The photo at left shows the completed power supply module. Position the inductor (L1) so that it's well clear of surrounding components and secure it to the PC board using small cable ties. At right is a 5W Luxeon star LED, shown about 50% larger than actual size.

STARPOWER

High-efficiency supply for Luxeon Star LEDs

Based on a switching regulator IC, this simple project is just the shot for powering 1W to 5W ultrabright Luxeon Star LEDs. It's easy to build, runs off 12V DC and can be easily tailored to suit your requirements.

By PETER SMITH

BACK IN THE December 2003 issue, we presented a simple linear power supply for powering 1W Luxeon Star LEDs from a 12V supply. Predictably, we've already received requests for a version that will drive the newer, brighter 3W Stars. In addition, many constructors want a higher efficiency supply for use in boats, caravans and cars.

This new design fits the bill and includes low battery cutout as well.

Unlike the original design, which is based on a linear regulator, this new supply employs a step-down switching regulator. The advantages of this method include much improved efficiency and significantly reduced heat generation.

In fact, when driving a single 3W Star, this supply is at least twice as efficient as a linear supply or simple current-limiting resistor. Obviously, this means longer battery life. Lower heat generation also means that you can build the supply into a case without the need for additional heatsinking.

The project can be powered from any 12V DC (nominal) supply and can be set up to source 350mA, 700mA or 1000mA of regulated current to suit all of the Luxeon Star LED range.

Block diagram

The circuit is based around a Motorola MC34063 DC-DC converter IC. This chip contains all of the functions necessary to construct a complete low-power step-down switchmode regulator – see Fig.1.

A simplified block diagram of the step-down regulator appears in Fig.2. Essentially, when transistor Q1 switches on, current though the series inductor (L1) increases with time, storing energy in its magnetic field. When Q1 is switched off, the magnetic field collapses and the energy is discharged into the output filter capacitor and load via diode D3.

A free-running sawtooth oscillator in the MC34063 determines the maximum switch "on" time. The "on" time of the switch (Q1) versus its "off" time determines the fraction of the input voltage that appears at the output.

IC1 controls the "on" time by monitoring the voltage on its feedback pin. As this voltage falls below 1.25V, Q1's "on" time increases. Conversely, as the feedback voltage increases, the "on" time decreases. Complete "on" cycles are skipped if the feedback voltage remains above the 1.25V set point for the duration of the "on" period.

In a typical implementation, the feedback pin would be connected to the output via a voltage divider to regulate the output voltage. However, our design regulates output current instead.

Current through the LED(s) is sensed via resistor R1 and amplified by op amp IC2. The result is applied to the

Main Features

- Powers one or two 1W or 3W Stars, or a single 5W Star
- High efficiency for minimum battery drain
- Low battery cutout (11.5V)
- Input polarity & transient protected
- Output short-circuit protected
- Ideal for use in boats, caravans & cars

feedback pin of IC1 via a trimpot, allowing accurate current adjustment.

Simply put, the output current is regulated by maintaining the voltage across the sense resistor at about 100mV. In practice, the actual sense voltage depends on the value of R1 and the position of the trimpot.

Circuit details

The complete circuit diagram appears in Fig.3. Following the circuit from the input voltage side, diode D1 provides reverse-polarity protection. A Schottky type is used here to reduce voltage losses.

Next, a 24V zener diode (ZD1) clamps input transients to less than the maximum voltage rating of downstream components. A 470μF capacitor then filters the input and provides a low-impedance source for the high-frequency switching circuitry.

As described above, transistor Q1 acts as a switch in series with the inductor (L1). A Zetex low VCE_{SAT} (collector-emitter saturation voltage) type was chosen for Q1 to improve efficiency and reduce heat dissipation.

The performance of the switching circuit is further enhanced by a turn-off speed-up circuit, which operates as follows:

During an "on" cycle, transistors internal to the MC34063 switch on, bringing pins 1 & 8 towards ground. This forward-biases the base-emitter junction of Q1 via D4 & L2, switching the transistor on.

