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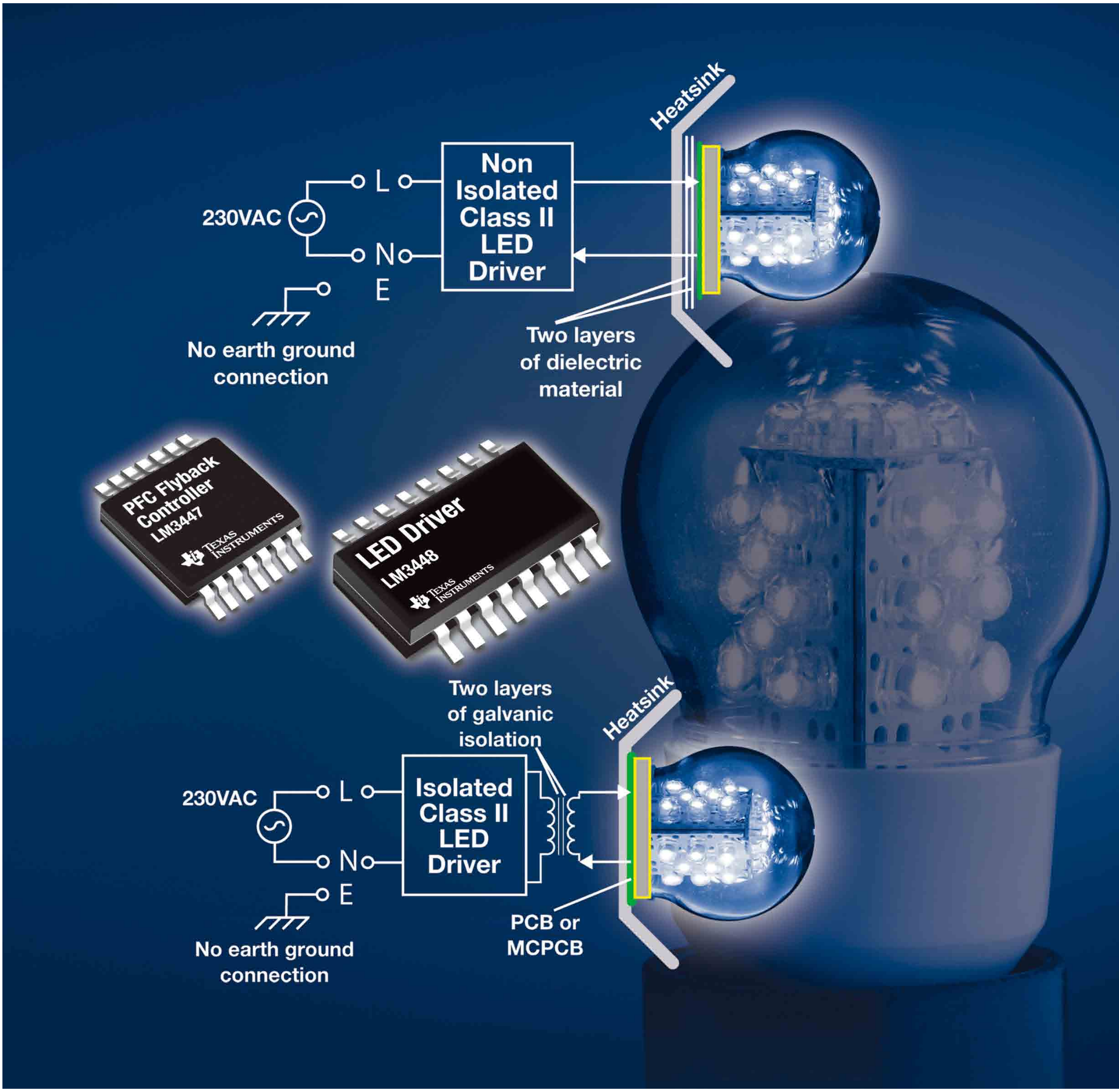

SPECIAL REPORT: LIGHTING PRODUCTS & SYSTEMS (PG 33)

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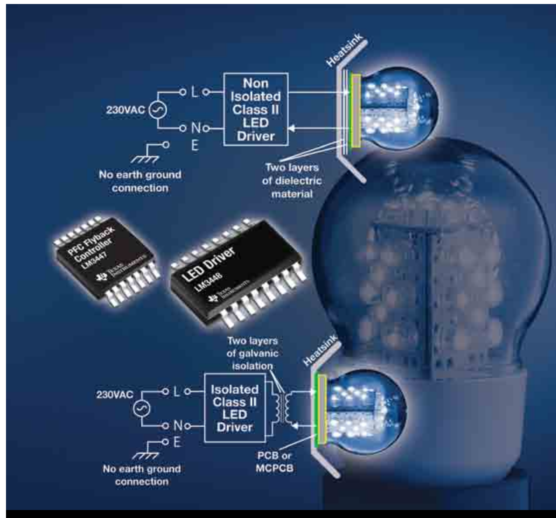

COVER STORY

A Touch of Safety Class: Keeping Our Fingers out of Harm's Way (pg 14)

Highlighted Products News, Industry News and more web-only content, to:

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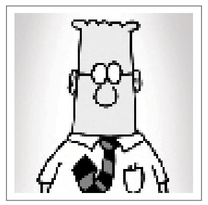

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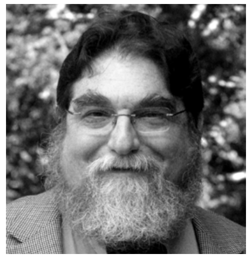

SHEDDING SOME LIGHT

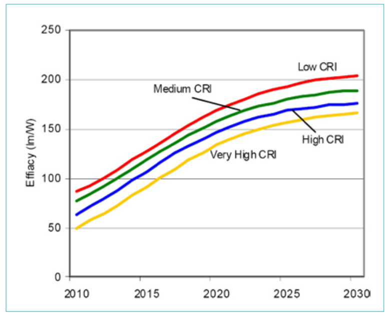

Figure 1: The US DOE predicts steady improvement in SSL efficacy over the next decade, decelerating, but continuing through 2030. (Image courtesy US DOE)

At their introduction, white LEDs were at once revolutionary and the obvious next-logical evolutionary step for visible-light devices that began a half century ago.

Nick Holonyak, Jr invented the first practical visible-spectrum LED in 1962 with a GaAsP process at General Electric. As you may note with some sense of irony as you read this month's special report on lighting products and systems, Holonyak is also the inventor of the household dimmer switch.

Since Holonyak's first red LED, decades of process and device engineering dramatically improved LED's yield, operating lifetime, robustness, brightness, and cost and gave rise to devices of shorter wavelength. Shuji Nakamura demonstrated the first high-brightness blue LED in 1993. The addition of a yellow down-converting phosphor lens coating, resulted in the first white LED almost immediately. The market ramifications of white LEDs were clear, yet it took many more years of engineering to develop practical devices for general illumination, particularly with regard to color quality, efficacy, and cost.

This is not, however, to peer into rear-view mirror: Of greater interest is the current state of SSL (solid-state lighting) technology and its applications. Toward this end, in addition to this month's special report, I recommend to your attention three resources from the US DOE (Department of Energy).

The CALiPER summary reports detail tests of commercially-available LED-lighting products, including comparisons to conventional lighting devices. Between the initial December 2006 pilot round and the October 2011 Round 13 Report, the CALiPER summaries covered a variety of lighting products. Starting in March 2012, DOE renamed the series Application summary reports, which focus on a single product type or application.

A forward-looking report, Energy savings potential of solid-state lighting in general-illumination applications 2010 to 2030, provides insight into current trends and expectations for lighting demand and technology improvements in both conventional and solid-state lighting. With much current industry focus going to efficacy, one exhibit caught my eye—the LED efficacy prediction for commercialized SSL devices—that predicts a near-constant rate of improvement over the next decade or so (Figure 1). The segment of the curve SSLs are already on indicates roughly an octave improvement in six or seven years.

SSL lighting is already benefitting from reductions in device cost as commercial products continue to make inroads in interior commercial and residential applications. Apropos of this trend, DOE started a new report series, Retail replacement-lamp testing, which include test results and analysis for SSL replacement lamps available at retail.

A great deal of engineering effort continues to pour into SSL technology to address ongoing cost, color quality, efficacy, and control challenges. Enjoy this month's special report on lighting products and systems, which sheds more light on this important topic.

Joshua Israelsohn

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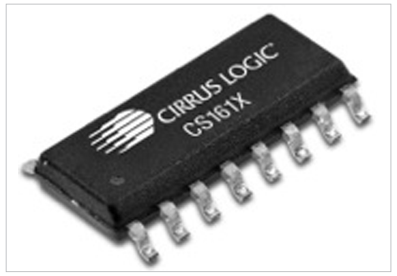
LED CONTROLLER PROVIDES NEAR 100% DIMMER COMPATIBILITY

Natively, LEDs are infinitely dimmable with brightness directly proportional forward current.



Wall dimmers, however, take the AC mains voltage and proceed to chop it up, and do so rather crudely. Incandescent bulbs don't respond to the time-domain hash dimmers output because they are RMS voltage devices that exhibit long time constants.

Dimmers' outputs, however, are not conducive to current control—the very thing one needs to drive LEDs. So, it comes as no surprise that many white-LED bulbs or, more precisely, their current-controller ICs, operate poorly with such a power source. The result has been a growing reputation for white-LED bulbs, like CFLs, as incompatible with dimmers.

A few companies have addressed this issue head on, despite the large number of dimmer types and the various power-line artifacts they present. One example, Cirrus Logic's CS163X family provides near 100% compatibility with the world's installed base of dimmers.

Controllers in this family provide two-channel LED color mixing capabilities. This allows LED-bulb manufacturers to more efficiently create warm, natural light quality while lowering the cost barrier for two-channel LED retrofit bulbs.

The CS163X family enables improved color quality at up to 30% greater efficacy than with single-channel white LEDs. The CS163X family controls two LED strings with the components that would typically control a single LED string, lowering system costs when compared to many other two-channel controllers.

Bulb manufacturers can calibrate the light output and CCT (correlated color temperature) during the final bulb-manufacturing stage. This arrangement allows manufacturers to use LEDs from a broader range of color bins, resulting in lower LED costs while maintaining consistency in light output and color temperature from bulb to bulb.

OSRAM Opto Semiconductors Applications Engineer Horst Varga said, "CS163X's high level of integration and performance enables many new opportunities for [OSRAM's] technology in LED retrofit applications requiring high CRI (color rendering index) and high efficacy. The combination of these technologies will accelerate the growth of LED bulbs that match the color-quality performance of today's incandescent and halogen bulbs."

CS163X family controllers identify the type of dimmer in use and adapt their dimmer compatibility algorithm to provide smooth dimming. They are available now in SO-16 packages at USD $1.06 (100,000 units).

www.cirrus.com

LED LAMPS TO TOPPLE INCUMBENT INCANDESCENTS

By: Will Draper

As worldwide laws banning most incandescent light bulbs take effect over the next few years, a market opportunity is accelerating for energy-efficient solid-state lighting technologies.

Originally fueled by environmental concerns and the steadily rising cost of electricity, regulations that will restrict the sale of most incandescent bulbs in North America, Europe, and Asia have accelerated the market for energy-efficient lighting. Over the next few years, SSL (solid-state lighting), CFL (compact fluorescent lighting), and other energy-saving technologies will replace billions of light sockets currently occupied by inefficient, filament-based bulbs. In combination with rapidly falling prices, research analyst firm McKinsey & Company predicts that the LED market segment will grow to one billion units by 2015 (Reference 1).

The Three Cs Challenge

The application of any SSL lamp must address several technical challenges before its successful adoption into the mainstream. The most immediate obstacles to mass-market acceptance are the three Cs: cost, color quality, and compatibility.

Cost is the central issue impeding SSL adoption. In the near term, as SSL bulbs enter the high-volume consumer market, the natural economies of scale should bring per unit retail prices down into a more palatable range of $10 to $15 USD. Like most developing technologies, these prices should continue on a downward trend to the $5 to $7 range by 2015.

The challenge posed by color quality improvements actually represents a significant opportunity for SSL technology, given that consumers are largely dissatisfied with the color emitting performance of existing CFLs. Improved color quality is a fundamental advantage for LEDs due to their more uniform optical characteristics. As a result, SSL products can more closely replicate the user experience of incandescent lighting by simultaneously delivering a warm color temperature with high CRI (color rendering index).

To address the third challenge of compatibility, SSL products must be near 100 percent compatible with the installed base of dimmers found within many of today's residential and commercial lighting systems. Dimmer compatibility is rare with today's CFLs, so the opportunity for SSL products to achieve a significant differentiating benefit is paramount. While cost reduction will be a direct result of growing economies of scale, and improved color quality is a fundamental advantage of LEDs, dimmer compatibility improvements will only come through focused attention and innovation.

The Dimmer Compatibility Challenge

All aspects of the Three Cs challenge are essential to solid-state lighting's quest for mainstream consumer acceptance. Compatibility, however, looms large as the critical variable, given that the starting purchase price of SSL products is considerably higher than incumbent lighting products. With higher per-unit retail costs, customers have similarly high expectations of SSL's overall performance. Many SSL products currently on the market use analog LED driver ICs that claim to "work with some dimmers," resulting in unacceptable return rates for both retailers and manufacturers. While the LED lamps available on the market today can demonstrate 50% to 60% compatibility, in the high-volume consumer market, even a 5% return rate cuts deeply into manufacturer and retailer profit margins and can damage a manufacturer's reputation and brand image. In addition, customer returns drive customer dissatisfaction and will severely limit the entire SSL industry's chances for rapid market acceptance.

Will Draper
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LED Lighting Division
Cirrus Logic

www.cirrus.com

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1. "Lighting the Way: Perspectives on the global lighting market," McKinsey & Company, 2011.

LED LIGHTING WILL DRIVE NEW OPPORTUNITIES FOR POWER COMPONENT MANUFACTURERS

By: Ryan Sanderson

Since the first 60W equivalent LED replacement light bulb (LED lamp) was unveiled by Philips Electronics in May 2010, the market for LED lamps and luminaires has been flooded by products from an ever increasing list of manufacturers.

A divide in the market is already apparent between manufacturers trying to address the cost-driven, high-volume, low-cost LED retrofit lamp market, and those targeting the more complex medium and high power applications that use specific LED luminaires. The good news for power component manufacturers is that large market opportunities exist in both!

The largest barriers for traditional lighting manufacturers producing LED lamps/luminaries are the challenges they face producing driver circuitry. The main selling points over competing lighting technologies used my manufacturers of LED lighting are higher efficiency (or reduction in power consumption for the same lumen output), longer lifetime, and better light quality. None of these can be achieved without a driver circuit which is optimised to the lamp/luminaire design. Whilst some manufacturers have the ability to achieve this "in-house", most require the expertise of a power supply/power semiconductor manufacturer.

The global market for power supplies used in LED lighting is projected to grow to almost $10 billion in 2016. Over half of this is predicted to be for power supplies used in low-power retrofit LED lamps. This portion of the market is, however, projected to become the most "captive"; with almost 80% of drivers predicted sold in 2016 to be produced "in-house".

Large LED lamp manufacturers, such as Philips Electronics, GE and Osram, already have these capabilities. Whilst this limits the opportunities in the retrofit LED lamp market for manufacturers of merchant power supplies, the lamp manufacturers still source power semiconductor components from mainstream suppliers. In fact the total market for power semiconductors (power ICs and discretes) for LED lighting is forecast to grow to more than $3 billion in 2016, with over 70% of this attributable to the retrofit LED lamp market. Power semiconductor market growth will be driven both by sales direct to OEM or lamp/luminaire manufacturers and to merchant power supply manufacturers.

The retrofit LED lamp market, however, is only one application in the total LED lighting market and there are many other opportunities. Over half the total power supply market for LED lighting in 2016 is forecast to come from sales of merchant power supplies. Medium power (25W-59W) and high power (60W+) LED applications tend to have multi-string architectures and therefore demand a more complex and more expensive driver solution. LED luminaires for these applications may use an "off-the-shelf" merchant power supply solution or approach a merchant vendor directly for an optimised design. Though some lighting manufacturers may be capable of designing a driver in-house, it is often much more complex and expensive to do this rather than purchase from a merchant specialist.

Of the medium and high power applications for LED lighting, industrial and street lighting offer the largest opportunities, their combined power supply revenues being projected to grow close to $1.5 billion in 2016. As these driver designs are more complex they often use high power MOSFETs and more expensive controllers/regulators which can drive multiple channels and therefore multiple strings of LEDs. The total global market for power semiconductors in industrial and street LED lighting applications is projected to grow to almost $400 million in 2016.

LED lamp/luminaire manufacturers along with power supply and power semiconductor manufacturers are already looking into more intelligent lighting solutions. Such solutions are predicted to create additional opportunities for manufacturers of microprocessors, communication ICs, digital power solutions and, in some cases, advanced materials.

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MANUAL FREQUENCY RESPONSE MEASUREMENTS FOR MAGNETICS - PART II

By: Dr. Ray Ridley

In this article, Dr. Ridley provides further insight into frequency response measurements of transformers and inductors using equipment that you probably already have in your laboratory. An improved signal generator allows errors in short-circuit measurements to be greatly reduced.

