High Current/High Speed LED Driver Revolutionizes PWM Dimming

by Josh Caldwell

Introduction

Power drivers that can produce regulated high current pulses are used in a number of lighting applications, ranging from high current LEDs in DLP projectors to high power laser diodes. For instance, in high end video projectors, high power LEDs are used to produce color illumination. The RGB LEDs in these projectors require precise dimming control for accurate color mixing—in this case, more control than simple PWM dimming can offer. Typically, to achieve the wide dynamic range required in color mixing, LED drivers must be able to rapidly switch between the two disparate regulated peak current states, *and* overlay PWM dimming without disruption. The LT3743 has the ability to meet these demanding accuracy and speed requirements.

The LT3743 is a synchronous buck DC/DC controller that utilizes fixed-frequency, average current mode control to accurately regulate the inductor current through a sense resistor in series with the inductor. The LT3743 regulates the current in any load with an output voltage range from 0V to 2V below the input rail with ±6% accuracy.

Precision, broad-range LED current control is achieved by combining accurate analog dimming (high and low states) with PWM dimming. Analog dimming is controlled via the CTRL_L, CTRL_H, and CTRL_T pins; PWM dimming via the PWM and CTRL_SEL pins. A rapid transition between the high and low analog states is made possible with the LT3743's unique use of externally switched load capacitors, which allows the LT3743 to change regulated LED current levels within several microseconds. The switching frequency may be programmed from 200kHz to 1MHz using an external resistor and synchronized to an external clock from 300kHz to 1MHz.

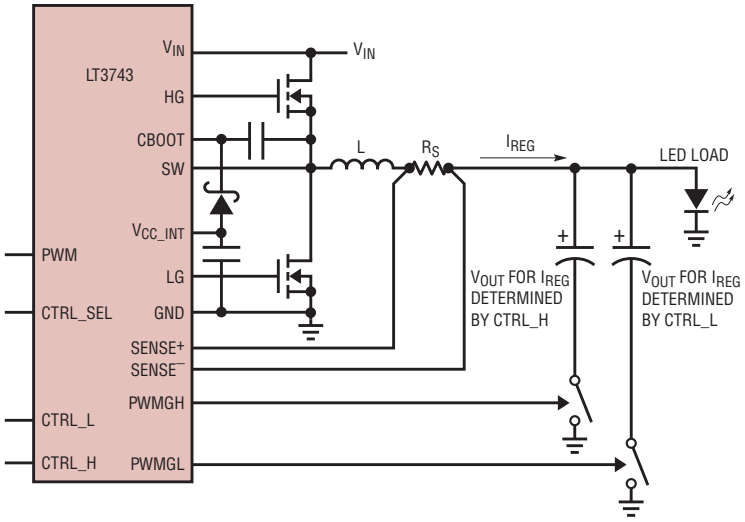

Figure 1. Basic switched-capacitor topology

Switched Output Capacitor Topology

In traditional current regulators, the voltage across the load is stored in the output capacitor. If the load current is suddenly changed, the voltage in the output capacitor must charge or discharge to match the new regulated current. During the transition, current in the load is poorly controlled, resulting in slow load current response time.

The LT3743 solves this problem with a unique switched output capacitor topology, which enables ultrafast load current rise and fall times. The basic idea behind the topology is that the LT3743 acts as a regulated current source driving into the load. The voltage drop across the load for a given current is stored in the first switched output capacitor. When a different regulated current state is desired, the first output capacitor is switched off and a second capacitor is switched in. This allows each capacitor to store the voltage drop for the load corresponding to the desired regulated current.

