous article in this magazine [1].)

After testing the gate drive waveforms, and correcting circuit problems in part II of this article, power was applied to the circuit. There are a couple of choices for doing this, one of which is to use a DC bench power supply to apply a fixed voltage. Such a supply must be capable of providing high voltages, up to 400 VDC, and high currents in order to operate at low line and full load. For a 350 W design, a 1 kW bench supply is typically needed, which is expensive, bulky, and potentially hazardous.

I always prefer working directly from an AC source at the very beginning of a project. This will often bring out problems with the AC connections that you do not want to delay finding until later in the project. An isolated AC source provides a good compromise of safety and instrumentation options, as discussed in [2].

Figure 2 shows the circuit for the initial power testing. The transformer of the power supply was removed, and replaced with a power resistor. This allows us to test the following elements of the power supply:

- Instrumentation connections and grounding
- Gate drive waveforms with voltage applied to FET
- Turn-on thresholds and gate drive levels
- Current sensing circuits
- FET operation with voltage applied

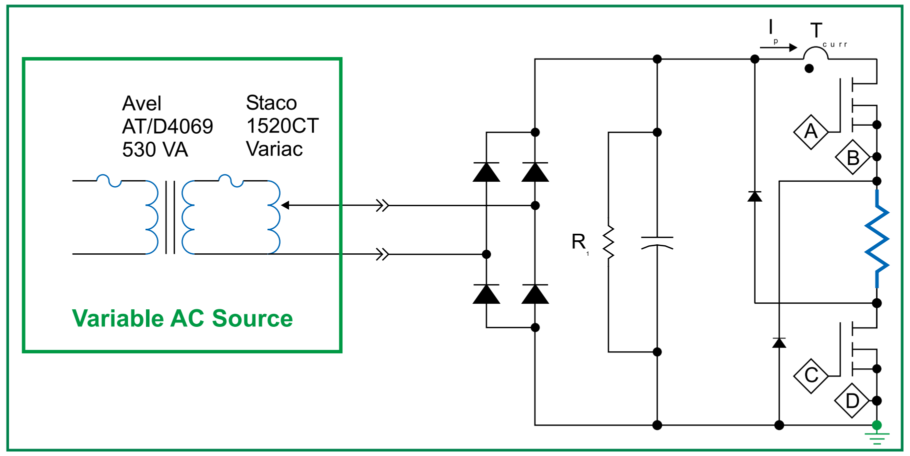


Figure 2: Power stage schematic with transformer and secondaries replaced with a test resistor.

The resistive testing of Figure 2 is something that I always do during the initial test phase of a power supply, regardless of the topology. There are simply too many variables involved when adding all of the magnetics and secondary elements to be able to initially verify that primary switching is operating properly.

Removable Magnetics

I have learned over the years that simple removal and replacement of magnetics is essential for rapid development. Regardless of the power level and topology used, it is highly likely that you will try multiple different versions of magnetics during the development process in order to optimize the design. If the parts can be quickly changed, this saves a lot of time and wear-and-tear on the PCB.

Figure 3 shows sockets inserted into a circuit board, ready for a transformer to be plugged in. Rugged sockets are available that provide solid connections with high current-carrying capability. The Mil-max sockets shown can be used for up to 10A for testing. (Once the magnetics design is finalized, you can always add solder to the sockets to improve measured efficiency.) These particular sockets can also be used for plugging in test resistors.

For higher current applications, you can use PCB inserts that allow you to bolt foil and bus-bar terminations to the board with very low connection resistance on the secondary, and still use sockets on the primary where

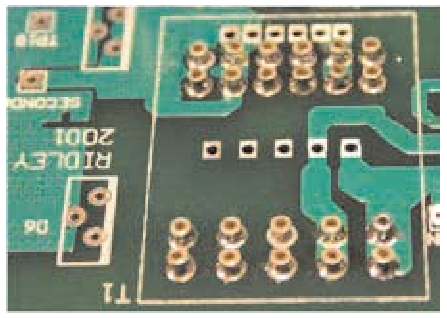


Figure 3: Socketed magnetics speed up the development process and allow fast iterations in the design.

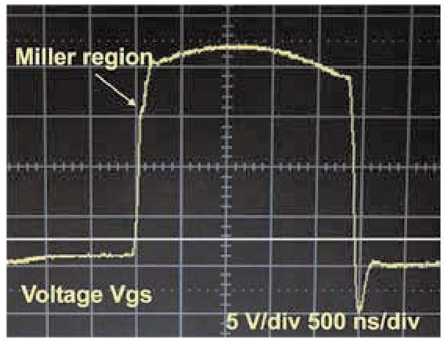


Figure 4: Gate drive waveform with resistive load of 160 Ohms. Note the Miller threshold region showing the switching level.

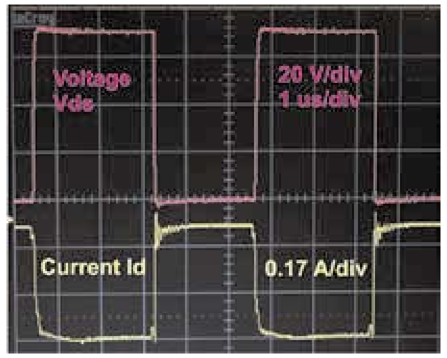


Figure 5: FET voltage and current waveforms. The current waveform is observed using the current transformer circuit.

currents are lower.

Initial Resistive Power Testing Waveforms

Figure 4 shows the gate drive waveform with voltage applied to the power stage. The waveform is almost the same as that without voltage applied, with the exception of the small region of switching due to the Miller threshold event. Once the FET begins switching, the drain voltage must fall, and the gate drive must provide current to charge the gate-to-drain capacitance.

The Miller threshold region of the waveform is very useful for identifying at which voltage the FET is actually switching. There should be plenty of drive available to provide several volts in excess of this threshold to ensure that the FET is turned fully on. For a transformer-coupled gate drive, the minimum voltage is applied at maximum duty cycle, which is shown in Figure 4.

Figure 5 shows the voltage and current waveforms of the FET. With a resistive load, both waveforms are close to square waves. It is always good to check the current sense network output under these conditions to make sure the protection is going to be available when the magnetics and secondaries are connected.

Using a resistive load of 160 ohms, the power supply was tested at up to 100 V dc input. This voltage was increased to 160 V with a 27 k resistor. Further testing could also be done at full input line voltages, taking care not to exceed the power dissipation capacity of the loading resistor. It is worthwhile doing this high-voltage testing with a resistor since it will show any voltage breakdown problems that may occur.

Failures and Build Errors Found

Event #6 Shorted Control Board Connection

After connecting the analog control board to the main power stage, control chip overheating was discovered, and several chips had to be replaced. The root cause was traced back to a washer shorting a PCB pad to ground. Mechanical shorts are common events in power supply construction. It is only when you assemble all the three dimensional parts that some mechanical clearance problems become apparent in a circuit. I have seen this kind of problem numerous times over the years at all different stages of production.

Event #7 Current Transformer Wired Backwards

When power was applied to the circuit, the initial current waveform was missing from the current transformer network. The root cause of this was traced to a wrong-polarity connection of the primary of the transformer. This may seem like a rudimentary error, but it is very common during the prototype and pre-production phase of design to have a polarity error in the custom magnetics designs.

Event #8 Input Capacitor Bleed Resistor Omitted

Very few papers talking about topologies discuss the need for the resistor R1 in Figure 1. This resistor is intended to discharge the input capacitor once the power supply is turned off. It is often tempting to omit the resistor since it increases dissipation and lowers the efficiency of the power stage. However, once you start testing, and you encounter failures, the value of the resistor soon becomes apparent. Holding a soldering iron in your hand, and confronting a capacitor charged to several hundred volts is not a desirable situation.

Make sure you put this resistor on your circuit for the development stage, even if you intend to remove it later on if you have a control chip that claims to provide the discharge path. If the control chip fails, you want to be sure that the input capacitor is fully discharged before working on the circuit.

Summary

Initial power should be applied to your power circuit with the transformer and secondaries disconnected, and replaced with a power resistor. This allows you to ensure that your ac source and instrumentation are properly connected, and that gate drives, current sensing, and other primary circuits are working properly before starting to deal with the complexities of magnetic design.

Magnetics should always be easy to remove from the circuit in order to try different designs later in your development process. In this article, socketed magnetics allowed the easy substitution of a resistor for initial testing.

In the next article of this series, the magnetics will be placed into the circuit.

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1. "Power Supply Development Diary Part II", Ray Ridley, Power Systems Design Magazine, April 2010.
2. "Testing Offline Power Supplies", Ray Ridley, Power Systems Design Magazine, January/February 2010.
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www.ridleyengineering.com

On the Road

Reported by Cliff Keys, Editor-in-Chief, PSDE

Bridgelux & Molex

I participated in the press conference for this new partnership between Molex and Bridgelux to create the industry's most cost-competitive, interchangeable and upgradeable Solid State lighting solution

Lighting Solutions Get Easier

Helieon™ LED light module to displace traditional lighting with plug-and-play solution - as simple to use as a light bulb

Bridgelux and Molex Incorporated have introduced the first LED lighting solution designed and priced to drive rapid, mass market adoption of LED lighting technology. The new Helieon™ Sustainable Light Module combines industry-leading solid state lighting technology from Bridgelux with innovative, easy-to-use interconnect technology from Molex, delivering to interior and exterior luminaire manufacturers effortless installation, interchangeability and upgradeability.

At a volume price point at less than $20 per unit* and a lifespan of more than 10 years**, Helieon is one of the industry's highest quality, most cost-effective solid state lighting solutions, and it will change the way LED lighting solutions are used. Helieon also helps lighting manufacturers reduce energy costs and environmental waste for a sustainably designed lighting environment.

"Helieon will quickly debunk the myth that solid state lighting isn't ready for mass adoption," said Mark Swoboda, President of Bridgelux. "Providing high quality light and an easy and familiar installation experience at a price point to enable mass adoption, Helieon delivers on the promise of solid state lighting. With Helieon, solid state lighting is poised to displace conventional incandescent, fluorescent and other technologies in many high-volume general lighting applications, creating a $100 billion market opportunity. Together, Bridgelux and Molex are creating a new, massive market segment for solid state lighting."

Bridgelux and Molex to break the LED lighting mould by developing and building products designed to meet specific lighting applications and market needs

Bridgelux and Molex Collaborate for Innovation

Bridgelux and Molex, both leaders in their respective industries, joined forces to create a best-in-class and price disruptive solid state light module comprised of completely recyclable components. Helieon combines LED Array products from Bridgelux with Molex interconnect technology to create a socketed plug-and-play solution that can be easily integrated into a wide variety of luminaires. The separable source and socket system emulates a traditional bulb and socket, allowing manufacturers to deliver a variety of lighting effects from a single luminaire design. Initial product offerings include between 500 and 1,500 lumens in 3000K warm white or 4100K neutral white, combined with precision optics to deliver narrow, medium or wide flood beam angles. The product's simple, adaptable design, high performance and competitive price point give lamp and luminaire manufacturers unprecedented flexibility and opportunities in design and marketing.

The Bridgelux Arrays used in the Helieon Sustainable Light Module deliver between 500 and 1,500 operational lumens (performance comparable to or

Mike Picini, Vice President of solid state lighting, Molex Incorporated

Mark Swoboda, President, Bridgelux Incorporated

greater than 40 to 75 Watt incandescent bulbs) in a compact high flux density light source. These integrated solutions deliver high quality light without pixilation, closely replicating the beam quality of traditional light sources. Patented Bridgelux technology enables an industry-leading thermal resistance with exceptional brightness and colour uniformity. Helieon combines the Bridgelux LED Array with a precision beam control optic to further simplify the design process for the luminaire manufacturer and enable high quality lighting.

The Molex interconnect technology provides a remarkably easy and familiar installation experience, simplifying the design effort and allowing luminaire designers, commercial end-users and consumers to upgrade, interchange, and replace modules, altering and controlling their environment as desired. Leading the industry in defining and driving an interconnect standard, the Molex patented design can adapt to a wide range of fixture configurations.

"Helieon represents the commitment of Bridgelux and Molex to break the LED lighting mould by developing and building products designed to meet specific lighting applications and market needs," said Mike Picini, vice president of solid state lighting, Molex Incorporated. "The availability of high quality, plug-and-play, flexible, and cost-effective solid state lighting solutions such as Helieon, delivers on the promise to simplify and enable LED integration for OEM fixture makers and critical players in the transformation of the lighting industry."

Product Availability

Helieon will be available for production shipments in May. The product carries a three year warranty and provides the efficacy to enable luminaires to meet Energy Star, Title 24, Part L and other global regulatory standards. Helieon is RoHS compliant, and the companies are in the process of securing UL recognition to further simplify the design and customer acceptance process.

For more information, please visit

www.helieon.com

Inductors for Illumination

Picking the right L for your LED driver

A wide variety of driver circuits is needed to support new LED applications and the demands for high performance are challenging designers to be as creative as possible with new circuit techniques. In order to fully optimize the new circuits, a strong understanding of component performance is necessary. In particular, inductor selection remains a key part of the design process and with the right tools, identifying the best inductor can be one of the most fruitful areas for optimizing LED driver circuits, and with power converters for all applications.

By Len Crane, Director - Technical Marketing, Coilcraft, Cary, IL, USA

LED Applications

For DC-DC LED drivers there are uses for buck, boost, buck-boost and SEPIC topologies. There are some requirements particular to driving LEDs, such as the need for a constant current source. In addition, many drivers use pulsed outputs for dimming capability, as well as to achieve higher efficiency, taking advantage of the phenomenon that the human eye does not perceive flicker above a certain frequency. Yet for all the variations, there are many commonalities among inductor based LED driver circuits. Whether they drive a single LED or a string, whether they have dimming capability or not, the essential inductor operation will be a function of the switching frequency, load current, and the input to output voltage ratio. These inputs feed the basic inductor relationship common to all DC-DC converters that is V = L x (di/dt). This relationship, along with different mechanical requirements will determine the type of inductor chosen. It is easy to imagine, for example, that the space constraints may be much different for a high brightness LED flashlight than for an LCD display backlight.

Inductor Specifics

Understanding the tradeoff between inductor size, performance, and cost, begins with a brief review of inductor operating principles. It can be shown that these basic principles translate directly from inductor performance to the data sheet specifications that designers must use to choose between components.

The design task for a power inductor is to maximize the inductance (L) and saturation current (Isat) product, otherwise known as volt-seconds, while at the same time minimizing the losses.

$$L = 4\pi\mu \frac{N^2 A_e}{l_e} \times 10^{-9} H$$

Figure 1

The formula in figure 1 shows that inductance is determined by a combination of material properties and geometry.

The permeability (μ), is a specific property of the chosen core material, whereas the effective cross-sectional area a_e ae and the effective magnetic path length l_e, describe the core geometry. It is important to note that while it seems obvious that a larger core cross-section increases the inductance, it is a little more counterintuitive that a larger le decreases the inductance. This would be the case in a larger l_e diameter toroid core, for example.

As shown in figure 2 we can describe the saturation current in terms of the same physical parameters as the inductance.

$$Isat = \frac{Bsat \times l_e}{\mu\,(0.4\pi N)}$$

Figure 2

Similar to the inductance, the saturation current (or volt-seconds) depends on geometry (l_e) as well as material properties, namely the saturation flux density (Bsat) and the relative permeability (μ). Note that Isat is inversely proportional to the permeability, directly opposite the effect it has on inductance. As this suggests, optimizing the inductance value and optimizing the saturation current rating will be in conflict with each other.

The Isat becomes the specification for how much peak current the inductor must be rated. The average current rating, on the other hand is loss dependent. To completely understand inductor loss, such phenomena as skin effect, core loss, and other frequency-dependent losses must be considered, but a good starting point is to consider the DC resistance (DCR). We commonly

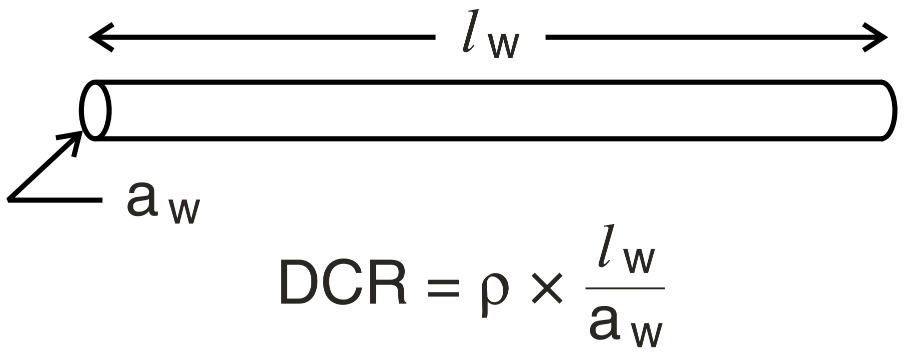


Figure 3

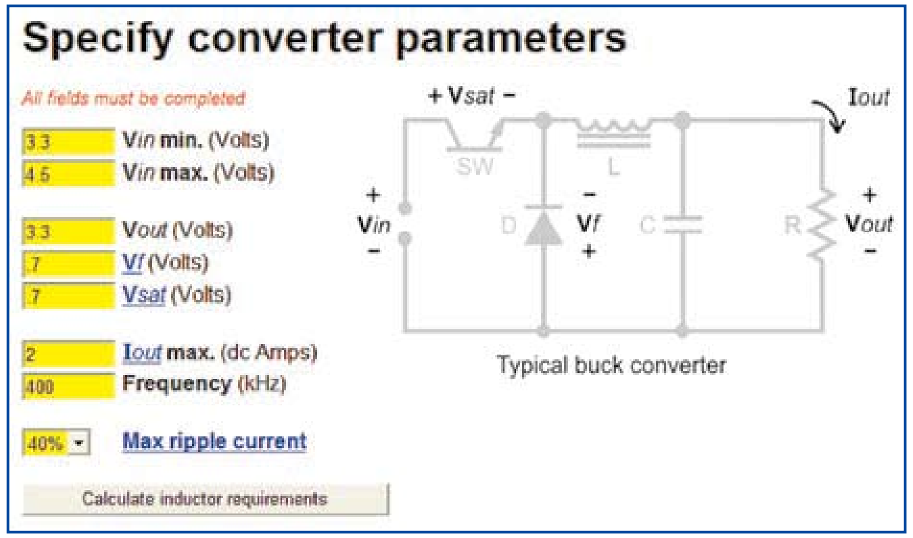


Figure 4

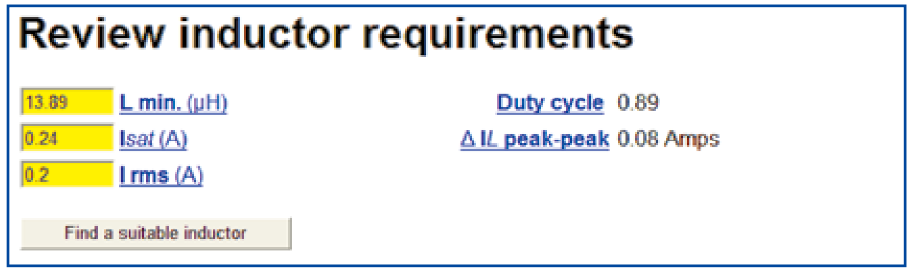
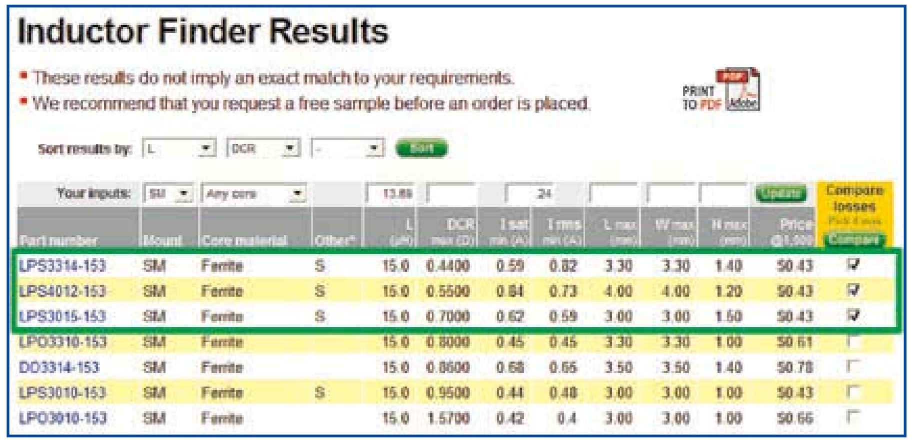


Figure 5


Inductor Finder Results

- These results do not imply an exact match to your requirements.
- We recommend that you request a free sample before an order is placed.

