Keywords: MR16, LED, HB LED, HBLED, HBLED Driver

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APPLICATION NOTE 4086

Replace Inefficient MR16 Halogen Lamps with LEDs

Abstract: Though commonly used for MR16-compatible lamps, halogen lamps have some drawbacks that reduce their potential, such as low efficiency and limited life. Using a driver circuit based on a specialized buck controller, a white LED with an integrated heatsink can replace a 10W halogen bulb in MR16 lamps, eliminating the concern for the halogen lamp's shortcomings.

This article was also featured in Maxim's Engineering Journal, vol. 61 (PDF, 440kB).

Halogen MR16 lamps are widely used in professional store and home decorative lighting applications, though they have several disadvantages that limit their potential. The power dissipation of the most commonly used halogen MR16 lamps ranges from 10W to 50W, and their light output ranges from 150 lumens (lm) to 800lm. That equates to an efficacy of about 15lm/W, or a luminous efficiency of 15%. The lifetime of a typical halogen bulb is limited to about 2000hrs. Additionally, the filament should not be exposed to high levels of vibration to prevent the bulb from failing prematurely.

Today's LED technologies offer an MR16-compatible, solid-state, cost-effective alternative to halogen lamps. For example, the latest generation of 5W (single-chip, 4mm x 4mm package) and 10W (four-chip, 7mm x 7mm package) high-power LEDs from LedEngin™ generate typical efficacies of 45lm/W at 1000mA with a junction temperature (T_J) of +120°C. Under actual operating conditions, these specifications equate to typical lumen output levels of 155lm (at 1000mA, T_J = +120°C) for the 5W package and 345lm (at 700mA, T_J = +120°C) for the 10W package. When these LEDs perform at the same brightness level as halogen bulbs, power dissipation can be reduced by about 50%. In addition, LedEngin predicts a remarkable lumen maintenance of 90% (at 100khr, T_J = +120°C), thus eliminating the need for bulb replacement throughout the life of the product.

MR16 LED Reference Design

For the MR16 LED reference design shown in **Figure 1**, Maxim selected the LedEngin 5W white LEDs (WLEDs) to demonstrate the 1000mA drive capabilities of the MAX16820. **Tables 1** and **2** detail the parts list and electrical specifications of the MR16 reference design, which has a 12VAC ±10% input voltage typical of most MR16 applications.