Figure 1 shows the basic topology with the various control pins. The PWM and CTRL_SEL pins are digital control pins that determine the state of the regulated current. The CTRL_H and CTRL_L pins are analog inputs with a

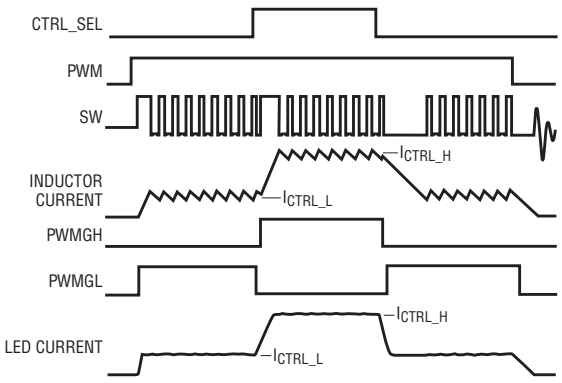

Figure 2. LED current PWM and CTRL_SEL dimming

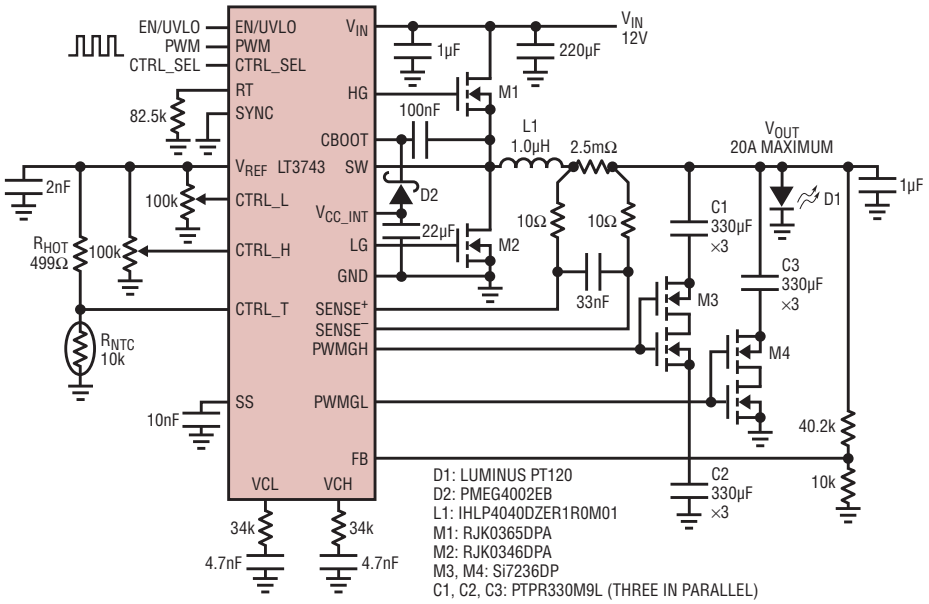

Figure 3. A 24V, 20A LED driver using switched output capacitors

full-scale range of 0 to 1.5V, producing a regulated voltage of 0mV to 50mV across the current sense resistor.

Figure 2 shows the timing waveforms in response to the various states of the PWM and CTRL_SEL pins. When PWM is low, all switching is terminated and both output capacitors are disconnected from the load.

Although the LT3743 may be configured with switched output capacitors, it is easily adapted to any traditional analog and/or PWM dimming scheme.

Switching Cycle Synchronization

The LT3743 synchronizes all switching edges to the PWM and CTRL_SEL rising edges. Synchronization gives system designers the freedom to use any periodic or non-periodic PWM-dimming pulse width and duty cycle. This is an essential feature for high current LED drivers during recovery from a zero or low current state to a high current state. By restarting the clock whenever the CTRL_SEL or PWM signals go high, the inductor current begins ramping up immediately without having to wait for a rising edge of the clock. Without synchronization, the phase relationship of the clock edge and the PWM edge would be uncontrolled, possibly resulting in visible jitter in the LED light output. When using an external clock with the SYNC pin, the switching cycle resynchronizes to the external clock within eight switching cycles.

