# LifeSaver for Lithium or SLA batteries

***Don't ruin an expensive SLA, Li-Ion, Li-Po or $LiFePO_4$ battery by over-discharging it. This small circuit will protect it by cutting off power before it reaches the danger zone. It has virtually no effect on available power or battery life. It's also ideal for preventing devices like uninterruptible power supplies and emergency lights from destroying their batteries in an extended blackout.***

**by Nicholas Vinen**

**Rechargeable lithium-based** batteries are great – they have high capacity, long service life, high discharge current, are light weight and fast charging.

But they're easy to destroy if you run them down below a particular voltage level and in a lot of applications, all you have to do is leave the device on a bit too long and your expensive battery is lost.

Radio-controlled cars/planes/helicopters generally have a low voltage cut-out feature built in to the motor speed controller, but if you use these batteries in other applications, you definitely need this *Battery LifeSaver*.

As mentioned above, it's also suitable for use with most lead-acid batteries. As with most offices, factories and public buildings, we have quite a few emergency lights/exit signs in our office. While we only have the occasional black-out, we still have to replace several back-up batteries a year which really should have lasted a lot longer except that they were discharged to the point of death.

## Features and specifications

- Works with sealed lead-acid, Li-ion, Li-Po and LiFePO4 batteries (6-24V)
- Very low quiescent current, <5µA
- Cut-out voltage adjustable from 5.25 to 25.5V
- High current-handling capability – 20A continuous, 30A peak (charge or discharge)
- 0.3-2V hysteresis, depending on battery type and voltage
- Very small PCB, to fit in tight spaces (34 × 18.5mm)
- Battery can be recharged once cut-out has engaged (maximum 1.5A)

Computer UPS (uninterruptible power supplies) often have the same problem, which can make having a black-out quite an expensive event.

The *Battery LifeSaver* works with 6-24V batteries and can handle currents of up to 20A continuous and 30A peak, making it suitable for use with cordless power tools, emergency lights, small to medium UPS (up to about 300VA) and a wide variety of other devices.

With a quiescent current less than 5µA, it has negligible effect on battery life and as long as the cut-off voltage is set high enough, it won't damage the battery even if left for quite a long time after it has activated (4.3µA continuous discharge equates to less than 38mAh per year).

It's very small – just 46 × 18.5 × 5mm assembled and light too (about 5g) so it can be slipped into a tiny space in a battery compartment. It won't cost a lot to build either, which is good, since if you have use for one, chances are you will have uses for several. We certainly do!

### Operation and charging

As shown in Fig.1, the unit connects between the battery and load so that it can stop the load drawing any further power once the battery voltage reaches its cut-off value.

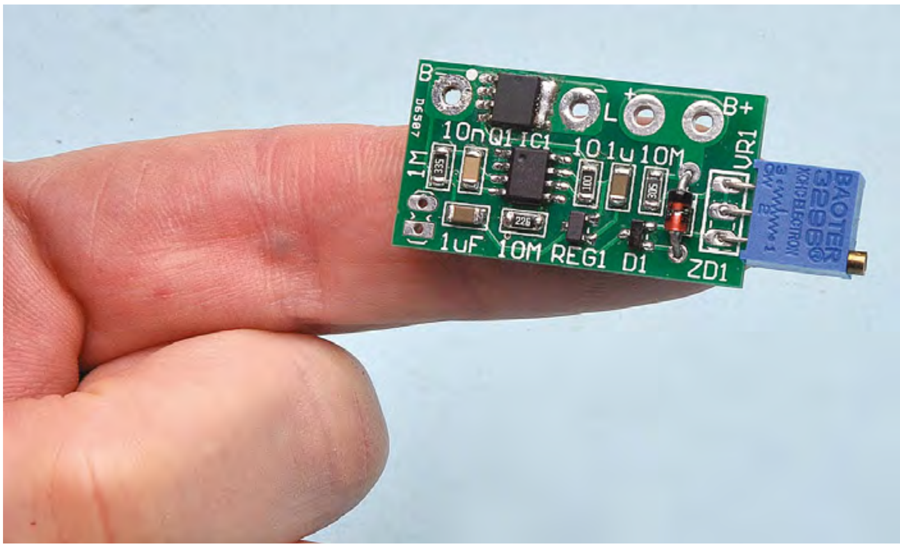
It is based on a MOSFET, shown here as a switch. When the MOSFET is off, the load cannot draw any further power from the battery. The MOSFET's intrinsic diode is reverse-biased in this condition, so no current flows through it either.

