High Voltage Boost/LED Controller Provides 3000:1 PWM Dimming Ratio

by Eugene Cheung

Performance, Accuracy, Versatility: LEDs and Beyond

The LTC3783 is a current-mode boost controller optimized for constant-current True Color PWM™ dimming of high-powered LEDs. Proprietary techniques provide extremely fast, true PWM load switching with no transient undervoltage or overvoltage issues. High dimming ratios of 3000:1 (at 100Hz), important for such applications as video projectors and LCD backlights, can be achieved digitally, maintaining the color integrity of white and RGB LEDs. The LTC3783 also provides an analog input for an additional 100:1 dimming (300,000:1 total).

This versatile part can also be used in a boost, buck, buck-boost, SEPIC, or flyback converter, and as a constant-current, constant-voltage regulator. No R_{SENSE}™ operation uses a MOSFET's on-resistance to eliminate the current-sense resistor, increasing efficiency. Applications for the LTC3783 include high voltage LED arrays and LED backlighting, as well as voltage regulators in telecom, automotive, and industrial control systems.

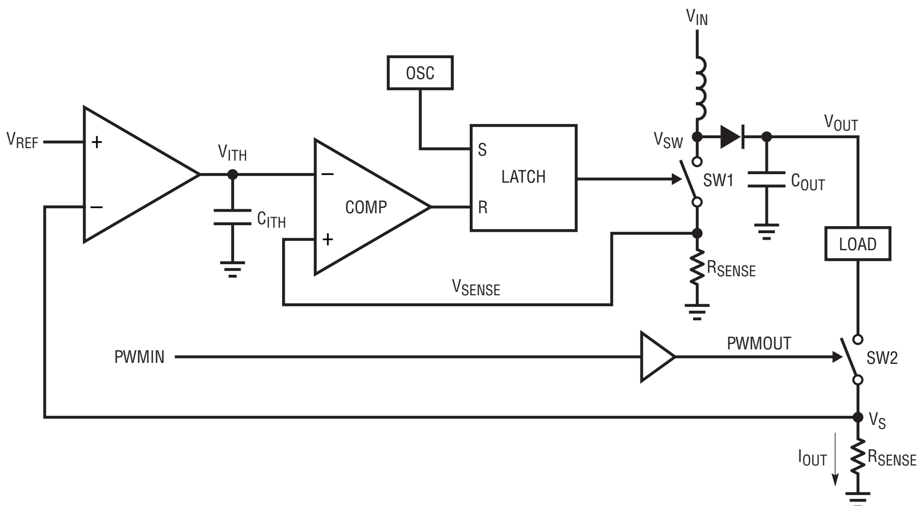

Figure 1. Simplified conventional boost converter with PWM dimming

The LTC3783 operates from input supplies ranging from 3V to 36V, and provides output overvoltage protection while regulating output current. When a sense resistor is used, the maximum output voltage is limited only by external components. The controller includes integrated drivers for power and PWM MOSFET switches, and a variable feedback voltage (0V to 1.23V) allows the designer full control over load current accuracy vs efficiency. These features make the part especially attractive for higher-power LED lighting applications. One resistor sets operating frequency from 20kHz to 1MHz, and, to reduce switching noise interference, the LTC3783 is synchronizable to an external clock. Programmable soft start limits inrush current during startup, preventing input current spikes. In addition to boost operation ($V_{OUT} > V_{IN}$), the controller offers an alternate constant-current, constant-voltage operating mode for buck-boost or buck applications. In these cases, the achievable PWM dimming ratios are generally lower.

