Converting A Flashlight to LEDs

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The motivation for this project came from reading the review of the LED torches in *HP81.* I've been using LED bike lights for several years now, and have replaced the small bulbs in penlight torches with red LEDs for use in the photographic darkroom, where a localised bright safelight can be most useful. But I had never ventured into the use of LEDs for a "proper torch."

In the United Kingdom, we seem to be years behind the United States with such innovations. When they do become available, we tend to pay dollar prices in UK pounds, so things cost around half again what they do in the States. Internet buying is of course an option, but freight charges, import duties, and customs charges almost double the cost.

I set out to make a simple conversion for an existing torch ("flashlight" to Americans) that would give me the efficiency and longevity of a similar commercial product. This proved to be quite simple to do, and may be of interest to others in a similar situation, or to anyone who prefers to modify a commercial torch rather than buy a manufactured LED torch.

The Choice of Torch

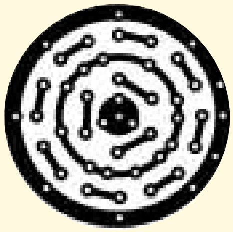
Because this was going to be quite an expensive exercise, it seemed foolish to skimp on the cost of the torch body itself. I wanted to produce a torch that would last for many years. The three main criteria for the torch were robustness, water resistance, and ease of connection for the new light unit. The torch also had to be of a three-cell design to give sufficient voltage for the white LEDs.

My choice was a three C-cell Mag-Lite, available from any good hardware or camping store. Though expensive on this side of the pond, it fulfilled all of the requirements. It is very robust, has a good positive switch, is fully waterproof, and has a very simple and electrically sound method of making all the connections.

LEDs

Light emitting diodes (LEDs) have improved over the last few years, with extremely high levels of output possible. There could be only one criterion for the LEDs for this project—the highest output possible!

There's not a lot of choice here in the UK, and again we tend to pay about half as much again as in the U.S. The brightest white LEDs that I could find were 5 mm, 20 degree types rated at 3,000 millicandelas (mcd) while drawing a current of 20 mA. (I believe that these are equilvalent to those advertised as 5,600 mcd while drawing 30 mA.)



The LED torch's printed circuit card.

The output power of a light source can be described in several ways. Light bulbs around the home and for automobile use tend to be rated in watts. The rated output of LEDs is usually quoted in candelas (cd). Early LEDs only gave out a few thousandths of a candela, so they were rated in millicandelas (mcd). High efficiency modern devices emit several thousand millicandelas.

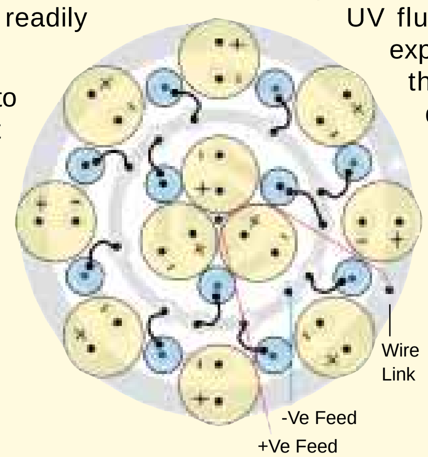
LEDs are very efficient, and will give out light even when drawing miniscule current. The current drawn is directly proportional to the voltage applied, so increasing the voltage will give a brighter light. This works up to a point, but just like a flashlight bulb, too high a voltage will burn it out. In practice, I guess it's a case of the best compromise between getting the highest light output, while taking the least current. LEDs reach this point at around 20 mA.

Current Limiting

White LEDs require an operating voltage of 3.6 VDC. For this reason, a two-cell, 3 volt torch is not suitable. On the other hand, connecting an LED directly to a three-cell, 4.5 volt supply will draw far too much current and fry it!

Some kind of current limiting is needed. The simplest way is just to add a series resistance. Rather than connect all the LEDs together and use a single current-limiting resistance to handle the total current, I prefer to use a separate resistance for each LED. This means that each one is balanced with regard to the current it will draw, and physically small resistors can be used.

Before deciding on the level of the limiting resistances required, I had to choose between using 1.2 volt NiCad rechargable cells or standard 1.5 volt alkaline types. Because the torch was for occasional use with a high degree of reliability, I decided on standard alkaline cells, which have a long shelf life and are readily available.



The LED torch's component overlay.

The output of an LED is proportional to the current it draws, but it is at its most efficient while drawing 20 mA. To limit the current to this level at 4.5 volts, a resistance of 330 ohms was needed for each one. Resistors with 1/4 watt power ratings would suffice. I wanted to get as bright a light as possible. After experimenting, I decided to use eleven LEDs, which would fit well into my proposed design.

If you want to use NiCd batteries (with a nominal voltage of 3.6 volts for three cells), the resistors could be replaced with wire links. Each LED will then draw about 23 mA using newly charged cells, dropping to about 8 mA at the nominal 1.2 volts level, so no resistors are really needed. If you do this, you must be careful not to ever put alkaline cells into the torch, since their higher voltage may ruin the LEDs.

