Lighting Systems
Part I

Power Electronics in Public Lighting Systems

Are LEDs the only viable solution?

Legislation concerning efficiency and the power factor of loads connected to the power line is becoming more and more rigid. The cost of energy is high and is increasing. Not less important are the environmental considerations of wasted energy turning into harmful pollution.

By Giampaolo Pantaleoni, R&D engineer, Bentivoglio (BO), Italy

Currently public lighting systems are realized through various points of light distributed over a public area to be lit. These points of light generally use high intensity discharge (HID) lamps and in particular, the high-pressure sodium types. This last kind of lamp has particular characteristics that make it suitable for the application. The luminous efficiency is quite high and the spectral luminous distribution, even if mainly concentrated on yellow, has a certain content of the other colours of the visible spectrum. Other types of lamps (e.g. low-pressure sodium) have greater efficiency, but the luminous emission is concentrated on a single spectral line, preventing therefore the recognition of colours, with obvious security problems for nocturnal driving. Considering the extremely fast progress in LED technology, it is not difficult to imagine that in the near future, LED-based lighting systems will be in competition with current technology. LED devices have also the certain advantage of having the highest average life and absence of ageing. These characteristics are of primary importance in the public lighting field.

Coming back to current times, it must be noticed that discharge lamps cannot be connected directly to the supply line (figure 1). To ignite them it is necessary to provide an extra voltage of some kV. Once the arc has fired, in order to limit the current, a choke in series with the lamp is typically used. In these conditions, the current absorbed from the main line is out of phase with the voltage (current is delayed compared with the voltage) and shows a considerable amount of distortion. In order to obtain an acceptable power factor (PF), a re-phasing capacitor is commonly used.

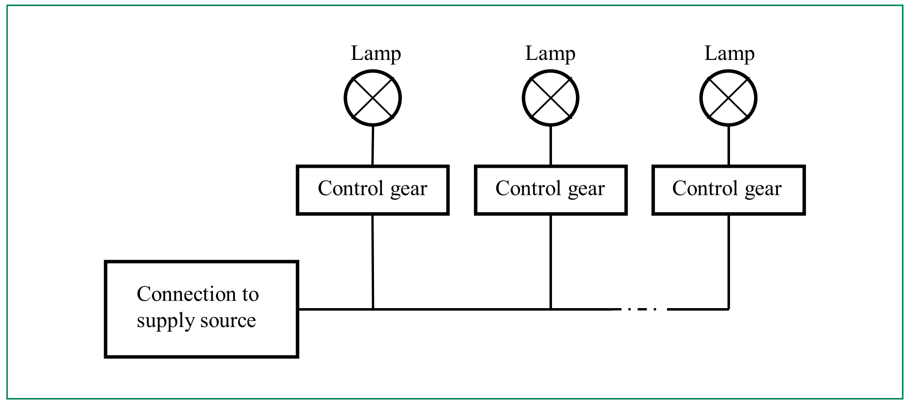

Figure 1: Lamps need high voltage in control gear to ignite.

It is exactly at this point that electronics enters the game. All these devices, conveniently called control gear, can be replaced with an electronic device able to offer several advantages. Obviously, these are still more important if in addition to modern power devices available on the market, you use a microcontroller to implement an intelligent control strategy. The continuous decrease in the cost of electronic components and the regulatory pressures now applied make the electronic solution more and more competitive.

As regards legislation issues, three main arguments can be summarized:

1) quality of the lighting service
2) electrical requirements
3) energy saving

For the first point, a light source suitable for the traffic on the road and with a sufficiently homogenous distribution must be guaranteed. Moreover, the number of faulty lamps must be less than a predefined limit. For the second point, legislation concerning the power factor of loads connected to the power line is becoming more and more restrictive. Thirdly, for energy saving, it must be kept in mind that the cost of energy is high and is continuously increasing. No less important are environmental considerations. Wastage of energy, in fact can turn into useless and harmful pollution. Recent European norms impose the use of chokes with an efficiency level over a certain minimum. The power lost in heat in these components could reach 10% of the power supplied to the lamp. Considering that the lamp remains on approximately 4000 hours/year, it translates that for a small 100 W lamp, every efficiency increment of a percentage point, means 4 kWh saved every year. This figure multiplied by the number of lights active in the world, leads to huge proportions.

The systems currently in use for energy saving in public lighting, can be synthesized into three main groups:

1) At a certain time of the night, alternate lamps are switched off. Naturally, this solution (probably the most diffused), does not concur to obtain a uniform lighting and it is unlikely that it will be applied to roads carrying a significant amount of traffic.
2) The supply voltage is lowered during the night, starting from a given hour. This solution will hardly adapt to lines in which lamps of different technology are used. If a lamp works at 50% of the nominal power with the given voltage, lamps of a different technology can work for example at 30% or 70% of their nominal power.
3) A device installed on every point of light, at a defined hour of the night reduces power for example up to 50% of the nominal.

In all the three cases the lamps are powered through the traditional electromechanical choke. A totally electronic solution, however, offers numerous advantages in many areas. The more usual topology makes use of a booster type input stage and a half bridge output stage. The booster allows the execution of the PFC (Power Factor Correction) function, closing the Power Factor (PF) to one. With a design goal to use small and inexpensive chokes with low losses, it will be necessary to operate at frequencies around one hundred kHz. The power devices that best fit the application are MOSFETs. Powering the lamp with high frequency currents, leads to another important advantage. The lamp works with a more constant ionization level and consequently generates greater luminous emission at the same power consumption. Measures carried out on Compact Fluorescent Lamps (CFL) bring back an increment of luminous emission of 20% (ST, AN1546). Of course, things will not be so good for every type of lamp. As regards the efficiency of the electronic circuit, today's generation of power MOSFETs provides excellent performance. As an example, in a prototype for firing 100 W lamps, the increment of temperature measured on the case (TO220 in free air) of the 2 MOSFETs in the final stage, was of approximately 25 °C. This means that the total power dissipated into the final stage is 800 mW only. Moreover, the MOSFET in the PFC stage shows improved performances in terms of power dissipation. Of course, in the complete equipment there will be other power losses distributed over various parts of the circuit. However, a careful design for every part of the circuit (in particular, magnetic components), promises high overall efficiency.

