# Battery Charge-n-Check

## For NiMH/NiCd and LiPo/Li-Ion packs and cells


Florent Coste

**More and more electronic devices use batteries, often of varying types. Finding a universal solution now seems more justified — one that's not only capable of handling a maximum of batteries but also with the ability to evaluate their status.**

Originally developed for receiver batteries in radio-controlled (RC) models, the circuit discussed in this article is used to charge, discharge and evaluate the capacity of battery packs composed of one up to eight NiMH or NiCd cells, or LiPo (Lithium Polymer) or Li-Ion (Lithium-Ion) batteries composed of two elements (serial charge). Model hobbyists, other rechargeable battery users and generally all soldering iron fans will find in the present circuit a low cost, simple solution that's also easily integrated.

### NOT JUST A SIMPLE CHARGER...

To update this category, integration and functionalities were pushed 'to the max' (just a glance at the size of the circuit makes that point). It really refers to a project that can verify the performance level of your battery packs. No exotic components, only one integrated circuit (a microcontroller from ST), a few transistors that are very easily obtained, all neatly done up with a few square centimetres of epoxy. Ready, set, to your soldering irons!

### THE BRAINS OF THE PROJECT

Everything depends on using only one unique microcontroller whose original function has been somewhat changed, since it is more specifically dedicated to motor control (see 'Brushless Motor Controller' in Elektor, February, 2006). Its very interesting particularity is that it can be integrated into a PWM cell (Pulse Width Modulation) which can work at high frequencies (50 kHz), all coupled with a current loop (see **Figure 1**). Even better, an internal operational amplifier makes it possible to avoid using any external analogue integrated circuit. That is the way to perfectly fulfil one's mission!

### CURRENT REGULATION: THE PRINCIPLE

Designed to make synchronous and asynchronous motors run, the ST7MC includes a current-level control cell that makes it possible to monitor the current intensity in a motor coil winding. Starting from this functionality, we had no doubts about substituting a battery (pack) for it! The behaviour of the current loop obviously remains unchanged.

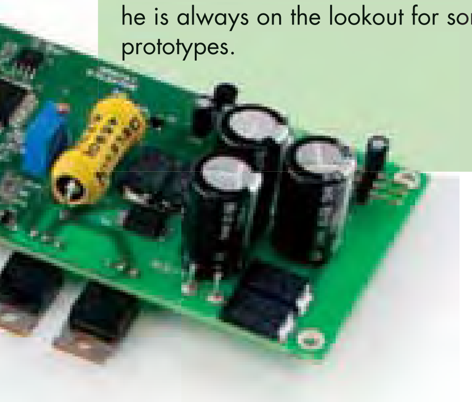
The principle of the regulation is very simple: when a preprogrammed intensity level is reached, the microcontroller automatically cuts off the output until the next PWM pulse (or as long as the current level remains above the reference level): the duty cycle is therefore directly controlled by the cell hardware, without the least external intervention. Therefore, only one adjustment of the current setpoint is necessary. **Figure 2** registers the incidence rate of the current readout on the PWM output of the microcontroller.

The operational amplifier included in the ST7MC comes to assist current detection — the amplifier is configured as an inverter with a gain of 9.2 times. Then we amplify the low signal to the terminals of the shunt resistor (low ohmic value) before it is processed by the current loop. In this way, we can

## The author

Florent Coste, electronics specialist, received his Electrical Engineering degree in 2000 at the Charles Fabry Institute, Marseilles, France. He is currently an STMICROELECTRONICS employee based in Hong-Kong.
Specialised in microcontroller software, Florent heads development for entirely new platforms based n STR750 (32-bit, ARM core-based) for vectorial motor control of synchronous and asynchronous motors intended for the Asian market. A passionate fan of microelectronics and attracted by everything high-tech and technical, he is always on the lookout for something new. Here, he presents one of the Cube prototypes.

Contact : florent.coste@st.com

eliminate any expensive Hall-effect transducers.