When the "on" cycle ends, pins 1 & 8 go open circuit and the current through L2 abruptly ceases. The magnetic field around L2 collapses, generating a voltage of opposite polarity to the charge voltage. This forward-biases the base-emitter junction of Q2, momentarily switching it on and connecting the

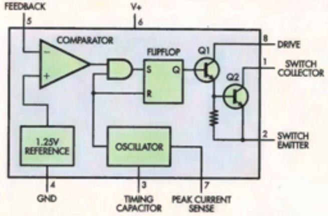


Fig.1: inside the MC34063 DC-DC Converter IC. It contains the circuitry to build a step-up, step-down or inverting switching regulator.

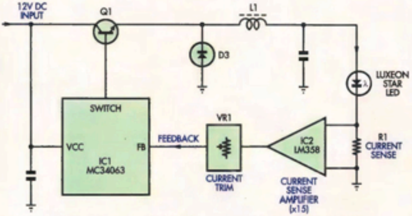


Fig.2: the basic block diagram of the step-down switching regulator section. A fraction of the input voltage is transferred to the output under control of an MC34063 switching regulator IC. The LED current is regulated by sensing the voltage drop across a small series resistance (R1).

base of Q1 to its emitter.

This results in significantly faster turn-off of Q1 than is possible with a resistive pull-up alone. By minimising the transition time between saturation and turn-off, collector power dissipation, and therefore switching losses, are effectively reduced.

When Q1 switches off, diode D3 provides a discharge path for the inductor (L1) to the output filter capacitor and load. Again, a Schottky diode is used for its fast switching and low forward voltage characteristics. Note that we've specified high current (3A) devices in order to withstand a continuous short-circuit condition at the output.

In normal operation, the peak current that flows in the transistor and inductor during each switching cycle is well within the limits of the component ratings. However, with an overloaded or short-circuited output, or with excessively high input voltages, the peak current could increase to destructive levels.

To counteract this problem, IC1 senses peak current via a 0.15Ω resistor in series with the input. When the peak voltage across this resistor nears 330mV, the MC34063 progressively reduces the maximum "on" time of the switch by shortening the positive ramp of the oscillator.

Current sensing

A resistor in series with the LED provides a means of sensing output current. The voltage developed across R1 is amplified by one half of a dual op amp (IC2b), which is configured as a differential amplifier. With the resistor values shown, the sense voltage is amplified by a factor of 15 and applied to one end of VR1.

Effectively, trimpot VR1 provides a

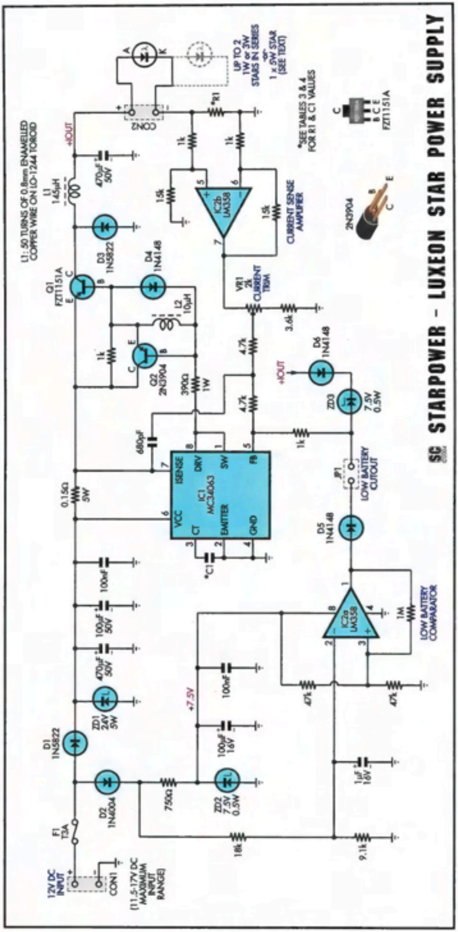


Fig.3: the complete circuit diagram for the power supply module. A low VCE_{SAT} transistor (Q1) is used for the switching circuit to minimise heat dissipation and improve efficiency. Output current is selectable in three ranges by choosing an appropriate value for R1.

means of adjusting the voltage drop across R1. As the wiper is moved towards the top (clockwise), less voltage is required across R1 to satisfy the feedback loop, so the output current decreases. The opposite occurs when the wiper is moved downwards, attenuating the op amp's output and thus increasing the output current.