Additionally, intelligent control of the power supplied to the lamp, can contribute to power savings up to a figure of 25-30%. In the nocturnal hours, during which road traffic is significantly reduced, luminous emission can be lowered. One simple reduction after a fixed time period is inadequate. In fact, between summer and winter, the timetable for ignition of the public lighting systems can vary up to 5-6 hours. A reduction after a fixed time will bring this decrease in light too late in winter or too soon in summer. With a small microcontroller (in the prototype a PIC16F870 from Microchip) it is possible to implement algorithms that modulate the intensity of the light, adapting it to the period of the year and the time of the night. Those changes in light are carried out completely automatically (without use of sensors or extra communication lines). A typical summer situation is showed in figure 2 (red line). Lamps are fired at nominal power at 21:00. At 23:00 the power is gradually reduced in order to

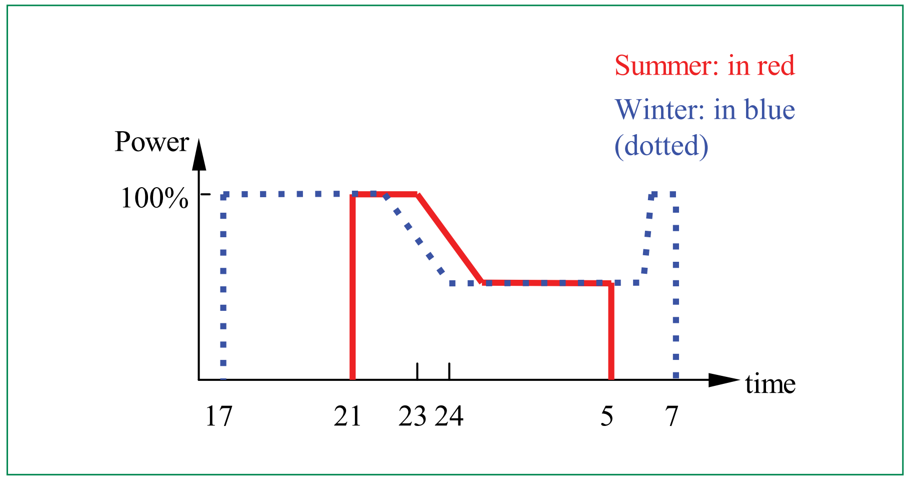

Figure 2: Timing and power levels for summer and winter.

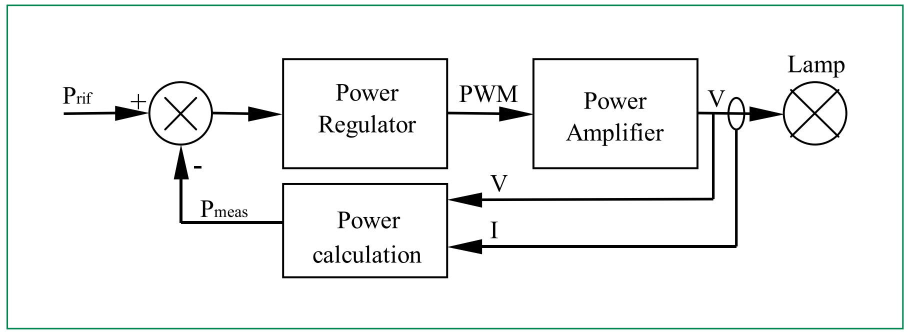

Figure 3: Power loop regulation.

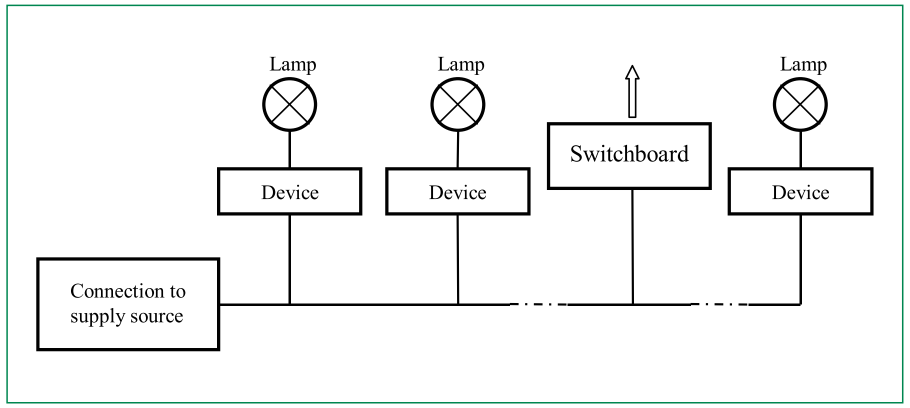

Figure 4: Low Cost diagnostic function.

adapt to the diminishing traffic. From 01:00 on, power is held at the minimal value. The light is finally switched off at 05:00. In the same figure, also shown is an example relative to the winter season (blue line). Lamps are fired at 17:00 and maintained at the nominal power until 22:00. After this time, light is gradually reduced until at minimal power. This happens around midnight. When traffic begins to increase, about 06:00, power is ramped again to the maximum value. In the example, daylight saving time is used. This idea is protected by a pending patent.

The use of a microcontroller enables a simple, full digital power regulation. Figure 3 illustrates a block diagram of the power loop. The measured power is compared to the reference and PWM (Pulse Width Modulation) is adjusted consequently. Therefore, the output power follows the desired reference. In a wired prototype, a small 8-bit microcontroller with 10 MHz clock closes the power loop every 800 µs. This time is short enough for the application. A true power regulation opens the door to two important advantages. The first is about the duration of the lamps, while the second refers to the variation of the luminous emission with the aging of the lamp. As far as the first point is concerned, it is necessary to notice that manufacturers declare data about the average life of the lamp in conditions of stable and nominal supply. If the voltage frequently presents sudden changes, the average life diminishes drastically. A precise regulation of the power reduces significantly the voltage variations applied to the lamp which implies an increase in the average life. As for the second point, it must be considered that the lamp supplied by the choke, with aging, reduces the absorbed power (the impedance increments) and luminous emission. The power regulation, maintaining constant the supplied power to the lamp, minimizes the light reduction. It is clear that this fact results in lower costs for the maintenance of the system and in a greater quality of the service.

A further advantage that an electronic solution offers is the ability to realize diagnostic functions at a particularly low cost. Figure 4 shows an example of this diagnostic concept. The power line supplies electric energy to the connected points of light. Every point of light uses this power line in order to transmit information about its operational state.

By means of a diagnostic system, you can concentrate the information concerning the whole lighting system at a single point (the switchboard in figure 4). The information collected at that point can be transferred in a simple way to another remote location. The plant manager, can then carry out interventions for maintenance only when they are required. In this way, periodic maintenance and costs are considerably reduced while service quality is improved. In the simpler and more economic form, the information collected will define whether the system is operating properly or if technical intervention is required. With reference to figure 4, two devices can be seen. The first makes the electrical measurements concerning the point of light to be monitored, processes them and finally takes care to send the required signalling across the supply line. The second one (switchboard), collects the information coming from the whole plant and makes them available to the user. Embedding the diagnostic function into the electronic dimmer/ballast device, involves a dramatic cost reduction. In order to implement this function in the simplest form, cost of additional electronic components can be as low as 1€. Of course, for information transmission, no additional communication lines, radio systems or convoyed waves are necessary. Laboratory tests on a prototype show encouraging results.

Before concluding, there are some points that cannot be neglected. The electronic devices for public lighting system work in rather onerous environmental conditions. In winter, ambient temperature can go down below -20 °C, while in summer, if the device is assembled near the lamp, temperature can rise above +60 °C. In the design phase, a careful choice of all the components must guarantee a very high average life. A lamp, in fact, can reach 24000 hours of work.

As stated earlier, future public lighting systems will probably make use of LED technology. For cost and efficiency reasons these devices are not yet competitive with HID lamps. The use of power electronics and of a microcontroller-based supervisor appears to be viable. In particular, it could just be that intelligent control strategies, such as the reduction in lighting power during the hours of lower traffic volumes, will anticipate the entry of LEDs into the market of public lighting systems.

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Compact and Flexible Off-Line SMPS Solution for LED Drive

Runs 10 lighting LEDs at an efficiency of nearly 85 %

LED's will make significant penetration into an ever wider range of lighting applications. The promise of greater efficiency, reliability and design flexibility are compelling factors for their adoption. Rapid improvements in brightness, efficiency and cost per lumen now seem set to greatly accelerate this.

