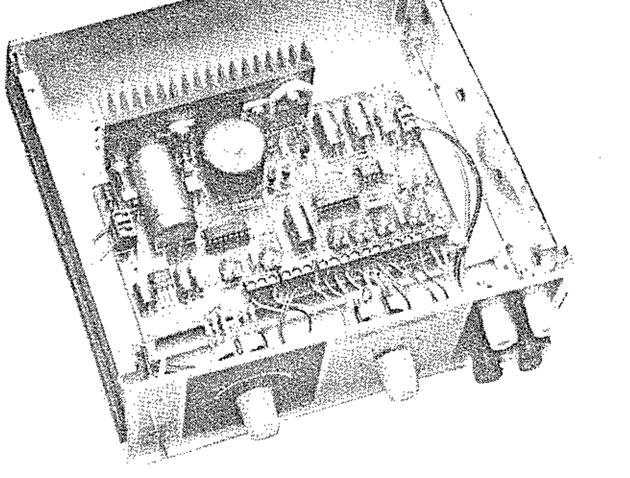
UNIVERSAL Ni-Cd BATTERY CHARGER

by A. Rigby



Ni-Cd batteries are now used in so much everyday equipment that most households need at least one suitable charger. The one presented here can be used to charge virtually all current Ni-Cd batteries.

THE charger is based on the Telefunken Type U2400B processor, which has been specially developed for this application. This device contains most of the logic circuits necessary for automatically controlling the charging of Ni-Cd batteries.

Initially, charging takes place during a predetermined period of time, after which trickle charging takes over. The trickle charging, which may continue for long periods of time, ensures that the battery capacity does not degrade during the life of the battery.

The charger has a number of safety features. For instance, if the temperature of the battery becomes too high or when the e.m.f. of the battery rises above a certain (predetermined) value, the charging cycle is discontinued immediately. The processor then assumes its stand-by mode and remains there until the temperature or the e.m.f. drops below its limiting value.

A flow diagram of the charging process is given in Fig. 2. After the battery has been connected and the start reset operated, the processor first arranges for the battery to be discharged. During the discharge cycle, the temperature of the battery ($T<T_{max}$) and its e.m.f. ($U<U_{min}$) are monitored continually. When the e.m.f. drops to the level of U_{min}, the processor assumes that the battery has been discharged completely, and sets its discharge register. The circuit then switches to the charging mode. During charging the lapsed charging time is compared with the preset charging time ($t>t_{max}$) and the e.m.f. with the maximum (preset) voltage ($U>U_{max}$). Furthermore, the content of the discharge register and the battery temperature are monitored constantly. At the end of the preset charging time ($t>t_{max}$), the charging cycle is terminated and the processor actuates the trickle charging mode.

As already mentioned, if during charging one of the preset parameters is exceeded, charging is discontinued. At the same time, the status of the error register is increased by 1 and reread. If no error occurred previously, the status of the counter after the present error will be smaller than 2($Z<2$). If the counter status is smaller than 2, the e.m.f. and temperature of the battery are checked once again; if these are all right, the charging process is continued. If the content of the error register is greater than, or equal to, 2, charging is continued or stopped, depending on the position of a switch as explained later.

As is seen in Fig. 1, the processor needs only a few external components to perform the functions discussed so far. During the discharge cycle, the e.m.f. of the battery is monitored via U_{min} (pin 6). In this, use is made of a switchable voltage divider, R_{35}–R_{43}-R_3–P_2, which attenuates the battery voltage. During the discharge cycle, output DIS(charge) (pin 10) is active and high. The discharging is assumed complete when the voltage level at pin 6 drops below the level (0.53 V) of the internal reference voltage.

During charging, output LOAD (pin 12) becomes active and high; the battery voltage is then applied to pin 4 (U_{max}) via potential divider R_{35}–R_{43}-R_2-P_1. If the voltage at pin 4 is higher than the internal reference potential, the processor switches to the stand-by mode.

Since it is important for the user to know in which state the processor is, two LEDs are driven via STATUS output pin 9. Table 1 shows the operation of these diodes in the various modes.

A reference voltage of 3 V (nominal) is applied to pin 7, the PWM input, switch S_1, network R_4-C_2, voltage divider R_5-R_6 and the two series-connected LEDs.