A 24V, 20A LED Driver Using Switched Output Capacitors for High End DLP Projectors

High end DLP projectors demand the highest quality image and color reproduction. To achieve high color accuracy, variations in the color of individual LEDs are corrected by mixing in the other two color LEDs. For example, when the red LED is on at full current, the blue and green LEDs are turned on at low current levels so they can be mixed in to produce accurate red. This technique requires the ability to rapidly transition between relatively low (~2A) and high (~20A) LED currents so that PWM dimming edges are preserved. Figure 3 shows a 24V/20A LED driver for use specifically with high end DLP projectors.

The relatively low switching frequency of 450kHz allows for a very small 1.0µH inductor. With 25% ripple current, the transition times between the high and low current states is about two microseconds. The large 1mF output capacitors store the voltage drop across the LED for the two different current states and provide instantaneous current when the MOSFET dimming switches are turned on. Use of several low ESR capacitors in parallel is critical to providing rapid LED current transitions.

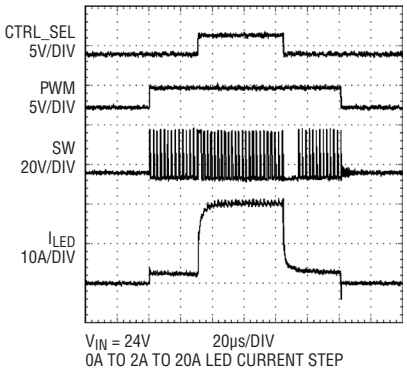

Figure 4. Zero to 2A to 20A LED current steps

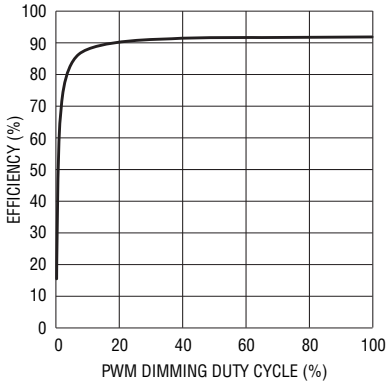

Figure 5. 12V, 20A PWM dimming efficiency using a green LED

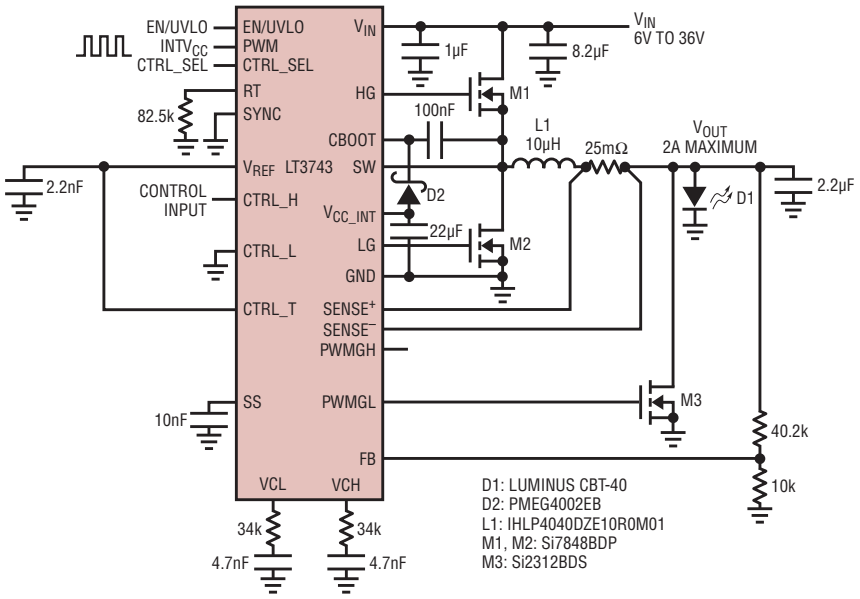

Figure 6. A 6V to 36V input, 2A LED driver with current limited shunted output

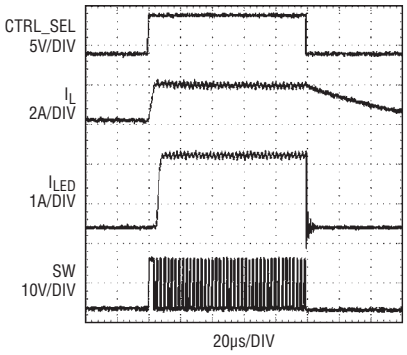

Figure 7. 0A to 2A current limited shunted output PWM dimming

The regulated high and low currents are set by voltage dividers from the V_{REF} pin to the CTRL_L and CTRL_H pins. The ±2%, 2V reference at V_{REF} is also used to provide the reference signal the temperature derating circuit applied at CTRL_T (see "Thermally Derating the LED Current" below).

