

APPLICATION NOTE 4086

Replace Inefficient MR16 Halogen Lamps with LEDs

Abstract: Replacing halogen lamps with LEDs in MR16 light fixtures can save substantial energy while reducing electricity and maintenance costs. This application note details the advantages of using LEDs in MR16 fixtures, and it presents an LED driver circuit that enables a 5W white LED with integrated heatsink to replace a 10W halogen bulb in MR16 lamps.

A similar version of this article was featured in [Maxim's Engineering Journal](#), vol. 61 (PDF, 440kB).

LED Lighting Offers Substantial Energy Savings

Today, lighting accounts for nearly one-fifth of electricity consumption in the U.S.,¹ with the vast majority of applications still using low-efficiency (< 5%) incandescent light bulbs. Thus, the deployment of energy-efficient lighting technologies promises to save substantial energy, reduce carbon dioxide emissions, and decrease the need for new power plants.

For example, the U.S. Department of Energy estimates that the conversion to LEDs in recessed downlights alone would save 81.2 trillion watt-hours (TWh) of electricity per year, which represents the annual electricity consumption of 6.7 million households. Altogether, the energy savings in this single application would avoid the need to build nearly 13 1000MW coal power plants.²

Halogen MR16 lamps are frequently used as a more-efficient alternative to incandescent bulbs in retail and residential lighting applications. The power consumption of the most commonly used MR16 lamps ranges from 10W to 50W, and their light output ranges from 150 lumens (lm) to 800lm. Typical halogen MR16 lamps, thus, provide an efficacy of about 15 lumens per watt (lm/W), or a luminous efficiency of 15%. Though an improvement over inefficient incandescent bulbs, halogen MR16 lamps leave much to be desired.

Today's LED technologies offer a cost-effective, MR16-compatible, solid-state alternative to halogen lamps. For example, the latest generation of 5W (single-chip, 4mm × 4mm package) and 10W (four-chip, 7mm × 7mm package) high-power LEDs from LedEngin™ have 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, $T_J = +120^\circ\text{C}$) for the 5W package and 345lm (at 700mA, $T_J = +120^\circ\text{C}$) for the 10W package. These LEDs consume 50% less power than halogen bulbs at the same brightness level.

Additionally, whereas the lifetime of a typical halogen bulb is limited to 2000hrs, LedEngin predicts a remarkable lumen maintenance of 90% (at 100,000hrs, $T_J = +120^\circ\text{C}$) for its LEDs. The extended lifespan of LEDs effectively eliminates the need for bulb replacement throughout the life of the product, translating into lower maintenance and life-cycle costs.

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.

