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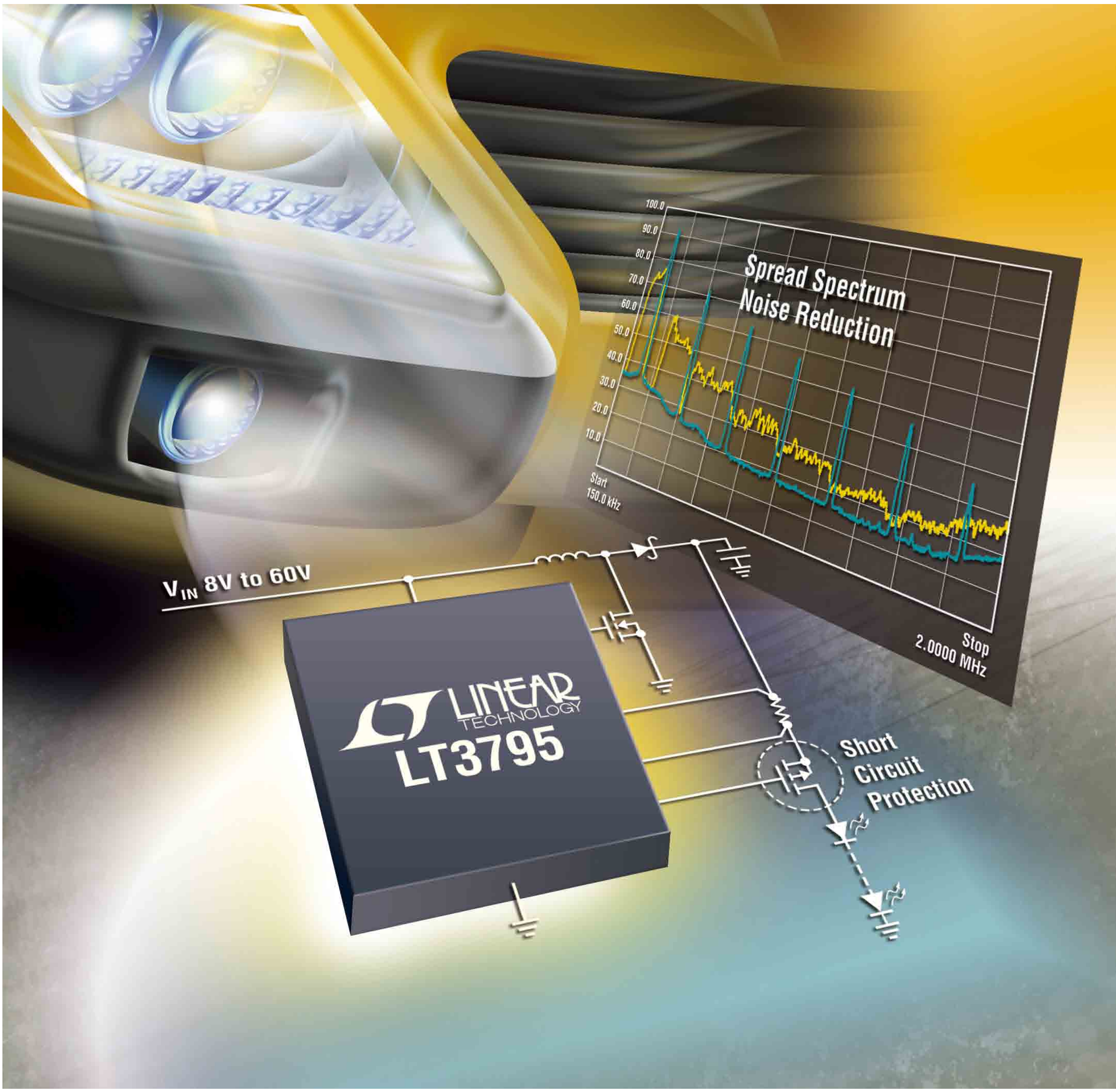

Special Report: Lighting (pg 25)

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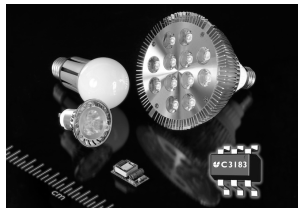
COVER STORY

LED headlights demand high-performance drivers (pg 13)



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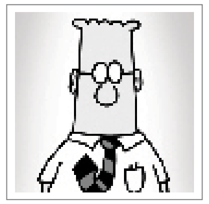

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Creating solutions for the "Internet of things"

One of the interesting things about working in the developing technology space is being constantly barraged by buzzwords and labels attempting to describe the myriad breakthroughs, developments, and trends constantly challenging us. This attempt to put a name on things can be illuminating, but the problem is that the labels applied don't often explain much. The "Internet of things (IOT)" is very straightforward, as it means pretty much what it says. It is impossible to overstate the ramifications of term and the concept behind it. (I propose we pronounce the acronym IOT as "eye-oat" just to make it sound interesting.)

At the recent Design West conference, everyone was talking about, creating tools for, and unveiling products that addressed their aspect of the IOT and how they could add value to your design process. Intelligent networks made up of wired and wireless modular building blocks from hardware and software companies provided current solutions for systems as small as a desktop and as large as a complex, while hinting at the completely enmeshed world to come.

We already take it for granted that many of our devices work within the cloud, and that number will grow as more ways are found to harness the IOT. Once a cloud-based information backplane is added to our electronic ecosystem, it will be used in ways that none of us can currently foresee. I recently did a search on a popular distribution site for RF Microcontrollers, and got 279 matches. There are so many ways to insert network-supported logic that eventually anything drawing current will be a part of the internet of things, if only for basic on/off and status commands.

There is a lot we can foresee when it comes to the IOT. We already have some functionality currently fielded; we have some functionality already in the development pipeline, and we have some functionality that everyone is expecting to see. Among the most important aspects of the IOT is its ability to manage the use of power (much of it battery-driven) in a complex and power-hungry society.

Power has coming into its own again. The growing recognition that energy usage, regardless of origin or type, is a primary value-add in a crowded and power-hungry world where reliable energy access and storage is as important an issue as clean water for modern civilization. This pressure for more and more efficiency is reminding designers that after determining primary functionality, a product's power source, usage, and budget should be among the first things specified.

As seen at Design West and other great trade shows in our industry, the design community has a very powerful palette of tools, from better semiconductors to highly integrated microcontrollers to advanced software. The IOT reminds us that a good designer must first be a power system designer.

Best Regards,

Alix Paultre

Editorial Director, Power Systems Design
alixp@powersystemsdesign.com

Low-cost LED driver IC serves LED lamps up to 20 W

Offering designers and manufacturers greater flexibility in their drive to develop lower cost and more energy-efficient A-series, GU10, and other space-constrained LED lamp types, the C3183 LED driver IC from CamSemi targets volume applications from 3 to 20 W, and is suitable for both high and low line applications (230 or 110 V). The C3183 uses recent advances in the company's patented Primary Side Sensing (PSS) and other power-saving technologies to boost system performance and energy efficiency while reducing significant costs. The device has a power factor of 0.7 without a high-voltage input electrolytic capacitor, saving cost while increasing the lifetime of the overall system. Use of quasi-resonant switching and other techniques enable operating efficiencies in excess of 90% and C3183 provides current regulation at a new 'best in class' level of +/- 3% allowing more margin for thermal design.

Features of the SOT23-6- packaged device include improved control for operation at frequencies up to 100 kHz with smaller transformers, on-chip frequency programing, and other aspects to further reduce component counts. The C3183 drives an external MOSFET, enabling one part to be specified across a wider power range. "CamSemi's new C3183 LED driver IC offers considerable design and manufacturing flexibility that allows one design to be easily adapted for multiple applications at minimum cost. Lighting manufacturers are urgently looking to develop lower cost, more energy-efficient LED lamp replacements for incandescent lamps and we believe C3183 will be a significant step towards more commercially viable, mass market solutions," said David Baillie, CEO of CamSemi.

CamSemi's LED driver IC can deliver true 'flicker-free' performance and be configured in isolated and non-isolated designs depending on the specific application requirements. Other features to further simplify design and reduce system cost include switching frequency dither and gate drive edge rate control to reduce EMI, as well as full-featured protection to guard against a range of fault conditions such as LED failure, over temperature, and output short-circuit.

www.camsemi.com

Powering F.I.R.S.T. Robotics

By: Arielle Singer, Bagel Bytes Team 702

I have been a participant of the FIRST (For Inspiration and Recognition of Science and Technology) Robotics program for the past four years through the Culver City High School. Our team's (and any team's) design decisions, from a power management perspective, are mostly limited to which of the three available motor controllers that we want to use for a given application. The voltage source is constant at 12 volts and aside from the drive motors, the robot's components are low current devices. The motor controllers adjust the voltage going through allowing motor speed to be adjusted instantly to match the situation. All 3 controllers can handle this task. However, each speed controller has some unique features.

The most basic of the controllers is the Victor. The Victor has been in use in the FIRST Robotics Competition for almost as long as the competition's existence. It has been upgraded over the years but the functionality remains the same. Victors take a Pulse Wave modulation (PWM) input that is standard to hobby RC controllers. From that input, a bank of transistors adjusts the input voltage from 12 volts to -12 volts.

The Jaguar is the standard motor controller on a FIRST Robot. It is the largest and heaviest of the controllers with an internal fan to dissipate the heat from the transistors that govern the voltage manipulation. The jaguar adds the ability to take input from both PWM signals and/or CAN Bus, letting the Jaguar give feedback such as current output and voltage variations. This data can be valuable in debugging mechanical errors by finding excess current draw as well as adding precision to drive systems by adjusting all outputs on the bus to match. The Jaguars and Victors are both capable of providing up to 480 Watts of continuous power (12V output at 40A continuous current), however the Jaguar has suffered from reliability issues in extreme situations when it burns out the transistors during quick maneuvering.

The Talon is the newest of the controllers. Smaller than a victor and possessing a heat sink, talons can do the job of a Victor without the need for as much space as a Jaguar The Talon is also capable of providing a much higher 720 Watts of output power to the motors (60A continuous output current).

Other design decisions that we can make involve protecting the components from electrical damage during the high-speed maneuvers required during competition. These include using our software to lock out motors under different condition. This can prevent overloading the main circuit breaker by running too many motors under high current conditions simultaneously. We can also off load the electrical system by using pneumatics to handle some high-force operations or use high gear ratios to reduce the amount of motor power needed to generate a given force at the point of use. With appropriate sensors, we can also incorporate automatic shutdowns of motor circuits if the current or power exceeds a certain amount for a certain period of time.

I would like to thank our Electronics mentor, an engineer from Raytheon, on the team for teaching me aspects of electronics beyond the "Plug and Play" instructions provided.

www.planet702.org

Power adapter opportunities in the LED lighting market

By: Jonanthon Eykyn, IMS Research

The adoption of LED lighting is shaping up to be one of the most radical changes to the lighting market for more than 100 years. The nature of LED products means that there is a fast growing opportunity for manufacturers of power semiconductors and power supplies for whom lighting had traditionally been a small, slow growing market.

The market for power semiconductors and power supplies used in LED lighting is forecast to be worth over $1.4 billion in 2017. That being said, the market is rapidly changing making it difficult for suppliers to get a foot-hold or find the right applications to target.

The power adapter market is fast approaching one of the largest changes to have ever affected the market. The cell phone adapter market, historically one of the largest applications in the market, is forecast to start declining in 2014. Although handset shipments are projected to continue to increase, the adoption of the wired universal charging solution is set to remove chargers from the box and so reduce the overall market in an attempt to reduce waste. Therefore, the major manufacturers of power adapters have been searching for the next "big thing" to help boost their sales and LED lighting is already becoming that.

Many of the leading suppliers of power adapters and chargers have already entered the LED lighting market to some degree but this has not always proved to be as lucrative as initially hoped.

The retrofit LED lamp market is projected to be by far the largest LED lighting application in unit and revenue terms. Several power adapter manufacturers have produced products aimed at this sector, typically very lower power AC-DC power supplies often mounted on a disc shaped board to fit into the base of the lamp. However, LED lighting manufacturers have been favouring a discrete solution, bypassing the power adapter manufacturers completely. Whilst the retrofit LED lamp market looks to be a limited market for power adapters, there are other opportunities. One of the fastest growing markets for power adapters over the next five years is projected to be low-power LED lighting applications such as spotlights, office lighting and other internal illumination. The majority of these products are generally under 50W and use an external power adapter.

Demand for external power adapters used in LED lighting is increasing rapidly with unit shipments set to increase eight-fold from 2013 to 2017. Price pressure is very high in the LED lighting market owing to LED luminaire manufacturers trying to drive down costs as well as power supply manufacturers attempting to capture market share. However, revenues for power adapters are still forecast to more than triple to over $400 million in five years, creating a lucrative opportunity for suppliers.

www.imsresearch.com

Flyback power supply development: Part IV

By: Dr. Ray Ridley, President, Ridley Engineering

This article is the fourth of a series in which Dr. Ridley shows the steps involved in designing and building an offline flyback converter. The power transformer is added to the circuit, and the current sensing and snubbers are designed to operate at full power without excessive stress on the components.

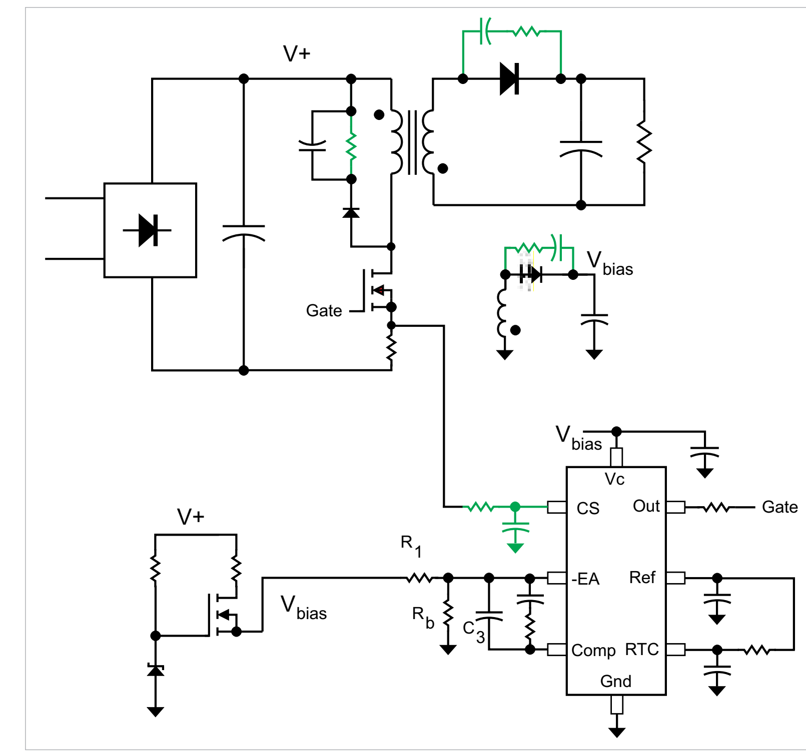

Figure 1: Schematic of the flyback converter. After the transformer is inserted, the elements in green have to be selected and tuned.

Power Transformer Testing

Figure 1 shows the schematic of the flyback converter with the transformer inserted into the circuit. Before applying the full load on the circuit, the elements in green have to be selected and tuned for proper operation. Current limiting is key to reliable operation of PWM converters. At low power levels, a sense resistor in series with the power FET is adequate to detect the current flowing when the switch is on. Design of this resistor is such that the peak voltage is just below the maximum allowed voltage at the input to the PWM comparator. For the 384x series of controllers, this is limited to 0.9 V, and most PWM controllers have a similar limit. For offline design, this voltage drop across the sense resistor does not represent significant power loss. With higher power converters, the use of a current transformer is recommended.

Figure 2a shows the raw unfiltered waveform on the source of the FET. There is a large leading-edge spike due to parasitic resistances and reverse recovery of the secondary diode, and this has to be filtered with an RC network so that it does not trip the PWM comparator.

Figure 2b shows the waveform after the filter. It is still very noisy, but this is due to the probing technique used. If the tip of the scope probe and the ground lead is removed, and the scope probe connected very close to the test points, the waveform of **Figure 2c** results. Now it can be seen that there is a clean signal. The leading edge spike is removed, but the waveform is not so heavily filtered that the current sense

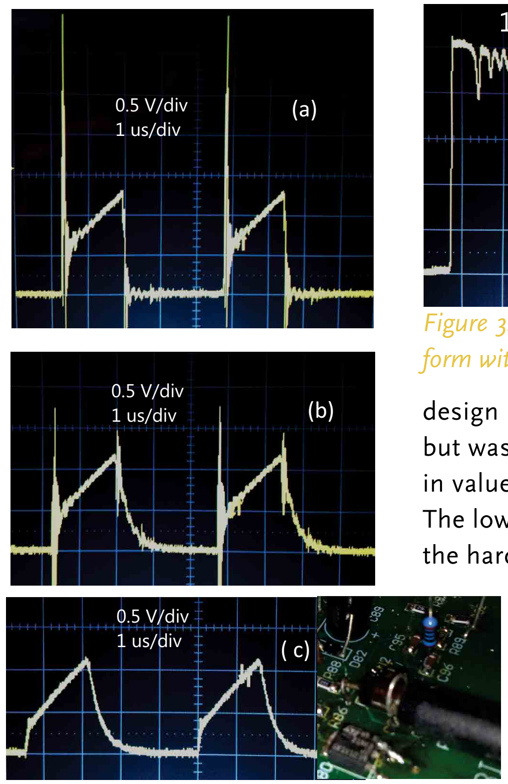

Figure 2: Primary current-sense signals (a) at source of FET (b) after RC filter and (c) with proper probe placement.

information is lost.