By Rainer Kling, Applications Engineer, Power Management and Supply, Infineon Technologies AG
David Compton, Product Marketing Manager, Power Management and Supply, Infineon Technologies AG

This article describes an off-line switch mode power supply (SMPS) for LED drive in wide line input voltage applications from VACIN = 90 V up to 270 V. The application is fully protected against open loop gain (OLP), short circuit (OCP), over temperature (OTP), over voltage at the Vcc stage (OVP), and under voltage (UVLO). It also provides highly accurate power limiting in case of over load (using Infineon patented Propagation Delay Compensation™). All protection features employ an auto restart mode. The LEDs are protected against high peak currents during load transients. The driver application uses the Infineon jitter system IC CoolSET™ F3 (with integrated CoolMOS™ MOSFET) and the TLE4305G as a constant voltage and current regulator. The application is designed to drive 10 LEDs (350 mA) at an ambient temperature up to 125 °C with high efficiency and low standby power.

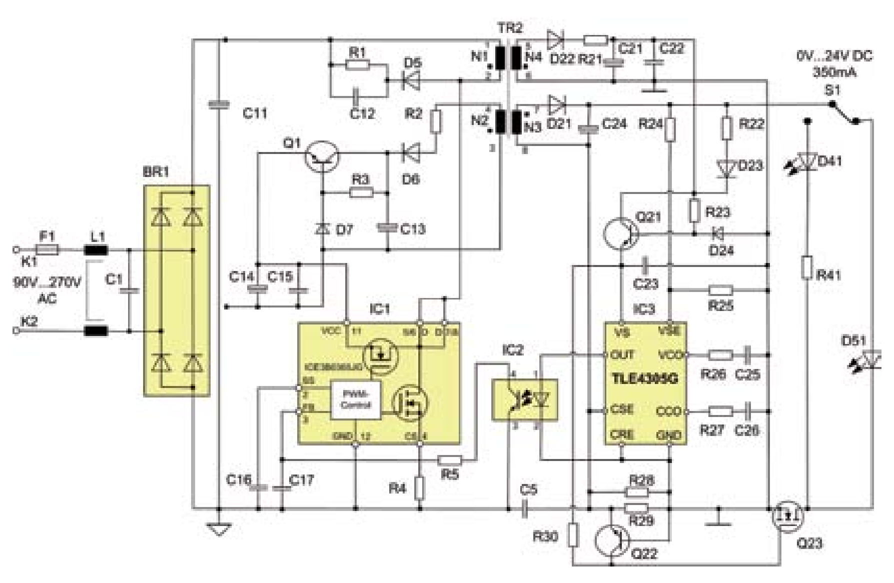

Figure 1: Schematic LED Application.

Circuit Description

The system comprises a low cost off-line discontinuous current mode (DCM) SMPS in forward mode using an ICE3B0365JG - the smallest system IC from the CoolSET™-F3 family. The circuit diagram (Figure 1) details a 24V, 10 W power supply that operates from an AC line input voltage range of 90 VAC to 265 VAC, and is suitable for open frame or enclosed designs.

The application is able to run with 10 LEDs at an efficiency of nearly 85 %. Figure 2 shows the efficiency (y-axis) versus output power (x-axis) of the LED SMPS at low line input voltage VACIN = 85V and high line input voltage VACIN = 270V for different numbers of LEDs. The TLE4305G provides constant current regulation. Figure 3 shows the regulation characteristic of the output stage. The output voltage (x-axis) rises with increasing load from POUT = 0W (no LEDs present) until maximum load (10 LEDs). If maximum load is exceeded

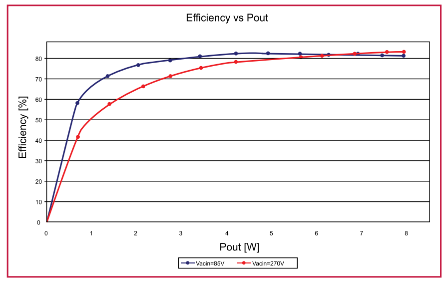

Figure 2: The efficiency (y-axis) versus output power (x-axis) of the LED SMPS at low line input voltage VACIN = 85 V and high line input voltage VACIN = 270 V for different numbers of LEDs.

the TLE4305G decreases the current (y-axis) down to zero and holds the output voltage stable at the maximum level of VOUT = 24V.

Upon application of the AC line input voltage, the integrated start up circuit charges the chip supply stage up to VCC = 15V and the controller starts working. To increase efficiency the start up circuit is then made inactive during normal operation. The IC will be supplied from the auxiliary winding N2 in forward mode via R2 and the rectifier diode D6. C13 and C14 stabilise VCC voltage through the range of operation modes. Due to the wide output voltage range from 0V up to 24 VDC, the chip supply voltage (VCC) of the CoolSET™ follows the line input voltage. In the case of VCC exceeding 19V, the network Q1, R3 and D7 clamps the chip supply voltage at VDC = 19V in order to protect the chip supply stage of the CoolSET™. An RCD snubber (R1, C12 and D5) clamps the drain source voltage below 600 V in order to prevent an avalanche breakdown of the MOSFET. Capacitor C16 provides soft start, reducing stress on the MOSFET / diode and preventing audible noise during start up. An optional low pass filter (C17 and R5) can be used to smooth the signal from the optocoupler (IC2) at the feedback PIN 3 of the CoolSET™. R4 adjusts the primary current.

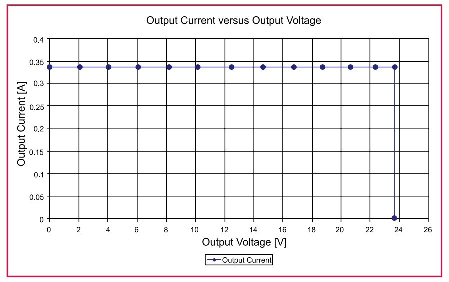

Figure 3: Controlled Output Current versus Output Voltage.

The secondary side voltage is rectified via fast rectifier diode D21 with a low forward voltage. Capacitor C24 buffers energy for the output stage. The output voltage is set by divider R24/R25 to VOUT = 24 VDCmax. The chip supply voltage of the TLE4305G is rectified via diode D22. R21 (optional) and capacitor C21 perform energy buffering for the chip supply stage at PIN VS. C22 and C23 eliminate glitches on the chip supply stage. R22 and D23 ensure stable operation during no load condition. Due to the wide output voltage range from 0 V up to 24 VDC, the chip supply voltage (VS) of the TLE4305G follows the line input voltage. If VCC exceeds 12V, the network Q21, R23 and D24 clamps the chip supply voltage at VDC = 12V. R26, C25 and R27, C26 are compensation networks for the output voltage and current. The current is sensed via shunt resistors R28 and R29. In the case of load transients, a current peak occurs. This current peak could result in damage to the LEDs. If the application inherently generates transients (e.g. when switching between LEDs of different colours), an optional compensation network can be implemented. The network R30, Q22 and Q23 control such peak currents and limit the discharging current from the capacitor C24.

