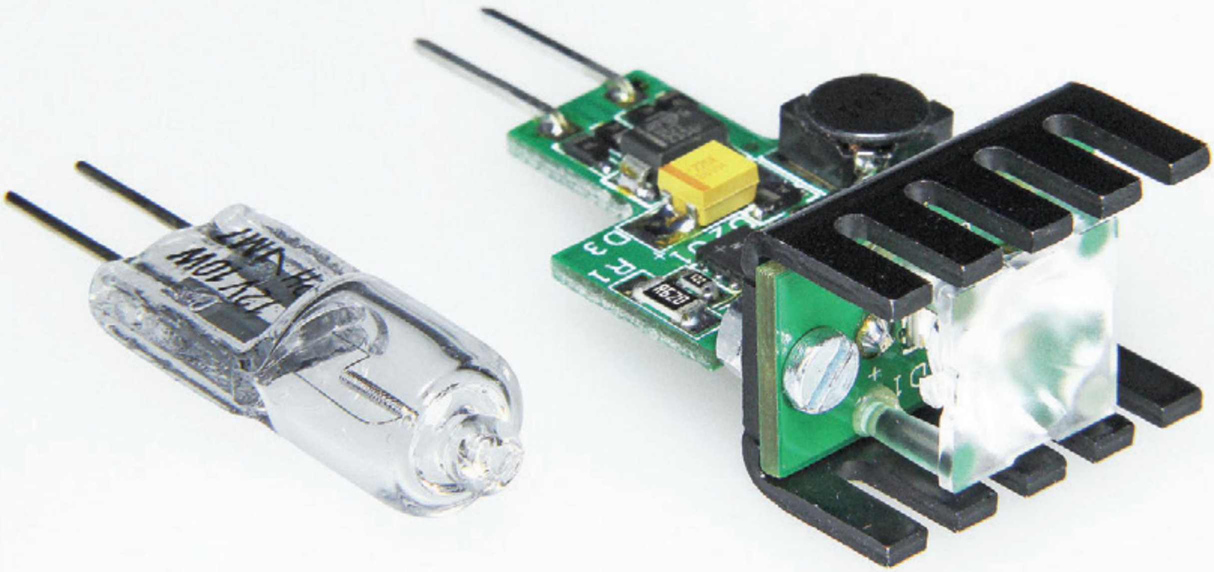
LED's Replace That Halogen Lamp

Economical alternative for the GU4



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There are numerous LED alternatives available these days for most types of incandescent and halogen lamps. But as an electronics hobbyist you can of course design and build something like this yourself, as this article illustrates. The LED lamp presented here can replace a GU4 model 10-watt halogen lamp, uses only one-tenth of the power and is barely bigger than the original.

LED lighting has experienced a great ascent, particularly since several government commissions have banned the good old incandescent lamp. Since 100% compatible LED retrofit lamps are very complex, because of all the optical, thermal, electrical and commercial requirements, the design of such a lamp is normally reserved for large development teams. This however, does not have to hold us back from designing such an LED amp ourselves!
The real Elektor reader does not shy away from a few compromises to nevertheless build a working lamp which can also save a lot of energy.

LED alternative for a 12-V capsule lamp

The LED lamp proposed here is an alternative for a so-called halogen capsule lamp, also known as the GU4 (the 4 refers to the distance of 4 mm between the pins). The headline photograph shows both lamps side by side. In practice the light output of the LED lamp at 1 watt is comparable to the light output of a 10-watt halogen capsule lamp. This is a saving of 90%!
By selecting 12 V as the power supply voltage, we don't have to worry much about electrical safety. That is because the 12 VAC transformer provides sufficient isolation from the powerline so that it is safe to touch the circuit without having to place trust in an earth-leakage circuit breaker.
As can be seen from the photo, the dimensions of the LED variant are somewhat larger than the original, with the consequence that it is not possible to replace every GU4 in any light fixture. There are, however, also applications where the additional space requirement is not a problem. A nice example is the so-called 'starry sky', where a matrix of lamps is spread across a ceiling. Our alternative fits exactly in the socket and, at most,

will stick out a little further than the original. Because the lamp is not enclosed it is very easy for it to dissipate its heat. Because an LED is a point source it is not pleasant to look at it directly. A special lens solves this problem and provides a nice beam of light.