The proper test for correct filtering is that there should be no false triggering, but also no current runaway on startup of the converter. This should be tested early on in the design process (after the snubber design below) to make sure that the circuit is properly protected.

Primary Clamp Design

Figure 3 shows the primary switch drain waveform for the main power FET. The clamp circuit was designed using a high-speed, fast recovery diode and a 0.01 F capacitor. The resistor was selected by the

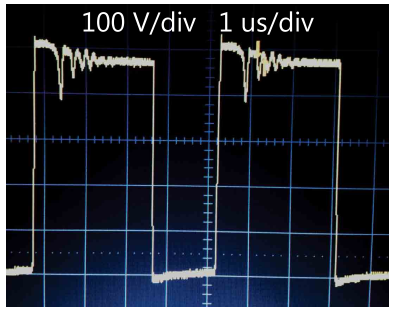

Figure 3: Primary switch drain waveform with RCD clamp.

design program POWER 4-5-6, but was subsequently adjusted in value by circuit observation. The lower the value of resistor, the harder the voltage on the FET is clamped, but at the expense of higher power dissipation. You can find an article analyzing this process in reference [2].

Secondary Snubber Design

After designing the primary clamp, the secondary snubber was addressed. During the process of looking at the secondary diode voltage, the ground of the scope probe inadvertently touched the wrong node of the circuit, resulting in an explosive failure. (Normally when writing papers, researchers don't mention the failures. However, for those of you who are new to power supply design, this is a standard part of the process. You will make mistakes, and with high-voltage power supplies, they will result in catastrophe sometimes.)

In this case (**see Figure 4**), the components in red shown in the circuit diagram were destroyed, including the FET, control chip, gate resistor, current sense resistor, and current filtering resistor. Even seasoned power supply designers have failures in their circuits [3], and this is often exacerbated by the dense packaging of modern electronics.

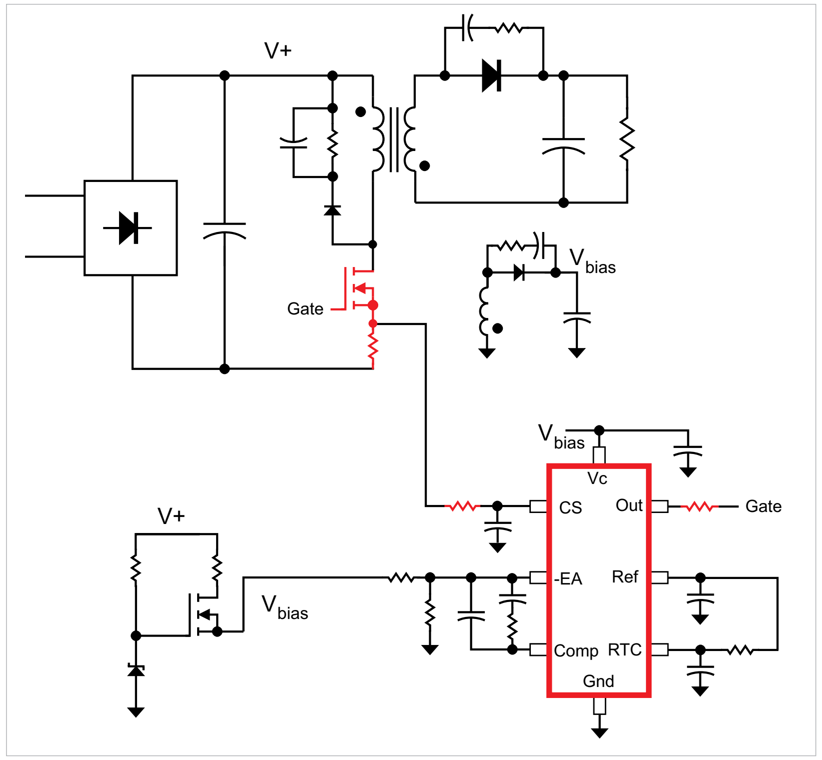

Figure 4: Components in red failed after touching the wrong circuit node with the voltage probe, shorting the transformer secondary.

With the failed circuit components replaced, the waveforms shown in **Figure 5** were observed on the main output diode. There was very substantial ringing due to the hard reverse recovery of the diode, and an RC snubber needs to be added to damp this. This is done according to the process to be found in reference [4].

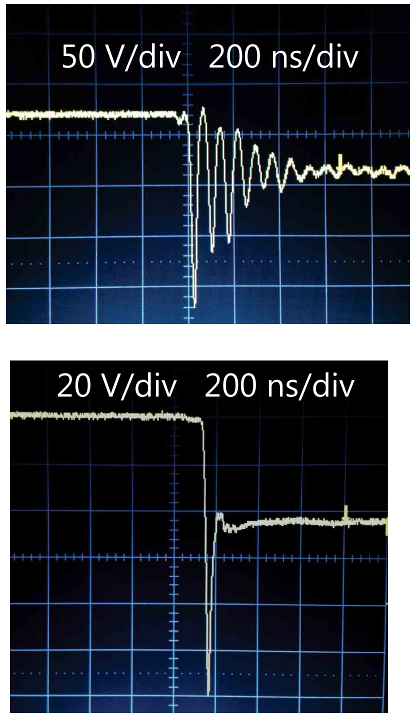

Figure 5: Secondary diode waveform before and after RC snubber is added. The peak stress from the voltage spike can be reduced if an RCD clamp is used on the secondary side.

Even after the RC snubber was added, there is significant overshoot on the diode. This can be fixed as in the primary by using an RCD clamp. Normally this is not done on the secondary side of a flyback, but it is an option if you want to use a lower voltage part for better efficiency. Of course, the dissipation in the RCD clamp will impact the efficiency, too.

The reverse spike can also be eliminated by choosing a much smaller magnetizing inductance of the power transformer, and running the converter in DCM. In this case, higher currents will flow in the switch as a tradeoff to

Main Output Voltage	Output Current
15.03 V	0.43 A
14.59 V	1.02 A
14.26 V	1.55 A
Regulated Bias Output 15.02 V	30 mA
Main Regulation Band	5.2%

Table 1: Output voltage regulation data with different loads.

the elimination of the spike. The optimal design point for your power converter will depend on many factors, and trying different transformers and values experimentally is a useful process.

Full Power Operation and Regulation

It is convenient early in the testing process to close a loop on the converter, even though you may not be ready to do full control analysis and an aggressive design. For low power circuits, you can add a large capacitor C3 in the circuit from the –EA to the COMP pin, in this case 4.7 μF was used. The value of the resistor R1 in Figure 1 was chosen to be 100k, and Rb was chosen to set the feedback voltage to be 15 V.

The combination of R1 and C3 form a low-gain integrator, and this allows the circuit to regulate on a slow basis. This is convenient for doing experiments on the power stage and transformer, and for verifying the DC regulation of a converter early in the design process.

(This is not necessarily a recommended procedure for high power converters. The very slow loop created allows for a large voltage overshoot on the output during startup and transient events, and this can potentially cause damage to the converter or to the loads.)

For this flyback converter design, as for the forward converter in reference [5], the objective was to regulate from the bias winding, and to design the transformer in such a way that the main output tracked the auxiliary output as closely as possible. With good tracking, an optocoupler and feedback amplifier (typically a TL431) can be avoided in the circuit design, saving parts cost and complication. As you can see from the **Table 1** above, the total voltage range was 5.2% with a 4:1 load range on the main output. Since the output voltage here was designed to be used to feed another switching regulator, the much variation is acceptable.

The regulation can be improved with more loading on the bias output, but this has a big impact on light load efficiency. In some modern green power applications, the additional dissipation is not acceptable.

Summary

The fourth part of this series has described the full power operation of the flyback converter. A combination of empirical design and calculations was used to set the proper values of snubbers, clamps, and the current sensing circuit. For offline converters, it is crucial that the current sense filter be designed properly so that it does not allow current runaway during startup. It must also be free of false-tripping issues due to the leading edge spike.

In the next part of this series, the control loop will be examined. It will be seen that the cross-coupled regulation has some interesting effects on the gain of the converter.

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LED headlights demand high-performance drivers

Driver solutions must be efficient, robust, compact, and cost effective

By: Jeff Gruetter, Linear Technology

Although LEDs have been used in many automotive lighting applications such as daytime running lights (DRL), brake lights, turn signals and interior lighting for several years, headlamp specific applications are relatively new. Currently, only a handful of production vehicles are offered with LED headlamps, including the Honda Accord (**Figure 1**), Acura RLX and MDX, Audi A8 and R8, Lexus's LS600h and RX450h, the Toyota Prius, Cadillac's Escalade and Porches Cayenne. Some industry estimates indicate that the current LED headlamp market is approximately $1.5B for 2013 and is expected to surpass $3B by 2015 and continue to grow exponentially.

One of the biggest challenges for automotive lighting systems designers is how to optimize all the benefits of the latest generation of HB LEDs. HB LEDs require an accurate and efficient DC current source with a means for dimming and must offer a variety of protection features. Additionally, these LED driver ICs must be designed to address

Figure 1: 2013 Honda Accord Touring/Hybrid LED DRL & Headlamp

these requirements under a wide variety of conditions. As a result, power solutions must be highly efficient, robust in features and reliability while being very compact and cost effective. Arguably, the most demanding applications for driving HB LEDs are found in automotive forward lighting applications, in both DRLs and headlamps as they are subjected to the rigors of the automotive electrical environment, must deliver high power, typically between 15W to 75W, and must fit into very space constrained enclosures, all while maintaining an attractive cost structure.

LED DRLs & Headlamps

Benefits, such as small size, extremely long life, low power consumption and enhanced dimming capability are the catalyst for the wide spread adoption of HB LED DRLs and headlights. Several manufacturers, such as Audi, Mercedes and most recently, Lexus and Honda/Acura have used LEDs to design very distinctive DRLs as "eyebrows" or "underlines" around the headlights as part of their unique branding. Not only are these applications very distinctive from a design perspective, they also create several design challenges to offer a reliable

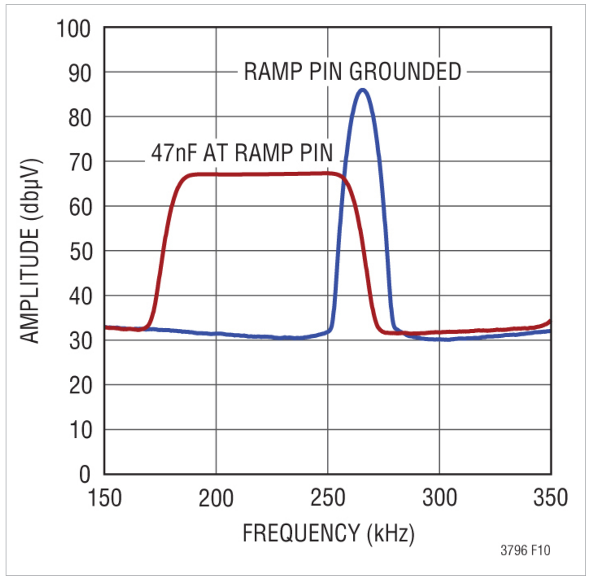

Figure 2: LT3975 Output Noise Spectrum Comparison (Ramp Pin Grounded = Conventional Switching, 47nF at Ramp Pin = Spread Spectrum)

and cost effective solution. As HB LEDs are adopted into both the low beam and high beam of the headlights, these challenges become even more pronounced.

Design Parameters

In order to ensure optimal performance and long operating life, LEDs require an effective drive circuit. This means that the driver ICs must deliver an accurate and efficient DC current as well as accurate LED voltage regulation regardless of the variations of the input voltage source. Secondly, they must offer a means of dimming and also provide a wide array of protection features just in case a LED open or short circuit is encountered. In addition to operating reliably from the electrically caustic automotive power bus, they must also be both cost and space effective.

Stop/Start, Cold Crank & Load Dump Conditions

Although automotive systems power bus operates from a nominal 14V when the alternator is charging the battery. Different scenarios in a cars operation can cause this voltage to temporarily drop to as low as 6V during a cold crank or stop/start scenario. A cold crank scenario pull high levels of current out of the battery to compensate for the high viscosity of the engine oil in very cold days, this is turn can pull the voltage down to ~6V. Similarly, a vehicle that uses a stop/start function can also pull the battery voltage to ~6V as the engine restarts, while the battery is heavily loaded with lighting, air conditioning and other amenities while the car's engine and alternator were turned off. A load-dump condition occurs when the battery cables are accidentally disconnected/reconnected (i.e. loose) while the alternator is still charging the battery, resulting in transient voltage spikes as high as 60V.

Short-Circuit Protection

For both DRLs and headlamps, the number of HB LEDs in a single string ranges from 6 to as many as 20. As the nominal input voltage is 13.8V and even lower in some transient conditions, a boost-based LED driver architecture is generally preferred as it is more efficient, simpler and more cost effective than a SEPIC or buck-boost design. However, until recently boost architectures have been difficult to protection against short circuits. This is particularly important in automotive applications as the LEDs are susceptible to damage in a front-end collision, and any electrical arcing can ignite any spilled gasoline. For this reason, in the past, most front lighting LED applications used a more costly and complex SEPIC solution which has inherent short-circuit protection. However, with the emergence of new boost LED drivers with very robust short-circuit protection, future applications will use this design to offer a more efficient and cost-effective solution.

EMI Concerns

Reducing any electromagnetic interference (EMI) of LED drivers is beneficial to the overall power buss design. As LED drivers are usually based on switching regulators lowering the level of switching noise is desirable. This can be achieved by incorporating spread spectrum frequency modulation. As can be seen in **Figure 2**, this modulation scheme lowers the output switching noise by 20db by spreading over a wider frequency range dramatically reducing EMI concerns.

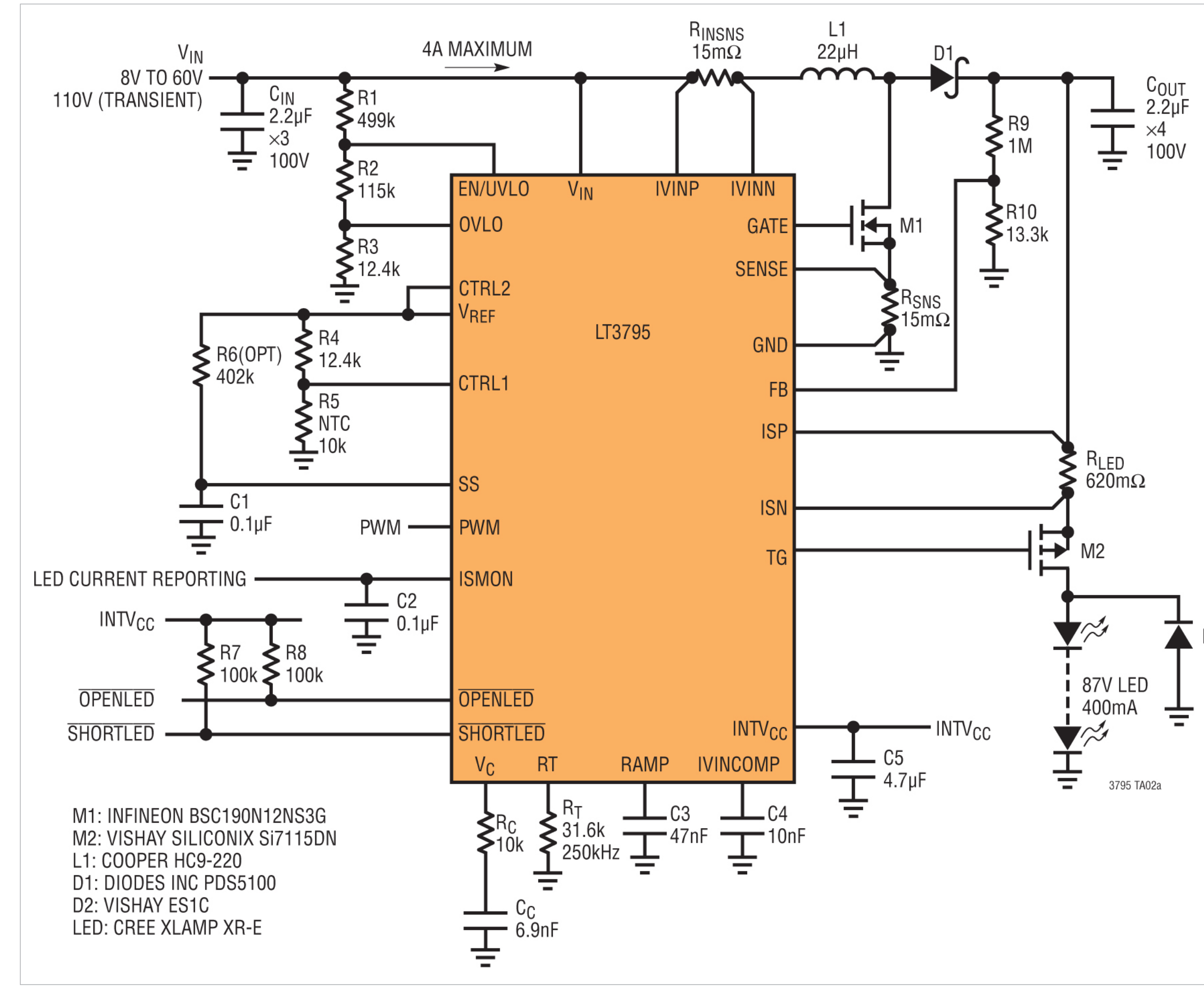

Figure 3: 93% Efficient 50W (87V, 575mA) Buck LED Driver with Input Current Limit & Spread Spectrum Frequency Modulation

A New Automotive HB LED Driver Controller

One example of a solution to this dilemma is the Linear Technology LT3795 LED driver. The LT3795 is a boost DC/DC LED driver that can deliver over 100W of LED power. Its 6V to 110V input voltage range makes it ideal for a wide variety of HB LED applications found in automotive, commercial truck and even avionic systems. Its high side current sense design can be configured in boost, buck-boost, SEPIC and buck mode architectures offering a wide range of design flexibility. Additionally, its output voltage can be set from 0V to 110V enabling to drive a wide range of LEDs in a single string, while offering very robust and simple short-circuit protection in a boost design.