To reduce potentially large start-up currents, the LT3743 uses a unique soft-start circuit that throttles back the regulated currents, providing full drive when the soft-start pin is charged to 1.5V. To minimize the transition time between current levels, the LT3743 employs individual compensation for each level so that the current control loop may return to steady-state operation as quickly as possible. Figure 4 shows the LED current step from 0A to 2A to 20A.

High Efficiency Over a Wide Range of PWM Duty Cycles

Power dissipation is a critical design parameter in portable DLP projectors. Unlike many shunt-type high current LED drivers currently available, the LT3743 has excellent efficiency over a wide range of PWM duty cycles. By delivering power only to the load instead of either shunting power away or charging the output capacitor, most of the energy lost in common traditional PWM-dimmed drivers is conserved. Figure 5 shows the efficiency with V_{IN} = 12V, driving a green LED between 0A and 20A over the entire duty cycle range.

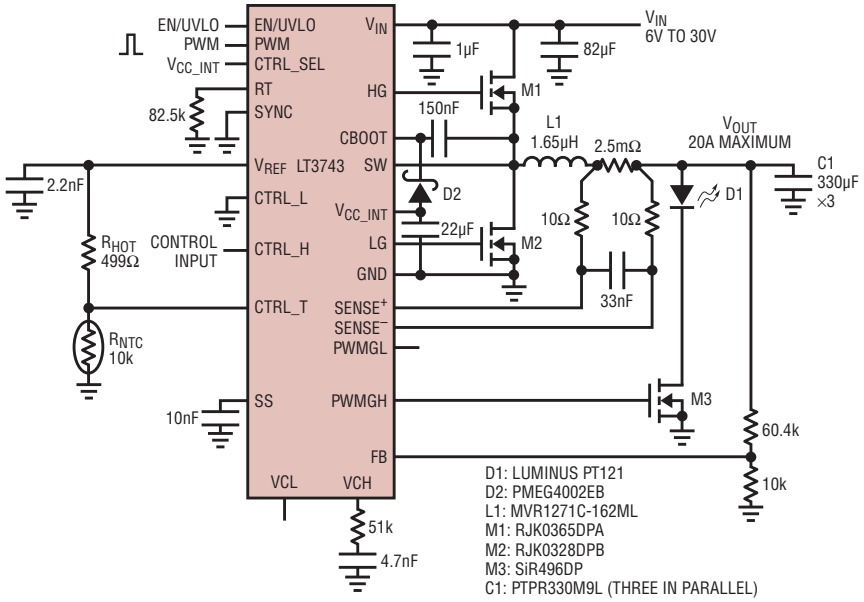

Figure 8. A 6V to 30V input, 20A LED driver with switched cathode PWM dimming

Shutdown and Precision Enable

When delivering high load currents, the amount of supply undervoltage lock-out (UVLO) hysteresis required for proper operation is highly dependent on board layout. For maximum flexibility, the LT3743 incorporates a precision enable threshold with a 5.5µA current source flowing into the pin when the EN/UVLO pin is lower than 1.55V. Using a voltage divider from the input supply to ground any amount of hysteresis may be added to the system. To conserve power in portable applications, the LT3743 is completely disabled and supply current drops below 1µA when the EN/UVLO pin is lower than 0.5V.