The battery can be recharged either by connecting the charger directly across the battery terminals (if they are accessible) or as shown in Fig.1, by connecting the charger across the load terminals, whether or not the load is still connected. Charge current flows in the opposite direction to discharge current, and this path is shown in green.

In many cases, it will be necessary or simply convenient to charge via the load side of the device. In this case, the positive output of the charger is connected directly to the positive terminal of the battery, while the negative output is connected via the internal electronic switch and parallel diode.

If the battery voltage is high enough then the switch is on and so charge current can flow through it and charging proceeds as if the charger was connected across the battery.

With the switch off, current can still flow from the charger to the battery but it must pass through the diode. There will be an associated voltage drop and power loss due to the diode junction, heating up the diode (inside the MOSFET). However, note that because the battery voltage will appear to be near-zero at the load terminals, some chargers may refuse to deliver current in this situation.




**Believe it or not, this photo is actually larger than life size, just to show the detail on the tiny (46 × 18.5mm) module. Although it's cheap to build, it could save you a fortune in ruined batteries! Once we attached the input and output leads, we encapsulated it in some transparent heatshrink tube.**

If the cut-out has activated, you should limit the charge current to 1.5A or else the diode could overheat. We tested charging under this condition using a Turnigy Accucell 6 charger and it worked fine as long as we turned the charge current down until the battery voltage had come back up a couple of volts. Once the switch is back on (as confirmed by a healthy voltage reading across the load terminals), you can proceed to charge at the full rate.

If your charger is too 'smart' and refuses to supply current with the cut-out activated, it's simply a matter of connecting some sort of current source (or current-limited voltage source) across the load terminals – a plugpack and low-value wire-wound resistor will generally do the trick. It usually doesn't take long to raise the voltage of a flat battery by a volt or two.

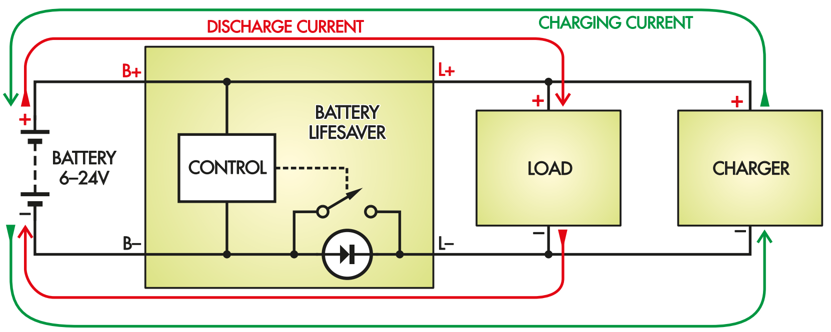



**Fig.1: block diagram for the *Battery Lifesaver*. The unit is connected between the battery and load and disconnects the two (at the negative end) if the battery voltage drops below a threshold. The battery can still be charged in this case, at a limited current, until the voltage rises enough for the cut-out to deactivate, at which point full charge current can resume.**