A typical 50W headlight application is shown in **Figure 3** below. This application uses boost architecture to deliver up to 87V of LED voltage, which can drive as many as 20 LEDs with LED currents in excess of 600mA. Most DRLs use between 8 and 15 LEDs in the 350mA range, whereas low beam headlights will use approximately 50V of 1A LEDs and high beams can use as much as 2A @ 50V. The LT3795 can be used for both of these applications.

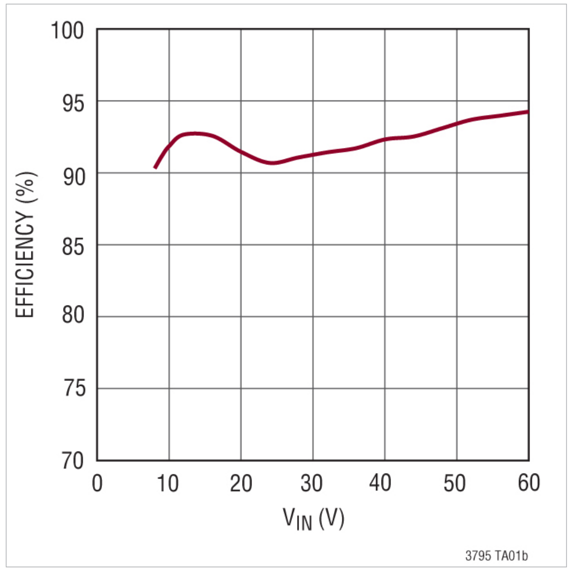

Figure 4: LED Efficiency of Figure 3 Using the LT3795

The LT3795 incorporates a high-side current sense, enabling its use in boost, buck, buck-boost or SEPIC and flyback topologies. Additionally, it offers both input and output current limiting and monitoring for added reliability and design flexibility. The LT3795 can also deliver efficiencies of over 94% in boost mode, minimizing the need for external heat sinking (see **Figure 4**). A frequency-adjust pin enables the user to program the frequency between 100kHz and 1MHz, optimizing efficiency while minimizing external component size and cost. Spread spectrum frequency modulation can be activated for improved electromagnetic compatibility by lowering switching noise by 20db.

The LT3795 has an integrated short-circuit protection feature that stops the regulator from switching when a short circuit is detected and disconnects the LED array from the power path. Furthermore, it reports a short-circuit condition on the SHORTLED pin. After short-circuit protection is enabled, the LT3795 can be programmed to utilize a hiccup mode to see if the short-circuit has been corrected or a latch off mode which requires the EN/ULVO to be toggled to restart the device. This feature offers very robust short-circuit protection for both boost and buck-boost applications, regardless of the output voltage. Additionally, the LT3795 also offers open LED protection and reporting so the LEDs aren't damaged, if one of the LEDs if one in the string experiences and open-circuit. (See **Figure 5**.)

The LT3795 delivers LED current accuracy of +3% which ensures constant lighting in an LED string while +2% output voltage accuracy offers several LED protection features and also enables the converter to operate as a constant voltage source. The LT3795 can utilize PWM dimming to offers dimming ratios as high as 3,000:1 or analog dimming for ratios up to 20:1. Additional features include output disconnect, input and output current limits/ monitors, and integrated fault protection. Its high level on integration and thermally enhanced TSSOP-28 package offer a very compact HB LED driver solution.

www.linear.com

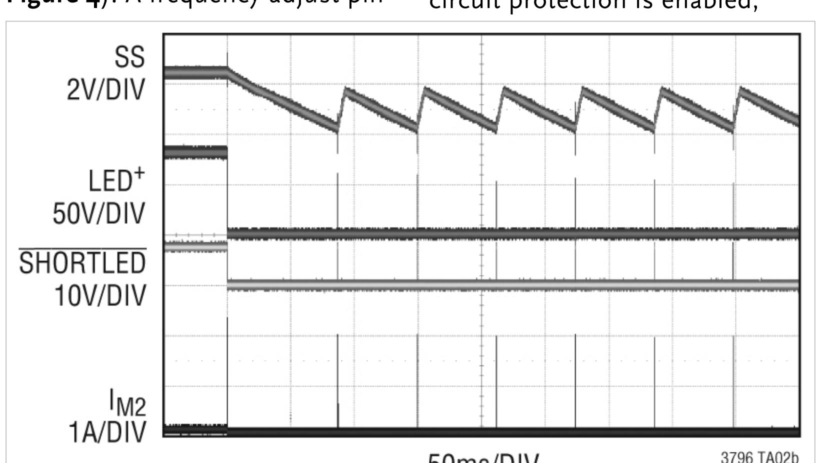

Figure 5: Short-Circuit Protection in Hiccup & Latchoff Mode for Circuit in Figure 3

Power conditioning in LED applications below 35W

Choosing the wrong approach can impact cost and reliability

By: Alexander Craig, Fairchild Semiconductor

By and large, the power supply of an LED light has to perform three functions: power conditioning, power conversion, and load control. To reduce cost in low-power applications, especially those running under 35W, the goal is to incorporate all three power-supply functions into a single stage. Of the various topologies available, this usually narrows it down to two -- a single-stage flyback PFC topology or a single-stage buck-boost PFC topology. But even then, after deciding to go with one or the other, there are still a number of decisions to be made.

In particular, there are several ways to manage power conditioning. Depending on the approach used, the power factor correction (PFC) and total harmonic distortion (THD) can be off, and choosing the wrong approach can impact cost and reliability. This article looks at some of the things to consider when evaluating a topology for its ability to perform power conditioning.

The importance of PFC

PFC circuits don't really improve the efficiency of the LED driver's power converter stage, but they're often required by law to calculate usage charges. Several regulations, including those issued by the California Energy Commission and the European Commission ErP Directive, have specific criteria for handling the power factor. Power factor (pF) is defined as the ratio of real power to apparent power. Electricity companies charge based on actual wattage used divided by pF.

Here's how it works: to output 800 lumens, an incandescent bulb uses 60W of power with a pF of 1.0. The consumer will pay for 60W of power (60W/1) to run the incandescent. An equivalent CFL bulb, though, outputs the same 800 lumens using only 13W, with a PF of 0.5. The consumer will pay for 26W (13W/0.5) to run the CFL. With an LED lamp, producing 800 lumens requires just 9.5W, with a PF of 0.98. The consumer will pay for only 9.7W (9.5W/9.8) to run the LED.

Since PFC is a requirement in so many places, it's important to use a power supply that supports it. Some topologies offer PFC as a built-in function, while others require the designer to add it separately.

Zeroing In On The Right Topology

If the design requires an isolated supply, then the flyback topology is the best choice. If not, then the buck-boost topology may result in higher efficiency. There are more options for flyback configurations, so we'll look at those first.

A common choice for an isolated flyback circuit is one that uses secondary-side regulation (SSR), meaning it has an optocoupler, a voltage reference, and a fast loop bandwidth of 1kHz to react to load charges. This type of supply also usually has a high-voltage electrolytic capacitor after the bridge rectifier, and doesn't have a built-in PFC circuit. There are several reasons why this kind of circuit is a bad choice for low-power LEDs. First, the SSR format is usually set up with a constant-voltage supply, but LEDs are better driven with a constant-current supply. For this reason, it's better to use a primary-side regulated (PSR) supply. Second, the presence of high-voltage electrolytic capacitors can shorten the life of the supply and third,

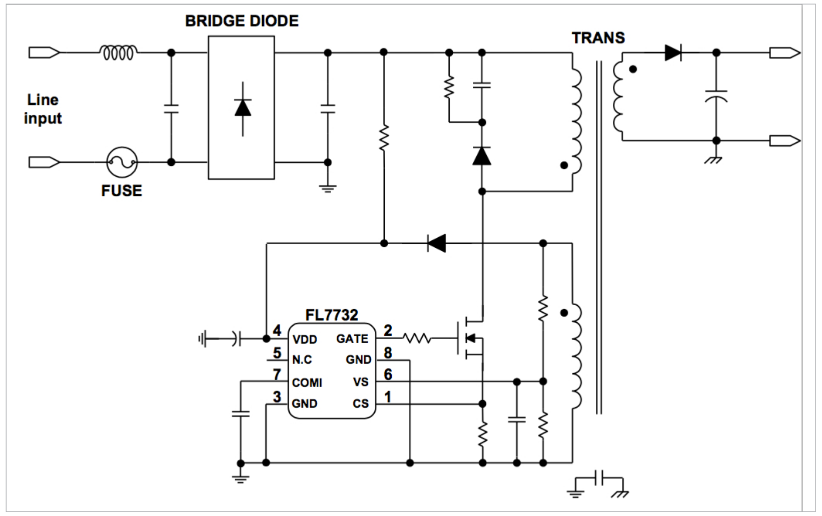

Figure 1: LED Driver with FL7732

having to add PFC to the design, by using a valley-filled circuit or a passive PFC circuit, increases cost and reduces efficiency.

Combining a PSR pulse width modulation (PWM) controller with a valley-filled circuit for PFC is another option, but the THD of this circuit is usually too high for use in an LED lamp. It also uses the high-voltage electrolytic capacitors that can impact reliability.

Another approach, which provides very good PFC and low THD, uses a two-stage format with a boost PFC circuit followed by a secondary-stage DC/DC converter. But having two stages isn't ideal, since it increases the size and cost of the design, and this approach doesn't solve the issue of using high-voltage electrolytic capacitors.

Yet another approach is to use a boundary conduction mode (BCM) or critical conduction mode (CCM) PFC control IC with a fixed on-time variable scheme for frequency switching. The PFC is good, but the design places restrictions on the turns ratio of the transformer. These restrictions can force the use of higher-voltage MOSFETs (800V to 900V), and that in turn can impact efficiency as there can be fairly high losses in the MOSFET and the snubber circuit.

Getting high PFC without the restrictions on turns ratio is possible when operating in discontinuous conduction mode (DCM) with a fixed on-time and fixed switching frequency for any given line or load condition. A quasi-resonant (QR) flyback control IC, which includes a high-voltage pin, soft start, and other features, is also an option.

Input Voltage	Min Current	Max Current	Tolerance
$90V_{AC}$ /60Hz	347mA	357mA	±1.5%
$110V_{AC}$ /60Hz	345mA	360mA	±2.1%
$140V_{AC}$ /60Hz	342mA	352mA	±1.5%
$180V_{AC}$ /50Hz	342mA	356mA	±2.0%
$220V_{AC}$ /50Hz	340mA	351mA	±1.7%
$265V_{AC}$ /50Hz	336mA	347mA	±1.7%

Table 1: Constant-Current Regulation With Line Compensation (FL773x)

Fairchild has developed two controllers, the FL7732 and the FL7730, that use a single-stage DCM topology with PSR. There's no need for a high-voltage input capacitor or SSR feedback circuitry. The two controllers build on Fairchild's TRUCURRENT® control technology, which has been highly successful in charger applications. Using TRUECURRENT calculation as the basis, they add two features just for LED control: line compensation and, in the case of the FL7730, dimming control. **Figure 1** shows the FL7732 configured as an LED driver.

Line Compensation

In the FL7730 and FL7732, the line compensator receives information about the line voltage form the Vs pin and uses it to modify the peak current circuitry. This allows for extremely tight tolerances and constant-current regulation over a wide input voltage range. **Table 1** gives the measured results from an evaluation board. Over the input voltage range of 11V to 28V, the deviation for constant current is less than 2.1 percent.

Dimming

The dimming-control function of the FL7730, shown in **Figure 2**, is a simple resistor divider network with an RC filter that converts the duty cycle of the AC line voltage into a DC voltage. The DC voltage is placed on the dedicated DIM pin.

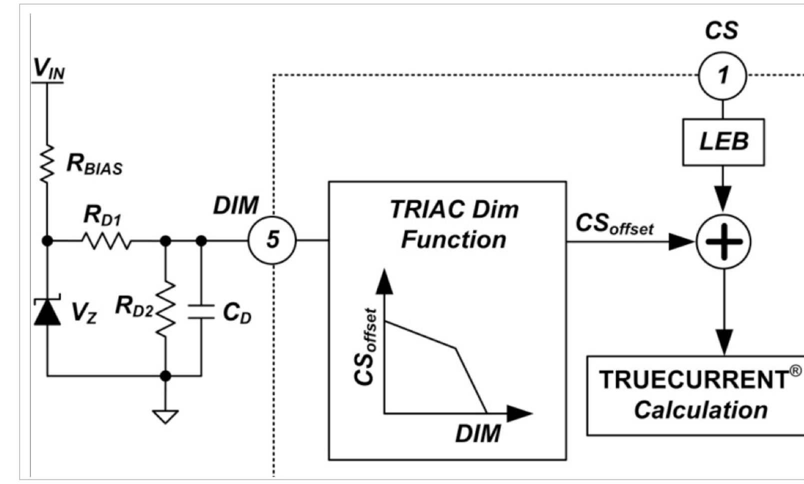

Figure 2: Dimming Control in the FL7730

A two-angle control block is used to offset the current-sense measurement and is used as an input to the TRUECURRENT calculation block. This simple yet effective method of controlling the intensity of the LEDs can be used with virtually all forms of dimming control, from simple DC- and PWM-input approaches to more complex TRIAC-based control.

Flyback or Buck-Boost

A non-isolated DCM buck-boost topology is basically the same, from the perspective of primary-side control, as an isolated flyback topology. For this reason the FL7732 and its integrated MOSFET versions the FLS3217 and FLS3247 along with the dimmable version FL7730 can be used in a Flyback or buck-boost configuration. All that's needed is to equate the turns ratio to the inductor ratios between the winding and the primary inductor.

This can be a very efficient approach if the LED configuration takes advantage of being non-isolated and is set up as a high-voltage, low-current string. The result is lower copper (I^2R) losses in the magnetics and no snubber losses. The topology still achieves very high pF and very low THD.

Conclusion

There are several ways to achieve perform power conditioning in a low-power LED design, but single-stage flyback and buck-boost topologies, with PFC, are generally the best options. Fairchild has developed two controllers, based on its proven TRUECURRENT technology, that are good choices for either topology. Offering line compensation and optional dimming, the FL773x controllers enable high-efficiency LED power supplies with fewer components and minimized cost.

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The no-load power crunch: 30 mW and beyond

No-load/vampire and standby power are hot buttons today

By: Adnaan Lokhandwala, Texas Instruments

The need to reduce active-mode power consumption is somewhat obvious. What has not been so obvious is the need to minimize power drain in standby and no-load when products are essentially doing nothing. Several studies have been performed worldwide to quantify this consumption by domestic equipment and AC power adapters, with emphasis on its environmental impact. The International Energy Agency (IEA) estimates that five to 15 percent (depending on country) of household electricity consumption is wasted in these modes and accounts for one percent of the global CO_2 emissions. This resulted in tighter regulations and new industry-specific initiatives encouraging manufacturers to develop more efficient AC/DC designs.

External power supplies (EPSs) have been in the forefront of these energy-saving discussions because it is the cumulative effect due to the billions of units sold each year and they do not have an on-off switch. Left plugged in the wall, these chargers continually consume power even when the device it powers is disconnected. Consumers are also becoming increasingly interested in green products. Many equipment manufacturers are developing designs that use energy more efficiently and marketing it to give them a competitive edge. The ultimate goal is to reduce the device's power drain to zero when not in use. The key is to achieve this performance at a reasonable cost.

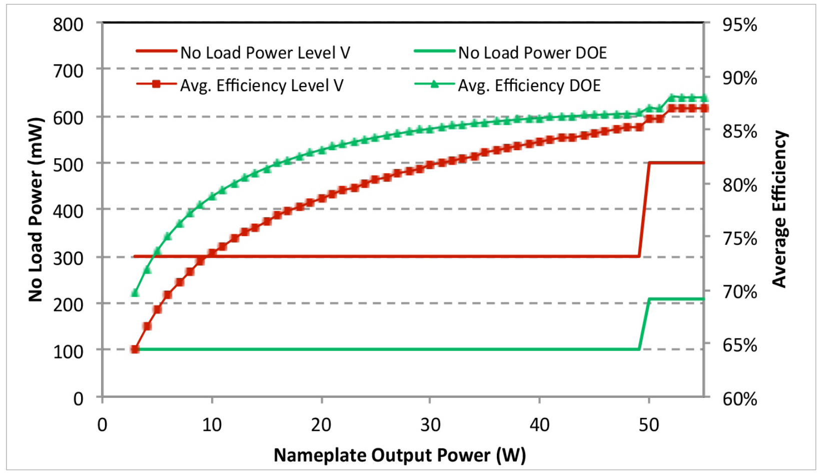

Figure 1: DOE proposed regulations vs. Level V performance for a 5V output EPS

Regulations driving green performance

Many global regions are introducing mandatory and voluntary limits for no-load power consumption and operating efficiency of EPSs. In the US the main drivers are California Energy Commission (CEC), which is mandatory, and the voluntary Energy Star program from the US Environmental Protection Agency (EPA). Energy Star defined the International Efficiency Marking Protocol (Level I-V) in 2006, which set the minimum efficiency and no-load power consumption levels for EPSs. Similarly, the European Commission has issued the Energy Using Products (EuP) Directive Lot 6 applicable for standby and off-mode losses of EuPs. In 2011, they lowered this level to 300 mW for adapters ≤ 51W or 500 mW for adapters > 51W. The IEA 1-Watt initiative to reduce standby power use by any appliance to not more than 1W in 2010, and 0.5W in 2013 has driven regulations in many countries and regions.