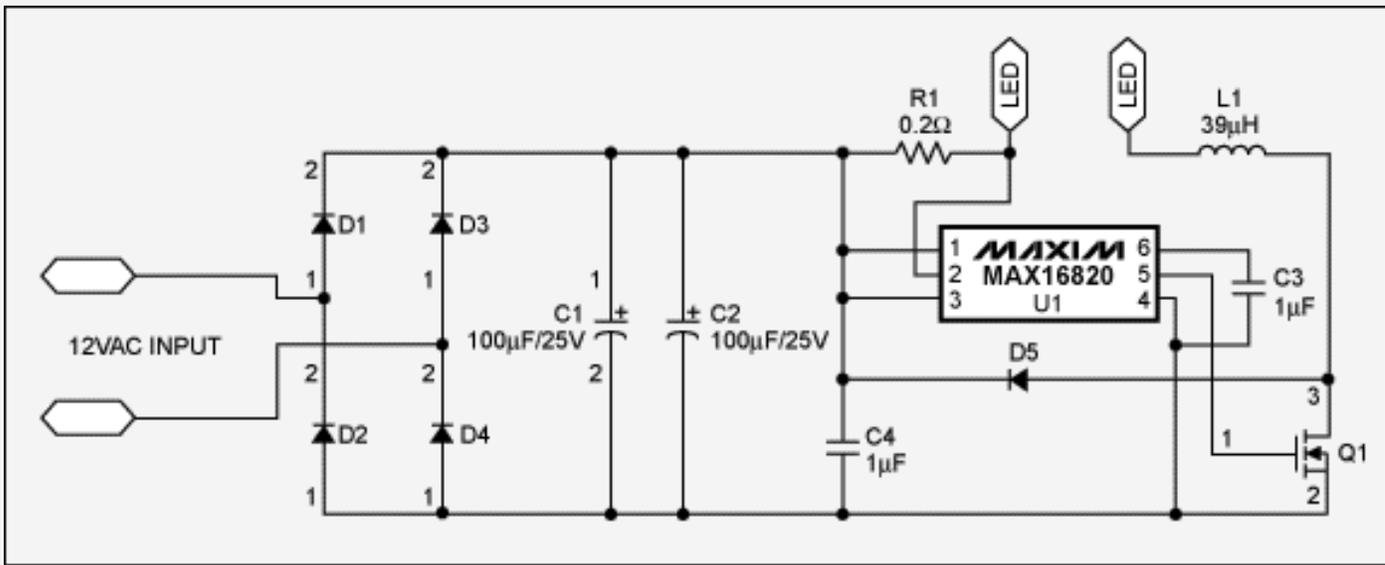


Figure 1. The 5W MR16 LED lamp circuit is shown using the MAX16820 LED driver. The LEDs shown are the LedEngin 5W WLEDs.

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

Designation	Description
D1–D4	Rectifier diodes FBR130
C1, C2	100µF/25V tantalum capacitors or one 220µF/25V electrolytic capacitor
C4	1µF/25V ceramic capacitor
R1	0.2Ω ±1% sense resistor IRC LRC-LR1206LF-01-R200-F
C3	1µF/6.3V ceramic capacitor
Q1	MOSFET FDN359BN
D5	Freewheeling diode FBR130
U1	MAX16820
L1	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, thus allowing the driver circuit to fit in the MR16 form factor.

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 (L1), power MOSFET (Q1), freewheeling diode (D5), and sense resistor (R1).

5W high-brightness LEDs (HB LEDs) require 1A of drive current. The buck LED driver is designed to output 1A DC current. A 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 the MAX16820 results in a simple and very robust driver, delivering 5% LED current accuracy.

To ensure that the 5W HB LED runs 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_{L1MAX} . The following equations can be used to calculate the value of the inductor L1:

$$V_{L1MAX} = V_{AC_IN} \times (1 + \delta) \times \sqrt{2} - V_O \quad \text{Eq. 1}$$

$$L1 = \frac{V_{L1MAX}}{\Delta I/\Delta T} \quad \text{Eq. 2}$$

For $V_{AC_IN} = 12V$, $\delta = 10\%$, and $V_O = 3.6V$, L1 must be greater than 37μH. Therefore, 39μH is the standard value chosen for L1, 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%.