The Importance of Impedance Measurements

As mentioned in the last article in this series, impedance measurements of transformers and inductors are an essential step in producing quality magnetics for prototyping and production. Ideally, the measurements of magnetics impedance should be made with a properly calibrated and automated piece of test equipment [1]. However, many students of power electronics and engineers beginning their careers only have access to the most basic laboratory instruments. The impedances of all magnetics should still be measured with the techniques described in these articles. The time spent on this process is very valuable.

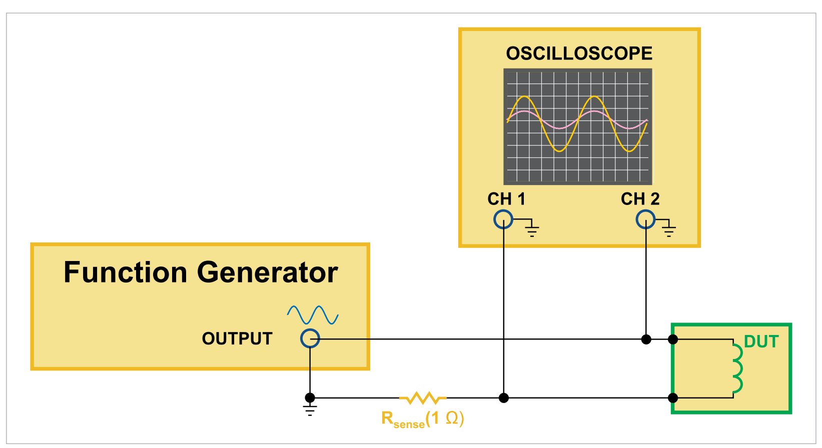

Fig. 1: Schematic of How to Measure Frequency Response of Magnetics Using a Signal Generator and Oscilloscope.

Manual Setup of Impedance Measurements

Figure 1 shows the recommended test setup for manually measuring magnetic components. The device under test is connected in series with a 1-ohm test resistor, and a signal applied across the series combination. The voltage across the 1-ohm resistor, representing the current, is measured with one channel of an oscilloscope. The voltage across the series combination is measured with the second channel.

Figure 2 shows a photograph of the actual lab test setup. A small test fixture containing the sense resistor was used to improve RF layout issues of the test setup [1]. It is very important that the impedance of the sense resistor setup be accurate up to the highest measurement frequency.

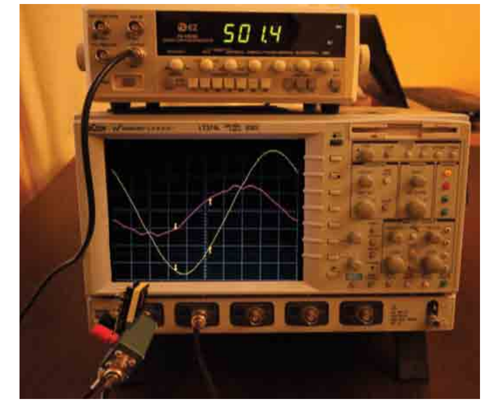

Fig. 2: Photograph of Manual Magnetics Impedance Test Setup.

This setup was used in the last article in this series. Very good results were obtained for the open-circuit measurements of a transformer. The measurements with the manual setup and with the AP300 analyzer setup were in very close agreement.

Experimental Results for Short-Circuit Impedance Measurements

Figure 3 shows the results of measurements with the transformer secondary shorted. In this case, the manual measurements did not agree very well with the AP300 measurements.

There are two areas of Figure 3 where discrepancies occur. The first, shown shaded in green, is due to the measurement setup and the value of the sense resistor. The manual measurement setup cannot extract data below the 1-ohm resistor value. If measurements are made more accurately together with phase information, it is possible to extract lower impedance information, but this is very time consuming. This is easy to do with automated equipment [1].

Alternatively, the resistor size can be reduced to 0.1 ohm, but this presents problems with accuracy of the sense resistor. Errors are introduced at low frequencies due to the contact resistance in the measurement setup. At high frequencies, errors are introduced due to the parasitic inductance of the sense resistor connections. The low frequency information below 1 ohm is not typically as important in understanding the characteristics of the magnetics, so the sense resistor was kept at the 1 ohm value as a practical compromise.

Signal Generator Waveform Distortion

The second area of discrepancy in the short-circuit impedance measurement is shown shaded in gold in Figure 3. This was caused by distorted drive signal from the signal generator. Most signal generators are designed to produce a small-signal output with an impedance of 50 ohms. With modern low-cost test equipment, the waveforms

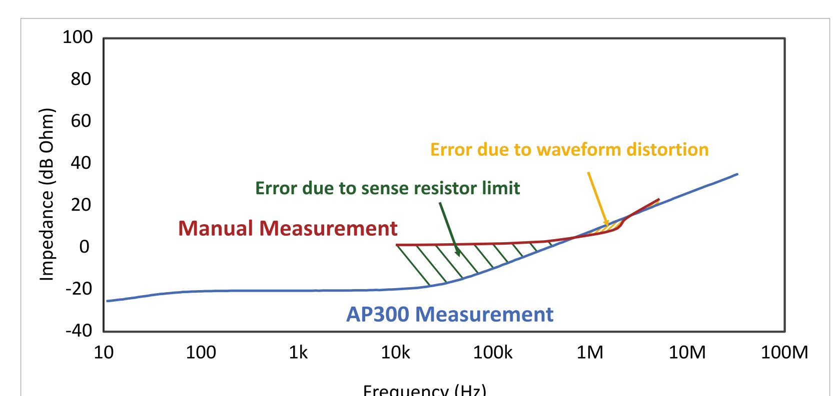

Fig. 3: Comparison of Manual Transformer Short-Circuit Impedance Measurements and Automated Measurements with the AP300.

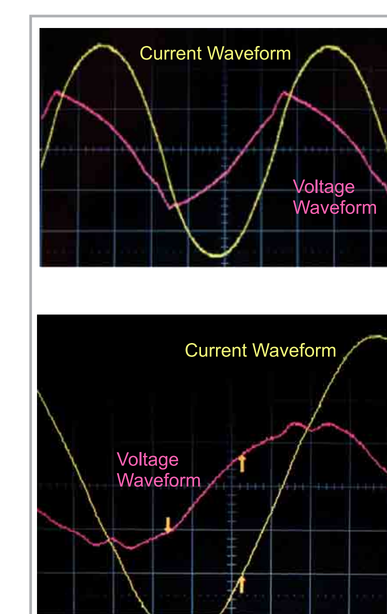

Fig. 4: Distorted Voltage and Current Waveforms from Signal Generator.

Frequency kHz	Channel 1 (A)	Channel 2 (V)	Impedance (Ohm)	Impedance (dB Ohm)
10.000	0.080	0.086	1.075	0.628
100.000	0.081	0.093	1.146	1.185
200.00	0.081	0.100	1.243	1.889
500.00	0.082	0.134	1.642	4.308
1000.00	0.082	0.202	2.460	7.820
2000.00	0.083	0.349	4.205	12.475
5000.0	0.082	0.773	9.473	19.530
10000.0	0.080	1.395	17.481	24.851
20000.0	0.069	2.180	31.548	29.980
30000.0	0.080	3.610	45.238	33.110

Fig. 5: Table of Data Collected with Manual Measurements.

can become very distorted as shown in the two sets of voltage and current waveforms shown in Figure 4.

To improve the measurement results, a better signal generator is needed, or you can use a low-impedance high-quality power

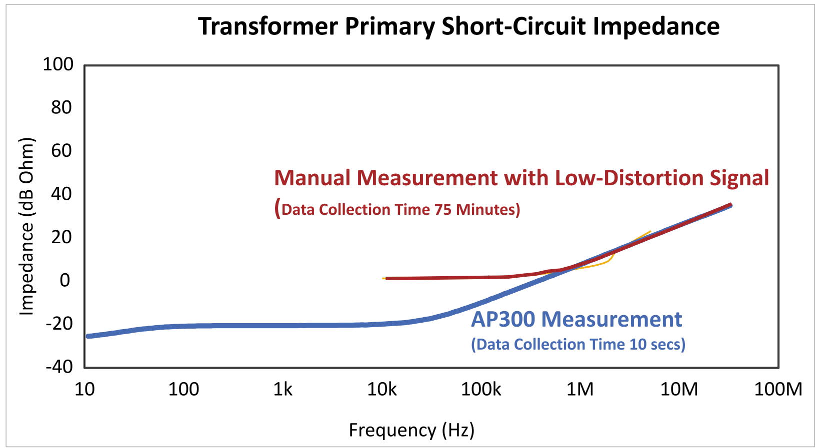

Fig. 6: Improved Short-Circuit Measurement Results with Low-Distortion Generator.

amplifier to drive the test setup. This experiment was done with a good signal generator and the table of results is presented in Figure 5.

Figure 6 shows a plot of the improved results using the better-quality signal generator. It can be seen that the results are very close to those obtained with the AP300 analyzer, validating the approach of manual measurements for the more difficult task of short-circuit measurements.

While these results are much improved, the manual measurements still consumed a considerable amount of time. Even with the better signal generator, distortion still occurred if the drive signal was set too high, and several iterations were required to obtain good quality results. The plot of Figure 6 took about 75 minutes to produce in the lab.

Summary

Magnetics impedance measurements should always be made for switching power supplies, whether you are a student, an engineer at a small company, or working for a large organization. If you have a sufficient equipment budget, then the AP300 analyzer provides the most accurate and rapid solution available. If you don't have available budget, take time to do the measurements manually. Whichever method you choose, do not be tempted to skip this crucial step in your magnetics development.

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www.ridleyengineering.com

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1. Ridley Engineering Frequency Response Analyzer from AP Instruments, www.ridleyengineering.com/index.php/analyzer.html

2. Ridley Engineering Design Center, www.ridleyengineering.com/index.php/design-center.html

A TOUCH OF SAFETY CLASS: KEEPING OUR FINGERS OUT OF HARM´S WAY

More than anything, LED-based lightbulbs must be safe.

By: Christopher Richardson

As a child, I had a love-hate relationship with electricity. My parents are fond of telling the story about the day I stuck a bobby pin in an electrical outlet as a toddler. "Pretty lights" was my commentary on the sparks that flew while my mother suffered heart palpitations.

Later I accidently stuck my finger into an empty lightbulb socket and got an important lesson in what 120 VAC at 60 Hz feels like (not good). Still later as a lab assistant at the power lab at university, there was an oscilloscope with a broken safety ground and about 60 VAC on the handle. We used to play who can hold on the longest. Just another way to get accustomed to our friend the electron.

So far as an adult living in Europe I´ve been fortunate enough not to electrocute myself with a full 230 VAC, but I do have respect for that much voltage. At university, we learned that the Europeans doubled their line voltage to reduce the currents and improve efficiency.

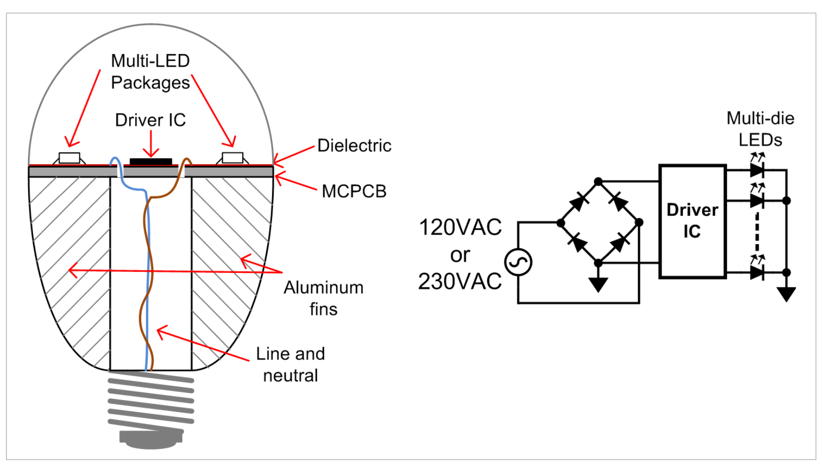

Figure 1: A simple but dangerous LED lightbulb

It sounded great in theory but, before I ever worked with an offline LED driver, I saw a fellow student on the electric-vehicle team accidently short a bus bar on the battery stack, at 400 VDC. The arc knocked her unconscious and vaporized a section of skin on her forearm—a reminder that high-potential electrons deserve great respect.

Not long ago I saw an experimental prototype of an LED lightbulb where the entire base was a single aluminum piece. The design used AC-type LEDs, arranged them in various strings, and connected them with a custom IC on a MCPCB (metal core PCB) (Figure 1). The engineer in charge went to plug the device into a standard wall socket and I couldn´t help but tense up. With no fuse or isolation and a 10 to 15 A current limit, there was only the MCPCB's thin dielectric layer between the engineer´s bare hand and 325 V pk. I knew that a sensitive differential circuit breaker would limit fault currents to 30 mA, and I couldn´t see any large capacitors, but I nonetheless declined to touch the bulb while the circuit was live.

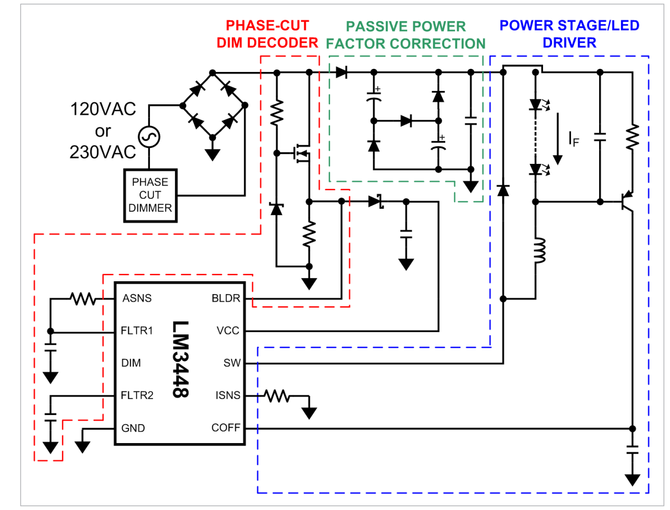

Figure 2: Non-Isolated Buck LED Driver for Class I or Class II LED Lamps

Taming the wild west

LED-lighting technology has evolved much faster than have the standards for safety—not to mention line harmonics, power factor, and EMC (electromagnetic compatibility). It´s still common to hear some refer to the wide-open field of LED lighting as The Wild West as some products come onto the market without meeting one or more of the applicable standards. Whether this is due to misconception or negligence is open to debate but, in the case of safety, standards such as UL´s 8750 are complete. Though the IEC´s 62560 for self-ballasted LED lamps is under development, it stands to reason that similar safety requirements for other line-powered electronics such as IEC 60590 represent best practice.

Most LED lightbulbs rectify the AC line and many boost it to as much as 400 VDC in the process of power factor correction. So, having witnessed what happens if you short 400 VDC, an LED lightbulb that meets a respected safety standard is the only kind you will find in my home. The piece of mind is well worth a few more euros.

Class I is for downlights

One thing that is clear is that a lightbulb does not have a connection to ground, and therefore cannot be a Class I device. Downlights for use in false ceilings are good candidates for Class I devices, where the exposed aluminum heatsink could connect to ground, and a differential circuit breaker would trip in the case of any short circuits between line or neutral and earth. Non-isolated driver circuits are well suited to Class I LED lamps because they tend to use simpler topologies, like the buck regulator, with fewer components and higher power efficiency than isolated circuits such as the flyback regulator.

Class II with mechanical isolation

The market for LED lightbulbs that simply screw into an Edison socket is enormous—far greater than that of recessed downlights. Add to this the fact that many recessed downlights are little more than housings for lightbulbs, and it stands to reason that LED lamps without connection to ground represent a large portion of the LED lighting market. To be legal for sale in the European Union or the United States, these LED lightbulbs need to meet safety Class-II, or even Class-III requirements.

One way to build a Class II lamp is to start with the same non-isolated LED driving circuit that was used for the Class I lamp. For example, the LM3448 is a buck regulator that provides constant current to a string of LEDs at power levels up to about 10 W. Optional passive power-factor correction blocks and circuits that detect and react to dimmers (such as forward-phase TRIAC dimmers or reverse-phase IGBT/MOSFET dimmers) complete an LED-drive design (Figure 2).

To be safe as defined by UL or the IEC, the assembly requires two layers of an approved material between the AC line and any metal part that could contact a human finger. The major advantages of this approach are the buck regulator's simplicity, low cost, small physical size, and power efficiency. As with all engineering, there are major disadvantages as well, which are mechanical and thermal in nature. The heatsink, which in a lightbulb can only be the body of the bulb, is clearly accessible to fingers and hands. (We all jump back just a little when screwing in a new lightbulb in an energized socket when the bulb lights with that last turn.)

The anode of the first LED in the chain is at nearly 400 VDC under worst-case conditions in 230 VAC areas of the world, though I wouldn´t volunteer to short the 190 VDC of a North American bulb´s first LED, either. Two dielectric layers must separate the LEDs from their heatsink, which significantly adds to their thermal resistance. The result is either less light or high temperatures, both of which are highly undesirable.

Class II with electrical isolation

A second approach to designing a safe LED lightbulb is to isolate electrically the circuit's output. The heatsink can now directly connect to the thermal tabs of the LEDs. This approach takes some of the burden off the mechanical engineering staff, only to drop it in the collective lap of the electrical engineers.

For example, the LM3447 can operate as a quasi-resonant flyback regulator—an isolating configuration. Quasi-resonant refers to the technique of adjusting the switching frequency so that the voltage across the main power MOSFET is always near zero when it turns on. The goal of this technique is to improve power efficiency by reducing switching loss and to improve EMC by reducing ringing during and after switching the power FET and output diode.

