Battery Monitor
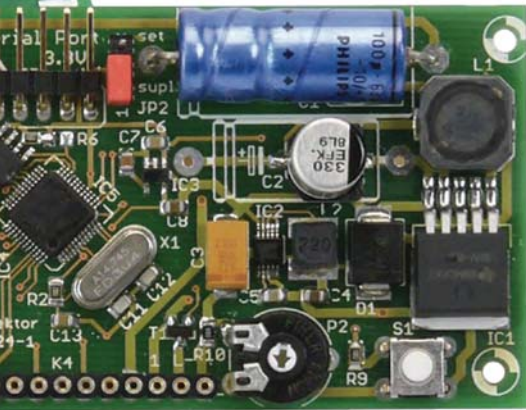## Everything under control

Steffen Graf (Germany)

This circuit was originally designed for monitoring the charge status of the batteries in a solar-powered water feature. However, it can be used in any application where batteries are charged and discharged. The circuit uses an LPC2103 microcontroller connected to a 22-bit analogue-to-digital (A/D) converter to measure charge and discharge currents, battery voltage, charge status (or available capacity) and the instantaneous power being supplied to or drawn from the battery.

There are various ways of providing rechargeable battery packs with an indication of their charge status. The most widespread uses a simple voltage measurement; however, NiMH and NiCd cells have a rather flat voltage discharge curve and so the method is not particularly accurate in this case. A better approach is also to measure the current into or out of the battery. This allows calculation of the flows of power and charge, and hence (if the initial state is known) also the available battery capacity. The module described

here offers all these features and can be used to monitor batteries or more generally to meter voltages, currents and power in any DC supply system. The author uses the module to monitor a small solar-powered installation.

The unit can work over a wide voltage range, from 6 V to 42 V, and so can be used in typical lead-acid battery applications at 6 V, 12 V, 24 V or 36 V. The current range is also very wide; despite this, resolution is high, with measurements accurate to around 1 mA. A 50 mΩ SMD shunt resistor, rated at 2 W, makes for a compact construction and allows currents of up to 6 A to be measured.

Summer Circuits (July/August) 2008 issue of Elektor. This remarkable IC (see text box) is a 22-bit delta-sigma converter with differential inputs and an SPI port, available in a reasonably easy-to-solder SMD package.

An important aspect of this project is the generation of the various supply voltages. The circuit requires 5 V for the LCD, 3.3 V for the A/D converter and for the microcontroller, 1.8 V for the microcontroller core and 1.2 V as a reference for the A/D converter. All these voltages must be generated

These devices require minimal external circuitry. The input side of IC6 (the MCP3550) is simply connected across the shunt resistor to measure the battery current: the shunt is connected directly between the input and output terminals on the printed circuit board. The board is inserted in the line to the battery using these terminals, and hence can monitor current flows into and out of the battery. Terminal K1 also provides the power supply for the circuit via 5 V switching regulator IC1, and, via the voltage divider formed by R3, P1 and R8, provides the volt-

Features

- **Display of current (in mA or A), voltage (mV), capacity (Ah) and power (mW or W)**
- **Suitable for monitoring all types of rechargeable battery**
- **Suitable for battery voltages from 6 V to 42 V**
- **Maximum measured current: ±6 A**
- **High precision: voltage resolution 76 mV, current resolution 12 μA (internal), 1 mA (displayed)**
- **Low power consumption due to use of high-efficiency step-down converters: <200 mW (backlight off), <300 mW (backlight on)**
- **Module takes into account its own power consumption in calculating current and capacity**
- **Display update rate 1 Hz**
- **Over- and under-voltage fault LED**
- **Backlit 2-by-16-character LCD**
- **Compact construction**
- **Serial interface for outputting measured values**
- **Firmware available for free download from Elektor website**