CoolSET™ System IC

CoolSET^{TM} F3 is a current mode control PWM IC with an integrated CoolMOS^{TM} Power MOSFET in one package. It enables a low external component count SMPS; standard applications require only 7 external components. CoolSET^{TM} combines the superior technology of a high voltage CoolMOSä and the optimized technology of the control IC. It offers enhanced protection features - all with auto restart - and a smart standby power concept using active burst mode. The integrated start up circuit obviates start up resistors. This cuts cost and allows high speed start up and increased efficiency. A programmable blanking window allows a short term current overshoot which prevents switch off in the event of a brief over current transient. The integrated Propagation Delay Compensation™ is responsible for highly accurate power limiting across the whole line input voltage range. This feature reduces the electrical stress and enables a cost effective SMPS design. The integrated 650 V highly rugged CoolMOS^{TM} eliminates or reduces the need for a heat sink and permits an SMPS design with a simple RCD snubber. Extremely low specific ON resistance reduces conduction losses and supports operation at high ambient temperatures. The integrated frequency jitter improves EMI performance and simplifies filter design.

TLE4305 Constant Voltage and Current Regulator

The TLE4305G is specifically designed to control the output voltage and current of an SMPS. Independent compensation networks for the voltage and the current loop can be realized by external circuitry. The device contains a high accuracy bandgap reference voltage, two operational transconductance amplifiers (OTA), an optocoupler driver output stage and a high-voltage bias circuit. The device is based on Infineon' s double isolated power line technology DOPL which enables high precision bipolar voltage regulators with breakdown voltages up to 45V. Efficiency is further improved by the very low voltage drop (only 200mV) across the shunt resistors R28 and R29 of the TLE4305G.

Conclusion

This off-line LED SMPS solution-using the Infineon ICE3B0365JG CoolSET™ and TLE4305G IC's - was designed to give maximum safety, reliability and improved EMI performance whilst protecting the LEDs during load transients. The compact design is able to be used worldwide and has a high efficiency with differing numbers of LEDs. The circuit also features a highly accurate output current control and a very low standby power rating during no load condition. The high level of integration in both devices enables maximum of protection features with a minimum of external components – resulting in a cost effective SMPS design.

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RGB LEDs Lead the Way for Flat Panel Displays

Broader spectrum and higher efficiency

LED backlighting is becoming increasingly popular versus CCFL (Cold cathode Fluorescent Light). LCD display panels with RGB LED backlighting render superior color reproduction that enhances the viewing experience.

By Bjoy Santos, Field Applications Engineer, Intersil, Milpitas CA USA

Unlike the typical CCFLs, RGB LEDs expand the range of visible colors. CCFL backlit displays have a limited color gamut (spectrum), and lack color vividness. See Figure 1. CCFL exhibit approximately 80% of the NTSC (National Television System Committee) defined colors while RGB can reveal up to 110% of the NTSC color gamut enabling a more accurate representation of images on screen.

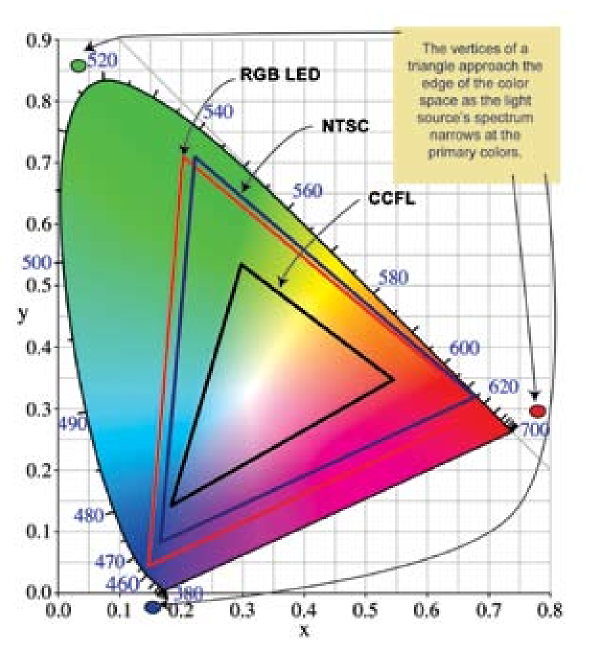


Figure 1 CIE color space resembles a horseshoe shape.
(1)NTSC displays all colors within borderline of the CCFL triangle.
(2)CCFL backlit display lacks vibrant colors.
(3)RGB LEDs backlighting extends the NTSC color space.

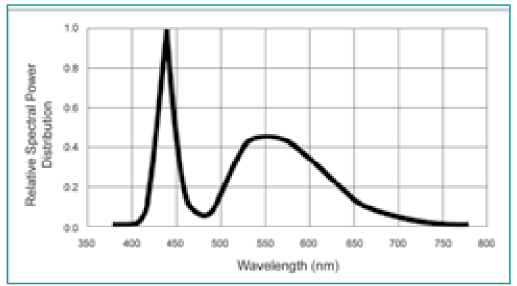


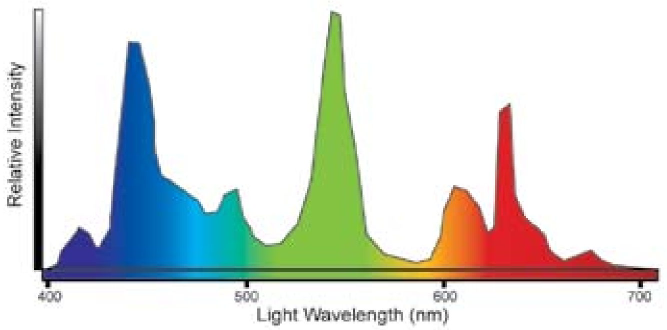
Figure 2 White LED typical spectrum. The broad spectrum of a white LED limits the color gamut of a display when used as a light source in the display panel.

The largest possible color gamut is achieved by using three monochromatic light sources such as blue, green, and red lasers. When viewed in the spectrum, lasers have narrow bands of energy at the 380nm, 520nm, and 700nm wavelength. The narrower the band, the closer it is to the edge of the CIE horseshoe, and hence the larger the region of the color gamut.

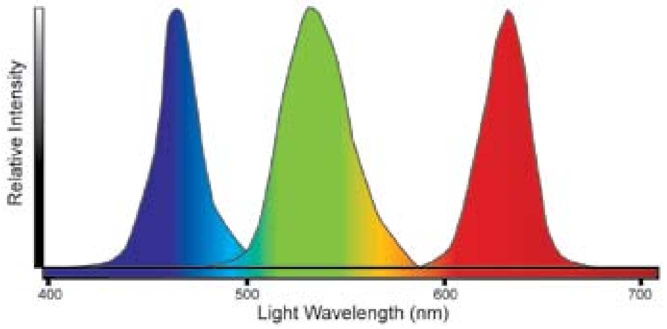
White LED vs. CCFL

White LED backlighting is well suited for handheld and mobile display panels because it is available in smaller form factors, is simpler to drive, is less sensitive to mechanical stress, and has twice the life expectancy. In addition, the rapid advancement of white LEDs' emission efficiency has made them a favorable choice in backlighting larger display panels such as notebook panels, LCD monitors and TVs. White LEDs have achieved 100 lumens/watt—an efficiency twice that of widely-used fluorescent lamps.

