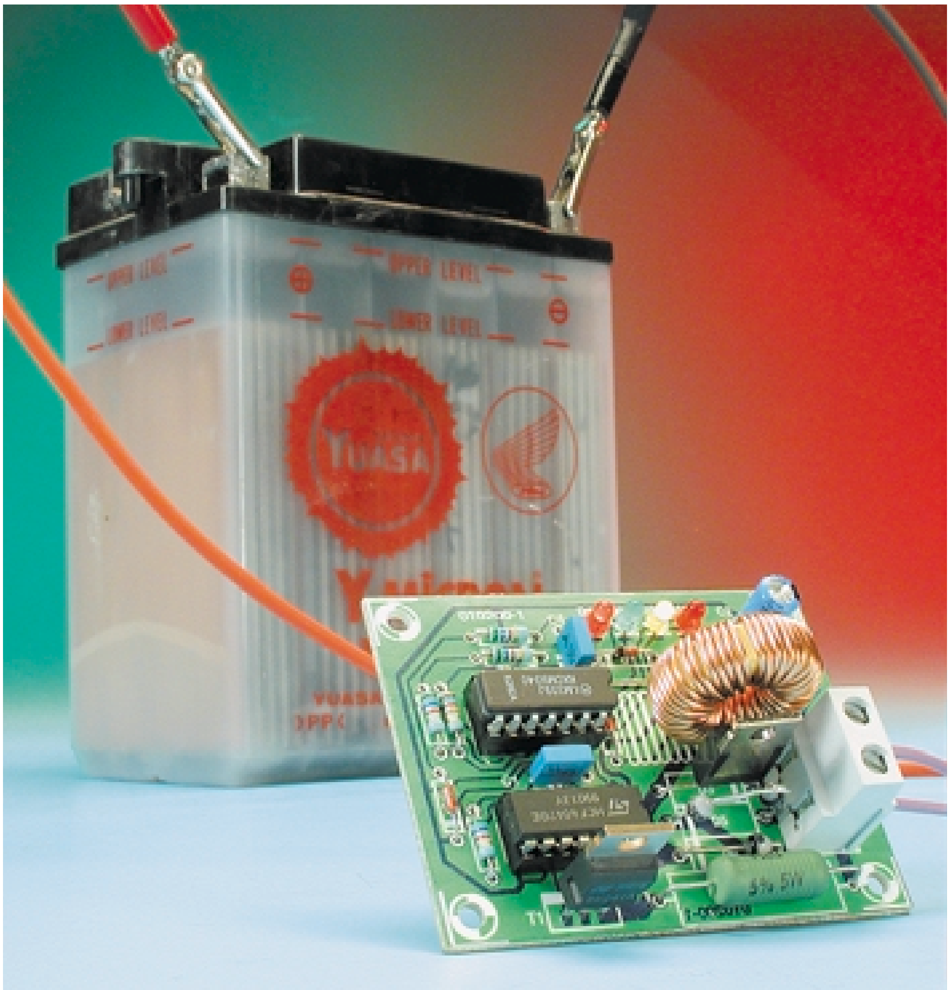
Lead-Acid Battery Revitaliser

a de-sulphation device for worn out batteries

Design by K. Walraven

This circuit makes it possible to do something that was previously unthinkable: reversing the effects of sulphation in tired lead-acid batteries. The circuit is also recommended for use as a conditioner for new batteries.



In a recent scientific journal it was stated that 80% of lead-acid batteries eventually fail due to sulphation. This sulphation occurs due to general old age, non-ideal charge/discharge cycles or storage in a discharged state for too long. The last happens often with batteries in motorbikes and classic cars, since these have an enforced rest during the winter months. To counter this, *Elektor Electronics* has designed a special charger a couple of years ago, which keeps the batteries in good condition during their winter sleep.

What exactly is 'sulphation'? This is a condition when the lead sulphate that is formed on the plates of a battery during its discharge changes in structure. Fairly large sulphate crystals are formed, which block the pores of the lead plates and hence reduce their active area. This causes the capacity of the battery to be reduced — it can no longer supply large currents and it can not be charged effectively in the usual way. When such a sulphated battery was charged, conducting bridges (short circuits) appeared between the plates, of which it was thought up to now that they could not be