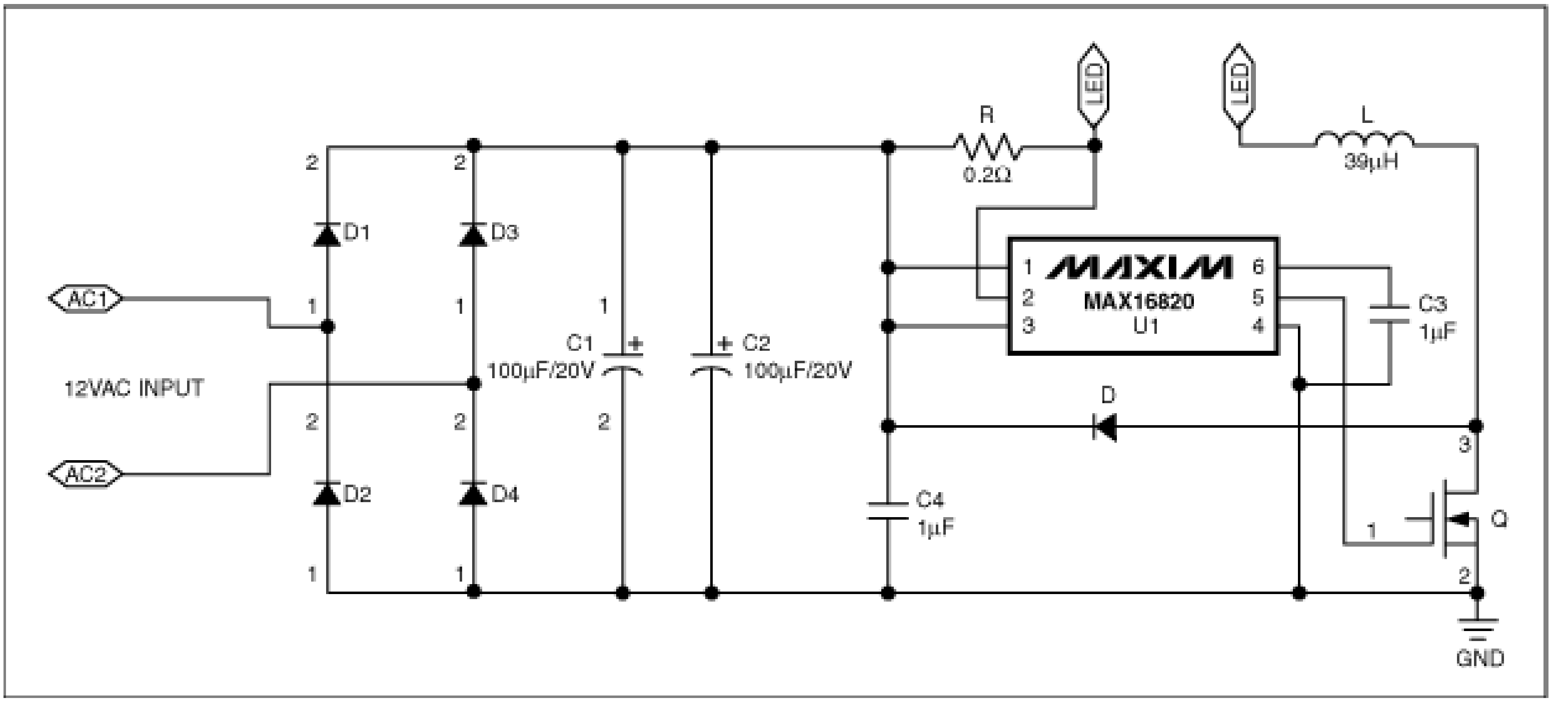

Figure 1. The 5W MR16 LED lamp circuit is shown using the MAX16820 LED driver. The LEDs shown are the LedEngin 5W WLEDs.

Table 1. Parts List for the 5W MR16 LED Lamp Driver Circuit

Designation	Description
D1–D4	Rectifier diodes 1N4001
C1, C2	100µF/20V tantalum capacitors or one 220µF/25V electrolytic capacitor
C4	1µF/25V ceramic capacitor
R	0.2Ω ±1% sense resistor IRC LRC-LR1206LF-01-R200-F
C3	1µF/6.3V ceramic capacitor
Q	MOSFET FDN359BN
D	Freewheeling diode FBR130
U1	MAX16820
L	39µH/1.2A buck inductor Sumida CDRH6D38NP-390NC

Table 2. Electrical Specifications for the 5W MR16 LED Lamp Driver Circuit

V_{IN} (min)	10.8VAC
V_{IN} (max)	13.2VAC
V_{LED} (min)	5V
V_{LED} (max)	3.1V
I_{LED}	1A
I_{LED} Tolerance	±15%
Open-LED Protection	Yes
Shorted-LED Protection	Yes

The MAX16820 has been specifically designed for LED driver applications targeting, among others, LED-based MR16s. The device was, therefore, the logical choice for the MR16 LED lamp circuit. The MAX16820 is available in a very small, 6-pin TDFN package, operates over a 4.5V to 28V input voltage range, and can drive external, cost-effective MOSFETs for a broad range of LED current-drive capabilities. It is specified over the wide, automotive operating temperature range (-40°C to +125°C), which allows the MAX16820 to be safely operated in the high- temperature environment of the MR16 light fixture. While the MAX16820 can control power levels up to 25W or even higher, its 2MHz (typ) switching frequency requires only small external inductors and capacitors, which allows the driver circuit to be placed in the MR16 fixture.

Figure 1 shows a 5W MR16 LED lamp driver composed of a rectifier bridge (D1–D4), 100µF filter capacitors (C1 and C2), and a buck converter circuit. The buck LED converter is composed of the MAX16820, buck inductor (L), power MOSFET (Q), freewheeling diode (D), and sense resistor (R).

5W high-brightness LEDs (HB LEDs) require 1A of drive current. The buck LED driver is designed to output 1A DC current. The hysteretic control method is used to control this buck inductor current which, in turn, provides the LED with its 1A current requirement. The hysteretic control implemented in MAX16820 results in a simple and very robust driver, delivering 5% LED current accuracy.