## LOOK AT THE SCHEMATICS CAREFULLY

The ST7MC functions at maximum speed, while an internal PLL doubles the frequency and filters the 8-MHz signal from the quartz crystal. The PWM frequency controlling the charge and discharge circuit has been set at 50 kHz, thus reducing the size of coil L1 and the noise pollution (slim chances your ears are still sensitive enough to hear it!). We can divide the diagram (**Figure 3**) into three distinct parts: one charge circuit, one discharge circuit and the control logic (on the left) that goes along with the rest.
The charge circuit is a traditional Buck converter, based on T1, L1, D2 and the connected charge (i.e., battery). The PWM control signal comes from pin 42 (MCO0= Motor Control Output Zero) and is applied to a level shifter handling the conversion from TTL level to the power supply (typically +12 V). The converter is based around MOSFET T4 and push-pull circuit T2/T3. Schottky-type diode D1, in parallel with resistor R1, enablles a slow activation (ON) of power MOSFET T1 (under 56 ohms), and a fast de-activation (OFF) (using the low on resistance of the biased diode).
L1 comes at the end to 'smooth out' the charge current injected into the battery.
The discharger section of the circuit is organized around a very traditional N-channel MOSFET type IRF640N, T5; the latter may be replaced by any other equivalent transistor, the most important characteristic being the thermal resistance (it dissipates lots of heat during the discharge phase!). The PWM control signal (pin 43, MCO1) is filtered with the help of the R8/C10 network. Then we have direct current again on the T5 grid, which works well in linear mode. This may seem atypical at first sight, but it is very efficient in

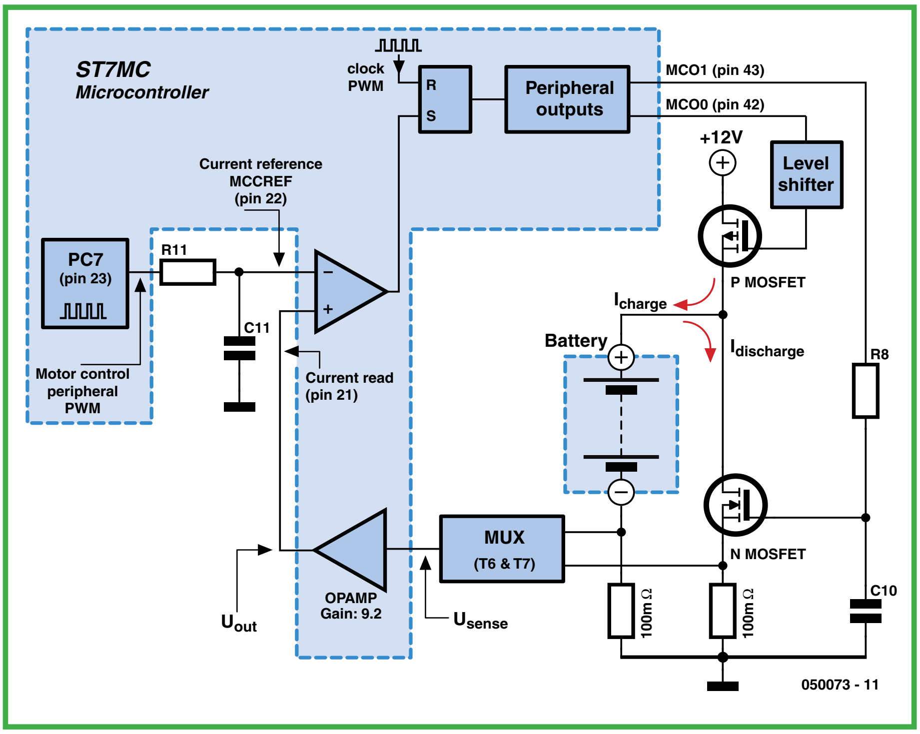



Figure 1. **Simplified diagram of the ST7MC-based current loop.**

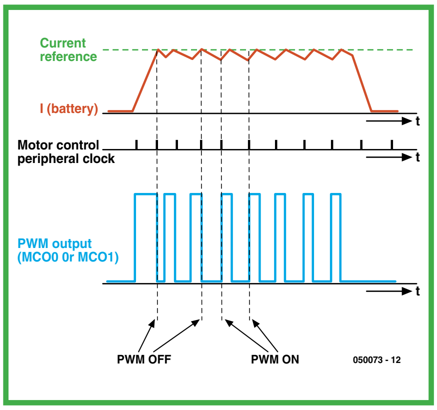



Figure 2. Effect of the current readout on the PWM output of the micro.