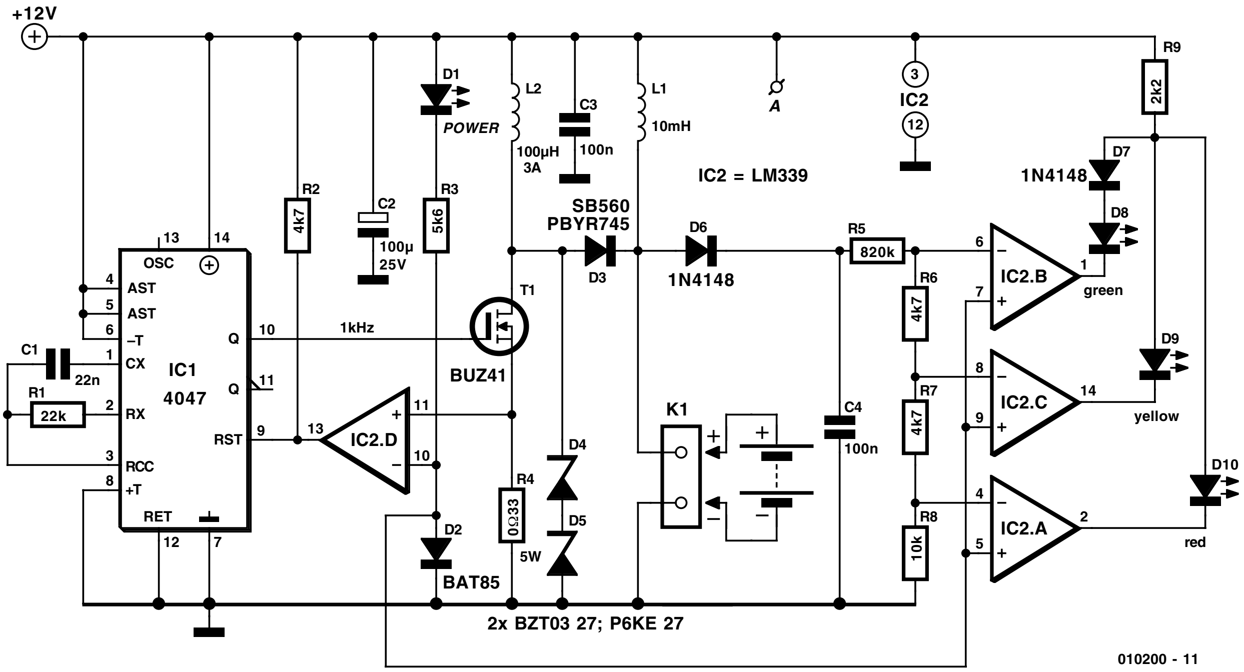


Figure 1. The circuit consists of a pulse generator and an indicator section.

removed. For the battery concerned it meant the end of its service life.

Known tricks

In the true spirit of electronics enthusiasts, you will not immediately take a tired battery to the recycling depot. After all, they aren't cheap and it is worth it to check that it really is at the end of its tether.

Insiders will undoubtedly know a few tricks that pep up a tired battery. One of the best known is to charge and discharge the battery repeatedly. This method causes a large part of the lost capacity to be restored for some reason or other. In other cases, applying large current pulses periodically seems to have some effect.

But both these method leave something to be desired in cases where badly sulphated batteries have to be brought back to life.

Cure

In recent years several manufacturers have been developing methods for the reversal of sulphation in lead-acid batteries, with varying success. The working methods seem to rely on some kind of pulsed charging. This is in contrast to normal charging procedures, which mostly use a constant voltage.

The design described here represents the latest techniques for revitalising lead-acid batteries. It is a device that periodically feeds short but fierce pulses to the battery, while discharging it slightly in between the pulses. This is, as far as known at the moment, the most effective way to break up unwanted deposits of sulphate crystals and to restore the battery plates to a reasonable condition.

Since the energy required for the charging pulses is derived from the battery itself (that may seem a bit weird at first, but the discharge of the battery is also part of this process), it is recommended to connect a charger in parallel with the battery and revitaliser when the battery has very little capacity left – but we'll go into detail of that later.

We have to be honest here and admit that our own experience of the circuit is not enough to give it an unconditional guarantee of successful operation. But since the circuit is not really expensive, its use deserves the benefit of the doubt.

Pulse generator

It can be seen from the circuit diagram in **Figure 1** that the electronics required for the revitaliser are very modest. The circuit contains two parts: a generator built round IC1, IC2d and T1, which creates the charging pulses, and an indicator circuit consisting of little more than three opamps (IC2a, b, c) and three LEDs, which show what state the battery is in.

Let's look at the pulse generator first. Just as the rest of the circuit, its supply is taken from the battery via K1. While we're talking about the supply, it should have a fairly constant voltage and be free from spikes (apart from the ones generated by the circuit itself). Suppression inductor L1 has been added to remove unwanted spikes, with C2 and C3 acting as reservoir capacitors. LED D1 lights up when the supply voltage is present.