Construction

Which challenges remain? The design of the lamp must be simple, robust and frugal. The individual components have to be readily available and the whole assembly cannot be too expensive.
As can be seen from the photo, this lamp shines from simplicity. There is no need for a separate enclosure; two circuit boards are connected together using standard right-angle header pins. The LED board is clamped firmly to a TO-220 heatsink using two M2 bolts. The small lens is attached with a couple of drops of glue to the LED board. The main connection pins use the same header pins as those used to interconnect the boards.
The LED that has been used here is the so-called *Rebel* from Philips Lumileds. This is readily obtainable and available in various colors and color temperatures. By limiting the power to 1 watt we kill two birds with one stone. Firstly, it is possible to use any type of Rebel-LED with that a similar power rating. The second advantage is that the heatsink can remain quite small and finally the LED will operate more efficiently since it doesn't become so hot. That is because LEDs do not like heat and operate more efficiently at lower temperatures.

Electronics schematic

Figure 1 shows the schematic for the circuit for the drive electronics. Diodes D1a through D1d form a bridge rectifier for the incoming 12 VAC voltage. The rectified voltage is filtered a little by C1. A tantalum capacitor is used because a ceramic type was found to produce an annoying 100 Hz (120 Hz) audible hum. D3 was added at a later stage of the project, after a few prototypes without this transient over-voltage protection went up in smoke. The LED driver IC, a MAX16820 van Maxim (IC1), has a 'buck' architecture and uses an external switching FET (T1). The IC attempts to regulate the voltage across shunt resistor R1 to 200 mV, so that the current through this resistor, the coil and the LED equals 200 mV/620 mΩ ≈ 320 mA. The forward voltage drop across the LED is about 3 V, so that the

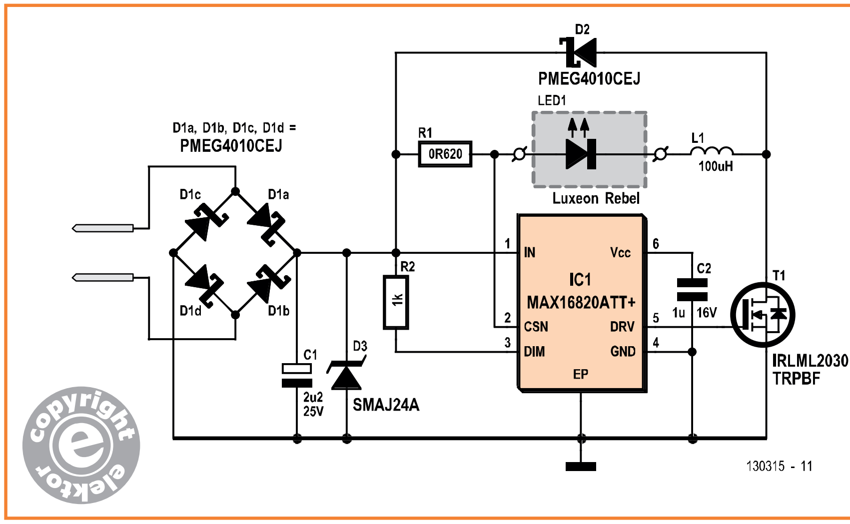


Figure 1.
Schematic diagram for the control electronics.

power in the LED amounts to about 1 W (3 V x 0.32 A). The control itself is quite simple. When the voltage across the shunt resistor is smaller than 190 mV FET T1 will be turned on. The current will increase linearly at a rate of

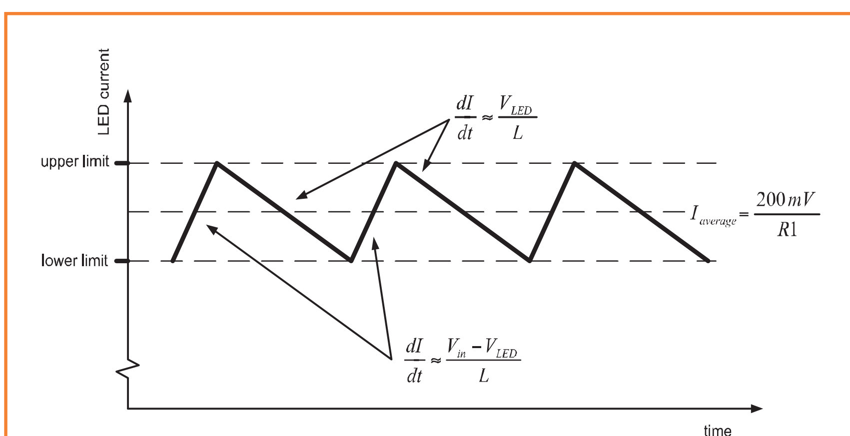
$$dI \,/\, dt \approx (V_{in} - V_{LED}) \,/\, L$$

As soon as the voltage has reached a value of 210 mV the FET is turned off again, with the result that the current will decrease at a rate of

$$dI \,/\, dt \approx V_{LED} \,/\, L$$

noting that the current is returned to the input via D2. As soon as the bottom threshold of 190 mV is reached again, the FET is again turned on and the cycle repeats. The result is a sawtooth shaped current as shown in **Figure 2**. The switching frequency depends on the input voltage. Since the input voltage is not constant, the switching

Figure 2.
The sawtooth shaped current through the LED.