Series combination R_4–C_2 at the input of the internal oscillator, pin 3, is a frequency-determining network.

Monitoring of the battery temperature is accomplished by R_6, which has a negative temperature coefficient. The potential at junction R_5–R_6 is monitored via input U_{temp} (pin 5). The charging process is stopped when the battery temperature reaches 40 °C; the resistance of R_6 is then about 440Ω.

The position of switch S_1 determines the selection made by the processor when two or more errors in the charging process have been signalled. If the switch is connected to the reference voltage, charging is continued even when two (but no more) errors have occurred; if it is connected to earth, however, full charging is discontinued and trickle charging commenced.

The charging time is preset via the TIME input, pin 13. When the internal 200 Hz oscillator is used, a high level at pin 13 sets the charging time to 1 hour. When the pin is connected to earth (low level), the charging time is 30 minutes.

The timer may also be driven by an ex-

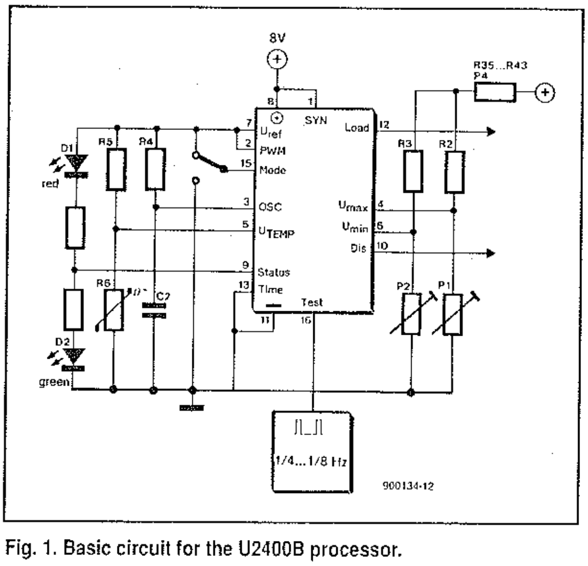


Fig. 1. Basic circuit for the U2400B processor.

Table 1			
D_1	D_2	S_1	Function
(red)	(green)		
on	off	x	no battery connected; battery faulty or battery flat
flashes	off	x	discharge cycle
off	flashes	x	charging cycle
off	on	x	trickle charge mode
flashes	flashes	E	charging continues after two errors
on	off	D	trickle charging after two errors

