By JIM ROWE

Lead-acid Battery Zapper!

This simple circuit is designed to extend the working life of liquid-electrolyte lead-acid batteries, by dissolving the lead-sulphate crystals which form on their plates. It's powered by the battery itself (or by a charger) and "zaps" the battery with a series of high-voltage pulses.

LEAD-ACID BATTERIES have been around for over 170 years now – ever since Gaston Plante built the first one back in 1834. They are used in huge numbers all around the world, mainly in the automotive industry. There's at least one in virtually every car, truck and bus to start the engine and power ancillary equipment, while multiple lead-acid batteries are also used in many electric vehicles to provide the motive power.

They're also used in large numbers for energy storage in solar and wind power plants. And by the way, we're talking about "wet" or liquid electrolyte batteries here (also called "flooded" lead-acid batteries).

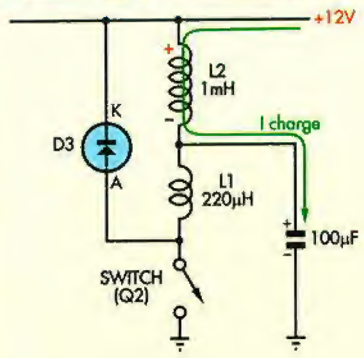
The lead-sulphate effect

Although we'd now be lost without them, lead-acid batteries are not without their faults. Probably their main drawback is that they have a relatively short working life, typically no more than about three or four years.

Why is this? Well, every time energy is drawn from a lead-acid battery, lead and sulphate ions from the electrolyte combine and are deposited on the plates in the form of soft lead-sulphate crystals. Then when the battery is recharged, these crystals dissolve again in the sulphuric acid electrolyte.

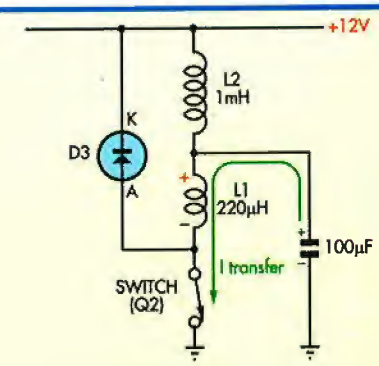
More accurately, MOST of them re-dissolve – but not all. Even if the battery is never over-discharged and is always recharged promptly after it has been discharged, a small proportion of the lead sulphate remains on the plates. These then harden into "hard" lead-sulphate crystals which are much less soluble and less conductive than before.

In practice, the formation of these



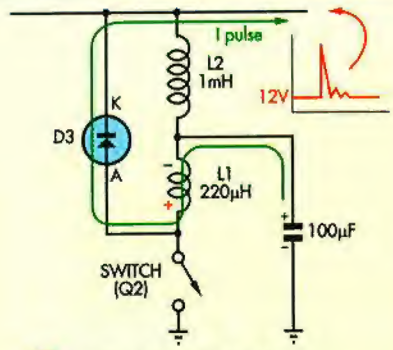
(A) CAPACITOR CHARGING PHASE

Fig.1(a): during the first phase of the circuit's operation, current flows from the battery (or charger) and charges a 100μF electrolytic capacitor via inductor L2.



(B) ENERGY TRANSFER PHASE

Fig.1(b): next, the switch is closed for 50μs, and current flows from the capacitor into L1. As a result, the energy stored in the capacitor is transferred to the inductor's magnetic field.



(C) DISCHARGE/PULSE PHASE

Fig.1(c): finally, the switch opens again, interrupting the inductor current and causing a high-voltage pulse across the inductor with the polarity shown. The green arrow shows the discharge current path.

hard lead-sulphate crystals gradually reduces the energy storage capacity of the battery. It does this both by masking the active areas on the plates and also by reducing the concentration of lead and sulphate ions in the electrolyte.

