High Brightness LEDs Demand High Performance LED Drivers

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Background

High brightness (HB) white LEDs (Light Emitting Diodes) are quickly replacing incandescent lighting in many home, institutional, government and industrial applications. In many cases, the higher efficiency of the LEDs reduces power consumption by as much as 88%, dramatically reducing carbon emissions required to generate the electricity to power them. Large arrays of white LEDs are replacing CCFL lighting for backlighting large LCD-TFT panels found in HDTV applications. LED's higher efficiency, long life and ability to offer local dimming capability have enabled LCD HDTVs to attain contrast ratios in excess of 7,000,000:1, exceeding the CCFL-based designs by orders of magnitude. So it is not surprising that with the proliferation of LED lighting in so many applications that their growth rate continues to accelerate. According to Strategies Unlimited, The HB white LED general lighting market is forecast to exceed $5 billion by 2012, corresponding to a compound annual growth rate (CAGR) of 28% from 2009 to 2012. So far, most of this growth has been dominated by lower current LEDs, primarily in the 100mA to 500mA range. However, higher current LED applications, requiring 2A to 20A of current to drive a single LED are becoming more common place. The first of these were found in automotive headlights but they can now be found in applications ranging from high power architectural lighting to high performance DLP (Digital Light Projection) projectors. The enhanced performance of these applications will continue to fuel the high growth rate of high current LEDs in the foreseeable future

Emerging High Power LED Applications

The introduction of high current LEDs enabled high power lighting applications to use them, replacing relatively inefficient incandescent bulbs. In applications such as architectural lighting and DLP projectors, which traditionally require 500watt to 1,000W halogen bulbs, 20A LEDs can offer the same light output (in lumens) but only require 20% of the electrical power. In architectural applications, the LED driver must be very efficient and offer wide dimming ratios to maintain a constant light output in a wide array of ambient conditions. In high end DLP projection applications, an array of red, green and blue (RGB) LEDs replaces the traditional halogen bulb, color wheel and array of mirrors (mems). However, in order to mix colors accurately, a LED driver must be able to rapidly switch between two disparate regulated peak current states and overlay PWM dimming without disruption. Designing high current LED driver ICs that are capable of meeting these demanding speed and accuracy requirements while optimizing overall efficiency, has posed many new challenges for IC designers

LED Lighting for DLP Projectors

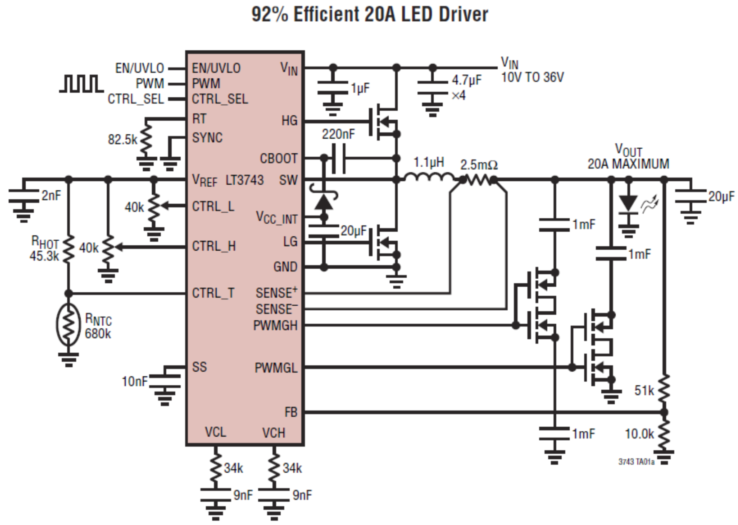
High-end DLP projectors have historically used high power incandescent bulbs combined with a color wheel and an array of mirrors to project a relatively high resolution image. As many of these projectors require 500W to even 5kW bulbs, thermal management of the entire system is a major design obstacle. Even with substantial thermal management systems requiring constant airflow cooling, bulb life spans are relatively short and are very expensive to replace. New designs use an array of high current RGB LEDs in lieu of a high power bulb, color wheel and mirrors, which dramatically reduces the magnitude of wasted heat, while improving the accuracy of color mixing, dramatically improving contrast ratios and overall resolution. However, in order to reach the desired level of performance, they require a unique LED driver design. First, the driver must be able to deliver up to 20A of continuous LED current and pulsed currents up to 40A. Secondly, it must offer efficiency in excess of 90% to minimize thermal considerations. Finally, in order to achieve the wide dynamic range required in color mixing, it must be able to switch between three well regulated current states rapidly and accurately without any disruptions.