x = irrelevant
E = connected to U_{ref}
D = connected to earth

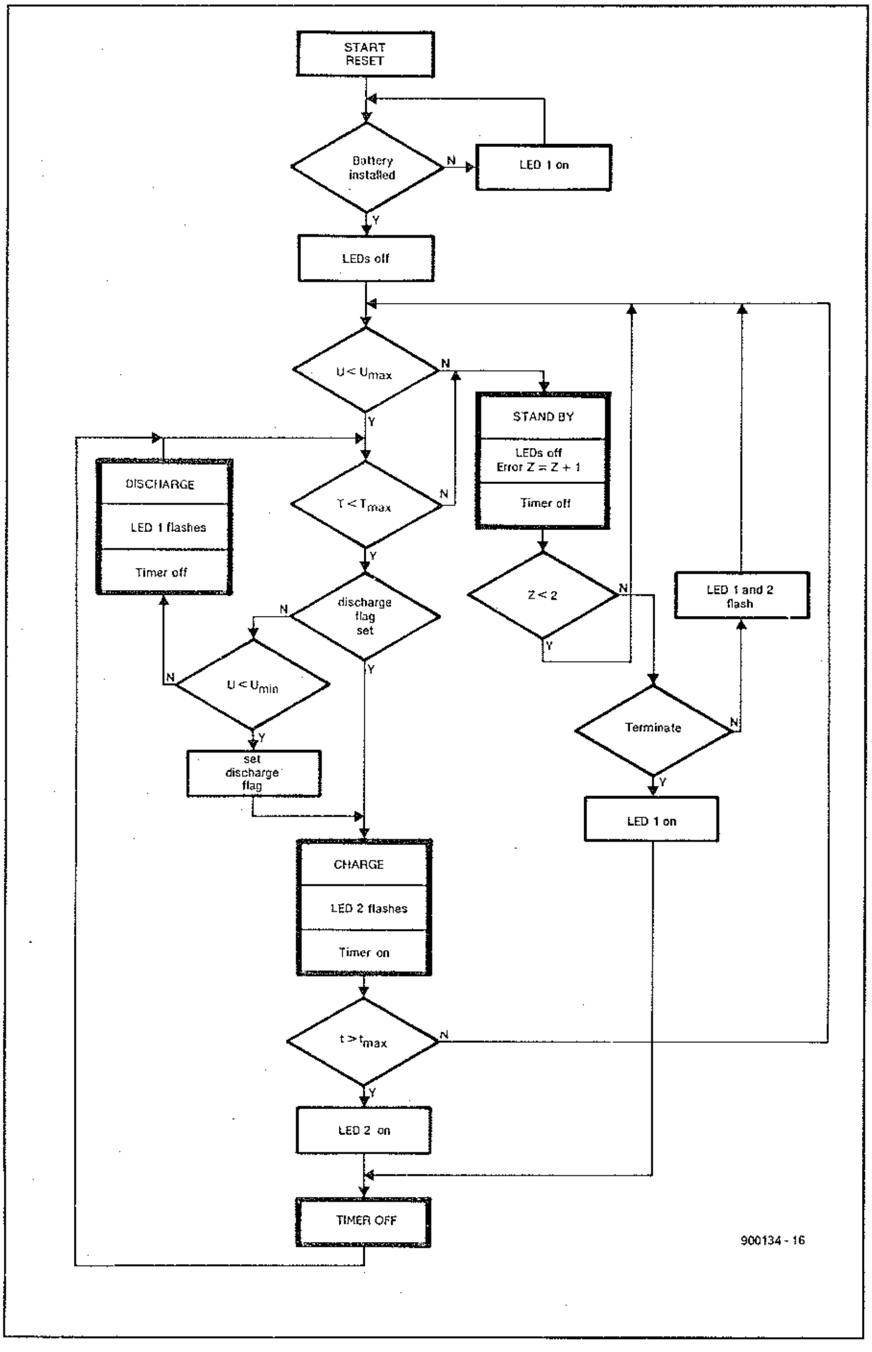


Fig. 2. Flow diagram of the battery charger.

ternal clock, connected to pin 16; pin 13 must then be earthed. The internal 200 Hz oscillator then provides the clock signals for the remaining functions of the processor. A frequency of 0.5 Hz at pin 16 sets the charging time to 1 hour; halving that frequency doubles the time. An external clock based on a 4060 IC as shown in Fig. 8 can provide frequencies down to 0.125 Hz, which would give a charging time of 4 hours.

Charging

In a practical charger, the processor does not drive a simple transistor, but a fairly complex current source, controlled as shown in Fig. 3. The charging current flows through R_{22}, resulting in a potential drop across this resistor that is directly proportional to the charging current:

$$U_{R22} = I_{load}R_{22}.$$

This voltage is used for controlling the charging current. Note that the negative battery voltage, U_{bat}, is in reality more positive than the supply voltage, U_V, because the positive terminal of the battery is connected to a second, higher supply voltage.

Since transistor T_5 is connected as a diode, the emitter of T_6 is connected to U_V at all times. Therefore, the potential drop across the emitter resistor, R_e, which is the equivalent of R_{29}–R_{34}–P_6 in Fig. 8, is exactly the same as that across R_{22}:

$$U_{Re} = U_{R22} = I_{Re}R_e.$$

As an example, assume that $R_{22} = 0.1\ \Omega$, $I_{load} = 1$ A, and that a current of 1 mA is required through the transistor. The drop across R_{22} is 100 mV, so that

$$R_e = 100\times10^{-3}/10^{-3} = 100\ \Omega.$$

Since the emitter current is now known, the voltage drop across the collector resistor is:

$$U_{Rc} = 1.2\times10^{3}\times10^{-3} = 1.2\ \text{V}.$$

This makes it clear that a change in the charging current results in a change in the voltage at F_B. That voltage may, therefore, be used for the control of a regulatory circuit in a switch-mode power supply.

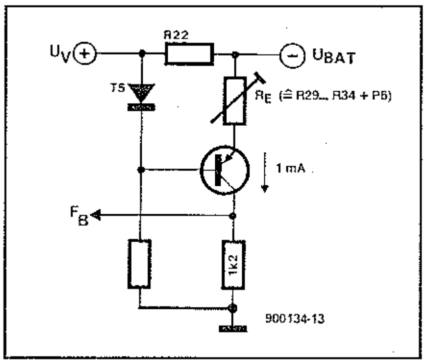


Fig. 3. Part of the circuit controlling the charging current.