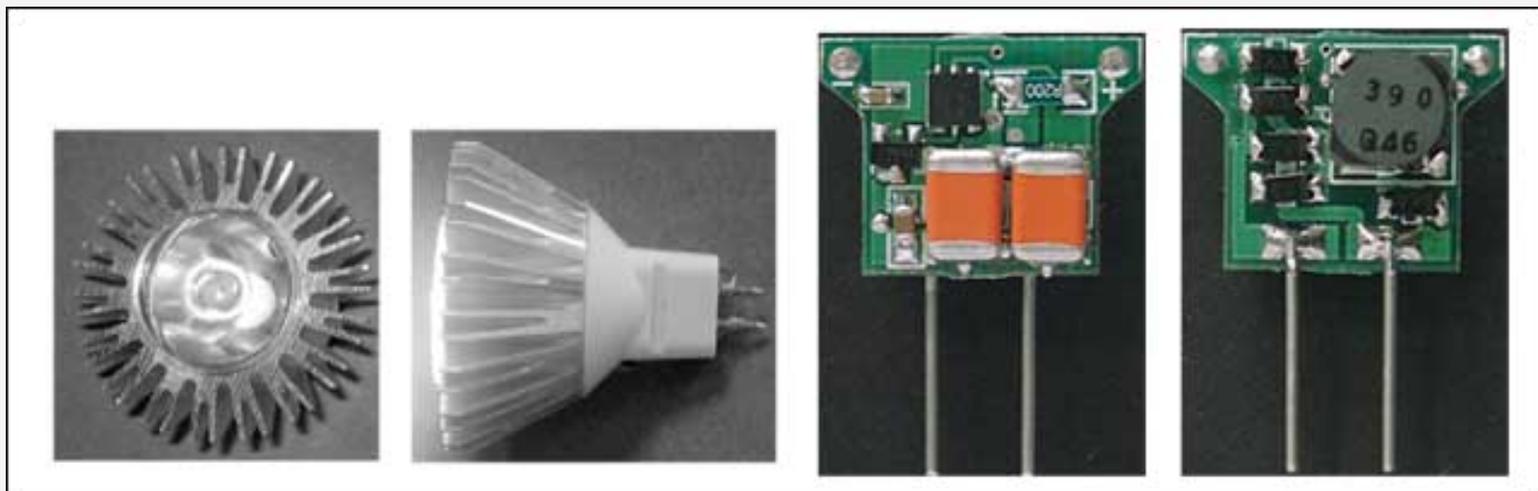


Figure 2. The LedEngin LED-based MR16 lamp has a very unique heatsink for dissipation of heat into the air. The MAX16820-based lamp driver board is placed just behind the heatsink.