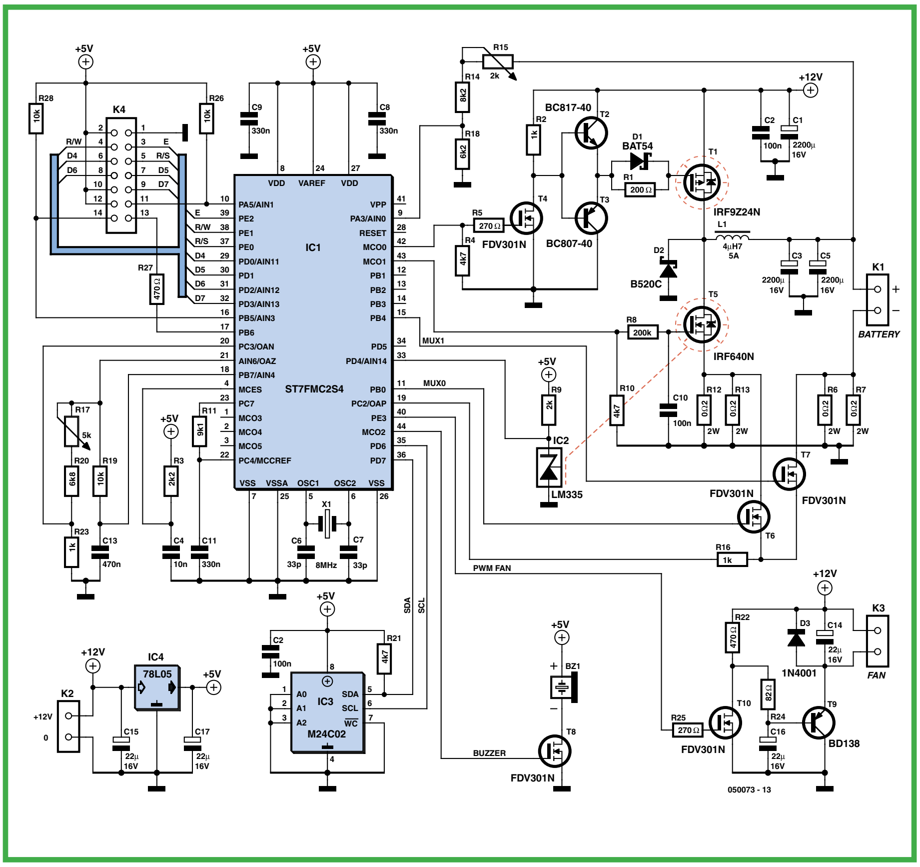



Figure 3. Circuit diagram of the electronics on the main board.

the end in order to simulate a variable resistor. As long as the current level detected at the terminals of resistors R12/R13 is not affected, the voltage on the grid will increase. Inversely, exceeding the current level will cause it to decrease. For that, implementing a pi-type closed-loop control was necessary to manage the input current set point. As previously noted, MOSFET T5 will be responsible for continuously dissipating heat during the discharge phase. Despite the fact that its cooling will be assisted by a fan, a 12-V battery with 4 amperes capacity will produce, for example, 48 W to be dissipated. Therefore, the circuit must be able to 'breathe' and the IC2 temperature sensor must be mounted as close as possible to the MOSFET. The circuit has been tested up to 80 watts (16 V, 5 A) without mishap, and an automatic cut-off has been planned, in case of overheating.

One last point: the circuit allows the discharge of any battery with a maximum voltage equal to the project's own supply voltage. In case of a battery voltage that's in excess of the supply voltage, the current will be drained off to the power supply by the intrinsic diode of the P-channel MOSFET (T1), a situa-