During construction, R1 is selected from Table 3 to suit the desired LED current. These values were chosen such that close to 100mV will be present across the resistor at the listed LED current level. It's then just a matter of adjusting VR1 to get the precise current level.

To reduce harmonics in the switching circuit, a novel scheme is used to "feed forward" a small portion of the switching signal into the feedback circuit. This is achieved with a 680pF capacitor between the ISENSE and FB pins.

Low battery cutout

IC2a is used as a simple voltage comparator for the low battery cutout circuit. It works as follows.

Zener diode ZD2 provides a clean +7.5V supply for this op amp. This 7.5V rail is also divided in half by two 47kΩ resistors and to provide a reference voltage for the comparator on pin 3. Similarly, the power supply input voltage is divided down by 18kΩ and 9.1kΩ resistors and applied to the negative input (pin 2).

When the voltage on pin 2 falls below that on pin 3 (corresponding to less than 11.5V at the supply input), the output swings towards the positive rail, forcing IC1's feedback input above the 1.25V set point. This stops IC1 from switching and reduces the input current drain to quiescent levels (less than 10mA).

A 1MΩ resistor between the op amp output (pin 1) and its positive input ensures fast switching and provides a few hundred millivolts of hysteresis. In addition, a 1µF capacitor at the inverting input filters out any momentary transients and ensures that

Parts List

1 PC board, code 11105041, 105mm x 60mm
1 powered iron toroid, 28 x 14 x 11mm (L1) (Jaycar LO-1244)
170cm (approx) 0.8mm enamelled copper wire
1 10µH RF choke (Altronics L-7022, Jaycar LF-1522)
2 2-way 5mm (or 5.08mm) terminal blocks (CON1, CON2)
1 2-way 2.54mm SIL header (JP1)
1 jumper shunt (JP1)
1 8-pin IC socket
2 M205 PC mount fuse clips
1 M205 3A slow blow fuse
4 M3 x 10mm tapped spacers
4 M3 x 6mm pan head screws
2 small cable ties
1 heatsink for 3W or 5W LEDs (see text)
1 2kΩ miniature horizontal trimpot (VR1)

Semiconductors
1 MC34063 DC-DC converter (IC1)
1 LM358 dual op-amp (IC2)
1 FZT1151A PNP transistor (Q1) (Farnell 935-499)
1 2N3904 NPN transistor (Q2)
2 1N5822 Schottky diodes (D1, D3)
1 1N4004 diode (D2)
3 1N4148 small signal diodes (D4 - D6)
1 24V 5W zener diode (ZD1)
2 7.5V 0.5W (or 1W) zener diodes (ZD2, ZD3)
1 or 2 1W or 3W Luxeon Star LEDs; or 1 5W Luxeon Star LED (see text)

Capacitors
2 470µF 50V low-ESR PC electrolytic (Altronics R-6167)
1 100µF 50V low-ESR PC electrolytic (Altronics R-6127)
1 100µF 16V PC electrolytic
1 1µF 16V PC electrolytic
2 100nF 50V monolithic ceramic
1 1.2nF 50V ceramic disc (or polyester)
2 680pF 50V ceramic disc
1 560pF 50V ceramic disc
1 330pF 50V ceramic disc

Resistors (0.25W 1%)

1 1MΩ	2 4.7kΩ
2 47kΩ	1 3.6kΩ
1 18kΩ	4 1kΩ
2 15kΩ	1 750Ω
1 9.1kΩ	1 390Ω 1W 5%

2 0.15Ω 5W (or 3W) 5% (Farnell 347-2693)
1 0.1Ω 5W (or 3W) 5%
1 0.27Ω 5W (or 3W) 5%

Additional resistors for testing
1 10Ω 5W 5% (350mA test)
1 4.7Ω 5W 5% (700mA test)
1 3.3Ω 5W 5% (1000mA test)

Note: parts shown with a Farnell catalog number can be ordered on-line direct from Farnell at **www.farnellinone.com.au** or phone 1300 361 005. The 0.15Ω 5W resistors are also available from WES Components, phone (02) 9797 9866.

the negative input remains below the positive input during power up.