Switch-mode power supply

A switch-mode power supply is used to enable the charger to cater for the simultaneous charging of, say, up to ten batteries; a conventional mains supply could be used, but the dissipation in this will be quite large when only a few batteries are being charged.

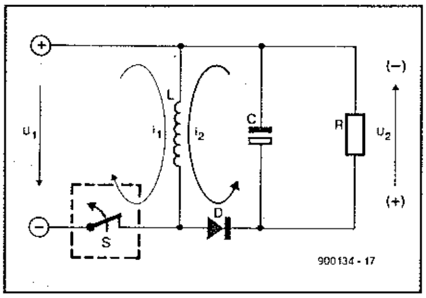


Fig. 4. Concept of a switch-mode power supply.

The basic operation of such a supply is shown in Fig. 4. Electronic switch S is switched on and off by electrical circuits. When it is closed, a current i_1 flows from the ⊕ supply terminal to earth via inductor *L*, resulting in a magnetic field around the inductor. Diode D is switched off and capacitor *C*, therefore, has no influence on the circuit, although it can discharge via load resistance *R* (representing the batteries to be charged).

When S is opened, the self-inductance of *L* causes a current i_2 in the opposite direction from i_1 and this charges *C* via the diode.

The level of output voltage U_2 depends on the properties of the inductor, the switching logics and the on-off ratio of the switch. In the present charger, a commercial inductor is used: it is not advisable to wind this yourself.

The circuit of the supply used is shown in Fig. 5. It is based on Linear Technology's Type LT 1070. A 40 kHz oscillator provides a train of rectangular pulses that are used to switch a transistor via a driver stage. The duty factor is determined primarily by the output voltage of the (differential) error amplifier.

The collector voltage of T_6 is 1.2 V when the regulator is in a stable condition. Because of its internal reference voltage of 1.24 V, the error amplifier then has no effect on the switching behaviour of the output transistor. When the charging current increases to too high a level, U_c rises, and the output of the error amplifier goes low. This results in an alteration of the on-off ratio of he transistor, which lowers the charging current.

Zener diode D_6 limits the voltage to 18 V.

Discharging

The discharge circuit shown in Fig. 6 has some points in common with the circuit in Fig. 3. Again, use is made of the voltage drop across emitter resistor R_{22}. The supply voltage and the battery voltage have, of course, changed places, since the discharge current flows into a different direction from the charging current.

The non-inverting input of the comparator in the collector circuit of T_3 is held at 2.7 V by zener diode D_3.

The value of R_{14} is determined by the collector current (1 mA) and the reference voltage:

$$R_{14} = 2.7/10^{-3} = 2.7\ k\Omega.$$

The connected batteries are discharged via R_{22} and T_8, which, with T_7, forms a darlington at the output of the comparator.

Voltage monitoring

The processor continually monitors the battery voltage via its pins 4 and 6. Since these inputs measure the voltage with respect to earth and the negative terminal of the battery is connected to the ⊕ supply rail, a simple circuit like that in Fig. 1 can not be used. This means that the battery voltage must be converted so that it *can* be measured with respect to earth.

To this end, a network as shown in Fig. 7 is used. The entire battery voltage is dropped across the emitter resistance, R_e, consisting of resistors R_{35}–R_{43}—see Fig. 8. Since R_e has a value of 1 kΩ per connected battery, the collector current, I_c, through T_1 is

$$I_c = n \times U_z / n \times R_e = U_z / R_e,$$

where U_z is the zener voltage.

When the batteries are charged, the collector current is $1.45/10^3 = 1.45$ mA, and the voltage drop across R_1 and potential dividers R_2–P_1 and R_3–P_2 is 1.74 V. This voltage has the correct polarity with respect to earth. The correct operating point is set with the two potentiometers: how many batteries are connected to the charger is then no longer of importance.

The complete circuit

Large parts of the diagram in Fig. 8 have already been discussed. Note that the switch-mode power supply operates only if pin 1 of the LT 1070 is connected to earth via the LOAD output of the processor and T_4.

