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REFERENCE DESIGN 4389 INCLUDES: √Tested Circuit √Schematic √BOM √Description √Test Data

Supply-Chopped Dimming Control Boosts LED Driver Efficiency and Keeps Inrush Currents to a Minimum

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Abstract: This LED driver reference design drives a 700mA constant current to a single string of LEDs with forward voltages up to 60V. The design allows PWM dimming based on supply chopping. The input power supply is chopped on and off at 300Hz to 1kHz frequency to achieve LED brightness control. The driver uses a fixed-frequency boost converter, controlled by the MAX16834 LED driver. This unique reference design limits the input inrush current to negligible levels without compromising either the input or output filtering. Design schematics and test results are provided.

General Description

There is a major advantage to using LEDs for lighting: various dimming techniques allow seamless control of the light output from the LED source. While LEDs are efficient light sources, the dimming feature also allows for considerable power savings. Control over the light output also helps to set the desired ambience.

PWM dimming is preferred to analog dimming for several reasons. For many applications PWM dimming maintains the color of the light output regardless of the dim level. For circuit design, PWM control is more immune to noise; the control signal need not be accurate in both voltage levels and dimming frequency; and the driver circuit design is less complex. PWM dimming usually requires a control line that carries the PWM dimming signal, in addition to the two power-supply lines. This standard configuration is, however, a drawback for applications that use common dimming for a large number of lights; the configuration also makes it difficult to replace the incandescent light installations with two-wire supply lines that depend on supply chopping for dimming control.

Traditional, crude LED driver circuits that work with power-supply dimming are problematic. Those drivers turn off power to the LEDs gradually as the input filter capacitors discharge to the minimum operating voltage of the driver. That process can cause the input and output filter capacitors to discharge to low levels. Then when the supply is turned back on, a huge surge of current flows to replenish the capacitor charge, thus causing EMI issues and premature dimmer damage. To prevent these various issues, those circuits use large inductor filters that increase cost.

The LED driver reference design described here addresses this basic design challenge with PWM dimming. This LED driver implements PWM dimming based on supply chopping; it does not cause any supply current overshoot. The design provides up to 90% efficiency while operating from a 24V supply. It allows a unidirectional supply input with an efficient semi-MOSFET bridge rectifier at the input. **Figure 1** shows the top view of the design board.

Important Design Features

- ±24VDC ±5% unidirectional power-supply input
- Drives LED strings with forward voltages up to 60V
- 700mA LED current
- Input supply-chopped dimming
- UVLO at 21V
- LED open protection at 65V
- As low as 5% dimming at 330Hz dimming frequency
- Greater than 90% efficiency

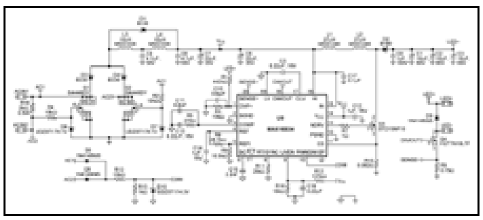
More detailed image (PDF, 2.61MB)

Figure 1. Reference design board (top view). The board size is 23mm x 138mm, in two layers, with components on the top side only.

Components List

Designator	Part	Package	Quantity
C1, C2, C3	10µF, 80V, EEEFK1K100XP	CAP_CD8X6.2	3
C4, C6	4.7µF, 50V	1210	2
C5, C13	0.22µF, 16V	0603	2
C7, C8	22µF, 35V, EEEFK1V220R	CAP_WF6.3	2
C9	1µF, 100V, X7R ceramic	1210	1
C11	6.8nF, X7R ceramic	0603	1
C12, C14	1µF, 16V, X7R ceramic	0603	2
C15	2.2nF, X7R ceramic	0603	1
C16	0.22µF, 16V, X7R ceramic	0603	1
C17	0.1µF, X7R ceramic	0603	1
D1	B130	SMA	1
D2	B180	SMB	1
D3, D4	B330	SMA	2
D5, D8, D9	1N4148WS	SOD323	3
D6, D7	UDZST179.1V	SOD323	2
D10	UDZST174.3V	SOD323	1
L1, L2	27µH, MSS1246	MSS1246	2
L3, L4	10µH, MSS1038	MSS1038	2
Q1, Q2	Si4446DY	SO-8	2
Q3	STD15NF10	DPAK	1
Q4	FQT7N10LTF	SOT223-4	1