Even though some of the pressure is off, the mechanical engineers can´t take an early lunch. Perhaps the biggest challenge for an electrically-isolated Class II LED lightbulb is the size of the transformer a flyback regulator requires. The two dielectric layers using UL and IEC approved materials this design removes from between the LEDs and the heatsink haven´t disappeared: they've

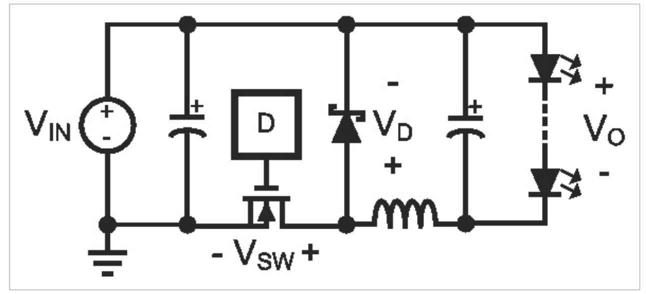

Figure 3: A generic low-side buck regulator

moved into the transformer where they take up space. Add to this the creepage and clearance requirements that specify minimum distance between the mains-connected primary and the isolated secondary, and the transformer is now by far the bulkiest part of the circuit. Fitting it inside the cramped confines of a lightbulb-shaped space is no easy task.

Buck and flyback from the electrical perspective

Mechanical challenges are not the only factors in choosing the best LED driver. The amplitude of the AC input voltage also has a strong influence over this choice. In North America and Japan where line current ranges from 100 to 120 VACRMS the job of converting the AC mains voltage to a fairly low DC voltage is a lot easier due to a basic principal of power conversion: the closer VIN and VOUT are to one another, the more efficient the conversion will be. Some LED manufacturers have noted this and introduced multi-die LED packages with 10 or 12 dice in series that operate at lower current in order to stay within a total power of around 10

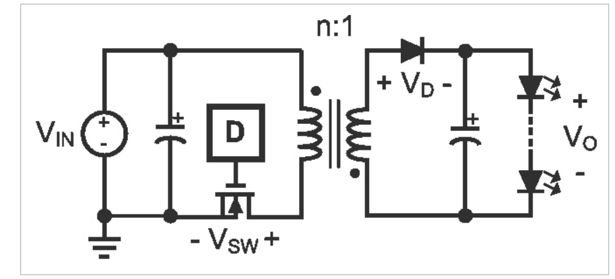

Figure 4: A generic flyback LED driver

W. (This limit is purely thermal: With passive cooling it is quite difficult to go much higher in power dissipation.)

The duty cycle of a low-side generic buck regulator (Figure 3) is:

$$D = \frac{V_O + V_D}{V_{IN} - V_{SW} + V_D},$$

where D is the decimal duty cycle, VO is the output voltage, VD is the gate voltage, and VSW is the voltage across the switch.

As a switching converter of any topology nears the extremes of duty cycle, for example above 90% or below 10%, it becomes increasingly difficult to make efficient use of the power switches. For example, one of the LM3448´s evaluation boards is a non-isolated, low-side buck that drives eight to 12 LEDs in series at 180 mA. The average output voltage is 36 V from a mains range of 85 to 135 VACRMS. Using typical values for the switches VGS and VDS of 0.9 and 0.65 V, respectively, and a converter-input voltage of 169 V, the duty cycle is about 22%.

Using a similar circuit operating on a 230 VACRMS mains would put the duty cycle much lower, at around 11%. This gets into the range where the recirculating diode carries the current for a much greater portion of the duty cycle. Since it's the lossier of the two switches, efficiency suffers.

Further complicating matters, when input voltage doubles, the switching losses in the power FET and diode will double unless the design allows higher ripple current or lower a lower switching frequency. Higher ripple current means higher RMS currents and greater losses, so halving switching frequency is more attractive, but exacts a price in inductance, which doubles, leading to larger power inductors.

The flyback topology has the advantage of using a coupled inductor or flyback transformer with a user-selectable turns ratio, n (Figure 4). Beyond providing galvanic isolation, the main benefit of using a transformer is that, by selecting n, the designer can set the duty cycle to almost any value:

$$D = \frac{n(V_O + V_D)}{V_{IN} - V_{SW} + n(V_O + V_D)}$$

In practice, adjusting the turns ratio so that duty cycle is typically at 50% is usually the most efficient, dividing the time that the power FET and the output diode carry the current into equal portions.

From the mechanical perspective

The challenge with any flyback regulator is the size of the transformer. Lightbulb designs usually place the PCB along the center axis of the body. This means that footprint is not the only factor: height is often even more important.

By contrast, the buck converter's inductor is quite small and the output capacitor is by far the largest component. The LM3448 buck-circuit demo board's back side provides enough space that, with some component shuffling, you can include two smaller inductors in series if necessary. Finally, because the isolation for the LM3448 will be mechanical, there is no primary or secondary to separate with voids or gaps in the PCB to meet the creepage and clearance requirements.

Producing products that meet all the applicable norms for safety, EMC, and power factor increases the cost. There is a basic theory of marketing that states that once a certain price is set in the mind of the consumer, it is very difficult to change the perceived value of that product. Unlike most downlights, streetlights, or lighting for warehouses, lightbulbs are very much a consumer product. Considering their filament-based predecessors typically cost less than one euro each, it´s not hard to see why many manufacturers fall prey to the siren song of corner cutting to produce a product at minimum cost. Enforcement in the EU is lax: Manufacturers don't test most products unless they cause a problem.

I currently have two LED lightbulbs in my home, that I purchased on the open market for 12€ each. They use isolated flyback circuits similar to the LM3447. Before I bought them I saw one taken apart, and that was what convinced me that they were safe. The LEDs attach to a transformer-isolated metal mass and, where a hand can touch the metal, it's coated with a non-conductive enamel.

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EFFICIENT POWER PROTECTION HELPS DATA CENTER RUN GREEN

Robustness and energy-efficiency go hand-in-hand

By: Louis Pinkham

NetRiver has been racking up utility rebates, generating significant energy savings, and garnering accolades for its commitment to green efficiency.

NetRiver supports two facilities that function as primary data centers for its 100-plus customers. Prior to revamping the Lynnwood location's power-protection system, NetRiver, like many organizations, was feeling the burden of ever-escalating power demands.

Inefficiencies in UPSs (uninterruptible power systems) are a significant contributor to rising energy costs. While the efficiency of a typical UPS generally ranges from 94 to 95%, that rating plunges as the load decreases. Because the majority of IT loads use a dual-bus architecture for redundancy, most UPSs are supporting loads of less than 50%, and often as little as 20 to 40%.

For data centers, even small increases in efficiency can translate to thousands of dollars in savings, resulting from the ability to achieve more real power while lowering cooling costs—outcomes that NetRiver has experienced since deploying three 550 kVA Eaton 9395 UPSs equipped with Eaton's ESS (Energy-Saver System).

In ESS mode, the UPS safely provides mains current directly to the load when the input is within the acceptable voltage and frequency limits. If input power exceeds the predefined limits, the UPS switches to double conversion. If input power is outside the system's tolerances, the UPS draws power from battery modules. Detection and control algorithms continuously monitor incoming power quality and allow the UPS to engage power converters in less than 2 ms when the utility source exceeds predefined voltage or frequency limits. In this way, the ESS system always provides secured power to the critical load while maximizing efficiency.

If the UPS detects a fault condition while operating in ESS mode, it is able to determine whether the fault is on the load side or if it is upstream of the UPS. A fault at the source results in an immediate switchover to the inverter; a fault in the load keeps the UPS in ESS mode.

Using ESS, the UPS intelligently adapts to utility power conditions while supplying clean power to the IT equipment. Even more, because UPSs using ESS maintain 99 percent efficiency during normal operation, even when lightly loaded, the technology can deliver efficiency gains of up to 15% over traditional models in the typical operating range (Figure 1).

According to sales and marketing manager, Adam Vierra, for every 1% efficiency improvement the facil-

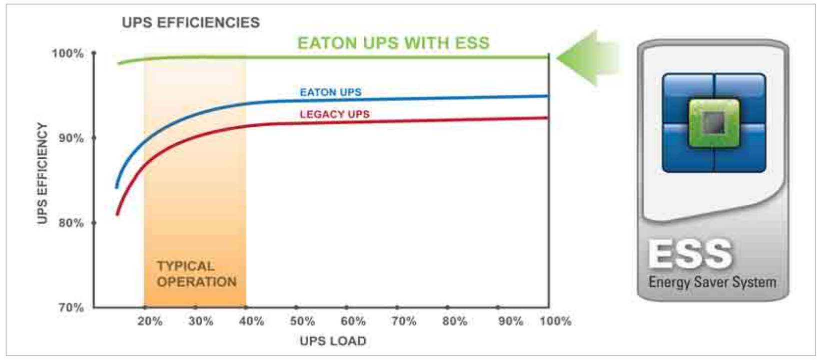

Figure 1: Even at light loads, where you would expect efficiency to be much lower, the UPS maintains a consistently high efficiency profile.

ity saves about $10,000 per year. Indeed, the data center's projected savings of 1.5 GWh/yr reduces the facilities annual utility bill by $110,000.

To reduce the capital outlay required to install the equipment, NetRiver worked with its local utility company, Snohomish County PUD. The PUD offers technical advice and cash incentives, based on anticipated annual electricity savings and project type, to customers who install qualifying energy-efficient equipment.

The need for an additional 1.5 MW of clean power initially prompted NetRiver's management team to consider the Eaton product line for its data-center expansion. But high efficiency and bolstered power capacity were just two of the company's prerequisites for a UPS installation.

Scalability was another key consideration, since NetRiver can incur unexpected increases in power consumption as it adds new customers. With that in mind, the company sought a power-protection system capable of easily scaling to match its growth. The company can expand its 9395-based system in building-block increments by adding additional UPS modules.

The trio of 9395 UPSs with ESS has also dramatically transformed the company's PUE (power-usage effectiveness), a metric that the Green Grid Alliance created that describes the energy efficiency of a data center (Reference 1, Figure 2). According to Vierra, the facility attains a PUE of 1.3 compared to competitors that score between 1.7 and 2.

Figure 2: NetRiver's three Eaton 9395 UPSs with ESS deliver 1.5 MW of clean power.

The lower PUE indicates a reduction in power consumption with correspondig reductions in operating costs.

NetRiver's installation also included three PDUs (power-distribution units) and five RPPs (rack power panels)—dual-fed quad panels that bring high-density power distribution closer to IT enclosures to streamline cabling while providing a more adaptable infrastructure. The PDUs and RPPs are equipped with the Eaton EMS (Energy Management System), which continuously measures the current on all breaker levels. With real-time insights into power conditions throughout the data center, managers can more effectively prevent overload conditions, optimize power distribution, and track each customer's energy use.

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RENEWABLE ENERGY PARKING: NEW SOLAR CARPORT TURNS PARKING SPACE INTO ENERGY SOURCE

New solar carport turns parking space into energy source

By: Doris Hirsch

Lightweight Plexiglas panels give rise to an innovative photovoltaic-carport design that advances efficacy, ease of construction, and aesthetics.

While useful, carports tend to be less than spectacular from an architectural perspective. A flat roof supported by four columns protects the car parked below from the sun, rain, snow, and hail. However, it does not need to be a design wasteland, as the Sunovation Eco Technics shows. The new photovoltaic carport developed by Mage Sunovation GmbH uses Plexiglas from Evonik as a carrier sheet for the solar cells.

Futuristic in design, the carport has everything one would expect of a high-tech parking space: solar modules for power generation, energy-conserving high-performance LEDs, motion detectors that switch on the lighting, and a power socket for charging an electric vehicle (Figure 1).

Figure 1: The solar carport from Evonik Industries takes advantage of the Evonik Plexiglas's transmission properties, which align well with the spectral response of solar cells.

Evonik has installed a carport designed for the company on the premises of the Darmstadt site. The carport sits directly in front of the new lightweight design studio in which Evonik presents sophisticated plastic components for applications in the automotive

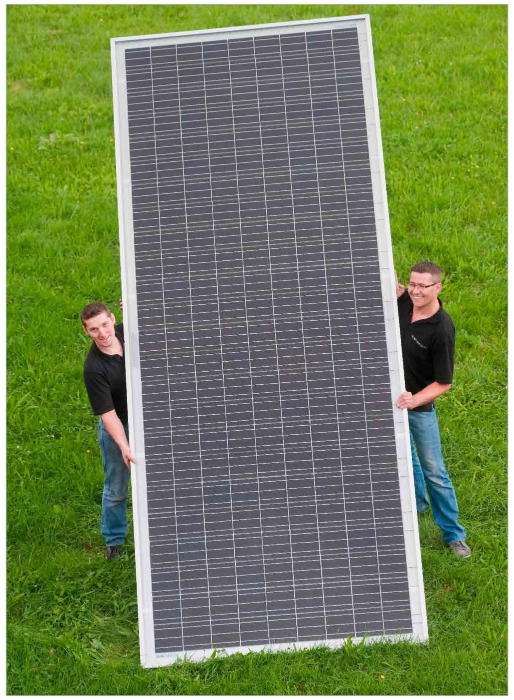

Figure 2: Evonik's solar module weighs 60% less than comparable glass-on-glass designs.

industry, aviation, solar technology, and architecture. Here, the solar carport rises upwards in an elegant arch. Its 8-m2 photovoltaic surface produces enough power "to cover the consumption needs of an electric vehicle driving about 40 kilometers a day," states Markus Krall, founder of Mage Sunovation GmbH. The solar cells can generate around one 1 kW pk.

Lightweight solar module permits filigree design

A lightweight plastic solar module makes the carport's filigree design possible. The solar cells embed between two Plexiglas sheets. While the cover sheet is made of solid material, designers chose a lighter multi-skin sheet that delivers additional weight savings for the lower carrier sheet. A special multi-component gel between the two layers holds the solar cells in place (Figure 2).

The low weight of the solar module–about 60% less than a comparable glass-on-glass design–makes an elaborate substructure unnecessary and provides numerous design options ranging from different colors to a satin underside.

For the model in Darmstadt the designers opted for backlighting the modules with Plexiglas LED rods. When LEDs at both end illuminate, they spread the light evenly along the entire length of the rod. Motion detectors can control the LEDs.

Weather resistance, mechanical properties, and transmission are the cover sheet's main features. "Not only does the Plexiglas have the highest transmission among transparent plastics, but it is also highly UV and weather resistant," says Uwe Löffler, who is responsible for establishing new business in the Solar market segment in Evonik's Acrylic Polymers Business Line. In the carport in Darmstadt, the cover sheet is made of the newly developed Plexiglas Solar, whose transmission properties are compatible with the spectral response of solar cells. This material allows high-energy radiation of 350 to 380 nm to pass through far better than other plastics. Consequently, more high-energy light reaches the solar cells improving the overall system efficacy.

Lightweight solar modules are operating in a broad range of applications including bus stops, golf carts, boats, and radio tow-ers. Evonik's largest solar module measures about 1.6 by 4 m.

The Mage Sunovation carport design takes advantage of modular construction techniques, which makes it easily expandable for large-scale applications. Installation is simple requiring only an even, stable substrate. The carport does not require a foundation and, in many cases, does not require a construction permit either.

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www.plexiglas.de

USB'S ROLE IN BATTERY CHARGING FOR PORTABLE ELECTRONICS

The USB charging specification enables faster charging for portable devices.

By: Dave Sroka

In addition to conveying data, the ubiquitous USB interface is central to powering handheld consumer devices.

These include cell phones, personal video players, tablet computers, MP3 players, digital cameras, portable gaming consoles, and eBooksWhile it does so, it circumvents the need for a collection of different proprietary adaptors only suitable for goods from specific manufacturers. With the goal of reducing the quantity of electronic waste we introduce into the environment, legislative acts in many regions of the world are now focusing attention on USB as a universal power interconnect for portable devices.

USB's capacity to transfer current, as well as data, was originally restricted essentially for powering PC peripherals. For the interface to become the principal way to charge handheld electronics, its performance would need enhancing. Charging

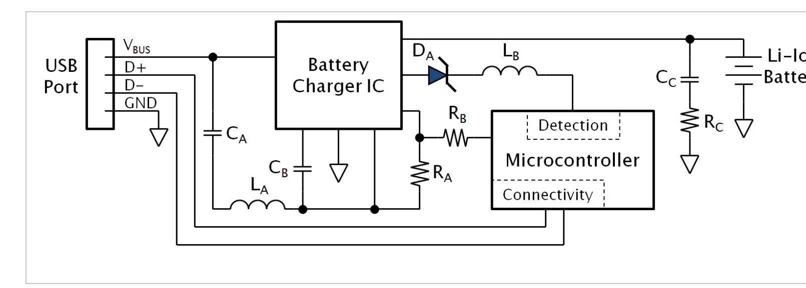

Figure 1: Regular USB Battery Charging Circuit

Specification rev 1.2 furnishes the USB standard with new powering modes and outlines use of a DCP (dedicated charging port). The DCP supports currents up to 1.8 A—more than trebling what an SDP (standard downstream port) USB interconnect will provide and greatly shortening the recharge period.

A USB interface has four shielded wires: the VBUS and GND power lines and the D+ and D- data differential pair. A DCP shorts its D- and D+ lines to prevent any data transfer. For the charging device to benefit from the higher charge current DCPs can provide, they must indicate to the device whether the port is only for charging or provides data transfer capabilities. Typical charging circuits with DCP identification capability for wall-wart type USB chargers require a many discrete components (Figure 1). Additionally, the MCU (microcontroller unit) needs to devote some of its processing capacity to carry out identification. Finally, time and effort are necessary to realize such a system design and write the necessary code.