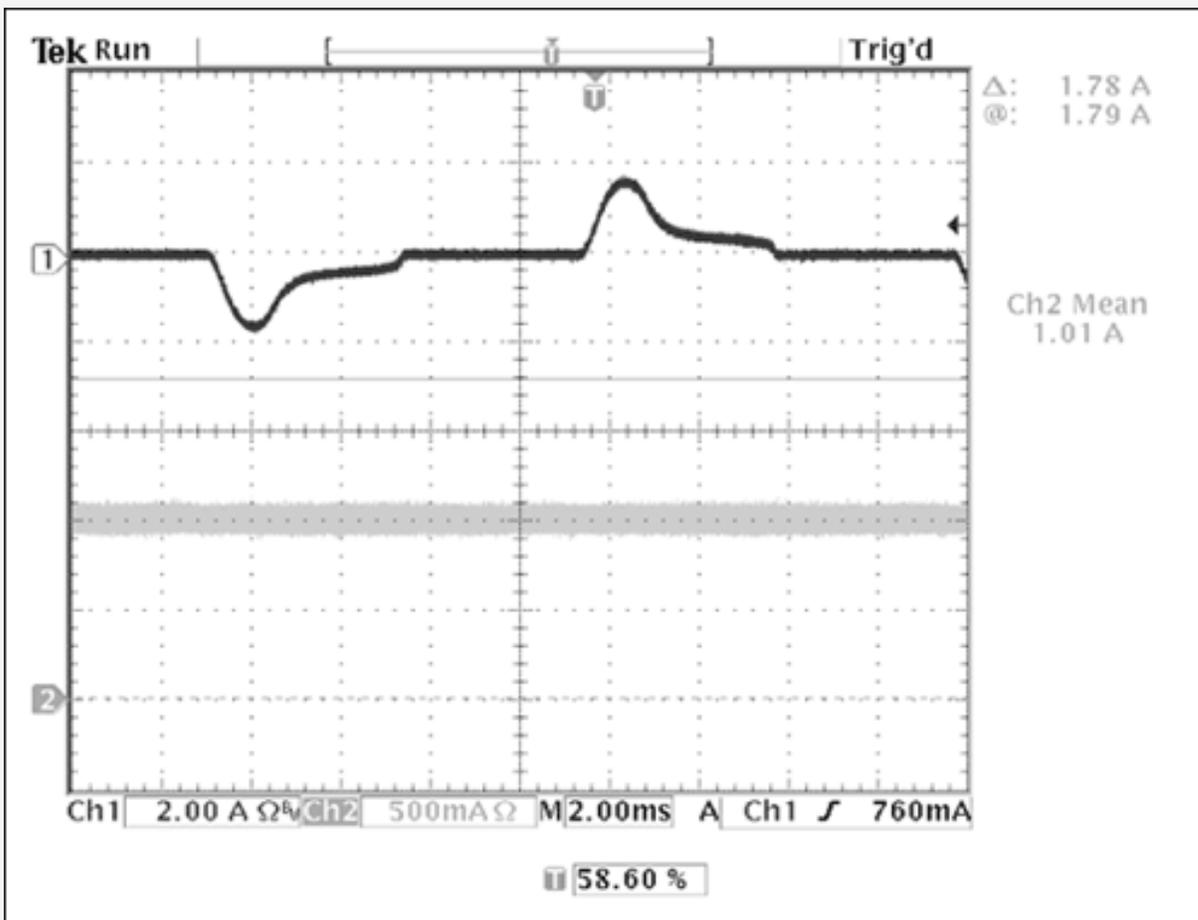


Figure 3. The first MR16 reference design bench test has the input AC current as CH1, and the output DC current as CH2.

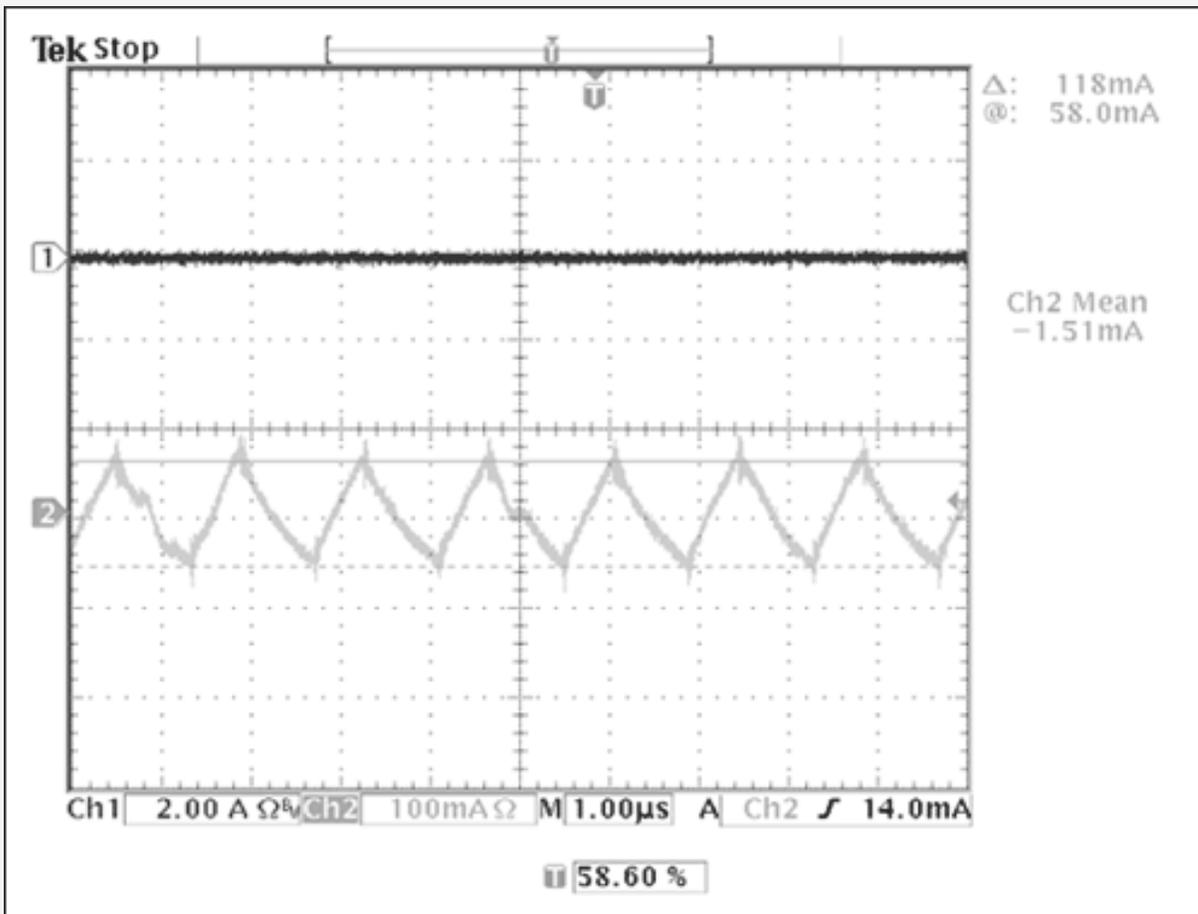


Figure 4. This detailed waveform has the output current ripple as CH2.