Printed Circuit Card

I could have used Veroboard (0.1 inch pitch, prototype copper strip board), but decided that a printed circuit would be more elegant. CorelDraw software came to the rescue. A simple design was soon drawn up and photographed, and a board made (circuit card shown actual size for direct copying).

A printed circuit board starts off life as a wafer-thin coating of copper that is firmly attached to a sheet of either paxolin or fibreglass. Fibreglass is much stronger and better suited for homebrew construction. Boards can be purchased either plain or with the copper side pre-coated with a light-sensitive emulsion. If plain boards are used, the circuit design can simply be drawn on the board with a special etch-resistant pen. This process works for very simple designs, but for anything more complicated, a photo-resist process is better.

I usually buy off-cuts of plain board in the local electronics shop. After a rub down with fine wire wool, I spray them with a light sensitive lacquer, known as photo-resist. This comes in an aerosol can and is very easy to apply. It is sensitive to ultraviolet (UV) light, so it should not be applied in direct sunlight, and must be used in well-ventilated conditions! After about half an hour of drying, the lacquer is insoluble in the developer (sodium hydroxide).

Exposing the board to ultraviolet light changes the property of the lacquer, making it soluble—this is known as a positive resist. A special light box, housing small UV fluorescent tubes is normally used for exposure. But bright sunlight can also do the job, after a little experimenting to determine the exposure time needed.

After exposure, the resist becomes soluble, except where the drawn pattern has prevented the light from reaching the lacquer. When the board is put in the developer, the developer dissolves away the exposed parts, leaving the pattern on the board as a thin coating of lacquer. The board can then be put into a dish of ferric chloride, which eats away the exposed, unwanted copper. This leaves the printed circuit pattern

LED Torch Costs

Torch Components	*Costs (UK£)*	*Costs (US$)*
11 white LEDs, 20 degree, 3,000 mcd	£33.00	$49.50
Mag-Lite, 3 C-cell	25.00	37.00
Photo-resist positive aerosol spray, #YM62S	9.99	14.99
Photo-resist developer, 250 ml, #YJ38R	4.99	7.79
Fibreglass board, single-sided, 203 x 102 mm (8 x 4 in.), #HX01B	1.99	2.99
11 resistors, 33 Ω 1/4 watt	0.55	0.83
Wire (scavenged)	0.00	0.00
Bulb for connection (scavenged)	0.00	0.00
Total Cost	£75.52	$113.10

beneath the resist, and the board can then be drilled to take the components.

Putting it Together

The resistors (available from any electronics store) were soldered into the board first. This minimised the heat to the LEDs, which were held in a small forceps used as a heatsink during their installation. As can be seen on the component overlay (enlarged to show details), a small length of wire on the component side of the board is soldered from the inner positive connection to the outer ring to complete the circuit to the outer LEDs.

Connecting the assembly to the Mag-Lite couldn't be simpler. The standard torch bulb is held in with a very robust screw collar. To make the connection to the torch, I simply broke the glass out of an old bulb, and soldered the two thin flexible wires from the PC board into the metal bulb base (first passing them through the reflector and screw collar). The base of the bulb is the positive supply, and the torch body the negative.

The torch doesn't have to be modified in any way whatsoever. The PC board sits in the reflector, and the LEDs just press against the plastic top of the torch. You can do this conversion on any flashlight designed to run on 4.5 volts, providing that the reflector housing is large enough to accommodate the PC board and the LEDs.

Results

The finished product is fantastic! It doesn't give a 100 yard pencil beam, of course, but that wasn't the point. The flashlight gives a very even spread of white light that is easily bright enough to illuminate a room or tent, or to light your way over the roughest of terrain.

I chose to optimise the LEDs for maximum light output, not being overly concerned with battery life. Higher value resistances could have been used to reduce current drain, giving longer battery life. But this would have been at the expense of the light output.

Easy access to the reflector and connections made the conversion simple.

Reliability and occasional use were the main requirements. Overall current consumption at around 220 mA may seem a little high, but nowhere near as much as the standard three-cell bulb at 750 mA. These LEDs are very efficient. Even when NiCds supplying only 3.6 volts are used, they will produce high levels of light, while reducing the current drain to 10 mA for each LED.

My total cost was around UK£55 (US$75). Expensive, yes, but still about UK£15 (US$23) less than buying the CC Expedition Flashlight in the UK. And I ended up with a torch with eleven LEDs rather than seven!

I was lucky enough to buy a twin pack containing a three C-cell Mag-Lite and a mini AAA Mag-Lite at the local wholesale warehouse for a total price of UK£19 (US$30). The mini AAA Mag-Lite is destined to have a single white LED fitted to run from one AAA cell via a single transistor inverter, but that's another story!

The bonus of using solid state lights is their long life—at least 100,000 hours is expected. They also give a constant colour as the voltage of the battery drops, yet they still give a very useable light source.

The converted torch has been running for several weeks now, and after many hours of use, I've seen no noticeable drop in brightness. I took it on the first camping weekend of the season, arriving at the site by motorcycle just after dusk. The even spread of light made it ideal to use while I set up my tent. It also provided a really good interior light, easily bright enough to read by, even when reflected from the roof of the tent.