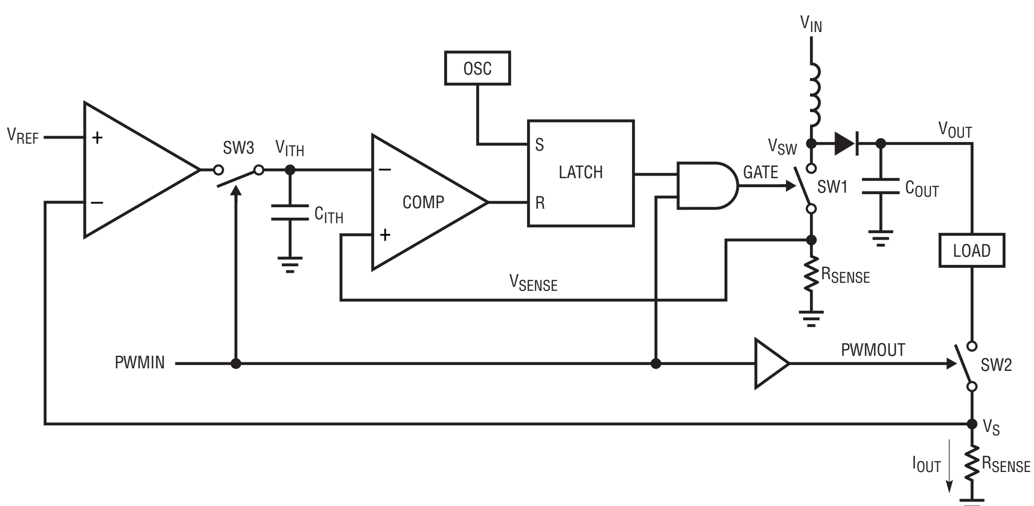

Figure 2. Simplified boost converter with True Color PWM dimming

A Novel, Simple, yet Highly Effective PWM Dimming Scheme

Why PWM, Anyway?

The brightness of an LED is a function of the current through it. Analog dimming simply reduces the DC current flowing through the LED, while digital, or PWM, dimming alters the duty cycle of an otherwise-constant LED current, thus varying the effective average current. The problem with analog dimming is that the chromacity of the LED also changes with current. PWM dimming avoids this problem because the on-current is constant, allowing the light intensity, i.e. average current, to be varied without a color shift.

Enter True Color PWM

A simplified conventional current-source boost controller is shown in Figure 1, where I_{OUT} is the regulated current source. When the output load is abruptly disconnected by PWMIN via SW2, the feedback loop cannot adjust the inductor current I_L, controlled by I_{TH} (cycle-to-cycle current threshold), instantaneously. Consequently, V_{OUT} rises due to excess current being fed into C_{OUT}, causing an output overvoltage condition while the error amp slews its I_{TH} compensation capacitor C_{ITH} down to the appropriate zero-current level. When the load is reconnected, V_{OUT} is pulled lower by the load current as the compensation capacitor is slewed up to match output current demand. Depending on the particulars of the application (compensation, load parameters, and component values) with respect to PWMIN on-time, the load current will generally overshoot or undershoot, causing a color shift with varying light intensity.

True Color PWM dimming, as implemented in the LTC3783, is depicted in simplified form in Figure 2. When PWMIN goes low, the output load is disconnected (SW2), switching is simultaneously disabled (SW1), and compensation capacitor C_{ITH} is disconnected (SW3). Disabling SW1 switching with PWMIN low prevents the V_{OUT} overvoltage condition from occurring, and disconnecting C_{ITH} preserves the appropriate steady-state I_{TH} value. When PWMIN goes high again and the load is reconnected, V_{OUT} and V_{ITH} are already at their respective full-load values, and load current is restored virtually instantaneously.

This new technique allows the load to be quickly connected and disconnected. This results in a higher effective PWM dimming ratio, since, for a given PWM frequency, the dimming ratio is constrained by the shortest pulse duration (hence, lowest duty cycle) that can be delivered.