To make a 5W HB LED run at a constant 1A current for the entire line-frequency period, DC bus filter capacitors are added to limit the DC bus voltage ripple. The total capacitance should be at least 200µF provided by tantalum or electrolytic DC capacitors with a 220µF/25V rating for low cost.

To keep the accuracy of the output current high enough, the inductor current's maximum $\Delta I/\Delta T$ should be limited to less than 0.4A/µs. As shown in Figure 1, the maximum voltage drop on the inductor is V_{LMAX}. The following equations can be used to calculate the value of the inductor L:

$$V_{LMAX} - V_{AC\_IN} \times (1 + \delta) \times \sqrt{2} - V_O \qquad \text{Eq. 1}$$

$$L = \frac{V_{LMAX}}{\Delta I/\Delta T} \qquad \text{Eq. 2}$$

For V_{AC_IN} = 12V, δ = 10%, and V_O = 3.6V, L must be greater than 37µH. Therefore, 39µH is the standard value chosen for L, where δ is the allowed AC-input-variation percentage and V_O is LED forward voltage.

The design was tested using a LedEngin 5W WLED-based MR16 light fixture; **Figure 2** shows the setup. The bench-test waveforms for this design are shown in Figures 3 through 6. The input voltage is 12VAC (nom), and the output current ripple is approximately 10%.

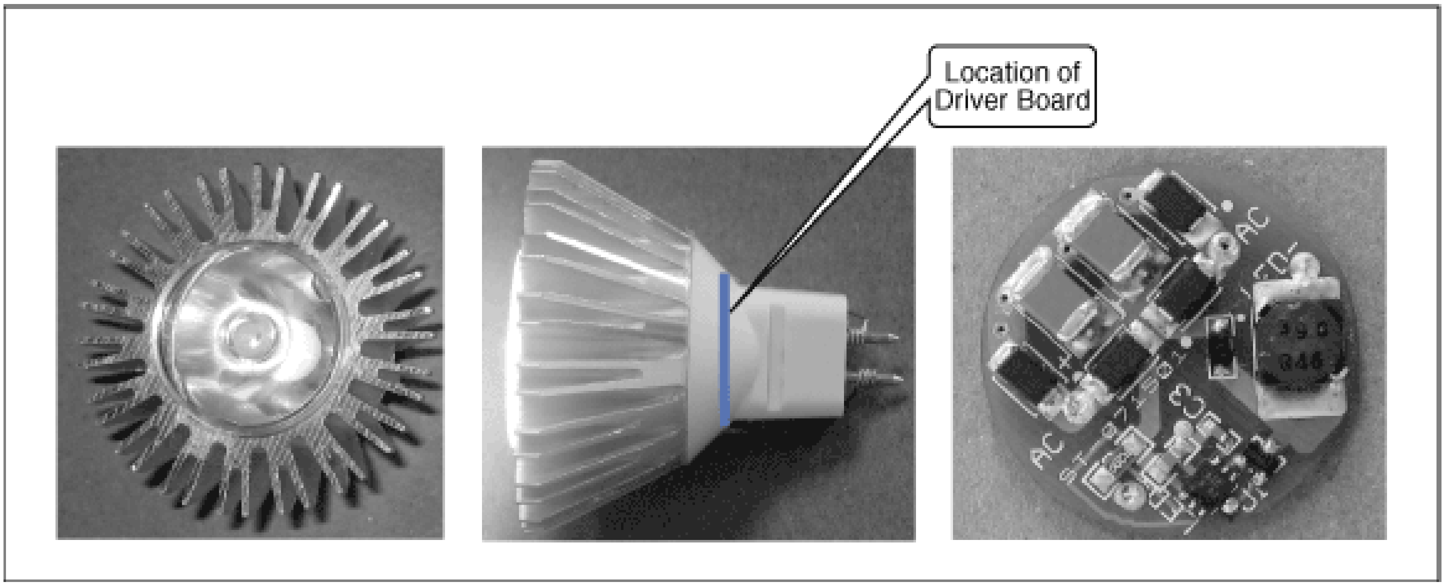

Figure 2. The LedEngin LED-based MR16 lamp has a very unique heatsink for dissipation of heat into the air. The MAX16820-based lamp driver board is placed just behind the heatsink.