To continue with the pulse generator, IC1 (a 4047) creates a square wave with a frequency of 1 kHz and a duty cycle that normally is 50%. As soon as the Q output of IC1 becomes high, FET T1 will turn on. This causes a (discharge) current to flow from the battery through L2, which increases linearly until the voltage across R4 is about 0.35 V; the current is then about 1 A.

At that moment comparator IC2d will switch over, causing IC1 to be reset and T1 to be turned off. The stored magnetic energy in L2 is now converted into a voltage spike,

COMPONENTS LIST

Resistors:
R1 = 22kΩ
R2,R6,R7 = 4kΩ7
R3 = 5kΩ6
R4 = 0Ω33 5W
R5 = 820kΩ
R8 = 10kΩ
R9 = 2kΩ2

Capacitors:
C1 = 22nF
C2 = 100µF 25V radial
C3,C4 = 100nF

Inductors:
L1 = 10mH
L2 = 100µH 3A suppressor coil

Semiconductors:
D1 = LED
D2 = BAT85
D3 = SB560 or PBYR745
D4,D5 = BZT03 27 or P6KE 27
D6,D7 = 1N4148
D8 = LED, green (high efficiency)
D9 = LED, yellow (high efficiency)
D10 = LED, red (high efficiency)
T1 = BUZ41
IC1 = 4047
IC2 = LM339

Miscellaneous:
K1 = 2-way PCB terminal block, lead pitch 7.5mm
PCB, order code **010200-1** (see Readers Services or Elektor Electronics website)

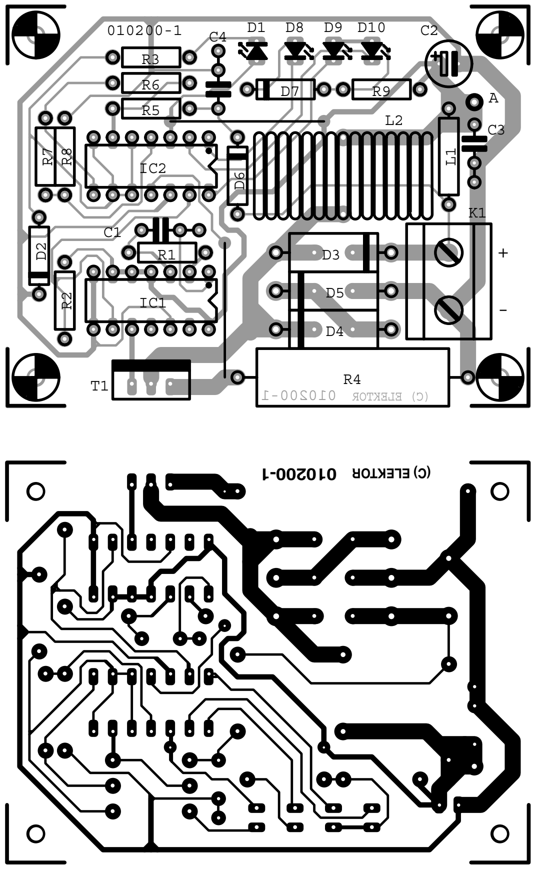


Figure 2. The use of this printed circuit board makes construction easy.

which is fed to the battery via D3.

The size of the spike is dependent on the state of the battery. When the battery is in a reasonable condition and its internal resistance is fairly low, then the peak of the spike will also be low (less than 15 V). With a high internal resistance the peak can be as big as 50 V. Its maximum value is limited by the two series connected zener diodes, D4 and D5.

Indicators

Since the condition of the battery can be determined by the size of the charging pulses, we've added a simple circuit that indicates the peak value of the pulses. The three comparators IC2a-c measure the peak value stored in C4 and switch over at voltages of 15, 20 and 30 V respectively. So when the battery is in a fairly good condition, the green LED (D8) lights up, with a mediocre battery the yellow LED (D9) and with a really poor battery the red LED (D10).

There is a detail that should be mentioned about the indicator circuit: to avoid all three LEDs from lighting up at the same time when the peak voltage is very high, they have been connected in parallel to one common series resistor (R9). Because the red LED has a lower voltage drop than the yellow LED, they will never light up at the same time. Since the yellow and green LEDs have a similar voltage drop, the same trick won't work here, which is why the green LED has an ordinary diode (D7) connected in series with it.

Construction

A compact printed circuit board (**Figure 2**) has been designed for this circuit, making the construction of this clever revitaliser a simple task even for the less experienced hobbyists. It's just a matter following the component layout and parts list carefully before construction. The battery is connected to terminal block K1 (observe the polarity!). Don't forget the wire links though; there are only two in this case, but without them the circuit will not work at all!

Because the charging pulses can cause high frequency interference, the completed printed circuit board should be mounted in a metal case.

The choice of components is not very critical. Any small Schottky diode can be used for D2. For D3 any fast power Schottky diode rated for at least 60 V/3 A is suitable.