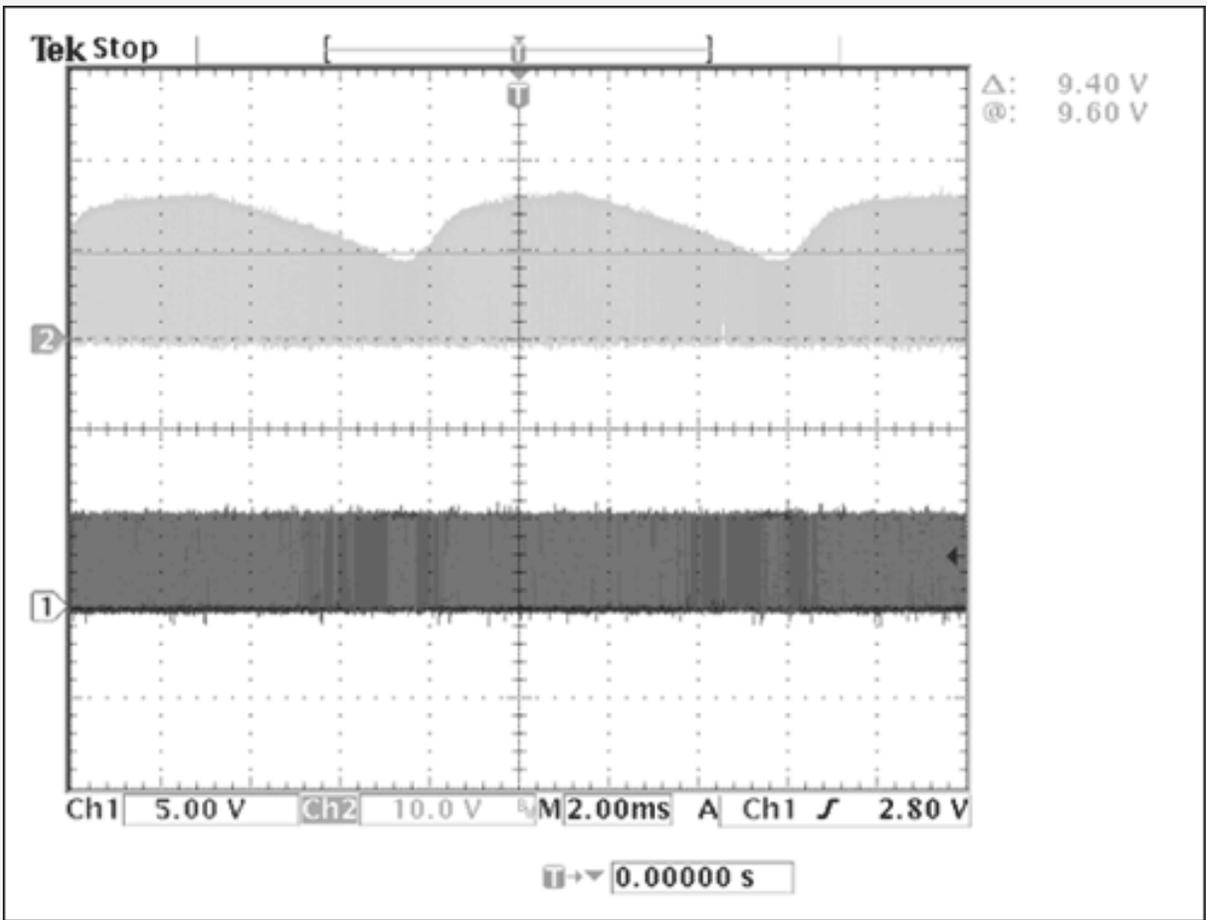


Figure 5. In this bench test, CH1 is the MOSFET gate-driver voltage envelope, and CH2 is the drain-source voltage envelope.