However, white LEDs share the same disadvantage in color gamut because a white LED is equivalently a broad-band light source. A white LED is a blue diode covered with phosphor to convert a portion of the blue light to yellow light. The blue and yellow bands peak at 445nm and 540nm respectively. The combined spectrum is perceived as white light. See Figure 2. In order to achieve a larger color gamut, the light source has to



(a) Typical CCFL Spectrum



(b) RBG LED Combined Spectrum

Figure 3. CCFL vs. RGB LED comparison. (a) Unwanted colors in the CCFL spectrum detriments LCD's color gamut display. (b)RGB LED has a narrow band at the primary colors.

consist of narrow bands at the primary colors.

Why RGB LEDs?

RGB LEDs come close in delivering narrow-band spectrum (Figure 3b) at a fraction of the cost compared to monochromatic light sources. CCFL, which is a broad-band light source, radiates a wide spectrum of colors shown in Figure 3a. Although both CCFL and the combined RGB spectrums are perceived as white by the human eye, the broad spectral range of the CCFL limit the color gamut of panel displays because of unwanted colors such as orange, yellow and cyan. Color gamut can also be improved by filtering the primary colors into a narrower spectrum. However, color filtering greatly attenuates the amount of light, reducing the overall brightness. Color filtering as of today is not a practical solution.

Not only does the RGB LED improve color gamut, it also improves efficiency as well because RGB LEDs only emit optical energy that is needed—red, green and blue. Broadband light sources such as white LEDs and CCFL have a relatively high presence of unwanted colors which deteriorate the color gamut and therefore cause a loss in efficiency.

Because individual colors can be driven independently, the white point or the color temperature of an RGB LED can be corrected, while the CCFLs and white LEDs have a fixed white point.

There are added complexities in driving RGB LEDs. First, there is an aging effect or lumen depreciation over time which is measured in change in lumen output versus time. Most light sources will dim when driven with a constant current. For a white LED and CCFL, light depreciation due to aging is easily compensated by driving them with more current. This is not the case for RGB LEDs. It is a little bit more complicated because each color has a different depreciation rate. See Figure 5. Red and green LEDs typically dim by 10%, while blue LEDs deteriorate to 70% after a year. For this reason, color temperature and luminance of an RGB LED are both degraded over time when driven with a constant current source. Light depreciation for each color has to be determined individually before compensating with higher current. Otherwise, the color temperature or white point will be altered. A method compensating for light depreciation is shown in Circuit 1.

The effect of temperature is another concern. For CCFL and white LEDs, light variation due to temperature deviation is compensated by driving more or less current through the light source. RGB LEDs add a bit more difficulty. Blue has a positive temperature coefficient while red and green, although both negative, also have different temperature coefficients. See Figure 6. A crude method is to have a temperature sensor monitor the light source and determine how much current to drive the individual colors. Compensation due to temperature fluctuations is also accomplished in Circuit 1.

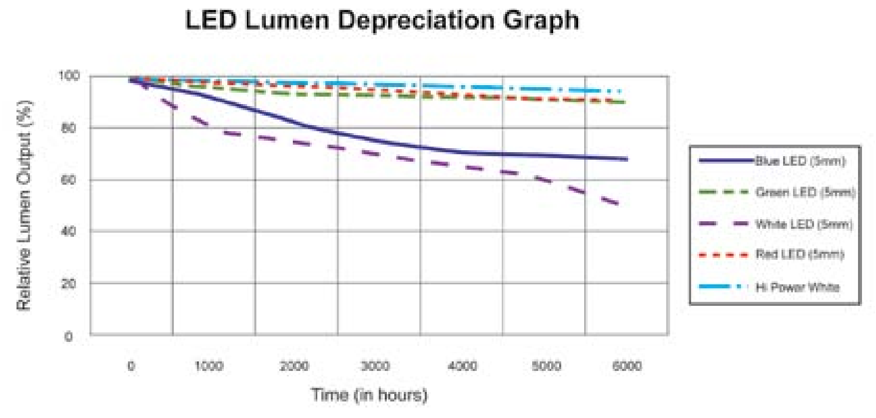


Figure 4. LED typical lumen output vs. time.

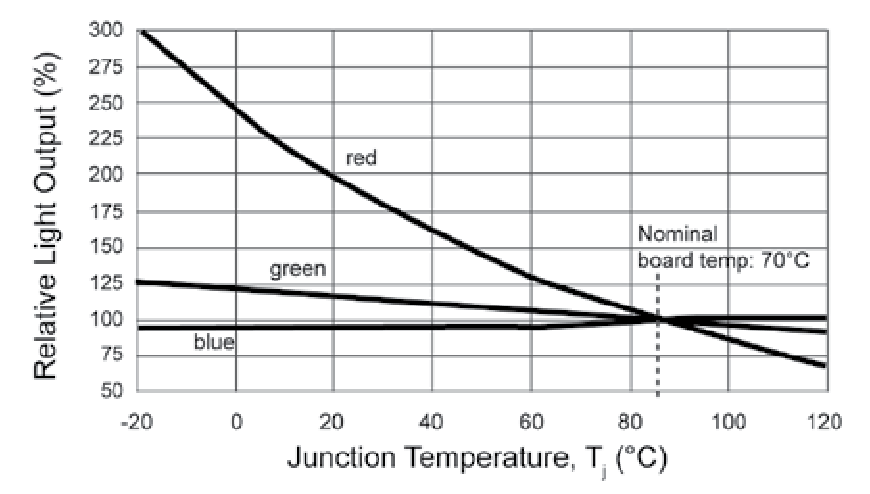
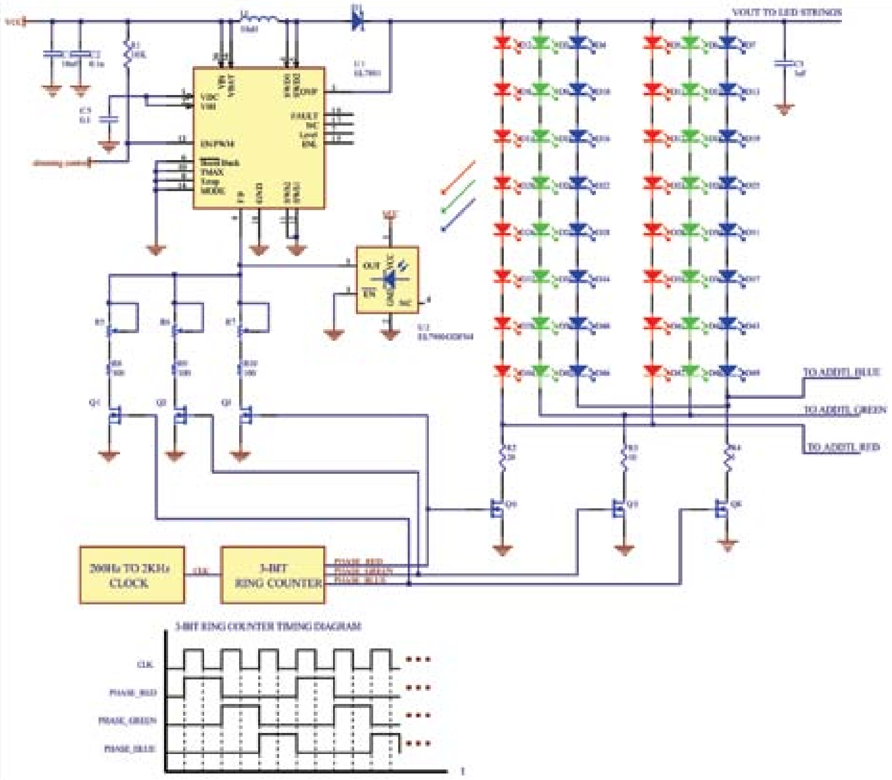


Figure 5. Relative Luminous Light Output vs. Junction Temperature for individual colors.