The choice of T1 is also fairly wide, because in practice any power FET is suitable which is rated for 3 A and 100 V. The well-known BUZ10 would even be suitable, but then the zener voltage would have to be reduced to 27 V by replacing one of the zeners (D4 or D5) with a wire link. One important thing about these zeners: they can't be normal ones, but should be fast types. The zener voltage isn't critical as such, but the basic assumption is that the total voltage of zeners D4/D5 should be in the region of 40 to 50 V. In any case, don't leave out the zener diodes as that is a sure way to destroy MOSFET T1!

For L2 a standard suppression choke is used, which is rated for at least 3 A. The inductance of the choke is not critical; any value between 50 μH and 200 μH is fine. Special inductors for switch mode supplies are also suitable; often they function even better. The value of L1 also is not critical and can be anywhere between half and double the stated 10 mH.

Usage

There are three different ways in which the revitaliser can be used.

The first is to use it in an existing system (in a car for example) to prevent sulphation from occurring in a battery with little or no sulphation. The circuit is integrated with the system by connecting it directly to the battery using as short as possible cables. Since the circuit can be left connected permanently, nothing else has to be done. The current consumption is about 20 mA, so the battery could discharge if it is not charged up occasionally.

Restoration of batteries that have already sulphated can be done in two ways. The first way is to charge the battery, remove the charger and then connect the revitaliser. Because the energy for the charging pulses is taken from the battery itself it will slowly discharge. This process has to be followed closely since a fully discharged battery has to be recharged immediately. It is likely that in practice many charge/discharge cycles will be required before a badly sulphated battery can be brought back to life.

Because the method mentioned above requires a lot of attention and carries a risk that the battery can be left in a discharged state unnecessarily (which is very bad for a lead-acid battery!), the next way is probably better.

The battery is connected to the revitaliser, with a trickle charger connected in parallel. So no chargers should be used which give a current of 7 A or more, but one which gives a maximum of 1 or 2 A. This can be left connected to the battery continuously without any problems.

As already mentioned, it is possible to connect the revitaliser in a car to the battery permanently. This does however carry the risk that pulses of around 50 V can be created in the car's wiring when the internal resistance of the battery is high, that ism when the battery is known to suffer from sulphation already. The pulses are something which electronic equipment isn't very fond of. So, if there is reason assume the battery is in a poor state, it's better to be careful and not connect the revitaliser permanently. Instead, disconnect the battery from the car before connecting the revitaliser.

Effect?

With the three LEDs it is very easy to see what effect the pulse charging has. If the sulphation does reduce, the active area of the plates increases and the internal resistance of the battery becomes less. The charge peaks supplied by the revitaliser then become smaller. This can be seen by the colour of the lit LED. With a very poor battery the red LED will be lit initially. When the pulse charging has had some effect, the red LED will go out at some stage and the yellow LED will light up. And when the green LED finally takes over from the yellow one, it is a sign that the battery can be considered to be in a fairly good state again. A final check with a voltmeter should establish that the battery voltage (without the charger of course) is in the region of its nominal value of 12 V.

This check can be extended with a discharge test. A known load is connected to the battery and you simply time how long the battery can supply the load current. The useable capacity is calculated simply by multiplying the current by the time. When a 12 V battery is loaded by a 50 W lamp, a current of about 4 A will flow. If the battery lasts for five hours then its useable capacity is 20 Ah.

When the capacity is still a long way below the nominal value given by the manufacturer, the revitalising can be continued without any objection. Any further improvement should not be expected too quickly, since the restoration can easily take from several days to several weeks, depending on the state of the battery.