R1	442kΩ 1%	0603	1
R2, R3, R4, R13, R14	10kΩ 1%	0603	5
R5	274Ω, 1%	0603	1
R6	26.7kΩ 1%	0603	1
R7	1Ω	0603	1
R8	10.5kΩ 1%	0603	1
R9	0.15Ω, 1%	1206	1
R10	0.062Ω, 1%	2512	1
R11	20kΩ 1%	0603	1
R12	137kΩ 1%	0603	1
R15	1kΩ 1%	0603	1
U1	MAX16834	4mm x 4mm, 20-pin TQFN-EP	1



More detailed image (PDF, 236kB)
Figure 2. Circuit schematic for the reference design features the MAX16834.

Detailed Description

This LED driver reference design uses a boost converter topology to drive a constant current to the LED load. The boost topology is suitable for this design, as the LED forward voltage is always above the input voltage. The MAX16834 provides all the necessary features to implement this boost-type LED driver with very efficient PWM dimming. Other popular topologies like buck-boost, SEPIC, or high-side buck can be implemented using the MAX16834 with equal ease.

Figure 2 shows the circuit schematic for this LED driver application. To make the power-supply input unidirectional, a bridge rectifier is used at the input. The bridge rectifier uses a 2-diode, 2-MOSFET (n-channel) configuration to reduce voltage drop and power dissipation in the input bridge. Diodes D3 and D4 are not replaced with p-channel MOSFETS, as this configuration would cause the input supply capacitors to discharge during a PWM off (supply off) condition and thus produce large inrush currents. An input filter comprising L3, C4, L4, C6, C7, and C8 limits the switching frequency components in the input current to very low values. During PWM dimming, electrolytic capacitors are used for input and output filtering to avoid any audible noise—a problematic characteristic of high-value ceramic capacitors.

This boost-type LED driver operates at a switching frequency of 250kHz in continuous-conduction mode. A peak-to-peak ripple current of 30% is selected for the inductor. Reduced inductor current ripple increases efficiency, reduces noise, and stabilizes the current control loop. But these advantages do come with reduced system bandwidth because of the reduced right-half-plane zero frequency. With a conventional LED driver, reduced bandwidth affects PWM dimming. But the MAX16834 incorporates a specific feedback topology to address this issue, and consequently provides a best-in-class PWM dimming response without compromising stability.

The boost converter output (i.e., LED+ node), with respect to the driver ground, is connected to the anode of the LED string. The LED cathode is connected to ground through the dimming MOSFET, Q4, and the LED current-sense resistor, R9. Q4 is turned on and off during PWM dimming. R9 provides the LED current information to the MAX16834; it thus regulates the LED current by controlling the boost converter.

Undervoltage Lockout (UVLO)

The LED driver is turned on when the supply voltage (VIN node) is above 21V. This ensures that the converter, which is optimized for this minimum supply input, does not start before the input voltage settles. The filter capacitor, C16, filters any noise spikes that can cause the UVLO to activate by mistake.

Slope Compensation

As the boost converter used in this driver operates in CCM with more than 50% duty cycle, the internal inductor current-control loop can become unstable and cause subharmonic oscillations unless slope compensation is implemented. A single capacitor, C15, from the SC pin to ground adds the necessary slope to the current-sense waveforms for slope compensation. Refer to the MAX16834 data sheet for more details on the design of slope compensation capacitor.

Feedback Compensation

The boost-converter, power-circuit transfer function has a right-half-plane zero due to the boost topology; the CCM operation; and an output pole caused by the output filter capacitors, LED dynamic impedance, and the LED current-sense resistor. The feedback compensation network, consisting of R5, C13, and C7 from the COMP pin to ground, introduces a pole at the origin, a zero at the output pole frequency, and a high-frequency pole.

The compensation zero cancels the output pole and maintains the slope of the system's gain-frequency response to -20dB/decade. The total loop gain of the system should cross 0dB gain at a -20dB/decade slope below one-fifth of the right-half-plane zero frequency to stabilize the system and to have sufficient phase margin. The compensation resistor sets the error-amplifier gain above the compensating zero frequency so that the above condition for stability is satisfied. Compensation capacitor C11 introduces a pole at half the switching frequency to provide attenuation to high-frequency components and noise. Refer to the MAX16834 data sheet for more details on the design of feedback compensation.