This "sulphation" effect has been understood for many years. It's also well known that the effect occurs much faster if a battery is over-discharged, left in a discharged state for more than a few hours, or frequently under charged. In fact, batteries mistreated in any of these ways tend to have a very short working life indeed.

For a long time, sulphation was regarded as non-reversible and batteries that had lost too much capacity due to this effect were simply discarded. This was not only wasteful but was also an environmental problem, because both lead and sulphuric acid are highly toxic materials.

Around the middle of last century, though, people in rural areas discovered that they could "resuscitate" sulphated batteries by zapping them with high-voltage pulses from their electric fence controllers. They didn't exactly understand why this method worked but kept using it because it did.

Subsequently, in 1976, the US Patent Office granted a patent to William H. Clark of Salt Lake City, Utah, for a method of charging lead-acid batteries by means of narrow high-current pulses. This was claimed to more effectively dissolve the lead sulphate crystals and hence prolong battery life. Since then a number of designs for pulse-type battery rejuvenators or "zappers" have appeared in electronics magazines, including one published in SILICON CHIP (Circuit Notebook) in February 2003 .

There is still a lot of argument about whether or not battery sulphation can be reversed and hence about the effectiveness of "zapper" type pulse rejuvenators. Our prototype did initially seem to achieve a useful amount of rejuvenation on a badly sulphated battery (which later went short circuit) but we really cannot vouch for the overall effectiveness of this circuit. It simply hasn't been tested on a wide enough range of batteries.

However, it's cheap enough to build, so interested readers can put one together and try it out for themselves.

By the way, please note that there is evidence that only "flooded" (liquid electrolyte) lead-acid batteries respond to this type of pulse desulphation. Sealed batteries with "gel" electrolyte don't respond much at all, so we don't recommend using the zapper on this type of battery.

It's also worth noting that even on flooded lead-acid batteries, pulse desulphation is not quick. It can take tens or even hundreds of hours to achieve a significant amount of rejuvenation.

A problem with many of the published zapper designs, including the one in our February 2003 issue, is that they use a P-channel power MOSFET. However, these are more expensive and harder to obtain than N-channel devices, so we've had quite a few requests for a new design using one of the latter devices instead. And that's exactly what we've done, with the design described here using a low-cost IRF540N MOSFET.

How it works

The basic principle used in desulphating zappers is quite simple: they draw a small amount of energy from either the battery itself or a charger connected to it, store this energy in a capacitor and then deliver it back to the battery as a narrow high-voltage pulse. In other words, a short pulse of current is forced through the battery

Disclaimer!

As stated in the article, our initial experiences with the Lead-Acid Battery Zapper indicated positive results. However, we must emphasise that our testing has been much too limited for us to make any claims or give any guarantees regarding the effectiveness of this unit.

In practice, you may find that the zapper successfully "rejuvenates" some batteries, particularly if the battery has simply sulphated due to lack of use. However, it cannot possibly rejuvenate a battery that is worn out – ie, one in which the active material on the plates has been severely degraded.

Depending on the battery, it's also possible that any rejuvenation effects may be only temporary in nature.