In March 2012, the U.S. Department of Energy (DOE) issued a Notice of Proposed Rulemaking (NOPR) that lays out the first mandatory regulations for external battery chargers and further tighten regulations on EPSs. In the Level VI standard, the proposed regulations significantly tighten and expand the range of the current minimum efficiency requirements. The proposal contains seven new product classifications (B-E, X, H & N), and multiple output and >250W EPSs. In **Figure 1** the performance requirements per this new regulation for a 5V output direct operation EPS (Class C) are compared with the current Level V standards.

The European Commission's Integrated Product Policy Program (ECIPP) and the world's top mobile phone makers introduced a voluntary energy rating system for mobile phone chargers, making it easier for consumers to determine which ones use the least energy at no load. The rating system ranges from five stars (<30 mW no-load power) for the most efficient chargers down to zero stars for chargers consuming the most energy (see **Figure 2**).

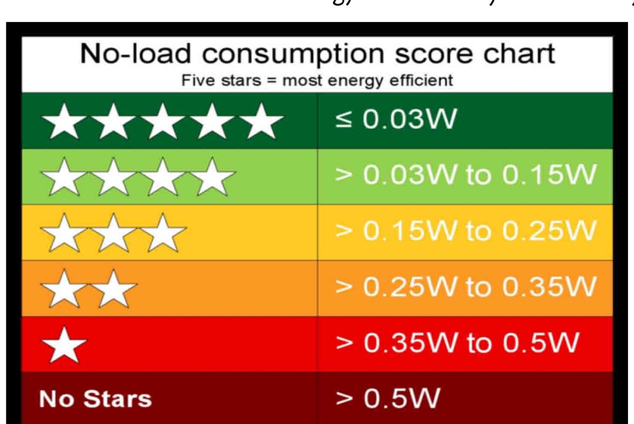

Figure 2: EC-IPP five-star charger rating for mobile phone chargers

There is a strong momentum building in the EPS market to push this 30 mW no-load performance point beyond the mobile charger market to higher power applications like tablets, ultra books, notebook, TVs, and other electronics. Minuscule power consumption within the power supply leaves much more power available for use by electronic systems designed to comply with standby power limits. For example, a power supply that consumes only 10 mW at no-load allows a higher margin for other leaky circuit components (such as input filters, capacitors, and bias components), while still providing the power required to support system standby activities like remote activation, LCD display panel, and the like.

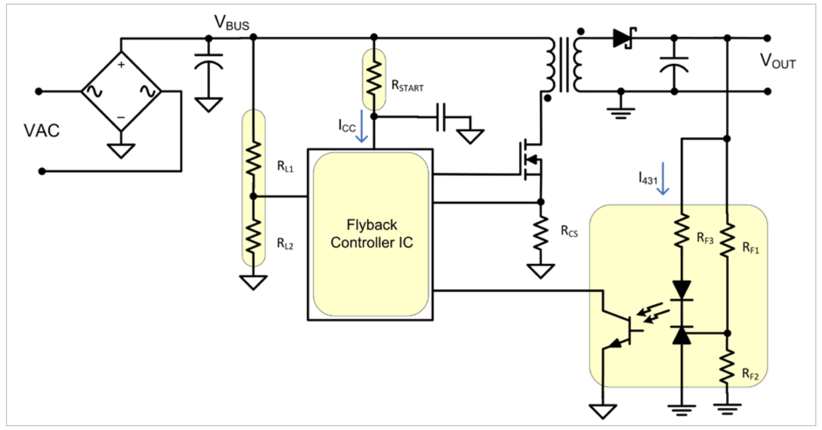

Figure 3: Conventional AC/DC flyback architecture

Understanding no-load power losses

The flyback topology remains the preferred choice for non-PFC EPS adapters due to its simplicity and low cost. Four key elements that contribute most to the system no-load power losses are highlighted in **Figure 3**: startup bias resistor, input line sense network, IC bias power (no-load current, switching frequency, etc), and feedback bias power. An electromagnetic interference (EMI) filter, snubber and MOSFET switching losses make up the remaining no-load power consumption.

Resistive start-up circuits are used in power supplies to start the controller IC when the AC input is first applied. There is a tradeoff between start-up time and no-load power. To decrease start-up time, RSTART must be lowered, which increases no-load power. (See **Equation 1**) Most designs also require AC line brownout protection to disable the power supply and prevent over-heating (if thermistor thermal protection is not included). This function usually is implemented with high-voltage (HV) line-sensing resistors that add to the no-load power consumption. (See **Equation 2**)

$$P_{START\_UP} \approx \frac{V_{BUS}^2}{R_{START}} \qquad \text{(Eq. 1)}$$

$$P_{LINE\_SENSE} = \frac{V_{BUS}^2}{R_{L1} + R_{L2}} \qquad \text{(Eq. 2)}$$

Typical AC/DC power supplies have a feedback network to send the error signal from the isolated secondary to the primary-side controller via a TL431 shunt regulator and optocoupler. There are two fundamental issues with this approach: a) the TL431 needs a minimum cathode bias current (I_{431_MIN}) under all conditions; and b) the standard optocoupler configuration consumes the most current at no-load conditions (I_{431_SAT}). The overall losses from this feedback network are shown is **Equation 3**. Note that this loss becomes a significant portion of the no-load power budget when the converter output voltage increases. The IC current consumption during no-load I_{CCNO_LOAD} (quiescent current + the averaged MOSFET gate-drive current) is accounted for in **Equation 4**. For example, a recent state-of-the-art 5V/2A USB wall charger was tested for no-load power consumption and measured 121 mW at 230V AC.

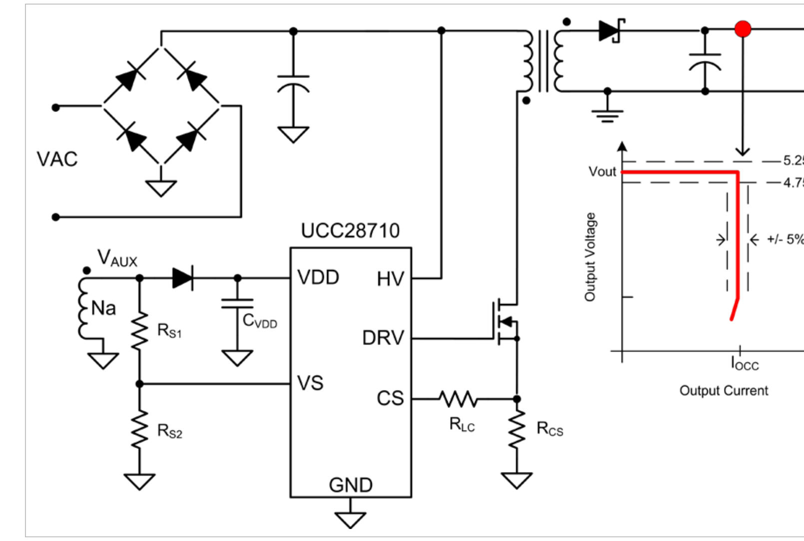

Figure 4: Simplified flyback schematic with a CVCC controller with PSR

(Eq. 3)

$$P_{FEEDBACK} = \frac{V_{OUT}^2}{R_{F1} + R_{F2}} + V_{OUT} \times I_{431\_sat}$$

(Eq. 4)

$$P_{IC} = V_{CC} \times I_{CCNO\_LOAD}$$

Green power: low no-load power + high average efficiency

How does a constant-voltage, constant-current (CVCC) controller with primary-side regulation (PSR) like the UCC28710 [1] simplify AC/DC designs and help achieve best-in-class efficiency with no-load power performance? The controller regulates the output voltage and output current within five percent accuracy without optocoupler feedback. It processes information from the primary power MOSFET and an auxiliary winding on the power transformer for precise CVCC control (see **Figure 4**).

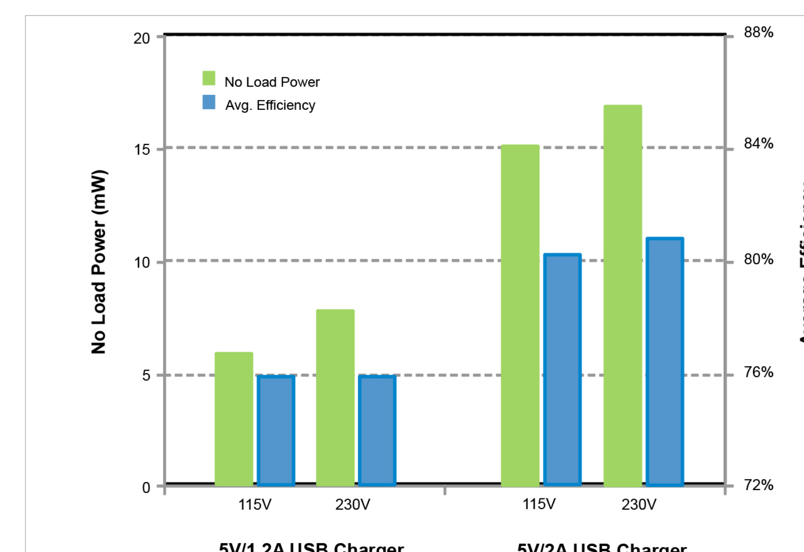

Figure 5: Test data for smartphone (left) and tablet (right) charger designs using UCC28710

The UCC28710 implements three key features to support ultra-low no-load power consumption: an internal 700V JFET start-up switch, dynamically-controlled operating states, and a tailored modulation profile. The 700V JFET allows the IC to cut off the current path from the HV DC bus after the IC is turned on and has a leakage of less than 1 μA in the off state. The controller enters smart sleep modes as the converter load decreases and reduces its average current consumption down to 95 μA during no-load operation. The IC control algorithm modulates the converter switching frequency and primary current peak amplitude (FM and AM) to provide a wide dynamic operating range of output power to achieve ultra-low no-load power, and also maintains high conversion efficiency across line/load. Other green features include converter valley-switching to reduce MOSFET switching losses, and line under-voltage protection (quasi-brownout) without any direct line-sensing resistors.

For example, two USB chargers were designed using the UCC28710: one at 5V/1.2A for smartphones, the other at 5V/2A for a tablet application. Test data for the two designs are summarized in **Figure 5**. The controller enables ultra-low no-load power consumption (8 mW and 17 mW respectively when operating at 230V AC), while the optimized modulation scheme also facilitates achieving high average efficiency. Please refer to references 2 and 3 for full test data and bill of materials for these designs. Efficiency can be further improved by implementing synchronous output rectification [4, 5].

Summary

With billions of power supplies in use today that typically are left plugged in and unused for an average of 20 hours a day, the issue of no-load power is cumulatively huge with a correspondingly huge payback potential, if carefully addressed with industry regulations and smart power supply design choices. Devices like the UCC28710 green-mode flyback controller address this global need for green power supplies with the added benefit of offering a lower total component and solution cost.

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Special Report: Lighting

EUROPE

Power Systems Design: Empowering Global Innovation

Inside:

Automobile lighting in the face of things to come

Demands on automotive lighting have increased in the last decades

By: Mike Godwin, Osram

Going from lanterns to LEDs, in a nutshell, describes the course of development in automotive lighting since cars first came on the scene 100 years ago. What originally served only a functional purpose has long since evolved into a matter of design. For example, every vehicle can be given an individual appearance, thanks to its characteristic lighting. In this light, LED compact light diodes open up a world of new possibilities.

In the early days of the automobile, the aesthetics of illumination still played a subordinate role. Lights have dominated a car's since they were lanterns placed on the outside of the vehicle. As early as 1925, during the era of light bulbs, Osram made a significant contribution to automotive lighting: Bilux double-filament lamps, which were the first lamps to use only one lighting source for both dimmed light and head beams, thus improving lighting conditions. Since the 1970s, halogen car lamps have become established as the standard, and to this very day they are built

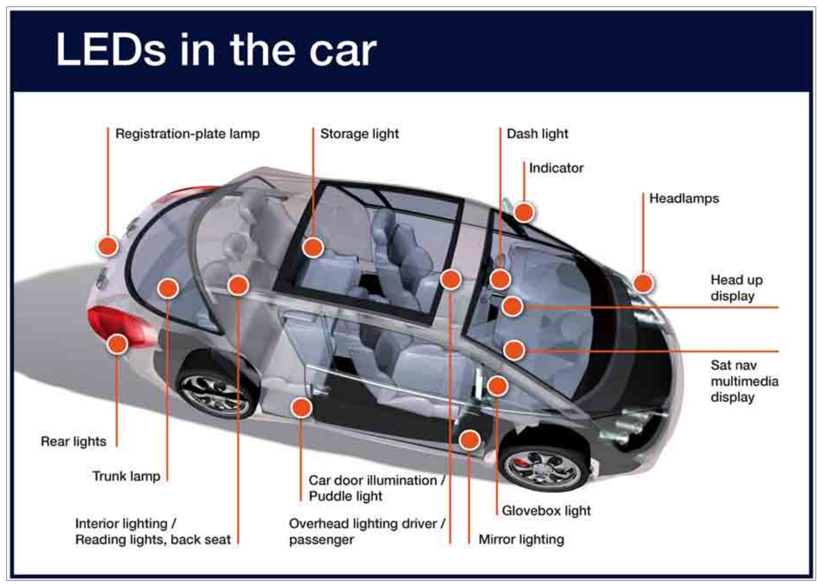

Figure 1

into approximately 90 percent of all vehicles. However, with this source of lighting being used, it is very difficult to realize a unique design.

Headlamps with glow-discharge lamps – so-called Xenon lamps – entered the market in the 1990s. The color temperature is similar to that of daylight. This is what makes the Xenon light appear whiter and thus enables better sight, especially in bad weather. What is more, the „high-tech" look of the lights adds to the design of the vehicle. Therefore, Xenon lights are offered as optional original equipment in more and more cars, contributing significantly to their look.

LED: characteristic at first sight

Nevertheless, three little letters will change the future face of automobiles: LED. They combine the practical aspects of the car's design with aesthetic factors in all respects. The compact light diodes, which originally merely served as substitutes for the very small light bulbs in vehicle cockpits, are presently conquering the entire spectrum of automotive lighting. Their greatest benefit: they require only little space and can be arranged in virtually any imaginable way. Hence, not only can they be used as singular, point-shaped light sources, but also as solid lighting strips or illuminating surfaces. They combine a variety of different functions, such as dimmed lights and indicators, within one single luminaire and provide space for even more functions – for instance a night vision device. The manufacturer-specific definition of function and configuration ensures a striking design, also at night. (**Figure 1**.)

When used as rear or front lighting, LEDs succeed in giving modern vehicles a "facial" appearance with a clear recognition value. In the new BMW models for instance, the characteristic lighting rings have been replaced by light diodes. In the latest Audi A8 and CLS-Coupé by Mercedes-Benz, for instance, LEDs for the first time combine all headlamp functions: dimmed lights as well as high beams, motorway lights, curve lighting and all-weather lighting are all realized with the light diodes in the Osram Ostar Headlamp Product platform by Osram Opto Semiconductors. Lighting strips, lighting points or surfaces create an appearance entirely different from the round headlamp bulbs formerly used, which clearly distinguishes the vehicle from other cars. In this regard, the possibilities for designing are boundless – with LED technology the front lighting is no longer restricted to one headlamp located on each side. Instead, it is also possible to integrate solid strips of light, or to apply lighting surfaces vertically or arched around the mudguard. (**Figure 2**.)

Safety and Design

By now, LED vehicle front lighting has left the niche market of small series and luxury vehicles and is successfully established within large scale production. Following up on the success of daytime headlights, LED headlamps, too,

Figure 2

Figure 3

are now conquering the middle class market. With a market leader like Osram Opto Semiconductors, which provides a vast product range, illuminating visions can now become reality.

Yet LEDs do not only win over manufacturers of automobiles with regard to design or lighting quality. The fundamental advantages of LED, such as their long durability (up to a maximum of 50,000 hours) and their robustness, as well as their defined lighting radiation characteristics, set new standards.

As is the case with Xenon lights, LEDs also generate a light similar to that of daylight, which increases contrast sensitivity. Especially in the peripheral field of vision, where passers-by, animals or poorly lit vehicles can suddenly appear out of nowhere, these objects are noticed better thanks to the white LED light. An additional benefit: because the color temperature is so close to that of sunlight, drivers' eyes do not tire as quickly. At the end of the day, this technology has the potential of preventing numerous accidents that may happen at night.

Universal application

The "face" of a vehicle is its most distinctive feature – but manufacturers also use LEDs for rear lights or the interior of a vehicle in order to distinguish their cars from other designers'. For instance, in the interior of the vehicle LEDs can be applied as mood lights in the roof lining or foot-well area. The range varies from manufacturer-specific colors, which also create a unique ambience in the interior of the vehicle, right up to individually customized colors. The drivers can enjoy their individual interior for as long as they have their vehicle.

After all, the lifespan of high-quality LEDs exceeds that of the vehicle. What is more, with LED technology, a variety of different lighting profiles can be configured in accordance with specific driving situations: the light of the vehicle's interior adapts to the light of the streets in town, thus becoming lighter, while on an unlit motorway the lighting is reduced – either by decreasing the number of LEDs in use or by a dimming function. The latter is operated by brightness sensors, the respective speed, or manually. (**Figure 3**.)

