ELABS PROJECT

Lead-acid Battery Activator 0-30 V

Also shows the battery quality

A well-known electronics store has been selling a very simple lead-acid battery activator for many years [1]. Although I can't prove it, my lead-acid batteries do seem to last longer since I started using the activator. The principle behind this circuit is very simple. The battery is loaded with a current of about 100 A for a period of 100 µs, which is repeated every 30 seconds. But this circuit is capable of more, which we'll show you in this article.

By **Jan Lichtenbelt** (The Netherlands)

PROJECT INFO

Test & Measurement
Hobby · Modelling · Batteries

entry level
➡ intermediate level
expert level

3 hours approx.

No special tools are required

€60 / $65 / £50 approx.

The theory is that short (large) current pulses will revert the sulfating of the lead plates [2]. I have used the Conrad Electronics circuit in parallel with a simple power supply, which is based on an LM317, set to 13.8 V, and used with a 7-Ah lead-acid battery. This power supply didn't seem to have any problems with these large current pulses.
Not only is sulfating prevented, but these types of peak current can also be used to determine the quality of batteries. We do this by letting a large current (I) flow for a very short period through an external shunt while measuring the reduction in the terminal voltage (V_t). The current flow is given by:

$$I = \Delta V_{shunt} / R_{shunt}$$

The internal resistance is:

$$R_i = (V_0 - V_t) / I$$

Where V_0 is the no load terminal voltage and V_t is the terminal voltage under load. This internal resistance gives an indication as to the quality of the battery: the lower it is, the better. The circuit shown here has an extended functionality. The design is suitable for use with 2, 6, 12 and 24V lead-acid batteries and works as both an activator as well as for the measurement of the internal resistance of all primary cells and batteries up to 30 V.
At first we thought we'd enhance the Conrad design, but that resulted in a ramshackle circuit that wasn't really suitable for use with such high currents. The disadvantage of the Conrad circuit is that the 0.1 Ω / 2 W shunt wasn't designed for use with these current pulses. In practice it could fail without you noticing.
It is shown in the literature [3] that the internal resistance depends mostly on the temperature, the State of Charge (SOC) and the age of the battery. The resistance increases when the temperature drops. It also increases when the battery is heavily discharged. Older batteries can also cause the internal resistance to increase. When you want to compare internal resis-

tance values, you should always measure them as much as possible under the same conditions. In other words, you should only vary one of the three previously mentioned parameters. Note that a relatively high temperature at room temperature is an indication that the battery is probably old or badly charged. In any case, you will obtain more detailed information on the state of your battery if you have its internal resistance as well as its terminal voltage.

2, 6, 12 and 24-V lead-acid battery activator

From the circuit in **Figure 1** we can see that the lead-acid battery activator uses a microprocessor to output a 100-µs long pulse to a MOSFET every 30 s. A shunt is connected to the battery in series with this MOSFET, which is protected against reverse polarity connections by a diode. The theoretical peak current when a shunt of 50 mΩ is used is about 100 A for a 6-V lead-acid battery.

The voltage measurement at the battery terminals is done with a separate set of wires, so that the large current flow doesn't distort the reading (four point measurement). Both circuits are separated from each other, and they're only connected together at the terminals using battery clips. As mentioned earlier, the current is calculated by measuring the voltage across the shunt.

The microprocessor takes care of the pulse generation. This is made visible via a blue led (LED1). This pulse needs to be fed to the shunt circuit, which happens via an optocoupler. The function of the LEDs for 6, 12 and 24-V lead-acid batteries is explained in **Table 1**.

This activator circuit is also perfectly suitable for use with 2V lead-acid batteries. One disadvantage in this case is that an external supply is required for the generation of the pulses. However, this could be implemented with a 2-5 volt step-up converter. The red, orange and green leds unfortunately won't be able to show the status of 2-V batteries.

Table 1. The three LEDs give a quick overview of the state of charge of lead-acid batteries.

Measurement range	0-10 V			0-20 V	0-30 V
Voltage	V < 2.5	2.5 < V < 5	5 < V < 10		
LED	2-V battery	4-V battery	6-V battery	12-V battery	24-V battery
Red	< 1.98 V	2.5 - 4.00 V	5 - 5.95 V	< 11.9 V	< 23.8V
Orange	1.98 - 2.08 V	4.00 - 4.16 V	5.95 - 6.25 V	11.9 - 12.5 V	23.8 - 25.0 V
Green	2.08 - 2.5 V	4.16 - 5 V	6.25 - 10 V	> 12.5 V	> 25.0 V