Overview

The microcontroller used is the LPC2103, a 32-bit ARM7-based RISC device from NXP. It differs in only minor details from the LPC2106 device used in the ARMee development board described in the April 2005 issue of Elektor and in the article 'Automatic Running-in Bench' published in April 2009. Both are based on the 32-bit ARM7TDMI core, which we described in an article in the March 2005 issue. The LPC2103's internal A/D converter has a resolution of only 10 bits: this is enough for our voltage measurement, but not enough for the current measurements we want to make. Furthermore, since we want to be able to measure current flow in either direction (charge and discharge) we need an A/ D converter with a differential input. We therefore use the internal A/D converter only for voltage measurement, and employ an external converter for current measurement. We selected the Microchip MCP3550-50, which was briefly described on page 87 of the

efficiently from a highly variable input supply (between 6 V and 42 V). That demands a switching converter to provide a 5 V regulated supply directly from the input. A second switching converter drops the 5 V supply to 3.3 V, and the remaining voltages (1.8 V and 1.2 V) are generated from the 3.3 V supply using linear regulators. Even at high input voltages the power dissipation of the circuit is low, removing the need for a bulky heatsink.

Circuit and construction

The complete circuit is shown in **Figure 1**. Out of the total of six ICs, four are voltage regulators. The switching regulators (IC1 and IC2) can be identified by the inductors connected to them, while the linear regulators (IC3 and IC4) just have decoupling and smoothing capacitors. The meter circuit itself comprises just the LPC2103 (IC5) and the A/D converter (IC6).

age measurement input. The divider reduces the voltage to a level suitable for input to the A/D converter built in to the LPC2013, which can only accept voltages from 0 V to 3.3 V. The potential divider can be set up in two different ways:

1. use 0.1 % tolerance components for R3 and R8, in which case P1 can be dispensed with;

2. use normal (1%) resistors and then calibrate the measured voltage by adjusting P1. R8 is then omitted.

If the input voltage is over 40 V then adjustment of P1 will be necessary in any case for best accuracy; and if the input voltage is over 42 V adjustments to the software are also needed.

Jumper JP2 allows the unit's 5 V supply to be taken from the programming interface. This allows the microcontrol-
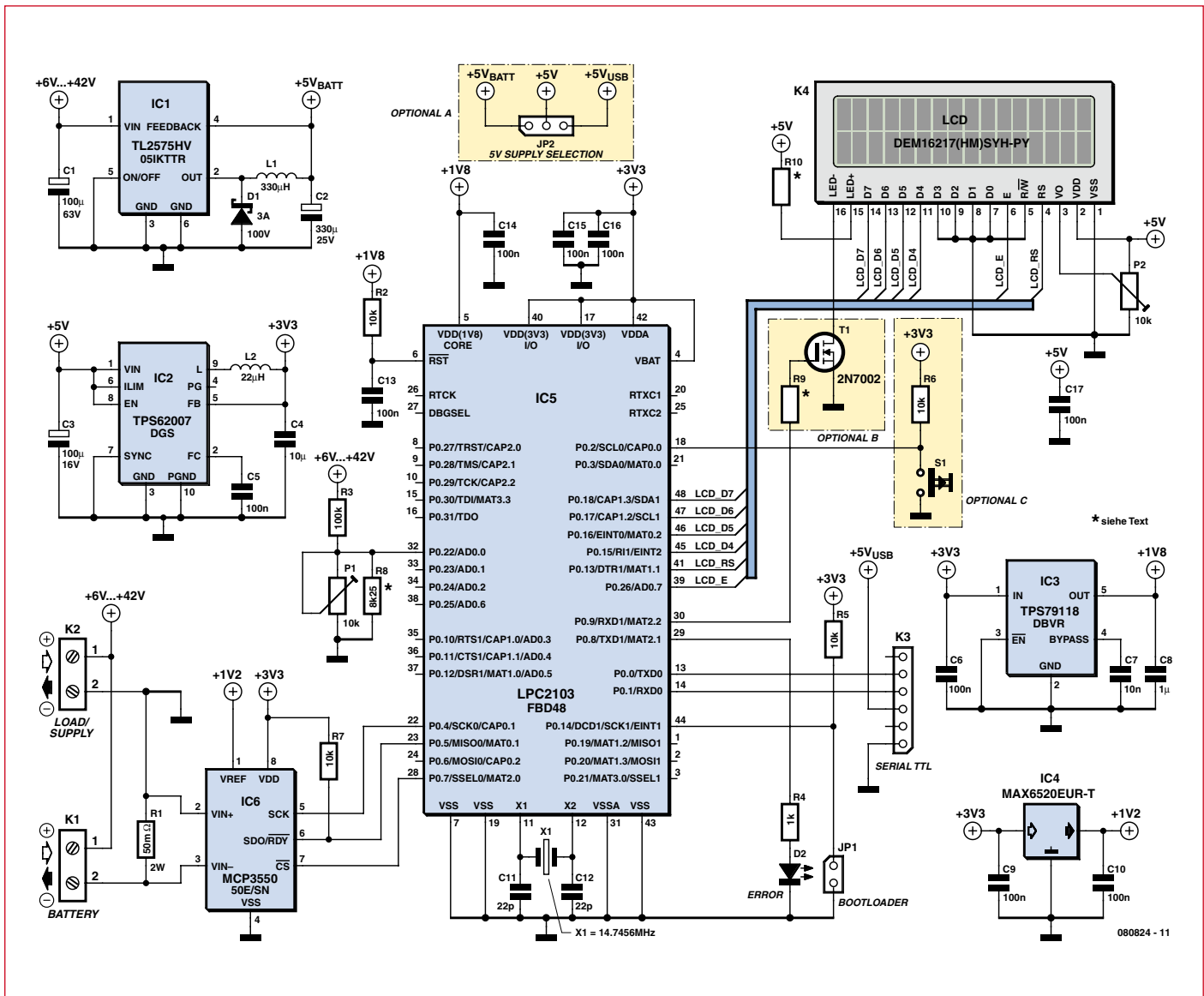
Figure 1. Circuit diagram of the battery monitor. Out of the total of six ICs, four are voltage regulators. The meter circuit proper consists of a 32-bit ARM7 microcontroller (IC5) and a 22-bit A/D converter (IC6).