The LT3743

The LT3743 is a synchronous step-down DC/DC converter designed to deliver constant current to drive high current LEDs. The device's 5.5V to 36V input voltage range makes it ideal for a wide variety of applications, including industrial, DLP projection and architectural lighting. The LT3743 provides up to 20A of continuous LED current from a nominal 12V input, delivering in excess of 80 Watts. In pulsed LED applications, it can deliver up to 40A of LED current or 160 Watts from a 12V input. 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 100kHz and 1MHz so designers can optimize efficiency while minimizing external component size. Combined with a 4mm x 5mm QFN or thermally enhanced TSSOP-28 package, the LT3743 offers a very compact high-power LED driver solution.

The LT3743 has both PWM and CTRL_SELECT dimming (see figure 1), offering 3,000:1 dimming capability at three LED current levels, making it ideal for color mixing applications such as those required in DLP projectors. Similarly, the LT3743's unique topology enables it to transition between two regulated LED current levels in less than 2us, enabling more accurate color mixing in RGB applications. LED current accuracy of ±6% is maintained in order to ensure the most accurate luminosity of light from the LED. Additional features include output voltage regulation, open-LED protection, overcurrent protection and a thermal derating circuit.

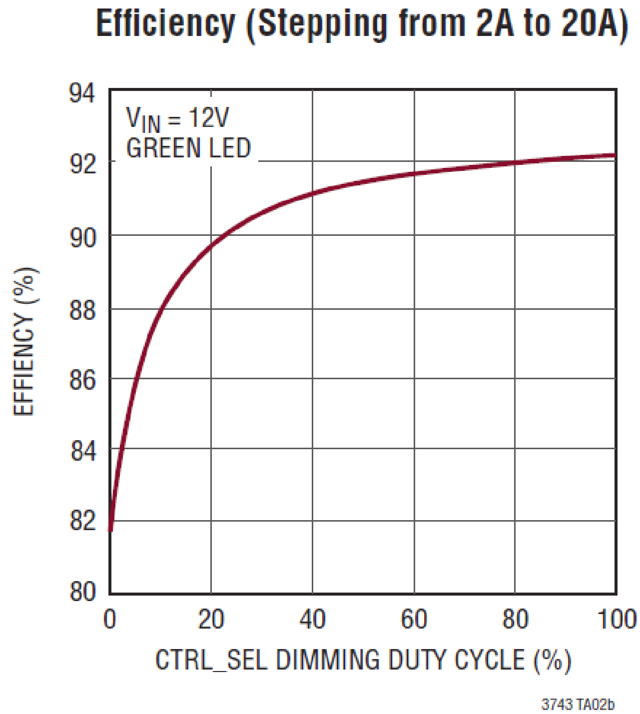
Figure 1. LT3743 LED Driver with Three-State Current Control



High Efficiency Operation

In driving LEDs which require drive currents as high as 20A, conversion efficiency is critical. First, in order to maintain the high efficiency of the LEDs in delivering light, an IC driver must also offer high efficiency to minimized wasted energy in the form of heat. Secondly, many applications such as DLP projectors and architectural lighting require very compact solution footprints. As a result, the LED driver IC should not require any additional heat sinking to dissipate wasted power. In DLP applications, this enables designers to eliminate the requirement for cooling fans and the audible noise associated with them. As DLP projectors use RGB LEDs to accurately mix colors, running each LED at relatively low duty cycles (approximately 30% on average), it is imperative that high efficiency is maintained even at these relatively low duty cycles. The LT3743 utilizes a unique design implementing synchronous rectification and external switched load capacitors for both the CTRL_L and CTRL_H current circuits to deliver efficiencies greater than 90% for the most commonly required duty cycles. Figure 2 shows how the LT3743's efficiency varies with duty cycle while driving a green LED with current between 2A and 20A. Other industrial applications, such as laser diode drivers, also require this high efficiency in pulsed applications.