Illuminated radiator grille as a vision of the future

The launch of new vehicles, such as electrically powered cars, will become another milestone in automobile design. The design idiom, which is adapted in accordance with alternative modes of driving, will have a significant impact on the design of both the interior and exterior lighting of vehicles and increase the call for distinctiveness. Developers have already tested this when designing radiator grilles: when the battery is being charged, the front of the car might be lit up in blue, or the current mode of the vehicle might be indicated by the light behind the lamellae. In any case, LEDs will be indispensable for the future of automotive lighting.

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Lighting Control - How much do you need?

A main drivers for new lighting technologies is the focus on reduced energy consumption

By: Dave Cooper, AEG

Lighting controls are becoming ever more sophisticated with the capability to provide real-time data on system status, settings, light levels, energy consumption, etc. For some applications this level of sophistication is extremely beneficial but there are many applications where a simpler approach can pay off. This article describes a wireless lighting control system that can offer a high degree of flexibility and control capability without the complexity of some centralized systems.

In the past, lighting has been seen as a market with little need for sophisticated power management. All that was needed was a fuse or circuit breaker, a switch and possibly a dimmer. This is rapidly changing with the advent of dimmable electronic rather than magnetic ballasts for fluorescent and HID lights, and most recently with the increasing adoption of LED lighting. Every LED luminaire requires a DC power source with well-controlled output current, and in most cases industry regulations also dictate control of power factor, standby power, harmonics and efficacy in terms of light output (lumens per watt).

One of the main drivers for new lighting technologies is of course the global focus on reduced energy consumption together with reductions in CO_2 emissions. In addition to the energy savings inherent in the new technologies, there is now a rapidly increasing focus on controlling the light levels to more closely follow the needs of the users. This takes it one step beyond efficiency of light production, to consider the effectiveness in terms of light levels actually needed. The days of lights blazing all night in empty offices and unused parking garages are coming to an end.

A basic feature set

A modern lighting control system must provide a number of basic features: control of brightness in response to time of day, ambient light level and presence of users; ability to configure the response to suit a particular location; and simple installation and setup. In addition to these basic features, it is desirable to be able to operate with a wide range of luminaires and with different lighting technologies. The lighting technology itself will dictate the degree of control that can be achieved, from fully dimmable LED lighting with virtually instantaneous response, to legacy HID lighting with magnetic ballast that can take several minutes to switch on and cannot be dimmed.

To cover the widest possible range it makes sense to have a dedicated, programmable control module that can interface with any standard lighting ballast or driver through a standard control interface, such as the analog 0-10V standard or the digital DALI interface. It also makes sense to include a relay to switch power to a non-dimmable lamp ñ this same relay can completely shut down power to a dimmable driver to reduce standby consumption.

Flexible configuration dictates a programmable system, while simple installation is best achieved with wireless control

Figure 1: Lighting control module

since it avoids the need to install dedicated control wiring. There are many different wireless options available, some of which are proprietary, and others that are based on industry standards. There are obvious benefits in the use of a standard wireless communication protocol, both in terms of the readily available components and the extensive testing carried out by the standards consortium.

Wireless luminaire considerations

However, the published standards generally only define the protocol used and other factors such as the output power, the antenna and the mounting into the luminaire are critical in ensuring reliable communication in field conditions. Several manufacturers offer this kind of wireless module, for example the one shown in **Figure 1**.

The control module itself determines the basic capabilities of the system, and must have sufficient capacity and features to support the intended lighting installation. The module illustrated is based on a wireless mesh network standard, and uses an external antenna to provide optimum performance and flexibility. It operates from wide range AC input, and can switch up to 5A/500W of lighting load. It has a standard 0-10V dimming output, and includes inputs for motion sensor, lumen sensor and temperature sensor. The auxiliary output can be switched to 5V, 12V or 24V for added flexibility in choice of sensors.

This module provides the hardware interface, but most of the functionality comes from the firmware in the module, while user convenience is determined mainly by user-interface software.

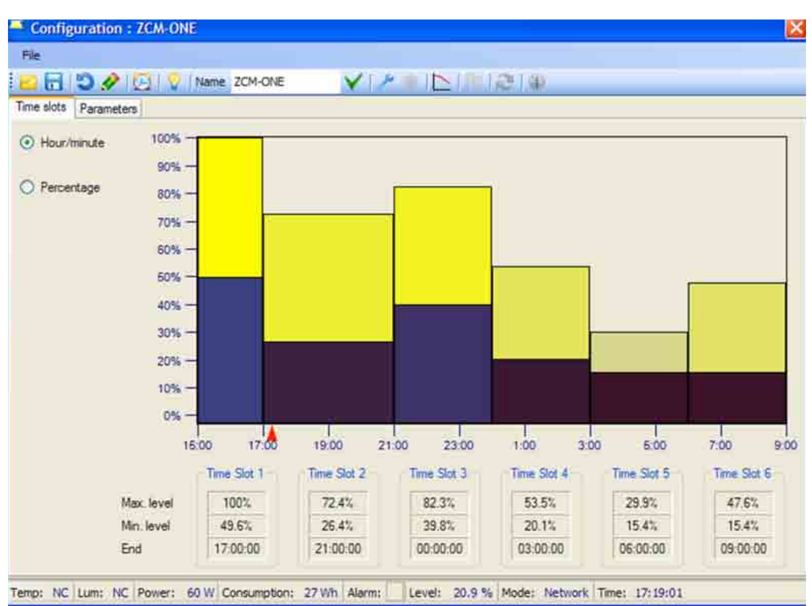

Figure 2: Drag and drop brightness setting

There are two basic approaches to the software: a standalone system that can be configured and then left to operate; or a fully comprehensive central system that provides real-time data collection, as well as remote monitoring via the internet.

Right-size your design

A well-designed standalone system can provide all the flexibility and lighting control options needed in smaller installations, and can avoid the added costs and complexity associated with the central monitoring system. It is not always necessary to be able to measure the instantaneous power consumption and present the data in a graphical format, or to be able to monitor the system status from the other side of the city or the other side of the country. For these less-demanding applications what is more important is a user interface for programming that is as simple and convenient as possible.

For example, the interface shown in **Figure 2** uses a drag-and-drop approach to set the brightness levels in different timeslots through the night, and to adjust the duration of the timeslots. There are two brightness levels in each timeslot, the lower when there is no motion and the higher when there is motion. This software runs on a standard PC (no need or expense of an additional gateway) and communicates with the luminaire module using a wireless USB dongle. An equally simple screen allows linking between sensors and lights just by a series of check-marks in a table, as shown in **Figure 3**. A final screen allows the user to configure the response to the motion sensor and lumen sensor, shown in **Figure 4**.

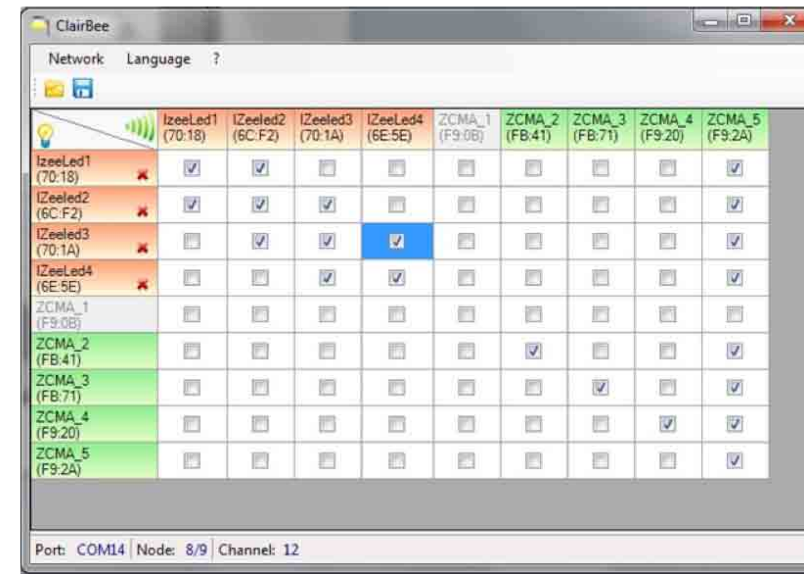

Figure 3: Associating sensors with luminaires

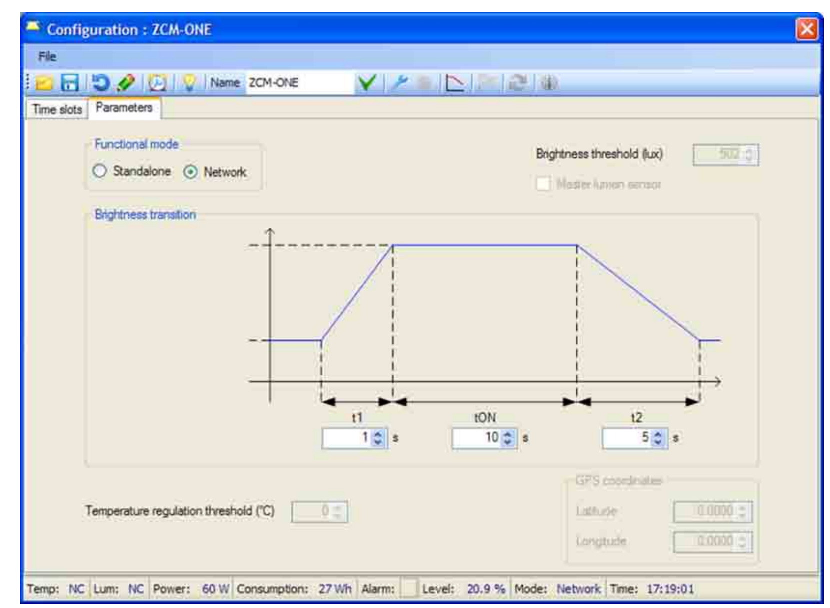

Figure 4: Response to sensors

Once the system has been configured, the PC can be removed and the lights will continue to operate as they have been programmed. There is no need for further intervention unless the user wants to change some of the settings.

This system also provides a readout showing the current conditions including power consumption, temperature, brightness setting, and internal time. This information can be useful during setup, and can also help with troubleshooting when necessary. Other features include the ability to assign a name to each luminaire, programmable compensation for LED lumen degradation, and the ability to store and recall parameter settings at will.

This type of simple lighting control can never provide all the features needed or wanted by everyone in every application. Its strength is to be cost-effective in those applications where the main focus is on return on investment through energy savings, and where centralized monitoring is a lower priority.

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Integrated power management enables smaller machine vision systems

Solutions integrate multiple switching regulators, LDOs, and supervisory/watching timers into a single chip IC

By: Maurice O' Brien, Product Marketing Manager, Analog Devices

As the form factor of machine vision systems continues to get smaller while the processing power in these systems continues to increase rapidly. Power management is becoming a more important design aspect for new machines vision systems. The latest FPGAs and processors used in machine vision systems today have a common requirements of needed multiple rails to power them. Traditionally the power supply for these FPGAs and processors required multiple discrete switching regulators and LDOs. In these discrete power designs the switching regulators where used to power the high current core rails and the LDOs used to power the more nose sensitive, lower current clocking rails.

New more integrated power management solutions are being developed to meet the smaller PCB area requirements such as in machine vision systems. These new multi-channel integrated power management solutions that integrate multiple switching regulators, LDOs and supervisory/watching timers into a single chip IC, significantly reduce the solution size, cost and design time of typical multi rail power supply for an FPGAs. As customers design cycles continue to shorten it is becoming more important to have a single power IC that generates multiple rails that are very flexible and easy to configure so that this one multi-channel IC, can be used in different applications/configuration quickly and easily reducing design time and reducing time to market for new products. (**Figure 1**.)

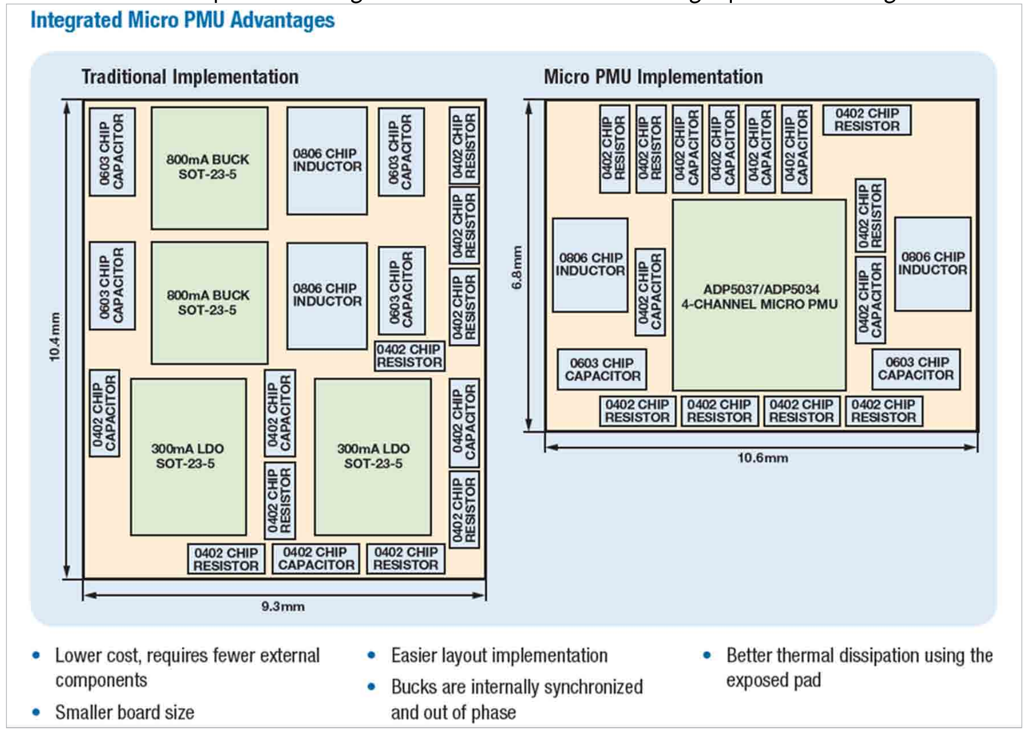

Figure 1

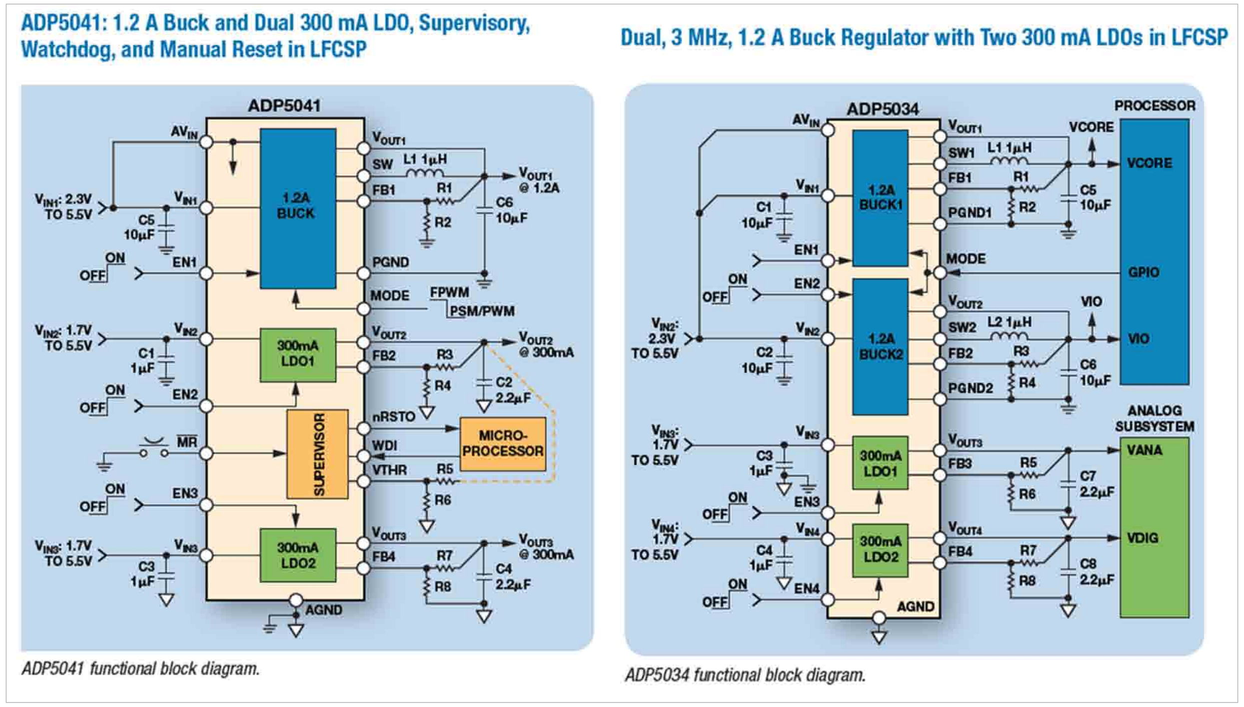

Figure 2

The Advantages of using uPMUs to power FPGAs and Processors include:

- Cost effective solution
- Small board footprint
- Can simplify sequencing and voltage tracking
- Low Noise, switchers out-of-phase operation, reduces EMI
- No need for external synchronization signal
- Easy to use, does not need much power expertise
- Less components and improved reliability

Let's look at four of these key advantages in detail:

Solution Size

By integrating multiple switching buck regulators, LDOs, supervisory and watchdog functionality in to a single chip solution, the PCB area of a multi-rail power supply solution can be significantly decreased. The ADP5034 is a dual 1.2A buck regulator with two 300-mA LDOs in a 24-LFCSP package and provides a good example case. The ADP5034 enables a new generation of highly integrated multi-output regulators that require very little board space by integrating multiple switching regulators and LDOs in a single package. The integrated switching regulators operate at 3MHz switching frequency allowing very small chip inductors to be used, significantly reducing the total solution size. The ADP5034 total solution size is only 72mm square.