Note that despite this filtering, the LED will flash momentarily at power on and power off. This is because unlike the LM358 op amp, the MC34063 operates right down to 3V.

Finally, a series diode (D10) and 7.5V zener diode (ZD3) connected between the output and the feedback circuits prevents the output voltage rising much above 9V if the LED is inadvertently disconnected. This helps to reduce the peak current flow that occurs if the output is reconnected with power applied.

Construction

The assembly is straightforward, with all the parts mounted on a PC board coded 11105041 and measuring 105 x 60mm. The parts are all installed on the board in the conventional manner except for switching transistor Q1, a surface-mount (SMT) device which is installed on the copper side.

The first job is to mount Q1. Although this is an SMT device, it has relatively large pins with ample spacing that are easy to solder.

To install it, place the copper side of the board up and position Q1 precisely as shown on the overlay diagram (Fig.6) before soldering the leads.

With Q1 in place, turn the board over and install the two wire links using 0.7mm tinned copper wire or similar. One of the links (shown dotted) goes underneath IC2, so it's important that it goes in first!

Next, install all the low-profile components, starting with the 0.25W resistors and diodes. All the diodes, including the zeners, are polarised devices and are installed with their banded ends oriented as shown.

An IC socket can be installed for IC2. However, IC1 should be soldered directly to the board (no socket!) to eliminate the effects of contact resistance. Be sure to align the notched (pin 1) ends as indicated.

All remaining components can now be installed except for the electrolytic capacitors. It's easier to leave these until after the inductor (L1) is in place.

Select appropriate values for C1 & R1 from Tables 3 & 4. It's very impor-

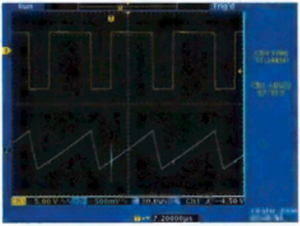
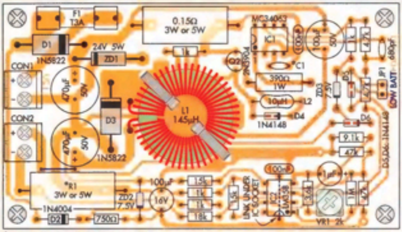
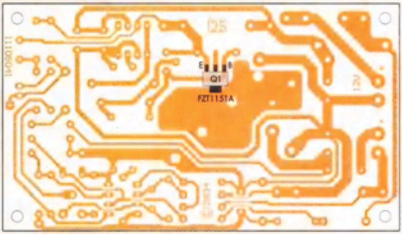


Fig.4: this scope shot shows the switching waveform present on the cathode of D3 (top trace) versus the MC34063's on-board oscillator on pin 3 (bottom trace). Note that the switching frequency will vary significantly according to LED type and number and will not necessarily equal the oscillator frequency.



*SEE TABLES 3 & 4 FOR R1 & C1 VALUES

Fig.5: follow this layout diagram when installing the parts on the PC board and don't forget the link under IC2.



BOTTOM (COPPER) SIDE

Fig.6: the mounting details for transistor Q1. It's soldered on the copper side of the board using a fine-tipped soldering iron.

tant that these match your intended application (type of LED and one or two LEDs in series). The parts list includes all of these parts, so you will have an extra three ceramic capacitors and two 5W (or 3W) resistors left over once assembly is complete.

Winding the inductor

The inductor (L1) must be hand-wound using the specified toroidal core and about 170cm of 0.8mm enamelled copper wire. Play out the wire into a straight length, removing any kinks before you begin.

It's easier to wind one half at a time, so start by feeding about half of the wire through the centre of the core. Wind on the first half using firm even tension and keep the turns as close as possible without overlapping.

Now repeat this procedure with the second half of the wire. In total, the core will accommodate 50 turns if there are no gaps between adjacent turns on the inside of the core.