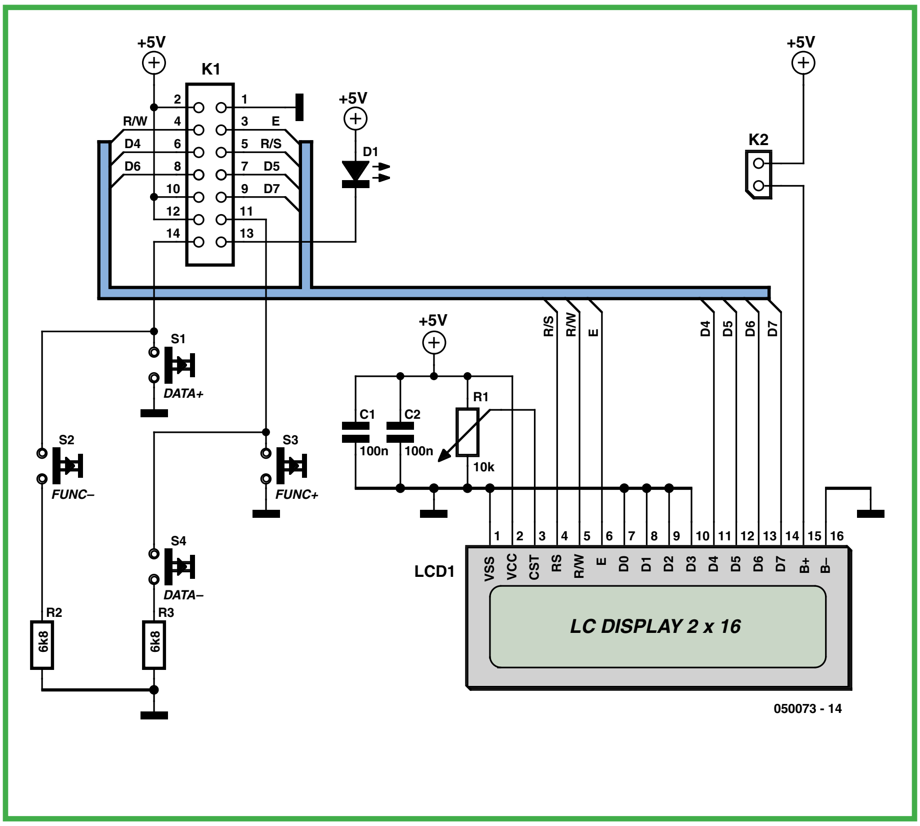



Figure 4. Electronics for the display (LCD) and the 4-button control sub-unit.

tion which should be avoided!

Finally, the rest of the circuit makes it possible to control different external parameters. An I C EEPROM, IC3, is included with 256 bytes storage space. A type 24C02 will work perfectly (24C04, 24C08, ...remaining compatible). The latter makes it possible to store data, such as the name of the batteries (or miniature models for our hobbyist friends), as well as the charge and discharge currents selected, the type of battery (NiMH, LiPo), etc.

Transistors T6 and T7 allow for the multiplexing function to be executed, which is necessary to sample the charge or discharge intensities. The layout retains the use of distinct shunt resistors in order to detect the charge (R6 & R7) and discharge (R12 & R13) current. If we had only kept one of the two shunts, it would have been necessary to read the positive and negative voltage levels on the latter (since the current circulates in both directions, depending on whether we are supplying or draining the battery). Of course, we could have done without a multiplexer (which costs practically nothing in this case), but we would have had to add an external operational amplifier (set up as an inverter) and a DC/DC converter in order to be able to work in negative voltage range.

Moreover, the use of small MOSFETS (functioning as switches, here) is largely adequate. For example, during discharging, T6 is on and T7, off. Whatever the discharge current, the voltage gap between the source and grid will be too low to turn back to on or to interfere with the measurement taken with T6.

The voltage level of the battery is evaluated by the resistive divider R15/R14/R18.

Temperature control is handled by the venerable sensor LM335 (IC2) connected to the 10-bit ADC input on the microcontroller. Depending on the amount of heat to be dissipated, we will find a PWM signal on pin 40 (PE3) applied to the T10 grid for which the drain will supply an RC filter (R22/R24/C16) connected to the base of T9, configured as an emitter-follower. It results in an output (T9 emitter) of nearly continuous voltage: the simplicity of the project results in a few compromises in terms of residual ripple, but is more than adequate to permit control of a small external PC-type fan (12 V). In addition, it is useless to spend a lot for the radiator and fan unit, you just have to find it in the computer 'flea market'

## Principles and measurements

Whether referring to LiPo or Li-Ion, the principle for recharging) is the same: constant voltage and limited current intensity. This may seems simple at first if this type of battery was not very squeamish about two things: one, it cannot withstand overcharging, however slight; and second, the level of voltage is to be respected absolutely or else charging will be interrupted. Then nominal voltage of the current generation of LiPo and Li-Ion batteries is stated as 3.7 V. A charging voltage of 4.1 V per element was adopted by the author.