ler to be programmed without a battery being connected. If a battery is connected while power is being supplied over the programming interface, IC1 will only draw a few milliamps from it: the rest of the circuit will still take its power from the programming interface. Don't forget to change the jumper back to battery power after programming the microcontroller. Alternatively, if the ability to power the unit over the programming interface is not needed, JP1 can be replaced by a wire link joining +5 V$_{BATT}$ and +5 V.

The LCD panel used has a backlight. In the interests of reducing power consumption the light can be turned on and off. Button S1, connected to port pin P0.2 on the microcontroller, controls

a routine in software that causes a PWM signal to appear on pin P0.9. This in turn drives MOSFET T1 to provide a dimmable backlight. If the ability to turn the backlight off is not needed, R10 can be replaced by a 220 Ω resistor (instead of 0 Ω) and the MOSFET replaced by a wire link joining source and drain. R9, as well as R6 and S1, can be dispensed with. If the backlight is not required, all the related components (S1, R6, R9, R10 and T1) can be dispensed with.

In order to make the module no larger than the LCD, the printed circuit board (**Figure 2**) is almost entirely populated with SMD components. This demands a certain amount of deftness with the soldering iron, especially when it

comes to the LPC2103 in its LQFP48 package. Despite the 0.5 mm lead pitch, it is lining the device up with the pads on the board that is the tricky part of assembly, not the soldering itself. The easiest way to solder the device is to melt solder over all of the leads on one side at a time (not worrying about short circuits) and then remove excess solder using braid. It is helpful to use a little flux. It is best to mount the microcontroller first so that the other components do not get in the way of the action. Then solder all the other ICs and finally the other SMD components. Finally mount the leaded components. **Figure 3** shows our prototype board, which differs in minor details from the final layout shown in Figure 2.
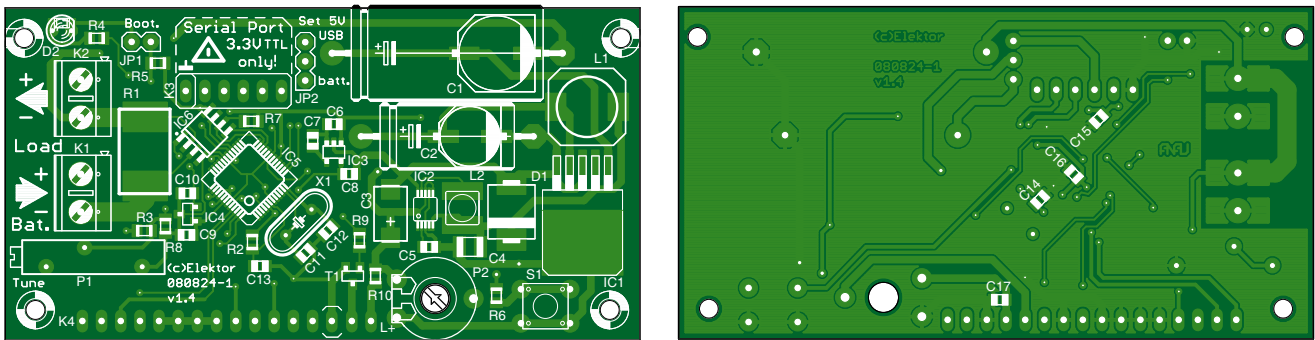
Figure 2. The printed circuit board is mostly populated with SMD components and is the same size as the LCD panel.