Component List

Resistors
R1 = 0.620Ω (SMD1206)
R2 = 1kΩ (SMD0603)

Capacitors
C1 = 2.2µF 25V (SMD3528)
C2 = 1µF 16V (SMD0603)

Inductors
L1 = 100µH (e.g. LPS5030-104MLB)

Semiconductors
D1a,b,c,d,D2 = PMEG4010CEJ (SOD323F)
D3 = SMAJ24A (SMA)
LED1 = Luxeon Rebel LED
T1 = IRLML2030TRPBF (SOT23)
U1 = MAX16820ATT+ (6 TDFN–EP)

Miscellaneous
PL1 = right angled pinheader (4 per lamp)
Lens: RS Components # 697-4288

Starry Night set: e.g. Conrad Electronics #'s 570590–89, 570591–89, 570592–89 or 570593–89

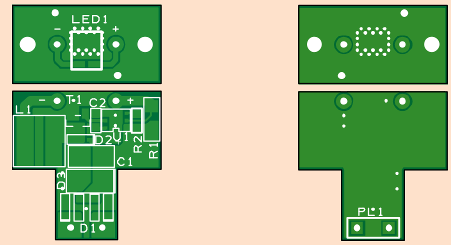


Figure 3. The printed circuit board design comprises two parts. Because of space constraints D1a through D1d are indicated with a single 'D1'.

frequency will vary with the input voltage. For a detailed explanation of this LED driver refer to the article 'Get a Grip on LED Drivers' in Elektor April 2009 [1].

The design of the circuit boards

The printed circuit boards were designed using the well-known CAD program DesignSpark. The only through-hole components are the header pins—all the other parts are SMD types, which allows the boards to be as compact as possible. The design is shown in **Figure 3**. The DesignSpark design files are available as a free download [2].

To make the cooling of the LED as good as is possible, there are a large number of thermal vias around the LED. The purpose of these is to conduct the heat from the LED to the other side of the board, which in turn is in contact with the heatsink. Use the LED board as a template to locate the holes in the heatsink. The standard hole in a TO-220 heatsink corresponds with one of the LED terminals. The other three holes can be drilled using a 2-mm drill.

The solder mask on the bottom of the LED-board covers all the electrical connections to prevent short circuits. The header pins therefore have to be soldered only on the top side of the circuit board; make sure that the header pins do not short to the heatsink. It is therefore very important that the holes are exactly in the right place. On both sides of the LED are two more small holes, which are for the alignment pins of the lens.

The mounting of most SMD components using tweezers and a fine soldering iron should not be a problem if you have some experience with soldering. The IC and the LED are a little more troublesome and require a hot-air workstation or a reflow oven.

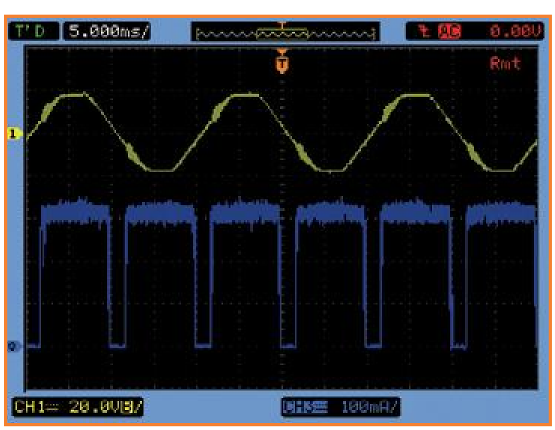
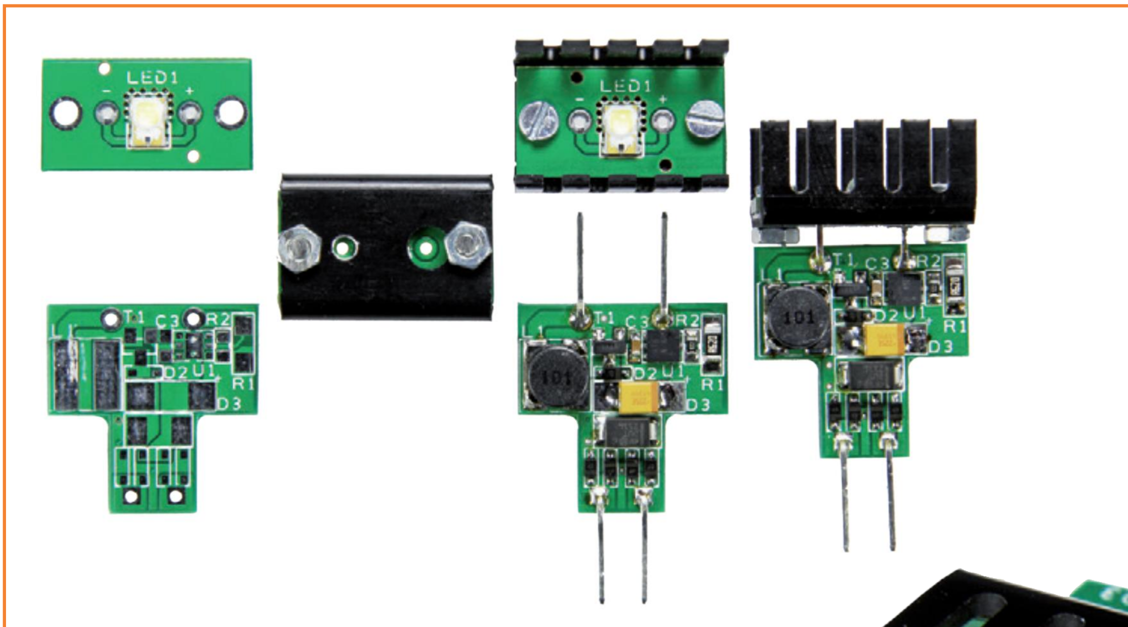