Now count the total number of turns. With a bit of luck, you should have 49 or 50 (one less is OK!). Trim and fashion the ends of the wire so that the assembly slips home easily into the holes in the PC board with a few millimetres protruding out the opposite side.

Next, scrape the enamel off the ends of the wire, tin them and reposition the inductor on the PC board. Don't solder the wires just yet though. It's important to first attach the inductor to the board using small cable ties. Position the inductor so that it is well clear of surrounding components before tightening up the ties. That done, solder and trim the wire ends.

Table 2: Capacitor Codes

Value	µF Code	EIA Code	IEC Code
100nF	0.1µF	104	100n
1.2nF	.0012µF	122	1n2
680pF	–	681	680p
560pF	–	561	560p
330pF	–	331	330p

Table 1: Resistor Colour Codes

	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	1	1MΩ	brown black green brown	brown black black yellow brown
❑	2	47kΩ	yellow violet orange brown	yellow violet black red brown
❑	1	18kΩ	brown grey orange brown	brown grey black red brown
❑	2	15kΩ	brown green orange brown	brown green black red brown
❑	1	9.1kΩ	white brown red brown	white brown black brown brown
❑	2	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❑	1	3.6kΩ	orange blue red brown	orange blue black brown brown
❑	4	1kΩ	brown black red brown	brown black black brown brown
❑	1	750Ω	violet green brown brown	violet green black black brown
❑	1	390Ω 5%	orange white brown gold	not applicable

Finally, install all the electrolytic capacitors to complete the job. Take particular care with orientation – their positive leads must go in as indicated by the "+" markings on the overlay diagram.

Setup & testing

Before connecting an LED to the output for the first time, the supply should be checked for correct operation. During the test, we'll also set the output current to an initial value to suit the type of LEDs being used.

The test involves inserting a 5W test resistor in the LED output terminals. The resistor value to use depends on the output current level selected during assembly. For 350mA of current, use a 10Ω test resistor, for 700mA a 4.7Ω value and 1000mA a 3.3Ω value.

Don't cut the resistor leads short. It should be screwed into the LED output terminal block and suspended in mid-air, such that it's not in contact with anything; it will get very hot! With this in mind, the circuit should not be powered up for more than a few minutes with the test resistor in place.

Remove the jumper shunt on JP1 if you installed it earlier and rotate VR1 fully clockwise. Connect a 12V DC (1A or higher) power source to the input terminals and power up. Monitor the voltage across R1 (not the test resistor) with your multimeter and adjust VR1 to get the desired current level. The correct sense voltage for each current level is listed in Table 3.

For example, if you want 700mA for a 3W LED, you will have installed a 0.15Ω resistor for R1, so adjust VR1 to get a 105mV reading on your meter.

If all checks out, you're almost ready to go. Remove the test resistor and replace it with the LED leads. Power up again and check that the voltage across R1 is as previously set. If necessary, readjust VR1 to get the listed reading.

Note: the light output from these LEDs could damage your eyesight. Do not stare directly into the LED beam at close range!

If you have a variable DC bench supply, you can also test the low battery cutout circuit by slowly reducing the input voltage. At about 11.5V, the LED should switch off. Remember to install the jumper shunt on JP1 to enable this function.

Note: in a quiet environment, you may be able to hear a low level "squeal" coming from the inductor (L1). This is completely normal and is due to the harmonics caused by the gated oscillator architecture of the MC34063 switching regulator IC.

Fault-finding

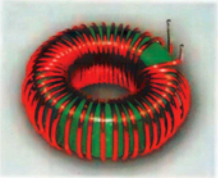
If your meter reads way off the mark and/or adjusting VR1 has no effect, then there is a fault on the board. Switch off and remove the test resistor, then power up again with nothing connected to the output.

With your meter set to read volts, first measure between pins 1 & 8 of IC2. These are the op amp supply pins, so you should get close to 7.5V. If not, look for problems around ZD2 and its associated circuitry.

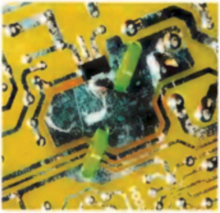
Next, measure between pins 6 & 4 of IC1. Again, these are the supply pins of the IC but this time, expect about 0.3V less than the input voltage.