### Circuit description

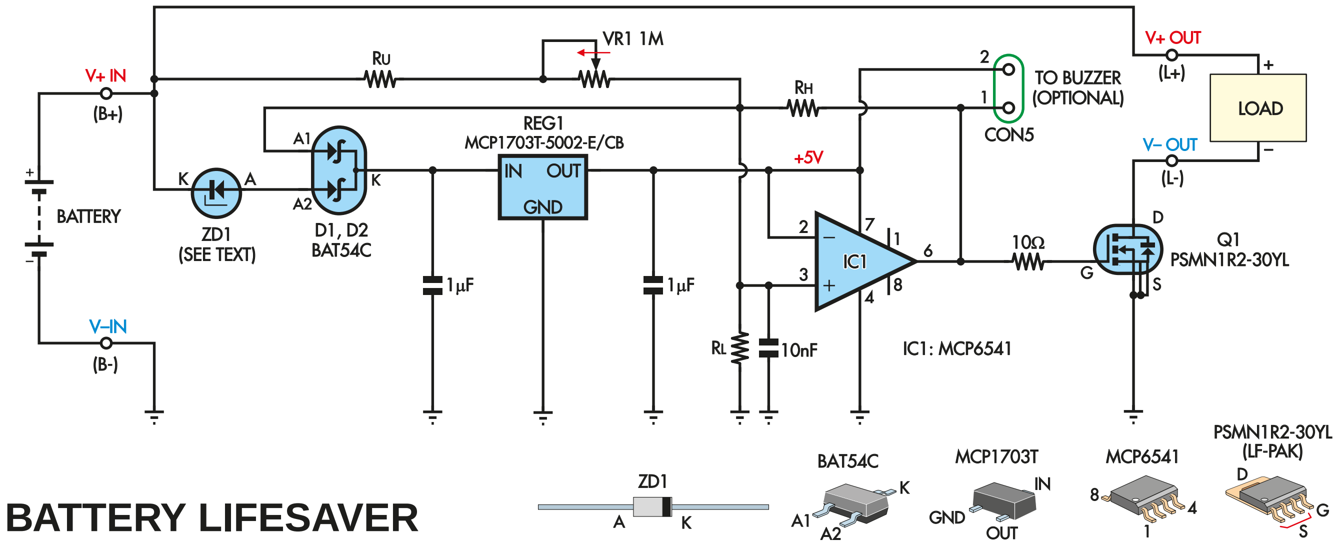
The full circuit is shown in Fig.2. We have published similar circuits in the past that used special-purpose ICs, but they can be hard to get, so this one is based on general-purpose parts: a low quiescent current low-dropout linear regulator (REG1), an ultra-low-power comparator (IC1) and a very low on-resistance MOSFET (Q1).

REG1 has a dual purpose. It limits comparator IC1's supply to 5V, which is desirable since IC1 has an absolute maximum rating of 7V. The regulated 5V is also used as a reference for comparison with the battery voltage.

IC1 has rail-to-rail inputs and this means that we can tie its inverting input (pin 2) directly to 5V. In fact, its common-mode input range extends 0.2V beyond both supply rails. Pin 3, the non-inverting input, is connected to a resistive voltage divider that is connected across the battery.

The upper leg of this divider consists of a fixed upper resistor (RU) and a trimpot (VR1) while the bottom leg is a single resistor (RL). RU and RL are chosen so that VR1 can be adjusted to give 5V on pin 3 of IC1 when the battery voltage is at its lower operating limit.

With the battery voltage above this limit, the voltage at pin 3 of IC1 is above that of pin 2 and so the comparator output (pin 6) is high, switching




## BATTERY LIFESAVER

**Fig.2: circuit diagram for the *Battery LifeSaver*. It's based on a low-dropout 5V regulator (REG1), very low power comparator (IC1) and MOSFET Q1, which acts as the switch. Values for resistors RU, RH and RL are chosen to suit a particular battery cut-out voltage threshold; VR1 provides fine adjustment of this voltage. ZD1 is selected to keep the supply voltage to REG1 within its ratings.**

on MOSFET Q1 via a 10Ω resistor. This connects the load to the battery. When on, Q1 not only has a very low on-resistance (about 1.3mΩ) but is fully on with its gate just 4.5V above its source.

If the battery voltage drops too much, the voltage at pin 3 of IC1 goes below that at pin 2, the comparator output goes low and MOSFET Q1 turns off. The only remaining load on the battery is the circuit itself, drawing about 3.2-4.5µA.

Resistor RH, connected between the output and non-inverting input of IC1, gives a small amount of positive feedback, which provides 1-2V of hysteresis for the circuit. Its value is selected so that this hysteresis is about 8% of the battery voltage. Without this, as soon as the load is switched off, the battery voltage would rebound and this will cause the load to be switched back on and the circuit would oscillate.

Say the low voltage cut-out threshold is set to 19.8V (for a 24V Li-Po battery). Once the output of IC1 goes high, the switch-on voltage rises to about 21.4V. The battery is unlikely to rebound this much – at least, not right away – so the MOSFET will remain off until the battery is re-charged. This hysteresis should be sufficient for most batteries, but if necessary, it can be increased by lowering the value of RH.

The 10nF capacitor across RL filters out noise which may be picked up due to the high impedance of the divider network and smooths battery voltage ripple. It also slows the action of this hysteresis considerably, but IC1 has a small amount of built-in hysteresis (about 3.3mV worth) which helps compensate for this.