Figure 4. Oscilloscope printout showing the input voltage (top) and the LED current (bottom).

Measurements

Figure 4 shows the LED current together with the input voltage. As can be seen, the current is regulated nicely at 320 mA for most of the time. However, the driver circuit cannot operate when the input voltage drops below 4.5 V. The consequence of this is that the LED current is interrupted around the zero-crossings of the line voltage. This is however not visible because



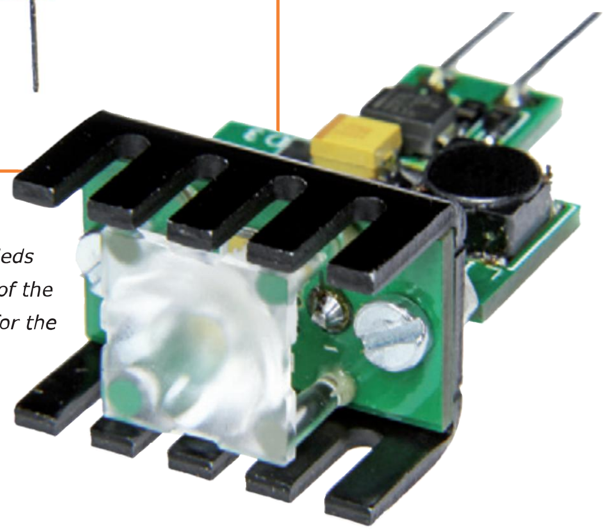


Figure 5.
Here you can see the various stages of building the lamp: the individual circuit boards (but with LED mounted), the holes in the bottom of the heatsink, the assembled boards with mounted heatsink, the boards soldered together and finally a detail of the lens in front of the LED.

the human eye cannot sense this frequency of 100 Hz (120 Hz). As a result the filter capacitor can remain small. The LED is on for about 80% of the time, so that the effective power consumption is 0.8 x 320 mA x 3 V = 0.77 W. The efficiency of the driver circuit, including the losses in the bridge rectifier, amounts to about 77%, so that the lamp has a total power consumption of about 1 W. By changing the value of R1 it is possible to increase or decrease the LED current to your requirements. Just make sure that the temperature of the LED does not become too high.

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With thanks to Philips Lumileds for help with the mounting of the LEDs on the circuit boards for the prototypes.

Internet Links

[1] www.elektor-magazine.com/080888
[2] www.elektor-magazine.nl/130315

Electronic transformers

A source of headaches with 12-V LED lighting is the compatibility with electronic halogen transformers. These transformers come in many variants, but have as a common requirement that they need a substantial load connected to their output. If that is not so (and this is the case with LED lamps), they will protest. The consequence is that the LED lamp will not turn on at all or starts to flash annoyingly. The solution to this requires quite a complex circuit that is outside the scope of this application. This lamp can therefore only be powered from a standard 50-Hz (60-Hz) line transformer. By the way, an old laptop power supply is also a good alternative. In principle the diodes D1a through D1d could be omitted, because such a power supply has a DC output. However we recommend that you leave them as they will then operate as reverse-polarity protection, for it is easy to make the mistake of reversing the lamp in its socket. Keep in mind that the LED power when operating a DC input will increase by about 25% because there are no zero-crossings and the LED is on continuously.