Circuit 1. RGB LED driver with optical feedback.

A method of driving strings of RGB LEDs with an optical feedback loop is shown in Circuit 1. An inductor-based boost converter, the EL7801, drives a combination of series and parallel RGB LEDs. The EL7900 is an optical photosensor that senses and converts optical signal into an electrical signal. The electrical signal is fed back to the EL7801 controller to adjust the current through the LEDs. A unique modulation technique with the use of a 3-bit ring counter is employed such that a costly RGB optical sensor is avoided. The circuit ensures that the luminance (brightness) and the white point (color temperature) are kept constant over time and regardless of temperature fluctuations.

Each color is turned on sequentially one at a time at a rate determined by the clock CLK. See 3-bit ring counter timing diagram in Circuit 1. During the first clock cycle, PHASE_RED is exclusively high; PHASE_GREEN and PHASE_BLUE are low. Consequently, transistor Q6 is on to conduct current through red LEDs, and transistor Q3 is on to allow current path from the EL7900 light sensor, whose current output IOUT is proportional to the optical output of the red LED. Note that only red light is present during PHASE_RED. Red intensity is adjusted via variable resistor R7 whose resistance is inversely proportional to red light intensity. The lower the resistance, the higher the red luminance because the EL7801 controller will boost the current through the red LED, increasing red intensity until the voltage at the FB is at its nominal value of 100mV.

On the second clock cycle, PHASE_GREEN is exclusively high, turning off Q3 and Q6 and shutting off the red LED. During this phase, Q2 and Q5 are on. The light sensor sees green light alone and starts another closed loop operation with the green LED.

The third cycle exclusively closes the loop on the blue LED. Note that the light sensor exclusively converts one color light at a time while the other colors are off. This method of modulation avoids the use of an RGB sensor.

At extremely slow clock rates, one can see individual colors turn on at a time. At higher clock rates we perceive a constant white light because the human eyes are natural integrators. The complete cycle is analogous to a color wheel composed of primary colors. When spun slowly, humans see red, green and blue separately. When spun fast, the human eyes integrate and the human perception is a white wheel.

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Highly Integrated IC Enables LED Lamps to Meet EMC and Power Quality Standards

Plug-in replacements now become a reality

Incandescent lamps are being replaced by more efficient lighting technologies such as compact fluorescent and LED bulbs, but early attempts caused problems with EMC and current unbalance on the supply.

By Don Ashley, Product Marketing Manager, Power Integrations

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

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

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

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

Design Objectives

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

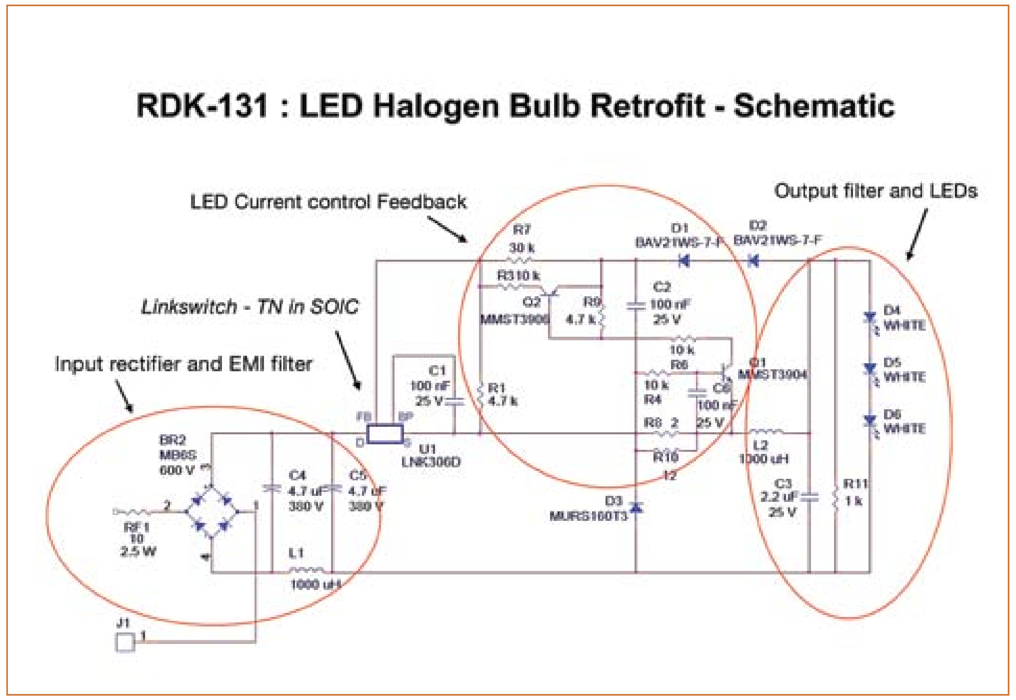

Figure 1. Schematic from RDR-131 Title "Converter and EMI Filter Schematic".

EMI Considerations

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

Design Details

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

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

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

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

Early on in the design process it became clear that a circular PCB large enough to house all the components

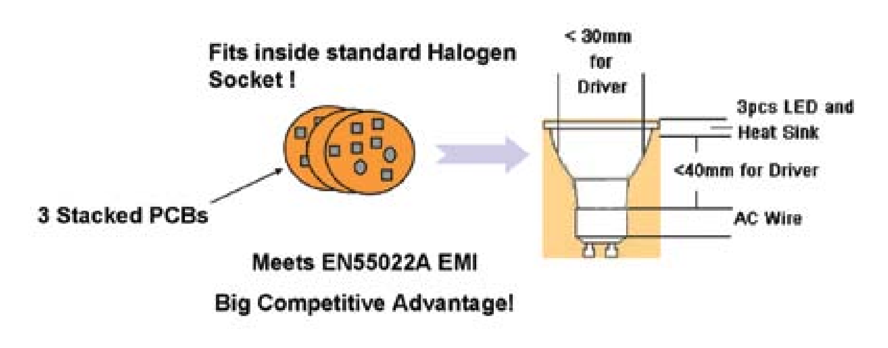

Figure 2. Drawing showing PCB and Halogen lamp base dimensioned side view Title "Mechanical Packaging Challenge".

for both the converter and the EMI filter would not fit into the lamp socket base. So a decision was made to partition the design onto two circular PCBs, one for the converter circuitry and another for the EMI filter. The final diameter of the converter board is 19.66 mm while the diameter of the EMI filter board is 16.91 mm. These boards were then stacked and interconnected with discrete wires to complete the assembly.

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

Performance

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

Conclusion

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

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Coping with New Lighting Requirements in Portable System Designs

Every new development needs a design solution

Recent advances in power management help designers offload processing overheads, drive down system footprint, and costs.