Handheld-device manufacturers

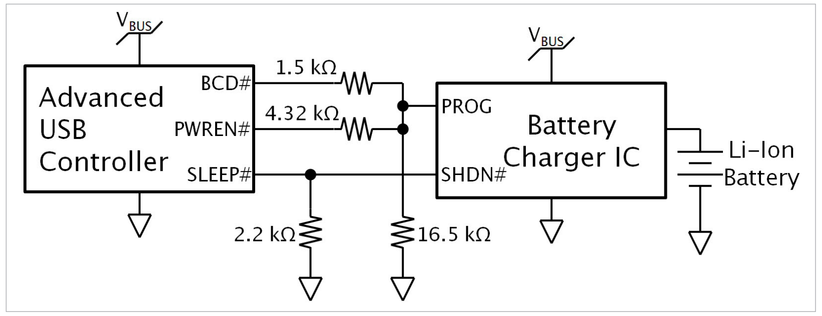

Figure 2: Simplified USB Battery Charging Circuit

can now implement USB-based battery charging by using advanced USB controller chips such as those in FTDI's X-Chip line. These ICs integrate automatic DCP detection. If an advanced USB controller detects a DCP, it asserts a signal on one of its CBUS pins, enabling the higher level charging current.

Figure 2 shows a battery charging circuit using such an interface. This circuit can charge a battery when it connects to either a USB-Host port or a DCP. The resistance between the charge controller's PROG pin and ground defines the charge rate.

There are three output signal pins on the CBUS. The IC asserts the BCD# pin to indicate connection to a DCP. It also participates in configuring the resistors on the PROG pin to set the charging current. When the USB-Host controller enumerates the device, it indicates this status through the PWREN#. The pin also selects the PROG-pin resistance that enables 500 mA charging. The SLEEP# pin indicates when the IC is in its suspend mode—shutting down the charge controller.

The charging current value is:

$$I_{CHG} = \frac{1.5\,\text{k}\Omega}{R_{PROG}}$$

where ICHG is in amperes and RPROG is the resistance from the charge controller's PROG pin to ground in Ohms.

The BCD# pin is an open-drain output that connects a resistor to ground. When the BCD# pin asserts, the charge controller's

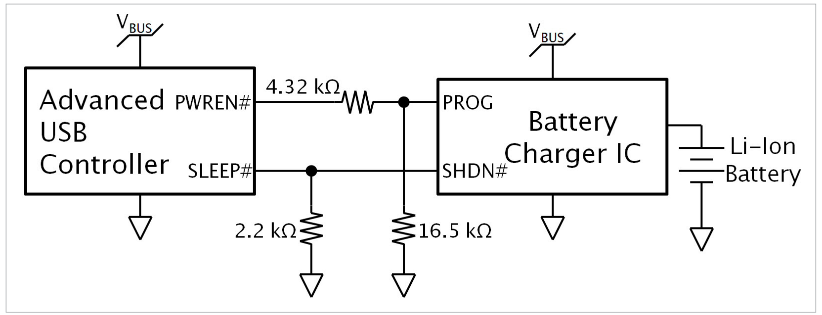

Figure 3: Battery Charging with 2 CBUS Pins

PROG pin will see a resistance of 16.5 kΩ in parallel with 1.5 kΩ to ground. It results in a value of RPROG given by:

$$R_{PROG} = \frac{16.5\,\text{k}\Omega \times 1.5\,\text{k}\Omega}{16.5\,\text{k}\Omega + 1.5\,\text{k}\Omega} = 1.375\,\text{k}\Omega$$

which, using the formula above, corresponds to a charging current of 1.09 A.

If the IC connects to a conventional USB Host that enumerates the device then the BCD# will not assert because the circuit does not detect a DCP. PWREN# will assert which connects the 4.32 kΩ resistor to ground. The charge controller's PROG pin will see a resistance of 16.5 kΩ in parallel with 4.32 kΩ to ground, resulting in an RPROG value of:

$$R_{PROG} = \frac{16.5\,\text{k}\Omega \times 4.32\,\text{k}\Omega}{16.5\,\text{k}\Omega + 4.32\,\text{k}\Omega} = 3.424\,\text{k}\Omega$$

resulting in a charging current of 438 mA.

Although charge circuits normally use three CBUS pins—BCD#, PWREN# and SLEEP#—it's possible to implement the charge function with a smaller number of pins. This is useful in cases that use some of the CBUS pins for other purposes, such as controlling an LED to indicate data traffic or to drive a TXDEN signal in RS485 applications. Using a smaller number of pins does not necessarily mean losing the charging features an application requires. By careful selection of the signals that

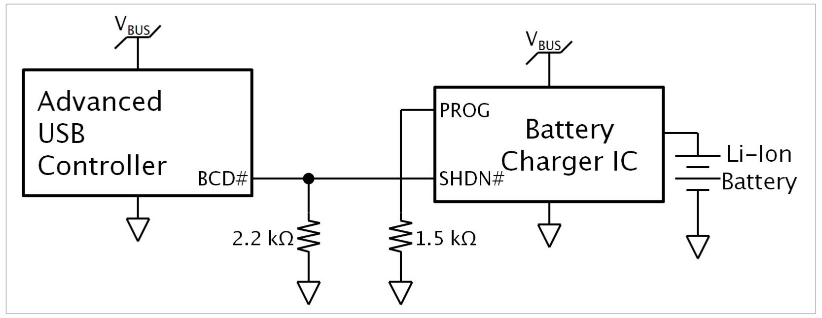

Figure 4: Battery Charging with 1 CBUS Pins

map onto the available CBUS pins, the design engineer can often implement the necessary functions.

If only two CBUS pins (PWREN# and SLEEP#) are available, the charging circuit can no longer distinguish between an enumerated USB-Host port and a DCP (Figure 3). The charge system must, therefore, keep the charging current below 500 mA to ensure compliance with the specification for a standard USB Host. This configuration applies to cases in which the battery must charge from a DCP or USB-Host port and conventional charge currents are sufficient.

When only the one CBUS pin, BCD#, is available, it is no longer possible for the chip to indicate its enumeration status to the charging circuit (Figure 4). In such cases, it disables charging when it connects to a USB-Host port. Otherwise, the charge circuit could draw current beyond the device's safe level. This configuration is useful in applications where the battery needs to charge when the device connects to a DCP, but not when it connects to a USB-Host.

The obvious appeal of USB as a universal means to charge handheld devices has led to the need to update USB-charging specifications to support high currents. The high charge currents reduce charging times, bringing them in line with what conventional power adaptors can achieve. Highly integrated interface chips make it possible for handheld-device manufacturers to incorporate advanced USB charging into their products while mitigating the costs of doing so.

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SAVING POWER USING CLOSED-LOOP VOLTAGE-SCALING CONTROL

Dynamic voltage control strategies hold the key to power savings.

By: Randy Skinner

For some designs, reducing circuit-board power dissipation by 25% to 30% would just be a nice outcome. For other designs, it's an absolute necessity.

Designers of products using the latest high-performance integrated circuits must carefully manage circuit-board power dissipation because one can describe new ASICs, SoCs (systems on chip), and processors in only one way: They are hot! What led to this problem is increasing power density in IC technologies.

Even with shrinking transistor sizes and lower operating voltages, the number of transistors on a chip and the frequency at which they switch have been increasing at even greater rates. The result is more power dissipation in smaller areas that ever before.

Converged network-adapter evolution

In the CNA (converged network-adaptor) market, ASICs combine

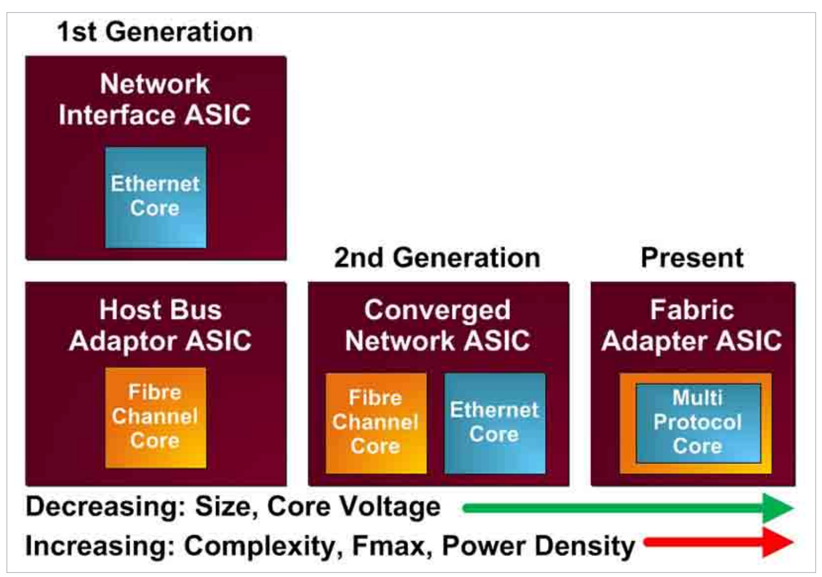

Figure 1: Development of CNA ASICs

the functionality of a NIC (network-interface card) with an Ethernet-processing core and an HBA (host-bus adapter) using Fiber-Channel processing cores. The development of these highly adapted ASICs traces from separate functional ICs to devices with multiple core types on a single SoC. The evolution continued to the present-day Fabric-Adapter ASIC capable of handling multiple protocols natively through a single IC core (Figure 1). This feat is possible thanks to smaller IC-fabrication-process nodes and higher transistor counts than ever before possible. Multiple and lower operating voltages, along with higher clock switching speeds, facilitate this processing power in a smaller footprint than previously possible.

While this advancement is exciting, there are limits to any technology, including these powerful new ASICs. Board designers who use these ICs now have more challenges than ever to deal with. On small, compact boards, the design challenges that higher power densities create include:

- High local IC temperatures, which are near or at specified maximums
- The need for heat sinks or other heat-mitigation measures
- Increased operating temperatures of adjacent devices

Power-management strategy through voltage-supply scaling

Using the example of the CNA card, a new technique for reducing power dissipation is to lower the ASIC core's operating voltage(s) while maintaining manufacturer-specified operating conditions. The savings can be significant, as power dissipation is primarily a function of the square of the device's operating voltage. When load and digital processing conditions permit, reducing the ASIC's Vcore can yield power savings of 30% or more per IC. Those conditions include I/O loading, clock speed, and other parameters such as temperature and operational characteristics.

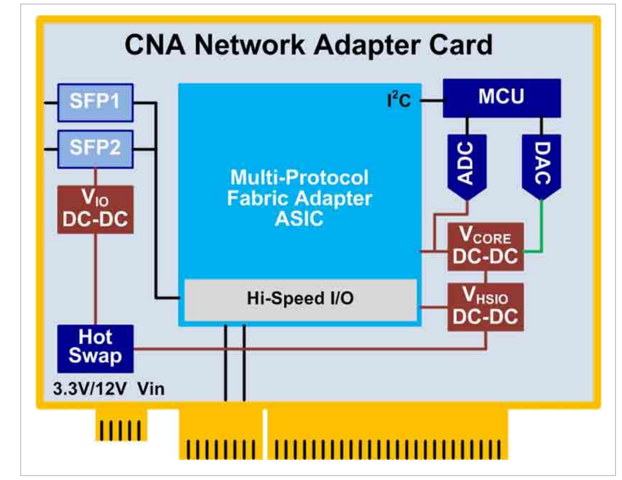

Figure 2: CNA voltage-scaling block diagram

At appropriate times, a circuit controlling the ASIC's Vcore can change the Vout of the supply delivering that voltage. In Figure 2, a dedicated MCU communicates with the ASIC and, by implementing a closed-loop trimming algorithm, adjusts the Vcore DC-DC converter in real time. The MCU measures Vcore from the DC-DC and then sends digital correction signals to the DC-DC by means of a voltage it generates with an external DAC.

Challenges of traditional voltage-scaling methods

One of the challenges of implementing a method for setting the Vcore power supply to multiple values is the need for multiple external components in a closed-loop-control configuration. The measurement of the power supply's output voltage is subject to the accumulation of errors due to ground potential variations and single-ended voltage-measurement techniques. Another disadvantage of single-ended measurement is that it's not immune to noise. Traditional single-ended measurement is a poor alternative to differential input sensing and results in accuracies no better than 1.5% error (min). Other MCU-based implementation challenges include the need for an external watchdog timer to ensure that a hung-processor condition does not occur.

Finally, a custom-built implementation is the most expensive alternative, especially when it requires a large number of discrete ICs. Another item often overlooked is the risk and complexity of the stable closed-loop trimming algorithm itself. A hung MCU or over-ranged ADC or DAC condition can result in unpredictable operation. Being too conservative and missing specification values will reduce power savings.

A complete power-management implementation

In addition to accurately scaling Vcore for multiple operating values, a complete board-management implementation

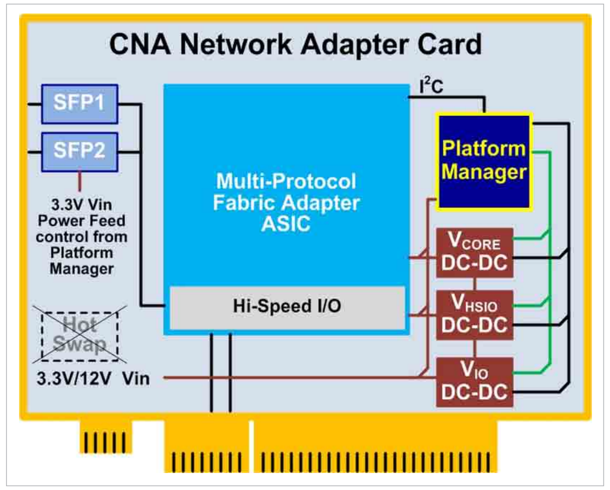

Figure 3: Improved CNA voltage scaling with full Platform-Management integration

should offer all of the following features:

- Voltage monitoring (all supplies)
- Power supply sequencing
- PCIe requirements for hot swap of 3.3V and 12V
- Power feed control to SFPs
- Reset-Tree generation
- I2C link for multiple-purpose communications

Power-management integration benefits

When there is an opportunity to scale supply voltages in applications such as the advanced CNA ASICs, it is important to adjust the programmed voltages automatically with speed and precision. To take advantage of lower operating voltages, the adjustment must also be stable over time, temperature, and IC-fabrication-process variations. Using an IC such as the Lattice Platform Manager to set multiple Vcore values ensures less than 10mV max error in Vout values over all the conditions noted above. Due to its programmability and simulation capabilities, the Platform Manager device is easy to use and to verify its precision operation. These platform-management products incorporate differential sensing as a standard feature that makes them immune to errors due to ground-potential fluctuations.

Setting the DC-DC to a very precise value yields maximum power savings without violating the manufacturer's minimum setting and endangering reliable device operation. In other words, if operation at a lower power setting is allowable, it is important to take advantage of it, because it will also lower the clock rate. Any operating voltage higher than the precise minimum would fail to achieve maximum savings while also forfeiting precious performance margins. Precise, closed-loop setting of the Vcore supply voltage eliminates this problem and, when set by a precision ADC and reference combination, results in a design that is stable over operating conditions, including input voltage, temperature, and IC-fabrication-process variations.

Design software such as Lattice's PAC-Designer simplifies interfacing with a wide variety of DC-DC converters. The software computes all necessary external components for optimum control over all DC-DC converter errors. When placed under Platform-Manager closed-loop control, a power supply's Vout errors are less than 10mV (max) . Designers simply specify what operating voltages they want from various DC-DC outputs and the software chooses all the necessary external components and internal device settings to achieve precision trimming of the external power supplies. As successive designs reuse various supplies, a DC-DC component library further eases the design task.

Some advanced digital-processing-engine ASICs and other ICs found in modern circuit board electronics now include a flexible I2C interface including programmable GPIO to interface directly with proprietary voltage-scaling circuitry. A device such as the Platform Manager can easily accept these control signals from the advanced ASIC, eliminating the need for an external power-supply controller.

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SMART AND SIMPLE SENSOR INTERFACES PROMOTE ENERGY-EFFICIENCY AND PRODUCTIVITY

Promoting energy-efficiency and productivity

By: Tamara Schmitz

Automation is providing improvements in safety, accuracy, and convenience for many everyday applications.

Consider the precision and advantages of computer-assisted surgery or the array of automation now available in automotive applications such as blind-spot detection, automatic bright-light adjustment of rear-view mirrors, back-up cameras, and parallel-parking assistance. The first sector to embrace automation, however, was the industrial segment. Major advances in robotics and factory automation have improved production efficiency and factory safety. The four major technology sectors that have enjoyed these investments are sensors, transducers, motors, and control electronics.

Figure 1: Modern robotic systems featuring sophisticated multi-axis arms are adding to factory productivity and safety. Simply picking up an object can require several sensors.

Smart Sensors and Simple Sensors

Since they lack human-like powers of observation, robotic systems need sensors to observe and interpret their environment. motion control typically involve accelerometers in conjunction with continuous position feedback from other system sensors. This simple example assumes the item is stationary and doesn't exhibit certain material behaviors such as magnetism or heat that specific conditions, there is a risk that the microprocessor may not be able to calculate fast enough or even to service interrupts quickly enough. These limitations can cap the achievable robotic performance.