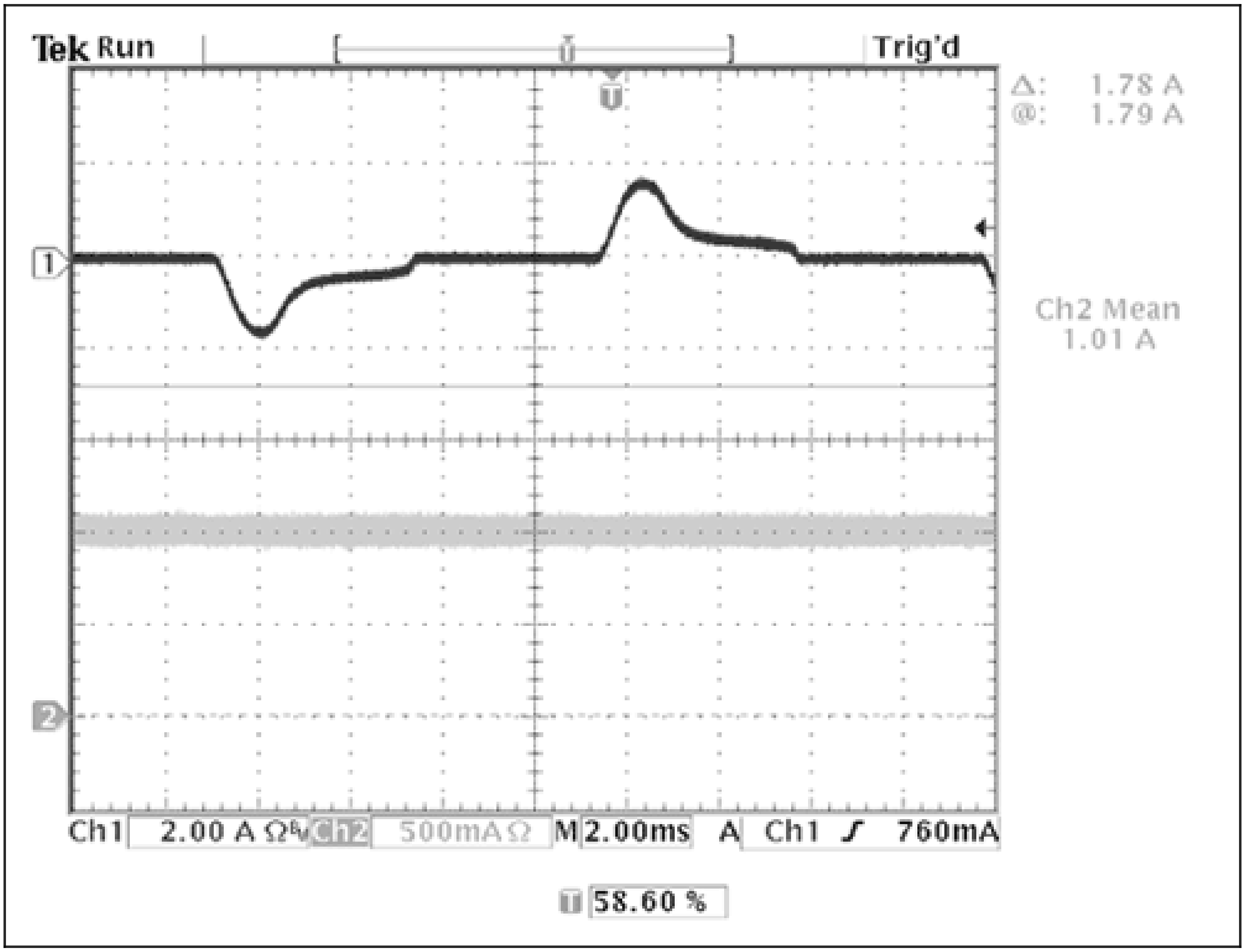

Figure 3. The first MR16 reference design bench test has the input AC current as CH1, and the output DC current as CH2.