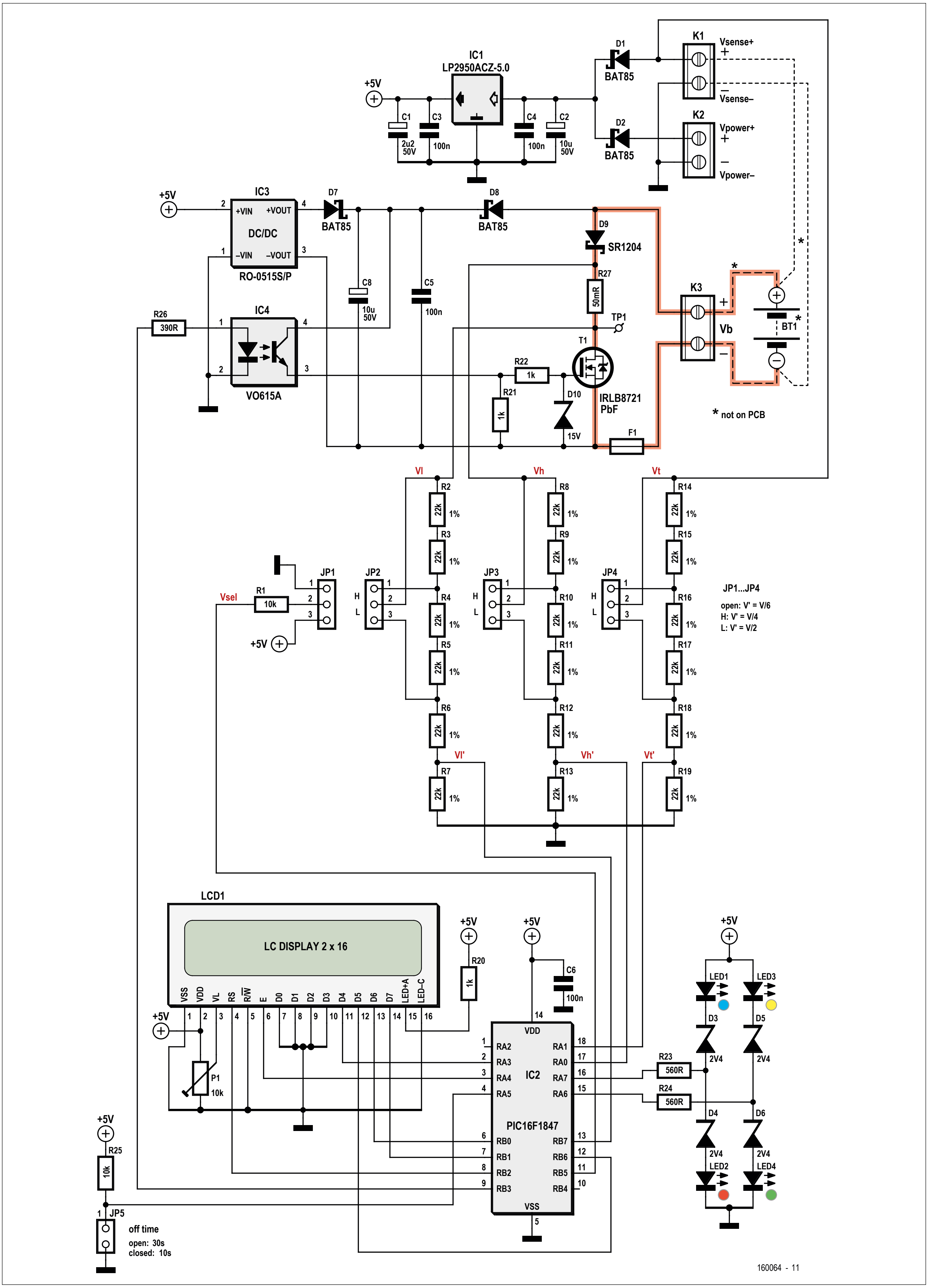

IC1
LP2950ACZ-5.0
+5V
C1
2u2
50V
C3
100n
C4
100n
C2
10u
50V
D1
BAT85
D2
BAT85
K1
Vsense+
Vsense–
K2
Vpower+
Vpower–
IC3
+VIN
+VOUT
DC/DC
–VIN
–VOUT
RO-0515S/P
D7
BAT85
D8
BAT85
D9
SR1204
R27
50mR
TP1
C8
10u
50V
C5
100n
R26
390R
IC4
VO615A
R22
1k
R21
1k
T1
IRLB8721
PbF
D10
15V
F1
K3
Vb
BT1
* not on PCB
Vl
Vh
Vt
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
22k
1%
JP1
JP2
JP3
JP4
Vsel
R1
10k
H
L
JP1...JP4
open: V' = V/6
H: V' = V/4
L: V' = V/2
Vl'
Vh'
Vt'
LCD1
LC DISPLAY 2 x 16
VSS VDD VL RS R/W E D0 D1 D2 D3 D4 D5 D6 D7 LED+A LED–C
P1
10k
R20
1k
C6
100n
IC2
PIC16F1847
VDD
VSS
RA2 RA3 RA4 RA5
RB0 RB1 RB2 RB3
RA1 RA0 RA7 RA6
RB7 RB6 RB5 RB4
R23
560R
R24
560R
LED1
LED2
LED3
LED4
D3
D4
D5
D6
2V4
R25
10k
JP5
off time
open: 30s
closed: 10s
160064 - 11