Ease of Use

As the design cycle of new products continue to decrease, the need for new power management solutions that are easy to design initially but also easy to modify for future design requirements is becoming more important to meet new product release dates. The ADP5041 multi-output regulator provides a 1.2A buck regulator with two 300mA LDOs along with an integrated power on reset and watchdog timer for high reliability processor based systems. All the ADP5041 integrated regulators have dedicated enable pins to allow maximum flexibility for the power supply designer to enable/disable each of the three regulators in hardware without any software overhead, enabling easy power supply sequencing for the three rails. The output voltage of each of the three regulators is set using an external resistor divider again allowing the power supply designer to quickly and easily change the output voltages during prototyping and for new design re-use requiring a different combination of output voltages. The combination of individual enable pins with resistor programmable output voltages on each integrated regulator of a multi-output regulator significantly help power supply designs reduce the design complexity and design time help to get new products to market sooner.

Less Components and Improved Manufacturing Reliability

Figure 2 shows an example layout of a discrete dual 1.2A buck regulator and dual 300mA LDO power solutions against the single chip ADP5034 multi-output regulator. The discrete power solution requires 22 components to be placed on 97mm2 PCB area compared to the ADP5034 solution of 19 components to be placed on 72mm2 PCB area. The ADP5034 solution requires 35% PCB area and saves the cost of placing 3 components, the cost of placing a component on a PCB can be as high as three cents, when the cost of purchasing, inventory, placement, inspection are considered. The more components that you have to place on a PCB the higher the risk of manufacturing defects, by reducing the number of components to be placed on a PCB the cost of manufacture is reduced but the reliability of the manufacturing process is increased.

Low Noise Solutions

A dedicated MODE pin on the switching buck regulators can be conveniently controlled by a microprocessor GPIO port forcing the switching regulators to operate in constant PWM mode, this can be necessary when the supplied circuit (Transceiver, ADC, Audio) is sensitive to wide band noise due to the burst operation of a switcher when operating in light load condition. The LDOs integrated into these multi-output regulators have an input voltage range of 1.7 V to 5.5 V, the low input voltage range of the LDOs allows them provide a very high efficiency low noise output by combing one of the buck regulators with an LDO. For example the buck regulators can be used as pre-regulators to give a high efficiency drop from a 5V input to 1.8V output on the buck regulator, this 1.8V is then applied to the input of the LDO to provide a very low noise 1.2V output voltage for powering very sensitive analog circuitry with very high power efficiency from the initial 5V input. The integrated LDOs have high PSRR, even with a low Vin-Vout headroom, and low inherent noise, in addition cross-talk between regulators has been minimized. All these characteristics are important when supplying noise sensitive circuits.

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Advanced LED drivers for automotive instrument clusters

It is no longer sufficient to simply drive the LED with discretes

By: Raimund Wagner, ROHM Semiconductor Europe

The usage of LEDs in automotive applications continues to grow due to their longer service life and lower power consumption. Simultaneously, the diversity and size of integrated state-of-the-art instrument cluster displays and in parallel the increasing complexity of automotive instrument clusters increase the demand in the LED technology. It is no longer sufficient to simply drive the LED with discrete components.

What is really needed is a precise and constant light output for the different LEDs while dimming as well, for example, to different ambient light conditions. Demanding automotive environments also require several protection circuits and diagnostic functions in order to prevent a complete failure due to a single component in the fault state. Moreover, the fact that more and more performance has to be accommodated in a small space puts high demand onto the electronic circuits.

Ultimately, a technological solution should also satisfy the different requirements of the automotive manufacturers in terms of color scheme, and provide the appropriate versatility and design options. This article will describe one approach to a 12-channel LED driver solution which ROHM feels provides an ideal answer to these requirements, and which is well-suited for applications including a large number of LEDs such as automotive backlight applications.

An LED driver can be developed in a way that it provides a combination of serial and parallel LED control in order to address displays in instrument clusters, specific panels as well as panel elements in the center console such as air conditioning and radio. Components with this feature offer developers the flexibility to drive LEDs in various applications with a single driver and therefore save development and qualification time. Such highly integrated LED drivers have many advantages over simple current limiting circuits, as they reduce the need for external components and take up less space on the PCB.

ROHM has developed an LED driver which includes twelve constant current drivers in a single chip to control a large number of LEDs, a 6-bit per channel power calibration, and a global PWM brightness control as well as diagnostic functionality. Combined with the ultra flat RGB LEDs of the SRGB series the AEC-Q100 qualified device in a compact HTSSOP20 packaging offers a complete solution for automotive clusters.

The first requirement for the LED power management is to provide constant current with high accuracy at the outputs to avoid fluctuating supply voltage and different LED VF values as well as different influences on the LED current and thus unwanted brightness variations.

ROHM addressed this via a three-channel serial input (Serial-in, clock, latch-in) that controls a total of twelve driver channels to drive multiple LEDs with an output current of 15 to 50 mA per channel. The regulation of the maximum current is done via an external resistor. If additional power is needed, multiple channels can be activated in parallel. Via the serial interface register settings can be read too in order to verify

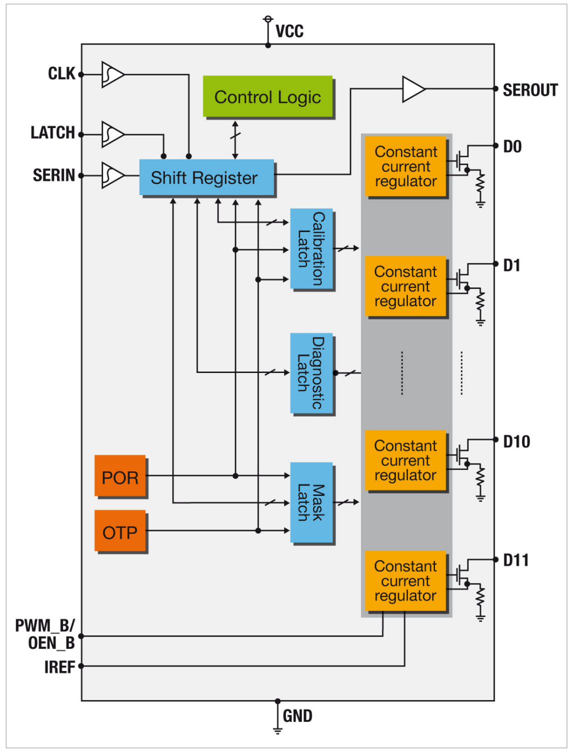

Figure 1: BD18377 block diagram

the settings at any time. This way, the driver can also address the built-in diagnostics functions. It also enables the detection of open or shorted connections (faulty LEDs) and to take appropriate countermeasures in order to prevent the failure of the entire system. (**Figure 1**.)

Similarly, a too high temperature on the chip can be detected as well. If the temperature rises above 125° C, a warning indicator is set within this solution while the chip remains fully functional. However, measures can be taken (for example the reduction of the brightness of the global PWM dimming) to prevent that the temperature is further rising. In such a case, multiple LED drivers can communicate with each other by means of a proprietary communication line to reduce the performance. In case that the temperature still rises, a power-on reset is conducted when it exceeds 150°C in order to protect the chip from irreparable destruction.

The BD18377 device also sets standards when it comes to output current accuracy. At 30 mA, an accuracy is achieved of + / -2.5% from channel to channel (of one device) as well as of +/-1,7% between two different devices. The brightness of each LED can be individually adjusted via current control, calibrating from 1,6% up

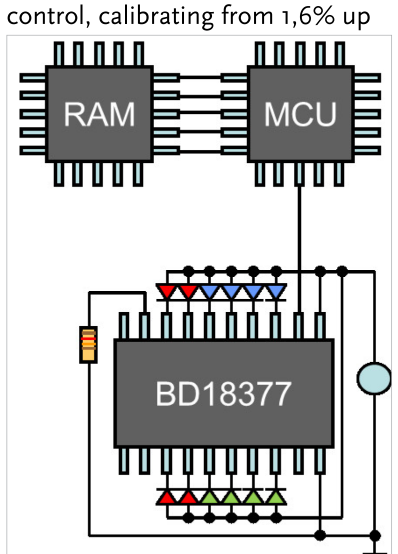

Figure 2: Example application with four red, blue and green LEDs

to 100% (6 Bit). Additionally, a global calibration of 0.1% to 100% is possible via PWM. Thus, LEDs with different brightness from different binnings can be deployed without having these adjusted to different resistor values. Only the register settings must be adjusted to the deployed LEDs. This way, subjective differences between LEDs featuring different colors can be regulated as well. (**Figure 2**.)

Advanced dimming

The latest panel specifications define a brightness range that starts at very low light intensities, and can be widely scaled. Moreover, in order to implement different RGB color combinations, each LED must receive a dedicated dimming signal which can be set separately. **Figure 3** shows the calibration and dimming of the output current and the ratio of these two settings. The maximum current I_{Dmax} is adjusted via an external resistor R_{ext}. The adjustment of the calibration bit changes the current value of the associated channel while the duty cycle in all active channels is simultaneously regulated through the PWM input. The PWM input is completely independent of the clock signal.

The use of a "PWM Control CR timer" block in addition to the switching regulator enables the adjustment of the modulation frequency and the duty ratio for a given product at a fixed resistor capacitor combination. The time required for the design is in this

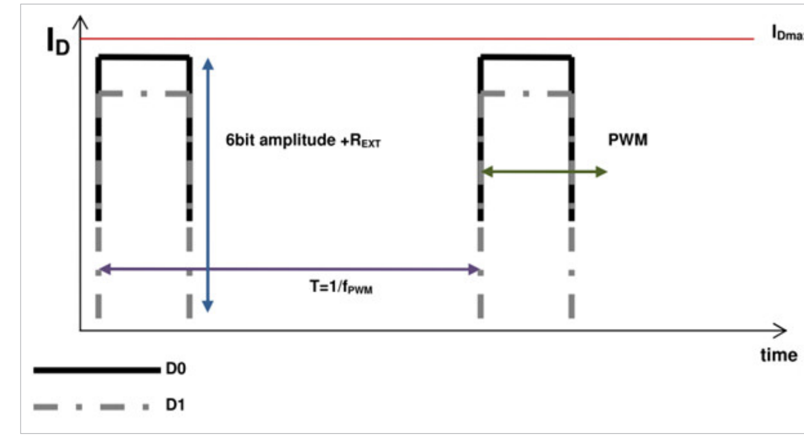

Figure 3: Calibration and dimming of the output current

case reduced by the ability to use a single product platform. This way, less expensive (and overall less) devices can be used for the design. In the given example, Do and D1 are calibrated at a value below the maximum current, and D1 has set a lower current than Do. As indicated, the brightness of both channels can be simultaneously influenced by the PWM signal. Due to the fact that the defined current value and the duty cycle are independent of each other, it is ensured that the calibration of each of the channels does not affect the dimming curve and that no clang delay occurs. The propagation delay during the rise and fall has the same sizes and guarantees the linearity between input and output.

Diagnostics and reliability

High reliability in automotive applications is indicated by the need for protection circuits against over voltage, under voltage, polarity, overcurrent, short circuit and heat. Particularly overheating - especially in case of excessive system voltage - is a challenge in LED solutions due to the dependence of the current from the supply voltage. The voltage in cars ranges from a normal operating voltage of 9 V to 16 V (normal is 14 V) to load the 12.6 battery. In addition, one has to consider extreme conditions such as inverse polarity protection up to 12V, jump start aid conditions with continuous double battery voltage (+24V) to failures such as load dump / over voltage which occurs when the battery is disconnected from the generator while the engine is running, as well as other power transitions. An undamped load drop may take several hundred milliseconds and easily exceed 80V but nowadays, many manufacturers have centralized limiting circuits for a load drop and therefore demand that components resist transient voltages of a range between 60 or 40V.

In order to meet the specifications of car manufacturers in terms of warranty requirements which may last more than 10 years, the BD18377 offers several features for system protection. Hence, shorted and open circuits are detected which could lead to high currents and voltages at the LED output. The extensive diagnostic functions can identify errors and can be read by the microcontroller. This allows corrective actions to be taken to prevent the destruction of individual components. Doing so, the reliability of the cluster can be increased significantly, and an expensive replacement of a complete system can be avoided in terms of cost minimization.

Summary

The presented LED driver - in combination with the SRGB RGB LED series - provides developers a complete solution for the energy-efficient and reliable lighting of vehicle clusters in a small, compact packaging and is also compatible with other device series. With its built-in protection functions it meets the demanding industry standards and stringent purchasing specifications of the automotive industry. The multi-channel configuration also allows the usage for various functions. The built-in communication features enable the individual adjustment of LED currents and voltages as well as protection functions which are different from one application to another. This facilitates the design of a consistent platform solution. ROHM will continue the development of multi-channel LED drivers featuring integrated communication capabilities to further drive these integration possibilities.

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Wireless systems for Internet control of smart lighting

Comparing the operating mechanisms of the key relevant standards

By: Colin Faulkner, NXP Semiconductors

Electric lighting has been around since the first commercial incandescent lamps were sold in 1880. Since then, we have seen little widely adopted innovation – the introduction of the fluorescent in 1938, dimmer switches and a certain amount of simple networked control systems such as DALI for commercial lighting. These systems have been limited by the control capabilities of the lamps themselves, cost of installation and the lack of a key driver to initiate widespread innovation. However, we now have a combination of key factors that make truly "smart" lighting systems a practical reality. From an economic perspective, lighting represents one of the largest opportunities for saving energy and reducing Co2 emissions. With more than 12 billion bulbs sold each year, lighting can represent 25% of energy usage in the home.

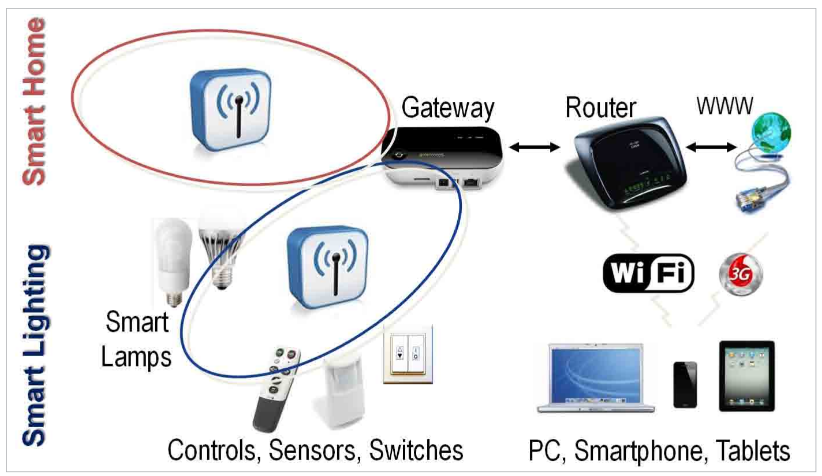

Figure 1: Smart Lighting and Home Automation Architecture

With Governments and utility companies recognizing the need for energy reduction and with many potential solutions such as upgrading to smarter grid infrastructure taking may years to implement, one of the quickest ways to reduce energy is through improved efficiency. For example, a 30% saving in street lighting energy for a city the size of Paris could save 13,000 tons of CO_2 emissions and about $2.5M per year in cost. Improved controls can also lead to a significant enhancement of the user experience. A truly smart lighting system can be programmed to different "scenes" to suit the occupant's activity – when watching TV, any lamps close to the TV can be turned off and the rest of the room dimmed to suit requirements, when going to sleep, a single button press can switch off all the lights in the house.

There are several reasons why the timing is now right for systems of this complexity to be realized. There are now standards that exist that can provide a control system for the whole of the house – ZigBee LightLink and JenNet-IP are described in this paper and broadly conform to the architecture shown in **Figure 1** below. The rapid advances in LED lamp technology now provide acceptable light quality in a package that have an operating life of up to 50,000 hours. With no regular replacement cycle now needed, it becomes cost effective to include a wireless control chip in each lamp. Contributing to this is the inexorable downward trend of chip pricing, such that a single chip wireless control device is approaching the sub $1 price point. The availability of the core technology is just one contributor. Any sophisticated control system requires a fairly flexible and powerful user interface to allow the user to set up the scenes he requires. This is readily available in most households now through the Smartphone. This provides a powerful remote control capability with the ability to use easy-to-use graphical techniques to program and control the lighting systems. These three factors between them enable true smart lighting systems to be developed now.

Requirements and Architecture

There are a number of top-level requirements that have to be met by any domestic lighting control system. Ease of use is perhaps the most important – consumers like the convenience of a simple switch, so anything that adds more complexity into the system must be presented in an easy to use, intuitive fashion. Using remote controls or switches for very simple functionality and Smartphones for more complex functions helps to manage the complexity of operation. One of the most important performance parameters is the latency between requesting an action and it happening. Consumers expect their lighting to respond almost instantaneously.

There are 3 key elements to the functionality that needs to be provided to meet these requirements; Commissioning, Networking and Control. Commissioning allows devices to join the network easily but also securely. Consumers could easily get very confused if the lamp they have just installed joins their neighbors network! The commissioning process must also allow for the easy manipulation of lamps into groups and scenes. Networking is key to ensuring that the system works reliably. There are likely to be many 10s of lamps in a typical house, each of which will form a node in the network. Combining these in a network means that the communications between lamps is always being managed in the background. For example, if one of the lamps fails or becomes disconnected, the networking stack will ensure that connections to all the other devices in the network are maintained.