By Adolfo Garcia, Product Line Director for Lighting Products, AnalogicTech

Lighting requirements in handsets and portable devices have undergone a dramatic evolution over the past few years. Not so very long ago a typical cellphone featured a simple passive LCD display with little or no backlighting. The greatest challenge designers faced was how to most efficiently drive a number of LEDs in parallel or in series without draining the system's battery.

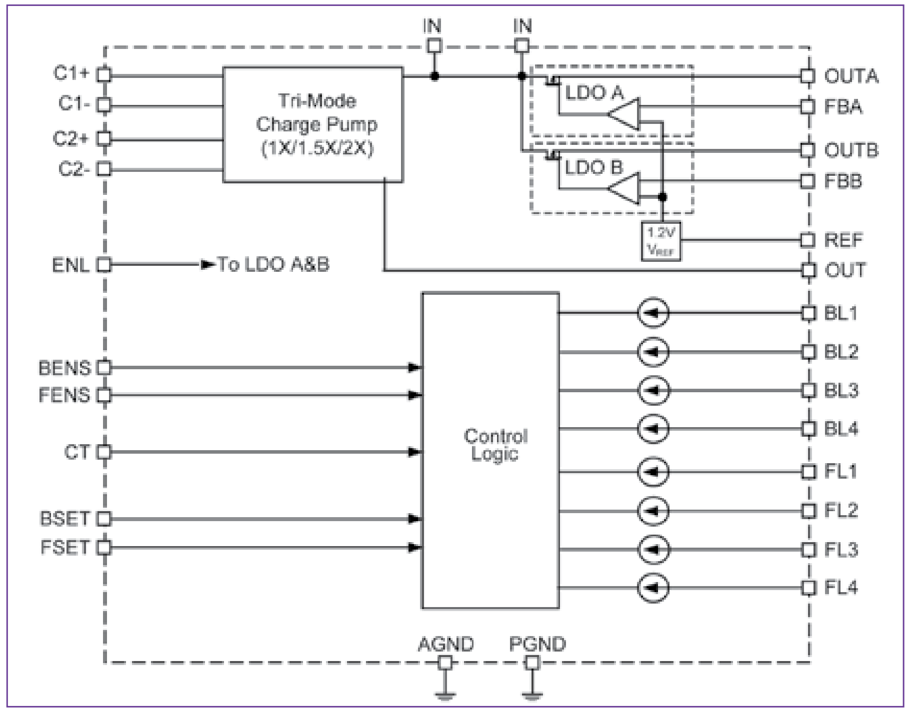
As designers moved to higher performance colour displays and began to embed a wide variety of value-added features such as cameras into their portable systems, power requirements have dramatically escalated. Today the typical cellular handset or handheld device features a relatively high resolution main display which is backlit by four or more LEDs. Many now also add a second, smaller display, such as those used on the outside of a clamshell-style phone, to deliver additional information. Usually these sub panels require two additional LEDs for backlighting. Power circuits are also often needed to drive auxiliary RGB status lights and to backlight the keypad on the device.

At the same time, the integration of camera functionality has brought an entirely new set of power requirements to portable system design. Embedded cameras require a flash typically implemented by driving one, or a small number of LEDs at high power for a very short duration. Early camera implementations, which used CCDs of less than 1 Megapixel, demanded flash drivers of little more than 100mA. But as portable system designers have moved to higher resolution CCDs, power requirements for flash functions have risen as well. Today many portable devices require as much as 600mA (or more for Xenon flash lamps) of power just to drive the camera flash function and achieve maximum photo resolution and red-eye correction. (see diagram: AAT3171 typical application). Furthermore, the addition of new flashlight or movie-mode functions promises to further complicate power management requirements and system design.

Discrete implementations

Traditionally, portable system designers have relied primarily on discrete implementations to manage power for lighting applications. For backlight applications, designers have typically used discrete charge pumps to drive a number of LEDs in parallel or boost converters to drive a number of LEDs in series to provide basic illumination. Colour displays increased power requirements, but few early implementations offered designers any flexibility in terms of setting light intensity. Gradually, issues such as white balancing to control light intensity and colour balancing to create different colours for status lighting became increasingly important and required more sophisticated control by the system controller or a housekeeping microcontroller. Early on, most designers relied on relatively noisy analogue PWM control signals to control LED brightness and backlight functions.

Flash LED functions were first implemented as single units with simple on/off control. Designers later added rudimentary algorithms residing in the system processor to control the flash subsystem. Since few systems offered any flash intensity control, designers

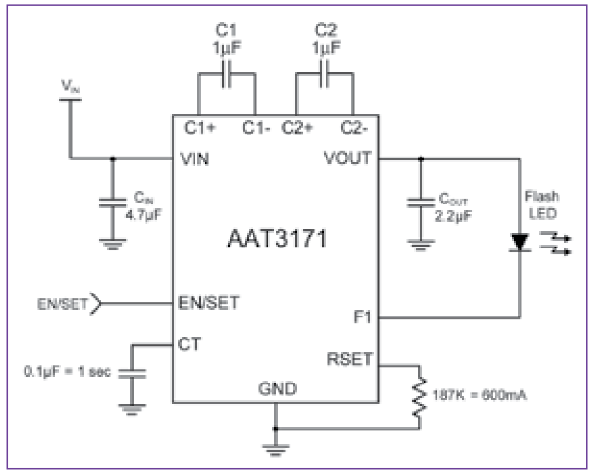


controlled the amount of light reaching the CCD by managing the camera shutter. As embedded camera performance improved, however, designers were forced to also upgrade the performance of their flash power management system. These advances demanded a fixed camera shutter and better control of the amount of light emitted by the flash. To reduce the overhead on the system controller, designers gradually migrated to more intelligent flash LED controllers. But as market pressure to reduce system size and cost has continued to mount, and the number, variety and complexity of lighting functions has continued to expand, portable system designers have begun to look for new ways to replace these discrete lighting subsystems.

Maximizing integration

Recently, power management semiconductor manufacturers have announced major advances in the vertical integration of these functions. By combining many of these circuits into a single IC, these new devices reduce component count, shrink PCB space requirements, minimize the overhead requirements of the system processor, and help portable system designers drive down cost.

As a result, instead of using a dedicated white LED driver for display backlight applications, a dedicated camera flash driver IC and discrete general purpose LDOs or a dual LDO IC, designers can now use highly integrated ICs, such as AnalogicTech's AAT2842 Total Display Solution to combine all three functions in a single 4 x 4mm package (See diagram: AAT2842 block diagram). These complex circuits combine a high current tri-mode charge pump with four 30mA outputs for backlight white LED, four 150mA outputs for flash LEDs and two general purpose 200mA LDOs. The four flash LED outputs can be combined to drive a single camera flash LED at up to 600mA, sufficient power to support the light requirements of today's high resolution embedded cameras. The backlight outputs can also be used for lower current keypad applications. Each LDO is capable of supplying a continuous load current of 200mA at a 200mV drop-out voltage. In addition, the output voltage of each of the LDOs embedded in this display power management device is user programmable via a resistor divider from 1.2 to 5V allowing them to meet the power requirements of a broad range of functions. To help simplify design, a single control enables both LDO outputs.