REG1 has 1µF ceramic input bypass and output filter capacitors for stability, the minimum suggested value for this part. Dual Schottky diode D1/D2 protects the circuit against reverse battery polarity, although it won't stop current flowing through Q1's body diode and the load, if connected. .

Zener diode ZD1 reduces the battery voltage for REG1 and its voltage is selected to suit the type of battery used. REG1's absolute maximum input is 16V. For batteries well below 16V, ZD1 is replaced with a link (see Table 1).

During operation, REG1 consumes about 2µA, while IC1 draws just 600nA. The rest of the quiescent current flows through the resistive divider, hence the resistors used have as high a value as is practical to minimise this current. This is why we have used a combination


**When we say tiny, we mean it: here is the *LifeSaver* sitting on top of a 12V, 7Ah SLA battery – it's not even as high as the spade lugs!**

of resistors and a trimpot to set the cut-off voltage; the highest value of trimpot commonly available is 1MΩ.

**Optional buzzer/LED**

The PCB has a pair of pads so that a piezo buzzer or LED can be connected to indicate when the battery voltage drops below the cut-off threshold. However, fitting this may be not a good idea if you are concerned about the extra current drain on a battery which has been drained to the cut-off voltage.

A buzzer/LED could run the battery flat in a matter of hours, so you will need to immediately recharge it once it sounds/lights up.

If you do want to fit a buzzer or LED, it will be driven at 5V by the output of comparator IC1, which can sink a maximum of 30mA. LEDs will require a series current-limiting resistor.

**Component selection**

Since the battery voltage divider is formed from a combination of fixed resistors and trimpot VR1, we must change the values of these resistors so that the adjustment range of VR1 includes the desired cut-off voltage for your battery.

High value input dividers for comparators pose a problem in that the hysteresis resistor typically must be a much higher value, so we are limited by the highest value readily available. Luckily, it's quite easy to get resistors up to about 22MΩ in SMD packages, which is higher than the typical maximum of 10MΩ for through-hole parts.

To determine which parts you need, first locate your battery or its closest equivalent in Table 1 and read off the value for ZD1. Next, decide which cut-off voltage you want to use; in very high current drain applications (10A+), especially when using a relatively small battery, you may want to set it a bit lower than specified.

Once you have determined the cut-off voltage to use, find an entry in Table 2, which has a range covering it, and then read off the values for resistors RL, RU and RH. These are chosen to give a hysteresis of about 8% of the battery voltage, thus the hysteresis is

## Parts List – Battery LifeSaver

1 double-sided PCB, available from the *EPE PCB Service* coded 11108131, 34 × 18.5mm
1 50mm length 25mm-diameter heatshrink tubing
1 length heavy-duty black wire (to suit installation)
1 length heavy-duty red wire (to suit installation)
2 female 6.4mm spade quick connectors (optional; for use with gel cell batteries)
2 male 6.4mm spade quick connectors (optional; for use with gel cell batteries)

**Semiconductors**
1 MCP6541-E/SN ultra-low-power comparator (IC1) (RS Components 669-6200)
1 MCP1703-5002-E/CB micropower LDO 5V regulator (REG1) (element14 1439519)
1 PSMN1R2-30YL 30V 100A MOSFET (Q1) [SOT-669/LFPAK] (element14 1895403)
1 BAT54C dual Schottky diode (D1) [SOT-23] (element14 1467518)
1 0.4W or 1W Zener diode (see Table 1 for voltage) (ZD1)

**Capacitors (all SMD 3216/1206)**
2 1µF 50V (element14 1857302)
1 10nF 50V (element14 8820155 or similar)

**Resistors (SMD 3216/1206)**
1 10Ω
plus three resistors, 330kΩ-22MΩ, as per Table 2
1 1MΩ 25-turn vertical trimpot (VR1)

**Visit Jaycar Electronics UK (www.jaycar.co.uk) for a Battery LifeSaver kit: Cat No KC-5523 @ £11.00**

## ST Micro's LFPAK series SMD MOSFETs


MOSFET Q1 is an ST Micro part with an incredibly low on-resistance – barely more than a milliohm. It is rated to carry 100A but it will dissipate around 1W at 30A ($I^2$ x R) so without heatsinking (other than the PCB), it won't handle much more than that.