Control functionality needs to be able to form groups of lamps that can all be controlled together, to provide ways of setting up scenes like watching TV, like the example discussed earlier, and then to enable on/off, dimming and perhaps color control for all lamps. In order to react to the networking and control systems, a smart lamp is obviously more complex than a standard lamp. Many of the modern lamp technologies such as Compact Fluorescent or LED already use silicon chips to provide the drive and dimming capability. The truly smart light simply adds a wireless microcontroller and, perhaps a separate power supply, a relatively small cost overhead compared with the standard lamp. Now let us examine two systems for providing this smart lighting functionality.

ZigBee LightLink

In ZigBee LightLink, based on the well-known ZigBee mesh-networking stack, all individual lamps act as repeaters. Messages destined for a distant part of the network can discover a route by hopping from lamp to lamp until they reach the desired destination. If an individual lamp fails, then a new route would be discovered using a different combination of lamps. This approach works well for lighting systems where there is usually a fairly high density of nodes. LightLink provides two main innovations compared with other ZigBee profiles. Firstly it avoids the need for a dedicated coordinator by using a remote control device to establish the network and manage the security and uses a simple system of commissioning, known as "Touchlinking".

Touchlinking involves bringing the remote control close to the lamp being commissioned. The remote control sends out a scan request and the lamp responds. Multiple lamps could respond to this command, but the remote control will select only the one with the highest signal strength. Once the identity of the lamp being commissioned is established, the remote control can share the network security key and accept it into the network. It can also assign the lamp into one or more groups to enable the setting of scenes. Once multiple lamps are commissioned into the network and are members of groups, they need to be individually controlled to allow

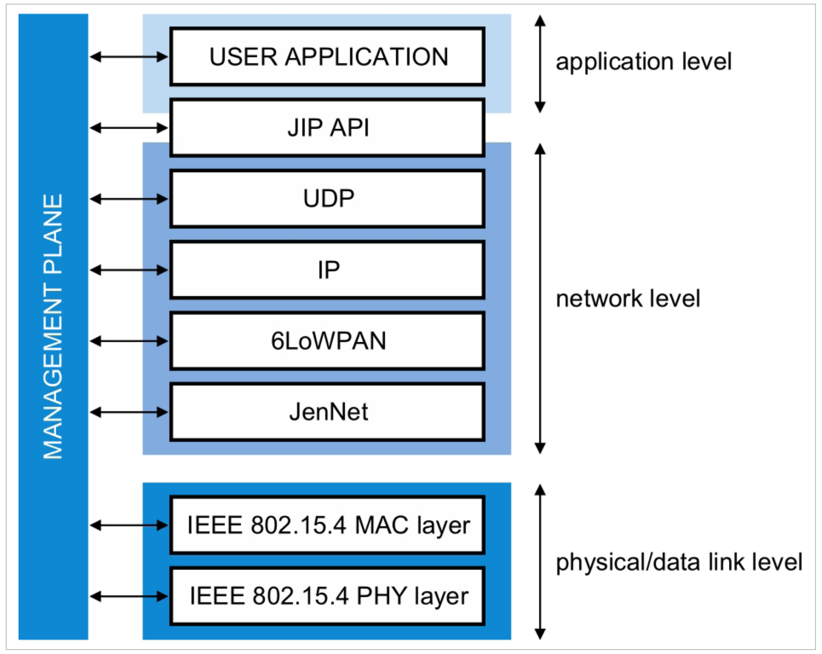

Figure 2: JenNet-IP Stack Architecture

the setting of scenes. In order to do this, it is necessary to be able to address lamps individually to set them to their role in the scene. This is done by means of an "identify" command, which enables the remote control to toggle through all the attached devices to find the appropriate one. It can then be set to the desired color or dim level. By working through a number of lamps in this way, a scene can be built up. The individual properties of the lamps are defined using standard ZigBee "Clusters". These include properties such as on/off, level control, color control etc. By setting these values, the lamps are controlled by the remote control. Other devices available in the system include sensors which allow lighting to be automatically controlled, for example by an occupancy sensor and a control bridge which enables control of the system to be exerted from outside the LightLink network, for example from a WiFi connected Smartphone.

JenNet-IP

In many respects, the operation of JenNet-IP is very similar. The major difference is that JenNet-IP uses Internet Protocol (v6) packets throughout the entire system. This means that every device on the network has it's own IPv6 address and can, in principle, be directly controlled from anywhere on the Internet. In order to realize this capability, JenNet-IP uses a number of protocols from the Internet Engineering Task Force (IETF). These are standardized worldwide and are highly familiar to the engineering community. The network stack architecture is described in **Figure 2** below.

JenNet-IP uses the same IEEE802.15.4 MAC and PHY layers as ZigBee. The networking layer uses a robust tree network layer known as JenNet. In order to maintain the robustness of the system, this layer includes a self repair mechanism. If an individual routing node breaks or loses power, any nodes below it in the tree will try and rejoin the network, restoring communications. The 6LoWPAN layer implements an IETF standard for enabling IPv6 packets to fit into the maximum 128 bytes length of the IEEE802.15.4 standard. It does this in two ways; firstly by providing a means to fragment any long packets into a number of segments which can be sent individually across the network and reassembled at the destination and secondly by providing compression of the IP addresses. Standard IP and UDP provide the transport layers such that the wireless system looks like a normal UDP interface to the outside world.

One of the benefits of this approach is that an IP packet destined for a particular IP address will always make its way there without the need for translation into a different format. Provided the end device knows how to interpret the packet, it will result in the desired action. What is missing from this picture so far is the application layer; the mechanism that defines exactly how a device will behave when it receives a packet. The IETF have defined a structure called Simple Network Management Protocol (SNMP) but this is too unwieldy for use on simple devices with limited resources.

JenNet-IP takes the same basic principle of SNMP and adapts it for use with low power wireless nodes. The basic approach is to use a technique known as Management Information Base (MIB). This defines device characteristics in a number of small database entries, which can then be interrogated or modified using simple self-explanatory commands like "SET" and "GET". This is a powerful technique that allows complex behaviors to be built up for any type of device. Examples for a lamp will include "ON/OFF", "DIM LEVEL", "GROUP MEMBERSHIP" etc. Using this approach, it is possible for a remote internet connected controller such as a Smartphone to send the relevant "SET" commands directly to a lamp.

Devices within the network such as remote controls or light switches can also be added to provide local control. Groups and scenes also have addresses assigned to them in the same way as individual lamps. Lamps know which groups they are members of and the characteristics to set up in scenes and simply respond to those addresses as well as their own individual ones. In this way, JenNet-IP can set up similar lighting control functions to ZigBee LightLink, and indeed, can be easily expanded to cover the wider home automation or building automation functionality using the same basic approach.

To summarize, Smart Lighting is a reality right now with the advent of low cost silicon, long life LED lamps and smart controllers in the form of smart phones. There has been a huge amount of effort invested in the development of new wireless standards such as ZigBee LightLink and JenNet-IP that will allow consumers to experience new control functionality and reduced energy bills. With these capabilities in place, the future of Smart Lighting is starting right now.

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Migrating from "power-centric" to "space-sensing" daylighting systems

How much light does the user really want or need?

By: Sajol Ghoshal, Director, ams AG

Incumbent lighting installations today fail to address the most important energy saving "feature" a lighting system can implement, namely maintaining a user-defined amount of light that considers the effect other ambient light sources, especially daylight, and provides supplemental light, and only when the space is in use. In the commercial office environment, automated occupancy controls have long-since replaced the simple on/off switch. While an occupancy sensor may have solved part it, the rest of the problem remains unsolved – how much light does the user really want or need?

What the user really wants is the light set to a particular level in the space, and then for the luminaires to maintain that constant level as long as the space is occupied. Other than when they are actually setting the desired level, they will not want to see adjustments happening. In a sense, the "dimmer" should not be perceived as controlling the light output (in reality, the power input) for the luminaires it controls, but rather as an overall ambient level controller that sets the brightness of the space.

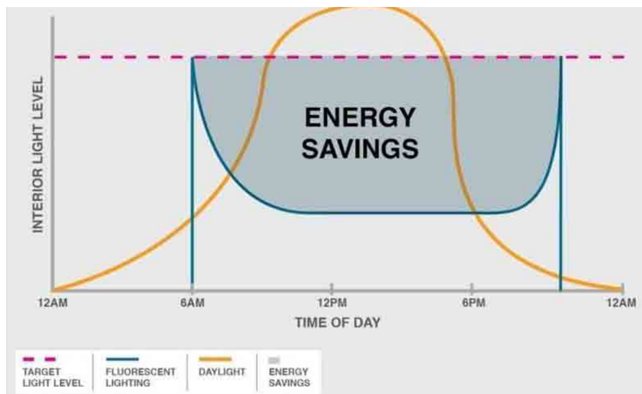

Figure 1: Daylight harvesting energy savings

The solution to this type of design comes from Cognitive Lighting™ – lighting systems that are "aware" of the ambient environment and can "learn" the correct adaptations to maintain the user's preferred and productive lighting level in response to changes in the available ambient daylight.

What is "daylight harvesting"?
While some leading-edge lighting installations have attempted to respond to, or "harvest" daylight across larger spaces, the coming wave of more flexibly controllable luminaires will usher in an era of more granular control, resulting in substantial additional energy savings (**Figure 1**), as well as enhancing user comfort and productivity.

As a result, a Cognitive Lighting™ system design is best addressed at the luminaire or lamp level, rather than attempting to instigate daylight responsiveness at the building level. Daylight-responsive lighting system can be greatly simplified when the sensors and intelligence reside at the luminaire level. In its most basic sense, if you design a luminaire (fixture) or replacement lamp to correctly respond to, and compensate for, the ambient daylight that it senses, the building-level task of lighting management has been simplified by orders of magnitude.

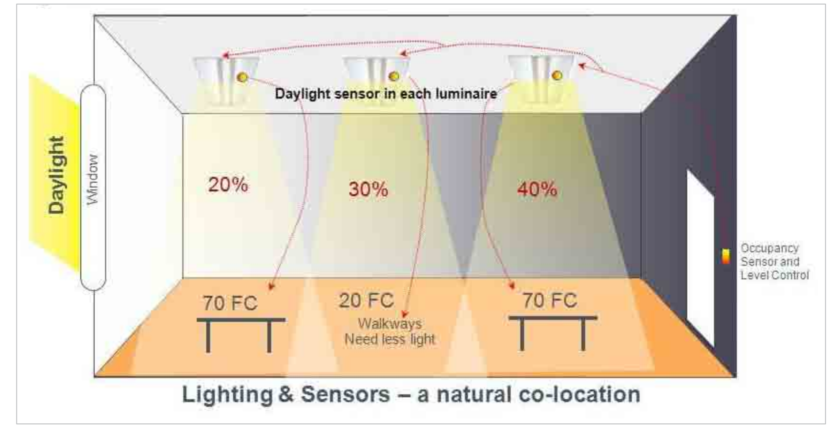

Figure 2: The "decision-directed" Intelligent Lighting Controller (ILC)

Four basic ingredients are needed to implement a Cognitive Lighting™ design:

- Precision ambient light sensors, specifically optimized for daylight harvesting – the "daylight sensor"
- A microcontroller-based intelligent lighting controller (ILC) that serves as the light-processing "decision engine"
- A dimmable driver or power supply (also referred to as a "ballast" in fluorescent systems)
- The light engine – In the past that would have most likely been a fluorescent tube, but with a current luminaire design it is more likely to be an LED based solution in which proper consideration has been given to optical design and thermal management

Overview of a sensor-based closed loop daylight-responsive control structure
The task of the Cognitive Lighting™ -based space-sensing luminaire is a straightforward one: Start from a user-set ambient light level or "target ambient level setting", and then maintain that target level as illumination from other sources, most especially sunlight, is added or removed from the room. The process of accomplishing that depends upon utilizing a high-quality daylight sensor, that is specifically designed to respond to daylight-driven implementations and which will measure and integrate the lux level that is reflected back at it from the target area.

The daylight sensor should perceive the ambient lux value in the same way that the user of the space would, which requires that it operate in a photopic mode, meaning that it assigns a relative value to the photons reflecting back towards it, and thereby accurately approximating the ambient brightness that a human would "see", while additionally rejecting IR (Infra-red) and UV Ultra-violet) wavelengths. It is also important that the daylight sensor only responds to a realistic average lux value, and not to cyclic 60Hz peaks and valleys, such as might be generated by older fixtures in the nearby hallway or other transient sources.

Figure 2 is a simplified illustration of space-sensing Cognitive Lighting™ functionality. In this design, each luminaire acts independently to maintain the target illumination level selected by the user. With the Cognitive Lighting™ -based luminaire architecture in **Figure 3**, the daylight sensor is positioned to allow it a clear field of view of the target space, and is connected to the ILC via an industry-standard serial bus, such as I2C. The ILC serves as the "decision engine", accepting data from the daylight sensor, as well as inputs from the occupancy sensor and illumination level control, typically making use of standard 0-10V control signals or DALI inputs. The ILC then drives an output 0-10V signal or PWM signal to the power control system that has been designed to incorporate 0-10V or other types of dimming controls.

As sunlight enters the room the daylight sensor detects the increase in ambient light in the room, reducing the 0-10V signal proportionally to maintain a constant ambient lux as determined by the user-programed target. The light engine dimming is performed on a non-linear scale optimized to provide smooth dimming that would be a more

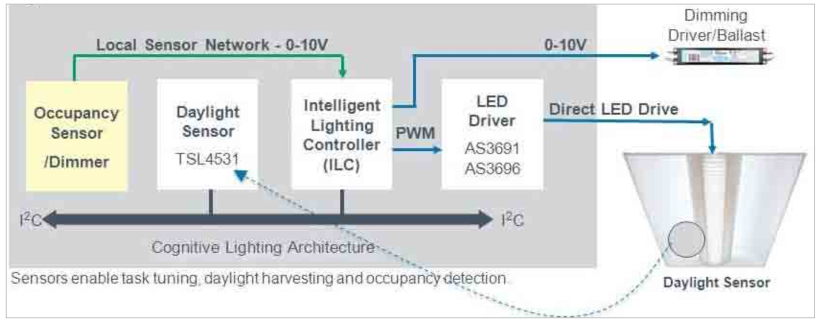

Figure 3: Cognitive Lighting™ -based luminaire architecture

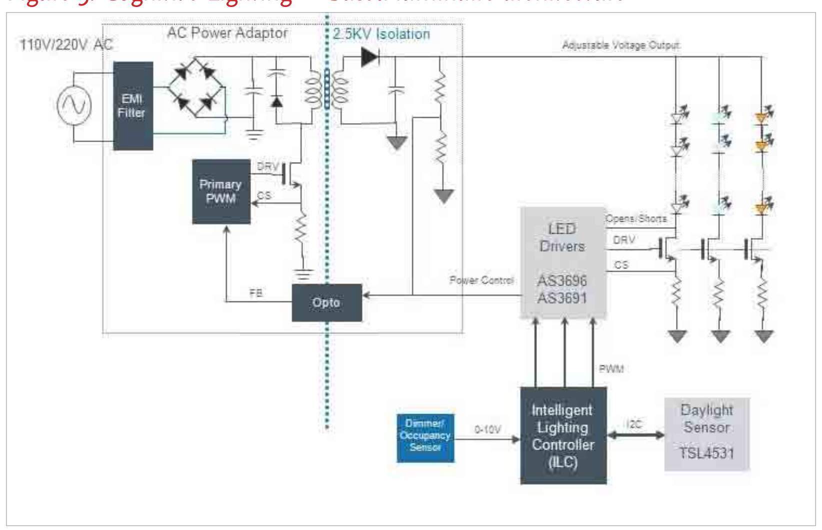

Figure 4: A full lighting solution from AC to lumens in an LED-based luminaire

visually pleasing experience to the human eye, enabled through programmable ramp times and adjustable lux goal targets. **Figure 4** illustrates a full lighting solution from AC to lumens in an LED-based luminaire.

In this architecture, power is fed from the AC to DC converter, providing the 2.5KV isolation with EMI and power factor correction. The LED driver supports two control loops:
1) The constant current driver loop which maintains a fixed current through the bottom of the LEDs and; 2) The power control loop which maintains the exact output voltage headroom needed on the top of the LEDs by modulating the feedback tap of the AC/DC converter connected to the primary PWM through the opto-coupler. This single-stage conversion delivers the highest power efficiency. The LED drivers should match the current in each string, as well as driver-to-driver, to achieve output and color consistency between strings and luminaires. For commercial quality applications, the strings should be matched to 1% or better.

The ILC is constantly monitoring the occupancy sensor, reading information from the dimmer to determine the target illumination set point, and sensing the illumination of the room via the daylight sensor to which it is connected via an I2C port. Each occupancy event resets the "time on" timer, which should be a preset based upon the type of room and other parameters determined by the facility operator. In the on state, the direct lux output from the daylight sensor is continuously compared against the user-set target illumination level, and the light output is dimmed or increased to meet the target ambient lux value.

Summary

Energy savings continues to be a major driver in building systems design, with daylighting harvesting with occupancy sensing as the path that will maximum this energy savings opportunity. As we've seen, the key to a fully-capable daylight responsive lighting system hinges upon the ability to integrate sensors into the luminaire's individual control system. The lighting market is currently at the inflection point where intelligent lighting is being recognized as both necessary and practical, which suggests that luminaire manufacturers must address those needs by placing designs on the drawing-board now if they want to capture their share of that market.

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Improving the reliability of MR16 LED lamps

The MR16 luminaire presents challenges to the designer

By: Ian Moulding, Marketing Manager, Diodes Incorporated

With their attractive low forward voltage drop and significant cost advantage, it's no surprise that Schottky diodes have become a defacto standard for AC bridge rectification in a myriad of different reference designs for MR16 LED lamp drivers. Problems include the extreme confines of a standard MR16 housing and the inhospitable environment from conducted heat dissipated by an LED cluster, where driver circuits are subject to ambient temperatures of up to 100C°.