COMPONENT LIST

Resistors:
(SMD0805, 0.125W, 1% unless otherwise indicated)
R1 = 0Ω05 2W 1% (SMD shunt resistor, 5mm x 0.3mm, e.g. Vishay/Dale)
R2,R5,R6,R7 = 10kΩ
R3 = 100kΩ (see text)
R4 = 1kΩ
R8 = 8kΩ25 (see text)
R9,R10 = 0Ω (or 1Ω, R10 also 220Ω, see text)
P1 = 10kΩ multiturn preset, 19mm (see text)
P2 = 100kΩ preset, horizontal mounting, 10mm

Capacitors
C1 = 100μF 63V 20%, aluminium, SMD (G) or axial wired
C2 = 330μF 25V 20%, aluminium, SMD (F) or axial wired
C3 = 100μF 16V 10%, tantalum SMD (7343-31)
C4 = 10μF 16V 10%, X5R, multilayer SMD 1210

C5,C6,C9,C10,C13–C17 = 100nF 50V 10 %, XR7, multilayer SMD 0805
C7 = 10nF 50V, 10%, XR7, multilayer SMD 0805
C8 = 1μF 16V 10 %, XR7, multilayer SMD 0805
C11,C12 = 22pF 50V 5%, multilayer SMD 0805

Inductors
L1 = 330μH, 590mA, 20%, SMD 10mm x 10mm (e.g. EPCOS)
L2 = 22μH, 925 mA, 30%, 5mm x 35mm (e.g. WE-TPC, Würth)

Semiconductors
D1 = 3A Schottky diode, 100V, 620mV, SMC case, e.g. 30BQ100TRPBF (Vishay, IRF)
D2 = LED, red, low current (2mA)
T1 = 2N7002 (N-channel MOSFET, 60V 115mA, Fairchild, SOT-323)
IC1 = TL2575HV-05 (5V 1A step-down switch-mode regulator, TI, TO263)
IC2 = TPS62007 (step-down switch-mode regulator, TI, MSOP10)
IC3 = TPS79118 (LDO regulator, 1.8V 100

mA, TI, SOT-23-5)
IC4 = MAX6520 (1.2V voltage reference, Maxim, SOT23-39
IC5 = LPC2103FBD48 (70MHz ARM7, 16KB Flash, 8KB RAM, NXP, LQFP48)
IC6 = MCP3550-50 (22-bit delta-sigma ADC, Microchip, SOIC08)

Miscellaneous
X1 = 14.7456MHz quartz crystal, 18pF load capacitance, 30ppm
S1 = SPNO pushbutton, PCB mount (e.g. Omron B3W-1000)
K1,K2 = PCB screw terminals, 16A, pitch 5mm
K3 = SIL 6-way right-angled pinheader
K4 = SIL 16-way socket strip, for LCD mounting
JP1 = 2-way pinheader for jumper
JP2 = 3-way pinheader for jumper
LC display, 2 lines of 16 characters, with backlight; see text (e.g. Elektor Shop # 030451-72)
2 jumpers, pitch 2.54 mm
4 standoffs M2.5, l = 15mm
PCB no. 080824-1 from the Elektor Shop

Software

The ARM core used in the LPC2103 offers plenty of processing power to extend the capabilities of the unit. The firmware is written in C and source code is available for free download from the Elektor web pages for the project [1]. The program is easy to understand and modify. Only the start-up code has to be in assembler (for which thanks to Alexander Graf, who wrote that code). The free GCC C compiler is used.