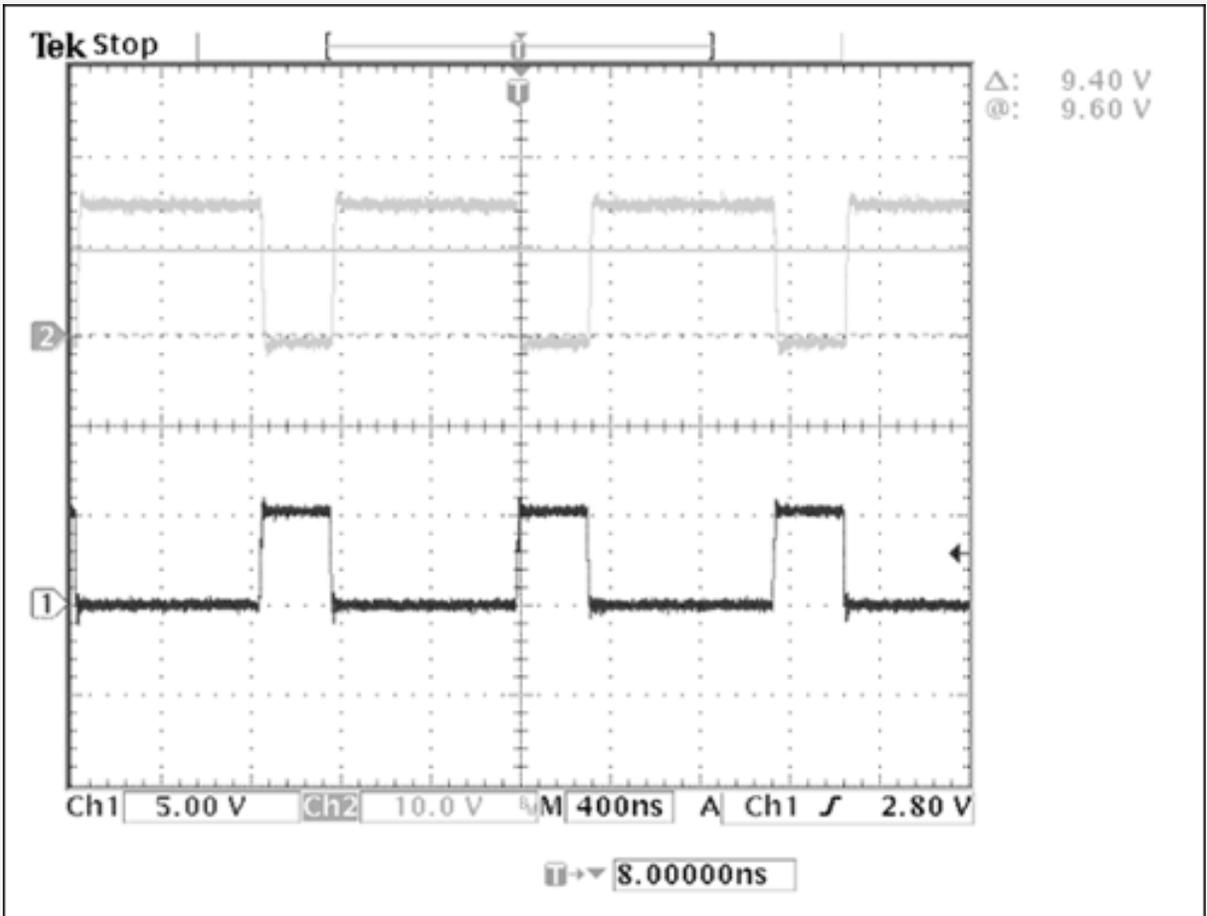


Figure 6. These detailed waveforms show the MOSFET gate driver as CH1, and the drain-source voltage as CH2.

Figure 4 shows that, with a 200 μ F 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 both the top and bottom layers, including the two AC-input connection pads and the two DC-output connection pads (labeled LED+ and LED-).