Table 2. Overview of warnings and when the program stops.			
	LED	**Flash rate**	**Action**
Possible open circuit	Green	Slow (1 s)	Wait until this is corrected
No terminal voltage*	Green	Fast (400 ms)	Wait until this is corrected
Terminal voltage above measurement range	Orange	Fast (400 ms)	The program stops. *Disconnect the battery from the circuit as quickly as possible!*
Current too large	Red	Fast (400 ms)	The program stops. Add an extra external series resistor (R_{ext}) and try again.
*This can only happen when an external power source is used to supply the microcontroller, with battery voltages less than 5.5 V.			

Battery quality measurements 0.2-30 V

From here on, when we talk about batteries this implies both lead-acid batteries as well as primary cells.

If a single shunt of 50 mΩ is used, the theoretical value of the current through the shunt varies from 40 A to some 600 A. In practice the total resistance of the shunt circuit will be higher due to the connecting cables, contacts, the internal resistance of the battery and the voltage drop across Schottky diode D9. The resulting currents will therefore be lower than the theoretical ones. Ideally, the current pulse would have a value of 10 A for the range from 0.2-10 volt and 100 A for anything above that.

When an extra resistor is connected externally in series with the discharge circuit, the maximum current will be restricted at higher voltages. Alternatively, you may decide to use a shunt for one specific range only. For ranges of about 0.2-10 V, 5.5-20 V or 5.5-30 V you should use a shunt of 50, 100 or 220 mΩ respectively. As mentioned earlier, you must always use an external supply when the voltage is less than 5.5 V.

The input voltage at the ADC may have a maximum value of 5 V. A potential divider is therefore required for the above-mentioned ranges, with values of 1:2, 1:4 or 1:6 respectively. This can be selected using a set of jumpers in the circuit.

Under certain conditions the program stops, see **Table 2**. The reason is shown on the LCD. However, since the LCD may not be in use, the error condition is also shown using the leds. The most severe error condition is when the current is too high. When this occurs, the red led lights up and the shunt won't be connected again. The circuit will have to be restarted in order to get out of this error condition.

Negative values may be possible when the battery isn't connected properly. The values read will then depend on the charges that happen to be present at the time.

When the circuit starts, the red, orange and green leds flash alternately. When you want to test a number of batteries in quick succession, it would be useful if the pulses would repeat more quickly. A jumper on the board is used to set the period to either 10 s or 30 s. For lead-acid batteries you must always select 30 s.

Figure 1. In the circuit the different sections can be clearly seen from top to bottom: supply, MOSFET circuit, potential divider with jumpers, and control and display via the microprocessor.

Safety measures

In a circuit with currents of 100 A and above, good safety measures are paramount. Of concern here is the shunt circuit. Three safety measures have been put into place (two circuit improvements and one preventative measure).

1. The connections in the shunt circuit have to be able to cope with the short, large pulses. All the copper tracks in the battery shunt circuit on the PCB must therefore be tinned with a thick layer of extra solder. In addition, the long leads of the diode, shunt and MOSFET have to be used to connect them together. The space left between the leads and the copper track should be filled with solder.
2. Cables should be kept as short as possible. Under no circumstances should they be rolled up, which would create inductive loads, along with very high peak voltages. The program stops when the load is too high, but only after the current has been measured. The damage will have been done by then.
3. If for any reason the MOSFET conducts too long or breaks down, the fuse (F1) will blow. For 1.2V batteries we would recommend a 3 A fast blow fuse. For other primary batteries and lead-acid batteries with higher voltages you should use a fuse with a maximum rating of 10 A fast blow.

Electrical circuit

The section with large currents consists of the shunt circuit with D9 as protection diode, low-inductance shunt resistor R27 and finally MOSFET T1. A current of 100 A can be switched using a gate voltage (V_{gs}) of 5.5 V. For a current of 220 A, V_{gs} should be 9-10 V. The switching times given are in the order of 10 ns, but will be longer in practice because of the use of a resistor at the gate input.