The microcontroller runs in an infinite loop, and once per second calls a function which performs the measurement process and displays the results. To obtain the one second period, Timer 0 is configured so that its counter is incremented every millisecond. The infinite loops tests to see whether the counter has reached 1000 (as 1000 * 1 ms = 1 s).

The calculation routine first reads a value from the A/D converter to obtain a current reading. This is relatively straightforward as there is no need to send any data to the MCP3550: it is simply a matter of taking its chip select signal /CS low. It is then necessary to wait while the conversion takes place. The MCP3550 signals that the conversion is complete by taking the data output line low. We need to switch the port to the correct mode in order to detect this event.
Once the conversion is complete the

data bits can be read out. There is a total of three eight-bit data blocks, which are logically ORed into the appropriate positions in a variable. The twenty-second bit gives the polarity of the voltage measured at the device's input: if the bit is a '1' the value is negative and the collected value must be suitably modified: the two's complement is taken by calculating a bitwise (ones') complement (ad_current = ~ad_current;) and then incrementing by one. Since we only want the least significant 22 bits of the result we mask off the remainder using a logical AND operation: ad_current &= 0x3fffff;.

Now we can compute the actual current flowing. To avoid floating-point
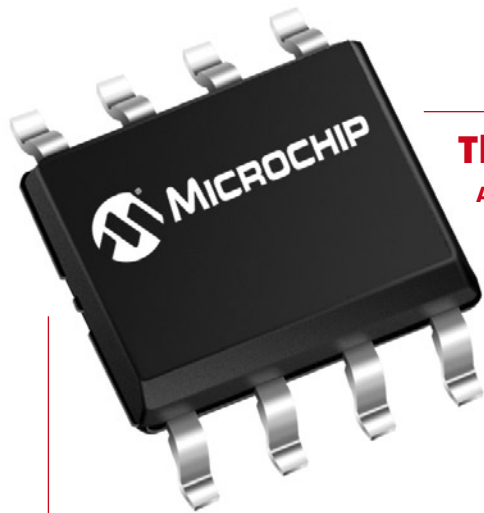
The MCP3550

A simple and accurate delta-sigma A/D converter

The MCP3550 is a rather slow, but thrifty and accurate analogue-to-digital converter. Its current consumption is just 110 μA! The MCP3550-50 was selected for this project because it has a differential input and a notch filter for suppressing 50 Hz mains hum.

080824 - 14
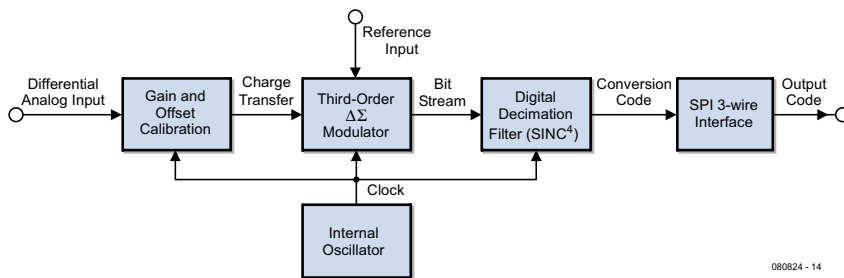
Its innards, as shown in the block diagram, appear simple. At the input is a 'gain and offset calibration' circuit. This compensates for offset and slope errors in the rest of the circuit. The actual A/D conversion is performed, with the help of the reference voltage, by the 'third order delta-sigma modulator', a one-bit converter that produces at its output a stream of bits at a high sample rate. The digital decimation filter then reduces the sample rate of this stream while simultaneously increasing its word length (and hence precision) to 22 bits. The digital circuitry is clocked from an internal oscillator, operating at 102.4 kHz in the case of the MCP3550-50.

080824 - 15
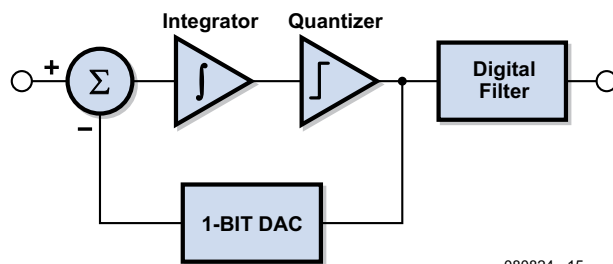
Even simpler is the block diagram of a first-order delta-sigma modulator. The input signal forms one input to a voltage subtractor. The other input to the subtractor comes from a 1-bit D/A converter fed from the output of the modulator, forming a negative feedback loop. The output of the subtractor can be thought of as an error signal, being the difference between the output of the modulator and its input. The error is integrated and quantised to form the output of the modulator. This loop operates at a much higher frequency than the quoted overall sample rate of the A/D converter and produces a high-frequency bitstream.