The use of smart sensors moves

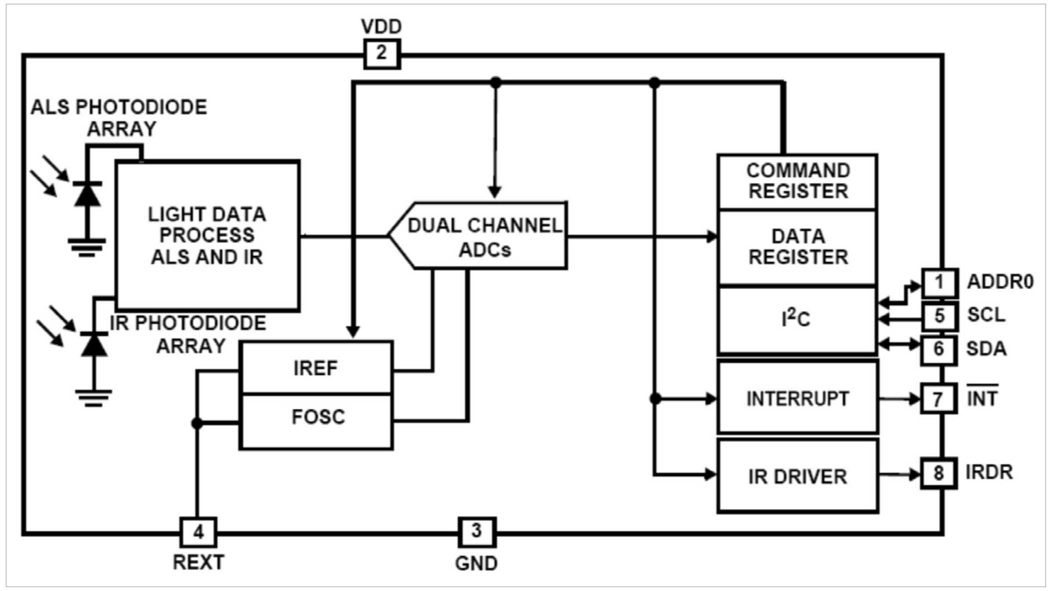

Figure 2: The block diagram of the ISL29028A ambient light and proximity sensor shows both precision analog signal processing capabilities and sufficient digital resources to form a semi-autonomous sensor interface.

the decision making process to the point of interest, in this case the arm and gripping mechanism, and thus improves the system's capabilities. It also allows the automation system to control multiple simultaneous events. Remember that distributed control makes the system design more complex, but removing the central bottleneck enhances the system's capabilities.

Sensor Interfaces

Technology companies have been and will continue to develop and deploy devices to propel the field of robotics forward. It is of particular interest when component vendors can integrate the sensor and related electronics into a simple-to-use, monolithic device.

One of the most popular types of sensors detects proximity. These sensors are common in all sorts of consumer and communications products, ranging from vending machines, ATMs, security systems, cell phones, and leading-edge personal computers. They not only can provide positioning information, like in the robotic example, they are useful in safety systems and intrusion detection. One type of proximity sensor operates with infrared wavelengths, which are invisible to the human eye. This allows a system to monitor how close objects are without constantly blasting visible light in a variety of directions, possibly distracting people nearby.

In cell phones, a proximity sensor allows the phone to detect when the user has brought it to his or her ear to engage in a phone conversation. During this time, handset can disable the screen, saving power and increasing battery life. This type of sensor-based control also prevents accidental hang-up or muting.

An example of a proximity sensor for this type of application is the ISL29028A, which integrates ambient light and proximity sensors, an IR LED driver, and I2C interface (Figure 2). The ambient light sensor allows the system to reduce the screen brightness in lower light situations, which is more pleasant for the user and reduces power consumption. The IR LED driver sends out short bursts of current to an IR LED. An object within a few centimeters will reflect this signal to the proximity sensor, alerting the system to a nearby object.

The ISL29028A's interrupt scheme is an example of how increasing a sensor interface's intelligence reduces the central microcontroller's load: The microcontroller needn't continually pole the sensor to search for an object approaching the phone. Instead, the ISL29028A provides an interrupt signal. If it has no other tasks, the microcontroller can even power down and wait for an interrupt such as one from the sensor interface to inform it of an approaching object. This allows for minimal loading on the microcontroller and an obvious savings in power.

Smart Sensor Support

To function effectively, smart sensors require interface ICs that include low-power and low-noise signal conditioning-elements. High-input-impedance instrumentation amps such as Intersil's ISL28274 provide the rail-to-rail inputs and outputs many sensor applications require. In addition, they exhibit extremely low input bias current and high CMRR necessary for strain and pressure sensing in tactile robotic applications.

Another sensor-interface IC is the ISL28133 micro-power chopper-stabilized op amp. This amplifier operates on a single-supply in the range of 1.65 V to 5.5 V, drawing only 18-μA quiescent current and 8-μV (max) input-offset voltage. Since it is a chopper-stabilized op amp, it continually measures and cancels input offsets, so the input-offset temperature coefficient is just 75 nV/°C (max).The amplifier maintains a low noise floor of 1.1 μV p-p, measured from 0.01 Hz to 10 Hz.

Robotics in various forms have returned impressive gains in efficiency and productivity. This trend has been in full force, through both fast-growing and slow-growing economic conditions. The right combination of smart or simple sensors like ambient-light and proximity sensors along with precision interface devices such as instrumentation and sensor amplifiers, assures the industry of continuing innovation and productivity enhancement.

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Special Report: Lighting Products & Systems

PSD EUROPE
Power Systems Design: Empowering Global Innovation

Inside:

FLICKER AND DIMMER CHALLENGES IN LED-LAMP DESIGN

Could flicker derail LED-lighting adoption?

By: Scott Brown

The SSL (solid-state lighting) industry is in a state of excitement mixed with trepidation.

With the obvious need for lighting more efficient than traditional incandescents, key market drivers are converging in favor of LED-based SSL: environmental concerns, energy costs, and legislation. Lamp designers, however, still have to address issues such as operating life, dimmer compatibility, and the flicker caused by both line frequency and the way some LED drivers interact with dimmers.

Incandescent replacement: CFL or LED?

For most applications, the only reasonable incandescent bulb replacements are CFLs (compact-fluorescent lamps) or LEDs (light-emitting diodes). Many factors have negatively affected CFL adoption. Perception problems started with the relatively high price, but consumers became more accepting after the introduction of incentives. Economies of scale allowed CFL prices to drop and, with experience, consumers began to appreciate the CFL's benefits including lower operating costs, which balanced some of the high cost of ownership.

A start-up delay at turn on and the warm-up period also gave CFL lighting a black eye in the market. Dimmer incompatibility, though, has significantly limited CFL success, particularly in the residential market: On the benign side, most CFLs don't work with dimmers, which can disappoint consumers. On the dangerous side, a few (granted, a statistically small number of) CFLs have caused house fires when interacting with dimmers. Lastly, like all fluorescent lamps, CFLs contain mercury, which makes the lamps' disposal in an environmentally-responsible fashion inconvenient at best and, in some locales, difficult.
With CFLs losing the popularity race and LED efficacy continuing to improve, most believe LED-based SSL lighting will grow to represent an increasing share of future lighting applications. As the LED-lighting market continues to develop, companies are jockeying for position and nervously anticipating what could go wrong to derail the SSL market, and that's the source of trepidation.

Avoiding CFL pitfalls in LED lighting

The famous saying goes, "Those who don't know history are destined to repeat it" (Reference 1). So, with the CFL rollout fresh in everyone's mind, here is the let's-not-repeat-the-mistakes-of-CFL checklist:

- Fast turn-on time
- No warm-up period
- No mercury content
- Work with dimmers

Dimmer compatibility has dominated industry attention. Fortunately, there haven't been any highly publicized house fires, but SSL lights, in less dramatic form than CFL, have not always worked well with dimmers. Some designs are just incompatible with dimmers, and that's fine so long as their packaging makes that fact apparent. Otherwise, the consumer is unpleasantly surprised when their new premium-priced bulb fails to exhibit attributes they took for granted in the incandescent bulb from which they upgraded. The issues have been the total dimming range, dimming linearity, and light flicker.

Dimmers aren't easy to work with

Most dimmers use TRIACs to phase cut the AC waveform. Many don't do that cleanly or consistently and there are no standards. Some phase cut the leading edge of the waveform, others cut the trailing edge, and many introduce glitches. The circuitry inside the CFL or LED light struggles to handle such behaviors. Note in defense of dimmer manufacturers: They designed their products to drive incandescent bulbs—simple resistive loads. Dimmers have performed that duty efficiently and cost-effectively for years.

To keep history from repeating itself, the industry is fixated on dimmer compatibility. It is equally important, however, to factor in SSL's unique challenges.

Could flicker derail LED- lighting adoption?

Yes, flicker is on the industry's mind but because the issue didn't give CFL a black eye, it might not be getting the attention it deserves. As research continues to surface, however, that's likely to change.

Several industry groups are researching flicker, including a US government team at the PNNL (Pacific Northwest National Laboratory), led by senior energy engineer Michael Poplawski (Reference 2). The PNNL is one among ten US DOE (Department of Energy) national laboratories that the agency's Office of Science manages (Reference 3).

Speaking at the Design West conference in San Jose on March 27 this year, Poplawski named flicker as one of four problems affecting LED lighting adoption that his group is working to resolve, along with dimming, power-quality, and operating-life problems. He cited the danger of seizures, as well as headaches, fatigue, blurred vision, eyestrain, and job distraction as potential side effects of flicker.

Driving an incandescent bulb—a simple resistive load —is far less complex than driving an LED light, which is a solid-state electric device. Poplawski explained that flicker is inherent in every form of electric lighting and it affects everyone differently. He said that LED lighting could reduce flicker, especially compared to CFL, but that flicker is more complicated in SSL and varies substantially, in both amplitude and frequency, in different LED bulbs.

Poplawski proposed that researchers should be able to identify and measure qualitatively—in terms of human reaction—the presence and level of flicker in a reportable way that consumers can understand.

Another working group, the IEEE PAR1789, is scrutinizing low-frequency (100 and 120 Hz) flicker, which is imperceptible to the human eye. This group published a paper in 2010 and plans a follow-up later this year. The group's 2010 document refers to research that shows that the brain responds to light at frequencies up to and beyond 120 Hz, linking it to headaches. Even worse, some SSL bulbs interact with dimmers in a way that creates light flicker at frequencies known to induce epileptic seizures (Reference 4).

SSL flicker: sources and mitigation

All AC-powered systems must deal with a line-frequency component. So-called driverless high-voltage LEDs that connect directly to the line voltage provide light that contains a rectified sine-wave artifact. Even sophisticated systems with IC LED drivers don't always completely eliminate the line-frequency and in some cases contain significant light-output ripple at twice the line frequency.

One approach to eliminate this line frequency ripple and the resulting output flicker is through a two-stage PFC (power-factor-correction) scheme. A single-stage driver converts and smoothes the

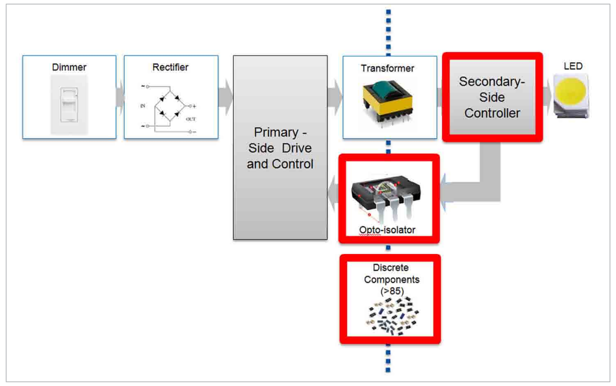

Figure 1: One-Stage Approach: The driver converts an AC-rectified line voltage to the necessary DC current through a flyback transformer and filter. Unfortunately, the rectified voltage contains ripple at twice the line frequency (100 or 120 Hz).

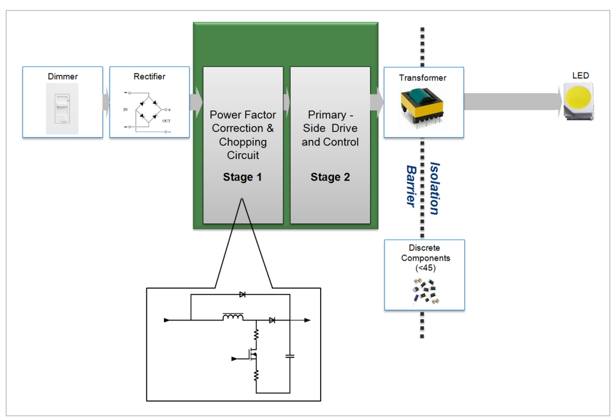

Figure 2: Two-Stage with PFC (power-factor correction): A front-stage chopper circuit (shown below stage 1) boosts the input voltage as it improves power factor to greater than 0.9. The second stage, a flyback circuit, converts the output of the chopper circuit to the required DC current on the secondary side.

AC-rectified line voltage through a flyback transformer and filter and delivers DC current to the LEDs (Figure 1). Unfortunately, the rectified voltage contains ripple at twice the line frequency, 100 or 120 Hz depending on locale. The ripple component survives the voltage transformation and appears on the output as an alternating current perturbation on the LEDs, which can cause flicker.

In two-stage designs, a first-stage chopper circuit implements PFC, supporting power factors greater than 0.9 (Figure 2). A chopper circuit is essentially a boost converter. Boosting the incoming rectified AC provides a higher DC voltage to the input of the flyback converter, which removes the AC frequency component. In the second stage, the flyback converter converts the DC voltage on the primary side of the transformer to the required DC current on the secondary side.

The second, more subtle, source of flicker presents itself in dimming systems. The interaction between some LED drivers and dimmers can introduce flicker at lower frequencies that, evidence suggests, can trigger epileptic seizures in some cases. LED drivers with digital control help solve the nonlinear attributes of this dimmer problem. While most LED drivers are all-analog, digital drivers analyze and adapt to the dimmer to which they are connected. Intelligent digital algorithms map the operating characteristics of dimmers and digitally filter the LED drive current to eliminate spikes that would otherwise cause flicker.

A digital core can also help reduce BOM costs by eliminating components such as the secondary-side controller and opto-isolator from isolated systems. Meanwhile, digital signal control maintains accurate control of the current driving the LEDs on the secondary-side.

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LED-DRIVER ICS LEAD TO A BROAD SPECTRUM OF LIGHTING

LED processing and packaging advances yield greater brightness and efficiency, longer lifetime, and decreasing cost.

By: Tony Armstrong

Incandescent light bulbs waste 90% of the energy they consume in the form of heat.

The light outputs from HB (high-brightness) LEDs have already exceeded the critical milestone of 100 lm/W. In fact, some manufacturers are already claiming 200 lm/W in the laboratory. Clearly then, LEDs have surpassed incandescent light bulbs—approximately 14 lm/W for a typical 60 W bulb—in terms of luminous efficacy. Even so, it is likely that within the next 12 months, LEDs with 150 lm/W output will be readily available in the marketplace.

Another added benefit is LED lifetime. Depending on how one calculates it, a white LED bulb has at least a 35-khr lifetime and some even claim up to 100 khrs, while an incandescent bulb's life is around 1 khrs. To put this into perspective, if you were to use an LED bulb for 10 hours per day, every day, it should last up to 9 1/2 years – a far cry from the pitiful one-third of a year afforded by the standard incandescent bulb!

The cost of HB LED lighting has also come down very quickly. The price of individual white-light diodes, which go into an LED-based bulb and make up much of the cost, have come down in price over the past few years to less than $1 today. Many LED-industry analysts predict that over the course of the year, LED bulb replacements for the incandescent light bulb will be available at prices that will be acceptable to the consumer. Some LED manufacturers already claim that they have designed light-emitting chips that could power an LED bulb producing light output comparable to a 75 W incandescent bulb so common in most homes. This type of LED chip usually requires only about 9 W to produce the same lumen output. This is less than 1/8th of the power dissipated by the equivalent incandescent bulb. However, few people realize that the key to these efficient LED light bulbs is the circuitry that drives the LEDs inside them. Amazingly, at the heart of this circuitry is the analog LED-driver IC.

One key performance feature that an LED-driver IC must have today is an adequate ability to dim LEDs. LEDs operate with a constant current proportional to their brightness, but two distinct current-control methods are available to implement the dimming function. The first method is analog dimming, which uses a control pin to adjust the constant LED current. Reducing the LED current, however, can change the output color or reduce the current-control accuracy. The second method is PWM (pulse-width-modulation) dimming. PWM dimming switches the LED on and off at a frequency at or above 100Hz, which is not perceivable to the human eye. The PWM dimming duty cycle is proportional to LED brightness, while the on-

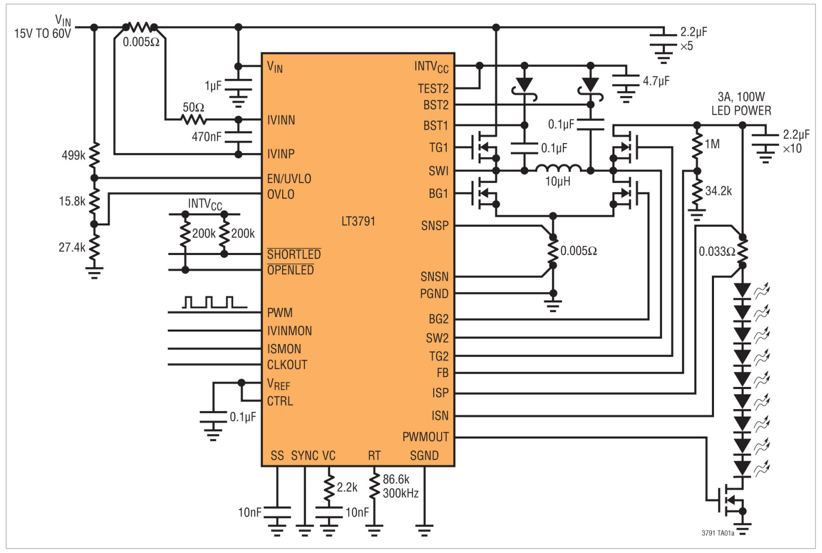

Figure 1: The LT3791 Driving a 3 A LED Array at up to 100 W

time LED current remains at the same level—as set by an LED-driver IC—maintaining constant LED color during high dimming ratios. This method of PWM dimming is useful with ratios as high as 30,000:1 in certain applications.