Supply-Chopped PWM Dimming

Supply-chopped PWM dimming is used in this design: to reduce another input line for a dim signal and to enable existing dimming solutions that use power-supply chopping. Popular DC dimmer circuits implement dimming by employing an n-channel MOSFET at the return path of the power-supply input to the LED driver that alternately turns on and off with the dimming control. This design breaks the current flow to the LED driver alternately, and makes the ground input float.

To obtain a negligible inrush current when the dimmer turns back on, the filter capacitors in the LED driver should maintain their charge throughout the PWM off period. Now with very little charge replenishing, the capacitor voltages should return to their normal level with out causing any inrush current. This LED driver quickly detects when a power supply turns off during PWM dimming, and then it turns off the LED current. With PWM off, resistors R13 and R15 discharge any capacitance at the input and the DIM pin is made low. This approach works the same regardless of the direction of the input power supply. A low at the DIM pin instantly turns off the LED current by turning off the dimming MOSFET Q4.

When the DIM input is disabled, the MAX16834 consumes very little power as the boost converter is also turned off; it need not wait for the feedback to respond. Meanwhile, a switch at the output of the error amplifier holds the last point of stable feedback as charge, stored in compensation capacitors C13 and C11. The next time that the power-supply input is turned on, the error-amplifier output immediately jumps to the previous stable state, thereby causing the LED current to reach the set value almost instantly.

Overvoltage Protection (OVP)

In the event of an open-LED condition, the output voltage of the boost converter can reach unsafe levels unless it is protected. The MAX16834 incorporates OVP: the boost converter is turned off, if the voltage at the OVP pin increases beyond 1.435V. The boost converter is restarted once the voltage at the OVP pin falls below the lower threshold. This restart feature enables LED current as soon as the LED is reconnected. A filter capacitor, C10, ensures that the OVP is not triggered by noise.

Test Results

Figures 3 through **8** show the test results for this reference design.

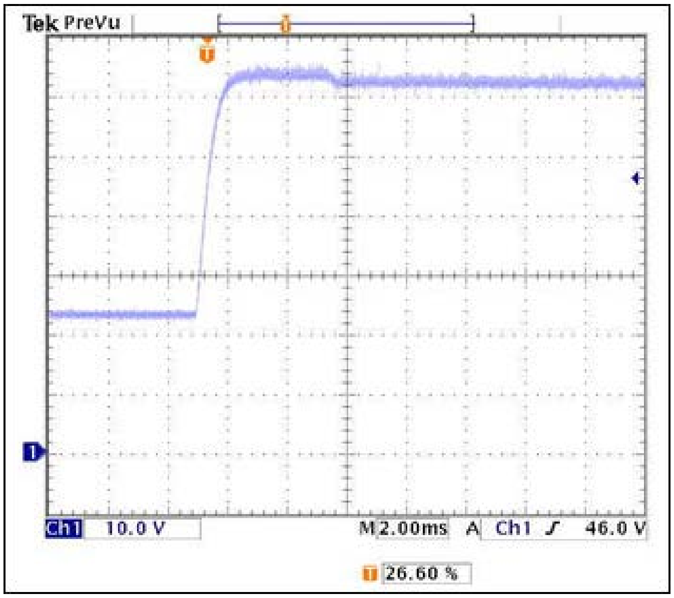


Figure 3. LED voltage at startup with respect to ground.