The MCP3550 uses a third-order delta-sigma modulator, which is an extension of the idea described above. Instead of one subtractor and integrator stage there are three connected in series. There is a quantiser after the final stage which feeds back to all three stages.

The bitstream produced is digitally filtered to produce a usable signal. In the MCP3550 this is a fourth-order modified sinc filter. A sinc filter (that is, a filter whose impulse response takes the form of a sinc function) has an ideal low-pass characteristic. It is here that the 50 Hz notch filtering also takes place. The output of the filter is a high-resolution representation of the input voltage, which can be read out over the SPI port.

operations we work with currents in nA and voltages in μV. The resulting error in the measured result is negligible, deviating from the exact value by less than the tolerance of the reference voltage or voltage divider.

All the displayed information is also output over the serial port in the following format:

Voltage: 12599mV
Current: –0050mA
Power: –0629mW
Capacity: –0035mAh

The output data can be fed to a data logger for subsequent analysis. If two of the units are used it is possible to make simple and accurate measurements of the efficiency of switching power supplies.

Programming

The battery monitor has a serial interface which uses TTL voltage levels rather than RS-232 voltage levels. Despite its 3.3 V supply, the ports of the LPC2103 are compatible with logic powered from 5 V.

The serial interface is used for uploading firmware to the device as well as for outputting readings. To program the device over USB the USB-to-TTL serial cable described in the June 2008 issue of Elektor [2] can be used: this is available from the Elektor shop (order code 080213-91). The pinout of the cable is compatible with that of K3 on the printed circuit board. Of course, you can equally well read the pinout of the connector from Figure 1 and use your own serial adaptor cable, as long as it uses 5 V logic levels.

When the circuit has been assembled the firmware must be flashed into the microcontroller. Close jumper JP1 and then apply power to the circuit. If the circuit is to be powered over the USB-to-TTL cable, JP2 must be set to position 2–3 (linking +5 V and +5 V$_{USB}$). At this point only the first row should appear on the display: if it is not visible, adjust the contrast using P2. The firmware can be downloaded using the free Flash Magic software [3]. **Figure 4** shows how this program is configured: only the COM port to be used and the path need to be set.

If you wish to avoid the fuss of programming the microcontroller yourself, it is available ready-programmed from the Elektor shop (order code 080824-41).

Start-up

When programming has successfully completed, remove JP1 and check that JP2 is correctly set (+5 V linked to +5 V$_{BATT}$). Connect a battery (rechargeable or not), or a bench power supply with an output voltage between 6 V and 40 V, to K1. If a voltage source was already connected to terminals K1, it will be necessary to remove it briefly to reset the circuit.

The LCD should now show a brief message and then display the measured values. If nothing appears, check the contrast setting (P2) again. If the welcome message does not disappear from the display, it is likely that there is a fault in the connection to IC6.

If everything is working as expected the LCD should show the current consumption of the meter module and the
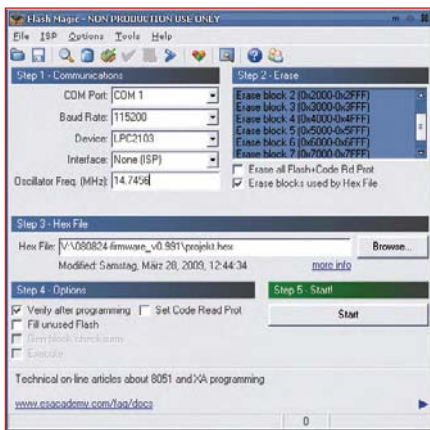

Figure 3. Our populated prototype.

Figure 4. Settings required for the Flash Magic software to upload the firmware into the microcontroller's flash memory.

supply voltage on the top row. The second row shows the charge that has been transferred (in Ah) and the power draw (in mW or in W): see **Figure 5**. The current draw is strongly dependent on the supply voltage; at 12 V around 15 mA should flow.