The author happily proceeded with a few measurements and logged them in an Excel file. The curves clearly illustrate the process of charging and discharging. We can see the versatility of "Cube" which can accommodate a NiCd pack with 8 cells (Figure a) as well as an LiPo battery composed of two cells (Figure b). Rarely has the fundamental difference between NiMH and LiPo battery charging been so clearly illustrated.

For users of Li-Ion cells, the bracket of end of charge stabilisation is set at 8.2 V (2 x 4.1 V, corresponding to the maximum cell voltage recommended by the manufacturers).

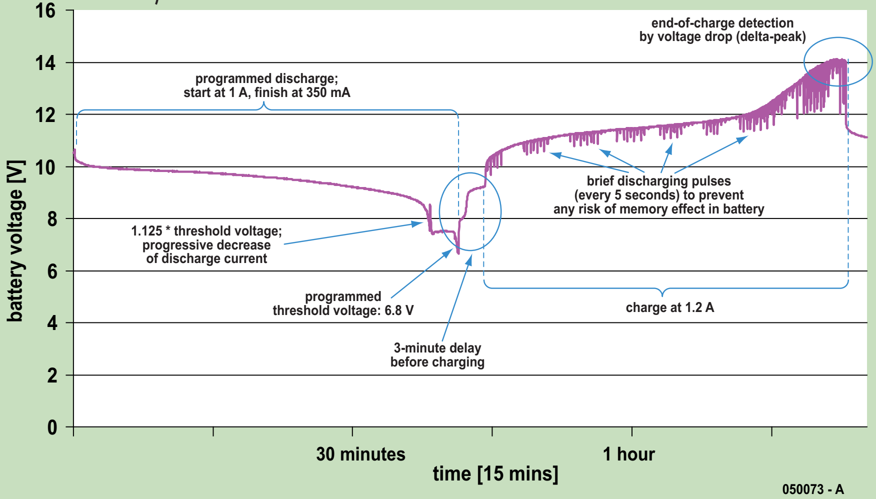



**Figure a.** Oscillograms taken during a discharge/charge cycle of a NiCd battery (8 cells, 1,300 mAh)

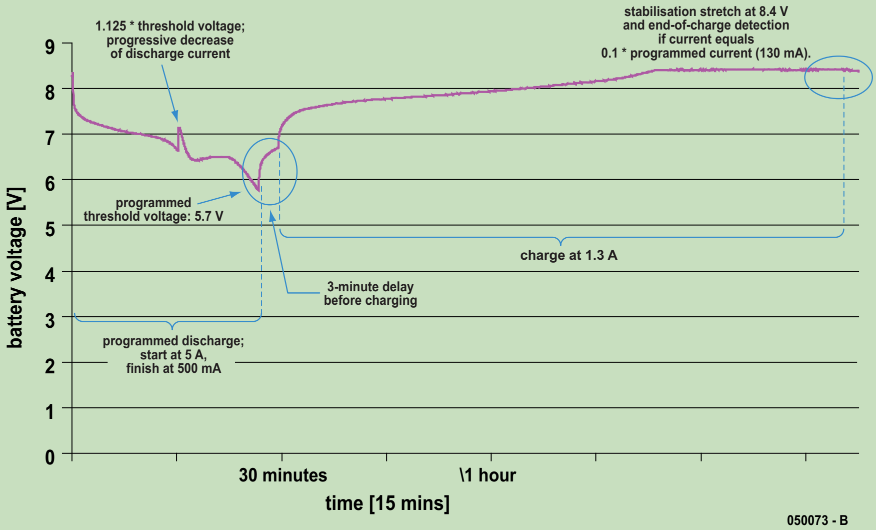



**Figure b.** Oscillograms taken during a discharge/charge cycle of a LiPo battery (2 cells, 1,400 mAh).

for a few pence, or salvage the whole thing from an old PC motherboard. Buzzer Bz1 will indicate the end of the discharge and/or charge process, loud enough to wake you up if you are asleep! One last point: LCD display control is established with the help of a connection over 7 wires (4-bit mode), used to limit the size of the flatcable connected between the boards. See **Figure 4** for the diagram of this part of the project.