PRINT TO PDF

Sort results by: L | DCR | - | Sort

Your inputs: SM | Any core | 13.89 | 24 | Update

Part number	Mount	Core material	Other*	L (µH)	DCR max (Ω)	I sat min (A)	I rms min (A)	L max (mm)	W max (mm)	H max (mm)	Price @1,000	Compare losses
LPS3314-153	SM	Ferrite	S	15.0	0.4400	0.59	0.82	3.30	3.30	1.40	$0.43	☑
LPS4012-153	SM	Ferrite	S	15.0	0.5500	0.84	0.73	4.00	4.00	1.20	$0.43	☑
LPS3015-153	SM	Ferrite	S	15.0	0.7000	0.62	0.59	3.00	3.00	1.50	$0.43	☑
LPO3310-153	SM	Ferrite		15.0	0.8000	0.45	0.45	3.30	3.30	1.00	$0.61	☐
DO3314-153	SM	Ferrite		15.0	0.8600	0.68	0.65	3.50	3.50	1.40	$0.78	☐
LPS3010-153	SM	Ferrite	S	15.0	0.9500	0.44	0.48	3.00	3.00	1.00	$0.43	☐
LPO3010-153	SM	Ferrite		15.0	1.5700	0.42	0.4	3.00	3.00	1.00	$0.66	☐

Figure 6

think of this as a single value found in a wire table, but it too is a function of both material property and geometry. The material property is the resistivity (ρ), and the length and cross-section of the winding wire are the geometric dimensions.

The DCR, Isat, and L equations demonstrate that these properties correlate differently to the same physical parameters, presenting a challenge to optimize for all three properties. For example, increasing the core cross-section will increase the L and Isat, but detrimentally increase the DCR. Increasing the core permeability will correspondingly increase the inductance and reduce DCR, but conversely Isat will be decreased. The end result is that any design must be a combination of these factors and no one design will provide optimization in all parameters. It is key, therefore, that the designer have access to selection tools that identify the combination of parameters best suited to a particular application. Those tools should include clearly defined specifications and some method for sorting/finding an inductor that best fits those specifications.

Buck Regulator Example

To demonstrate how the required circuit performance can be translated in to the necessary inductor specifications for inductance, peak current, and average current ratings, consider the example of driving a single white LED at .2A drive current and forward voltage of 3.3V, from a Li ion cell over the range of 3.3V to 4.5V. Further, as is typical for a portable device, assume the footprint and component height are limited.

Vin = 3.3 to 4.5VDC
Vo = 3.3VDC
Io = .2A
F = 400kHz
Z = 1.5mm max.
X x Y = 4mm x 4mm max.

For this voltage step-down application, the required input for calculating inductor parameters for a buck converter is shown highlighted in figure 4.

This information and V = L x (di/dt) is all that is required to calculate the required L value, along with peak current (Isat) and the average current (Irms) inductor ratings. Figure 5 shows the result for this example.

The inductance calculation is based on the amount of inductance required to minimize the desired output ripple current and maintain continuous current conduction in the inductor. The effective output voltage ripple is a result of the current ripple times the ESR of the output filter capacitor. In general, the ripple for LED drivers does not have to be as low as for many other applications.

The Isat specification shows the minimum peak current rating the inductor must have in order to insure against core saturation, otherwise when saturated the inductance will drop and the converter operation will not be as expected. The Irms rating indicates the average current that will flow through the inductor, which in the buck converter is the same as the average load current.

The peak-peak ripple current included in the calculations, will be needed later for calculation of frequency dependent losses.

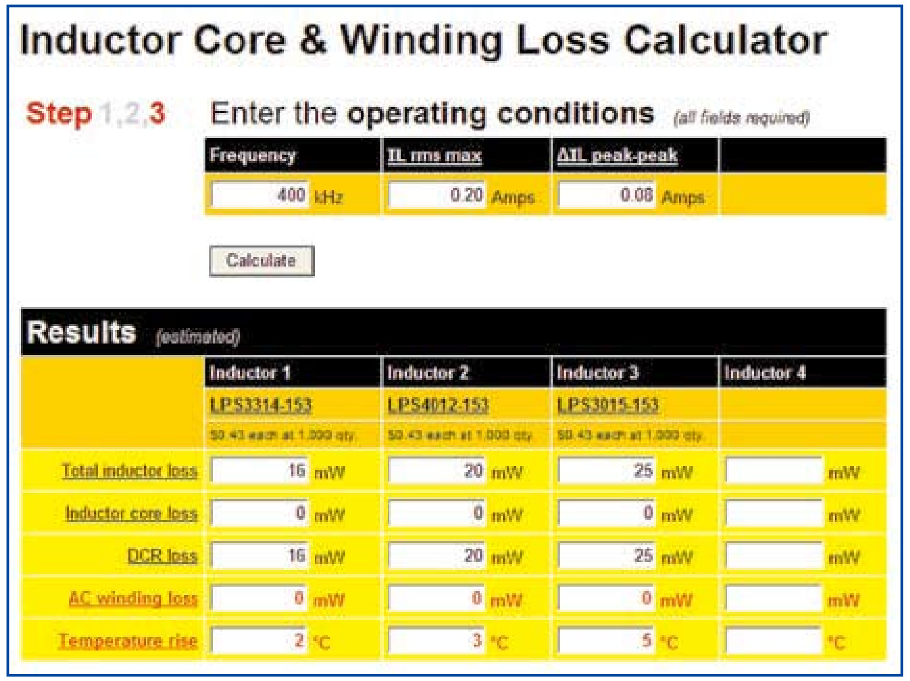
The inductor specifications having been determined, the next step is to identify a real component that meets these requirements. Based on the L and current specifications, and the physical size constraints, the Coilcraft Inductor Finder tool returns a list of suitable inductors.

Having multiple options is necessary to make an optimal match for the application. Consider the first three choices. All three parts meet the requirements. The footprint dimensions range from 3.3mm to 4.0mm and the heights are 1.2mm, 1.4mm, and 1.5mm. One could certainly make a selection based on the size, if that is most important for the application. If component height is most important, then the LPS4012-153 is the best choice, whereas the LPS3015-153 is the winner if saving printed circuit board space is more important.

Assuming all of these sizes are acceptable, there are other considerations. Many LED applications are developed specifically for the purpose of saving energy, so choosing the component with the best average power loss is an important consideration. Of the three parts, the DCR ranges from .44Ω to .70Ω, certainly a wide swing that would suggest LPS3314-153 as the choice for most efficient operation.

Conversely, for many converter designs it is desired to have extra Isat rating in order to accommodate load surges or short circuit conditions, which would place greater emphasis on finding the inductor with the highest Isat rating.

There are more opportunities for optimization beyond the values shown in the table. One of the most common decisions to be considered for any dc-dc converter including LED drivers is switching frequency, balancing the smaller component size enabled by high frequency against the generally better efficiency at lower frequency. The Coilcraft Core and Winding Loss Calculator gives a quick and easy way to judge the potential performance gain at different


Inductor Core & Winding Loss Calculator

Step 1,2,3 Enter the operating conditions (all fields required)

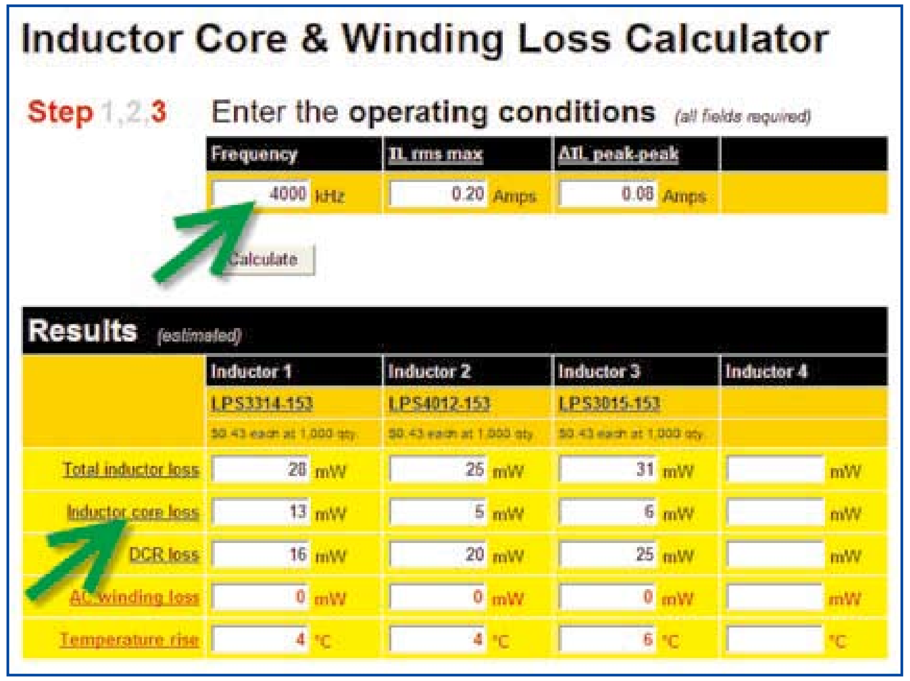
Frequency	IL rms max	ΔIL peak-peak
400 kHz	0.20 Amps	0.08 Amps

Calculate

Results (estimated)

	Inductor 1	Inductor 2	Inductor 3	Inductor 4
	LPS3314-153	LPS4012-153	LPS3015-153	
	$0.43 each at 1,000 qty	$0.43 each at 1,000 qty	$0.43 each at 1,000 qty	
Total inductor loss	16 mW	20 mW	25 mW	mW
Inductor core loss	0 mW	0 mW	0 mW	mW
DCR loss	16 mW	20 mW	25 mW	mW
AC winding loss	0 mW	0 mW	0 mW	mW
Temperature rise	2 °C	3 °C	5 °C	°C

Figure 7


Inductor Core & Winding Loss Calculator

Step 1,2,3 Enter the operating conditions (all fields required)

Frequency	IL rms max	ΔIL peak-peak
4000 kHz	0.20 Amps	0.08 Amps

Calculate

Results (estimated)

	Inductor 1	Inductor 2	Inductor 3	Inductor 4
	LPS3314-153	LPS4012-153	LPS3015-153	
	$0.43 each at 1,000 qty	$0.43 each at 1,000 qty	$0.43 each at 1,000 qty	
Total inductor loss	28 mW	25 mW	31 mW	mW
Inductor core loss	13 mW	5 mW	6 mW	mW
DCR loss	16 mW	20 mW	25 mW	mW
AC winding loss	0 mW	0 mW	0 mW	mW
Temperature rise	4 °C	4 °C	6 °C	°C

Figure 8

COVER STORY

switching frequencies.

Predicted losses can be calculated based on the combination of switching frequency, average current, and peak-peak ripple current. For this example the results are summarized in figure 7.

For these operating conditions, no core loss is predicted nor is ac winding loss. The predicted loss is entirely made up of the DCR conduction loss. This situation suggests that the inductors could operate at much higher frequency before introducing significant core or ac winding loss.

In fact, examining the inductors at 4MHz instead of 400kHz, does show core loss increasing. The three inductors chosen have roughly the same efficiency and any would likely be suitable for this application. The designer is free to make the final selection based on other factors – footprint, height, availability, cost, etc.

Of course in this example, we have simply examined the impact of operating the same inductors at higher frequency. In order to truly take advantage of the higher frequency, the same tools and procedure should be used to re-calculate the (smaller) L needed at higher frequencies and determine the options for using physically smaller inductors.

SEPIC Converter Example

For portable applications, not only is high operating efficiency desired, but it is also important to operate from as wide a voltage range in order to give the longest battery life per charge cycle. In the previous example the minimum input voltage was limited to 3.3V, but for a typical lithium ion source it would be desirable to operate as low as possible on the discharge cycle, typically as low as 2.7V. This places the 3.3V output inside the input voltage range, no longer making this a purely step-down application. One very popular topology for this situation is the SEPIC converter, which uses two inductive elements to provide step-up/step-down capability. In this case the calculations are again based on V = L x (di/dt), with the added stipulation that the two inductances are calculated separately, having some performance analogous to transformer operation in which the input and output windings have different current requirements. While it is possible to use physically separate devices for the input and output inductors, using two windings coupled together on one core as a single device saves valuable pc board area and has the added benefit that only one half the inductance is required per winding to achieve the same performance.

Using the Coilcraft SEPIC Converter Inductor Selector for this example, with input voltage range extended down to 2.7V, provides the needed inductance values along with the current rating for each winding as shown in figure 9.

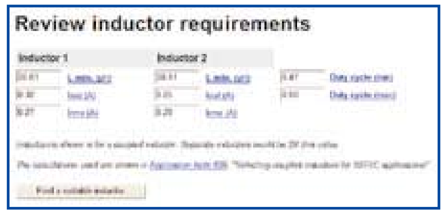


Figure 9

It is seen in this result that a little more inductance is now required due to the lower input voltage and the different current ratings are shown for the two windings. Note that the Inductor 2 average current is exactly the same as the load current. Similar to the buck regulator inductor, both are series connected to the load. The results shown in figure 10 are for separate inductors. Only one half the inductor value is required if the inductors are coupled on the same core. Figure 10 shows the solutions available for this SEPIC converter, both coupled and separate inductors.

Suitable SEPIC inductors

- Click on a part number to view the complete data sheet.
- We recommend that you request free evaluation samples for testing.
- New Search

Sort results 1) - 2) - 3) - Sort

Part number	Mounting	Other *	L (µH)	DCR (Ohms)	I sat (A)	I rms (A)	L (mm)	W (mm)	H (mm)	Price @ 1,000	Compare losses
Coupled inductors (1 required)		20.61 uH	Isat 0.32 A	Irms 0.27 A							Pick 4 Max
MSD1278-223	SM	S,C	22.0	0.0960	6.8	2.81	12.30	12.30	8.05	$0.70	☐
MSD1278T-223	SM	S,C	22.0	0.0960	8.34	2.81	12.30	12.30	8.05	$0.90	☐
MSD1260-223	SM	S,C	22.0	0.1160	5.01	2.49	12.30	12.30	6.00	$0.64	☐
MSD1260T-223	SM	S,C	22.0	0.1160	5.44	2.49	12.30	12.30	6.00	$0.87	☐
MSD7342-223	SM	S,C	22.0	0.2200	2.1	1.19	7.50	7.50	4.60	$0.64	☐
LPD4012-223	SM	S,C	22.0	1.6300	0.84	0.48	4.02	4.02	1.20	$0.60	☐
LPD3015-223	SM	S,C	22.0	1.8900	0.44	0.4	3.08	3.08	1.40	$0.60	☐
Separate inductors (2 required)		41.22 uH	Isat 0.32 A	Irms 0.27 A							
PCH-45-473	Leaded		47.0	0.0350	4.08	3.4	23.00	11.50	11.50	$0.64	☐
DO5040H-473	SM		47.0	0.0520	7.8	3.7	18.54	15.24	12.00	$1.06	☐
MSS1278T-473	SM	S	47.0	0.0723	5.66	2.9	12.30	12.30	8.05	$0.77	☐
MSS1278-473	SM	S	47.0	0.0723	5.32	2.9	12.30	12.30	8.05	$0.69	☐
MSS1260-473	SM	S	47.0	0.0801	3.3	2.5	12.30	12.30	6.20	$0.63	☐
MSS1260T-473	SM	S	47.0	0.0801	3.54	2.5	12.30	12.30	6.20	$0.72	☐
RFB1010-470	Leaded		47.0	0.0820	2.8	3.5	11.00	11.00	11.50	$0.38	
DO5010H-473	SM		47.0	0.0860	4.5	2.6	18.54	15.24	7.62	$0.80	☐
DO5022P-473	SM		47.0	0.0860	4.7	2.6	18.54	15.24	7.11	$0.80	☐
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	☐

Figure 10

Conclusion

LED drivers require new circuit techniques to meet high efficiency performance goals. In order to meet these goals in applications that are often tightly space constrained, inductor selection can be crucially important. Fortunately for today's user, many inductor shapes, sizes, and types are available, along with the tools necessary to identify them.

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Power Systems Design

Special Report- Lighting Systems

Image courtesy of eco-electrician.net

Symbiosis of Active and Passive

High-efficiency converter with PFC for LED street-lighting applications

For an advanced PCB-design, developers want to make the right choice by knowing thoroughly the application and specific requirements. Next to the design assistance this is the most important reason for App-Notes issued by the IC makers. In this early stage, IC makers such as ST need the support of a broad liner in passive components like TDK-EPC. The wide portfolio of TDK-EPC, allows the choice of the right components out of this portfolio.

By Claudio Spini, Senior Engineer, Application Laboratory, STMicroelectronics, Italy; Davide Giavarini, EPCOS AG (Group Company of TDK-EPC), IC Reference Design, Italy; Wolfgang Dreipelcher, EPCOS AG, Senior Director IC Reference Design, Germany

As a result of features such as high efficiency and very long lifetime, LEDs are becoming increasingly popular. They are driving innovation of current lamp types and make a substantial contribution to energy reduction for internal or external lighting. This is also happening in street lighting applications, where the higher efficiency and lifetime are vital for reducing total costs (including maintenance) and energy consumption. For these reasons, a street lighting power supply designed to power an LED lamp has to have high efficiency and at least similar lifetime to the LED, in order to guarantee the maintenance-free operation required by this kind of application during the LED's useful lifetime.

This article describes the characteristics and features of a 130W reference design board adapted to a LED power supply specifically designed for street lighting.

The circuit is composed of two stages: a front-end PFC using ST's L6562AT and an LLC resonant converter based on ST's L6599AT. The main features of this design are very high efficiency (more than 90%), a wide input mains range (85-305 VAC) operation and long term reliability.

Because reliability (MTBF - mean time between failures) in power supplies is typically affected by electrolytic capacitors and their high failure rate, unless very expensive types are used, this board shows an extremely innovative design approach. This board uses film capacitors from Epcos instead of electrolytic capacitors. Component derating has also been carefully applied during the design phase, so decreasing the component stress as recommended by MIL-HDBK-217D. With the use of ST's new L6562AT and L6599AT devices, the number of components used for this solution has also been minimized, thus increasing the MTBF and optimizing the total component cost. As a result of the high efficiency achieved, only a small heatsink for the PFC stage is needed, while the other power components are SMT like most passive components, thus decreasing the production labour cost.