If P1 has been fitted it should now be adjusted so that the displayed voltage agrees with the actual voltage at K1 (as measured by your trusty multimeter). The Battery Monitor is now ready for use.
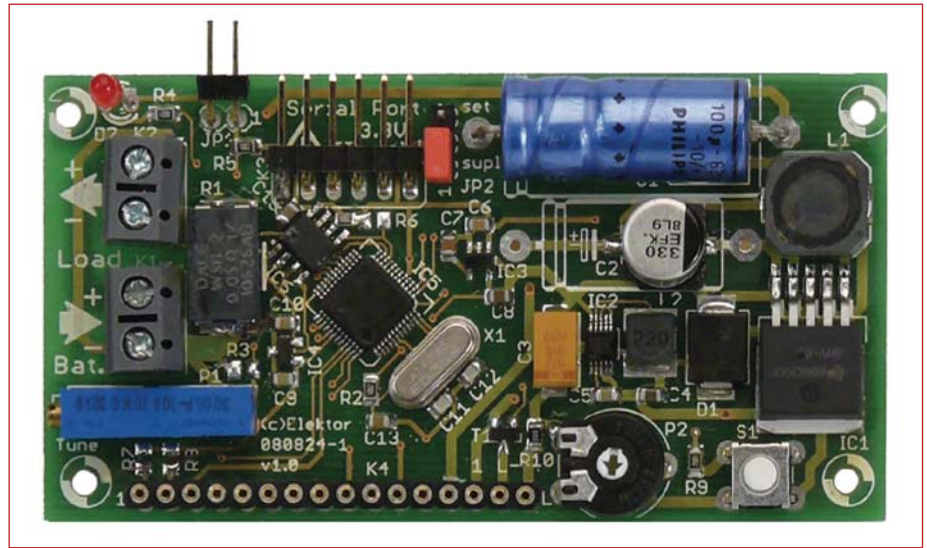
(080824-I)

Internet Links

[1] http://www.elektor.com/080824

[2] http://www.elektor.com/080213

[3] http://www.flashmagictool.com/download.html

Datasheets

TL2575HV-05:
www.ti.com/lit/gpn/tl2575hv-05

LPC2103:
www.nxp.com/acrobat/datasheets/LPC2101_02_03_3.pdf

MCP3550:
http://ww1.microchip.com/downloads/en/DeviceDoc/21950D.pdf

TPS62007:
www.ti.com/lit/gpn/tps62007

TPS79118:
www.ti.com/lit/gpn/tps79118

MAX6520:
http://datasheets.maxim-ic.com/en/ds/MAX6520.pdf

DEM16217:
www.display-elektronik.de/DEM16217SYH-LY.PDF

About the author

Steffen Graf is 20 years old and is in his second semester studying Electronics and Information Technology at the Technical University of Darmstadt, Germany. Electronics has been one of his main hobbies for many years. In 2008 he entered a battery capacity monitor design for a German regional youth science competition, winning second prize in the 'Working World' category. He also won a special prize for a practical and useful invention.

Figure 5. The LCD panel in normal operation.