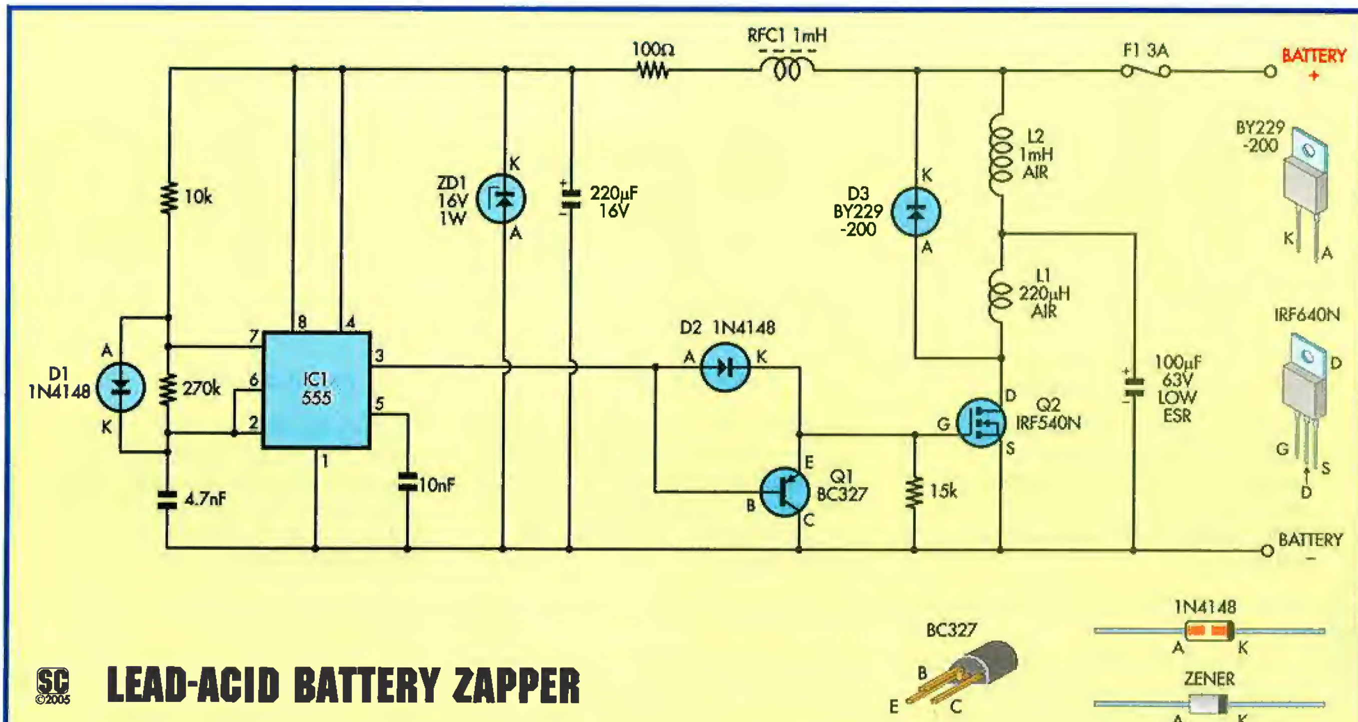


Fig.2: the circuit for the battery zapper uses a 555 timer IC to turn MOSFET Q2 on for 50µs every 1ms (ie, at a 1kHz rate). Q1 shorts Q2's gate to ground each time IC1's pin 3 output switches low, to ensure a fast turn off.

in the "charging" direction. It is these short current pulses which are claimed to dissolve the sulphate crystals (providing you're patient).

Fig.1 shows the basic scheme. As shown, the circuit consists of two small inductors, a 100µF electrolytic capacitor, a fast-recovery diode (D3) and a high speed electronic switch. The switch is actually the N-channel power MOSFET (Q2) but it's shown in Fig.1 as a switch because that's how it's being used.

During the first phase of the circuit's operation (A), current flows from the battery (or charger) and charges the 100µF electrolytic capacitor via 1mH inductor L2. This charging phase lasts about 950µs, which is quite long compared with the next phase.

Next, during the second phase of operation (B), the switch is closed. This connects 220µH inductor L1 to ground (battery negative), resulting in a sudden flow of current from the capacitor into L1. As a result, the energy stored in the capacitor is transferred to the inductor's magnetic field.

This phase only lasts for about 50µs – ie, just long enough for the energy transfer to take place.

At the end of the second phase, the switch is opened again (C). This sudden interruption of the inductor current causes an immediate reversal of the voltage across the inductor and so a high-voltage pulse appears across the inductor with the polarity shown. As a result, a discharge current pulse flows from the 100µF capacitor, down through L1, up through diode D3 and then out through the battery. This is the third phase of the circuit's operation.