Since the resistors at like positions of S_{4a} and S_{4b} have the same value, the discharge and charging currents of batteries are iden-

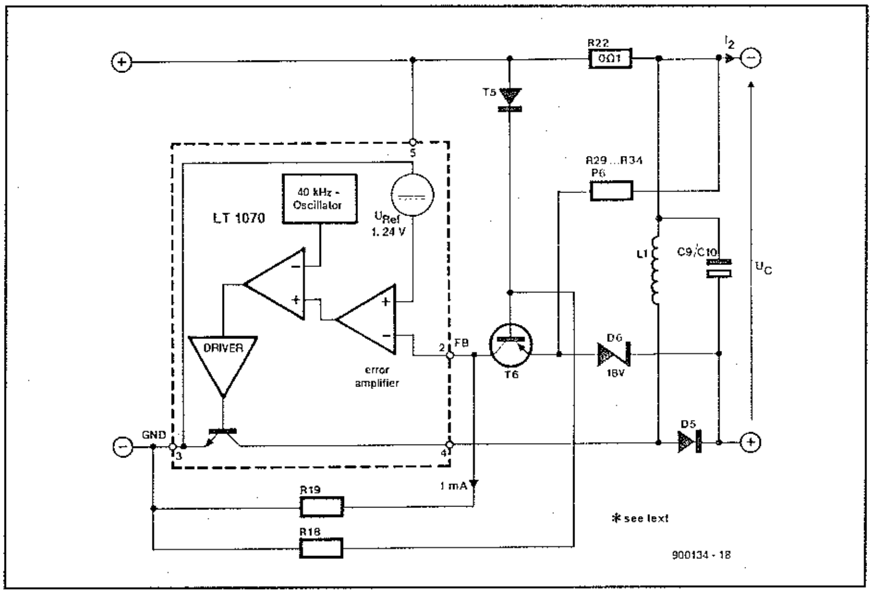


Fig. 5. The switch-mode power supply – see also Fig. 8.

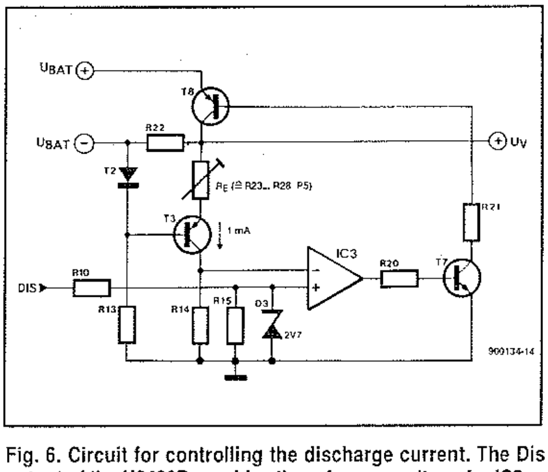


Fig. 6. Circuit for controlling the discharge current. The Dis output of the U2400B provides the reference voltage for IC3.

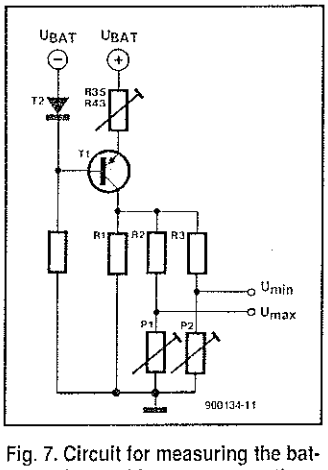


Fig. 7. Circuit for measuring the battery voltage with respect to earth.