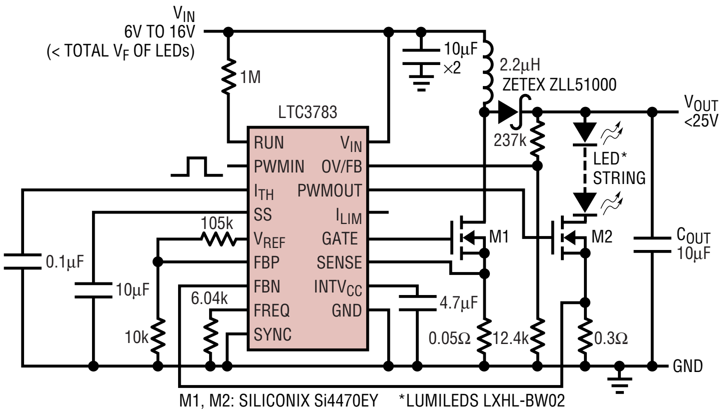

Figure 3. PWM-dimmed boost LED application

Applications

Boost PWM LED Driver

Multi-LED systems usually connect the LEDs in series to ensure that the current through each LED is the same, regardless of the varying I-V characteristics of each LED. In such systems, the cumulative LED string voltage is often higher than the system supply, thus calling for a boost converter ($V_{OUT} > V_{IN}$). Figure 3 shows such a solution with PWM dimming.

V_{FBP} across R_L sets the LED load current level. V_{FBP} is set (via R_1 and R_2) to 0.1V in the interests of higher efficiency in light of load current accuracy. Setting the load current sense resistor voltage to 0.1V allows for only 35mW power dissipation in the