The MOSFET was selected because of its low total gate charge (Q_g) of 7.6 nC at 4.5 V. This results in a corresponding capacitance of:

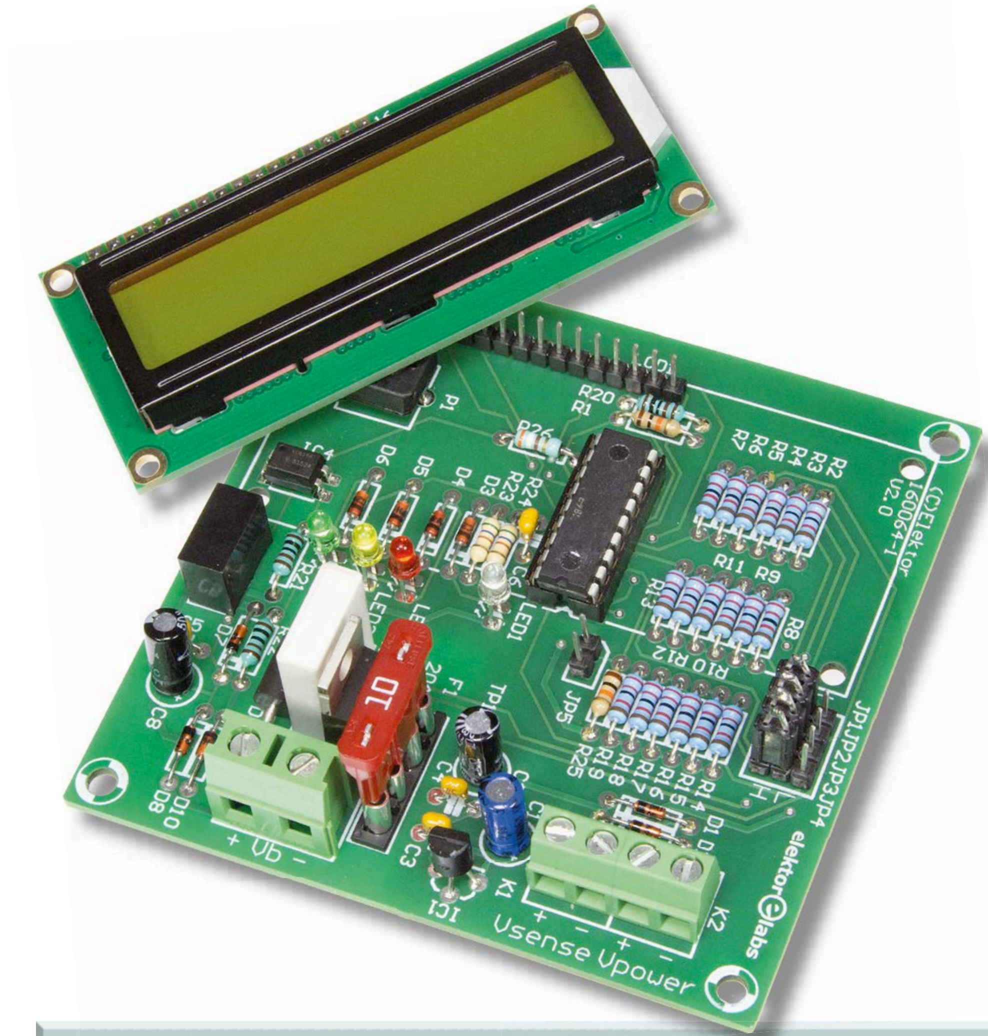
$$C = Q / V = 7.6 / 4.5 \approx 2 \text{ nF}.$$

With a 1-kΩ resistor (R22), the RC time is:

$$T_{on} = 10^3 \times 2 \times 10^{-9} = 2 \text{ µs}.$$

Adding R21, T_{off} becomes 4 µs. These are very good switching times for a 100µs pulse.

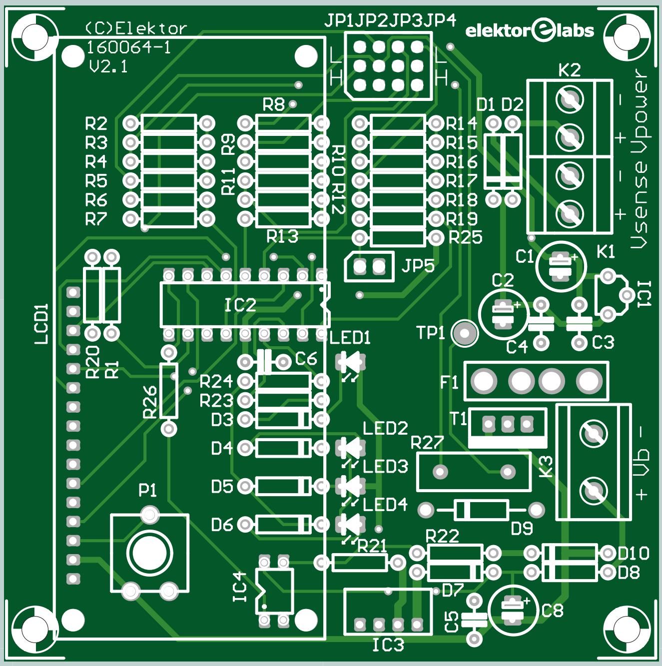
The MOSFET is brought into conduction by raising the gate voltage to a sufficient level in a very short time. Since this gate circuit has to be isolated from the microcontroller circuit, an optocoupler seems the most appropriate to drive the gate. There are commercial opto gate-drivers available that can even supply the required energy to drive the gate. We tried many, but none of them was able to produce a good pulse of 100 A for 100 µs with short switching times. It was often the case that either the turn-on time or the turn-off time was good, but never both. The supply required for the gate voltage (V_{gs}) has to be at least 8 V in order to make currents of 100 A to 220 A flow. When the battery voltage is less than this, the voltage has to be generated some-