Its on-resistance is so low that losses in the MOSFET itself are a minor component of the dissipation, most of it being in the PCB and wiring. This is only really possible with SMDs since a TO-220 through-hole package has 1mΩ of resistance in the package/leads alone.

By comparison, the LFPAK package (also known as SOT-669) has a resistance of just 0.2mΩ. The semiconductor die is sandwiched between the metal drain pad on the bottom of the device (which also acts as a heat spreader) and a metal plate on top, which also forms the three source leads (pins 1-3). This gives a very large contact area between the device leads and the MOSFET itself, hence the low resistance possible.

The LFPAK has roughly the same footprint as an 8-pin Small Outline Integrated Circuit (SOIC-8), a common SMD IC package. There is a lot of equipment already designed to handle SOIC parts – pick and place machines, storage schemes, etc – and these can generally work with LFPAK MOSFETs with little or no modification.

At a pinch, SOIC-8 MOSFETs can be substituted for LFPAK devices and can be soldered to the PCB without needing to modify it. However, losses will be higher in this case. MOSFETs in LFPAK use the same pin configuration as typical N-channel MOSFETs in SOIC packages. For more information, see: **www.nxp.com/documents/leaflet/75016838.pdf**

## Table 1: battery types, voltages and values for ZD1

| Battery type | Nominal | Fully charged | Cut-out (best life) | (Safe) | (Minimum) | ZD1 |
|---|---|---|---|---|---|---|
| Lead-acid | 6V | 7.2V/7.35V* | 5.75V | 5.5V | 5.25V | link |
| Lead-acid | 12V | 14.4V/14.7V* | 11.5V | 11.0V | 10.5V | 3.3V |
| Lead-acid | 24V | 28.8V/29.4V* | 23.0V | 22.0V | 21.0V | 15V |
| LiFe 2S | 6.6V | 7.2V | 6.2V | 6.0V | 5.6V | link |
| Li-ion 2S | 7.2V | 8.2-8.4V | 6.6V | 6.0V | 5.4V | link |
| Li-po 2S | 7.4V | 8.4V | 7.2V | 6.6V | 6.0V | link |
| LiFe 3S | 9.9V | 10.8V | 9.3V | 9.0V | 8.4V | link |
| Li-ion 3S | 10.8V | 12.3-12.6V | 9.9V | 9.0V | 8.1V | 3.3V |
| Li-po 3S | 11.1V | 12.6V | 10.8V | 9.9V | 9.0V | 3.3V |
| LiFe 4S | 13.2V | 14.4V | 12.4V | 12.0V | 11.2V | 3.3V |
| Li-ion 4S | 14.4V | 16.4-16.8V | 13.2V | 12.0V | 10.8V | 3.3V |
| Li-po 4S | 14.8V | 16.8V | 14.4V | 13.2V | 12.0V | 5.1V |
| LiFe 5S | 16.5V | 18.0V | 15.5V | 15.0V | 14.0V | 5.1V |
| Li-ion 5S | 18.0V | 20.5-21.0V | 16.5V | 15.0V | 13.5V | 8.2V |
| Li-po 5S | 18.5V | 21.0V | 18.0V | 16.5V | 15.0V | 8.2V |
| LiFe 6S | 19.8V | 21.6V | 18.6V | 18.0V | 16.8V | 8.2V |
| Li-ion 6S | 21.6V | 24.6-25.2V | 19.8V | 18.0V | 16.2V | 8.2V |
| Li-po 6S | 22.2V | 25.2V | 21.6V | 19.8V | 18.0V | 10V |

Note: 2S/3S/4S/5S/6S refers to the number of cells in series    * gel cell or AGM type lead-acid battery

roughly proportional to the number of cells for a given battery chemistry.

As mentioned earlier, you can adjust the value for RH if necessary – lower values give more hysteresis and higher values less. This will not affect the cut-off voltage, although hysteresis does vary slightly as VR1 is adjusted.

### Construction

The *Battery LifeSaver* is built on a PCB which is available from the *EPE PCB Service,* coded 11108131, measuring 34 × 18.5mm. Referring to the overlay diagram (Fig.3), start by soldering MOSFET Q1. It has a large pad on the underside which must be in intimate contact with the large pad on the PCB to ensure both low resistance (so it can handle high currents) and a good thermal bond for proper heat dissipation.