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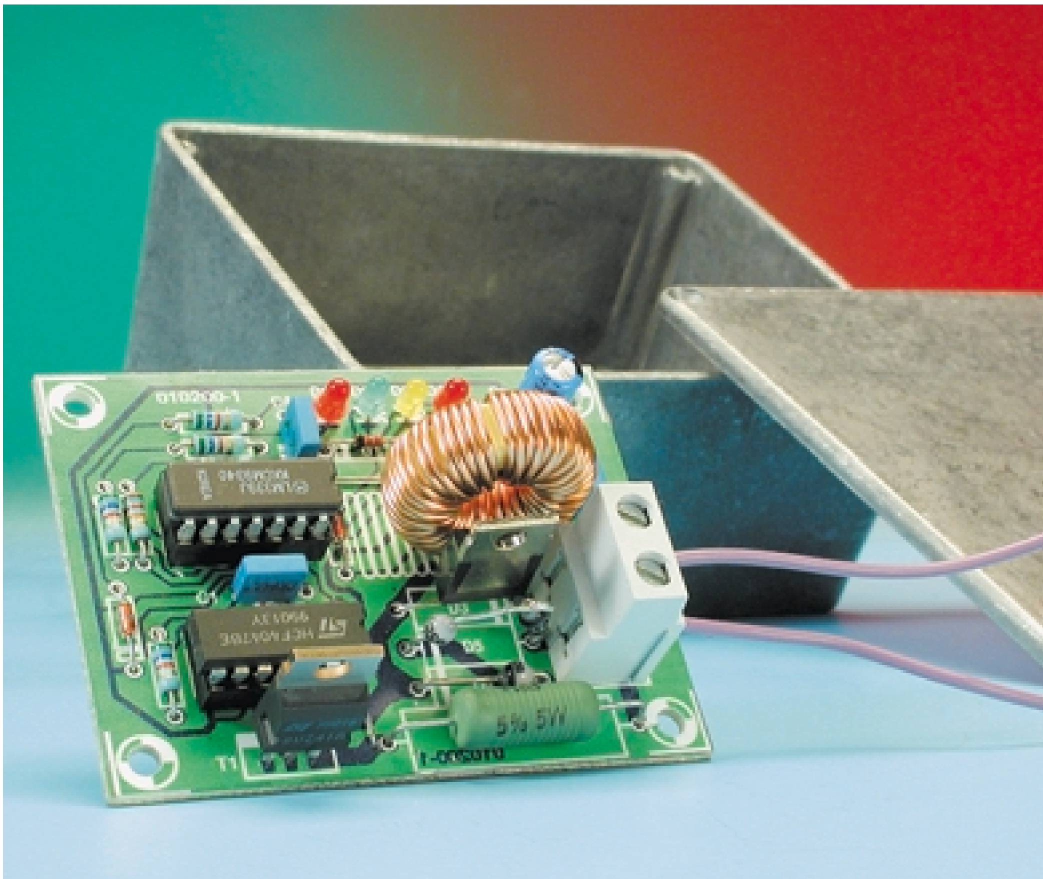


Figure 3. Keeping the possibility of interference in mind, the circuit is best mounted in a metal case.

VEHICLE BATTERY

Karel Walraven

This design is a follow-up to the triumphant 'Battery Revitaliser' project published in the September 2001 issue of *Elector Electronics*. From numerous reader responses, it appears that defective batteries are a common problem. Since prevention is naturally better than cure, here we present a circuit that can keep your battery in shape in a simple but effective manner.

JOGGER keep your battery fresh and young

The quality of lead-acid storage batteries has always been an awkward subject. Motorcyclists among our readers will be the first to agree with this. The most common example is a motorcycle that's put in storage for the winter and proves to have battery problems when spring comes. This involves more than just the fact that the battery has become partially discharged, since in many cases the battery has also noticeably deteriorated. That can be seen from the fact that even immediately after being charged, it performs poorly and quickly loses it charge.

This is also true for all situations in which lead-acid batteries are not used for an extended length of time. You might immediately think of cars 'put away' for the winter, but this problem also occur in other situations, such as batteries in backup power supplies (UPSs) that are not used for a while, batteries used with voltage inverters (in caravans), and batteries in pleasure boats that simply sit around doing nothing for most of the year after the boating season is over. It's thus easy to think of situations in which lead-acid batteries age prematurely due to lack of use. The inset provides additional information about the background of the process responsible for all of this, which is called 'sulphation'.

Idleness is deadly

For the purpose of this article, it's actually not necessary to know exactly why unused batteries deteriorate. It's sufficient to note that a bit of exercise at the right time can help keep them in shape. And that's what the circuit described here provides.

Unlike the 'Battery Revitaliser' described in the September 2001 issue of *Elektor Electronics*, this design is not intended to resuscitate apparently defective batteries, but instead to prevent premature aging due to lack of use. To avoid possible misunderstandings, it should be noted that this circuit cannot counteract normal aging or other conditions that can lead to defects.

As the whole idea is to keep the battery a little bit active, the circuit does not require a separate power supply. The necessary energy is simply taken directly from the battery itself. In the process, sulphation is prevented by loading the battery with a hefty current (40 A) for a short interval (50 µs) approximately every two minutes. Of course, this will ultimately cause the battery to discharge more quickly, but a fully charged car or motorcycle battery will easily make it through the winter. After all, the current consumption at 12 V is only around 2 mA.

Operation

The first 555 timer (IC1 in **Figure 1**) operates as an astable multivibrator and generates a continuous stream of pulses. The second 555 is a monostable multivibrator that is triggered on each negative edge of the pulses coming from its companion. As a result, it generates short pulses that drive power FET T1 fully on. The FET connects the battery directly to a power resistor, causing a heavy current to flow. The size of this current is primarily determined by the value of resistor R8.