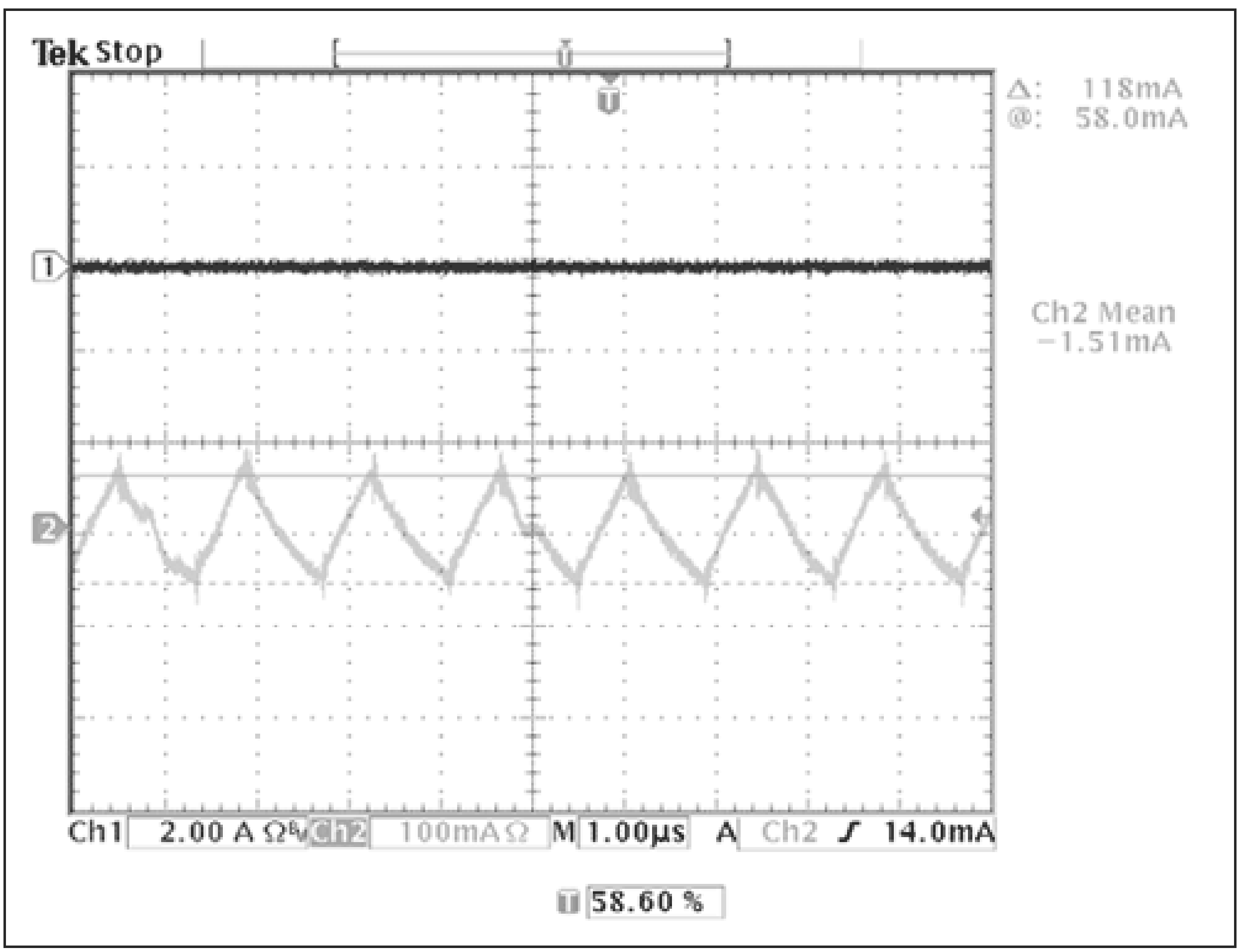

Figure 4. This detailed waveform has the output current ripple as CH2.