Thermally Derating the LED Current

Proper thermal management is vital with any high current load to protect expensive high current LEDs and prevent system-wide damage. The LT3743 uses the CTRL_T pin to reduce the effective regulated current in the load for both the high and low control currents. Whenever CTRL_T is lower than the control voltage on the CTRL_L or CTRL_H pins, the regulated current is reduced. The temperature derating is programmed using a temperature dependent resistor divider from the V_{REF} pin to ground.

Output Voltage Protection

Voltage protection is important to prevent damaging expensive projector LEDs. The LT3743 utilizes the FB pin to provide a regulated voltage point for the output. To simplify system design, the LT3743 uses an internal 1V reference, softly reducing the regulated current when the FB voltage reaches 900mV.

Powerful Gate Drivers

To provide adequate drive and reduce switching losses in high current power MOSFETs, the LT3743 uses very strong switching MOSFET drivers. The on-resistance of the LG and HG PMOS pull-up drivers is typically 2.5Ω. The LG and HG NMOS pull-down drivers on-resistance is typically less than 1.3Ω. With on-resistance this low, two high current MOSFETs may be used in parallel for applications exceeding 20A. Most currently available LED drivers do not provide adequate gate drive for dimming MOSFETs and as a result need an additional external gate driver. The LT3743 integrates this into the PWMGL and PWMGH drivers and has a 2Ω typical NMOS pull-down and a 3.7Ω typical PMOS pull-up to drive any 5V dimming MOSFET.

Traditional PWM Dimming

The LT3743 adapts to any traditional PWM dimming method. Shunted output dimming used by competing LED drivers wastes energy and has poor efficiency for LED duty cycles below approximately 50%. Since the LT3743 has two levels of current regulation, the regulated current can to drop to zero when the shunt is engaged. This provides excellent efficiency even for low LED duty cycles.

The LT3743 produces ultrafast high current LED rise times while providing accurate current regulation. Its ability to support multiple current states meets the demands of high performance theater-quality DLP projectors by allowing LED colors to be easily mixed. In addition to speed, the LT3743's switched capacitor topology reduces board size by allowing the use of a compact, low value inductor. Additional features include switching cycle synchronization, overvoltage protection, high efficiency and easy adaptability for varied application needs.

Figure 6 shows a 2A LED driver configured with a current-limited shunted output. Note that the CTRL_L pin is tied to ground, PWMGL is used to drive the shunting MOSFET, and CTRL_SEL is used for dimming. With CTRL_L tied to ground, when the CTRL_SEL pin is low, the shunt is engaged and the current in the inductor is regulated at 0A. When CTRL_SEL is high, the shunting MOSFET is turned off, and the regulated current is determined by the voltage at the CTRL_H pin. Figure 7 shows the current-limited shunted PWM dimming with a 12V input.

In addition to the shunt, the LT3743 is readily configured to driving the dimming MOSFET in series with the cathode of the LED. When multiple current states are not required, this is the preferred method of PWM dimming. Figure 8 illustrates a 6V to 30V, 20A LED driver with switched cathode PWM dimming. Figure 9 shows switched cathode, PWM dimming with a 0A to 20A current step and a dimming ratio of 100:1.

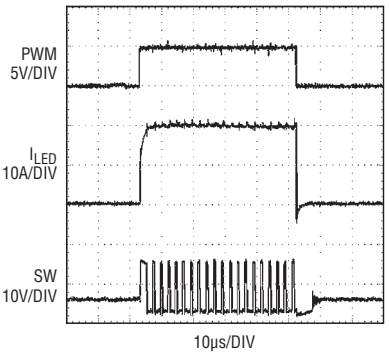

Figure 9. 0A to 20A switched cathode PWM dimming

Conclusion

The LT3743 produces ultrafast high current LED rise times while providing accurate current regulation. Its ability to support multiple current states meets the demands of high performance theater-quality DLP projectors by allowing LED colors to be easily mixed. In addition to speed, the LT3743's switched capacitor topology reduces board size by allowing the use of a compact, low value inductor. Additional features include switching cycle synchronization, overvoltage protection, high efficiency and easy adaptability for varied application needs.