The FET is intentionally driven here via a gate stopper resistor with a relatively high value. This causes it to switch on and off somewhat more slowly, which reduces the amount of interference generated. In this case, 'slow' means a few microseconds; a FET that's driven hard switches within a few nanoseconds. Here it isn't necessary to switch quickly, and there's no need to be concerned about a bit of extra power dissipation.

Despite the relatively slow switching, rather large voltage spikes can occur when the FET switches off. It is thus essential to connect a **fast** Zener diode (D5) across the FET for protection.

Construction

It's important to ensure that the ICs and IC sockets are fitted with the correct orientation. The sockets usually have a notched or bevelled corner, and the ICs have a dimple in the package. As seen from above, the topmost pin to the left of this marking is pin 1. It's best to use CMOS versions of the ICs, since this will keep the standby current consumption as low as possible. Several different manufacturers make the CMOS version of the 555, so type numbers such as TLC555, ICM7555 and LMC555 (as well as many others) all refer to the same kind of IC. However, the NE555, SE555 and LM555 are not CMOS types. They can also be used, but the current consumption will then be quite a bit higher (more than 10 mA).

Most of the current is actually used by the LED, so you should use a low-current type here (also referred to as a '2-mA LED'). When fitting it to the circuit board, make sure the long lead goes next to the triangle marking.

The capacitors in the circuit (except for the electrolytic capacitors) are ceramic types. That's because component value tolerance is not terribly important in this case, and a bit of temperature dependence also doesn't particularly matter.

New electrolytic capacitors also have one lead that's longer than the other one. That's usually the positive lead. On the circuit board, it must be placed next to the open rectangle. There's usually also a white stripe with minus (–) signs printed on the case of the capacitor. This marks the negative lead, which is indicated on the circuit board by a solid rectangle (the open rectangle is the + terminal).

Safety

Most people don't realise that despite the modest voltage, working with vehicle batteries can be quite hazardous. This is because such batteries can deliver especially high currents. That means you have to be especially careful with metal objects in the vicinity of a charged battery. A dangerous short circuit can be caused not only by a simple screwdriver or wrench, but also by dangling jewellery and wristwatches, both of which are notorious causes of avoidable suffering.

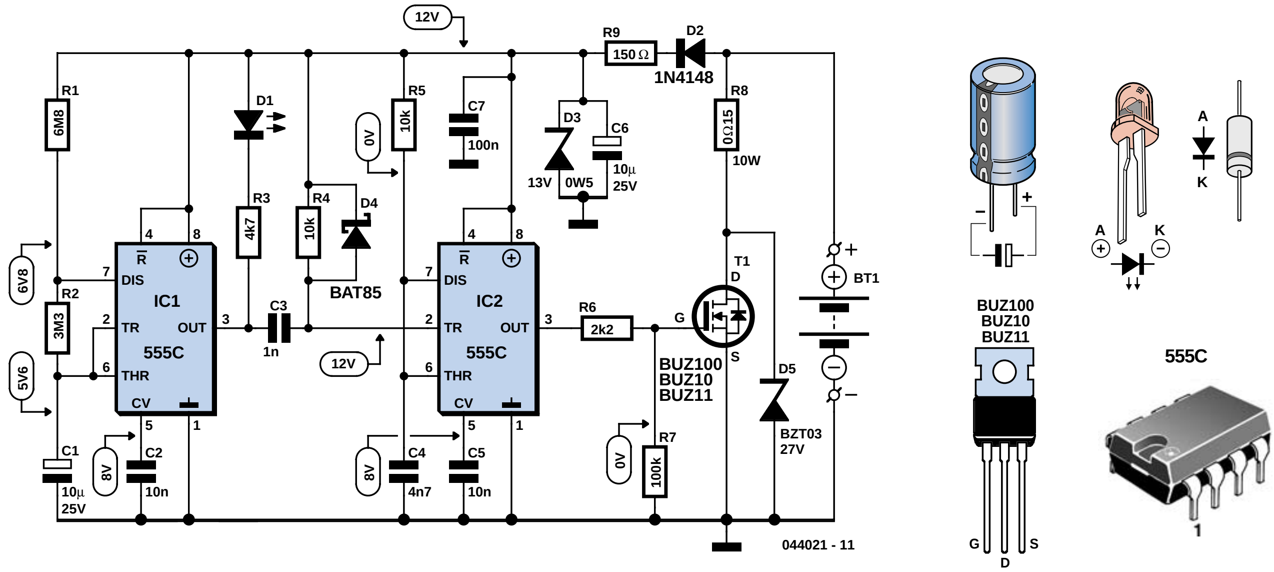
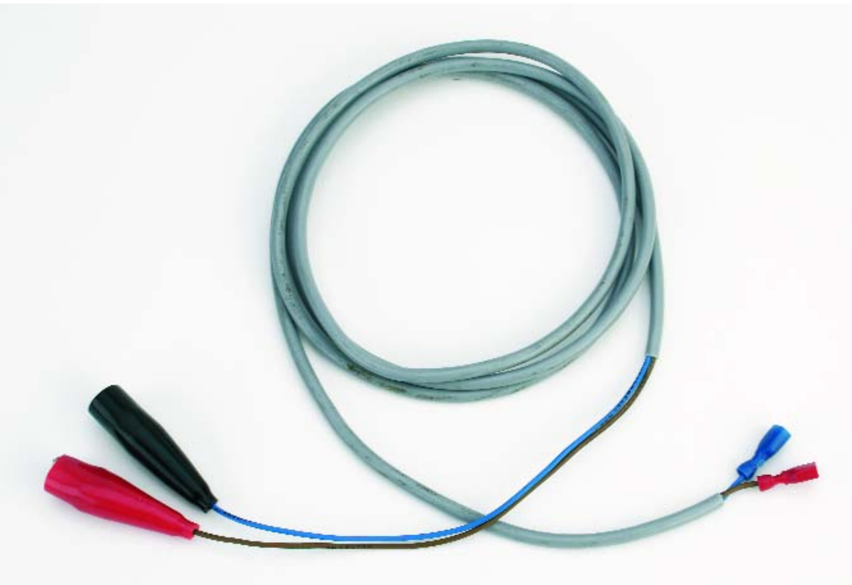


