Replacing Halogen Lights With LEDs

A practical guide for designing ac powered LED lamps with guaranteed good regulation and reduced heat dissipation

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Halogen lamps are widely used in home and commercial lighting applications, but with high heat, low efficiency and limited lifespan, they are primed and ready for *greening*. Halogen lights can be replaced today by high-brightness LEDs in the compact MR16 form factor, replacing halogen shortcomings with the long life time and high power efficiency benefits of LEDs. With some of the latest white LEDs delivering near 100 lumens at 350 mA, such as the Cree XR-E, one to three 1 W LEDs are sufficient for lighting purposes. The 12 V ac, class 2 wall transformers powering halogen lamps can be used together with bridge rectifiers and LED driver ICs to provide a regulated current for the LEDs, helping to simplify the design transition from halogen.

Fig. 1 shows an example of a step-down circuit driving an LED lamp, comprised of two main blocks. The *ac rectification and filtering* block on the left side converts an ac supply into a near dc voltage rail, with some residual ripple. The *LED driver* block generates the constant current to drive LEDs at the desired brightness. The performance of the LED driver is measured by the accuracy of the current regulation as well as its efficiency [(Pout ÷ Pin) x 100%] across the operating conditions.

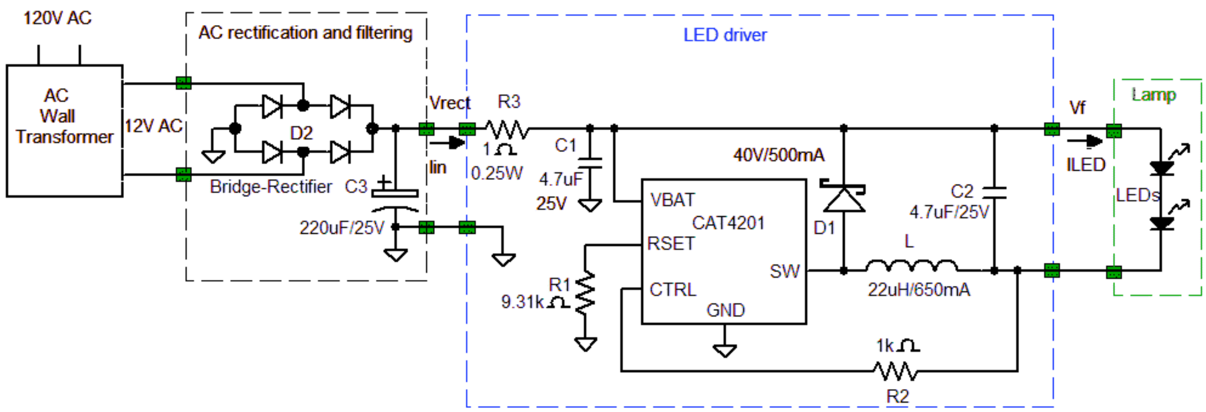

Fig. 1: Lamp Block Diagram

Converting Ac

The virtues of the *ac rectification and filtering* element are its conversion efficiency and ripple reduction under maximum load condition. The loss in the bridge-rectifier comes from the forward voltage of each diode. Assuming 0.8 V per diode, the total voltage drop is 1.6 V. Either four discrete diodes or an integrated bridge rectifier such as a Fairchild MB1S (in SOIC-4) can be used. To further reduce the loss, Schottky diodes can be used instead. The ripple voltage amplitude is inversely proportional to the C3 capacitor size. Increasing the value of the capacitor unfortunately increases its cost and its physical size. The peak-to-peak ripple voltage is also proportional to the load current. The voltage rating of capacitor C3 should be greater than the peak ac voltage. For example, 12 V ac (rms) has a peak voltage equal to $\sqrt{2} \times 12\text{ V} \approx 1.4 \times 12\text{ V} \approx 17\text{ V}$, and capacitors with a voltage rating of 20 V or 25 V are appropriate. Electrolytic capacitors of about 220 µF are fine for driving LEDs at 350 mA.

The voltage ripple on Vrect can be calculated as follows:

$$\Delta V[V] \cong \frac{I_{IN}[mA] * T_{DISCHARGE}[ms]}{C3[\mu F]}$$

where, ΔV is the peak-to-peak ripple voltage and $T_{DISCHARGE}$ is the discharge time on Vrect.

In the US, where the line frequency is 60 Hz, this translates to a 120 Hz ripple after rectification. For the test condition shown in Fig. 2, with C3 = 220 μF and I_{IN} = 160 mA, the ripple voltage is:

$$\Delta V = \frac{160mA * 6ms}{220\mu F}$$

or about 4 V.