If you have an oscilloscope, you can check that the oscillator in the MC34063 is working by examining the waveform on pin 3. You should see a clean sawtooth waveform like that shown in Fig.4.

Assuming the above measurements are OK, then it's back to basics. Examine the board closely for correct component placement and soldering defects, especially around IC1, IC2 and the 100µF 16V capacitor. It's easy to



Bend and shape the ends of the winding so that the assembly slips easily into the holes in the PC board. This shot of the underside of L1 shows the general idea, although this core doesn't have the full 50 turns!



This larger-than-life size view shows how transistor Q1 is mounted on the underside of the PC board.

Table 3: Selecting Resistor R1

LED Type	LED Current	R1	Sense Voltage
1W Star	350mA	0.27Ω	94.5mV
3W Star	700mA	0.15Ω	105mV
3W Star	1000mA	0.1Ω	100mV
5W Star	700mA	0.15Ω	105mV

Table 4: Selecting Capacitor C1

LED Type	No. of LEDs in Series	Colour	C1
1W Star	1	Red, Red-Orange, Amber	330pF
1W Star	2	Red, Red-Orange, Amber	680pF
1W Star	1	White, Green, Cyan, Blue, Royal Blue	560pF
1W Star	2	White, Green, Cyan, Blue, Royal Blue	1.2nF
3W Star	1	All	560pF
3W Star	2	All	1.2nF
5W Star	1	All	1.2nF

Where To Get Luxeon Stars

Luxeon Star LEDs and the heatsinks mentioned in the text can be purchased from one or more of the following sources:

(1). Alternative Technology Association, phone (03) 9388 9311, **www.ata.org.au**

(2). Altronics, phone 1300 780 999, **www.altronics.com.au**

(3). Jaycar Electronics, phone 1800 022 888, **www.jaycar.com.au**

(4). Oatley Electronics, phone (02) 9584 3563, **www.oatleye.com**

(5). Prime Electronics, phone (02) 9746 1211, **www.prime-electronics.com.au**

Detailed technical information on Luxeon Star LEDs can be obtained from the Lumileds web site at **www.lumileds.com**

get solder bridges between the closely spaced tracks in these areas.

Mounting & wiring

The completed power supply module can be mounted without an enclosure if a protected location is available. Alternatively, it can be housed in a UB3-sized "Jiffy" box for ruggedness. Jaycar Electronics has a range of flanged ABS boxes that would be ideal for the job.

For marine applications, the entire assembly will need to be conformally coated or installed in a sealed enclosure to keep corrosion at bay.

The power input and LED output wiring must be run using heavy-duty (7.5A) cable. We recommend no more than about 25cm of cable length between the power supply output and the LEDs.

Keeping your LEDs cool

This project can be used to power any of the 1W, 3W or 5W Luxeon Star range. Out of these, the 1W version is by far the easiest to use because of its relaxed heatsinking requirements.

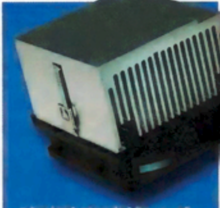
In fact, when operated in low ambient temperatures, no additional heatsinking is necessary for versions with board mounted optics (Star/O).

However, in most real-world applications, a small heatsink will help to keep the LED junction temperature within specs, as well as prevent heat damage to the acrylic lens. This can often be as simple as a flat metal panel or the lid of a metal case, for example.

Unlike the 1W types, the 3W & 5W Stars require careful attention to heatsinking, particularly when reliability and long service life are important. Despite this requirement, the excellent "lumens per buck" rating of the new 3W Stars definitely makes them worth a look. So how is the heatsink size determined? Let's find out!

Heatsink basics

As with any power semiconductor device, we can calculate the required heatsink thermal resistance once we know the maximum junction temperature, ambient temperature and power dissipated.