## CONSTRUCTION

This setup has two boards, the main board with the processor and the board for the control units and the LCD display. Nothing too difficult, the double-sided boards for this setup are easily made using simple UV exposure and transparencies made on the printer (you have my word!).
For those who do not have access to boards with metallized holes (order code **050073-1** /**-2**, available from the usual sources), it is best to place the through-hole contacts using wire-wrap wire, for example (you will also have to solder some of the pins like those of the K4 base on each side of the printed circuit), then install the resistors, capacitors and SMA integrated circuits, to finish with the largest components (connectors, 2-W resistors, electrolyticl capacitors, etc.).
Also note that Schottky diode D2 will need to be soldered 'in the air', between the circuit ground and the T1 drain. The latter may be replaced by any (near-) equivalent with the same package (DO-201).
We will assume that you will use two ready-made boards (**Figure 5**) to avoid any problems All components, except the two power transistors T1 and T5, are mounted on the component side of the board (see the photo of our prototype in **Figure 6**).
As far as power transistors T1 and T5 are concerned, it is best to orient them so that their metal tabs are turned toward the centre of the board; then you must fold their pins to an angle of 90 degrees and thread them through the holes in the printed circuit, without soldering them right away.
Next, we will attach the radiator to the circuit (held in place by a screw and clamp), and we will mark the points for drilling the attachment holes for T1, T5, as well as the one to be used to mount the temperature sensor LM335 (IC2), to be positioned as close as possible to N-channel MOSFET (thermal coupling demands!). This sensor will be held in place with a simple clamp. Finally, we can solder T1 and T5.
Next, drill all the necessary holes, attach the radiator to the circuit again, without forgetting to first add a bit of thermal paste on T1, T5 and IC2. You should also solder a few centimetres of flexible cable to IC2 in order to connect to the three points identified (IC2) on the printed circuit.
Finish by connecting the LCD board using a piece of flatcable. If you have an LCD display with an LED backlight, you should create a solder point on K2 (double solder island) on the LCD board, to allow the +5 V supply to be carried. Note: this will result in an additional power consumption of

## COMPONENTS LIST

**main board # 050073-1**

### Resistors

(SMA case shape 0805 except unless indicated differently)
R1 = 200Ω
R2 = 1kΩ
R3 = 2kΩ2
R4,R10,R21 = 4kΩ7
R5,R25 = 270Ω
R6,R7R12,R13 = 0Ω2 2W (not SMA)
R8 = 200kΩ
R9 = 2kΩ
R11 = 9kΩ1
R14= 8kΩ2
R15 = 2kΩ preset
R16,R23 = 1kΩ
R17 = 5kΩ preset
R18 = 6kΩ2
R19,R26,R28 = 10kΩ
R20 = 6kΩ8
R22,R27 = 470Ω
R24 = 82Ω

### Capacitors

C1 = 220μF 16V radial (low profile)
C2,C10,C12 = 100nF
C3,C5 = 2200μF 16V radial (low profile)
C4 = 10nF
C6,C7 = 33pF
C8,C9,C11 = 330nF
C13 = 470nF
C14 à C17 = 22μF 16V

### Inductor

L1 = 4μH 5A

### Semiconductors

D1 = BAT54
D2 = B520C
D3 = 1N4001
T1 = IRF9Z24N
T2 = BC817-40
T3 = BC807-40
T4,T6,T7,T8,T10 = FDV301N
T5 = IRF640N
T9 = BD138
IC1 = ST7FMC2S4, programmed, order code 050073-41 (SMA device; STMicroelectronics)
IC2 = LM335 (National Semiconductor)
IC3 = M24C02 (SMA device)
IC4 = 78L05

### Miscellaneous

X1 = 8MHz quartz crystal
K2 = 2-way SIL pinheader, lead pitch 0.1 inch
K3 = 3-way connector for PC CPU fan
K4 = 14-way boxheader or pinheader
Bz1 = piezo ceramic resonator (buzzer)
Heatsink and fan for T1 & T5
PCB, ref. 050073-1

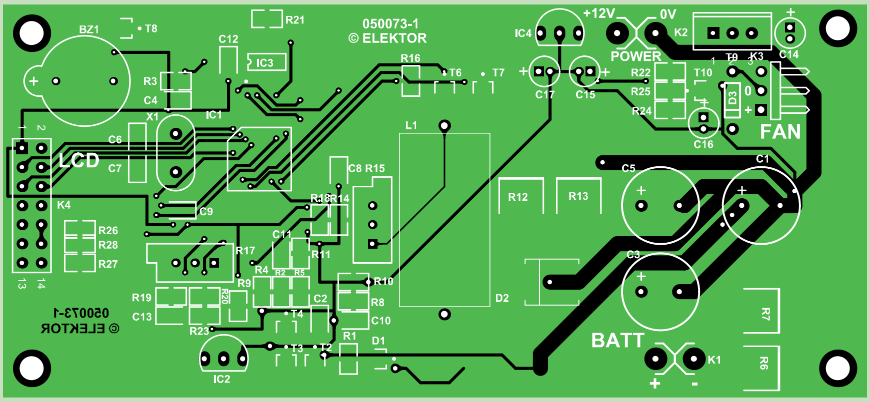



Figure 5. Copper track layout and component mounting plan of the two boards required to make the multi-purpose charger.