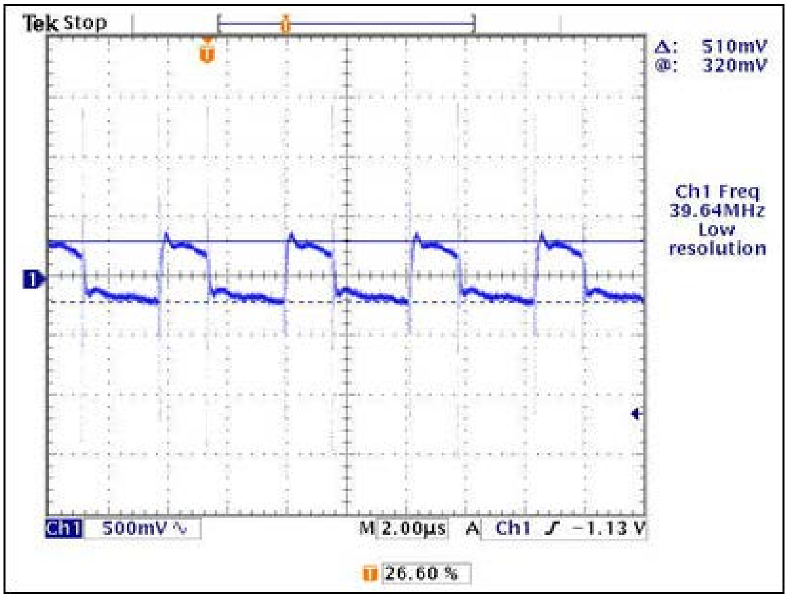


Figure 4. LED voltage ripple (voltage at LED+).

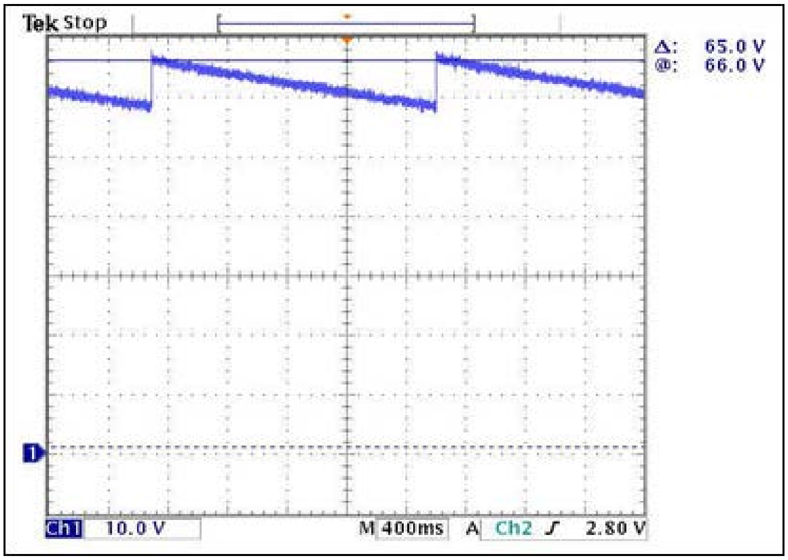


Figure 5. Open LED OVP (voltage at LED+).

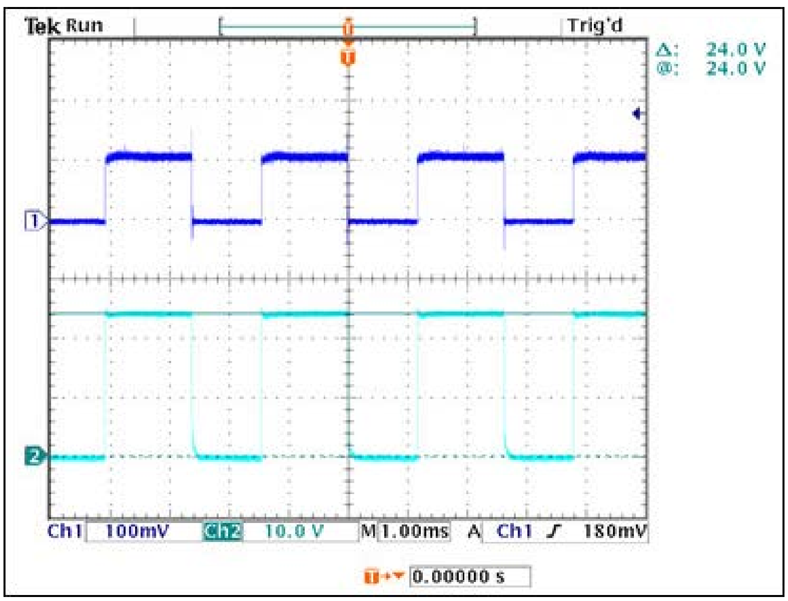


Figure 6. LED current measured across resistor R9 (150mΩ) and chopped input-supply voltage.