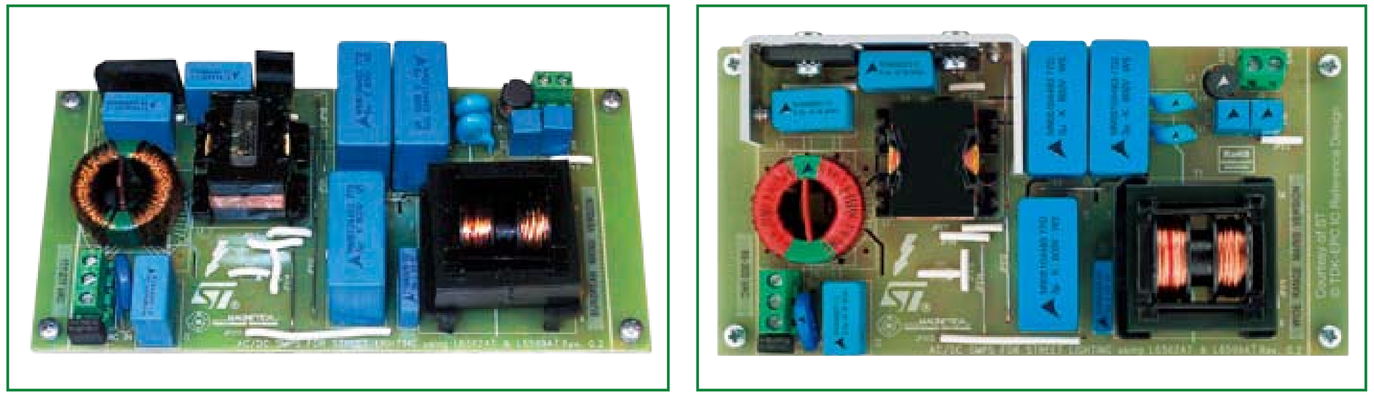

Figure 1: Main board

The board is also protected against overload or short circuit, open loop of each stage or input overvoltage because of the particular application, after intervention the system auto-restarts.

Characteristics and main functional block description

Main features of the SMPS:

- Extended European input mains range: 85 to 305 VAC - Frequency 45 to 55Hz
- Output voltage: 48V at 2.7A
- Long lifetime through use of film capacitors from EPCOS
- Mains harmonics: according to EN61000-3-2 Class-C
- Efficiency at nominal load: better than 90%
- EMI: according to EN55022-Class-B, EN55015
- Safety: double insulation, according to EN60950, SELV

Test	230 V, 50 Hz					115 V, 60 Hz				
	Vout [V]	Iout [A]	Pout [W]	Pin [W]	Eff. [%]	Vout [V]	Iout [mA]	Pout [W]	Pin [W]	Eff. [%]
25% load efficiency	47.58	0.689	32.8	37.87	86.57%	47.59	0.689	32.8	37.87	86.58%
50% load efficiency	47.57	1.378	65.6	71.66	91.48%	47.58	1.378	65.6	72.93	89.90%
75% load efficiency	47.56	2.008	95.5	102.96	92.75%	47.56	2.001	95.2	105.0	90.64%
100% load efficiency	47.55	2.708	128.8	137.6	93.38%	47.56	2.703	128.6	141.33	90.96%
Average efficiency					**91.04%**					**89.52%**

Overall efficiency data

PFC circuit

The PFC stage, working in transition mode, acts as pre-regulator and powers the resonant stage with the output voltage of 450V. The PFC power stage is a conventional boost converter, connected to the output of the rectifier bridge. It is completed by the boost coil, the rectifier diode and the output capacitors. The PFC output capacitors are film type, 5μF, 800V from Epcos.

The boost switch uses a MOSFET. The board is equipped with an input EMI filter required to filter the commutation noise coming from the boost stage. The PFC implements the controller L6562AT, a small and inexpensive controller guaranteed for operation over a wide temperature range necessary for outdoor operation.

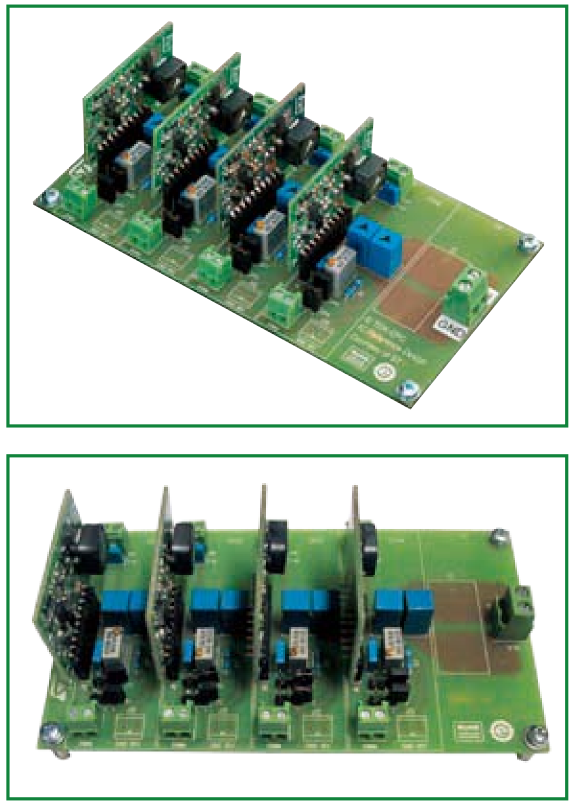

Figure 2: Board with the line DC/DC modules

Resonant stage

The downstream converter implements the ST L6599AT, incorporating all the functions necessary to correctly control the resonant converter and working with 50 percent fixed duty cycle and variable frequency. The transformer uses the integrated magnetic approach, incorporating the resonant series inductance. Thus, no additional external coil is needed for the resonance. The transformer configuration chosen for the secondary winding is the typical center tap, using a couple of power Schottky rectifiers, type STPS10150CG. The output capacitors are film type, 4.7μF, 63V from Epcos. A small LC filter completes the output section in order to filter the high frequency ripple. A feedback network guarantees the required stability of the output voltage.

Efficiency measurement

Table 1 shows the overall efficiency, measured at 230Vac, 50Hz and 115V, 60Hz with different loads also. At 115Vac and full load, the overall efficiency is 90.96% and it increases up to 93.39% at 230Vac. This makes this design suitable for applications requiring high efficiency.

Measuring the efficiency at 25%, 50%, 75% and 100% according to the ES-2 standard and calculating the average efficiency, this is 91.04% at 230Vac and 89.52% at 115Vac. This shows that the converter can operate with a high efficiency not only at full load but also at lower loads such as in the case of LED deep dimming.

Conclusion

A 48V to 130W power supply for street lighting applications has been designed and the prototype has been tested. The adopted solutions meet the LED street-lighting specifications for wide input voltage range, wide temperature range operation and high efficiency. Additionally, the design guidelines and solution implemented meet the required MTBF target.

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LED Ballast Design

Energy efficiency also reduces electronic waste

In 2009 the EU decided to abandon incandescent lighting step by step, starting with the poorest efficiency bulbs in 2010. Higher efficiency alternatives like CFL lamps or high efficiency LEDs are readily available but attention must be paid to the actual design to confirm that it is as environmentally friendly as possible.

By Dr. Michael Weirich, Applications Manager, Fairchild Semiconductor GmbH, Germany

Environmentally friendly does not just refer to the components themselves but the number of components used and their lifetime - things that are meant by the term ecodesign. Longer lifetime of electronic equipment, resulting in less waste, is achieved by reducing the number of components and increasing their durability. This article explores the design of a primary side regulated (PSR) off-line ballast for LED with constant current output. The low component count and long lifetime makes the design both cost-effective and environmental friendly.

The majority of electronic ballasts for high power LEDs operate in constant current mode. Due to the V-I characteristic of a LED a current limiting element is mandatory for stable operation. Consequently, the most popular approach is to put a number of LED in series and drive them with a current source.

The traditional approach of implementing a constant output current power supply is to measure the load current, e.g., with a shunt resistor and feed this signal back to the PWM controller. Actually, unless one doesn't care about power dissipation and efficiency, the signal generated by the shunt is too small and has to be amplified in some way. This can be done by a simple single stage BJT amplifier or an integrated operational amplifier.

The BJT has an advantage of having a built-in 'reference voltage', the forward voltage VBE of the base-emitter diode. But the latter is not very accurate and has a considerable negative temperature coefficient. If the BJT amplifier is used in cost-effective applications like mobile phone chargers, consequently there is some kind of compensation for this temperature coefficient of VBE as e.g. the PTC THR1 in the schematic Figure 1.

The schematic further shows that there are additional things to consider when designing a current source PSU. At no load current the output voltage would rise to an unacceptable high value. Hence there is an additional voltage regulation loop that is implemented with the reference/error amplifier KA431. Finally, if the output has to be isolated from the mains input, an optocoupler is needed in the feedback path. This optocoupler is an often overlooked component that can limit the lifetime of a PSU.

While in consumer applications a lifetime of say 10000h is excellent and most applications don't need such a long one, the situation in lighting applications is different. Doubtless one expects the ballast to live at least as long as the light source itself. But since in a lot of applications electric lighting may be used a significant part of the day, one doesn't want to replace the electronics each time the light source is defective but expects a lifetime of up to 50000h from the ballast.

Actually, electrolytic capacitors are the electronic components with the shortest lifetime and in fluorescent lamp ballasts, one with extraordinary long lifetimes and hence, high cost are used. Both the electrolytic capacitors' and the optocouplers' lifetimes are reduced by high temperatures. Unlike fluorescent lamps LEDs must be cooled and often the complete luminary is used as a heatsink. As a result the ambient temperature of the ballast and in turn, that of the optocoupler will be quite high. Thus, it would be advantageous to design LED ballasts without optocouplers.

For constant voltage output there is a well-known solution: the primary side regulated flyback. A primary side regulated PSU works without any direct feedback path from the secondary, reducing part count and cost while increasing reliability considerably. This topology has recently been extended to constant current output.

The actual ballast is designed around the FAN103, a dedicated PSR Flyback controller with patented constant current regulation circuit. The schematic of the ballast is shown in Figure 2 and looks quite unspectacular at first glance. Nevertheless the ballast can deliver up to 22V, enough to drive up to five LEDs in series, at a current level of up to 700mA from a universal mains input. The output current can be selected to be 350mA or 700mA by jumper J101 that changes the value of the current sense resistor. If a bigger transformer is used (EF25 core instead of EF20) and the current sense resistors R102 and R103 are adjusted, even 1A output is easily possible.

A detailed description of the operation of the ballast, that is available as a completely assembled evaluation board, is given in the following section. C101 and LF101 together with C1 form an EMI filter followed by the rectifier bridge D101 and the filtering capacitor C101. Initially C105 is charged via the internal start-up circuit of the controller to the device's start voltage. When the latter is reached, oscillation begins and the MOSFET is controlled by a PWM gate signal. The topology of the PSU is that of a flyback. When the MOSFET is in the off state, D201 at the secondary of the transformer is conducting and the energy stored in TR101 is transferred to C201 and the load. R101, C106 and D102 form the well-known clamping network the limits the voltage spikes due to the energy stored in the leakage inductance of the transformer. In steady state, the controller is supplied from a separate winding of the transformer. The voltage of this winding is rectified by D104 and filtered by C108. A simple linear regulator consisting of R111, D105 and Q102 limits the voltage at the VDD pin of the controller to 24V maximum. This is necessary since the ballast is designed to operate even with a single LED connected to the output i.e., voltages down to 2.8V in the worst case. The voltage across the supply winding of the transformer will vary with the same ratio of 17V/2.8V = 6.07. Since the minimum operating voltage of the FAN103 may be 7.25V the maximum VDD would be 44V, which would destroy the device.

The voltage of the supply winding is used to do the regulation of both, output current and voltage. In case of high load resistance the PSU is not in constant current but constant voltage mode. The FAN103 uses quite an elaborate method of regulating the output voltage tightly. The voltage of the supply winding, that

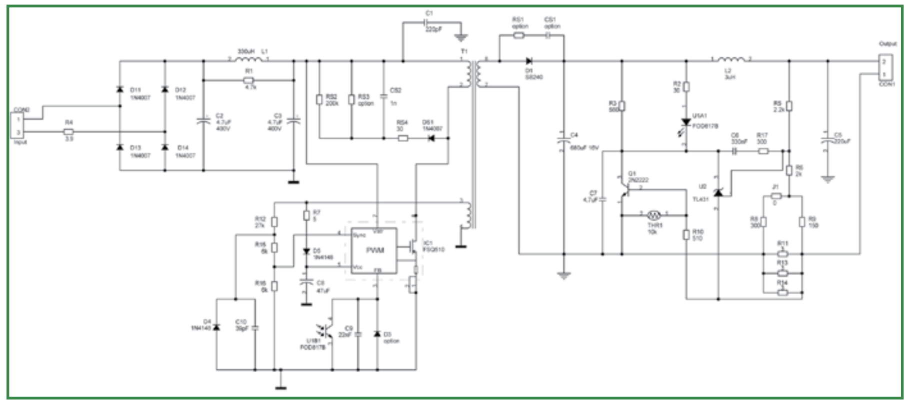

Figure 1: Schematic of a conventional constant current output PSU

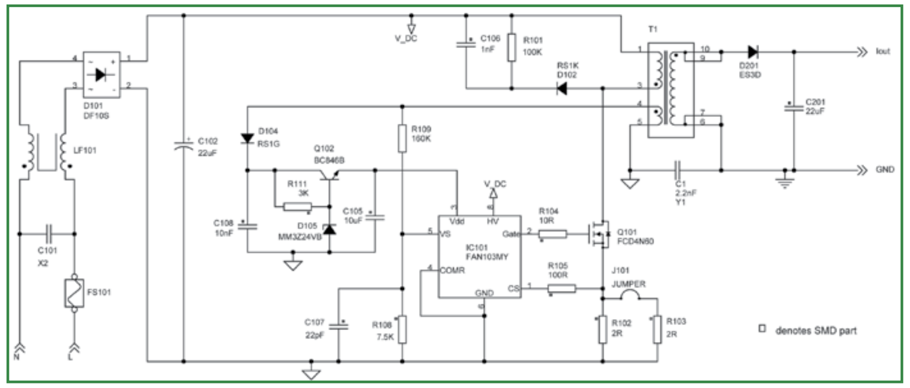

Figure 2: Schematic of primary side regulated (PSR) constant current output PSU

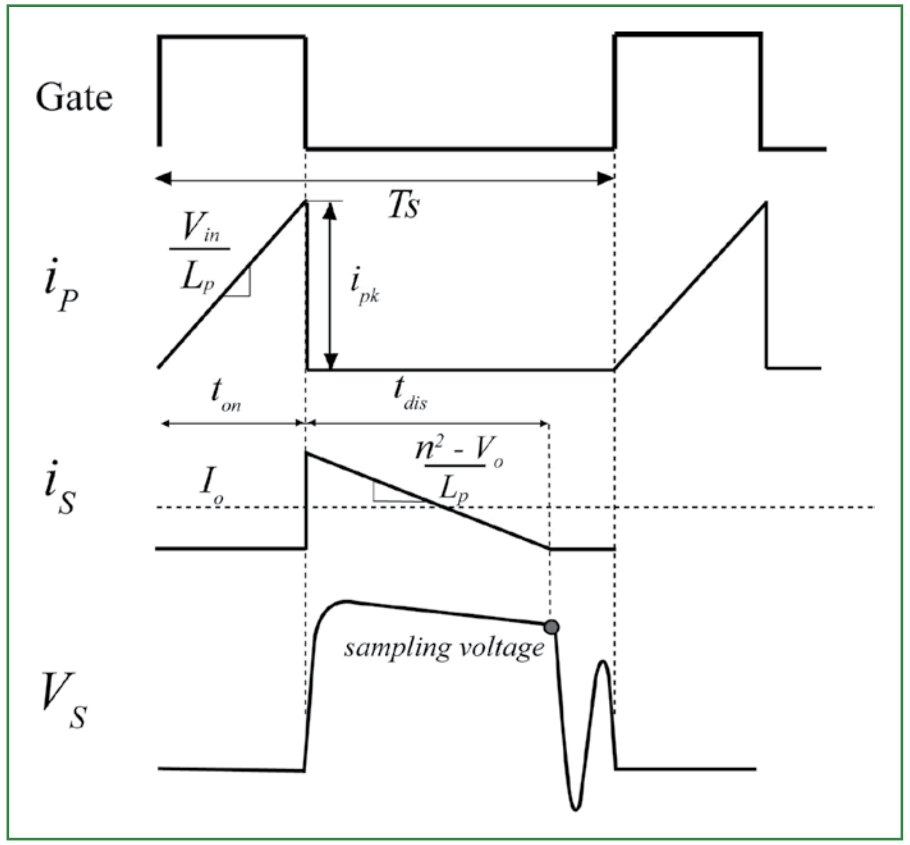

Figure 3: Typical waveforms of the design in Figure 2

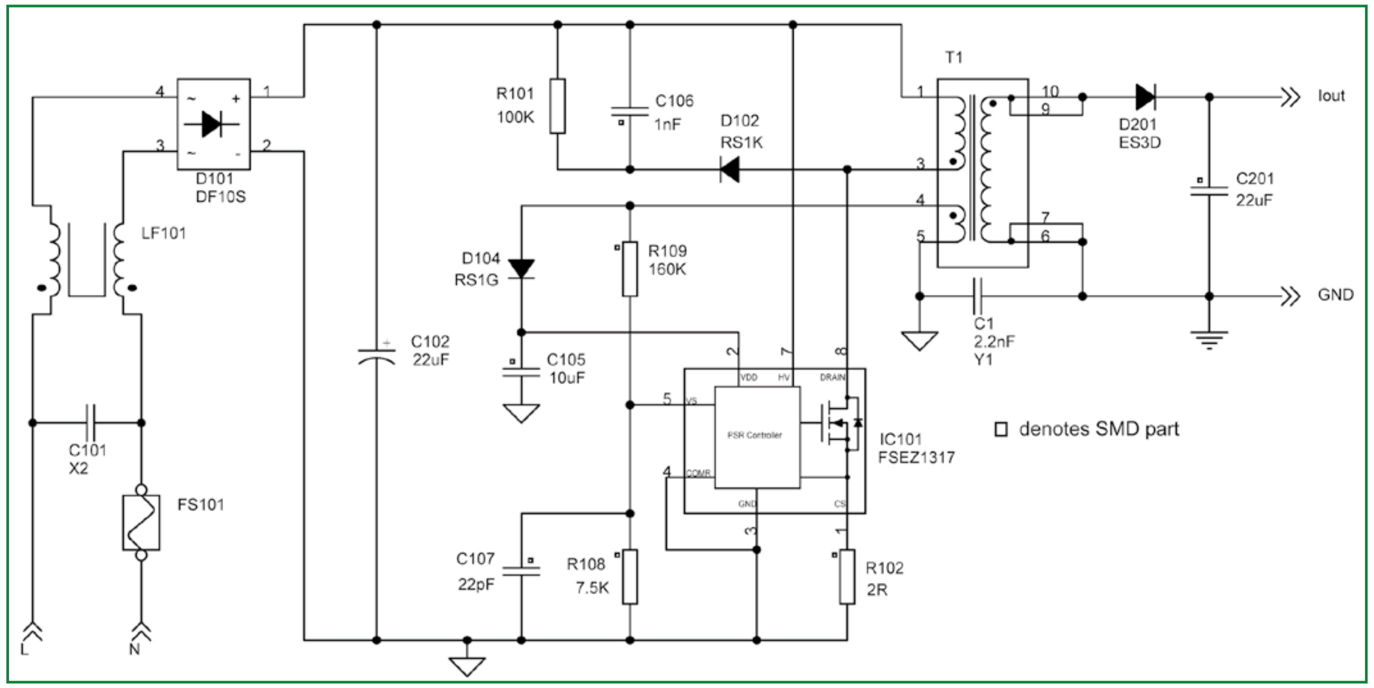

Figure 4: LED ballast with FSEZ1317

has almost the same waveform but lower voltage level as the drain of the MOSFET, is scaled by the divider R109 and R108, noise filtered with C107 and feed to the V_S pin. Internally the voltage is sampled and the zero crossing of the current through D201 is determined by monitoring the rate of change of V_S since the sample at this point gives the best estimate and hence regulation of the output voltage.