## COMPONENTS LIST

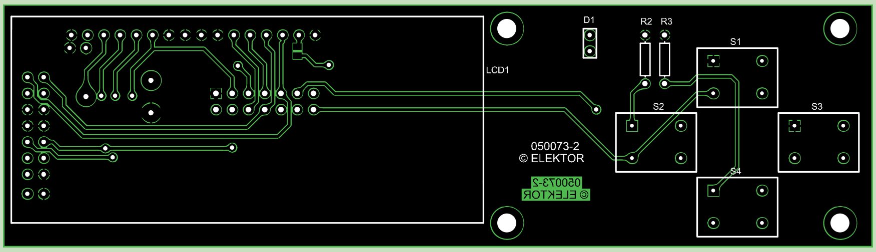
**Display board # 050073-2**

**Resistors**
R1 = 10k Ω potentiometer
R2,R3 = 6kΩ8

**Capacitors**
C1,C2 = 100nF

**Semiconductors**
D1 = LED

**Miscellaneous**
S1-S4 = 'Digitast' pushbutton with make contact
K1 = 14-way boxheader or pinheader
K2 = double solder point
LCD1 = general purpose LCD, 2x16 characters
PCB, ref 050073-2



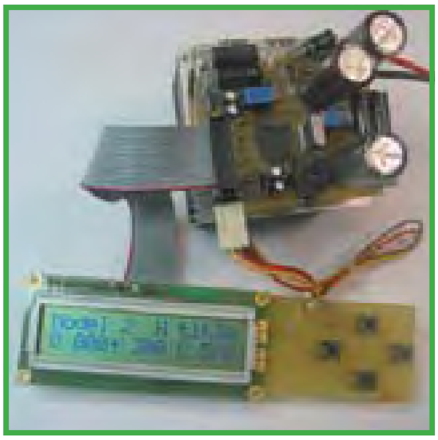



Figure 6. One of the charger/discharger prototypes built to validate the concept.

## Technical characteristics

### Charger

Input voltage: 11 to 16 V
Charge current: adjustable from 200 mA to 4.5 A
Supported batteries: from 1 to 8 NiMH or NiCd cells, 2 LiPo or Li-Ion cells
'Reflex' type charge for NiMH/NiCd batteries; continuous for LiPo/Li-Ion batteries
Detection of end of charge: automatic ('delta-peak' with adjustable sensibility)

### Discharger

Discharge current: adjustable from 200 mA to 5 A with programmable voltage threshold

### Capacity meter

14 models, with memory
Regulated fan and thermal protection

at least 200 mA.  Therefore, you must replace the 78L05 (5-V regulator) with a more robust model (likew the good old 7805), possibly with a small heatsink attached. The LCD display will be mounted on the control board and is attached using its connector. Since the attachment points depend on the type of display used, we did not plan them. It is easy to drill a pair of holes in the board, considering that there are no signals in that spot.

## CALIBRATION AND UTILISATION

For the first start-up, we recommend to not to connect the setup directly to a 12-V car battery; it is preferable to use a current-protected lab power supply! If there is a short-circuit on the board, the setup will be very grateful. The circuit should consume about 20 mA with no load (without backlighting). If the LCD is not detected (problem with connections, soldering, etc.), the buzzer will beep at regular intervals.

Before using it, you should calibrate the circuit. The setup should be supplied with 12 to 16 V (car battery, for example), and we will have a DC 5 to 9 V power supply capable of delivering at least 2 A (with an adjustable power supply, we will adjust the output to about 8.40 V, if possible, which corresponds to the voltage of two LiPo cells at the end of the charging process). As soon as it is connected to ground, you will simultaneously press the FUNC+ and FUNC– keys until an initial menu 'Calibration #1' appears (voltage calibration). Then connect the power supply to output BATT+ and BATT– of the setup (beware of inverted polarities!) and connect a multimeter in parallel (an accurate one...) in DC mode. Then turn potentiometer R15 until the same value is displayed on the LCD and on the multimeter.