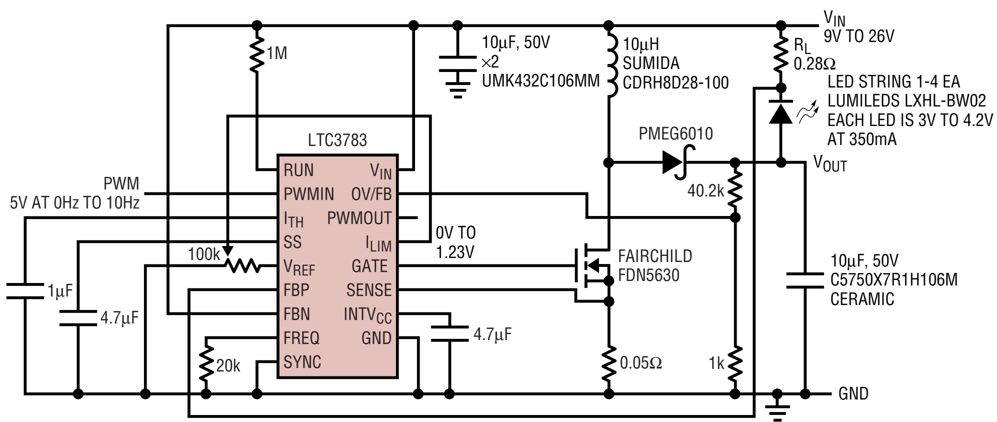

Figure 4. Buck-boost LED application

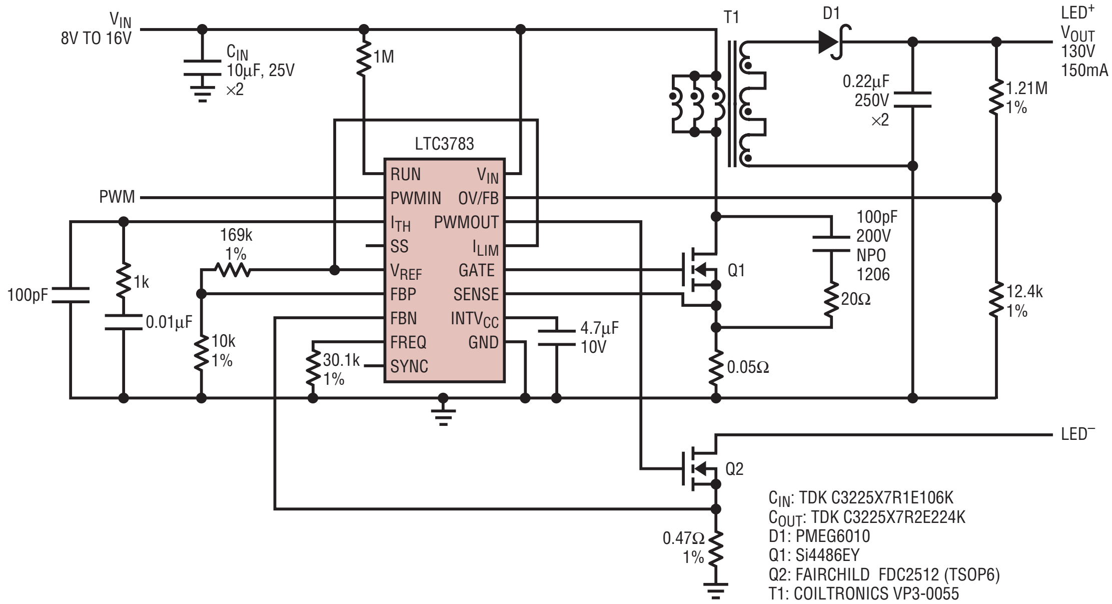

Figure 5. PWM-dimmed flyback LED application

resistor, as compared to 430mW for a 1.23V sense voltage. A worst-case V_{FB} offset of <3mV ensures better than 3% load current accuracy as well. Additional analog dimming could be accomplished by replacing R_1 and R_2 with a potentiometer or other variable voltage source.

Resistor R_T on the FREQ pin determines GATE switching frequency. The 6.04kΩ value chosen sets the system up for 1MHz switching, which permits a higher PWM dimming ratio than the standard 300kHz switching frequency allows. In case the LEDs are disconnected while the supply is running, resistors R_3 and R_4 set the maximum output overvoltage shutdown threshold, nominally at $V_{OV/FB}$ = 1.32V. Overvoltage protection is essential in current-source boost applications because with an open-load fault, capacitor and FET drain voltages can easily exceed maximum device ratings.

Because of the True Color PWM topology, and the 1MHz clock rate, this boost application circuit can achieve a PWM dimming ratio in excess of 3000:1.

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Buck-Boost PWM LED Driver

In some LED applications, the desired V_{IN} and V_{OUT} overlap, thus requiring buck-boost or SEPIC functionality. Figure 4 depicts such a system. In this setup, LED current is returned to V_{IN}, and the LEDs actually see a voltage of $V_{OUT} - V_{IN}$, allowing a nominally boost configuration to function as a buck-boost. In contrast, a SEPIC configuration would require a 2-inductor- or transformer-based solution, resulting in increased complexity and lower efficiency. However, a true SEPIC would also provide for a grounded load, which may be desirable in some applications.

In this mode, PWM dimming is available through the PWM input, albeit not at a dimming ratio comparable to the one in the boost configuration. Lack of a PWMOUT-controlled load switch means transient response cannot be as rapid, since the output voltage is then allowed to sag when PWMIN is low, necessitating some recovery period when PWMIN goes high again.

The I_{LIM} pin provides analog dimming, as the I_{LIM} range ($0.12V < V_{ILIM} < 1.23V$) controls the ($V_{FBP} - V_{FBN}$) differential proportionally from 10mV to 100mV. This allows the LED current to be linearly varied by an additional 10:1 ratio.

High Voltage (130V OVP) Flyback LED Driver

The 130V application shown in Figure 5 is similar to that of Figure 3, but because of the extremely high boost ratio, a 3:1 transformer is added in order to reduce the GATE duty cycle such that the part's maximum duty cycle is not violated.

This circuit is capable of driving a string of LEDs at 150mA, which can add up to less than 130V total forward voltage, at which point the OV/FB pin is activated to stop all switching. This prevents a potential overvoltage condition at the output.

As presented, the application circuit can provide a PWM dimming ratio of 500:1.

Other Functionality

In the 130V application above, because $V_{FBP} > 2.5V$, the LTC3783 is in constant-current, constant-voltage operation, meaning the control loop seeks to regulate the load sense resistor voltage ($V_{FBP} - V_{FBN}$) at 100mV. This is distinct from the pure voltage mode of the boost application, in which $V_{FBP} = V_{FBN}$. Also, in constant-current, constant-voltage mode the OV/FB pin becomes a linear feedback input, which regulates $V_{OV/FB}$ at 1.23V if ($V_{FBP} - V_{FBN}$) < 100mV.