where else. For this reason, a separate DC/DC converter (IC3, an RO-0515S/P) has been used to supply the gate voltage when the battery voltage is less than 8 V. Above this, the supply can come from the battery itself, via D8. To obtain a fast switching time, we've used a 5-15 V DC/DC-converter, which is more than enough to satisfy the minimum gate voltage (V_{gs}) requirement of 8 V. However, V_{gs} must not be greater than 18 V, so a 15-V zener diode (D10) and a 1-kΩ resistor (R22) have been added to the circuit to prevent this. Resistor R21 ensures that the gate voltage returns to 0 V quickly at the end of the pulse.

To enable the measurement of 6V lead-acid batteries without an external power supply, we've used a low-drop voltage regulator, IC1 (LP2950C), which requires just 5.3 V at the current of 30 mA used by the circuit. For measurements of voltages less than 5.5 V (increased by 0.2 V for the Schottky diode voltage drop) an external power supply has to be used, which is connected to a separate con-

PARTS LIST



Resistors
(0.25 W, 250 V, unless otherwise stated)
R1,R25 = 10 k Ω
R2…R19 = 22 k Ω, 1%, 0,6 W, 350 V
R20…R22 = 1 k Ω
R23,R24 = 560 Ω
R27 = 50 mΩ, 1 W, MPC75
R26 = 390 Ω
P1 = 10 k Ω, preset

Capacitors:
C1 = 2.2 µF, 50 V, 2 mm pitch, 5x11 mm
C2,C8 = 10 µF, 50 V, 2 mm pitch, 5x11 mm
C3…C6 = 100 nF, 50 V, X7R, 0.2" pitch

Semiconductors
D1,D2,D7,D8 = BAT85
D3…D6 = BZX79-C2V4
D9 = SR1204
D10 = BZX55C15V
LED1 = LED, blue, 3 mm
LED2 = LED, red, 3 mm
LED3 = LED, yellow, 3 mm
LED4 = LED, green, 3 mm
T1 = IRLB8721PBF
IC1 = LP2950ACZ-5.0
IC2 = PIC16F1847-I/P, programmed
(store # 160064-41)
IC3 = RO-0515S/P
IC4 = VO615A

Miscellaneous
F1 = PCB-mount fuseholder + fuse (see text)
LCD1 = LCD, 2x16 characters, EPS 120061-74
LCD1 = 16-pin pinheader, vertical, 0.1" pitch
LCD1 = 16-pin pinheader bus, vertical
K1,K2 = 2-way PCB screw terminal, 0.2" pitch
K3 = 2-way PCB screw terminal, 0.3" pitch
JP1…JP4 = 3-way header, vertical, 0.1" pitch
JP5 = 2-way header, vertical, 0.1" pitch
Jumper for JP5
2x5 header bus, vertical for JP1-JP5
IC socket, DIP-18, for IC2
PCB 160064-1 v2.1

nector (K2) in parallel with the connector for the terminal voltage measurement (K1). Note that these connectors aren't interchangeable! The terminal voltage is measured only via the V_{sense+} connection on K1. Another word of warning: the inputs to this connector must not be swapped since it would result in a negative voltage appearing on port A1 of the microcontroller, which could have some serious consequences.

The state of the lead-acid battery voltage is shown with the help of three leds: LED2, LED3 en LED4 (red, orange and green). The blue led (LED1) is used to indicate when a current pulse occurred. Note that it lights up for longer than the pulse itself, to make it clearly visible. The four leds are driven using just two outputs of the microcontroller. Because the two leds each have a zener diode of 2.4 V connected in series (D3+D4 or D5+D6, each 4.8 V combined), neither of the leds will light up at 5 V. When the output of the controller is set to tri-state, both the leds will therefore be off. When the output of the microcontroller is high or low, depending on which led has to be turned on, there will be enough of a voltage across the led to light it up. Apart from the leds, a lot more information is provided on the LCD.