Figure 2. LT3743 Efficiency vs. Duty Cycle



Three-State Current Control

The LT3743 utilizes a unique design that enables three-state current control with 3,000:1 dimming for each current level. Figure 3, shows how these different current levels are controlled. First, when the PWM signal goes high, it sets the LED current from zero to the current level set by CTRL_L, in this example I_{LED} =2A. Then, when the CTRL_SEL pin goes high, I_{LED}=20A. All of these current levels are maintained with $\pm$6% accuracy ensuring consistent brightness levels. Conversely, when CRTL_SEL goes low I_{LED} returns to 2A, and when the PWM signal goes low, I_{LED} goes into its off state. The LT3743's individual CTRL_L and CTRL_H control loops enable these current levels to transition very quickly, ~2usec while maintaining very high efficiency.

This three-state current control enables high end DLP projector applications using RGB LEDs to deliver unprecedented color accuracy and dynamic range. Figure 4 shows how three-state current control delivers this higher performance when compared to a dual state control. Traditionally, the dual state control would either turn each of the RGB LEDs either completely on or off depending on the relative duty cycle to define the color. This makes the projected color accuracy completely dependent on the color accuracy of the individual LEDs, which can vary considerably. However, as high end DLP projectors demand the highest quality image and color reproduction possible, a new means to achieve this is required. Namely, to achieve the highest color accuracy possible, variations in the individual LEDs must be corrected by mixing with the other two color LEDs to offer the most accurate color level. For example, when the red LED is turned on at full current, the blue and green LEDs are turned on at lower current levels so they can be mixed to produce the most accurate red. The 3,000:1 dimming capability both on the PWM and the CRTL_S pins further enhance the dynamic range of the mixed colors. The dynamics of this color mixing can be seen in figure 4.

Figure 3. Three-State LED Current Control

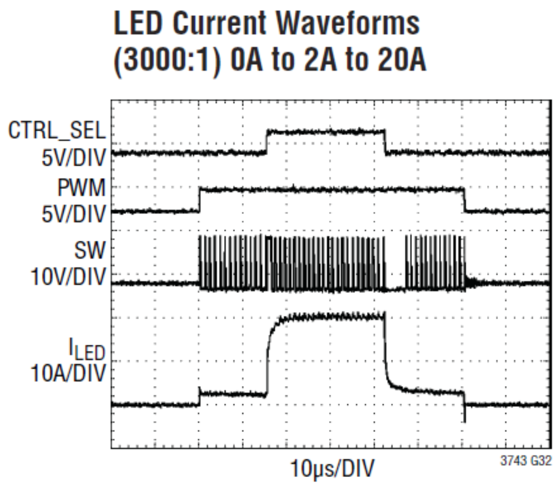
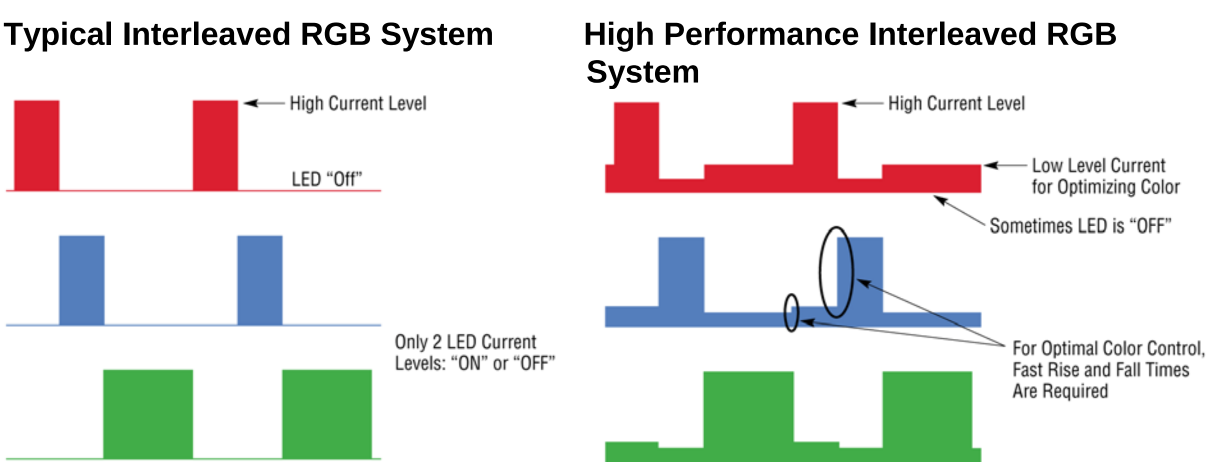