This sequence of events is repeated indefinitely while ever the "zapper" is connected to a 12V battery (or battery and charger combination). That's because as soon as the discharge energy pulse from L1 has ended, the 100µF capacitor begins charging again via L2. So the remainder of the third phase becomes the first phase of the next charge-transfer-discharge cycle and that's how it keeps going.

This view shows the completed PC board. It's dominated by the 1mH and 220µH inductor coils.

Circuit details

Fig.2 shows the full circuit details of the Lead-Acid Battery Zapper. It incorporates all the circuitry shown in Fig.1, plus some extra parts to generate the short pulses to turn MOSFET Q2 on for 50µs every 1ms. In other words, Q2's gate is driven with

50µs-wide positive pulses at a rate of 1kHz, which means that the pulses are spaced 950µs apart.

This train of narrow pulses is generated by 555 timer IC1, which is connected as an astable oscillator. Diode D1, the 10kΩ and 270kΩ resistors, and the 4.7nF timing capacitor ensure a very high mark-space ratio at the pin 3 output. In operation, D1 ensures that the 4.7nF capacitor charges up very quickly via the 10kΩ resistor but can only discharge relatively slowly via the 270kΩ resistor (ie, when the internal discharge transistor on pin 7 turns on). As a result, IC1's pin 3 output goes high for 50µs, then low for 950µs and so on.

Transistor Q1 and diode D2 are used to ensure that the pulse stream from pin 3 of IC1 turns switch Q2 on and (especially) off very rapidly. In effect, they compensate for the charge stored in Q2's gate-channel capacitance when the MOSFET is turned on.

They do this very simply: when IC1's output goes high, D2 conducts and the pulse is applied directly to Q2's gate to turn it on. When IC1's output subsequently drops low again, this suddenly turns on transistor Q1 and effectively connects a short-circuit between Q2's gate and ground. As a result, the gate charge in Q2 is discharged very rapidly, making Q2 turn off again in very short order.

There's very little else left to explain.

The large inductors on this prototype unit were secured using spacers, screws and washers but the final version uses cable ties to secure the inductors instead.

Inductor RFC1, the 100Ω series resistor and zener diode ZD1 allow the +12V DC rail to be applied to IC1 but block the high-voltage pulses generated in the output stage from reaching the IC. Fuse F1 is there to protect the circuit from damage if the supply leads to the battery (or charger) are connected with reverse polarity.

Construction

Construction of the Lead-Acid Battery Zapper is straightforward, with all parts (except for the fuse) mounted on a PC board coded 14107051 and measuring 122 x 57mm. This board has cutouts in each corner so that it fits snugly inside a standard UB-3 utility box (130 x 67 x 44mm).

Fig.3 shows the assembly details. As usual, it's easiest to fit the low profile resistors and inductor RFC1 first, followed by the smaller capacitors and then the electrolytics. Note that the electrolytics are polarised, so make sure they go in the right way around.

Next, fit diodes D1 and D2, again taking care to ensure correct polarity. The same applies to zener diode ZD1, which can also now go in.

That done, fit transistor Q1, MOSFET Q2 and diode D3, which is in a 2-pin TO220-style package similar to the package for Q2. These devices are