The microcontroller used here, a PIC16F1847 (IC2), is the most extensive 18-pin 8-bitter made by Microchip. Output B3 is used to drive the gate of MOSFET T1 via optocoupler IC4. Just before the pulse, it measures the no load terminal (V_0) and during the 100-µs pulse the terminal voltage under load (V_t), shunt high voltage (V_h), and shunt low voltage (V_l) are measured using its three ADCs on AN1, AN0 and AN6.
When the circuit is first switched on, the voltage across the MOSFET has to be measured between TP1 (MOSFET drain) and the –connection of K3 (MOSFET source). As mentioned earlier, this voltage must not drop when the circuit is turned on.

The microcontroller circuit (the 5-V regulator, the microcontroller, the LCD, and the leds) consumes about 7 mA. The DC/DC converter uses about 16-19 mA. This isn't very economical, but it can easily be provided by a 9-V battery when taking a couple of quick measurements of 1.2-1.5-V batteries.

Voltage measurements and jumpers

Several software settings can be configured using jumpers JP2, JP3 and JP4. JP1 is a tri-state input (high, open, low). The 10-kΩ resistor at the input is essential, since the input is also an output for a short period of time in order to determine the tri-state status. After all, an output must never be connected directly to 0 V or 5 V.
The voltages to be measured (V_t , V_h and V_l) have to be attenuated to no more than 5 V for the ADC inputs. This is done via the resistor networks built using R2-R19. Voltages up to 30 V have to be reduced by a factor of 6. This is achieved by connecting 6 resistors in series across the voltage to be measured. When the ADC is connected to the bottom resistor, the resulting voltage (V_{ADC}) is $V_{in}/6$. For the 0-20 V measurement range we short R2 and R3, with JP2 in the 'H' position. V_{ADC} is then $V_{in}/4$. And finally, we short R2-R5 by placing the jumper in the 'L' position to select the 0-10 V measurement range. V_{ADC} is then $V_{in}/2$.
Apart from the three potential dividers, there is a fourth jumper (JP1), which is used to tell the microcontroller which voltage division has been selected. JP1 to JP4 have been positioned neatly next to each other on a 100-mil grid. We have converted a 2x4-pin header to ensure that all jumpers will be in the same position at the same time, see **Figure 2**.
The repetition period of the pulses can be adjusted via JP5 to either 30 s (no jumper) or 10 s (jumper in place). With lead-acid batteries you must always select 30 s.

It is vital that the three voltage measurements take place during the 100µs pulse. Whether this is possible depends on both the hardware as well as the software. The critical components here are the optocoupler, the MOSFET and the de microcontroller. The VO615A optocoupler has rise times (T_{on}) and fall times (T_{off}) of 9-10 µs with a load of 1 kΩ. This implies that the time left for the three ADC measurements is 100 – (2 × 10) = 80 µs.
With a clock of 16 MHz the minimum time required to convert one bit ('T_{ad}') is 1.0 µs. For a 10-bit ADC the total time required is 11.5 T_{ad}, which is 11.5 µs. The acquisition time (T_{acq}) is equal to Amplifier Settling Time + Hold Capacitor

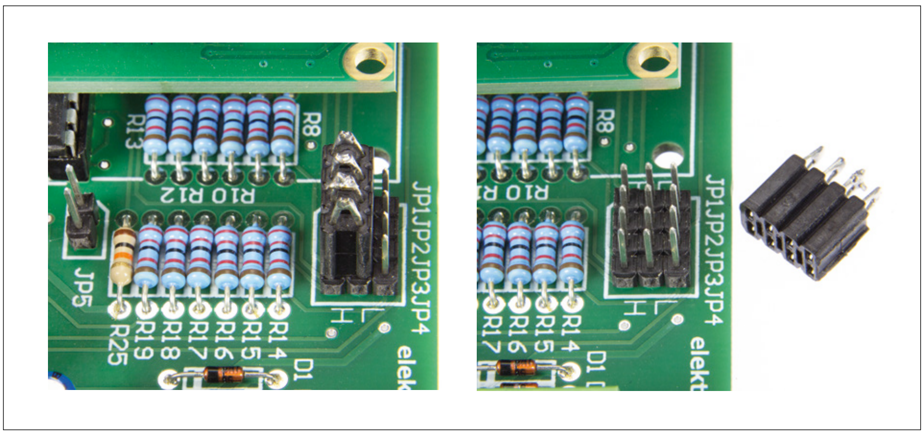


Figure 2. We've made a jumper-block from a 2x4-pin header to help with configuring the potential divider.