As load current increases, the output goes from constant voltage into constant current mode. To understand how the latter mode works a bit of math is indispensable. In DCM the output current IO of a flyback is (see Figure 3)

$$I_O = \frac{1}{2} \cdot \frac{t_{dis}}{T_S} \cdot i_{S,peak}$$

Using the transformer winding ratio $n = n_P / n_S$ the formula for the output current can be written with peak primary side current:

$$I_O = \frac{1}{2} \cdot \frac{t_{dis}}{T_S} \cdot n \cdot i_{P,peak}$$

Finally, the peak primary current is given by $i_{P,peak} = V_{CS} / R_S$ and the concluding equation is

$$I_O = \frac{n}{2 \cdot T_S \cdot R_{CS}} \cdot V_{CS} \cdot t_{dis}$$

Obviously the first factor is constant for a given design, VCS is the measured voltage at the CS pin and tdis is determined in the same step the zero crossing of ID201 is determined. In order to achieve a constant output current, the feedback loop has to regulate the on time of the MOSFET such that the product $t_{dis} \cdot i_{P,peak}$ is kept constant.

From the equation above it's clear that the output current for a given design is inversely proportional to the sense resistor RCS i.e., double the value gives half the output current.

Having a closer look at the schematic one will recognize that there is only a single electrolytic capacitor: C102. For universal input and the given power level of about 15W a capacitance value around the used 22uF is necessary. But if the input is limited to European power line voltage the latter can be made as small as 6.8uF, a value that is readily available as film capacitor. As mentioned earlier, replacing the electrolytic capacitor results in a ballast with an extraordinarily long lifetime, possibly longer than that of the LED itself.

The component count can be reduced even further by using the FSEZ1317, a Fairchild Power Switch (FPS™), incorporating the controller and a 600V / 1A MOSFET in one package. With this device the output is limited to 350mA. If the output is designed now to drive a minimum of three LED instead of one, the simple linear regulator around Q102 can be omitted as well. The resulting schematic in Figure 4 contains only 19 components in total but nevertheless implements a complete isolated constant current driver for high power LED. It goes without saying, that the reliability of the ballast will be increased at the same time.

Today's designers of electronic devices toned to keep the environmental impact of their designs in view. This does not only concern energy efficiency of the application but reducing electronic waste as well. By developing products with long lifetime and low component count that offer high efficiency, designers can come a step closer to this objective.

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Efficient and Cost Effective LEDs

Compact size meets high quality performance

The continuous demand for more efficient and cost effective LEDs is prevalent in the lighting industry. Many applications nowadays have space constraints and require the LEDs to have a smaller form factor while still delivering the expected high performance, light output, and efficiency.

By Osama Mannan, Technical Marketing Engineer, Future Lighting Solutions

Future Lighting Solutions now offers the ultra-compact LUXEON c that addresses those needs. Enabling applications in portable lighting, appliances, and power tools, LUXEON c incorporates high quality performance and high efficiency in an economical, compact package.

Features

With dimensions of only 2.04mm x 1.64mm x 0.7mm, LUXEON c, shown in Figure 1, delivers a typical light output of 85 lumens, at 350mA, and has an un-encapsulated light source which simplifies optical design. It also benefits from a low thermal resistance of 8oC/W and a typical forward voltage of 2.95V. This reduces the power consumption of the lighting application and improves its efficacy. The efficacy of LUXEON c is rated at 82-lumens/watt at nominal conditions.

Figure 1: LUXEON c

Furthermore, the CCT bins of LUXEON c are ANSI aligned and belong to pairs of adjacent bins along the blackbody curve to minimize color variation within the bin. The four CCT bins are part of the ANSI compliant bins of the LUXEON Rebel Illumination Portfolio LEDs. The CCT range of the LUXEON c is between 5000K and 6500K, and has the typical CRI of 75. The four bins are shown in Figure 2.

Performance

Despite its compact size, the performance of the LUXEON c is comparable, if not superior, to competitive LEDs that can be used in similar applications.

Table 1 shows a datasheet-to-datasheet comparison of a LUXEON c LED (LXCL-EYW4) and a competitive LED (referred to as LED X.)

From Table 1, it is clear that, in terms of light output, the performance from a datasheet standpoint is almost similar between the two LEDs. However, LUXEON c has the advantage of lower thermal resistance and forward voltage.

These datasheet values cannot be used for conclusive analysis because they are specified at 25oC junction temperature, while in a real-life application the junction temperature will be at higher values. Therefore, to perform a real-life analysis, Future Lighting Solutions' Usable Light Tool (ULT) is used to compare between the performance of LUXEON c (LXCL-EYW4) and that of competitive LED X.

In the analysis, three LEDs are driven at 350mA in an ambient temperature of 30oC. They are set to be mounted on an FR4 board with open thermal vias, which is placed on heatsink of 5oC/W thermal resistance. Table 2 shows the input parameters of the ULT analysis.

The results from the ULT analysis shown in Table 3 demonstrate how, under the same operating conditions,

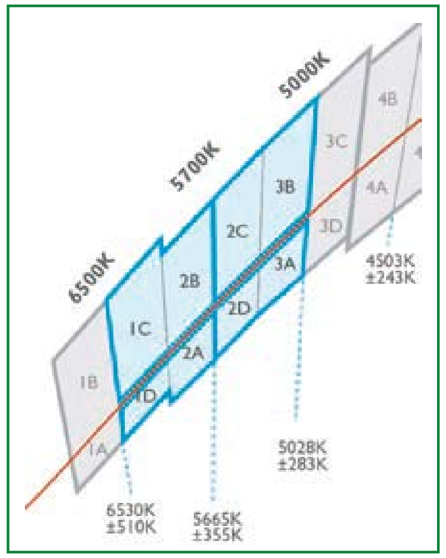

Figure 2 : LUXEON c ANSI CCT bins

	Typ. Lumen Output (at 350mA and Tj 25'C)	Thermal Resistance	Typ. Forward Voltage	Typ. Efficacy
LXCL-EYW4	85 lumens	8°C/W	2.95V	82 lm/W
LED X	84 lumens	12°C/W	3.4V	71 lm/W

Table 2: Input parameters for ULT analysis

	LUXEON c	***Competitive LED***
Power LED Part Number:	**LXCL-EYW4**	**LED X**
Number of Power LEDs:	3	3
Ambient Temperature (°C):	30	30
Circuit Board Rth for Single LED (°C/W):	25	25
Heat Sink Thermal Resistance (°C/W):	5	5
Drive Current (mA):	350	350
Typical Vf at Nominal Current (V):	2.95 @350mA	3.4 @350mA
Typical Flux at Nominal Current (lm):	85 @350mA	84 @350mA

Table 1: Datasheet comparison between LUXEON c and competitive LED X

	LUXEON c	***Competitive LED***
Power LED Part Number:	**LXCL-EYW4**	**LED X**
Calculated Forward Voltage (V):	2.83	3.19
Calculated LED Power Consumption (W):	0.99	1.12
Calc. Array Power Consumption (W):	2.97	3.35
Calculated LED Efficiency (W/W):	22.7%	19.2%
Calculated Junction Temperature (°C):	67	77
Calculated Usable LED Flux (lm):	75	71
Calculated Usable Array Flux (lm):	224	214
Calculated Usable Efficacy (lm/W):	75.35	63.82

Table 3: Output of ULT analysis

the high performance capabilities of LUXEON c help it to exceed the light output of the LED X, both at an LED and a system level. Note that the board used in this analysis had a thermal resistance of 25oC/W. The thermal resistance of the board is affected by the number of vias surrounding the LED; more thermal vias lowers the thermal resistance value. This in turn will reduce the junction temperature attained by the LED and allows it to deliver more light output. Figure 3 shows a LUXEON c LED mounted on a board with the recommended via layout. Information on mounting the LUXEON c on a board is available in the Assembly and Handling Information Application Brief (AB36.)

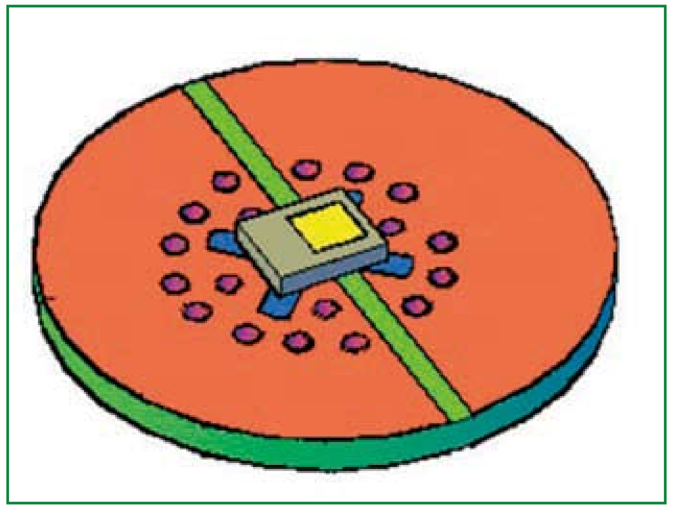

Figure 3: LUXEON c with recommended via layout

Also from the results, it can be noted that the LUXEON c consumes less power which leads to an increased efficacy of 75.35lm/W, while LED X only achieves an efficacy of 63.82lm/W.

Conclusion

Meeting the needs of the constantly developing lighting applications and satisfying their requirements are triggering the development of LEDs that not only have high quality performance, but also are cost effective and fit the targeted applications. LUXEON c enables lighting manufacturers to incorporate an efficient LED that provides high light output in a small, economical package. Numerous applications could benefit from the compact size and high quality light of LUXEON c. Applications such as portable flashlights, refrigerators, washing machines, and other commercial appliances can easily integrate LUXEON c for improved functionality.

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Fluorescent Lamp Dimming

Simple and cost effective dimming solutions

Dimming of fluorescent lamps will normally require the incorporation of a complex, high pin count controller IC into the circuit design. As a result, dimming circuits are more difficult to create than non-dimming alternatives, needing a larger number of components, taking up more board space, and raising the system's total price tag.

By Tom Ribarich, Director, Lighting Systems, International Rectifier, El Segundo, California

These issues are compounded still further when considering compact fluorescent lamps, due to the small form factors involved and the need to be highly cost effective. Here we look at a non-dimming ballast control based on an 8-pin controller IC and explain how dimming functionality can be added without needing to increase the pin count.

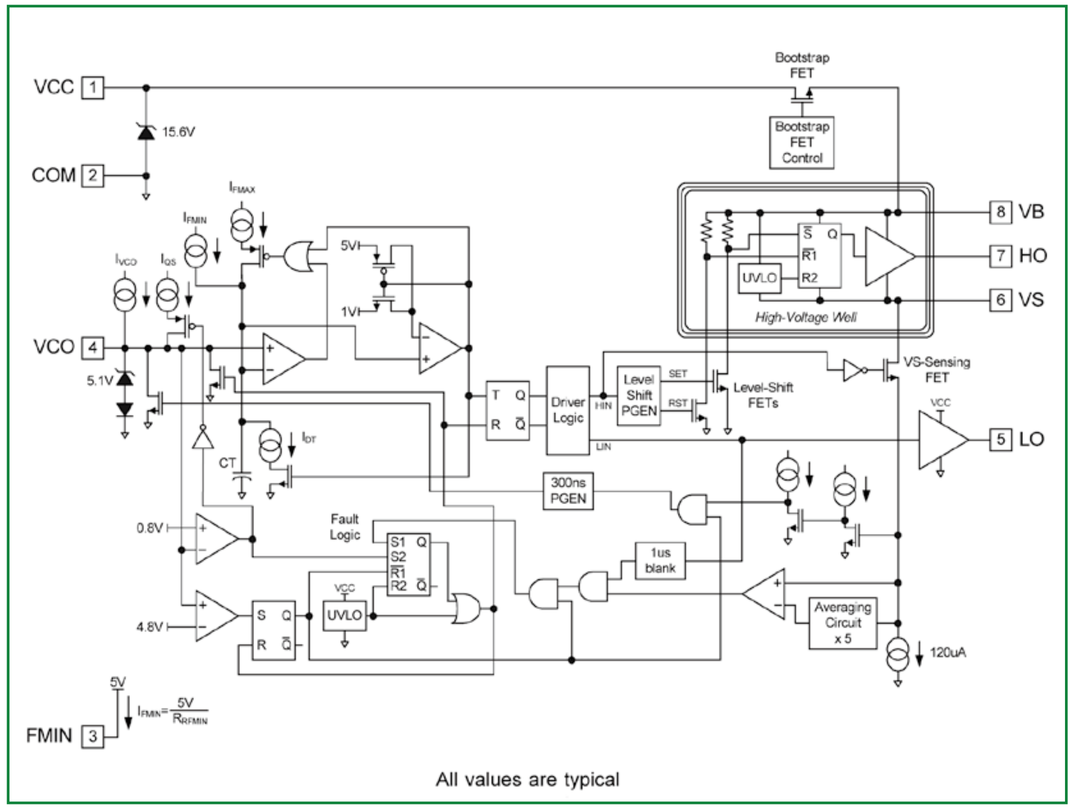

Figure 1: Block diagram of the IR2520D non-dimming ballast IC

With an existing 8-pin, non-dimming lighting ballast controller (for example, the IR2520D from International Rectifier, shown in Figures 1 and 2) only two pins are used (FMIN and VCO) to deal with preheat, ignition and running requirements of the fluorescent lamp. The remaining pins perform standard functions such as IC supply and ground (pins VCC and COM), plus high- and low-side gate drive for the half-bridge (pins LO, VS, HO and VB).

Within a non-dimming ballast circuit, current charges the VCC until it reaches the internal UVLO+ threshold. When VCC goes past this threshold, the IR2520D enters frequency sweep mode, the gate driver outputs (LO and HO) and the half-bridge circuit then starts oscillating at the maximum frequency. The charge-pump circuit then becomes the main supply circuit for the IC, maintaining the VCC at the internal clamp voltage. A small internal current source at the VCO pin slowly charges up an external capacitor causing the voltage on the VCO pin to ramp up linearly. This in turn ramp downs the frequency of the gate driver outputs (LO and HO), and the half-bridge switching circuit from

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Symbol	Description
VCC	Supply voltage
COM	IC power and signal ground
FMIN	Minimum frequency setting
VCO	Voltage controlled oscillator input
LO	Low-side gate driver output
VS	High-side floating return
HO	High-side gate driver output
VB	High-side gate driver floating supply

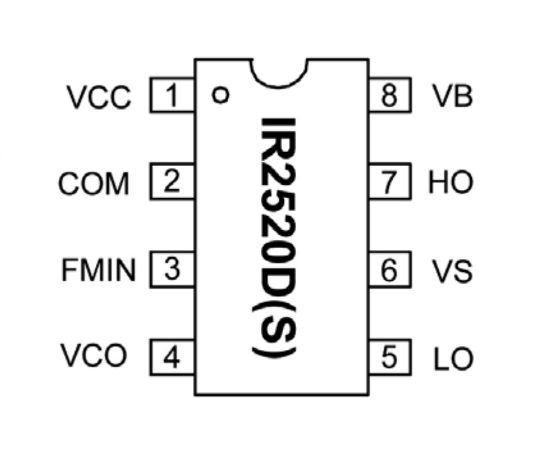

Figure 2: Lead assignment for IR2520D

its maximum starting value. The lamp voltage increases as the frequency ramps down towards the resonance frequency of the high-Q, under-damped output stage. The VCO pin voltage continues to increase and the frequency keeps decreasing until the lamp ignites. The output circuit then becomes an over-damped, low-Q circuit. The VCO voltage increases, causing the IC to enter run mode. The frequency level stops decreasing once the VCO pin surpasses 5V and stays at the minimum frequency as programmed by an external resistor on the FMIN pin.

With demand for dimming functionality becoming ever greater, but engineers not wanting to sacrifice the advantages of compact low pin count devices like the IR2520D, a way to control dimming through the pins already available needed to be found. As the VCO pin is required to perform the necessary frequency sweep for preheat and ignition, the FMIN pin was left as the only viable option through which this could be accomplished.

Dimming control through a single pin

The dimming of a fluorescent lamp can be achieved by using operating frequency to control the current being applied to the lamp. As the frequency of the half-bridge is increased, the gain of the resonant tank circuit decreases and the lamp current lowers. It is possible to regulate the lamp current to a dimming reference level by continuously adjusting the half-bridge frequency through closed-loop feedback circuit. Dimming is enabled by combining the AC lamp current measurement with a DC reference voltage at a single node. The AC lamp current is measured across sensing resistor RCS and coupled onto the DC dimming reference via feedback capacitor CFB and resistor RFB.

The feedback circuit regulates the valley of the AC+DC signal to COM as the DC dimming level is raised or lowered by continuously adjusting the half-bridge frequency. This causes the amplitude of the lamp current to then increase or decrease so that dimming can be carried out. If the DC reference is increased, the valley of the AC+DC signal will rise above COM and the feedback circuit will lower the frequency in order to enlarge the gain of the resonant tank. This will raise the lamp current, as well as the amplitude of the AC+DC signal at the DIM pin, until the valley reaches COM again. If the DC reference is decreased, the valley will decrease below COM. The feedback circuit will then increase the frequency to lower the resonant tank gain until the valley reaches COM again. The IR2520D's FMIN pin, used to program a single running frequency, has now been replaced with a DIM pin, which measures the AC+DC signal for dimming.

The IRS2530D dimming control IC offers a complete 8-pin solution that contains all dimming ballast functions. The VCO pin includes the frequency sweep timing control for preheat and ignition, and also programs the loop speed for the dimming feedback circuit during dim mode.

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

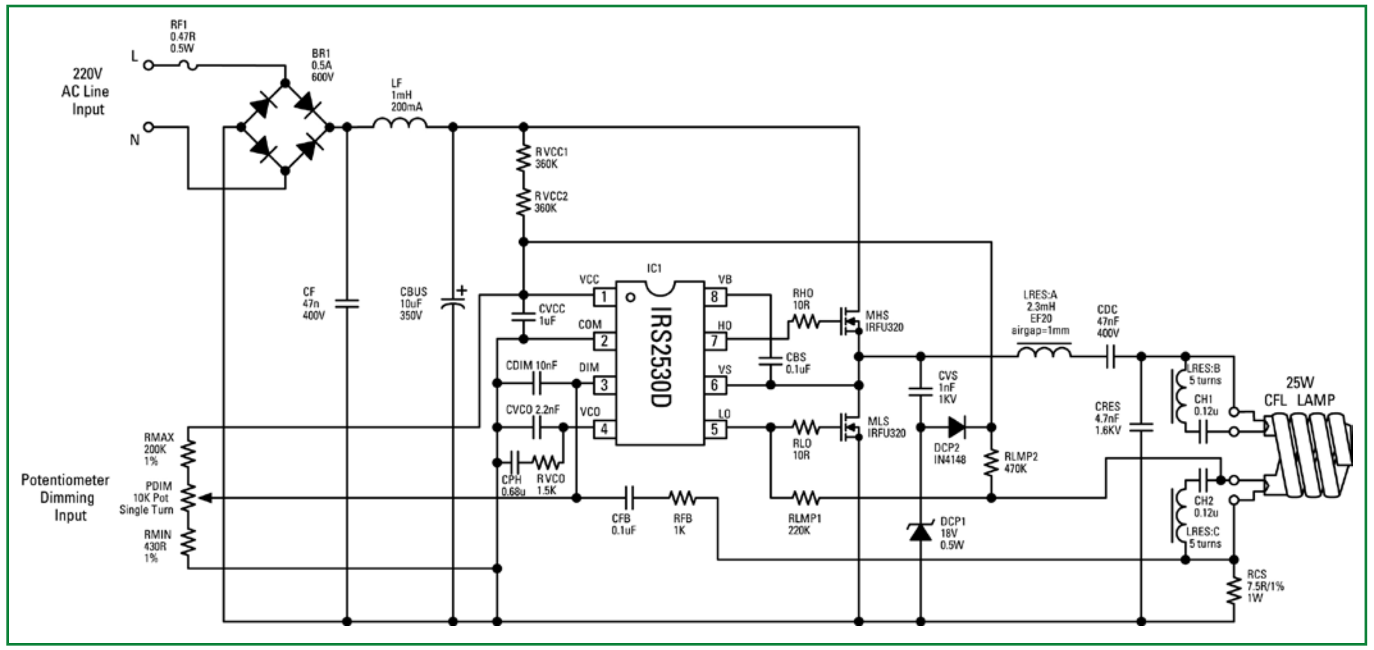

Figure 3: Dimming mini-ballast circuit using the IRS2530D

A schematic showing a complete dimming mini-ballast circuit is described in Figure 3. It is designed to run from a 220VAC line and to drive a 25W compact fluorescent lamp. The 220VAC/50Hz line input voltage is full-wave rectified (BR1) and then goes through the EMI filter (CF and LF) before being smoothed by the DC bus capacitor (CBUS). The half-bridge switches (MHS and MLS), which are controlled by the IRS2530D, allow preheating, igniting and dimming of the lamp. RVCC1 and RVCC2 provide the micro-power start-up current for the IC's VCC supply, and the charge pump (CSNUB, DCP1 and DCP2) takes over as the IC supply once the half-bridge begins to oscillate. The resonant tank circuit (LRES and CRES) provides the transfer function for generating the high voltages needed for lamp ignition and low-pass filtering for dimming. Secondary windings from the resonant inductor (LRES: A, B) are used to heat the filaments of the lamp during preheat and dimming, and also separate the lamp current from the filament current allowing for a single current-sensing resistor (RCS) to be utilized for sensing the lamp current. The AC lamp current measurement across RCS is coupled to the DIM pin through a feedback capacitor and resistor (CFB and RFB). A potentiometer dimming input circuit is used (PDIM, RMIN, RMAX) to convert the potentiometer resistance to the dimming reference voltage for the IRS2530D through the DIM pin. Protection against ballast fault conditions (failure to strike, open filament, and low AC line/brown-out) are incorporated into the IRS2530D to further reduce component count.