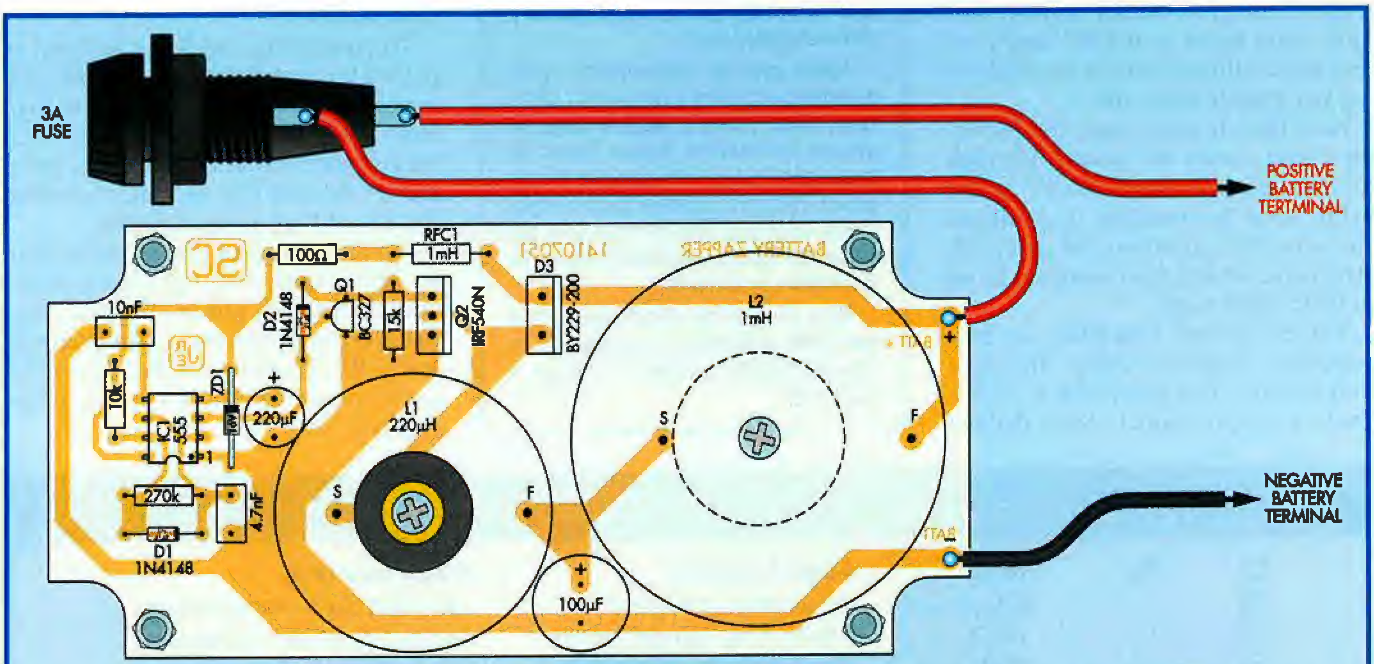


Fig.3: follow this parts layout diagram to build the PC board. Note that the PC board sold by Jaycar will have extra holes so that the large inductors can each be secured using two cable ties.

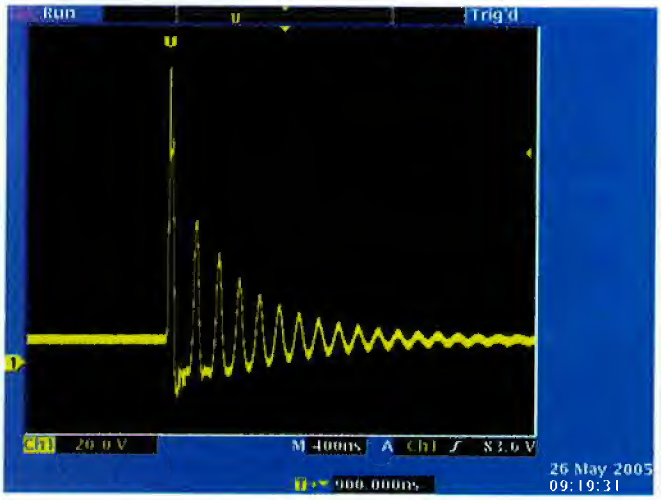


Fig.4: this scope shot shows the pulse waveform delivered to the battery. Note the ringing in the pulse waveform following the main 50μs spike.

all polarity sensitive, so again follow Fig.3 carefully to ensure correct orientation. Follow these parts with IC1, which should be fitted with its notched end towards the 270kΩ resistor.