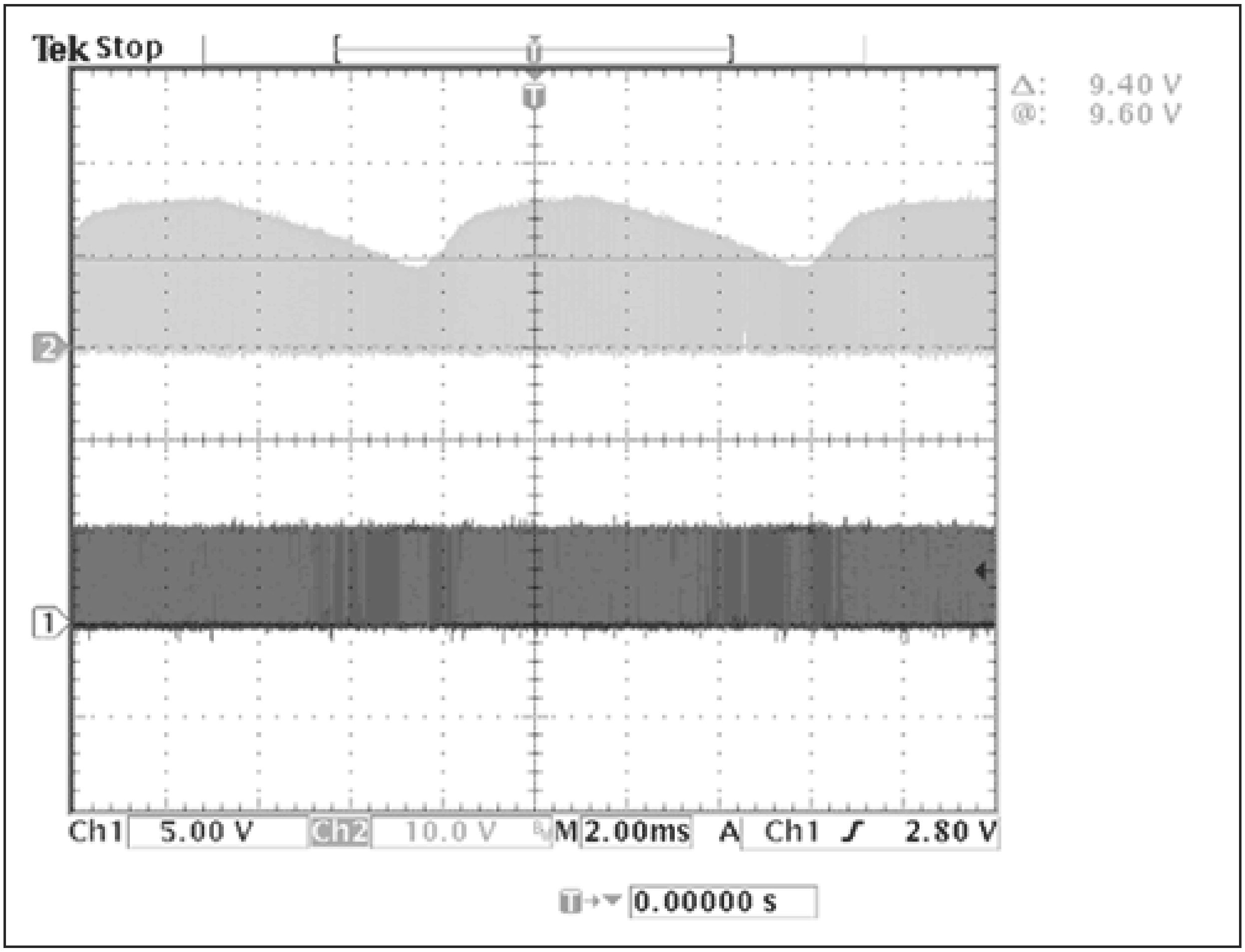

Figure 5. In this bench test, CH1 is the MOSFET gate-driver voltage envelope, and CH2 is the drain-source voltage envelope.