Low Cost 8051μC Starter Kit/ Development Board *HT-MC-02*

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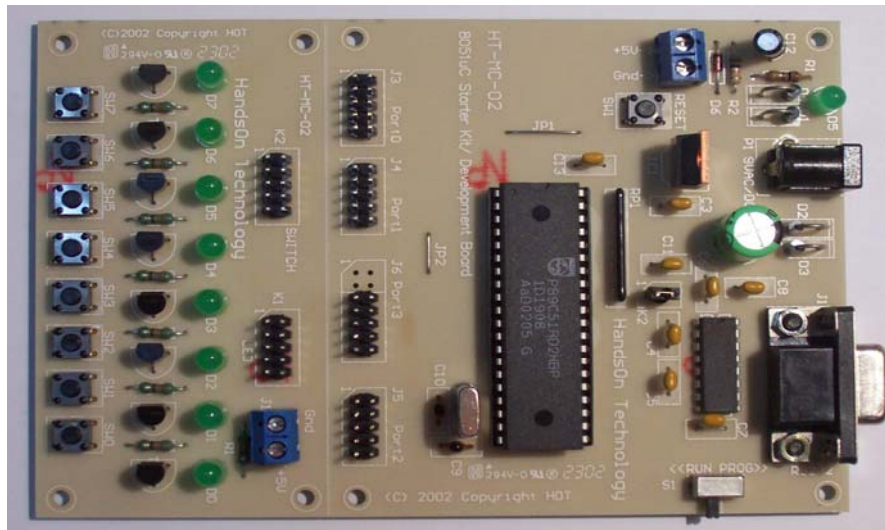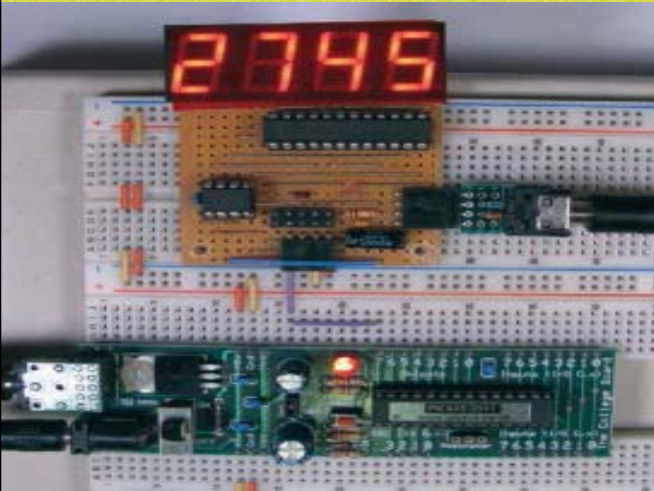

Main Features:

- 8051 Central Processing Unit.
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- Boot ROM contains low level Flash programming routines for downloading code via the RS232.
- Flash memory reliably stores program code even after 10,000 erase and program cycles.
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- Programmable Counter Array (PCA) & Pulse Width Modulation (PWM).
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- On board stabilized +5Vdc for other external interface circuit power supply.
- Included 8x LEDs and pushbuttons test board (free with *HT-MC-02* while stock last) for fast simple code testing.
- Industrial popular window *Keil* C compiler and assembler included (Eval. version).
- Free *Flash Magic* Windows software for easy program code down loading.

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> *INSTALL ACROBAT READER (AcrobatReader705 Application) TO OPEN AND PRINT ALL DOCUMENTS*

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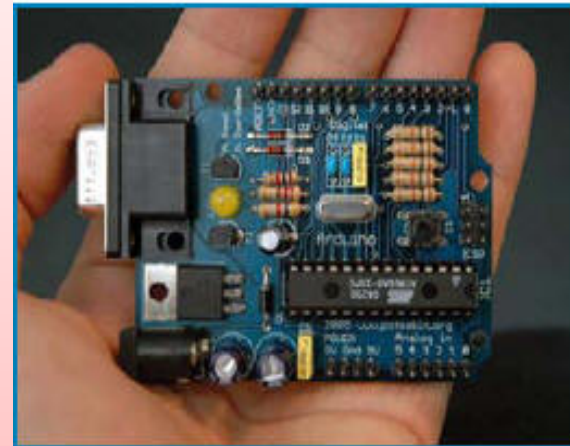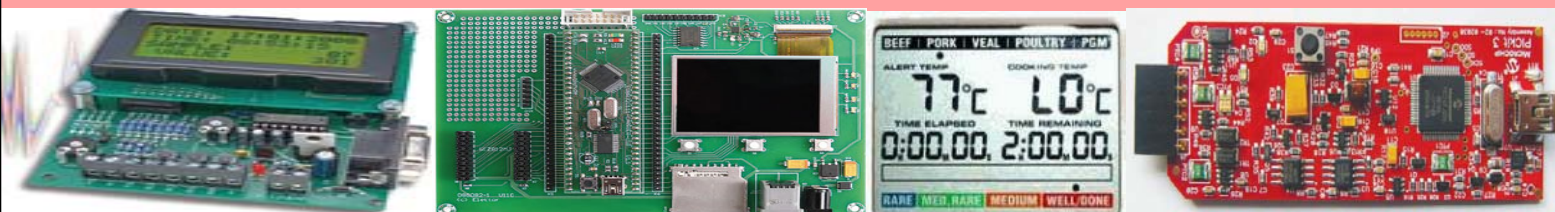
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