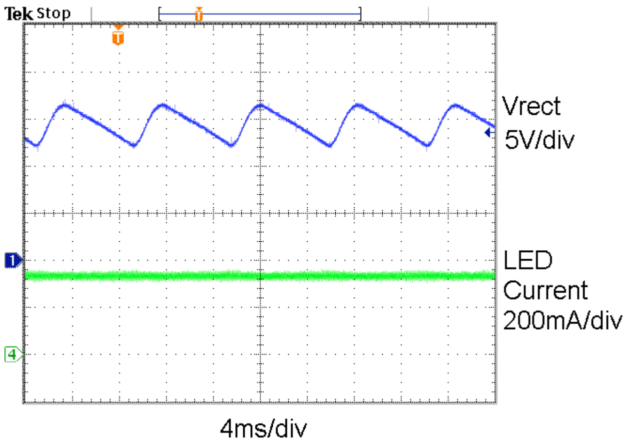

Fig. 2:
2-W LED Lamp Waveform
Good Regulation

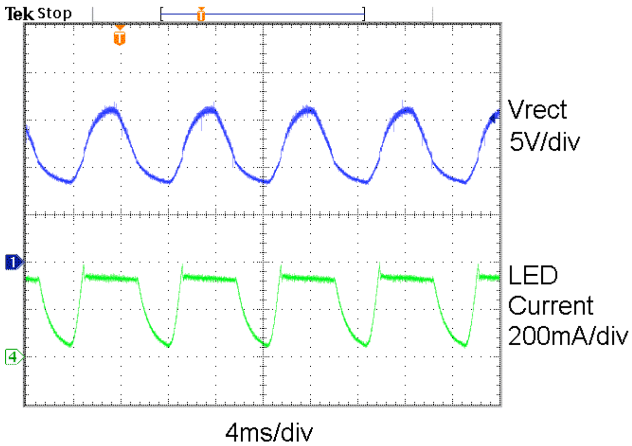

Fig. 3:
LED Lamp
Out Of Regulation

LED Driver Circuit And Performance

The LED driver, in order to maintain proper regulation, requires some headroom, or a minimum voltage difference between the input (Vrect) and the total LED forward voltage (Vf) to guarantee a constant LED current. The headroom voltage is a parameter of the LED driver IC. Fig. 2 is an example of LEDs in regulation and Fig. 3 an example of the LED driver dropping out, resulting in a flickering light.

Providing Sufficient Headroom

When the Vrect voltage drops too low, the driver might not be able to provide the correct LED current. Fig. 3 shows the performance of an LED lamp purchased on the market where the LED current is out of regulation. In this example, the LEDs are fully turned on only for 60% of the time with a pulse frequency of 120 Hz (2 x 60 Hz in the US). The LED flicker is actually not visible to the human eye because it is above the threshold of 70 Hz or so, but the light output is reduced proportionally to the duty cycle. In order to guarantee proper regulation, the driver should always be operated with sufficient headroom. For the step-down CAT4201 LED driver in Fig. 1, a 3 V headroom is required to guarantee full current regulation.

Managing Heat Dissipation

Two types of LED drivers can be used in halogen lighting applications: linear constant current drivers and step-down switching regulators. The linear constant current LED drivers result in large amounts of heat being dissipated in the driver and a great deal of wasted power. The switching step-down regulator is the best approach due to its high efficiency, resulting in minimum heat dissipated in the driver IC.

The overall efficiency of the lamp circuitry is equal to the efficiency of rectification times the efficiency of the LED driver. A typical value could be 90% x 85%, which equals 77%. As noted before, a way to reduce the loss in the bridge is to use Schottky diodes with lower Vf (0.3 V), but this increases the cost.

The power dissipated by an LED is equal to the LED forward voltage times the forward current. The LED heat is transferred via the PCB into the entire light fixture. Because of the heat generated by the LED(s), all components may operate under high temperature even at 25ºC room temperature. Special care should be taken to select the external components. Specifically, the electrolytic capacitor C3 temperature should remain within its specified operating range. For example, the aluminum electrolytic capacitor from Nichicon UHE1E221 220 μF is rated up to 105ºC.

Managing Dimming

The LED brightness can be controlled via two methods. One option is to apply a PWM (pulse-width modulation) digital signal onto the control pin of the driver (eg Fig. 1, CAT4201 CTRL pin). The other option is to have an additional resistor R2 with a FET in parallel with the R1. When the FET is off, the LED dims down (RSET = R1). When the FET is on, the LED is at full brightness (R1 in parallel with R2).

Conclusion

When designing an LED lamp, key considerations include providing sufficient headroom and managing dimming. But the primary challenge is how to dissipate the heat generated by the LEDs. By using step-down LED drivers, the driver IC temperature will remain just slightly above the inside temperature of the lamp, with almost no added heat beyond that of the LEDs, maintaining the LED performance and long life expectancy. On the other hand, the lower efficiency of linear constant-current LED drivers further increases the internal lamp temperature, adds more stress to the LEDs, and can even cause the driver to enter thermal shutdown.

LEDs incorporate an optical lens, which provides narrower beams, making them more efficient for spot lighting, compared to traditional filament lamps. As LED efficiencies improve, LED-based lighting will replace halogen lighting and emerge as the de facto *green lighting* standard of choice.

References:

[1] CAT4201 LED Driver Data Sheet, Catalyst Semiconductor 2007, http://www.catsemi.com/datasheets/4201.pdf
[2] XLamp XR-E LED Data Sheet, Cree, Inc., 2006, 2007, www.cree.com, http://www.cree.com/products/pdf/XLamp7090XR-E.pdf

About The Author

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