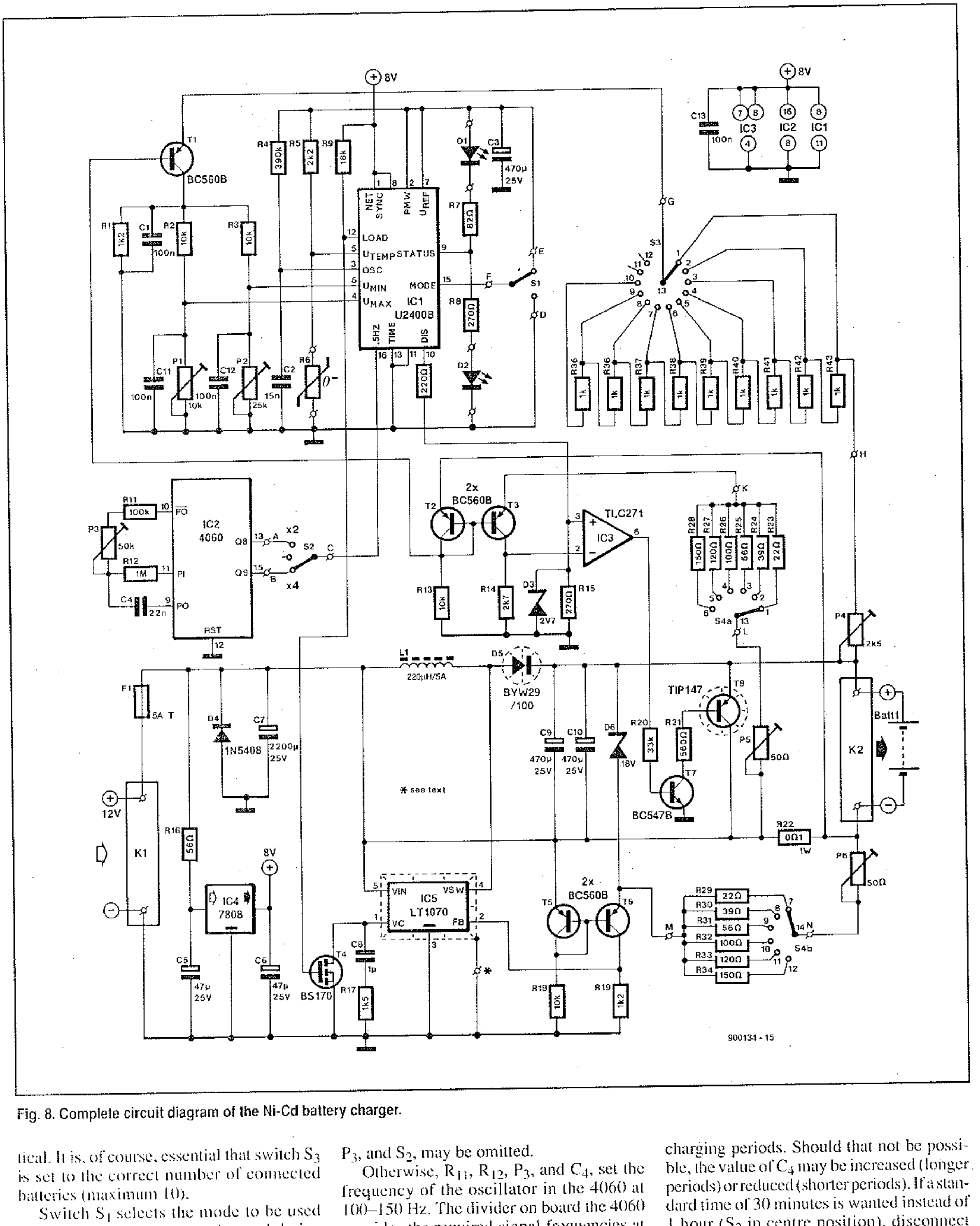


Fig. 8. Complete circuit diagram of the Ni-Cd battery charger.

tical. It is, of course, essential that switch S_3 is set to the correct number of connected batteries (maximum 10).

Switch S_1 selects the mode to be used when one or two errors are detected during the charging process—see Table 1.

When S_2 is in its centre position, the processor uses the standard time setting (of charging) of 1 hour. Its pin 13 is then connected to earth. If this meets all your requirements, the external clock generator consisting of the 4060 (IC_2), R_{11}, R_{12}, C_4, P_3, and S_2, may be omitted.

Otherwise, R_{11}, R_{12}, P_3, and C_4, set the frequency of the oscillator in the 4060 at 100–150 Hz. The divider on board the 4060 provides the required signal frequencies at outputs Q_8 and Q_9. The charging times of 2 and 4 hours respectively associated with these frequencies enable U7 and U11 size batteries to be charged in accordance with manufacturers' specifications.

Preset P_3 enables the correct setting of 2-hour (position A) and 4-hour (position B) charging periods. Should that not be possible, the value of C_4 may be increased (longer periods) or reduced (shorter periods). If a standard time of 30 minutes is wanted instead of 1 hour (S_2 in centre position), disconnect pin 13 of the U2400B from earth.