The last components to fit are the two large air-cored inductors (L1 and L2). These are both wound on plastic bobbins, with their wire ends emerging from holes or slots in the lower cheek.

Securing the inductors

Both inductors on the prototype were secured to the board using nylon spacers inside their centre void, with a screw at each end, along with an M3 flat washer and 16mm grommet at the top of L1. This is the method shown in the photos and on the wiring diagram (Fig.3). However, the kit version will have extra holes in the PC board, so that each inductor can be secured using two plastic cable ties.

Note that, in each case, the inductor's leads must be passed through their matching holes in the PC board before they are secured in position. Once they're in position, the assembly is turned over and their leads soldered to their board pads.

The PC board assembly is now complete. However before fitting it into the box, it's a good idea to solder the two supply leads to their pads at the righthand end of the board. Just strip 4mm of insulation from the end of each length of cable, pass these down through their respective holes in the PC board (red to positive, black to negative) and solder them to the PC pads underneath.

Final assembly

The PC board assembly is supported inside the case on four M3 x 6mm untapped spacers and secured using M3 x 12mm countersink head screws, lockwashers and nuts.

The first step is to use the board itself as a template to mark out the mounting holes. That done, remove the board, drill the holes to 3mm, and use an oversize drill-bit to countersink the holes from the back of the case.

A further two holes are required at one end of the case to pass the battery leads and these can be drilled to 4mm about 10mm down from the top. The panel-mount fuseholder is mounted at the other end of the case and requires a shaped hole to suit the threaded body. This hole can initially be drilled to 4mm, then carefully enlarged using a tapered reamer and shaped using a small flat file.

That done, the board assembly can be fitted to the case. This is done by first installing the four screws and fitting the 6mm-long spacers, after which the board assembly can be lowered into position while feeding its negative (black) power lead out through its matching hole at one end. It's then simply a matter of fitting the lockwashers and nuts and tightening up the screws, to secure the assembly in place.

The next step is to cut the positive (red) input/output lead about 120mm from the end of the board and remove about 5mm of insulation from the free end. That done, fit the fuseholder to the lefthand end of the case, with its side solder lug uppermost for access, and solder the positive lead from the PC board to it.

The remaining red lead can then be passed through its hole in the case and soldered to the fuseholder's other lug. Note that you will have to dress this lead carefully around L2 and the upper tabs of D3 and Q2, so that it reaches the fuseholder without strain.

Finally, complete the construction by fitting the lid to the case and attaching the two 32mm alligator clips to the far ends of the two input/output leads. Be sure to fit the red clip to the positive lead and the black clip to the negative lead.

WARNING!

Hydrogen gas (which is explosive) is generated by lead-acid batteries during charging. For this reason, be sure to always charge batteries in a well-ventilated area.

Never connect high-current loads directly to a battery's terminals. Similarly, when using a battery charger, always connect its output leads to the battery before switching on mains power. Failure to observe these simple precautions can lead to arcing at the battery terminals and could even cause the battery to explode!

Note too that the electrolyte inside lead-acid batteries is corrosive, so wearing safety glasses is always a good idea.

Table 1: Resistor Colour Codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	1	270kΩ	red violet yellow brown	red violet black orange brown
☐	1	15kΩ	brown green orange brown	brown green black red brown
☐	1	10kΩ	brown black orange brown	brown black black red brown
☐	1	100Ω	brown black brown brown	brown black black black brown

The PC board fits neatly inside a standard UB3 utility box and is secured using 6mm spacers and machine screws & nuts.