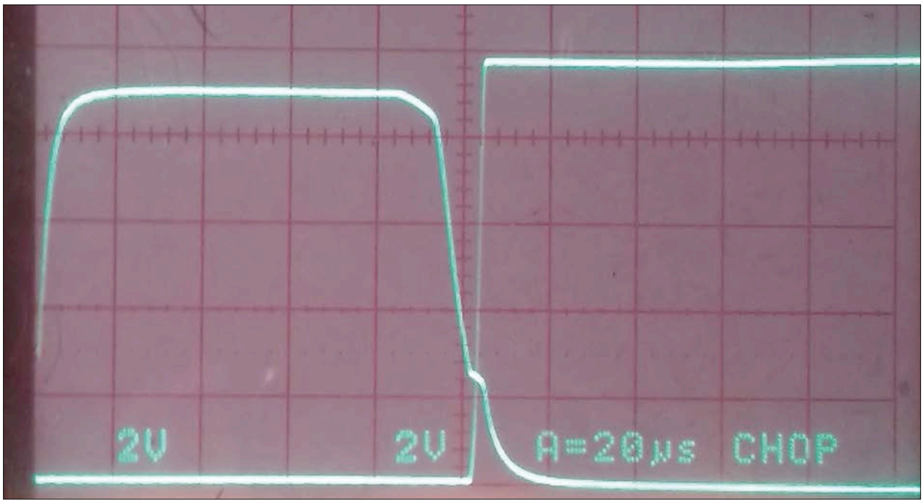


Figure 3: Top curve on the left: The gate voltage (V_{gs}) with a pulse duration of 94 μs for three ADC measurements. The other curve shows the voltage across the MOSFET (V_{ds}), with a total shunt time of about 105 μs (V_{gs} > 3 V at a shunt current of 0.4 A and V_o = 10 V).

Charging Time T_C + Temperature Coefficient = 2.0 μs + T_C + 0.05 ΔT (compared with 25 °C). T_C depends, among other things, on the source resistance (R_s) and for this microcontroller is equal to:
7.62 × 10 pF × (8 kΩ + R_s).

For the optimum source resistance of 10 kΩ, the value of T_C is 1.4 μs. In our circuit, R_s = 22 kΩ//22 kΩ = 11 kΩ to 22 kΩ||(5×22 kΩ) = 18 kΩ, so T_C is between 1-2 μs. The Temperature Coefficient is so small that it can be ignored. The total ADC conversion time then becomes about 11.5 + 2 + 2 = 16 μs at 25 °C. However, in the software a longer period of 10 μs is used for T_C, which makes the total ADC conversion time equal to 24 μs. Three ADC measurements therefore require 72 μs, which falls neatly inside the available 80 μs!
The software also requires 0.25 μs per program step (ADC enable, read, save and disable). The standard available procedures (in Flowcode 6) made the three ADC measurements take up about 150 μs, which was too long. When these Flowcode procedures were changed to procedures written in C, these times were reduced by 33%, which meant that three ADC measurements could take place within 80 μs. That was exactly what we needed.

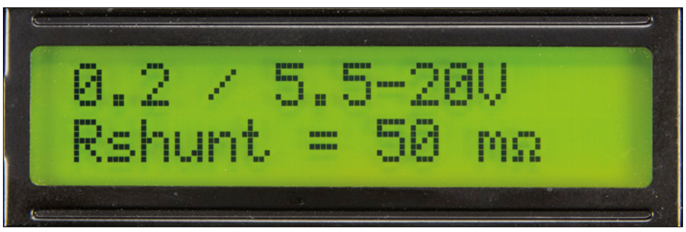
The previously calculated switching times for the gate correspond fairly well with those measured in practice, as can be seen in **Figure 3**. We can also see that V_{ds} is much steeper than V_{gs}, which is a good thing. The rise time of V_{ds} is about 0.8 μs and the fall time about 3 μs. This is a good result when you consider the high currents that are switched. There is therefore no need to provide the MOSFET with a heatsink.

Software

The software has been written in Flowcode 6. The Flowcode source file and the corresponding .hex file can be downloaded from [4]. The startup screen shows the selected voltage division, the voltage range, the shunt resistance and the repetition period. The program then waits until a battery voltage is measured at the shunt. Following the startup screen, the no load terminal voltage (V_0) and the terminal voltage under load (V_t) are automatically displayed on the first line of the 2x16 LCD. On the second line the size of the pulse current in Amps and the internal resistance of the battery in mΩ are shown. At the bottom-right is a countdown timer that shows how many seconds are left until the next pulse occurs. All of the values are displayed using three digits. The real accuracy is determined by several factors, although it's good enough to correlate the internal resistances with the state of charge of the batteries.
There is a one-second delay after the battery has been connected in order to avoid any readings of possible voltage changes while the battery is being connected. While the circuit starts up, the leds light up sequentially (red-orange-green).
If you wish to modify the Flowcode yourself, it is essential to set the clock to 'internal' and 16 MHz, and to turn off the external MCLR and low-voltage programming (Configuration words: config1 0x09A4 and config2 0x1CFF).