Specifically in the case of HB LEDs, LED-driver ICs must accommodate many different LED configurations with conversion topologies that meet application requirements for input voltage range, output voltage, and output current. Features of merit include:

- High efficiency conversion
- Tightly regulated LED current matching
- Low noise, constant frequency operation
- Independent current and dimming control
- Wide dimming range ratios
- Open LED-string protection
- LED pin to VOUT short protection
- Accurate under-voltage lock-out threshold
- Small footprint with minimal external components

Automotive HB-LED Example

There is no question that the majority of automotive headlights still use incandescent bulbs. However, this dominance is under pressure from both HID (high-intensity-discharge) lamps and HB-LED headlights going forward. HID lamps include all high-intensity discharge lamps common in general lighting such as high-pressure mercury vapor, high-pressure sodium, low-pressure sodium, and metal halide. General lighting sources are sufficiently bright to enable a working or living environment in a room, building or external space. This includes residential lighting, commercial and industrial lighting, street lighting, and automotive headlights. The automotive industry introduced HID-xenon lamps for use as headlights in the late 1990s. However, they are very expensive to produce, so their use has been limited to high-end vehicles. Going forward, due to the recent introduction of HB LEDs, the use of such HID-xenon lamps will quickly decline. Thus, the HB-LED headlight will have the largest growth rate in next decade.

One of the biggest obstacles facing automotive lighting-systems designers is how to optimize all of the features and benefits this newest generation of LEDs provide. Since LEDs generally require an accurate and efficient current source and a means for dimming them, an LED-driver IC's design must address these requirements under a wide variety of operating conditions. Further, their power supply architecture must be highly efficient, rugged, and reliable while also being very compact and cost effective.

Arguably, one of the most demanding applications for driving LEDs will be the headlamp assembly, consisting of high and low beams, daytime running lights, fog lights, and turn signal lights. LEDs in this application are subject to the rigors of an automotive electrical environment while simultaneously having to accommodate a wide variation of temperature conditions. All the while, they must fit in a very space-constrained area and offer an attractive cost structure.

As an example, Linear Technology's recently introduced LT3791 is a synchronous four-switch buck-boost LED driver and voltage

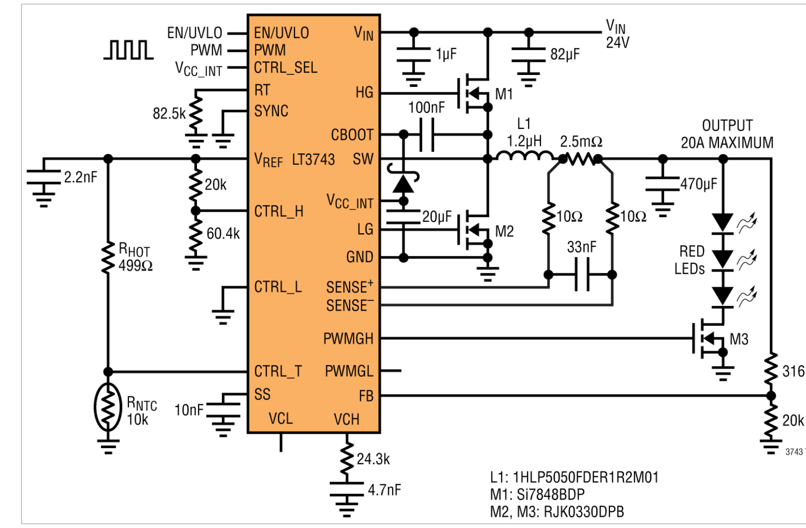

Figure 2: LT3743 Typical Application Schematic Delivering 20A of LED Current

regulator controller that drives HB LEDs for automotive headlamp applications. It has a wide 4.5 V to 60 V input and 0 V to 60 V output range, along with seamless transitions between its operating modes. Furthermore, its unique synchronous buck-boost topology enables operating efficiencies as high as 98%, which significantly reduces heatsink size and weight.

A ground-based reference-voltage feedback pin, FB, serves as the input for several LED protection features and makes it possible for the converter to operate as a constant-voltage source (Figure 1). The driver provides fault protection to survive and report an open- or shorted-LED condition, while a timer allows the LT3791 to latch off or restart when a fault occurs. It also has a proprietary current-mode topology and control architecture and uses a current sense resistor in both buck or boost modes.

Industrial HB LED example

Other end-market applications have their own unique needs for high power HB-LED drivers where LED currents of greater than 10 A are necessary. These include DLP projectors, laser drivers, and architectural lighting. However, delivering currents greater than 10 A can bring a host of design problems, not least of which are thermal-management issues within the end product.

For these applications, ICs such as the LT3743 synchronous step-down DC-DC converter deliver constant current to drive high-current LEDs. The converter can deliver up to 20A of continuous LED current from a nominal 12-V input, delivering in excess of 80 W (Figure 2). In pulsed LED applications, it can deliver up to 40 A or 160 W pk from a 12-V input. . The LT3743's unique design enables three-state current control, fast (< 2 μs) transition times between current levels, and LED-current accuracies of ±6%—all features that support color-mixing functions in RGB applications including DLP projectors. The fast transition times also support fast current pulsing in laser-driver applications.

Efficiencies as high as 95% eliminate any need for external heat sinking and significantly simplify the thermal design. A frequency-adjust pin enables the user to program the frequency between 100 kHz and 1 MHz so designers can optimize efficiency while minimizing external component size. Additional features include output voltage regulation, open-LED protection, over-current protection, and a thermal de-rating circuit. In combination with a 4 mm x 5 mm QFN or thermally-enhanced TSSOP-28 package, the LT3743 offers a compact high-power LED drive.

There is no doubt that there is a broad spectrum of applications for HB LEDs as many designers turn to them for their efficacy and longevity over their incandescent counterparts. Clearly, for any given application, it is the designer's responsibility to select an LED that can deliver the necessary light output. However, it is the oft-overlooked LED-driver IC that can significantly enhance the overall design.

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DESIGNING AND CONTROLLING HIGH-POWER LED-LIGHTING DRIVERS

Design considerations for resonant converters

By: Peter B. Green

Solid-state lighting applications such as streetlights and industrial lighting demand drivers that offer better efficiency than the traditional flyback topology in the 50—250 W power range.

As LED-emitter performance continues to improve, solid-state lighting is able to offer advantages such as lower energy consumption and longer lifetime in applications that metal-halide or sodium-type lamps traditionally address. These include street lighting and high-bay lights or spotlights in locations such as car parks, toll plazas, fuel stations, warehouses, and factories. The performance advantages LEDs offer enable enterprises to reduce operating costs and improve green credentials, and can help authorities reduce utility bills and maintenance overheads.

Growth markets such as these require drivers that offer high efficiency at higher power levels than those of typical domestic retrofits or interior luminaires. These lower-power applications have typically relied on the basic flyback-converter topology, which is relatively simple and is often a good choice for isolated LED drivers below 50 W. In the 50 W to 250 W power range typical of streetlights and high-bay lights, however, the flyback becomes bulky and less efficient compared to a topology such as the resonant converter.

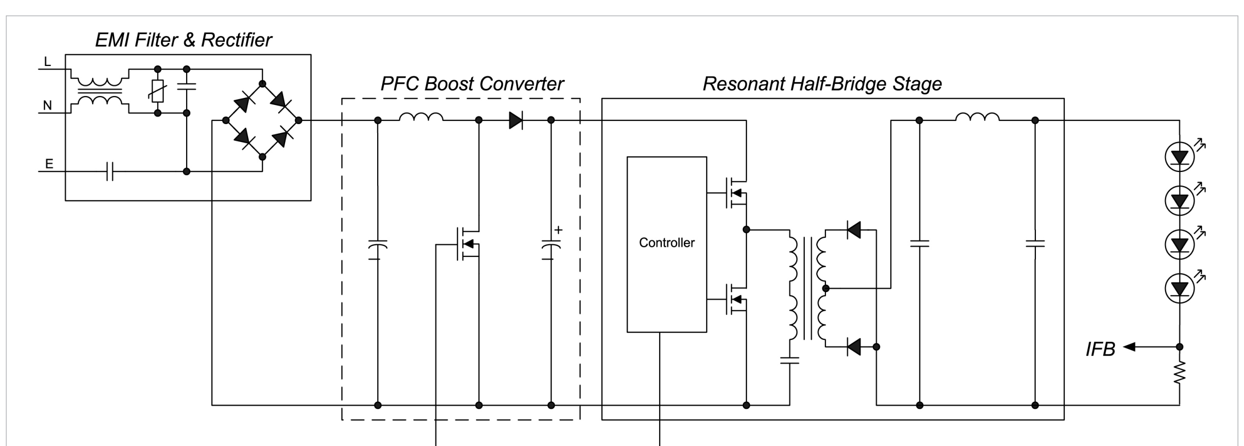

Figure 1: Resonant driver for high-power LED-lighting applications.

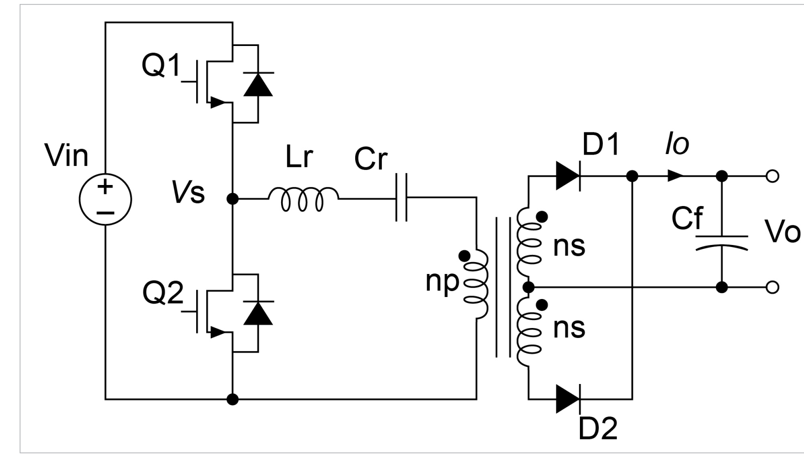

Figure 2: Second stage of a high-power LED-lighting driver; the LLC resonant circuit.

The resonant-converter topology offers several benefits at high power levels, including electrical isolation, high efficiency, small magnetic components, and no need for electrolytic capacitors at the output. These advantages enable engineers to achieve high power density.

A resonant LED driver follows the same basic design as a resonant power supply. It consists of a two-stage system with a front-end PFC (power-factor-correction) stage followed by a resonant isolation and step-down stage with a rectifier and filter at the output. The key difference between the two designs lies in the control system: The power supply produces a regulated constant output voltage, whereas the LED driver must produce a constant output current.

Resonant-LED-driver operation

Figure 1 shows the basic schematic of an LED driver using a resonant topology. The front-end PFC stage consists of a boost regulator that converts the full-wave rectified AC line voltage to a DC bus voltage usually between 400 V and 500 V. The DC bus voltage feedback loop responds slowly over many AC line cycles so that the MOSFET on time remains essentially constant during a cycle.

Control ICs often increase the on time as the AC line cycle approaches a zero crossing. This serves to compensate for crossover distortion and reduces THD (total harmonic distortion). The majority of controllers operate in CrM (critical conduction mode) at the boundary between continuous and discontinuous conduction modes. The off time varies during the AC line cycle producing an approximately sinusoidal AC input current in phase with the voltage. The converter designer must choose the PFC inductor's value to avoid saturation at IPK—the peak current—and maximum operating temperature.

The back-end stage consists of an LLC resonant converter that converts the DC bus voltage to a DC output of lower voltage and constant current. The transformer is the core element providing isolation and voltage conversion. In figure 1, the transformer exhibits a high primary-leakage inductance that forms a resonant circuit with the series capacitor, which also provides DC blocking. An alternative approach is to use a standard transformer design and add an external resonant inductor.

In the basic LLC resonant-converter section, the transformer-secondary circuit consists of two windings and two rectifier diodes (Figure 2). These are normally Schottky diodes to minimize conduction losses, although high-current designs may use MOSFETs as synchronous rectifiers. Most of the ripple at the output is at twice the switching frequency, which allows the stage to use ceramic filter capacitors in conjunction with an inductor to ensure sufficiently low ripple at the output.

The half-bridge switches operate

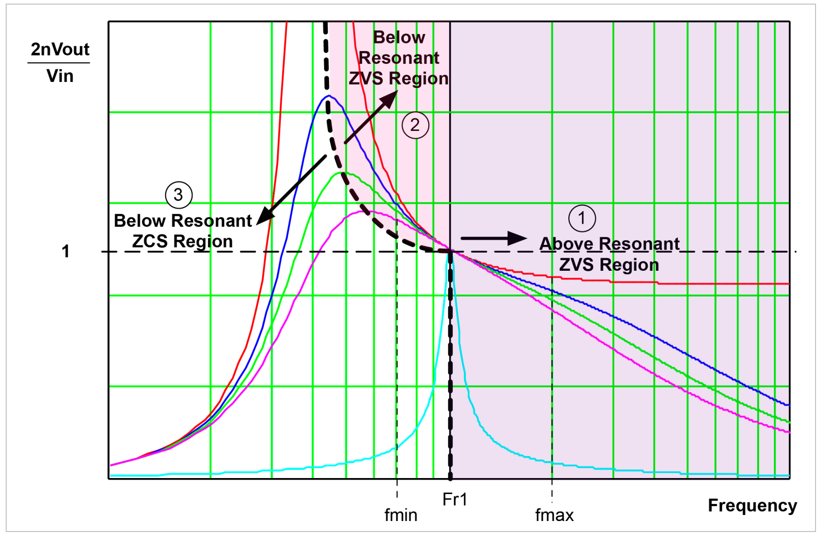

Figure 3: Typical frequency response of an LLC resonant converter.

at 50% duty cycle and the controller regulates the output voltage by varying the switching frequency. The controller can also effectively regulate the LED driving current by adjusting the frequency. Hence, the designer can select the frequency to provide the necessary drive current for any number of LEDs that connect to the output up to the maximum 60-V low-voltage safety limit. The half-bridge resonant stage has two resonant frequencies. The series inductor, Lr, and resonant capacitor, Cr, determine the first. Cr and the transformer's magnetizing inductance, Lm, determine the second. Soft switching will occur while the frequency remains in the inductive region.

Circuit and transformer design

You can model the LLC resonant circuit relatively easily, and then simulate the model in order to analyze the converter's frequency response. Divide the characteristics into three regions based on the three different modes of operation (Figure 3).

A key task in designing the resonant circuit is to optimize the ratio between the transformer's magnetizing inductance, Lm, and the resonant inductance, Lr, to control the gain curve's steepness while minimizing circulating power losses. Aim for ratios between 3:1 and 10:1.

You can determine Lr and Cr values by running several simulations or calculate them from the maximum Q value and your target resonant frequency. Calculate the maximum Q that allows the converter to stay in ZVS (zero-voltage switching). The maximum Q occurs at the minimum input voltage and the maximum load. Simple methods for calculating the necessary values make use of a spreadsheet or Mathcad script.

Several transformer-design methods exist. The most complex challenge lies in incorporating the Lr. Often the engineer will measure a sample transformer's Lr, plug that value back into the simulation, and recalculate the circuit parameters based on the transformer's characteristics.

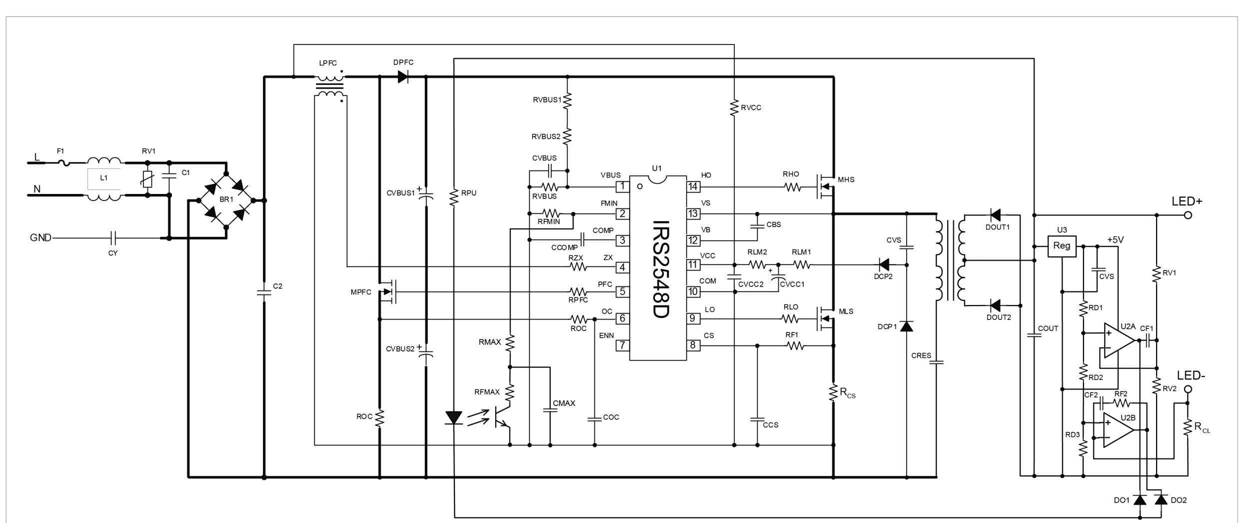

Figure 4: High-power LED driver using resonant converter control IC.