The weakest link

If an LED lamp's going to fail it'll be down to the rectifier and here the standard Schottky offers up an inherent and well observed weakness. A device remains sensitive to changes in ambient temperature due to its high leakage current. Fact. Even for reasonably modest amount of applied heat, the Schottky's low energy metal barrier design makes it susceptible to destructive thermal runaway – when reverse power exceeds the diode's ability to expel heat at the rate at which it's generated.

What makes the adoption of the Schottky all the more curious in this respect is that the importance of low leakage over and above that of a low forward voltage is well recognised. In an AC bridge rectifier each diode pair conducts for half a cycle and blocks for half a cycle. To minimise conduction losses, yes, a low forward voltage is a pre-requisite, but then in blocking mode, low leakage is paramount for minimising power losses.

If the load was purely resistive then of course the duty cycle would be 50%, however since capacitors are often connected in order to reduce LED ripple current, then the conduction cycle of each diode can reduce to as little as 10%. As such, reverse leakage performance is in reality of primary importance, the forward voltage of secondary importance. Should we reconsider the merits of a PN junction diode perhaps?

Well 'no' is the simple answer to the question. Yes, a fast recovery epitaxial device ('FRED') is certainly proven to exhibit far lower leakage at a higher temperature than the Schottky, but its forward voltage puts it at a distinct disadvantage. It is a source of higher power loss in the diode and greater heat generation, which is exactly what we're trying to avoid. So we continue to live with a compromise solution? Not necessarily.

Think SBR

The Super Barrier Rectifier (SBR®) is in reality nothing really new and has for sometime been successfully applied to improving the efficiency of higher power, high temperature power supplies. Combining the low forward voltage of characteristics of the Schottky with the low leakage attributes and stability of a PN junction diode, the SBR is however also a prime candidate for improving the reliability of MR16 LED lamps.

For the uninitiated, the SBR structure is very similar to that of a MOSFET, but with the gate shorted, and employs thousands of individual cells to create a network of gate channels working in parallel. The structure incorporates an inverted gate that creates an inverted N-MOS channel directly under the cell. In forward operating mode, a

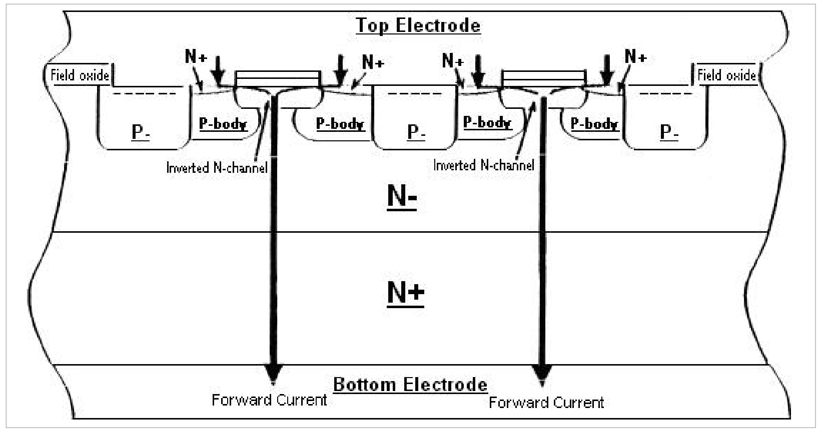

Figure 1: Forward operating mode of SBR structure

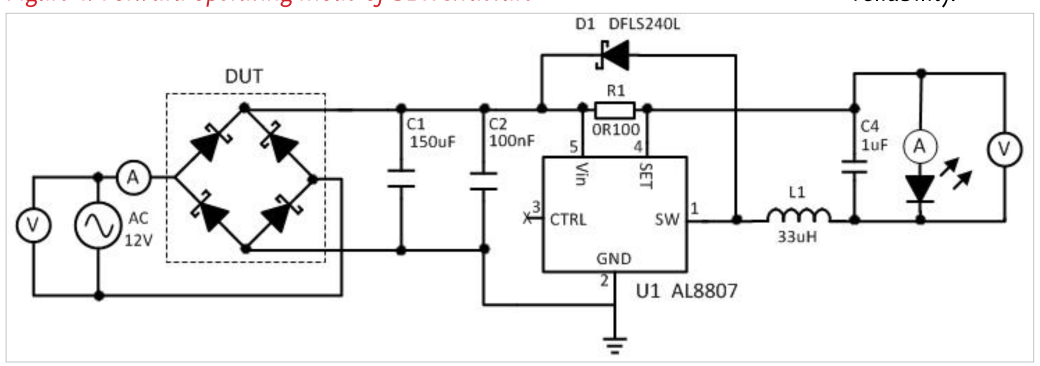

Figure 2: MR16 LED lamp evaluation circuit

large flow of electrons can move through the inverted N-channel with a reduced forward conduction loss. The current will flow from the top electrode, through the inverted N-channel, to the bottom electrode (**Figure 1**).

In reverse operating mode, when applied voltage reaches a few hundred mVs, a pinch-off occurs due to the overlapping region in the depletion layers. As reverse voltage increases, the reverse leakage changes much slower and remains flat up to the breakdown voltage. This behaviour means the SBR does not suffer from the disadvantage of the Schottky.

The SBR's forward conduction loss performance is also much better than that of a standard PN junction. In an input bridge application this advantage manifests itself as a significant power saving, which, with energy conservation in mind is not a factor to be ignored.

Put to the test

In an evaluation circuit built around Diodes Incorporated's AL8807 LED Driver (**Figure 2**), the relative performances of the company's own DFLS240 2A 40V Schottky and SBR3U60P1 3A 60V SBR can be compared. The circuit is powered by a 12V AC supply and serves a single 1-Watt LED.

The average continuous current through the bridge diodes is typically 300mA and the circuit is evaluated in ambient operating temperatures up to 1250C; selected as a 'worst case' temperature used by MR16 lamp designers to assess product performance and reliability.

Prior to real in-circuit evaluation, the suitability of the SBR or Schottky as a bridge diode in an MR16 LED lamp design can be assessed theoretically.

Product	V_F (V)@ 0.3A @125°C	I_R (mA)@ V_R=18V @125°C
DFLS240	0.32	0.8
SBR3U60P1	0.26	0.6

Table 1

The typical forward conduction losses (V_F) and reverse leakage losses (I_R), under the stated conditions are specified by the typical Forward Voltage and Reverse Voltage characteristic curves of the respective datasheets, and are summarised in **Table 1**. The power loss that each leg of the diode bridge will generate under these conditions is calculated using the equation:

$$P_D = (V_F * I_L + ((1-D) * (V_R * I_R))$$

In which,

P_D = Power dissipated
D = Duty cycle of between 0 and 1
V_F= Forward voltage at IL @ 1250C
I_L = Maximum continuous current
V_R= Reverse voltage
I_R= Reverse leakage @ 1250C

Substituting the parameters from Table 1 into the equation reveals that power dissipation losses for the DFLS240 are:

$$P_D = (V_F * I_L) + ((1-D) * (V_R * I_R))$$

$$P_D = (0.32* 0.3)) + ((1-0.3) * (18 * 0.0008))$$

$$P_D = 0.096 + 0.01$$

$$P_D = 0.106W$$

whereas for the SBR3U60P1 they are :

$$P_D = (V_F * I_L + ((1-D) * (V_R * I_R))$$

$$P_D = (0.26 * 0.3) + ((1-0.3) * (18 * 0.0006))$$

$$P_D = 0.078 + 0.00075$$

$$P_D = 0.0885W$$

The calculations already suggest then that the power dissipation of one leg of the diode bridge will be 16% lower when the SBR3U60P1 is used instead of the DFLS240. This lower power dissipation should result in the SBR operating at a far lower temperature in a real world test. It is worth noting that the actual in-circuit power dissipation would be doubled as two diodes conduct during each half cycle of the AC input.

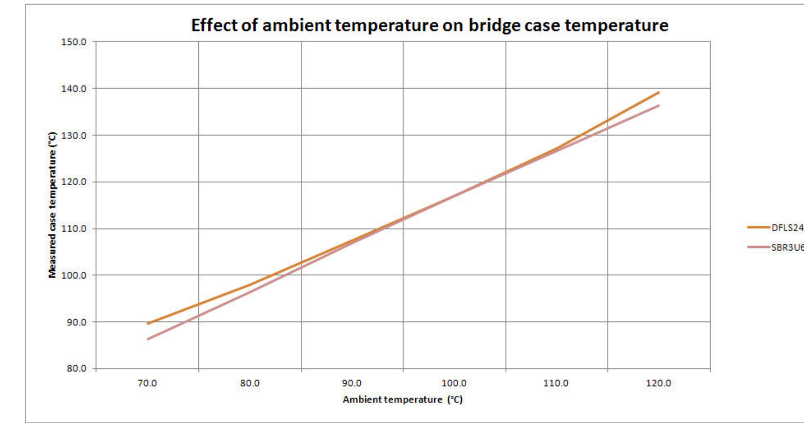

Figure 3. The effect of ambient temperature on bridge case temperature, Schottky vs SBR

The evaluation board, with bridge populated first with the Schottky, then with the SBR, was placed in a temperature controlled chamber and ambient temperature increased incrementally to the maximum of 125°C. A thermal camera was used to measure the case temperature of Schottky and SBR at each increase in ambient temperature. The resulting data is shown graphically in **Figure 3**.

As can be seen from the curves, at 120°C ambient, the case temperature (T_C) of the SBR is 3°C lower than the Schottky. Furthermore, as the junction temperature (T_J) of a diode is typically 8°C higher than that of the case temperature then the junction temperature of the Schottky will be approximately 147°C. This is very close to its maximum rated junction temperature of 150°C and due to the low energy metal barrier of its design, there is a very real risk of thermal runaway.

Taking into account the simple fact that for every 100C reduction in temperature, the reliability of an application doubles, then the significantly lower operating temperature of the SBR will therefore significantly improve high temperature reliability of MR16 designs.

In summary, the lower forward voltage and reverse leakage of the SBR reduces power dissipation, enabling lower operating temperatures and a greatly reduced risk of thermal runaway. Clearly, the Super Barrier Rectifier provides a ready alternative for MR16 LED lamp applications.

The economics of circuit design will for sure always have an important bearing, but if greater reliability and longer product life are the key design objective, then the price of challenging the status quo and making the change to an alternative high performance technology might prove a relatively small one to pay.

www.diodes.com

Creating the infrastructure of the future

By: Alix Paultre, Editorial Director, PSD

We all know that some form of smart grid is coming, but the real question is how that grid will manifest itself. Just because the concept of the smart grid is inherently "green" doesn't mean that its manifestation will be. The core technologies we deploy and how we deploy them will determine the true benefit of the smart grid in the long run.

The smart grid is a lot like 3-D printing in that the power is in the concept, not the actual product itself. Just as there are many ways to approach additive manufacturing, there are many ways to approach power generation, management, and storage. Some are very "green", and some are far from it. One of the biggest concerns should be how much functionality and reliability are we obtaining from our efforts.

One of the areas for the most potential confusion and potential harm is in the area of grid stiffening. Power stiffening is a term most known among the vehicular audio enthusiast crowd, as large capacitors are used in major car-stereo installations to provide energy storage for power availability during dynamic peaks, usually bass, that would otherwise tax the output of the amplifier. This philosophy, writ large, is the same concept used at the municipal level to balance the loads from multiple sources, some intermittent, and provide steady power to the grid.

How that energy could be stored is an exercise in design, business, and regulation in itself. Each manner of intermediate-range storage has its pros and cons, from system efficiency to reliability to toxic impact on the community. A lead-acid battery bank is pretty robust and reliable, but incurs significant ecological impact in both operation and disposal. Flywheels are "green", but are useless for anything but short-term bridge power. Fuel cells in most cases simply shift the power production burden onto hydrogen generation systems, and they also have operational safety issues, if only for thermal management.

This quandary of technological choice is not strange to the engineering community, as picking the appropriate tech for the application is one of the primary jobs of the designer. However, the fact that those choices are counterbalanced by potentially countervailing desires between the customer, the application, and the regulatory environment the solution must conform to. In the case of the smart grid, many of the rules and laws to be considered haven't even been created yet.

This issue extends to other aspects of the smart-grid infrastructure, with varying levels of impact. The software in and of itself is non-polluting and doesn't take up any physical space nor does it leave any residues, but the protocols in the software can make a very large difference in the "green" aspects of the system.

The bottom line is that we are in the process of creating our future energy infrastructure now, and the decisions we make will determine how much it will benefit society. This is not the time for short-term thinking or planning, as what we implement now will dominate the direction of our society for the next generation.

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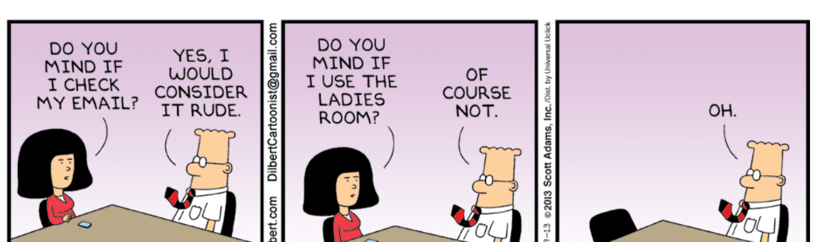

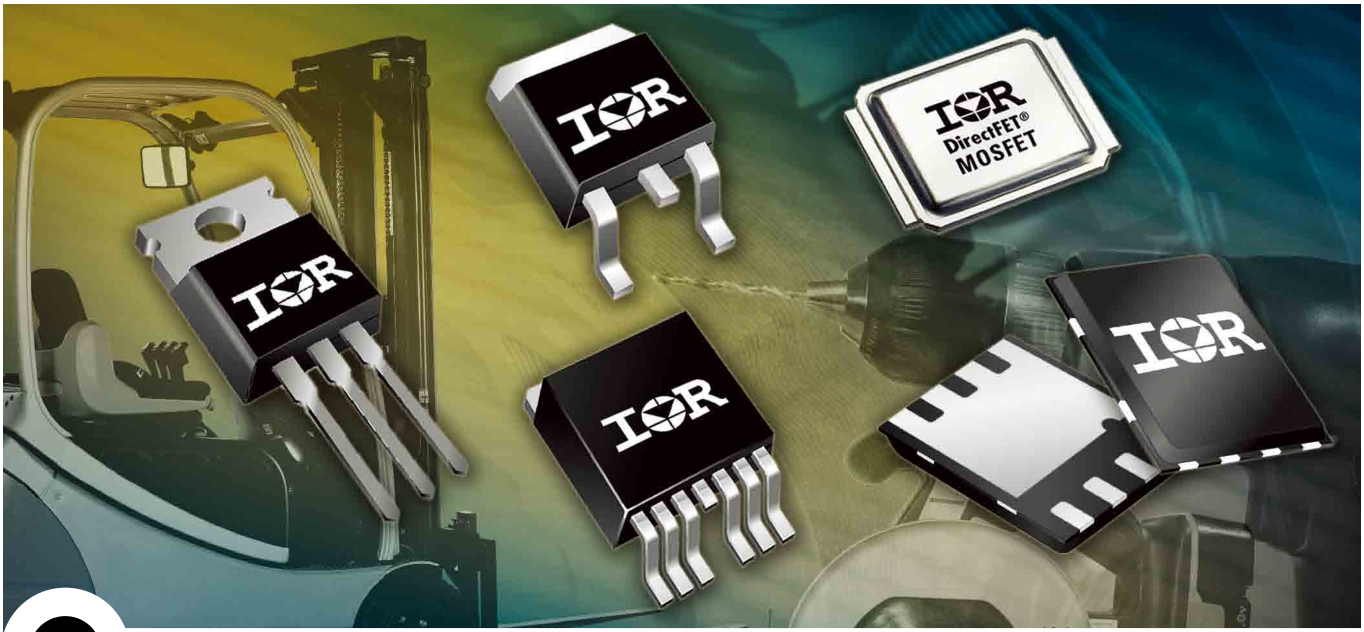

StrongIRFET™ Rugged, Reliable MOSFETs

Specifications

Part Number	B_{VDSS}	ID@ 25°C	$R_{DS(on)}$ max@ Vgs = 10V	Qg@ Vgs = 10V	Package
IRFH7004TRPbF	40 V	100 A	1.4 mΩ	134 nC	PQFN 5x6
IRFH7440TRPbF	40 V	85 A	2.4 mΩ	92 nC	PQFN 5x6
IRFH7446TRPbF	40 V	85 A	3.3 mΩ	65 nC	PQFN 5x6
IRF7946TRPbF	40 V	90 A	1.4 mΩ	141 nC	DirectFET Medium Can
IRFS7437TRLPbF	40 V	195 A	1.8 mΩ	150 nC	D^2-Pak
IRFS7440TRLPbF	40 V	120 A	2.8 mΩ	90 nC	D^2-Pak
IRFS7437TRL7PP	40 V	195 A	1.5 mΩ	150 nC	D^2-Pak 7pin
IRFR7440TRPbF	40 V	90 A	2.5 mΩ	89 nC	D-Pak
IRFB7430PbF	40 V	195 A	1.3 mΩ	300 nC	TO-220AB
IRFB7434PbF	40 V	195 A	1.6 mΩ	216 nC	TO-220AB
IRFB7437PbF	40 V	195 A	2 mΩ	150 nC	TO-220AB
IRFB7440PbF	40 V	120 A	2.5 mΩ	90 nC	TO-220AB
IRFB7446PbF	40 V	118 A	3.3 mΩ	62 nC	TO-220AB
IRFP7430PbF	40 V	195 A	1.3 mΩ	300 nC	TO-247

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