Some results

The circuit had to be tested on my car battery, of course. Since I often drive only short distances, the internal resistance of 6 mΩ shows that it's not in the



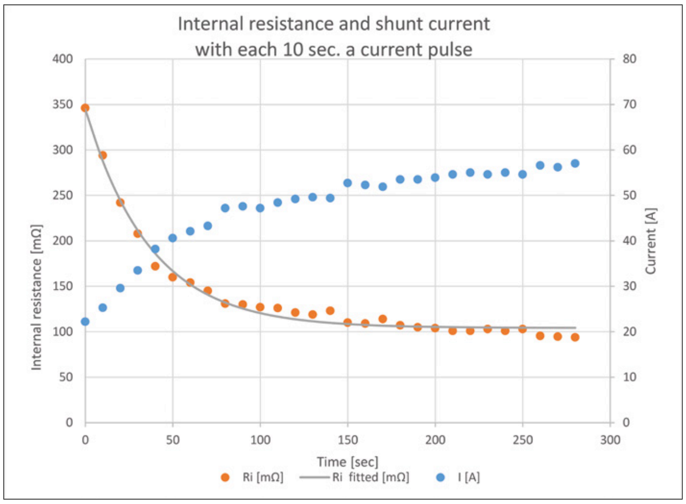


Figure 4. The restorative effect in a worn lead-acid battery (12 V, 7 Ah) with a 10.3 volt terminal voltage.

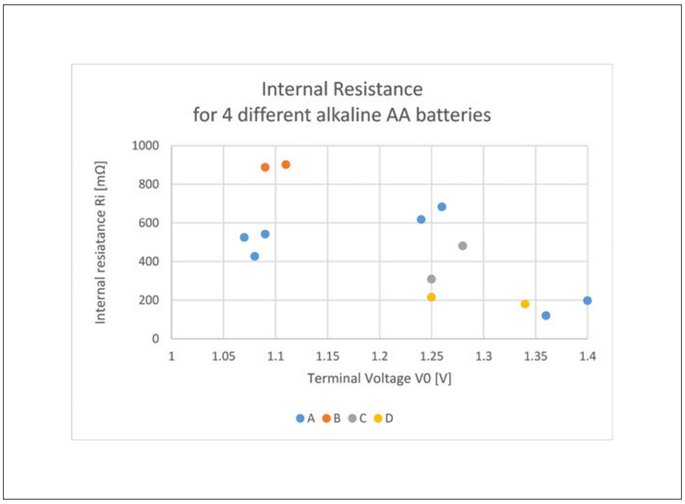


Figure 5. The internal resistance of AA alkaline batteries (type LR6) as a function of their no load terminal voltage. Four different brands of battery were measured, labeled A, B, C and D.

best of health. But at least the car still starts reliably!

The example in **Figure 4** shows the restorative effect of the current pulses in another battery. After just four or five pulses the internal resistance has halved and is getting close to its eventual value. In a 12-V lead-acid battery of 7 Ah we find that the temperature dependence of the internal resistance is about −0.7 mΩ/°C. It changes in value from 34 mΩ at room temperature to 62 mΩ in the freezer (−18 °C).

A new lead-acid battery (12 V, 7 Ah) has an internal resistance of 34 mΩ ± 2 % when it was charged, while an 8-year one of the same type had a resistance of 52 mΩ ± 3 %. Both types have a terminal voltage of 13.2 volts.

Twelve sub-C NiMH batteries of 4600 mAh, connected via solder tags with low resistances, where discharged and had an internal resistance of 101 mΩ. After charging them with 2000 mAh the value dropped to 86 mΩ.

We can report the following regarding the accuracy we experienced in practice: The lead-acid batteries returned values with a variation of 1% or less, which was very good. On the other hand, AAA and AA batteries (alkaline and NiMH) had variations of over 10% in the measurements. This means that one measurement of such a battery is not enough to get a reliable value. In order to obtain the correct result you should take a number of measurements for these batteries and then take the average. Fortunately it only takes a minute to take six measurements.

Lastly, I measured all of my AA alkaline batteries. The result of this can be seen in **Figure 5**. It's very noticeable that there was a large spread between the different brands. A well-known brand seems to come off worst, or was that just chance? It can be clearly seen that there is a tendency for the resistance to increase as the batteries are more discharged. However, further research is needed before the differences between the brands can be explained. It looks like this tester won't be getting much rest! ◀

(160064)

FROPM THE STORE

→160064-1
PCB

→160064-41
Programmed controller

→160064-71
Kit of parts

→120061-74
2x16 character LCD

Web Links

[1] Conrad lead-acid battery activator 191123: www.conrad.com/ce/en/product/191123/

[2] 'A lead-acid battery desulfatation tutorial': www.chargingchargers.com/tutorials/battery-desulfation.html

[3] Battery and Energy Technologies in Electropaedia: www.mpoweruk.com/performance.htm

[4] Software download: www.elektormagazine.com/160064