Controlling the resonant driver

The resonant converter requires a control IC. Using a combination PFC-plus-half-bridge driver IC, such as the IRS2548D for example, can help to reduce the driver's component count and size. These ICs provide all the functionality necessary for controlling the front-end PFC circuit and the resonant half bridge including a floating high-side gate driver for the upper bridge MOSFET.

The controller can adjust the half-bridge frequency using a conventional feedback circuit and opto isolator. It senses the output current through a shunt resistor and compares that measurement to a reference using an op-amp located on the secondary side. The error signal drives the opto diode and the transistor sinks current from the IRS2548D frequency control input to increase the frequency, which reduces the output current to the target level.

Adding a voltage-sensing circuit can prevent the output voltage from exceeding a set level in the event of an open-circuit failure. There are several ICs available for such applications that integrate both voltage and current feedback op-amps with an accurate reference and combine the amplifier outputs to drive a single opto isolator.

A complete driver using the IRS2548D controller requires a small number of external components (Figure 4). Optimizing the PFC-inductor and transformer selection helps minimize the driver's size.

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NEXT-GENERATION COMMERCIAL BUILDING NETWORK-CONNECTED LIGHTING SYSTEMS

New regulations mandate lower energy consumption and affect lighting designs and implementations.

By: Sajol Ghoshal

A significant percentage of a building's energy consumption is due to its lighting.

Historically, lighting was a coarsely controlled power load, managed manually with a simple on-off switch. With the advent of low-cost PIR (passive infrared) detection, a small percentage of rooms now have automatic controls. This is, however, still a far cry from the vision of lighting controlled by building systems to substantially reduce energy consumption and provide highly optimized lighting for enhanced user comfort and experience.

It has become too expensive to build additional power plants and leading energy-conscious countries and states, such as California, are demanding significant reductions in energy consumption over the next decade. California's Assembly Bill 32 requires that buildings reduce their energy consumption by 50 percent by 2018. Other building codes, such as California's Title 24, are even more specific, mandating energy reductions by exploiting daylight harvesting from windows and skylights. To this end, Title 24 requires implementation of automatic lighting controls.

Of course, the US isn't the only locale to require greater efficiency in commercial lighting. The European Union is in the midst of an aggressive plan to phase out inefficient light bulbs, and has regulations for commercial lighting mandating automated timer controls.

Lighting energy consumption

Lighting accounts for some 40% of a typical commercial building's electric bill, and commercial lighting accounts for approximately 70% of all lighting energy (Reference 1). Other major energy consumers include HVAC (heating, ventilation, and air conditioning) systems, responsible for 40% of the commercial energy load and other mechanical items, such as motors, which consume 20%.

HVAC systems came under building-network control in the 1980's. Proprietary control networks evolved to become standards-based networks, such as BACnet, KNX, and LONmark, which most building-control systems now use to connect to their HVAC systems. BACnet is an ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers), ANSI, and ISO standard communications protocol for building automation-and-control networks serving applications such as HVAC, lighting, and access controls and fire detection.

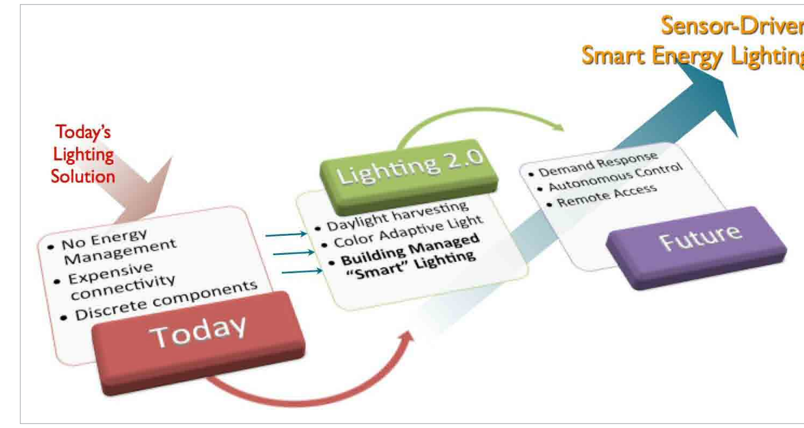

Figure 1: Lighting controls for next generation lighting.

Lighting-2.0 controls

Unfortunately, today's lighting systems don't lend themselves to cost-effective control for energy management. These systems use discrete power components, PWM ICs, FETs, resistors, capacitors, and inductors. These elements are difficult to control. Lighting must take advantage of digital technologies (Figure 1). By integrating power electronics, control functions, and network interfaces, the lighting controller will drive energy savings for next-generation light sources like LEDs.

Building connected HVAC and lighting networks

Lighting systems that allow dimming from zero to 100% and connect to building-network controls will enable demand response and autonomous control in large buildings.

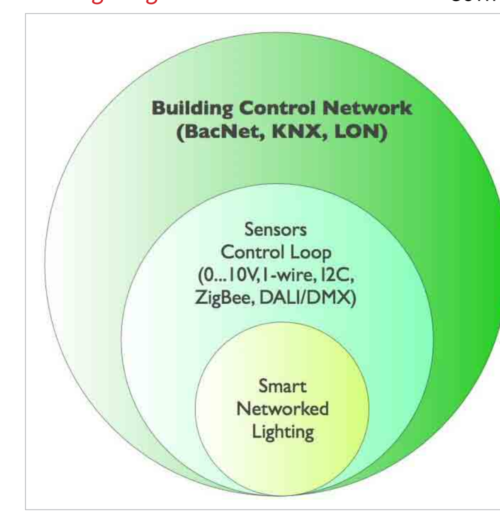

Figure 2: Building managed Networked Lighting.

The system's awareness of the environment increases through the implementation of smart sensors that can detect occupancy and light conditions. That information feeds to the lighting controller, which sends the information via the building network to central building controls. The central control can automatically manage lighting and HVAC systems throughout the building based on time of day and occupancy (Figure 2).

These smart sensor-driven network-connected lighting systems will provide significant energy savings. Consider for example underground parking garages where lights are on at full brightness 24x7. A network-controlled lighting system can automatically dim these lights by 50% or more when it observes no activity, potentially saving more than 50% in energy. These same sensor-driven network-connected lighting systems can also indicate which parking spaces are available through integrated proximity detection, alerting drivers to parking spaces, reducing gas consumption otherwise used in locating parking spaces, and reducing the carbon footprint.

Other prime applications include streetlights and outdoor parking-lot lights. In both environments, lighting is on at full brightness from dusk until dawn, regardless of whether auto or pedestrian traffic exists. Sensor-based lighting controls can dim streetlights by 50% after 2:00AM, and using integrated long-distance proximity detection can automatically turn on to full power when the system detects incoming traffic. Additionally, offices and high rises often have lighting at full brightness even when no one is around. Control systems can dim or turn off these lights until they detect activity, or

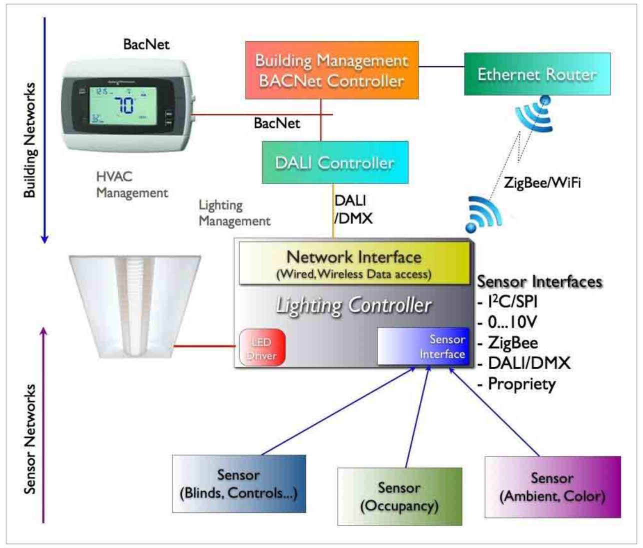

Figure 3: Building connected HVAC and Lighting Networks.

at a certain time, say 8:00PM.

Commercial lighting architecture for building connected lighting

With a keen eye on efficiency, commercial lighting will need to look at new digital architectures that will enable new services and reduce cost. Autonomous controls and sensors will reduce maintenance costs and enable significant energy savings, which will justify the cost of replacing outdated legacy lighting systems. LED lighting offers long-lasting performance (30 to 50 khrs) versus fluorescent lighting (10 to 25 khrs) and halogen incandescent lamps (5 to 11 khrs).

For some users, fluorescent light has gained a less-than-desirable overall reputation stemming from its subtle flickering at the AC line frequency and its limited spectrum. Although modern fluorescent lamps are efficient, adding the components that enable dimming can be costly, and the nature of their ballast systems does not lend fluorescent lighting to the fast on-off cycle times necessary for motion- or proximity-sensor based control scenarios. In addition to LED lighting's longer life, such sources produce a more pleasing spectrum with no flicker and are readily dimmable.

Strategies for automating energy saving in commercial lighting environments may include implementation of such features as occupancy or proximity detection to determine when people have left a room, timer controls, and daylight adaptation through ALS (ambient light sensing). Control systems may use the information obtained through sensing to control lights in several ways:

Dimming: Works best with LED lights. Using standard feedback loops and control mechanisms, the lighting controller can reduce the light output of the luminaire when full output is unnecessary, eliminating the energy waste of over lighting.

Selective Light Switching: In large rooms, patterns such as turning on every second or third light can create increments of light output, dimming in fixed steps.

Autonomous Light Controls: Today's network-connected technology with low-cost and low-power wireless networking (such as ZigBee, WiFi), or wired networks (DALI, DMX, 0-10 V), can organize lights with the most efficient lighting plan for individual locations, with centralized control systems for policy and demand-response management.

Designers of commercial luminaires and lighting systems face pressure from both new government regulations and customer self-interest to make ever-greener products offering higher energy efficiency. Building-connected lighting enables not only HVAC energy management but also lighting management, facilitating enterprise-wide total energy management. Building systems can optimize their energy consumption based on temperature and lighting in every room of a commercial enterprise, automatically considering occupancy and available daylight in all locations.

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www.ams.com

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1. Source: Strategies Unlimited 2011

WHAT TO EXPECT FROM YOUR LED DRIVER IN THE FUTURE

Realizing LEDs' performance potential requires drivers that simultaneously meet multiple criteria.

By: Shane Callanan

LEDs are gaining significant traction in the lighting market due to their long operating lifetime, low running cost, and ease of control for specific applications.

However, in order to realize all of these benefits, you need to specify correctly your LED drive to obtain the required performance. With a potential lifetime of 100 khrs or more (if you operate them correctly), no filaments or tubes, no mercury, easy to control light wavelength, and significantly greater efficiency, it's easy to see why this is the right choice of lighting source going forward. LED chip manufacturers have been playing their part by improving their products over the last number of years; the companies developing drivers must play their part as well.

What specifications your driver should meet

The driver's primary requirement is to convert AC power to DC power. In doing so, it must also deal with PFC (power-factor correction) and THD (total harmonic distortion) issues because an LED load is not purely resistive (Figure 1).

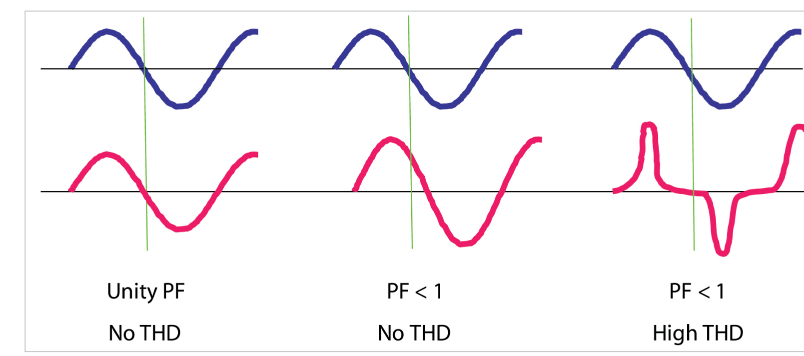

Figure 1: Incandescent light bulbs (blue curves) are purely resistive, LEDs (red curves) are not.

The driver must also meet safety and EMI requirements as well as circuit protection requirements such as OCP (over-current protection), SCP (short-circuit protection), and OTP (over-temperature protection).

Additionally, the electrical design alone does not completely determine the driver's performance so one needs to pay attention to the interaction between mechanical-design decisions and electrical performance. For example, polyurethane-based potting compound is more cost effective than a silicon-based material but, with its dielectric profile, will offer challenges in terms of EMI performance.

A real-world example

The LDB series product definition required the Excelsys design team to meet a number of market-leading requirements in a cost-effective manner.

- Efficiency: η = 91% at 100 W
- Conducted & radiated

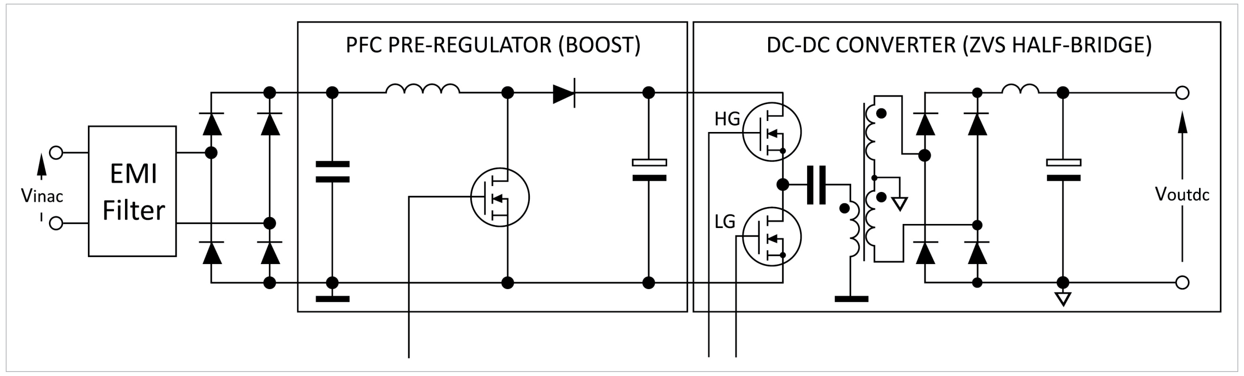

Figure 2: Efficiency, power level, and power density requirements determined the overall choice of topology.

emissions: Meet EN 55015
- Circuit Protection: on-board OCP, OVP, SCP
- Input Range: 90 to 264 VAC

The efficiency, power level, and power density requirements determined the overall choice of topology: ZVS (zero-volt switching) half-bridge (Figure 2). The LLC ZVS stage reduces the losses in the input to output transfer of energy, and reduces the conducted and radiated noise. Switching at higher frequencies permits the use of small magnetics, shorter response times, and low noise levels. Finally, ZCS (zero-current switching) in the output stage reduces the power loss and, again, reduces the conducted and radiated noise.

The future of power supplies

We will continue to see more integration from vendors. Currently, designers select components for a circuit. Circuits assemble into systems. Eventually, engineers will design systems as integrated components, leading to an overall decrease in size (Figure 3).

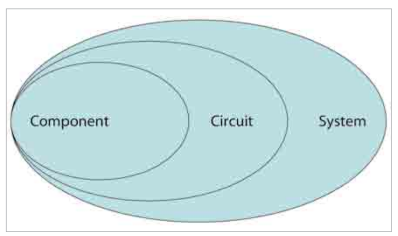

Figure 3: More integration from chip designers will mean smaller designs

However, a more significant improvement will be the closing of the control loop with a digital controller. This will allow both improved performance and further interaction with the supply. A digital control loop has many advantages over its analog counterpart in that we can now dynamically optimize the control loop for all operating conditions by moving poles and zeros on the fly (Figure 4).

Digital control also provides us with a means to communicate with our power supplies in order to understand if, for example, they are operating within specified limits. Digital control, and the communication it affords, also can provide get cycle-by-cycle feedback on the supply's performance. Of course, you can achieve this by adding a microcontroller for digital power management, but with a digital loop, you can implement this option more cost effectively. With a digital power-control loop, you can also integrate some additional features without increasing your analogue component count.