With the circuit adjusted, disconnect the multimeter and configure it as a DC ammeter (it should be able to withstand a current of at least 2 A). Then connect it in series with the DC power supply, all of it still connected to out-

## A few words about the firmware

All of it was written in C using the free version of IDE (Integrated Development Environment), available at SOFTEC (www.softecmicro.com) and with the COSMIC compiler (www.cosmic-software.com). Also a free version and limited to 16 kB of the C compiler, it allows you to practice on the entire line of ST micr ill not cost a lot (available at SOFTEC, http://www.softecmicro.com/products.html?type=detail&title=inDART-STX%2FD or else at RAISONANCE, http://www.raisonance.com/products/ST7.php#hardware). Those interested can download the source code from the ELEKTOR website; all you need to do is install the SOFTEC development environment and open the dedicated configuration file. You will then be able to make any modifications and re-program the ST7MC at will (long live Flash memory!).

puts BATT+ and BATT–. Holding down any button will get you to the second menu, this time for current calibration. Here all you need to do is adjust R17 until you see the same current value (about 2 A) on the LCD screen and the multimeter. Once this last operation is completed, you can disconnect all power supplies.

The interface for adjusting the various parameters is very easy to use. As soon as it is powered up, a welcome message is displayed, then you enter the main screen. The FUNC+ and FUNC- keys allow us to navigate between the different parameters, and the DATA+ and DATA– keys simply let you change those values.

We can navigate to our heart's content among the 14 batteries that can be memorised and adjusted independently:

- Battery name.
- Sensitivity of the delta-peak )CP) for the NiMH/NiCd batteries (at least for the most sensitive: 'L' for low, 1, 2, or 'H' for high). Strive to use high sensitivity for batteries with a low number of cells, so there is a smaller drop in voltage at the end of the charge (approximately from 5 to 15 mV per element).
- Maximum time allocated for recharging, in order to avoid overcharging a battery (frequent when defective) if the end of charge is not detected.
- Current values at the start and the end of discharge, in 50 and 100 mA increments. A closed-loop control is used to handle the process automatically (you may, for example, begin discharging at 3 A and end at 200 mA). The discharge process may be cancelled in order to only do one charge operation.
- Charge current value in 50 and 100 mA steps (this process may also be cancelled in order to only do one discharge operation).
- Battery type (NiMH/NiCd or LiPo/Li-Ion).
- Battery voltage at which the discharge process must be cut-off ($V_{cutoff}$).

Once your parameters have been adjusted (and automatically memorised in the EEPROM), you only have to launch the discharge and/or (re)charge operations by holding down the FUNC+ or FUNC– button.

During the battery discharge process, the capacity will be displayed as well as the voltage level. A 'full' battery of 1 Ah discharged at 500 mA should therefore display a capacity of approximately 1,000 mA after two hours. The user may carry out many experiments, for example, by changing the beginning and end of discharge parameters or increasing or decreasing the 'delta-peak' sensitivity. Finally, you can, at any time, interrupt the discharge and/or charge process by holding down any button.

### TWO FINAL POINTS TO HIGHLIGHT

Be sure to use properly-sized cables capable of carrying the anticipated currents! Also, if necessary, add dedicated cables and plugs. In order to charge the NiMH/NiCd accumulators with seven or eight cells, you will need at least 13 to 15 volts to power the circuit. This is justified during the charge by a voltage level that can exceed 1.5 V for each of the NiMH/NiCd cells (8 elements times 1.5 V = 12 V on the battery), as well as by the internal resistor causing a noticeable drop in voltage, especially at high current levels. If you observe a current charge setpoint that is lower than the one you have selected, raise the power supply voltage level of the setup!

(050073-I)

### Internet Links

Product sheet features for the ST7MC2S4:
http://www.st.com/stonline/products/literature/ds/9721/st7mc2s4.pdf

Application note for the ST7MC:
http://www.st.com/stonline/books/pdf/docs/10267.pdf

More information about charging LiPo and Li-Ion batteries:
http://www.ni-cd.net/accusphp/theorie/charge/liion.php