Figure 1. The general-purpose 555 once again proves its merits.



Prevent short circuits; make sure you use a properly insulated cord!

If something goes wrong with the circuit, there's thus an especially good chance that something will be destroyed. Normally, the victim will be the power resistor, the FET (see the inset) or a track on the circuit board. It's certainly possible for this to be accompanied by the release of heat, or even a bang and a bit of smoke. Consequently, you should always fit the circuit in an enclosure and ensure that no flammable materials are in the vicinity. Disconnect the circuit before charging the battery in the usual manner. Use flexible mains cable with a reasonably large cross-section (2×0.75 mm^2, for example) for the connections to the battery.

Everything OK?

For initial testing, we recommend leaving C1 off the circuit board and tem-

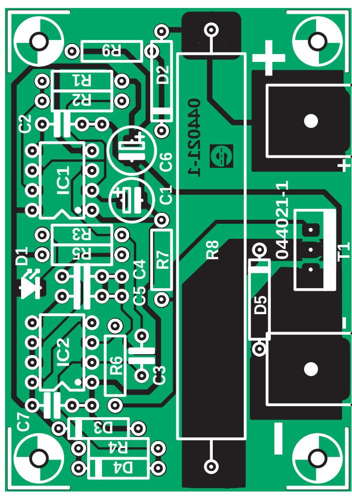


Figure 2. The circuit can be safely built using this printed circuit board design. Copper track layout available from our website.

COMPONENTS LIST

Resistors:
R1 = 6MΩ8
R2 = 3MΩ3
R3 = 4kΩ7
R4,R5 = 10kΩ
R6 = 2kΩ2
R7 = 100kΩ
R8 = 0Ω15, 5W or 10W
R9 = 150Ω

Capacitors:
C1,C6 = 10µF 25V, radial
C2,C5 = 10nF
C3 = 1nF
C4 = 4nF7
C7 = 100nF

Semiconductors:
D1 = LED, low current
D2 = 1N4148
D3 = zener diode, 13V 0.5W
D4 = Schottky diode, e.g., BAT43, BAT85
D5 = fast zener diode, e.g., BZT03 24V, 27V or 33V)
T1 = BUZ10, BUZ11, BUZ100 or IRF540
IC1,IC2 = 7555 (CMOS)
PCB, ready-made, order code **044021-1** (see Readers Services page). PCB layout available from Free Downloads section on www.elektor-electronics.co.uk

FETs

We have listed several options for FET T1, but the choice here is not critical. It's also unnecessary to make any changes to the circuit if you use it at 6 V. Still, in this case the preferred type for T1 is the IRF540. That's because this type of FET works with a lower gate voltage than the FETs in the BUZ family. For the same reason, FETs designated as 'logic-level FETs' are more suitable if you want to use the circuit at 6V, but they aren't essential. In principle, you can thus use any desired type of n-channel power FET that can handle at least 20 A at 50 V.

You're probably wondering how a FET rated at 20 A can handle a current of 40 A or more. To understand why this is possible, have a look at the 'Safe Operating Area' chart for the BUZ10 (**Figure 3**). It shows how much current can flow continuously (20 A), and how much current can flow for a short time. As the FET only conducts for a few tens of microseconds each time, the maximum allowable current during this short interval is just under 100 A. This information can also be obtained from the 'Absolute Maximum Ratings' in the date sheet, which specify 23 A and 92 A respectively.