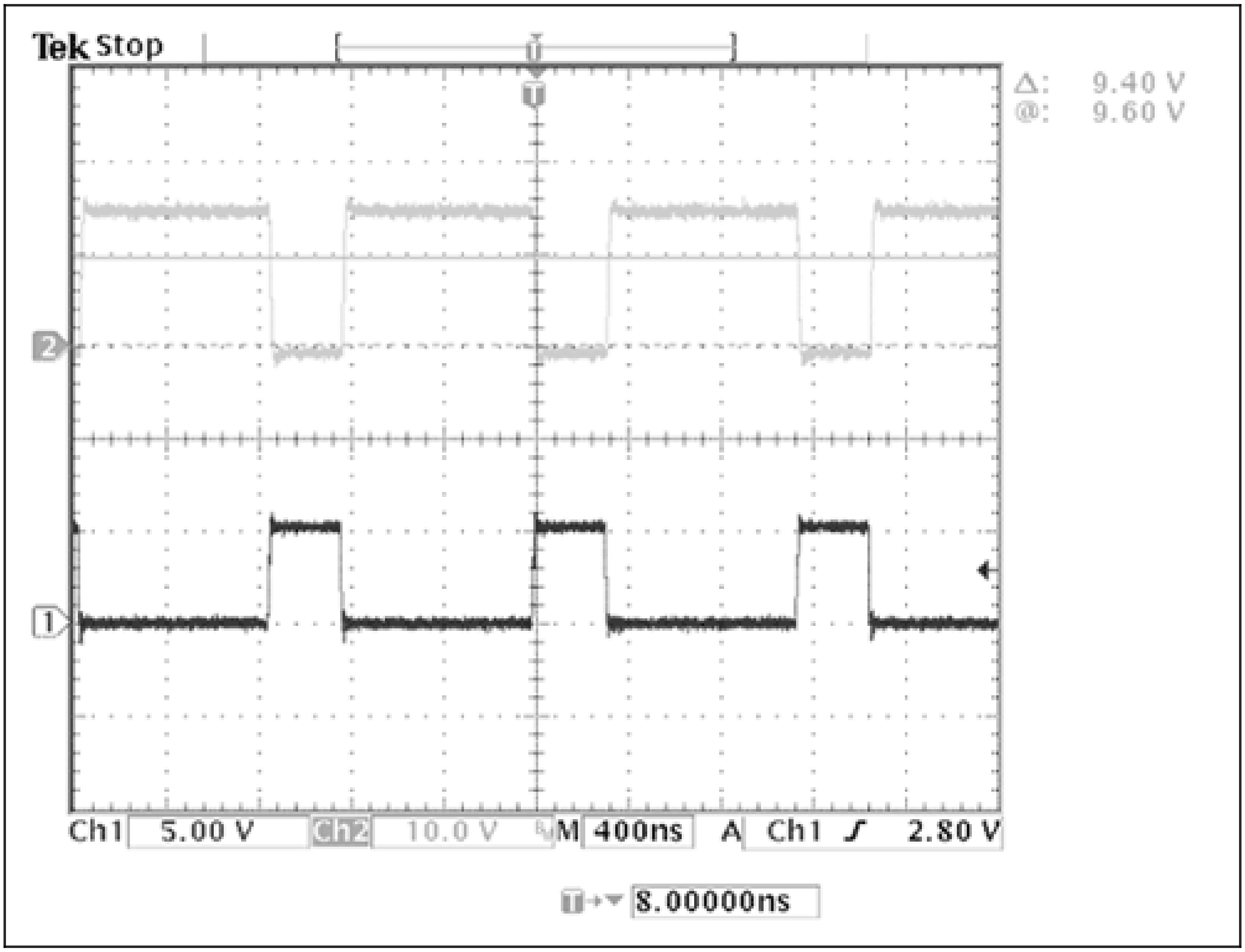

Figure 6. These detailed waveforms show the MOSFET gate driver as CH1, and the drain-source voltage as CH2.

Figure 4 shows that, with a 200µF DC filter capacitor, the DC-bus voltage ripple is 8.5V. The MAX16820-based hysteretic mode control is shown to have very good line-regulation performance. The output LED current has minimal variation as a result of the input-bus voltage. For the 5W MR16 LED lamp driver, the bench tests show that the AC-input ripple and variation can be more than 8.5V, while the output LED current is regulated to a constant 1A current.

The MR16 lamp driver PCB shown in **Figure 7** consists of two layers. All components are on the top layer, including the two AC-input connection pads and the two DC-output connection pads (labeled LED+ and LED-). The bottom layer exists solely for ground connection.