There is a clear need for simple and cost effective dimming solutions which take up the minimum of real estate and do not require a large number of components. The 8-pin IRS2530D offers the means to develop dimming circuits in a quick and unproblematic manner. Furthermore, it has the potential to bring dimming features to a broader spectrum of applications, thus allowing marked energy savings to be realized.

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New Automotive Display Backlighting

Need LED drivers delivering 30,000:1 dimming ratios

In 2010, the market size for high brightness LEDs is expected to reach $8.2 billion and grow to $20.2 billion by 2015 at a 30.6% compound annual growth rate (CAGR) according to Strategies Unlimited. LEDs used to backlight displays are currently the major driver to this growth. Applications range from HDTVs to automotive displays to a myriad of handheld devices.

By Jeff Gruetter, Product Marketing Engineer, Linear Technology

In order to maintain this impressive growth rate, LEDs must not only offer enhanced reliability, reduced power consumption and smaller/flatter form factors, but must also offer obvious improvements in contrast ratios, picture clarity and color accuracy. Additionally, automotive, avionic and marine displays must maximize all of these improvements while subjected to a wide array of ambient lighting conditions, ranging from bright sunlight to night-time environments. These transistor-liquid crystal display (TFT-LCD) applications range from infotainment systems, gauge clusters and a wide array of instruments. Backlighting these displays with LEDs creates some unique LED IC driver design challenges in order to optimize the displays' readability in such a wide range of ambient lighting conditions. This requires LED drivers that can offer very wide dimming ratios, high efficiency and withstand the rigors of the relatively caustic automotive electrical and physical environment. Finally, these solutions must offer very low profile, compact footprints while enhancing cost effectiveness.

How can such an impressive growth potential in automotive lighting be supported? First of all, LEDs are ten times more efficient at producing light than incandescent bulbs and almost twice as efficient as fluorescent lamps, including cold cathode fluorescent lamps (CCFL) thus reducing the amount of electrical power required to deliver a given amount of light output (measured in lumens), as well as the dissipated heat. As LEDs are further developed, their efficiency at producing lumens from electrical power will only continue to increase. Secondly, in a very environmentally conscience world, LED lighting does not require the handling, exposure and disposal of the toxic mercury vapor commonly found in CCFL/fluorescent bulbs. Thirdly, incandescent bulbs need to be replaced about every 1,000 hours, while fluorescent bulbs last up to 10,000 hours compared to a 100,000+ hour lifetime for LEDs. In most applications, this allows the LEDs to be permanently embedded into the final application without the need for a fixture. This is especially important for backlighting automotive instrument/navigation/infotainment panels that are embedded into a car's interior as they will never require replacement during the life of the car. Additionally, LEDs are orders of magnitude smaller and flatter then their counterparts so the LCD panels can be very thin, thereby requiring minimal space in the interior of the car. Furthermore, by using a configuration of Red, Green & Blue LEDs, an infinite number of colors can be delivered. LEDs also have the ability to dim and turn on/off much faster than the human eye can detect, enabling dramatic improvements in backlighting of LCD displays while simultaneously allowing dramatic contrast ratios and high resolution.

One of the biggest challenges for automotive lighting systems designers is how to optimize all the benefits of the latest generation of LEDs. As LEDs generally require an accurate and efficient DC current source and a means for dimming, the LED driver IC must be designed to address these requirements under a wide variety of conditions. Power solutions must be highly efficient, robust in features and be very compact as well as cost effective. Arguably, one of the most demanding applications for driving LEDs will be found in avionic, marine and automotive infotainment TFT-LCD backlighting applications as they are subjected to the rigors of the automotive electrical environment, must compensate for a wide variation of ambient lighting conditions and must fit in a very space-constrained footprint, all while maintaining an attractive cost structure.

Automotive LED Backlighting

Benefits such as small size, extremely

long life, low power consumption and enhanced dimming capability have triggered the wide spread adoption of LED TFT-LCD backlighting in today's automobiles, planes and boats. Infotainment systems usually have an LCD screen mounted somewhere in the center of the dashboard so both the driver and the passenger can easily view their location, perform audio tuning and a variety of other tasks. Additionally, many cars also have LCD displays that entertain passengers in the rear seat with movies, video games and so forth. Historically, these displays used CCFL backlighting, but it is becoming more common to replace these relatively large bulbs by very low-profile arrays of white LEDs which provide more precise and adjustable backlighting as well as a service life that will easily out live the vehicle .

The benefits of using LEDs in this environment have several positive implications. First, they never need to be replaced, since their solid state longevity of up to 100K+ hours (11.5 service years) surpasses the life of the vehicle. This allows automobile manufactures to permanently embed them into "in cabin" back lighting without requiring accessibility for replacement. Styling can also be dramatically changed as LED lighting systems do not require the depth or area required by CCFL bulbs.

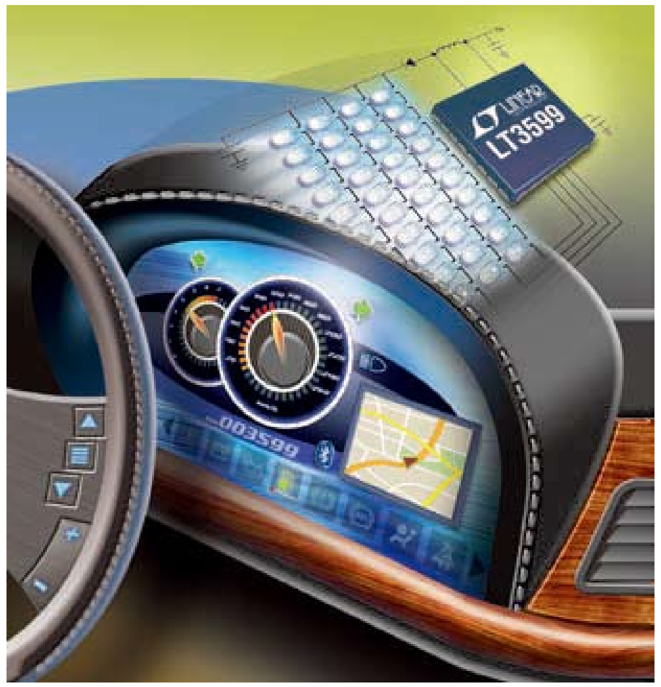

Figure 1: Virtual dashboard

LEDs are also generally more efficient than fluorescent bulbs at delivering light output (in lumens) from the input electrical power. This has two positive effects. First, it drains less electrical power from the automotive bus, and equally important, it reduces the amount of heat that needs to be dissipated in the display, eliminating any requirement for bulky and expensive heat sinking.

Another important benefit of LED backlighting is the wide dimming ratio capability provided by a high performance LED driver IC. As the interior of a car is subjected to a very wide variation of ambient lighting conditions, ranging from direct sunlight to complete darkness with every variation in between, it is imperative that the LED backlighting system is capable of very wide dimming ratios, generally up to 30,000:1. With the proper LED driver IC, these wide dimming ratios are relatively easy to attain which are not possible with CCFL backlighting. Figure 1 shows a typical LCD-based virtual dashboard.

Design parameters for automotive LED lighting

In order to ensure optimal performance and long operating life, LEDs require an effective drive circuit. These driver ICs must be capable of operating from the caustic automotive power bus and also be both cost and space effective. In order to maintain their long operating life, it is imperative that the LEDs current and temperature limits are not exceeded.

One of the automotive industry' s major challenges is overcoming the electrically caustic environment found on the car's power bus. The major challenges are transient conditions known as load dump and cold crank. Load-dump is a condition where the battery cables are disconnected while the alternator is still charging the battery. This can occur when a battery cable is loose while the car is operating, or when a battery cable breaks while the car is running. Such an abrupt disconnection of the battery cable can produce transient voltage spikes up to 40V as the alternator is attempting a full-charge of an absent battery. Transorbs on the alternator usually clamp the bus voltage to approximately 36V and absorb the majority of the current surge. However, DC/DC converters down stream of the alternator are subjected to these 36V to 40V transient voltage spikes. These converters are expected to survive and regulate an output voltage during this transient event. There are various alternative protection circuits, usually transorbs, which can be implemented externally. However, they add cost, weight and take up space.

"Cold crank" is a condition that occurs when a car's engine is subjected to cold or freezing temperatures for a period of time. The engine oil becomes extremely viscous and requires the starter motor to deliver more torque, which in turn, draws more current from the battery. This large current load can pull the battery/primary bus voltage below 4.0V upon ignition, after which it typically returns to a nominal 12V.

However, there is a new solution to the dilemmas, Linear Technology's LT3599, which is capable of both surviving and regulating a fixed output voltage through out both of these conditions. Its input voltage range of 3V to 30V with transient protection to 40V makes it ideal for the automotive environment. Even when VIN is greater than VOUT, which could occur during a 36V transient, the LT3599 will regulate the required output voltage.

As most LCD backlighting applications require between 10 and 15watts of LED power. Linear Technology's LT3599 has been designed to service this application. It can boost the automotive bus voltage (nominal 12V) to as high as 44V to drive up to four parallel strings, each containing ten 100mA LEDs in series. Figure 2 shows a schematic of the LT3599 driving four parallel strings, each string comprised of ten 80mA LEDs,

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delivering a total of 12W.

The LT3599 utilizes an adaptive feedback loop design which adjusts the output voltage slightly higher than the highest voltage LED string. This minimizes power lost through the ballasting circuitry to optimize the efficiency. Figure 3 illustrates the LT3599's efficiency that can be as high as 90%. This is important because it eliminates any requirement for heat sinking, enabling a very compact low profile footprint. Equally important for driving arrays of LEDs is to provide accurate current matching to insure that the backlighting brightness remains uniform across the entirety of the panel. The LT3599 is guaranteed to deliver less than 2% LED current variation across its -40˚C to 125˚C temperature range.

The LT3599 uses a fixed frequency, constant current boost converter topology. Its internal 44V, 2A switch is capable of driving four strings of up to ten 100mA LEDs connected in series. Its switching frequency is programmable and synchronizable between 200kHz and 2.5MHz, enabling it to keep switching frequency out of the AM radio band while minimizing the size of the external components. Its design also enables it to run one to four strings of LEDs, if fewer strings are used; each string is capable of delivering additional LED current. Each string of LEDs can use the same number of LEDs or can be run asymmetrically with a different number of LEDs per string.

The LT3599's offers direct PWM with dimming ratios as high as 3,000:1 and dimming analog dimming via the control pin, which offers ratios as high as 20:1. In applications which require dimming ratios of up to 30,000:1, these two dimming functions can be combined to reach the required ratio. Certain emerging automotive, marine and avionic applications often require these very high dimming ratios to compensate for a wide range of ambient light that the LCD panel is subjected to.

Furthermore, the LT3599 has integrated protection features that include open and short circuit protection and alert pins. For example if one or more LED strings are open circuit, the LT3599 will regulate the remaining strings. If all of the strings are left open, it will still regulate the output voltage and in both cases would signal the OPENLED pin. Similarly, if a short circuit occurs between VOUT and any LED pin, the LT3599 immediately turns off that channel and sets a SHORTLED flag. Disabling the channel protects the LT3599 from high power thermal dissipation and ensures reliable operation. Other features that optimize reliability include output disconnect in shutdown, programmable under voltage lockout and programmable LED temperature derating. The high voltage capability and high level of integration of the LT3599 offers an ideal LED driver solution for automotive backlighting applications.

The unprecedented acceleration of LED backlighting applications in automotive displays is driven by a continual demand for higher performance and cost effectiveness. These emerging performance requirements must be enabled by new LED driver ICs. These LED drivers must provide constant current in order to maintain uniform brightness, regardless of input voltage or LED forward voltage variations, operate with high efficiency, offer wide dimming ratios and have a variety of protection features to enhance system reliability. These LED driver circuits also require very compact, low-profile, thermally efficient solution footprints. Linear Technology is continually improving their family of LED drivers to meet these challenges head on with LED driver ICs like the LT3599 for display applications. In Addition, Linear Technology has developed an entire family of high current LED driver ICs aimed at myriad of automotive applications ranging from LCD backlighting to turn signals and even headlight applications. As automotive lighting systems continue to demand higher performance LED drivers, Linear Technology will meet these challenges.

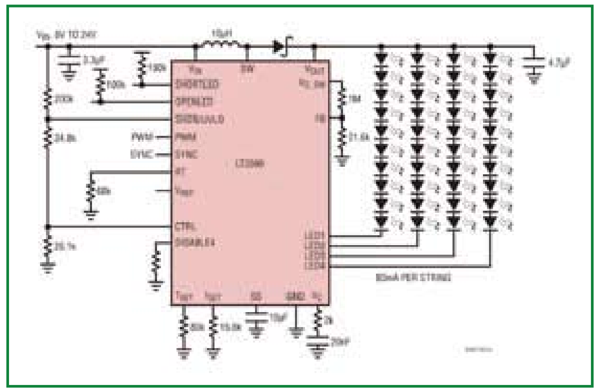
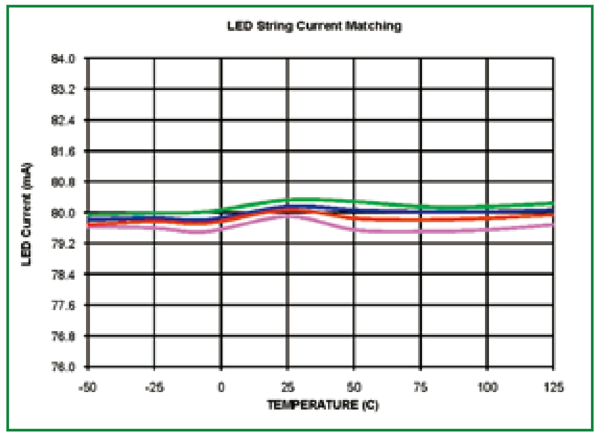


Figure 2: 90% Efficient 12 Watt LED backlighting circuit using the LT3599



(a) LT3599 Current Matching Over Temperature

(b) LT3599 Efficiency vs. LED Current Temperature

Figure 3: LED current matching & efficiency of LT3599 in Figure 2

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Better LED Intensity Control in Video Displays

When a video display application uses a pulse-width modulated LED driver such as the MAX6975, higher PWM resolution is needed to provide gamma (visual effect) correction, LED characteristic matching, and ambient light adjustment to the 8-bit or 10-bit video information. This article will explain how to emulate 16-bit PWM resolution for the video application even though the MAX6975 only has a native PWM resolution of 14 bits.

By Walter Chen, Principle Member of the Technical Staff, Applications, Maxim Integrated Products inc., Sunnyvale, California

For better power efficiency and color consistency, the intensity of an LED is typically controlled by regulating the duty cycle of a pulse-width modulation (PWM) period through an LED driver. A PWM period usually consists of a number of clock cycles equal to the 2 to the power of the number of control bits (2CONTROL BITS).

The control-bit resolution for consumer electronics applications is normally 8 bits. Thus with 8-bit PWM resolution, 256 different intensity levels can be provided and the corresponding PWM period consists of 256 clock cycles. For a typical consumer-electronics clock frequency of 32kHz, a PWM period lasts about 256/32kHz, or 8ms. Consequently, the PWM refresh rate is about 125Hz. Together, this PWM resolution and refresh rate provide enough lighting intensity adjustment, and avoid the flickering effects that can be seen by the human eye. However, for the latest generation HD displays, that resolution is not sufficient and thus the driver resolution must be extended to provide finer granularity.

Providing 16-Bit resolution for an LED driver

It is a challenge to meet the requirements for both the 16-bit PWM resolution and the

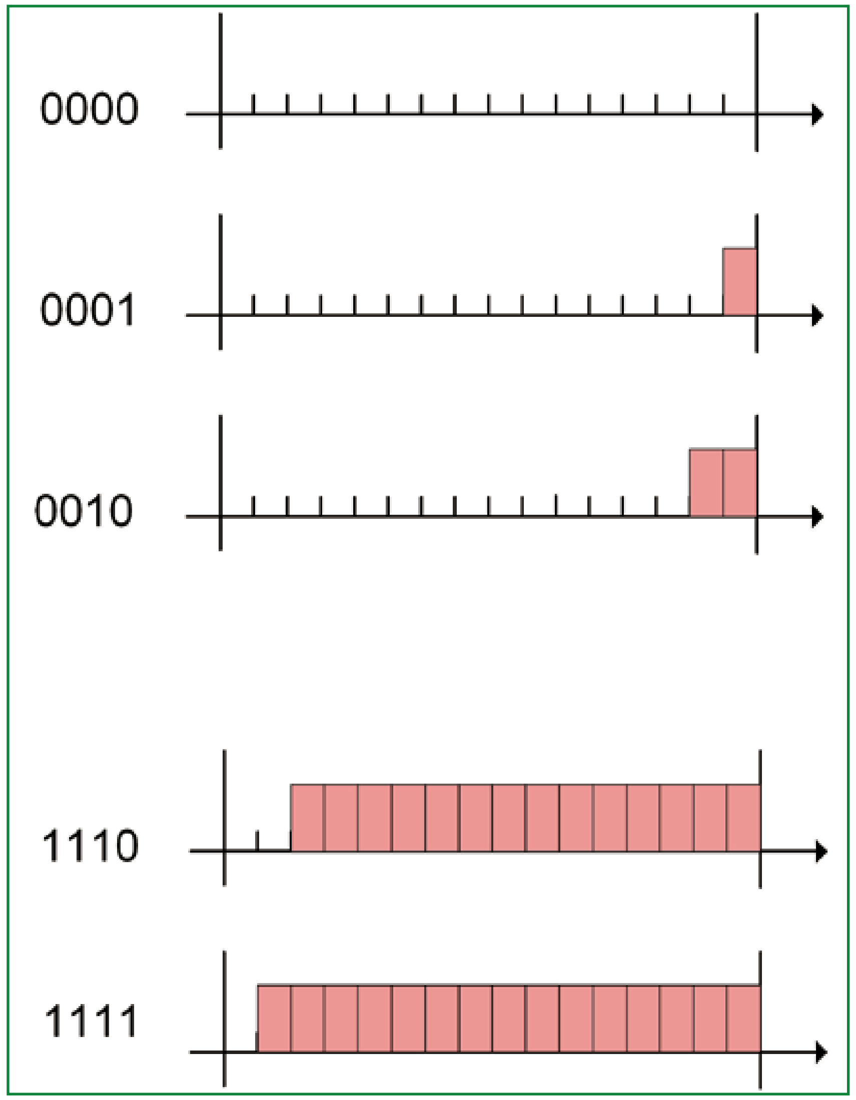

Figure 1: Conventional 4-bit and 16-position PWM waveform.