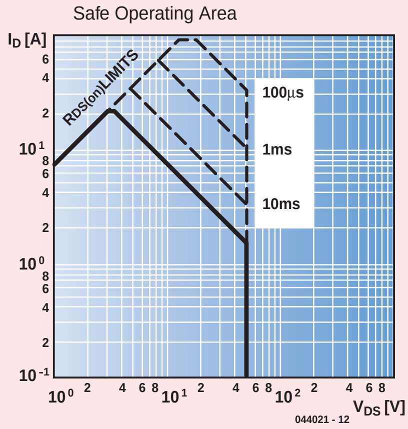
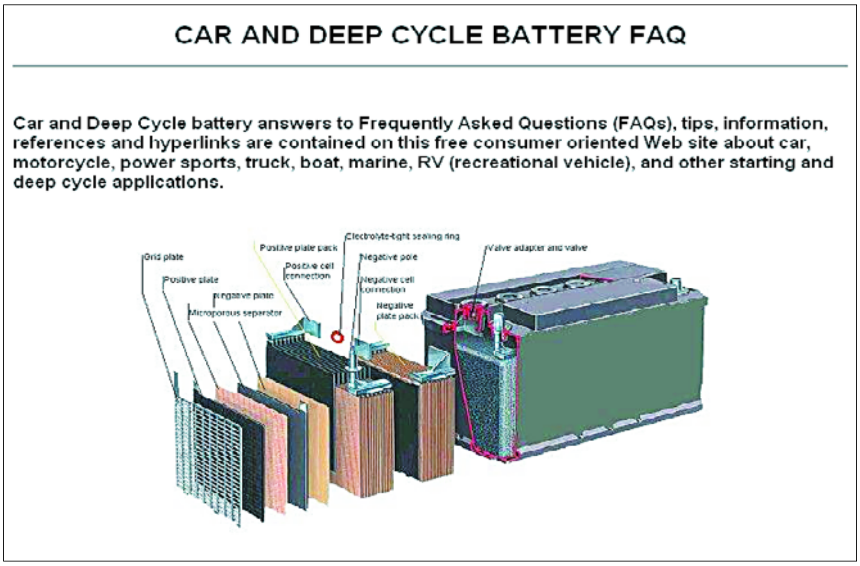


Figure 3. Safe Operating Area: maximum currents and voltages for the BUZ10.

porarily soldering a 100-nF capacitor to the board in its place. The LED should then flash approximately once a second. With a 10-µF capacitor fitted in this position, the period is a lot longer (2 to 3 minutes), and that's not so nice for testing. If the lamp blinks, you can confidently solder the 10-µF capacitor in place on the circuit board.

Voltages are marked at various places on the schematic diagram. If the circuit does not immediately work the way it should, you can compare your circuit with our tried & tested prototype by measuring these voltages. Here we should note that if you make measurements on pen 2, 6 or 7 of IC1, proper operation of IC1 will temporarily be disturbed, and you may have to wait a little while for the reading to stabilise. The stated values were measured using an electronic multimeter (10 MΩ impedance).



You can learn a lot more about lead-acid batteries and the dreaded sulphation process (among other things) at www.uuhome.de/william.darden/.

Six volts too

Many old-timers (vintage cars and motorcycles) use 6-volt batteries. Strictly speaking, this voltage is usually bit on the low side for switching a FET fully on. As a result, in practice the current through T1 will be a bit smaller, but it will still be sufficient to ensure obtaining the proper effect (keeping the battery fresh). It's thus not necessary to reduce the value of R8, since the circuit is designed to be used with 6-volt and 12-volt batteries without any modifications.

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Sulphation

The capacity of a lead-acid battery gradually decreases during its service life due to normal wear and tear, for a variety of reasons. However, the aging process is considerably accelerated if an uncharged battery is stored for longer than a week at a temperature below 10 °C or remains unused (while charged) for an extended length of time. That's because in such situations, a layer of non-conductive lead sulphate ($PbSO_4$) forms on and around the electrodes. This reduces the effective surface area of the electrodes, thus decreasing the capacity of the battery. This process is difficult or impossible to reverse by normal charging and discharging.

However, it is possible to break down sulphate crystals into lead and sulphuric acid by using high (or very high) charging currents. This method can be used to restore at least part of the lost capacity (see 'Lead-acid battery revitaliser' in the September 2001 issue). Still, it's better to prevent the formation of sulphate. One way to do this is to periodically apply a load to the idle battery. The circuit described in this article is especially suitable for this purpose.