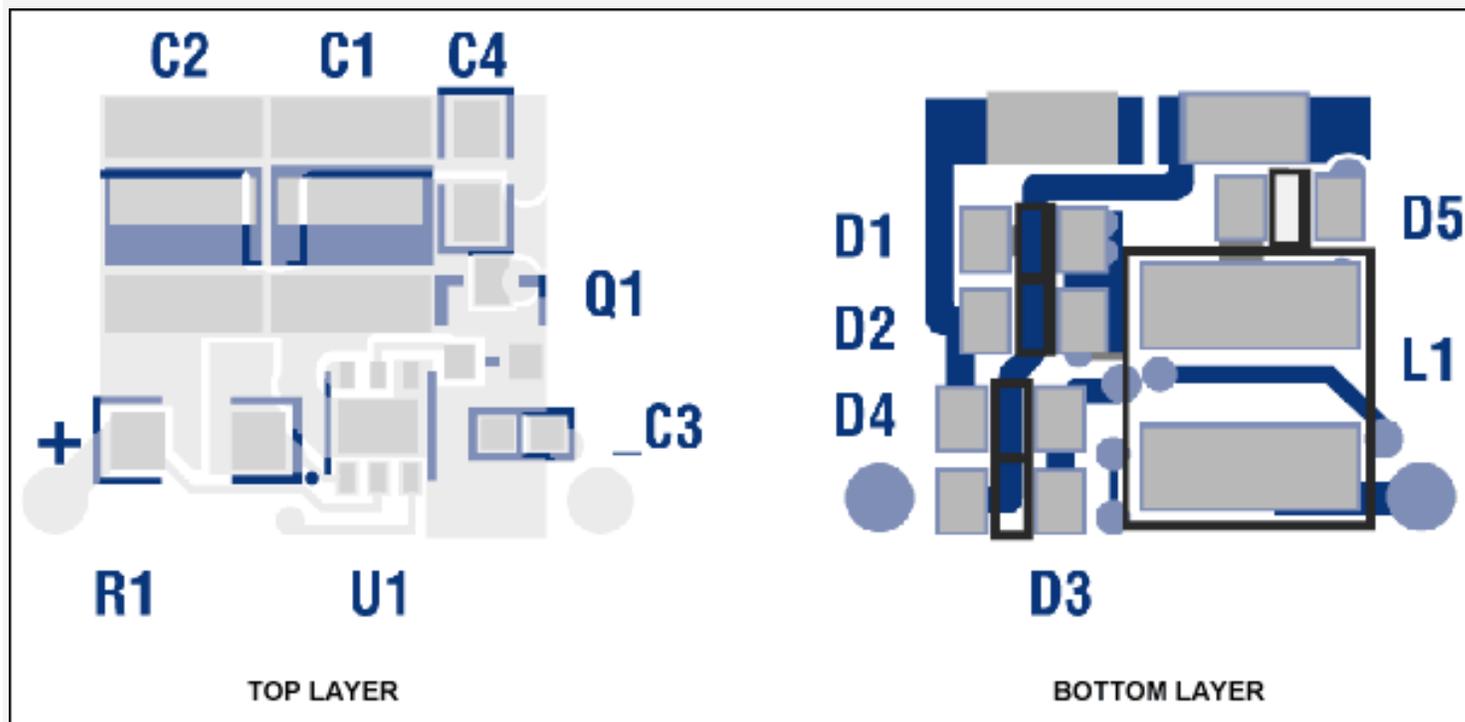


Figure 7. The LED+ and LED- DC-output connection pads can be seen on the 5W MR16 LED lamp driver PCB silk screen (top and bottom layers).

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.

Send your email request for Maxim's latest MR16 driver solution that works with standard wall dimmers and electronic transformers to: hbled@maxim-ic.com

References

- ¹Energy Information Administration, *Annual Energy Outlook 2008* (Washington DC, June 2008).
- ²U.S. Department of Energy, *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications* (Washington DC, 2008).

LedEngin is a trademark of LedEngin, Inc.

More Information

For technical support: www.maxim-ic.com/support

For samples: www.maxim-ic.com/samples

Other questions and comments: www.maxim-ic.com/contact

Automatic Updates

Would you like to be automatically notified when new application notes are published in your areas of interest? [Sign up for EE-Mail™](#).

AN4086, AN 4086, APP4086, Appnote4086, Appnote 4086

Copyright © by Maxim Integrated Products

Additional legal notices: www.maxim-ic.com/legal