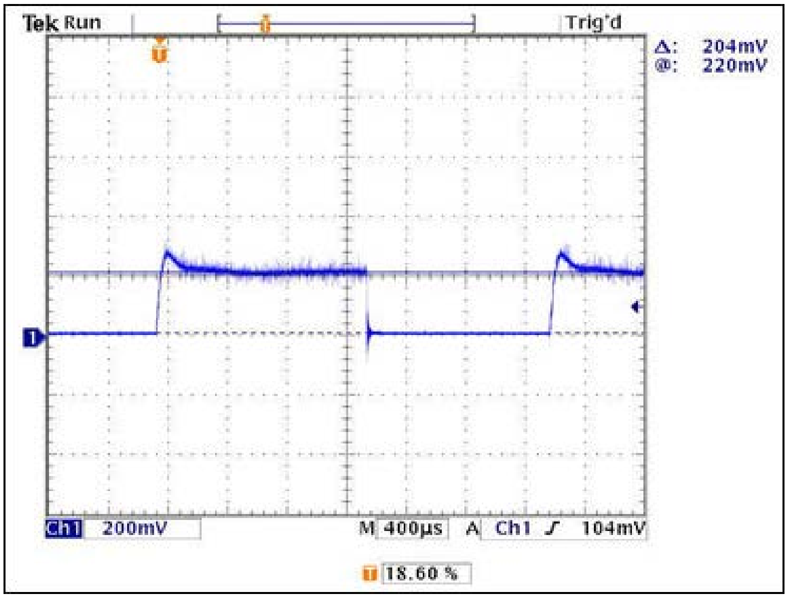


Figure 7. Input-supply current: measured across a 0.1#937; resistor.

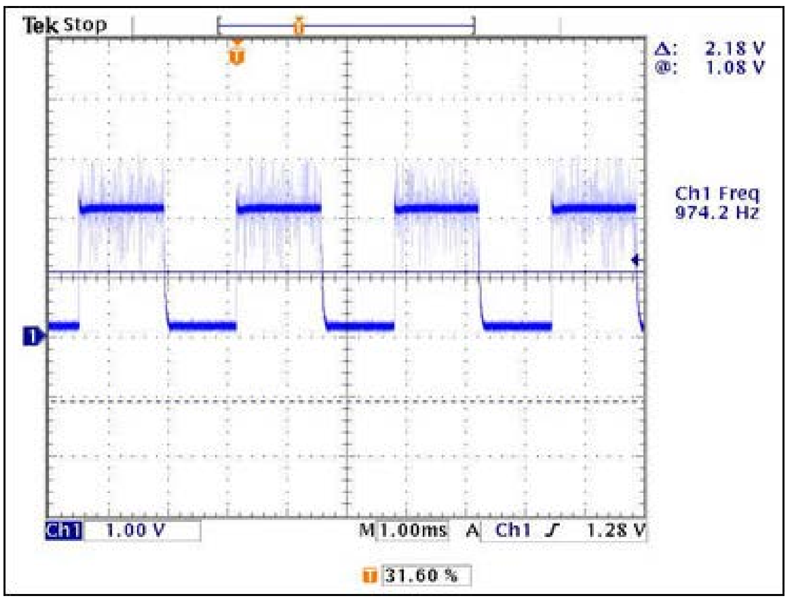


Figure 8. Voltage at the PWMDIM pin.

Power-Up Procedure

Use the following steps to power-up the board for the reference design.

1. Connect an LED string, with a forward voltage between 50V and 60V and a current rating between 700mA and 1A, to the LED+ and LED- terminals on the board.
2. Connect a power supply with a rating of 0 to 30V and 3A minimum to ACIN1 and ACIN2 in any direction.
3. Increase the supply voltage gradually to 22V. At about 21V the converter will start and the LED string will be driven with a 700mA current.
4. To start PWM dimming, chop the supply at 100Hz to 1kHz frequency with the desired duty cycle.

Related Parts		
MAX16834	High-Power LED Driver with Integrated High-Side LED Current Sense and PWM Dimming MOSFET Driver	Free Samples

More Information

For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

Application Note 4389: http://www.maximintegrated.com/an4389
REFERENCE DESIGN 4389, AN4389, AN 4389, APP4389, Appnote4389, Appnote 4389