2kHz refresh rate of the latest displays. The 16-bit resolution leads to a PWM period with 216 = 65,536 clock cycles. The corresponding clock frequency for a 2kHz PWM refresh rate is 2000 x 65,536 = 131.072MHz. Sending data over a CMOS interface at this speed becomes unreliable, even for reasonable distances. The real issue is that the LED driver's output ports cannot be switched on/off fast enough with the loading of the LED and associated wiring. Without accurate turn-on/off timing, the benefit of 16-bit resolution cannot be realized.

As a compromise, a group of PWM periods of less than 16 bits can be used to emulate a full 16-bit PWM period. By using this approach, the desired 2kHz PWM rate can be maintained at a lower clock frequency since the number of clock cycles is reduced in each PWM period. The visual effects of 16-bit resolution can be maintained, since the human eye cannot distinguish change/flicker once the PWM refresh rate is faster than a few hundred hertz.

Consider the example of a video camera operating at, or near, 1/2000 shutter speed. The camera will capture frames at lower resolution, but this is much better than capturing a black screen for lower refresh rates. Although the shutter speed can be very high, a video camera still captures 60 frames at every second. The averaging effect of these multiple video frames can still resemble a picture close to the desired 16-bit resolution.

The 16-bit resolution can be divided into different MSB/LSB (most/least significant bit) ratios for the emulation. There will be a number of PWM periods with the resolution of the MSBs: 2 to the power of the number of the most significant bits (2MSB). The number of periods equals the resolution of the LSBs: 2 to the power of the number of the LSBs (2LSB). There can also be different methods of bit distribution among the PWM emulation groups. A simple approach is to let the LSBs decide if the last clock cycle of each group should be on/off; the MSBs decide the remaining clock cycles. Restated simply, the clock cycles' on-/off-times determined by the MSBs are all the same for all groups.

Test case example

Let's use a 2/2 split emulation of a

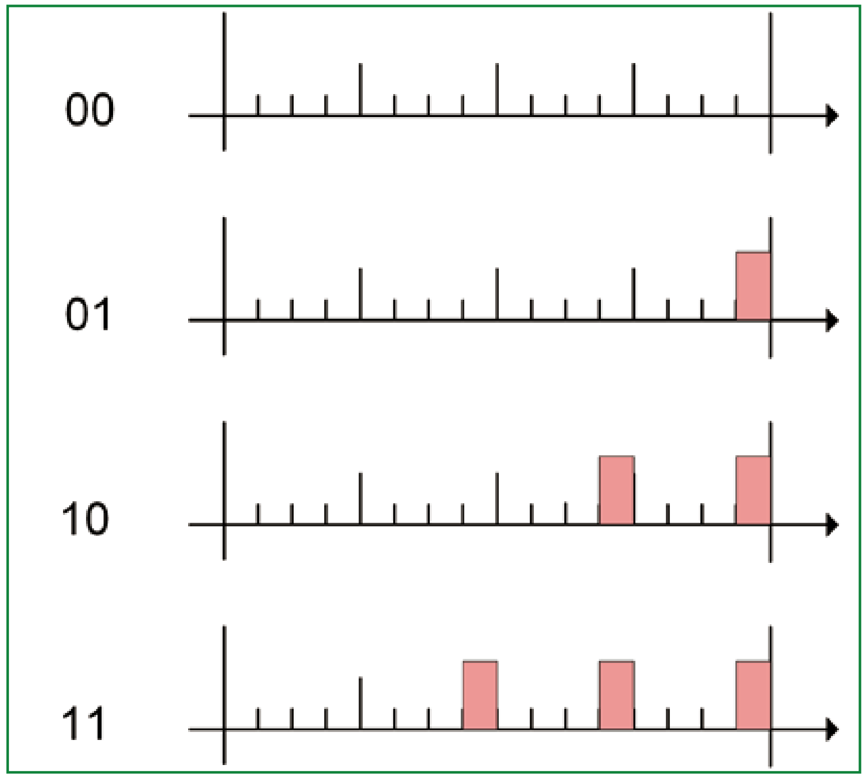

Figure 2: Effect of LSBs for a 2/2 split of a 4-bit emulation.

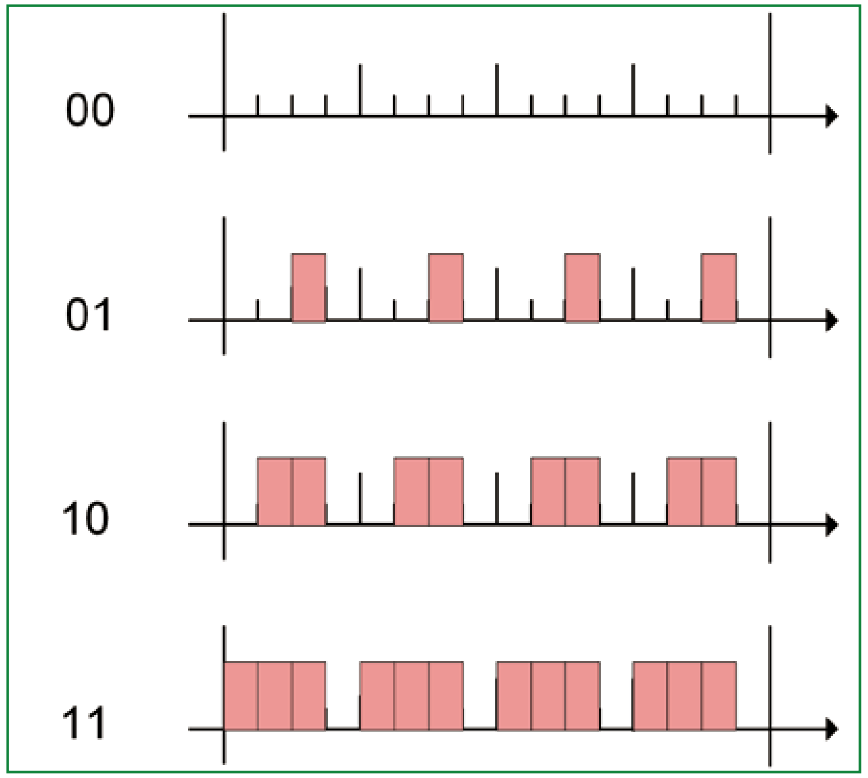

Figure 3: Effect of MSBs for a 2/2 split of a 4-bit emulation.

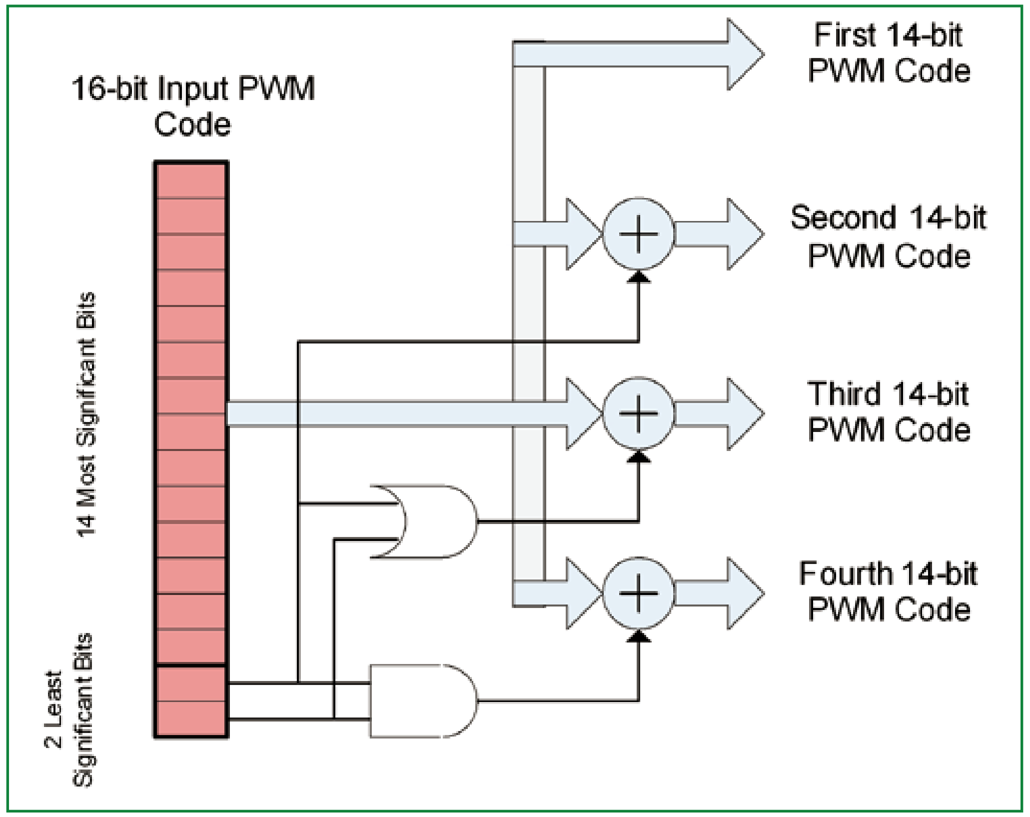

Figure 4: Structure of a 14/2 split 16-bit emulation encoder

4-bit resolution as an example to detail the approach. Figure 1 shows the direct 4-bit implementation of 16-position PWM waveform patterns.

A 2/2-split emulation will create four 4-position PWM groups. The 2 LSBs are used to select at which group the last clock cycle should be on. The 2 MSBs are used to determine the on-/off-pattern of the remaining three clock cycles. Figure 2 shows the effect of the 2 LSBs on the emulation PWM waveforms when the 2 MSBs are 0s.

Figure 3 shows the effect of the 2 MSBs on the emulation PWM waveforms when the 2 LSBs are 0s.

This approach can be used with the MAX6975 LED driver's built-in LVDS interface to emulate 16-bit resolution. It is done with a split of 14/2. A 16-bit video frame will be displayed by four 14-bit video frames of light, by one clock cycle, on/off differences. A simple encoder generates these 14-bit PWM codes using the 16-bit PWM code as input. The encoder uses the 14 MSBs as the base for the 14-bit code, and adds another bit depending on the pattern of these two LSBs. Figure 4 shows the emulation encoder. The first 14-bit PWM code takes the MSBs as they are. The second code adds the MSB of these two LSBs. The third code adds the OR operation of these prior two, and the fourth code adds the AND operation.

There are two small drawbacks for the proposed emulation approach. First, there will be some missing PWM codes at the highest brightness region. As shown in Figure 2, some emulation PWM codes will be fully turned on when selections of the MSBs and LSBs are combined. The full turn-on could not be produced with the MAX6975's original designed operation. The effect of these missing codes, however, will not be noticeable. These codes are near full brightness and not used often. Even when these codes are used, human vision is not sensitive to the slight variation of light intensity when it is that bright.

Second, the information sent to MAX6975 will be four times more or faster if the 60 video frames-per-second display rate is to be maintained. The data interface of the MAX6975 is still fast enough to supply many chips in a serial chain, but the number of chips in the chain will be reduced proportionally. At a clock frequency of 32MHz, 32,000,000/(14 x 24 x 60) = 1,587 x MAX6975 chips can be put in a serial chain to share the same data interface at a frame rate of 60 video frames per second. This number will be reduced to 396, if four emulation frames need to be delivered for each video frame. A video array of 32 x 32, or up to 56 x 56, pixels, can still be driven by a single data interface with all chips in a serial chain.

There is, finally, a small difference compared to the general emulation approach that is also worth noting. Each PWM frame is normally repeated 32 times as subframes for the global intensity control of the MAX6975. Therefore, the MAX6975's 14/2 implementation of a 16-bit resolution will also have each of these four emulation PWM frames repeated 32 times.

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LED Action

The art of dimming LEDs

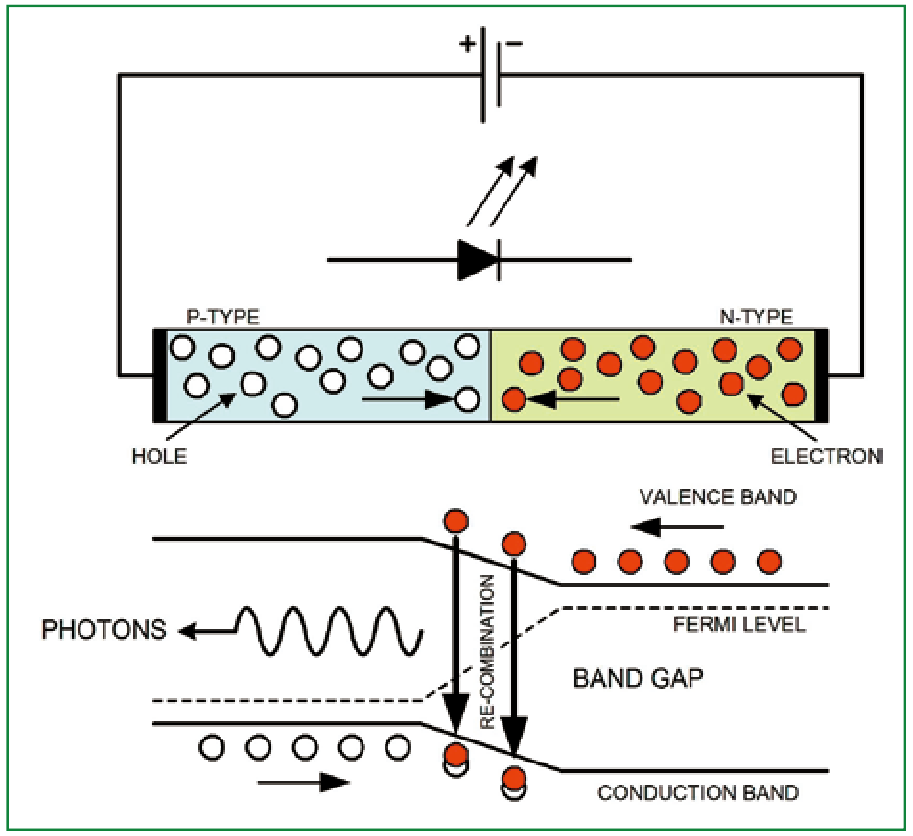
Light emitting diodes were first demonstrated by Nick Holnyak of General Electric in 1962. Over the following two decades the physics of LED illumination was understood sufficiently for LEDs to replace incandescent bulbs and vacuum tubes in indicators and numeric displays. In the early 1990s researchers at Hewlett-Packard, Toshiba and Nichia introduced high brightness red, green and blue LEDs.

By Paul Greenland, Technologist and Tushar Dhayagude, Co-Founder & Vice President
mSilica Inc., Santa Clara, California, USA

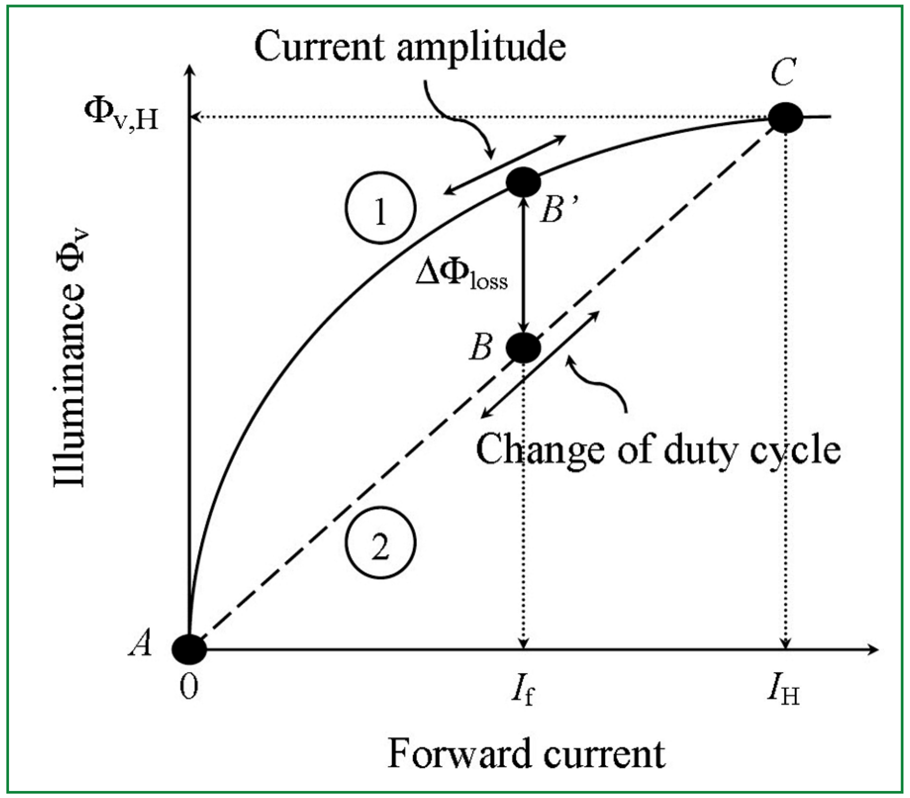
LEDs were starting to replace incandescent lamps in virtually all monochrome signaling applications, where their reliability and luminous efficacy, the ratio of light output to power input, is superior. A quick trip down the road will confirm this, most traffic lights, particularly new installations, use LEDs. In fact during the late 1990s luminous efficacy of LEDs has exceeded that of incandescent lamps and is approaching fluorescent lamps. LED action is shown in figure 1. The diode consists of an electron- carrying n-layer and a hole-carrying p-layer. When a forward voltage is applied to the structure (negative to the n-layer and positive to the p-layer), electrons injected from the n-layer radiatively recombine with holes emitting photons. The wavelength and colour of the photons is determined by the difference in the energy levels of the electrons and holes.

Why dimming?