One of the risks associated with integrating multiple functions on a single IC is the limitation it potentially places on the designer's ability to configure the system. To maximize design flexibility, these devices add two separate serial interfaces that allow the designer to drive the LEDs for backlight or keypad functions and the LEDs for flash applications independently. With these independent interfaces designers can enable, disable or set current up to 16 different levels for backlight/keypad and flash functions. In addition, by allowing the designer to tune the output of the backlight or flash LEDs to their respective applications, this capability also helps save power. Alternately, the backlight/keypad and flash LEDs can be controlled via external resistors.

Other new highly integrated power management ICs help designers develop more efficient and cost effective solutions when they have to backlight multiple displays or add auxiliary lighting. These devices combine a high efficiency tri-mode charge pump with drivers for backlight LEDs, camera flash and auxiliary lighting. Instead of just driving four LEDs for backlight functions, however, these ICs drive up to six. By supplying individual control for each channel, these new devices allow designers to drive up to four LEDs to backlight a main display and two for a sub panel or use all six to backlight a single display.

Some of these new ICs, such as AnalogicTech's AAT2830, supply up to 600mA to drive up to four flash LEDs and support increasingly common requirements for flashlight and movie-mode applications. Moreover, they add three additional drivers capable of handling up to 60mA each for RGB, keypad or other auxiliary lighting applications. The tri-mode charge pump sitting at the heart of these new devices is typically capable of supplying enough power to operate all three types of LED functions – backlight, flash and auxiliary – simultaneously.

To help reduce overhead on the system controller, many of these new display power management ICs also add an integrated flash timer. Traditionally, portable system designers have relied on a high-to-low transition on the flash enable pin to control the duration of a flash event. If the system controller software hangs up or the control line becomes disconnected, the designer using this architecture runs the risk of the flash LEDs staying on at full power. Since flash LEDs are only designed to work in very short bursts, a failure of this type could quickly damage the LEDs and rapidly deplete battery power.

The recent addition of integrated flash timers into this new generation of display power management ICs not only reduces overhead at the system controller, but also provides a unique safety feature to protect against these types of failures. This timer function enables the flash current sinks for a programmed amount of time. Length of on-time is set by loading the timing register in the device with a value and then selecting a value for an external timing capacitor. Once data is latched into the timing register, the flash current sinks are automatically enabled for the duration of the programmed time and then disabled. By letting the controller 'set and forget' the on-time duration, this integrated timer eliminates the need for the controller to track the duration of the flash event. It also ensures that the flash LEDs will only be illuminated for the prescribed amount of time limited by the value of the capacitor.

Conclusion

The continual evolution of lighting functions in portable system designs shows no signs of slowing. Next generation systems will likely add new lighting requirements as designers bring an ever-widening array of functionality to users. Inevitably, these innovations will pose new power management challenges for designers.

To address these power management issues, semiconductor manufacturers are already developing a wide range of devices that bring together new combinations of charge pumps, boost converters and backlight, flash, RGB and LDO functional blocks. As these lighting features proliferate and the size of mobile communications and personal electronics products continue to shrink, this new generation of vertically-integrated, system-level devices will play a pivotal role in designers' quest for lower cost, higher performance systems.

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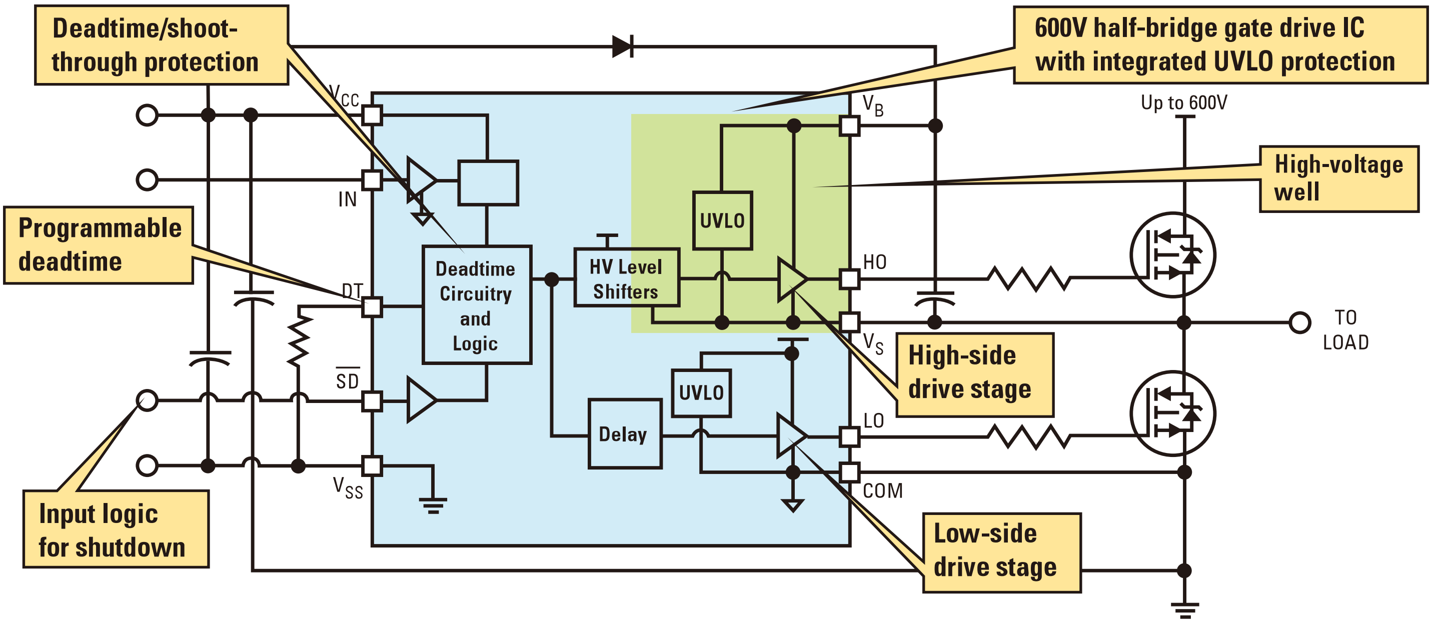

HALF-BRIDGE DRIVER ICs

Part Number	Pin Count	Sink/Source Current (mA)	Comments
IRS2103(S)PBF	8	290/600	UVLO V_{CC}
IRS2104(S)PBF	8	290/600	Input logic for shutdown; UVLO V_{CC}
IRS2108(S)PBF	8	290/600	UVLO V_{CC} & V_{BS}
IRS21084(S)PBF	14	290/600	Programmable deadtime; UVLO V_{CC} & V_{BS}
IRS2109(S)PBF	8	290/600	Input logic for shutdown; UVLO V_{CC} & V_{BS}
IRS21094(S)PBF	14	290/600	Input logic for shutdown; programmable deadtime; UVLO V_{CC} & V_{BS}
IRS2183(S)PBF	8	1900/2300	UVLO V_{CC} & V_{BS}
IRS21834(S)PBF	14	1900/2300	Programmable deadtime; UVLO V_{CC} & V_{BS}
IRS2184(S)PBF	8	1900/2300	Programmable deadtime; UVLO V_{CC} & V_{BS}
IRS21844(S)PBF	14	1900/2300	Input logic for shutdown; programmable deadtime; UVLO V_{CC} & V_{BS}

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Part Number	Pin Count	Sink/Source Current (mA)	Comments
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IRS2106/IRS21064(S)PBF	8 / 14	290/600	UVLO V_{CC} & V_{BS}
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