To achieve this, first spread a moderately thin layer of solder paste evenly over the pad and a good dollop of it on the smaller pin 4 pad, at lower left. Position Q1 over its pads and press it down, then apply heat to the small pin 4 pad so as to melt the solder paste until Q1 is held in place. You may find you have to add some solder wire to get a solid joint.

Check that Q1 can't move, then examine its alignment. In particular, ensure that the other three pins are correctly positioned over their pads and the tab is not totally covering the pad to which it is to be soldered; there should be a thin sliver of pad visible – although this may be obscured by solder paste.

To adjust the alignment, re-heat the solder on pin 4.

Once you are happy with its position, melt the solder paste along the edge of the large tab by running the tip of the iron along up and down along

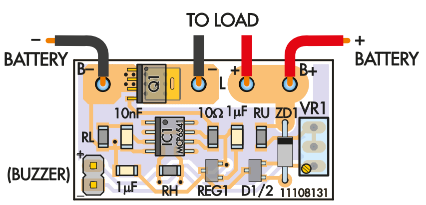



**Fig.3: follow this PCB overlay diagram to build the unit. Most parts are SMDs and all mount on the top side of the board. VR1 can be laid over to keep the whole thing relatively thin, so it can be squeezed next to a battery. Heavy-duty wires to the battery and load solder directly to the large pads at top. Use of the pads at lower-left is optional, for connecting a piezo buzzer for a low-voltage alarm.**

the exposed section. It may help to add a bit more solder.

You will need to keep the tab heated for several more seconds so that the paste underneath all melts and fills the gaps, forming a solid junction.

Note that this will require a fairly hot iron as there is a large area of copper connected to this pad. Note also that you will need to put the PCB on a heat-resistance surface as the underside will get very hot indeed.

To avoid overheating the MOSFET itself, stop after about ten seconds. You may need to let it partially cool down and then apply heat for another ten seconds or so, to ensure all the solder paste has melted.

When this happens, the volume of flux smoke produced should drop right off. You can then solder the remaining pins one at a time and clean up any bridges between them using solder wick. If necessary, clean up using isopropyl alcohol.

IC1 is a snack by comparison; it is the same size and has the same pin spacing, but there is no big pad underneath, so you simply pin it down by one lead, check the alignment and then solder the remaining pins once it is correctly oriented.

For the rest of the SMD components, apply some solder to one of the pads, heat it, slide the part in place using angled tweezers, remove the heat and check the alignment. If it's OK, make the remaining solder joint(s) and then refresh the first one with a dab of extra solder.

Don't get REG1 and D1 mixed up because they look very similar; the resistors will be labelled with their value (although you may need a magnifying glass to read it) but the capacitors won't be.

If you do get confused, you should be able to tell which is the 10nF as it will be thinner than the other two.

With the SMD components in place, fit ZD1 with the orientation shown and then VR1, with its adjustment screw towards the bottom of the board. You can bend its leads over before soldering, as we have, to keep the overall assembly thin so that it will fit into tight spaces.

Note that if you are going to use the unit with a sealed lead-acid battery ('gel cell'), these are often fitted with spade lugs.

So you could solder wires to the PCB and crimp female spade lugs onto those connected to the B+/B– terminals and male spade lugs to those connected to the L+/L– terminals. That would then allow you to easily connect the device in-line between the battery and device without any additional soldering.

## Testing and adjustment

The easiest way to set up the *Battery LifeSaver* is using a variable voltage power supply (eg, a bench supply) but if you don't have one, you can instead connect a fully charged battery (or power supply with a similar voltage) across a 1-10kΩ potentiometer.

The pot wiper connects to the B+ terminal on the PCB, while the negative terminal of the power supply goes to B–.

We used small hook probes to make the connection to these terminals, to avoid having to solder them initially (see photo) but if you do solder wires on, it's probably a good idea to keep them long and use thick, heavy-duty wire so that you can also use them for the final wiring.

Adjust the bench supply or pot to give the board close to the nominal battery voltage (measured across B+ and B–), then measure the current flow by connecting a multimeter, set to mA or µA, in series with one of the board's supply leads.