Figure 4. Dual Current Color Mixing vs. Three-State Coloring Mixing

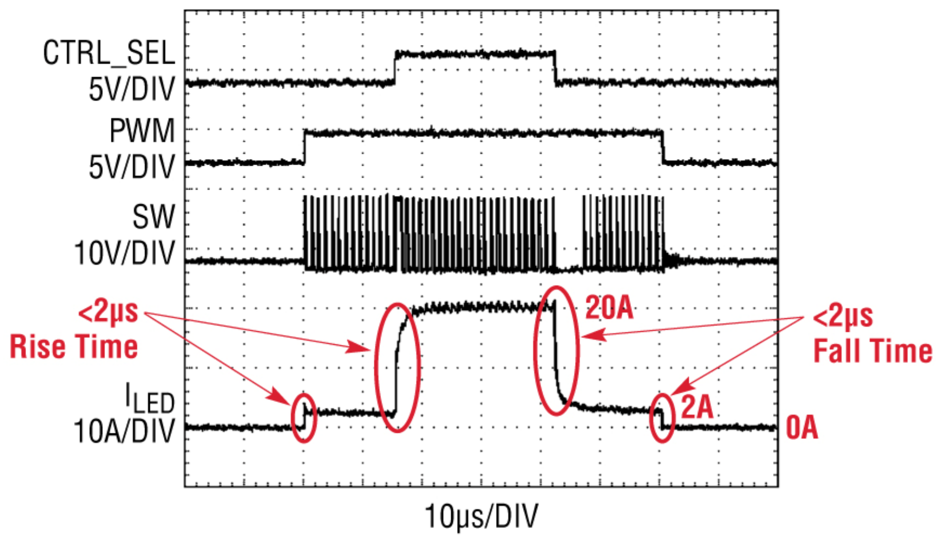


Fast Transition Times between Current Levels

To maintain the most accurate color mixing capability, not only must the LED drivers provide three-state current control and precise PWM dimming at three different current levels, they must also transition from a relatively low current regulated state (~2A) to a much higher regulated current level (~20A) so that the PWM dimming edges are preserved. The LT3743's unique design enables it to make these transitions very rapidly. Namely, as can be seen in figure 5, the LT3743 can transition from a 2A constant current state to a 20A state in under 2us making it ideal for color mixing RGB applications.

In addition to RGB LED color mixing applications, industrial applications driving high power laser diodes also require this ability to transition between two well regulated current levels, such as 2A to 20A, in the ~2us to ~5us range for pulsed laser applications.

Figure 5. 2us Rise & Fall Times Using the LT3743 with Three-State Dimming Using PWM & CTRL_SEL



Conclusion

The unprecedented acceleration of LED lighting applications in industrial and commercial lighting has created many specific performance requirements for LED driver ICs in high current LED applications. In industrial applications, these applications range from high power interior/exterior lighting to driving laser diodes for cutting and shaping raw materials. Commercial applications range from general architectural lighting to the newest generation of high end DLP projectors. All of these applications require high performance LED driver ICs. This new generation of LED drivers must deliver very high efficiency, offer very wide dimming ratios and have the ability to transition from three disparate currents levels very rapidly. Of course, these applications also require very compact, thermally efficient solution footprints. Fortunately, the LT3743 meets all of these criteria.