A heatsink intended for one of the later model processors (such as the AMD Athlon) would be more suitable in high ambient temperatures and will extend LED life. Simply remove and discard the fan & retaining clip before drilling the mounting holes. Recycled heatsinks may have an old sticky heat transfer pad in the centre, which must be removed with solvent before attaching your LED.

As only about 10% of the input power to the LED is emitted as light, it is disregarded in the following calculations. Assuming a nominal LED forward voltage of 3.6V, power dissipation can be found using Ohms law:

$$P_D = V/I = 3.6V/1A = 3.6W$$

Using the absolute maximum LED junction temperature of 135°C and an ambient temperature of 25°C, the junction to ambient thermal resistance is:

$$RTH_{J\text{-}A} = T_J - T_A / P_D$$
$$= 135°C - 25°C / 3.6W$$
$$= 30.5°C/W$$

Next, subtract the junction to board resistance ($RTH_{J\text{-}B}$) listed in the datasheet to find the board to ambient thermal resistance. For most board-mounted Stars, this is 17°C/W:

$$RTH_{B\text{-}A} = RTH_{J\text{-}A} - RTH_{J\text{-}B}$$
$$= 30.5°C/W - 17°C/W$$
$$= 13.5°C/W$$

The result is the maximum allowable heatsink resistance needed to keep the LED junction temperature at or below the maximum rating at 25°C ambient.

The 48 x 48mm finned heatsink shown in the adjacent photo was originally designed for cooling Intel 486 and Motorola 68000 series microprocessors but works equally well

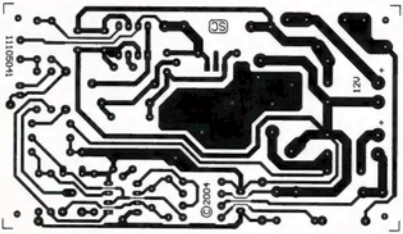


Fig.7: this is the full-size etching pattern for the PC board.

here. According to our rough calculations, it has a thermal resistance of about 8°C/W when operated in free air in the vertical position.

So far, we've assumed operation up to the maximum LED junction temperature of 135°C. However, when operated continuously at this maximum, LED light output decreases quite markedly over time. To achieve the 20,000 hours at 50% lumen maintenance figure shown in the datasheets, Lumileds specifies a lower maximum junction temperature of 90°C.

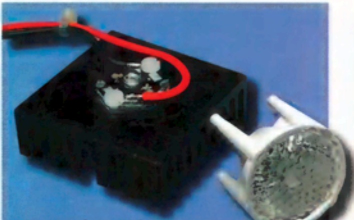
Reworking the figures for this lower temperature, you can see that a heatsink resistance of 1°C/W would be required. This would be difficult to implement in practice, necessitating a bulky heatsink, perhaps even with forced-air cooling.

For maximum life with a realistic heatsink size, the answer is to drive the LEDs at reduced current. For this reason, Lumileds also characterises the 3W Star for operation at 700mA, stating lumen maintenance of 70% after 50,000 hours at the lower temperature figure.

The maximum heatsink resistance needed in this case is 8.8°C/W at 25°C ambient, meaning our chosen heatsink barely makes the grade. If operation in the horizontal position is required or higher ambient temperatures are likely, then a lower resistance heatsink will be needed.

The above information is also applicable to the 5W Star, although it's life versus junction temperature figures are radically different to the 3W version. Note also that it's rated for a maximum of 700mA forward current and has a higher forward voltage than the 3W device. Refer to the individual device datasheets for more information.

To learn all about heatsinking, check out the "Thermal Design using Luxeon Power Light Sources" application brief, available from the Lumileds website at **www.lumileds.com**. **SC**



We mounted our 3W Star on a 48mm square heatsink pinched from an old 486 motherboard. Drill two 3mm mounting holes in line with the slot between the fins and then deburr the holes to obtain a smooth mounting surface. A thin smear of heatsink compound between surfaces will aid heat transfer. You'll need to use nylon washers under the heads of the screws to prevent short circuits to the solder pads on the Star PC board. Don't be tempted to run the 3W or 5W Stars without a heatsink – they'll quickly self-destruct! Wide, narrow and elliptical beam lenses similar to that shown here can be fitted to suit most applications.