The requirement for dimming LEDs first emerged in small format liquid crystal display backlighting in cellular handsets. Once the mobile phone evolved from the simple voice-centric application to one carrying multimedia content, especially video, the power consumed by a display and its backlighting became significant. White backlighting from RGB mixing or phosphor down-converted blue LEDs was available albeit at too high a power consumption for extended viewing. At the same time large format LCDs replaced CRT monitors in personal computers. Energy efficiency standards, which apply to office equipment together with the elimination of hazardous substances such as mercury from cold cathode fluorescent lamps used for backlighting bought solid-state lighting specifically LEDs to the forefront of technology. As dimming of LED backlights in the handset and PC monitor became more sophisticated approaches to saving energy and enhancing display contrast were under investigation for LCD-TV. In fact content-adaptive brightness control of LCD-TV displays in which the video processor dynamically adjusts the brightness in zones of the display according to the video content



LED Action



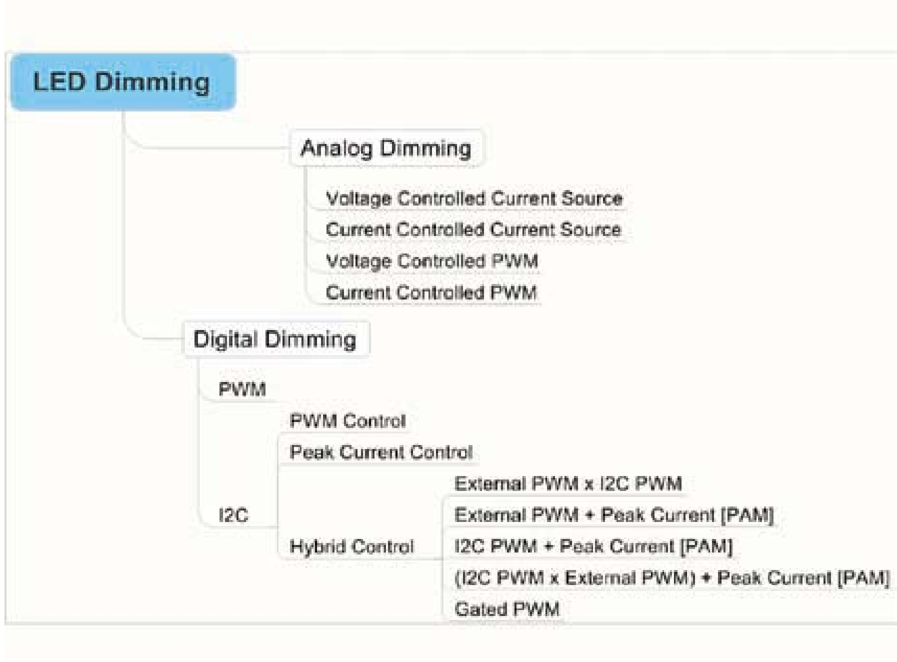
Luminance vs. Forward Current

in real-time is commonplace. This is by far the most demanding of dimming applications requiring precision timing and LED current control without interfering with the video signal or causing visible artifacts such as display shimmering, which is caused by intermodulation or beating between the video and harmonics of the dimming control signal. Visual display applications require the most sophisticated dimming solutions and are constantly under review with the aim of saving energy. It is with energy efficiency in mind that general lighting applications require dimming. For example in the newest generation of "smart buildings" the lighting is zoned so that artificial lighting at the periphery of the building next to windows is minimal during daylight hours. Luminaires are networked in such installations so that sensors deployed at certain points can keep the ambient light level constant or switch off zones altogether when passive infrared occupancy detectors signal that nobody is present in the area. Dimming is also used as part of RGB mixing to create lighting which enhances the subject. For example supermarkets use fluorescent lamps with a phosphor that emits a spectrum of light, which makes meat or vegetables look more appealing. RGB LEDs can be mixed for a particular spectral output with additional energy savings and higher reliability.

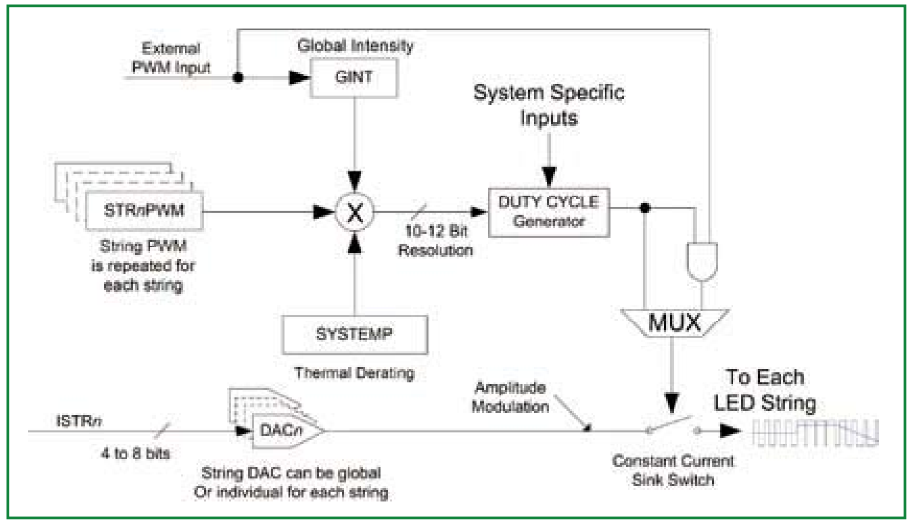
LEDs may be driven with a direct current (amplitude mode) or with a pulsating current (PWM) or by a hybrid technique. At first inspection it seems simple to operate the LEDs with dc. However the device's low dynamic resistance gives it a high sensitivity of forward current to a change in forward voltage. Additionally it has been found that a direct change of forward current can alter the emitted wavelength of the LED at different intensities. In contrast dimming may be achieved by pulse width modulation, which controls the pulse duration rather than current amplitude yielding improved colour stability. This stability is gained by sacrificing luminous efficacy as the LEDs have to operate at higher current amplitude during the forward current pulse for the same average current as the dc current case. The luminous output of LEDs has a tendency to saturate at higher forward currents. Figure 2 illustrates the two techniques for driving and dimming LEDs. Line 1 shows the non-linear luminous output from an LED driven by direct-current. Line 2 shows the same LED driven with a pulse width modulated for red current. For a particular average forward current it is shown that PWM drive results in a loss in luminous output $\Delta\Phi_{loss}$. The reason for this disparity is that the LED is operated at a point of lower luminous efficacy I_H. The hybrid case, which is a mix of the direct current and PWM techniques, is the best of both worlds. The only drawback of the hybrid approach is that the dimming range may be reduced.

The mSilica approach

The mSilica approach to LED dimming, illustrated in figure 3, is sophisticated and comprehensive. This is not surprising; these techniques were developed in anticipation of the most demanding LCD-TV backlighting requirements. Electromagnetic compatibility and energy efficiency are prime considerations for LCD-TV design along with the requirement for contrast ratios in excess of 50,000:1. Furthermore, this needs to be achieved in such a way that the driver is scalable for large format LCDs and independent of power source technology so that the drive scheme readily adapts to the customers' system implementation. Energy efficiency is assured via a closed loop system which modulates the dc voltage applied to the strings in order to set the voltage across the current source MOSFET at its optimum point for a particular string current. Consequently the energy consumed by the backlight is no more than that needed for optimum performance in real-time regardless of the operating point. In the case of RGB drivers three independent power optimization loops are used. Two top-level categories of LED dimming analog dimming and



Dimming Techniques



mSilica PWM Engine

digital dimming are available. Analog dimming is achieved using a variable dc voltage or current which sets the LED string current source. Alternatively that dc voltage or current may be compared with a sawtooth waveform at a PWM comparator that generates a PWM signal, which programs the average LED string current. Digital dimming may be further subdivided into PWM or I^2C categories depending on the interface. The PWM input may come from a simple oscillator with a variable mark-space ratio or a microcontroller. The I^2C signal may come from the microcontroller or the graphics interface depending on the sophistication of the solution. In each case there are a variety of options available depending on the dimming range (or contrast ratio) desired. Coupled with the high contrast ratio is the requirement for low noise and minimal interaction with video signals or sensitive circuitry. Low electromagnetic interference is achieved by synchronization, phase shifting and sequencing of pulsating string currents and programming signals such that low frequency ripple on the string supply is minimized and fast edges, or the harmonics thereof, do not interfere with video signals.

The PWM engine at the heart of the mSilica LED driver range is shown in figure 4. The register ISTRn sets the peak LED string current with 4 to 8-bit resolution. The DACn output controls the string current sinks. The current demand signal is switched by the output of the multiplexer MUX. If there is no phase delay or internally generated PWM signal the external PWM input modulates the current in the strings directly. If the internal duty cycle generator is active, string duty cycle, which is stored in a register STRnPWM with 12-bit resolution, sets the output. This drive may be modified by an 8-bit global intensity register, GINT that reduces the duty cycle for all strings or by a thermal derating factor, SYSTEMP. System-specific input to mark-space ratio and clock synchronization occurs in the DUTY CYCLE Generator. The mSilica PWM engine makes all the modes shown in figure 3 possible, without compromising efficiency, precision, signal to noise ratio or performance over temperature range.

Conclusion

LED dimming is not as simple as it seems. There is a bewildering array of options available ranging from dc or PWM current control to complex hybrid techniques, which offer unparalleled contrast ratio to the LCD-TV designer without compromising on overall system performance. All these options integrate seamlessly with the chosen power supply topology. The products of this harsh proving ground for LED dimming circuits are now available for general illumination applications. The highest contrast ratio methods may be excessive. However, RGB mixing and energy optimization are equally applicable wherever similar standards apply.

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Polymer Film Capacitors for LED Drivers

Applications demanding long life

As is typically found with most types of high-end equipment, LED lighting systems require a minimum of 5 to 10 years of working life with 100% up time in order to justify the user's cost and maintenance burden. It is simply impractical to try to drive long life LEDs with power components that can fail in only two years. Multi-layer ceramic (MLC), aluminum electrolytic and tantalum capacitors were originally intended for use in commodity applications for functions such as by-passing (decoupling), coupling, filtering, frequency discrimination, DC blocking and voltage transient suppression, but designers have erroneously been trying to extend their use into high performance applications (such as Military, Flight, high-end Telecom, medical, high-end consumer electronics).

By Ian W. Clelland and Rick A. Price, ITW Paktron, Lynchburg, VA

In these types of applications the performance and stability, as opposed to size and cost, are the critical criteria. Designing with commodity grade capacitors (i.e. MLC, aluminum electrolytic and tantalum capacitors) is applicable for use in commercial based, commodity applications, where all that is required is just having a capacitance be present, but in high performance applications, stability, and the hit that performance takes because of the lack of it, cannot be ignored. In critical applications where just 'getting by' is not acceptable design criteria, the selection of the proper capacitor technology is paramount to a product's success.

A specification listing 2000 hour product life for a component means only 83.3 days of continuous 24/7 run time operation making the extrapolation to 10 years life a far reach for most capacitor systems that are subject to electrical degradation with time. Instead of using capacitors that simply get by, critical applications require units with an established track record of both durability and reliability. Because of the need for high reliability and long life, high tech industries such as Telecom learned decades ago that while the commodity grade capacitor technologies (i.e. aluminum electrolytic, ceramic, tantalum, etc.) have their viable uses, in pivotal applications only metallized polymer film capacitors have the inherent performance, stability and reliability needed.

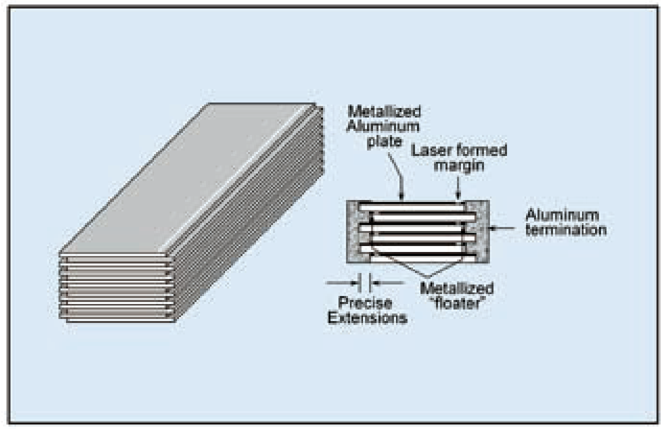


Figure 2: MLP Internal Structure

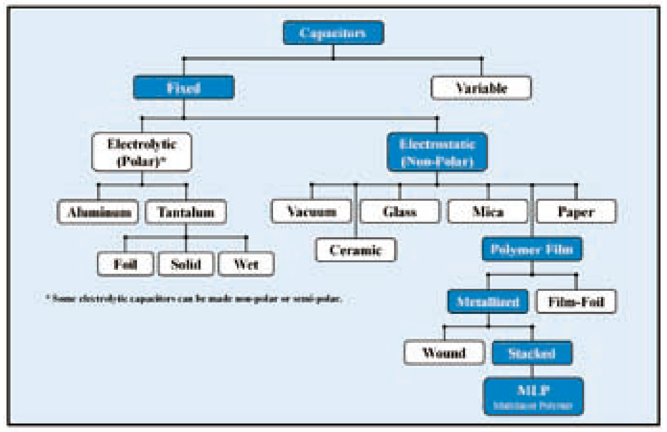


Figure 1: Family Tree of Capacitors

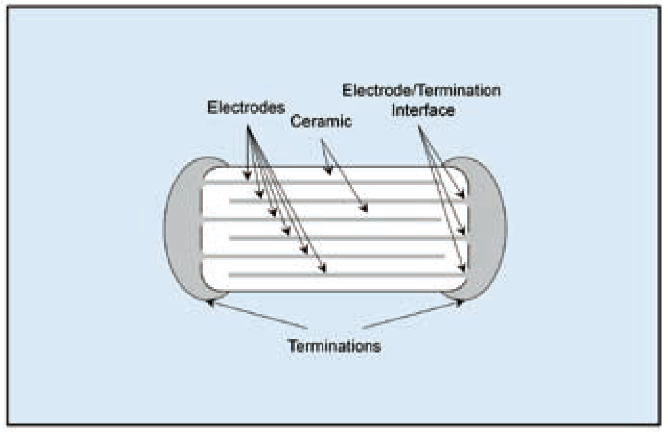


Figure 3: MLC Internal Structure

Data On Typical Capacitor Types

	Selected Value	DCV	Dissipation Factor (1kHz)	Dissipation Factor (100kHz)	ESR @ 25°C (100kHz)	Ripple Current (100kHz)
Aluminum	1000µf	6	10.0%	15.70%	0.025	1.0
Tantalum	680µf	6	6.0%	9.80%	0.023	3.0
Ceramic – X7R	10µf	100	2.5%	0.94%	0.015	6.0
Polymer Film	10µf	100	1.0%	0.69%	0.003	14.1
			Spec.	Actual	Spec.	

Figure 4: Comparison of Dielectrics

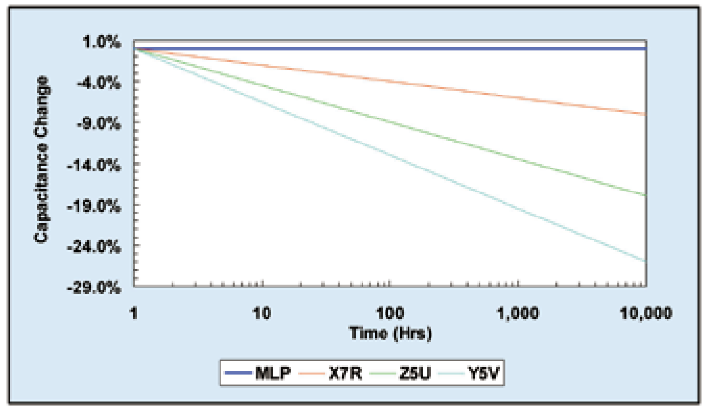


Figure 5: Ceramic Capacitor Aging

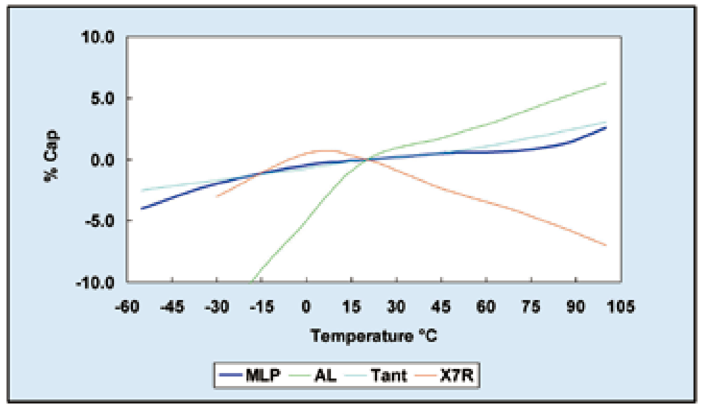


Figure 6: %Capacitance Change vs. Temperature

Capacitor Technologies

There are two basic types of fixed capacitor technologies: electrolytic and electrostatic (Figure 1). Electrostatic capacitors use a bulk dielectric made from an intrinsically insulating material while electrolytic capacitors have a dielectric that depends on the formation and maintenance of a microscopic oxide layer. The electrolytic capacitor differs from the electrostatic in that only one of its conducting surfaces is a metallic plate with the other conducting surface being a chemical compound or electrolyte. The dielectric in an electrolytic capacitor is a very thin film of oxide of the metal which constitutes one of the metallic plates used in the structure.

Metallized polymer film capacitors are electrostatic capacitors that consist of thin film layers of polymer based material upon which a metal has been vapor deposited to act as electrode plates. Polymer film capacitors have always been considered to be the premier capacitors for high performance applications. The latest form of this technology is called multilayer polymer (MLP) and is a "stacked" capacitor technology that takes two offset lengths of film (or more) and winds the layers together on a large wheel to form a mother capacitor. The mother capacitor has its layers laminated together and is sawed into individual capacitors.

Ceramic capacitors are electrostatic with the most common form being the multilayer ceramic capacitor (MLC).

Performance Advantages of MLP Capacitors	
Electrically Stable Under AC Voltage	Electrically Stable Under DC Voltage
TCE compatible with FR4	Electrically and Physically Stable over Temperature
No "Aging" Mechanism	Resilient Under Thermal Shock
Self-Clearing Thin Electrodes	Stable under Mechanical Stress
Low Cost	Ultra Low ESR
Dissipation Factor (DF) < 1.0%	High dv/dt rating
No Wear out Mode	Non-Piezoelectric
Non-Polar	Surface Mountable
Lead-Free (Pb-Free) Structure	Leak Free "Dry" construction
High Voltage capability (up to 500vdc)	Environmentally Benign

Special Report – Lighting Systems

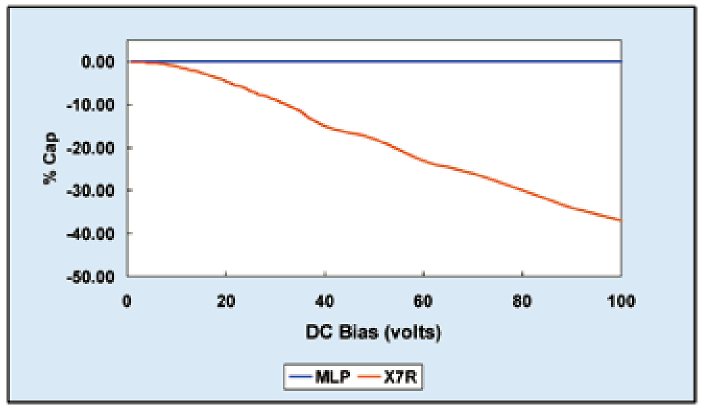


Figure 7: %Capacitance Change vs. DC Bias

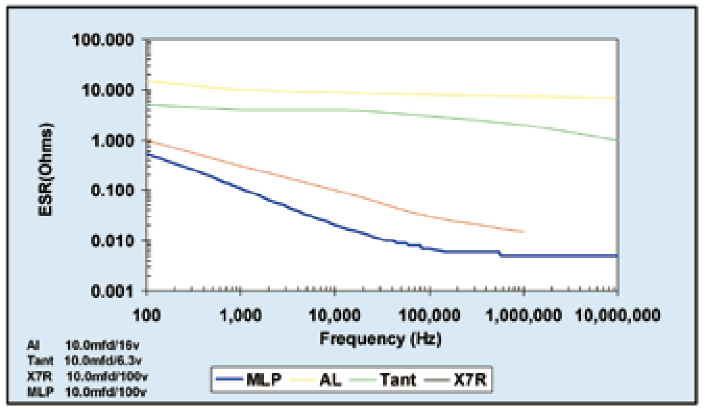


Figure 8: ESR vs. Frequency

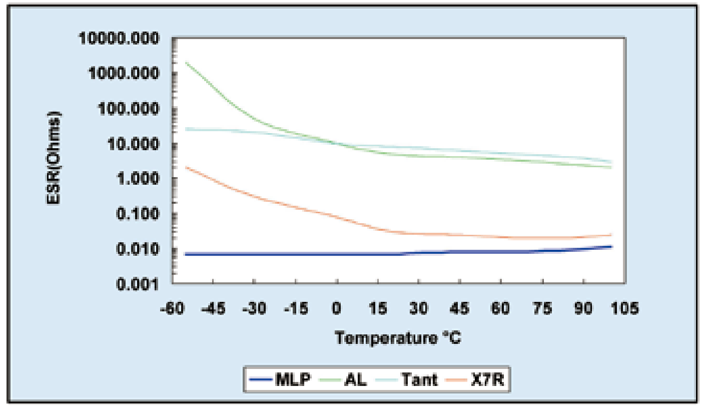


Figure 9: ESR vs. Temperature

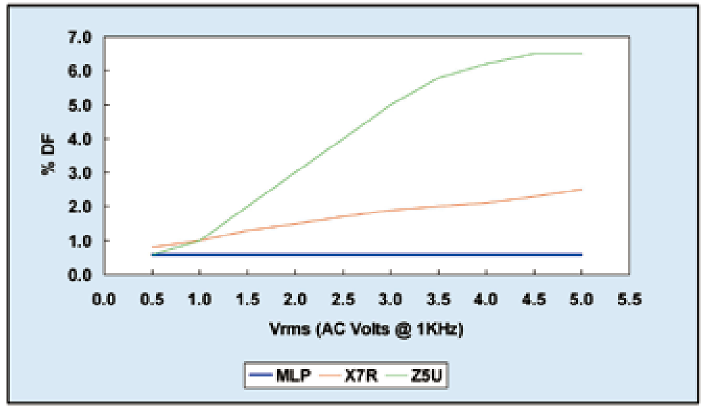


Figure 10: %DF vs. Vrms

The multiple layers and high dielectric constant ceramic allows for the production of relatively high capacitance values per unit size. These types of capacitors are easily surface mountable and have found wide acceptance in signal level applications.