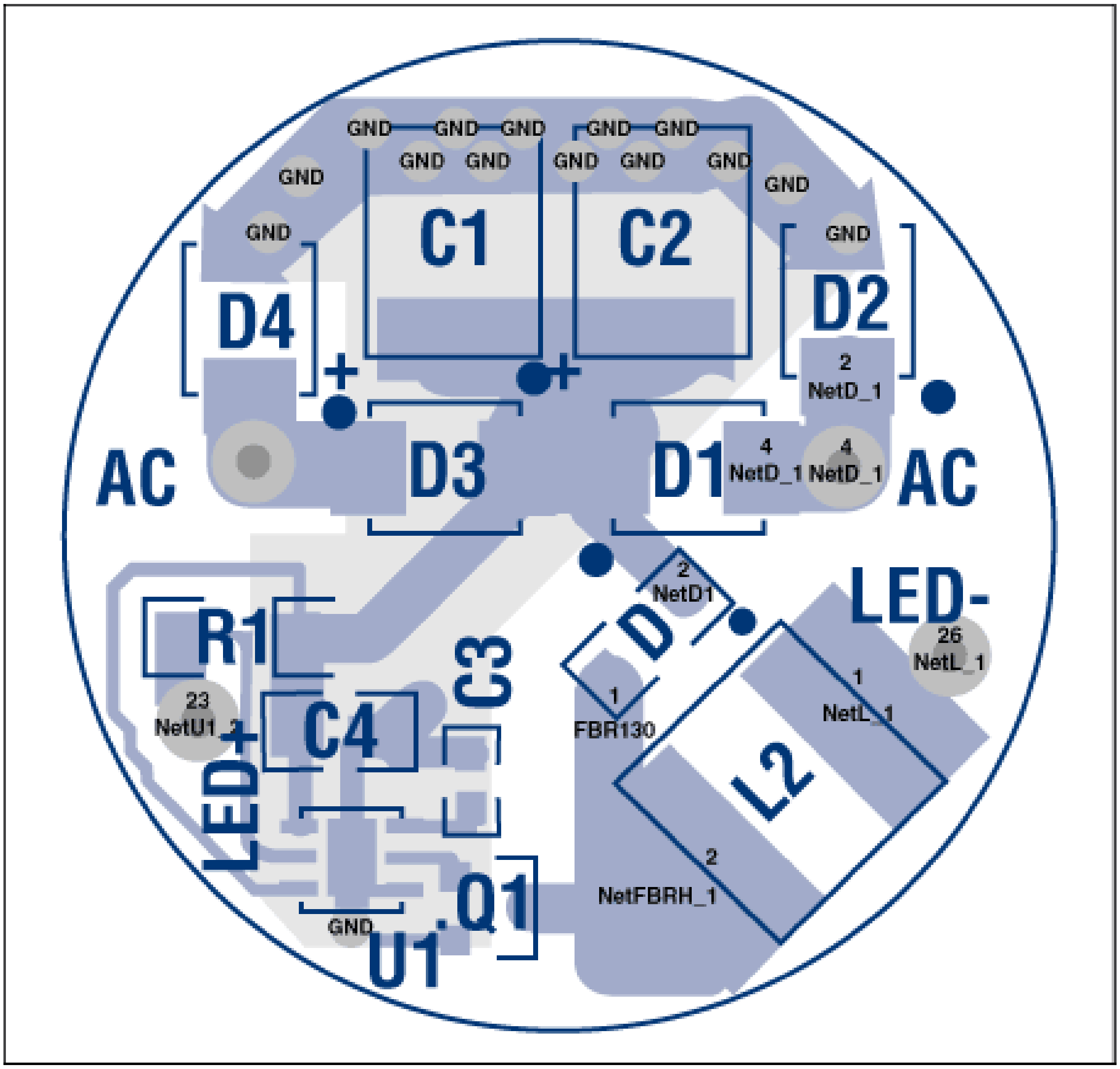

Figure 7. The LED+ and LED- DC-output connection pads can be seen on the 5W MR16 LED lamp driver PCB silk screen (top layer).

In HB LED applications, it is best to limit the junction temperature of the 5W LedEngin LED to less than +120°C when long-term lumen-maintenance performance of 90% after 100khr is required. Heatsinking is a low-cost solution to transfer the heat generated in the LED junction to the air. The 5W MR16 LED lamp has a heatsink to dissipate 5W of LED power. The 5W MR16 LED lamp driver PCB is mounted on the backside of the 5W MR16 LED lamp's heatsink.

Noteworthy is the unique heatsink design of the 5W MR16 LED lamp's assembly. Unlike in halogen-based assemblies where the lamp heat is primarily radiated to the environment, in LED-based designs the heat is conducted to the heatsink (such as the one shown in Figure 2) and then transferred to the surrounding air through convection.

Conclusion

When compared to other, lower power (1W and 3W) LED solutions, the high-power, 5W MR16 LED reference design significantly increases the amount of usable light. Therefore, this design eliminates the need for multiple emitter solutions required to meet the MR16 performance levels of a 10W halogen solution.

Application Note 4086: http://www.maxim-ic.com/an4086

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