You should get a reading of around 5µA. If it's more than 10µA or less than 2µA then something is wrong and you will need to carefully check the assembly (note that not all multimeters can read such low currents with precision).

Set the DMM to volts mode and measure between the + terminal of CON5 (upper) and the B– battery terminal. Assuming your DMM is accurately calibrated, you should get a reading in the range of 4.95-5.05V.

Now adjust VR1 fully anti-clockwise (until it clicks) and measure the resistance between the L– and B– terminals. The reading should be close to 0Ω, meaning Q1 is on. If not, check the supply voltage and try turning it up slightly, but don't exceed the full-charge voltage of your battery.

Assuming Q1 is on, reduce the supply voltage to the PCB until it is at your desired battery cut-off voltage, as measuring between B+ and B–.

Confirm that Q1 is still switched on, then slowly turn VR1 clockwise until Q1 switches off and the resistance reading increases dramatically. It should be above 10MΩ and may give a reading of 'oL' (ie, effectively open circuit) on your DMM.

To check this, we simply clipped the test leads connected to L– and B– onto our DMM probe tips and used clip leads to connect the power supply to B+ and B–. This allowed us to vary the voltage while watching the MOSFET's resistance.

You can confirm that the board is working properly by turning the supply voltage up by the hysteresis voltage (a couple of volts should do); Q1 should then turn back on again.

## Installation

Once you have soldered the leads to the PCB, it's a good idea to sleeve the whole thing with 25mm diameter heatshrink tubing so that once it's inside the battery compartment, or secured to the outside of a battery, it can't short against battery terminals or any other exposed metal.

Wire it up according to Fig.3. There are two different ways to connect the load's positive terminal. Ideally, it should go straight to the battery's positive terminal, but since that will already be wired to the *Battery LifeSaver* board, it may be easier to connect it to the L+ terminal on the PCB instead.

This means the full-load current has to pass through the PCB twice, which will slightly increase losses but should not cause any problems within the ratings we have provided.

### Table 2: resistor values for different cut-out voltage ranges

| Cut-out range | Hysteresis | RL (1%) | RU (1%) | RH | Iq* |
|---|---|---|---|---|---|
| 5.2-5.6V | ~0.3V | 10MΩ | 330kΩ | 10MΩ | 3.2µA |
| 5.6-5.9V | ~0.4V | 10MΩ | 1.0MΩ | 15MΩ | 3.2µA |
| 5.8-6.4V | ~0.5V | 6.8MΩ | 1.0MΩ | 15MΩ | 3.7µA |
| 6.4-7.4V | ~0.5V | 3.9MΩ | 1.0MΩ | 15MΩ | 4.4µA |
| 7.4-8.7V | ~0.6V | 3.3MΩ | 1.5MΩ | 15MΩ | 3.5µA |
| 8.4-9.7V | ~0.6V | 3.3MΩ | 2.2MΩ | 22MΩ | 3.8µA |
| 9.6-11.0V | ~0.8V | 3.3MΩ | 3.0MΩ | 22MΩ | 4.4µA |
| 11.0-12.3V | ~1.0V | 3.3MΩ | 3.9MΩ | 22MΩ | 4.3µA |
| 12.2-13.6V | ~1.1V | 3.3MΩ | 4.7MΩ | 22MΩ | 4.3µA |
| 13.6-15.1V | ~1.2V | 3.0MΩ | 5.1MΩ | 22MΩ | 4.6µA |
| 15.5-17.1V | ~1.4V | 2.7MΩ | 5.6MΩ | 22MΩ | 4.7µA |
| 16.2-17.9V | ~1.6V | 3.0MΩ | 6.8MΩ | 22MΩ | 4.6µA |
| 17.7-19.3V | ~1.6V | 2.7MΩ | 6.8MΩ | 22MΩ | 4.5µA |
| 19.3-21.1V | ~1.6V | 2.4MΩ | 6.8MΩ | 22MΩ | 4.6µA |
| 20.6-22.6V | ~1.6V | 2.2MΩ | 6.8MΩ | 22MΩ | 4.9µA |
| 22.2-24.2V | ~1.8V | 2.2MΩ | 7.5MΩ | 22MΩ | 4.9µA |
| 23.7-25.8V | ~2.0V | 2.2MΩ | 8.2MΩ | 22MΩ | 4.9µA |

* Approximate quiescent current at cut-off voltage