Electrolytic capacitors (aluminum electrolytic, tantalum, etc.) like batteries have their functionality based on a chemical reaction. Because of entropy, time will eventually slow, stop or reverse that reaction and the capacitors will become non-functioning. Electrostatic capacitors (ceramic, polymer film, etc.) do not function due to chemical reactions, but ceramic capacitors contain certain base elements and dopants that can radically affect their longevity.

The most commonly used ceramic capacitors are based on a barium-titanate dielectric that exhibits "aging" which produces decreases in capacitance values over decade-hours of time. Decade-hours are industry time periods of 1-10, 10-100, 100-1000 hours etc. For example, an X7R ceramic capacitor loses between 6.0-7.5% of its capacitance value in its initial 1000 hours while a Z5U capacitor can lose almost 20%.

Stability

The capacitance, dissipation factor and ESR of capacitors can be affected by: Temperature, Time (Aging), Frequency and Voltage (AC or DC). MLC capacitors are affected by these variables to a much greater degree than other electrostatic capacitors.

MLC capacitors have such wide variances in properties due to having not a natural but rather an "engineered" dielectric constant. Capacitance is directly proportional to the polarization capability of the dielectric material. Rather than being a simple set of molecules switching back and forth as in a polymer dielectric, the capacitance value of MLC capacitors is affected by material purity, grain size, sintering, grain boundaries, porosity, internal stress, the freedom of domain wall movement, reorientation, etc. Because of the nuances (tolerances) of each of the dielectric material variables at both the atomic and macro-material level, engineering the dielectric constant makes it susceptible to change from almost any outside influence. Although the basic attributes of ceramic dielectrics are well-publicized, every manufacturer's approach employs subtle details that can make a critical difference. While nearly all MLC capacitors start with a dielectric based on barium titanate ($BaTiO_3$), they then add small amounts of other materials, such as rare-earth and ferroelectric oxides, to tailor the parameters of the dielectric. They also use these oxides as additives to select a set of trade-offs among factors such as temperature coefficient, tolerance, stability, loss, distortion, breakdown voltage, and even micro-phonics.

The key to the lack of stability for MLCs is the term "trade-offs". The trade-offs that have been instituted have made the ceramic capacitor manufacturers victims of their own success. By succeeding to such a degree in maximizing the amount of capacitance available per unit volume, they have decreased the stability of their class II products to the point of limiting them to commercial/commodity products. Basically, modern MLC capacitors have morphed from electrostatic to becoming pseudo-electrolytic capacitors; enjoying new capabilities but now also taking on some electrolytic capacitor weaknesses while keeping their own.

Conclusion

In critical, long life applications manufacturers require the use of capacitors with established track records in both durability and reliability. For these applications, only capacitors with the necessary inherent performance, stability and reliability should be used. No matter how much circuit redundancy or accelerated screening testing is done there always exists a golden nexus that can produce a single point of failure (SPoF) requiring circuit designers to spend a great deal of time trying to minimize the probability of the occurrence of such failures. The one proven design approach over the last five decades is the use of polymer film capacitors. Multilayer polymer (MLP) capacitors do not suffer from the same parametric instability as commodity grade capacitors and have been the preferred capacitor technology for high performance applications. Trying to use commodity grade capacitors in high performance/critical applications without taking "special" measures to compensate for their instability can result in design failure.

The commodity grade capacitor industry's drive to lower cost and reduce component size has generally removed some of the safety margin in their designs or caused increased parasitic losses resulting in decreased capacitor stability. These non-ideal characteristics are detrimental to performance and are difficult to compensate for, especially when you don't realize exactly how they are impacting your circuit's operation.

Commodity grade capacitors do an excellent job in commodity/consumer applications, but their use is application specific and they have their limitations. This is not an unknown problem, with the information on their instability published in most capacitor manufacturers' data sheets. By comparison, due to their low mass, outstanding performance capabilities and unmatched inherent reliability, polymer film capacitors have long ago been established as the choice in high performance, long life applications.

www.paktron.com

LED Lighting Variants

Advantages of new light source technology

A power-saving, environmentally friendly, long-life, compact and (above all) cost-effective light source – LEDs have created an entirely new generation of lamps.

By Andreas Biss, New Business Development, Sharp Microelectronics Europe, Hamburg

According to the International Energy Agency (IEA), around 2650 terrawatt hours are used across the world every year for lighting alone. A consumption level with enormous potential for savings: in comparison to traditional light sources such as electric filament lamps, fluorescent tubes, halogen lamps, sodium and mercury vapour lamps etc, modern light sources only need a maximum of just less than half the energy. LEDs are one of the light sources with the highest energy efficiency on the market today. With a lighting efficiency of up to 105 lumens per watt depending on the module, the Sharp LEDs are at the forefront of today's LED lighting. They use only 11% of the power used by normal bulbs. Even conventional energy saving lamps still use twice as much as LEDs.

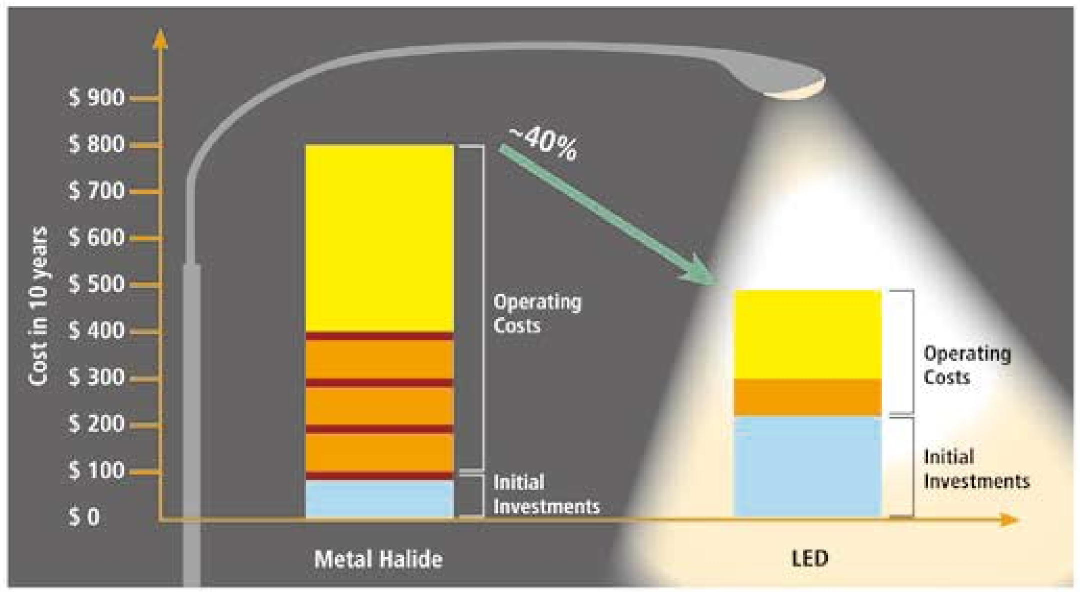
LEDs – cost-efficient even after only 1,500 operating hours

In addition to high energy efficiency, a long-term advantage of using LEDs as a light source is their long life cycle. For example, Sharp LED modules provide at least 40,000 hours of light at a substrate temperature of up to 80°C, depending on the module. Despite the comparatively high purchase costs, using LEDs as a light source pays off throughout their total life cycle.

According to Sharp's calculations, LED lights already have an advantage after approximately 1,500 operating hours over incandescent lamps in terms of costs. Even in comparison to fluorescent tubes, the break-even point for costs is around 8,000 operating hours, i.e. after a sixth of the life cycle of LED lights. Considering the high maintenance costs for hard-to-access applications such as streetlights, where changing the light source is extremely time-consuming, the total cost savings generated by LEDs in comparison to traditional light sources come to a total of around 38 percent. Some utilities companies are already converts: EnbW in Baden-Württemberg and the Italian company Enel Sole have already initiated pilot projects for LED-based street lighting. The latter intends to install 40,000 streetlights with LEDs as the light source over the next two years.

LEDs: wide ranges of colours and forms for more freedom in light design

In principal, LEDs are suitable for universal use as light sources for lamps, not just in streetlights: in interior spaces, e.g. for study, reading and desk lamps, decorative lighting, direct and indirect lighting for work benches in kitchens etc., as spotlights for stages and building sites or as components for large LED based displays. The LED modules are also a long-lasting solution for reading lamps on public transport such as trains, aeroplanes and buses. However, the different applications have their own individual requirements for light output, colour temperature and form factor. For the wide range of lighting applications, Sharp provides a correspondingly wide range of LEDs for lighting purposes. This comprises a total of approximately 50 different types, from white-light LEDs with a light output of 3.5 lumens to the high brightness modules with up to 540 lumens in five different categories of Wattage: <0.1 W, 0.5 W, 0.8 W, 3.6 W and 6.7 W. Only recently Sharp introduced two new series of LED modules: the Minizeni (as a smaller sized Zenigata) and the DoubleDome to address e.g. retrofit bulb and down light solutions respectively area light applications.



Despite all the differences, all LEDs have the same design in principle: they consist of a blue diode with a phosphorus coating. In addition to conventional yellow phosphorus, Sharp also uses a mixture of red and green phosphorus. This means that Sharp diodes cover a wider area of the natural colour space. In addition, LEDs can be manufactured in a large range of different colour temperatures. With traditional light sources, the physical properties of the gas filling and/or of the coatings of the glass skin determines the wave spectrum of the light, which provides only a small amount of leeway in the adjustment of the light properties. With white-light LEDs, specific colour temperatures can be achieved by altering the proportions of red and green phosphorus in accordance with the relevant mixture. Theoretically, white-light LEDs can be manufactured with a specific colour temperature for every application. In practice, Sharp supplies white-light LED lighting modules in four shades - 'Normal White light', 'Warm White light', comparable to a light bulb, and two shades in the field of 'High Colour Rendering White' - whereby the colour temperature lies in the range of 2,200 to 11,500 Kelvins. Light sources with warm white light up to approx. 3,000 K are mainly suitable for lighting living spaces, light sources in the average temperature range of 3,000 – 5,000 K are intended for use in general commercial lighting applications such as those in offices, public buildings and factories, whereas cooler colour tones of 5,000 K and more are particularly suitable for applications whereas high contrasts are required, e.g. in the medical sector.

By means of varying phosphorus mixtures, various 'High Colour Rendering' LEDs from the Zenigata and Minizeni series attain a CRI level of up to 90 and thereby provide high colour fastness and fidelity to detail. In general, all modules of the new Minizeni and DoubleDome series as well as all Zenigata and SAE products feature a CRI level of 80+. This is of significance in all circumstances in which artificial light may not falsify the depiction of the illuminated objects. 'High Colour Rendering' LED modules are for that reason particularly popular in areas such as photography, window-dressing for shops and the presentation of goods, and also in medical technology e.g. for OP lamps.

The compact design of LEDs provides designers with new freedom in the design of their light sources. Instead of designing lamps as a shield around comparatively large-format light sources, LEDs need only little space for mounting and therefore do not necessarily determine the overall form of the lighting application. This also means that integration into, for instance, items of furniture, ceilings, as reading lamps in car roof interiors etc., becomes substantially easier. 'Type 3228' Sharp LED modules measure as little as 3.2 x 2.8 x 0.9 millimetres. The smallest components in the white-light diode range are Ultra Small Package LEDs, with an edge length of 1.6 x 0.8 x 0.2 millimetres.

Low CRI High CRI

Even the high brightness module from the Zenigata series, measuring 18 x 18 x 2 millimetres, is much more compact than the traditional illuminants. Furthermore, LED-based lamps are much less complex systems: the starters that are needed for fluorescent tubes and low-energy light bulbs are unnecessary here.

Modular design for high product flexibility

In total, the Sharp LED lighting module range comprises just fewer than 50 different types. The greatest light output is provided by the 540 lumens series from the Zenigata series. This module has a light output of up to 540 lumens with 6.7 watt power consumption, achieving a level of brightness equivalent to traditional 40 - 60W light bulbs. Its little sisters from the 280 lumens series are similar in design, with 3.6 watt power consumption and a level of brightness equivalent to 30 – 35W light bulbs. The smallest components in the Sharp LED lighting range are the 3228 LED chips with a light output of 3.5 lumens upwards and a radiation angle of 120°.

Sharp achieves this high flexibility in light source design through the modular design of its LED components. The basic modules are individual blue LED dies coated with phosphorus, wired into a matrix fixed to a suitable substrate. For example, the high brightness module from the Zenigata series consists of 48 dies for the 6.7 watt versions, while the 3.6 watt models only use 30 dies and other models even less, connected in series or in parallel depending on the model.

Conclusion

Given their energy-saving potential and long life cycle, LEDs will rapidly gain in significance as light sources for general lighting and lamps. By 2012, lighting applications will grow to a volume of approx. USD 1.4 billion with a proportion of 12 percent on the overall LED market.

Crucial for their breakthrough on the market-place for light sources is the light output of the LEDs – what manufacturers want here is an efficiency of 100 lumens per watt and more. Once this hurdle has been overcome, the advantages of the LEDs are overwhelming: long life cycle, compact form factor, low system complexity, high energy efficiency, no pollutants and finally a wide range of different colour temperatures. Monochrome colour and RGB 3-chip LEDs will also allow the creation of designer light effects that would simply not have been possible to this extent with traditional light sources.

With the introduction of its LED lighting modules, Sharp is providing numerous marketable solutions for the use of LEDs as light sources for lamps. Used as light sources in so-called retrofit lamps, it is already possible today to substitute conventional light bulbs and energy saving lamps with LED lamps so that consumers can also directly benefit from the advantages that the new light source technology is ushering in.

www.sharpsme.com

Green Vote-Catchers?

Reported by Cliff Keys, Editor-in-Chief, PSDE

The articles and news reports covered in this issue I believe show clearly that throughout the world, governments, industry and consumers are 'getting real' about the need to conserve energy. We simply cannot go on using inefficient devices and systems which deplete the earth's resources and at the same time poison the environment in which we and our future generations will live. It's a well-used theme and one which will stay with us, but if we can sort out the politically motivated hype from the real need, we have a great opportunity to show the considerable talents of our creative engineering community, hopefully, steered by bold and innovative leadership.

I doubt that any government would support this simply because it's the right thing to do, but believe that it is indeed helpful when they actually do help the electronics industry and in particular engineering - and education in engineering - to innovate as only engineers can. With this, our industry can achieve the dramatic potential energy savings as well as providing the technology and products to provide energy from cleaner sources. Both these areas are where engineering needs to play a pivotal role.

SMA Wins the PV Inverter Race in 2009

The PV inverter market raced out of 2009, with record shipments of more than 8GW, 30% more than 2008, according to ongoing analysis from IMS Research. Demand rebounded strongly in Q3 after a weak start to the year and has remained high since.

Unsurprisingly, SMA Solar Technology remained the largest supplier of PV inverters in 2009 and increased its share of shipments to an estimated 42%. However, despite a record fourth quarter for the company, its share actually decreased quarter-on-quarter for the first time in the year. In the third quarter it shipped almost half of all PV inverters used worldwide.

Q4'09 saw huge demand for all PV products as investors rushed to complete systems before feed in tariffs were reduced in many key European markets. 2.3GW of installations were completed in Germany alone. This incredible demand resulted in 3.5GW of inverters being shipped worldwide in the final quarter. Demand has remained high into 2010 and we now see a complete contrast to the first half of last year with a shortage of components limiting the market, rather than weak demand.

The top 3 suppliers remained unchanged in 2009; Fronius International remained the second largest supplier worldwide and Kaco New Energy maintained its position as third largest. The competitive landscape changed somewhat more below these suppliers with Power-One and Sputnik Engineering emerging as winners, surpassing several suppliers to become the fourth and fifth largest in 2009.

www.powersystemsdesign.com/greenpage.htm

Same Package, 60% More Current

Part Number	B_{VDSS} (V)	$R_{DS(on)}$ (mΩ)	I_D@ 25˚C (A)	Qg typ (nC)	Package
IRFS3004-7PPBF	40	1.25	240*	160	D2PAK-7
IRFP4004PBF	40	1.7	195*	220	TO-247AC
IRFB3004PBF	40	1.75	195*	160	TO-220
IRFS3004PBF	40	1.75	195*	160	D2PAK
IRFS3006-7PPBF	60	2.1	240*	200	D^{2}PAK-7
IRFB3006PBF	60	2.5	195*	200	TO-220
IRFS3006PBF	60	2.5	195*	200	D^{2}PAK
IRFS3107-7PPBF	75	1.85	195*	380	TO-247AC
IRFS3107PBF	75	2.6	240*	160	D^{2}PAK-7
IRFP4368PBF	75	3.0	195*	160	D2PAK
IRFB4115PBF	100	2.6	195*	360	TO-247AC
IRFS4010-7PPBF	100	4.0	190	150	D^{2}PAK-7
IRFS4010PBF	100	4.7	180	143	D^{2}PAK
IRFS4127PBF	150	5.9	171	151	TO-247AC
IRFS4115-7PPBF	150	11	104	77	TO-220
IRFB4127PBF	150	11.8	105	73	D^{2}PAK-7
IRFS4115PBF	150	12.1	99	77	D^{2}PAK
IRFP4668PBF	200	9.7	130	161	TO-247AC
IRFP4568PBF	200	20	76	100	TO-220
IRFP4468PBF	200	22	72	100	D^{2}PAK
IRFP4768PBF	250	17	93	180	TO-247AC

* Package limited

International Rectifier has expanded its portfolio of high performance MOSFETs with a new series of HEXFET Trench MOSFETs ranging from 40V to 250V. The new devices feature a package current rating of up to 195A, delivering a 60 percent improvement over typical package current ratings. The new MOSFETs also provide improved on-state resistance ($R_{DS(on)}$) compared to previous offerings and are available in the popular TO-220, D^{2}PAK, 7 pin D^{2}PAK, TO-247 and TO-262 packages.

Applications

- Industrial battery
- Power supply
- High power DC motors
- DC to AC inverters
- Power tools
- Synchronous rectification
- Active ORing

Features

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- Moisture sensitivity level 1
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