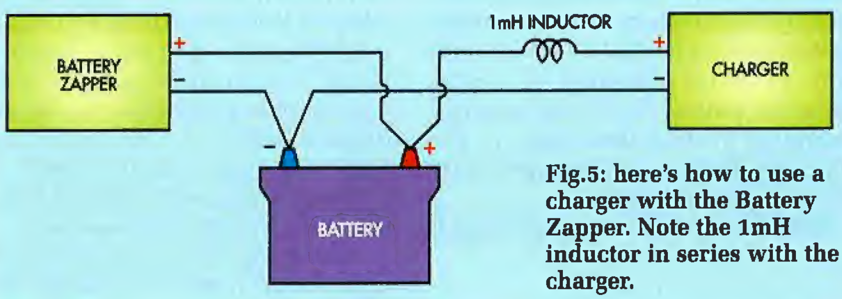


Fig.5: here's how to use a charger with the Battery Zapper. Note the 1mH inductor in series with the charger.

Your battery zapper is now complete and ready to use.

Putting it to use

Using the zapper is easy – just connect its leads to the terminals of the battery you want to rejuvenate (red to positive, black to negative).

There's only one qualification: if the battery is already so discharged that it can't supply the 50mA or so needed to operate the zapper, you'll need to connect a conventional trickle (or low-current) charger to the battery as well – at least to get the rejuvenation process started (see Fig.5). And if the battery is very badly sulphated as well, you'll have to keep the charger connected for quite a while.

After that, it's simply a matter of leaving it to pulse away until the sulphate crystals inside the battery have dissolved. This can take quite some time – from a few days to a few weeks – so you need to be patient.

If your charger doesn't have an inbuilt current meter, you can connect an ammeter in series with one of its leads so that you can monitor the charging rate. This should increase slowly as the sulphate crystals dissolve.

By the way, if you do have to connect a charger to the battery to power the zapper, you *must* use a 1mH air-cored inductor (the same as L2) in series with one of the charger's leads – see Fig.5. There are two reasons for this:
(1) to protect the output circuitry of the charger from possible damage; and
(2) to prevent the charger's relatively low output impedance from shunting the pulses, thereby reducing their effectiveness.

It doesn't always work

A final warning: not all lead-acid batteries are capable of being desulphated by using this zapper (or anything else, probably). In some batteries, the lead-sulphate crystals stubbornly resist the pulsing effect and the battery can sometimes even develop a short-circuit between the plates.

So if the battery charger current suddenly increases to a very high level, remove the power and write that battery off as one that cannot be saved. In other words, there are no guarantees that the zapper can resurrect *all* badly sulphated batteries – it can't. But, on the other hand, it's easy and cheap to build, so there's not much to lose in giving it a try. **SC**

Parts List

1 PC board, code 14107051, 122 x 57mm
1 utility box, UB3 size (130 x 67 x 44mm)
4 6mm long untapped metal spacers
4 12mm long M3 machine screws, countersink head
4 M3 nuts and star lockwashers
1 220µH air-cored crossover inductor (L1)
1 1mH air-cored crossover inductor (L2)
1 1mH RF choke (RFC1)
4 plastic cable ties (to secure inductors L1 & L2)
1 M205 panel-mount fuseholder
1 3A slow-blow M205 fuse
1 1.5-metre length of heavy-duty cable, red insulation
1 1-metre length of heavy-duty cable, black insulation
1 pair of 32mm alligator clips (red & black)

Semiconductors
1 555 timer (IC1)
1 BC327 PNP transistor (Q1)
1 IRF540N N-channel 60V/12A MOSFET (Q2)
1 16V 1W zener diode (ZD1)
2 1N4148 diodes (D1,D2)
1 BY229-200 fast recovery diode (D3)

Capacitors
1 220µF 16V RB electrolytic
1 100µF 63V low-ESR RB electrolytic
1 10nF greencap
1 4.7nF greencap

Resistors (0.25W 1%)
1 270kΩ   1 10kΩ
1 15kΩ   1 100Ω

Where To Buy A Kit
This project has been sponsored by Jaycar Electronics and they own the design copyright. A kit of parts is available from Jaycar for $A39.95 – Cat. KC-5414.