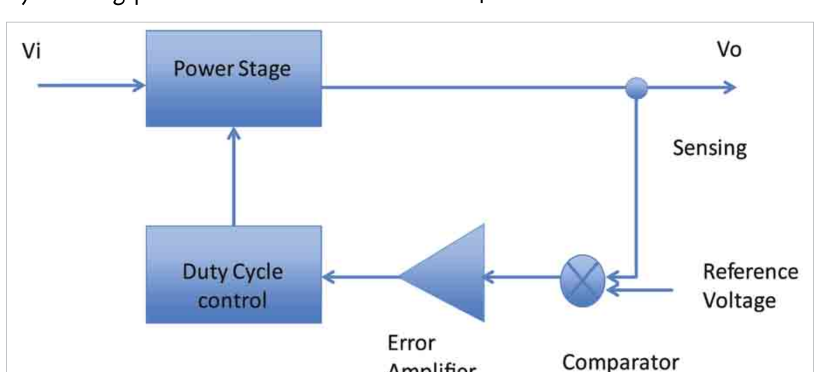

Figure 4: Closing the loop with a digital controller

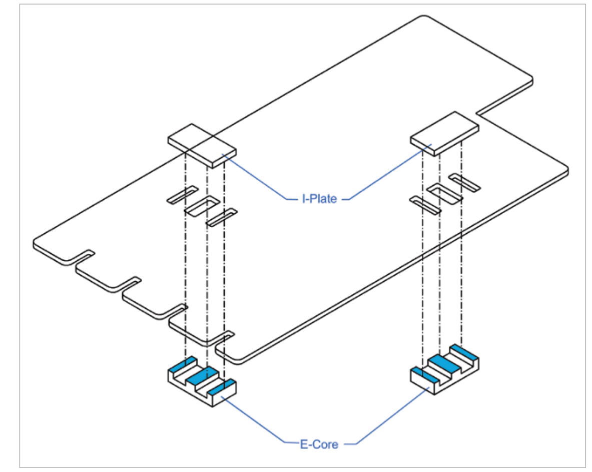

Figure 5: Transformer improvements will continue to increase power density.

Ongoing research into magnetics is proving very successful, and will result in significant improvements in overall power density. Incorporating the primary and secondary windings into the PCB and inserting the core through pre-cut holes in the PCB reduces the height and size of the transformer design and results in a much lighter component (Figure 5).

The LED driver of the future will be significantly different from the one we see available on the market now. Greater efficiencies will become the norm, as will greater degrees of integration to support increasing system complexity in terms of power monitoring and performance. More integration of SOCs (Systems on Chips) will continue to reduce the size, whilst maintaining reliability of the overall design. While no single element will cause a rollercoaster effect, incremental and continuous improvements will influence driver designs.

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LEDS ENABLE NEW LIGHTING APPLICATIONS WITH SPECIALIZED POWER NEEDS

By: David G. Morrison, Editor, How2Power.com

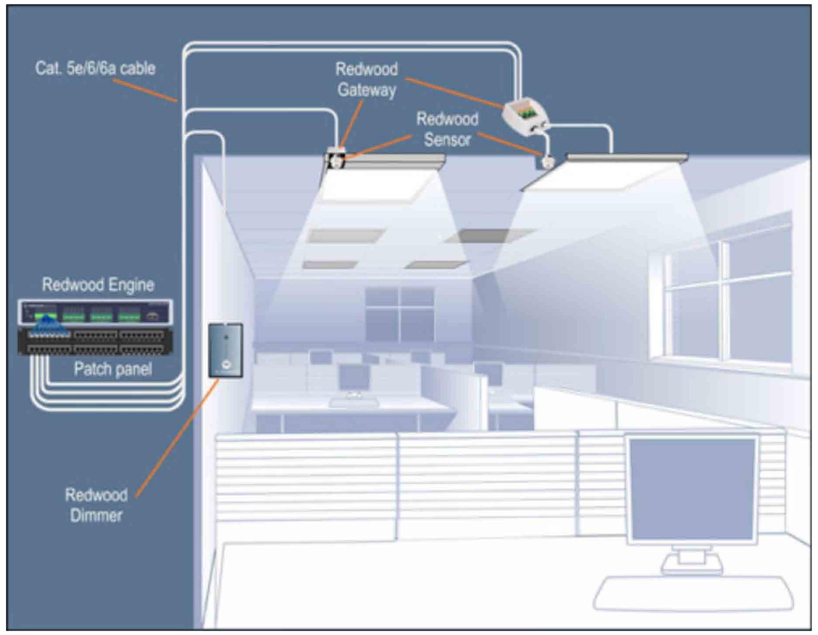
When new technologies emerge, they frequently inspire the development of unique products or systems that perform functions beyond those normally associated with the core technology. Such is the case with a lighting system developed by the Fremont, California-based Redwood Systems, which is leveraging advancements in LED lighting and other areas of electronics to develop what it calls a building performance lighting platform.

This company's story offers a case study in how LED lighting can also create opportunities for power electronics engineers in the lighting controls industry.

As Redwood Systems discovered, a specialized lighting system also has specialized power supply needs that are tightly interwoven with the system's design requirements and therefore require in-house power supply design expertise. And while their power supply requirements are different enough to necessitate a customized approach to power design, their underlying needs for power conversion are reasonably similar to mainstream applications. Consequently, power savvy engineers coming out of the power supply and semiconductor industries are well positioned to meet the needs of this lighting controls developer.

Managing Light Is Just a Part of It

At the heart of Redwood Systems' building performance lighting platform is technology that allows them to control a network of LED light fixtures in a commercial environment such as an office building or data center. A centralized controller transmits dc power to each lighting fixture over Cat 5 or other cabling, turning fixtures on or off, and providing dimming as necessary. However, the system also adds a communications gateway to each fixture along with a sensor pod that performs motion/occupancy sensing as well as temperature and light sensing. The gateway transmits the sensing information back to the controller, which then shares the information with a building management system. This networked array of sensors throughout a facility enables



Redwood Systems' building performance lighting platform merges lighting control with other aspects of building management such as monitoring space utilization, controlling HVAC systems, and maintaining building security. Taking a networked approach, in a typical application, a centralized controller (the "Redwood Engine") feeds dc power and communications signals to a network of LED luminaires with their associated gateways and sensor pods. The latter can measure occupancy, light, and temperature and the gateways transmit this data back to the engine. In addition to its novel functionality, the system promises lower installation costs and higher system-level energy efficiency than other approaches. The specialized power requirements of the system mean that power supply design expertise is crucial to system development.

a variety of functions to be performed (see the figure.)

The occupancy sensing capability allows lights to be turned off where they are not needed, for the sake of energy efficiency. Although occupancy sensing can be performed locally without the networking capability (as is the traditional approach), the ability to send this sensing information back to the controller means it can be used for other purposes. "If a space is unoccupied for some time, we could actually turn down the air conditioning or the heat to save additional energy," says Sam Klepper, chief marketing officer and executive VP at Redwood Systems. But as Klepper explains, this same data also has other uses.

"Our sensors are built on this lighting platform and lights are literally thoughout an entire facility. We have the so-called eyes and ears for a facility and can report on how often space is used to help in important space decisions." says Klepper, who notes that optimizing space usage is critical "given that it's very expensive to build new buildings." One client uses the occupancy sensing data to inform its employees, in real time, which conference rooms are in-use and which ones are available. The occupancy sensing data also finds use in monitoring building security. Meanwhile, there's also temperature data coming back from the fixtures, and this can be critical information when the facility is a data center, for example.

Mark Covaro, chief technical officer, notes a key aspect of the system architecture. "We deploy a sensor per light, so you get a very fine grid of sensoring capabilities throughout the building," says Covaro. "That was an architectural decision that we made early in, because in a lot of what we read, people complained that they couldn't control their buildings properly because they weren't able to gather data from their building."

Powering the System

Redwood Systems designs and manufactures three devices. One is the centralized controller, also known as the "engine," which both controls and powers the LED luminaires. "It's got 1300 watts at its output, so it can power and manage approximately 30 lights right now," says Covaro. The company also makes the gateway which is either integrated into the luminaire or mounted adjacent to the luminaire depending on the application. Redwood Systems also builds the sensor pod.

Covaro explains that this is a centralized power scheme. AC power, typically 277 Vac, is supplied to the engine and it performs ac-dc conversion and power factor correction, producing the dc power required by the luminaires, gateways, and sensor pods. Though only designed to power LED luminaires, the system can optionally be used to provide sensing and control (but not power) for fluorescent or HID fixtures.

The power system is categorized as Class 2, meaning that its dc power output must remain under 60 V. The class 2 architecture has important benefits. Unlike in conventional lighting systems, the power cabling no longer requires use of conduit or Romex cable. It can be wired with category 5 cable, which is standard for communications. As a result, an electrician is not required to install the cabling for this system and this lowers installation costs. Covaro describes this approach as "a new way of doing all your lighting wiring," although those familiar with networking technology will recognize the similarities to Power Over Ethernet (PoE) systems.

And because power is centralized, there are no LED drivers to burn out in the luminaire, so there's no need to send an electrician to service the light fixtures. The company also claims the centralized power scheme offers greater reliability than if power conversion was performed in the luminaire.

Design Challenges in the Engine

According to Covaro, the main design drivers for the power supply portion of the engine are cost and efficiency. "Our biggest challenges are around that. We are talking about converting a significant amount of power. The current generation is 1300 watts, the next generation will be going to approximately 1600 or 1700 watts at the output. We have to do that conversion in a fairly small space, so of course we run into thermal issues as well."

While these requirements are similar to those encountered in other applications, there are some twists specific to Redwood Systems' products. First, though the input to the power supply is typically 277 Vac nominal, the input range can vary all the way from 85 to 305 Vac, which is beyond the universal input range of 85 to 265 Vac. This input voltage requirement precludes the use of off-the-shelf power supplies.

There's another unique aspect to the power supply on the dc output that is supplied to the gateway and luminaire. "We needed to come up with a way to put all these gateways out at every light and not have them consume a bunch of extra power," says Covaro. "So we came up with a scheme of embedding the communications signal into the power in a way that you really can't tell the difference between the two. That allowed us to do a very electrically efficient as well as low cost design."

A common method of dimming LEDs is to apply pulse width modulation to the current signal that drives the LEDs. Duty cycle is varied to produce a lower or higher average value of current to achieve the desired brightness levels. In Redwood Systems' design, this PWM signal, which runs nominally at 1 kHz, is frequency modulated to embed commands to the gateway.

"We're around a kilohertz but to represent one state we go a little faster than a kilohertz and for another state we go a little bit slower than a kilohertz. So to go to one logic state we have a little bit longer period, to go to another logic state we have a little bit smaller period. And we keep the duty cycle the same within that period so that you don't notice the difference in terms of dimming."

Each luminaire requires two channels of pulse-width-modulated dc power for power and control of the luminaire and its associated gateway and sensor pod. So on the output of the engine there are a series of dc-dc converter stages to generate these supplies.

There are also power design challenges associated with satisfying the Class 2 requirement, which limits the maximum voltage on the output of the power supply to 60 V. The company needs to have as much of this voltage available to power LEDs as possible. Yet, ensuring that the power supply output never exceeds 60 V requires clamping circuitry with tolerances that cut into the voltage headroom available for driving LEDs. Losing voltage headroom either restricts the number of LEDs or the length of cable that can be driven by the power supply, so care must be taken in designing the clamping circuits. And future power system designs will include changes that avoid the need for this voltage clamping altogether.

As a design constraint, the company limits the voltage drop on the cable to 3%, which is the standard drop for a branch circuit as measured from the breaker panel to the luminaire. To that end, the system measures power levels at numerous points, using this information to ensure proper installation.

"We measure power everywhere," explains Covaro. "We measure power coming into the box and also measure power factor coming into the box. We measure power at an intermediate stage inside that box. We measure power going out on each channel of the engine, and then we measure power out at the gateway. So if someone incorrectly sets up the system, we can notify them, 'Hey you've got too much voltage drop, too much power loss in this cable, you need to go check and see what's wrong.'"

Because of all these requirements, Redwood Systems designed the complete power system for its first generation products in house. However, in the future, the company expects to purchase an ac-dc supply with PFC for the bulk power section. "We're looking at buying a PoE supply, so what we will need is basically 1600 watts of PoE output. But we will continue to design our own dc-dc output boards. There's just too much specialization in the dc-dc section to buy something that's off the shelf or that could even be modified to do what we want to do."

Going forward, the continued development of Redwood Systems' products will require further development of the power system. For more on this subject, see "Revamping the Power System for Next-Gen Products" in the online version of this article where you can also read more about the company's requirements for power electronics engineers in "Finding the Right Skillsets."

About the Author

When he's not writing this career development column, David G. Morrison is busy building an exotic power electronics portal called How2Power.com. Do not visit this website if you're looking for the same old, same old. Do come here if you enjoy discovering free technical resources that may help you develop power systems, components, or tools. Also, do not visit How2Power.com if you fancy annoying pop-up ads or having to register to view all the good material. How2Power.com was designed with the engineer's convenience in mind, so it does not offer such features. For a quick musical tour of the website and its monthly newsletter, watch the videos at www.how2power.com and http://www.how2power.com/newsletters/.

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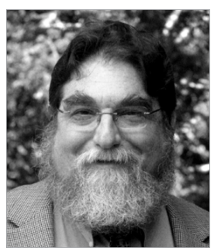
SCALING RENEWABLE-ENERGY GENERATION IS AS MUCH A POLITICAL CONSIDERATION AS A TECHNICAL ONE



By Joshua Israelsohn, Editor-in-Chief, Power Systems Design

The 3rd Massachusetts Sustainable Economy Conference: When thinking small is a big idea.

The Massachusetts Sustainable Economy Conference (http://bit.ly/LF65K8) covers a broad range of topics crossing government, business, academic, nonprofit, and community interests. One of these is renewable energy's effect on local businesses and communities.

Among the more interesting discussions on technical topics were those on Emerging Energy Issues and Technologies, with short presentations from Boston Power founder Dr. Christina Lampe-Önnerud and Aeronautica Windpower president Walt Wunder (http://bit.ly/KoQb7G and http://bit.ly/KXykSa, respectively).

Mr. Wunder noted that, considering the lengthy and often contentious siting and permitting processes for large-scale wind-power facilities, small- to medium-scale machines based on a finer-grained distributed-generation strategy may offer significant advantages. These extend beyond just siting and permitting to include financing, construction, and power distribution. Certainly, the pending Cape Wind offshore windfarm exemplifies the challenges large projects face (http://b.globe.com/KkZuqk).

Dr. Lampe-Önnerud briefly demonstrated Boston Power's flexible modular concept for LiIon battery construction, scalable for utility-storage, traction, and portable-power applications. Such scalability makes advanced electric storage technologies more readily available to a broader range of applications and does so at lower costs because key economies of scale operate at the cell level and thus cross applications.

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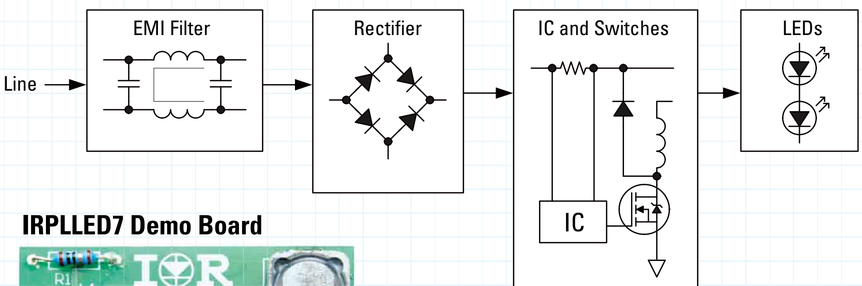
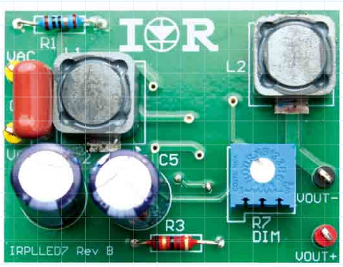
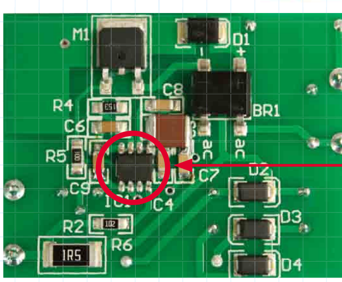
High-Voltage Buck Control ICs for Constant LED Current Regulation



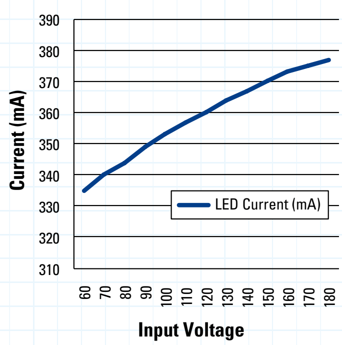
IRPLLED7 Demo Board





LEDrivIR™
IRS2980

IRPLLED7 Demo Board
LED Current vs Input Voltage



IRS2980 Features

- Internal high voltage regulator
- Hysteretic current control
- High side current sensing
- PWM dimming with analog or PWM control input
- Free running frequency with maximum limiting (150kHz)

IRS2980 Benefits

- Low component count
- Off-line operation
- Very simple design
- Inherent stability
- Inherent short circuit protection

Demo Board Specifications

- Input Voltage 70V to 250V (AC)
- Output Voltage 0V to 50V (DC)
- Regulated Output Current: 350mA
- Power Factor > 0.9
- Low component count
- Dimmable 0 to 100%
- Non-isolated Buck regulator

Part Number	Package	Voltage	Gate Drive Current	Startup Current	Frequency
IRS2980S	SO-8	450V	+180 / -260 mA	<250 µA	<150 kHz
IRS25401S	SO-8	200V	+500 / -700 mA	<500 µA	<500 kHz
IRS25411S	SO-8	600V	+500 / -700 mA	<500 µA	<500 kHz

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