If C_4 is replaced by a 10 nF type, periods of 30 minutes (S_2 in centre position), 1 hour (S_2 in position A), and 2 hours (S_2 in position B), may be selected

For trickle charging the normal charging circuit is used, but the on-off ratio is ar-

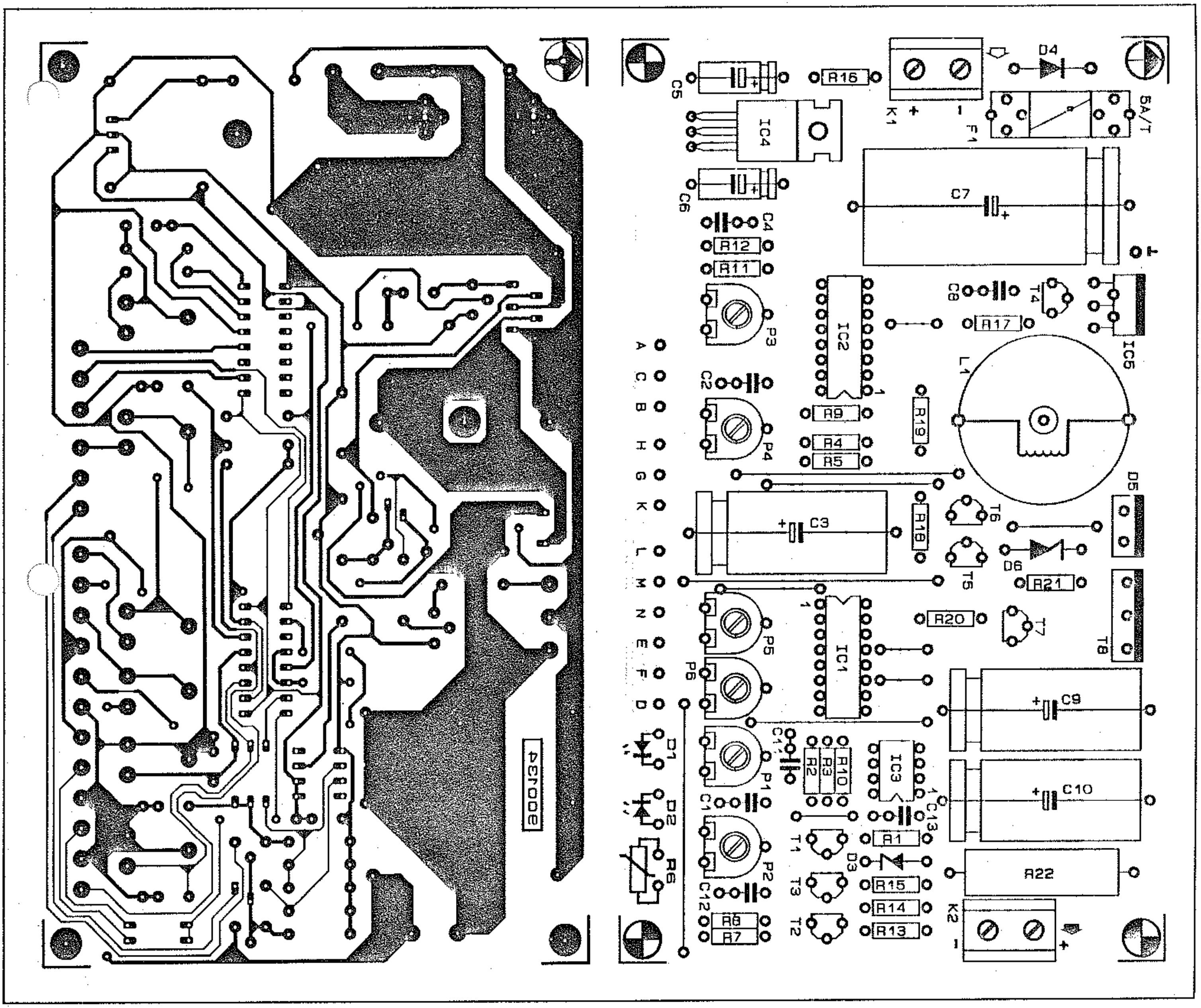


Fig. 9. Component layout and mirror image of track layout of the printed-circuit board for the Ni-Cd battery charger.

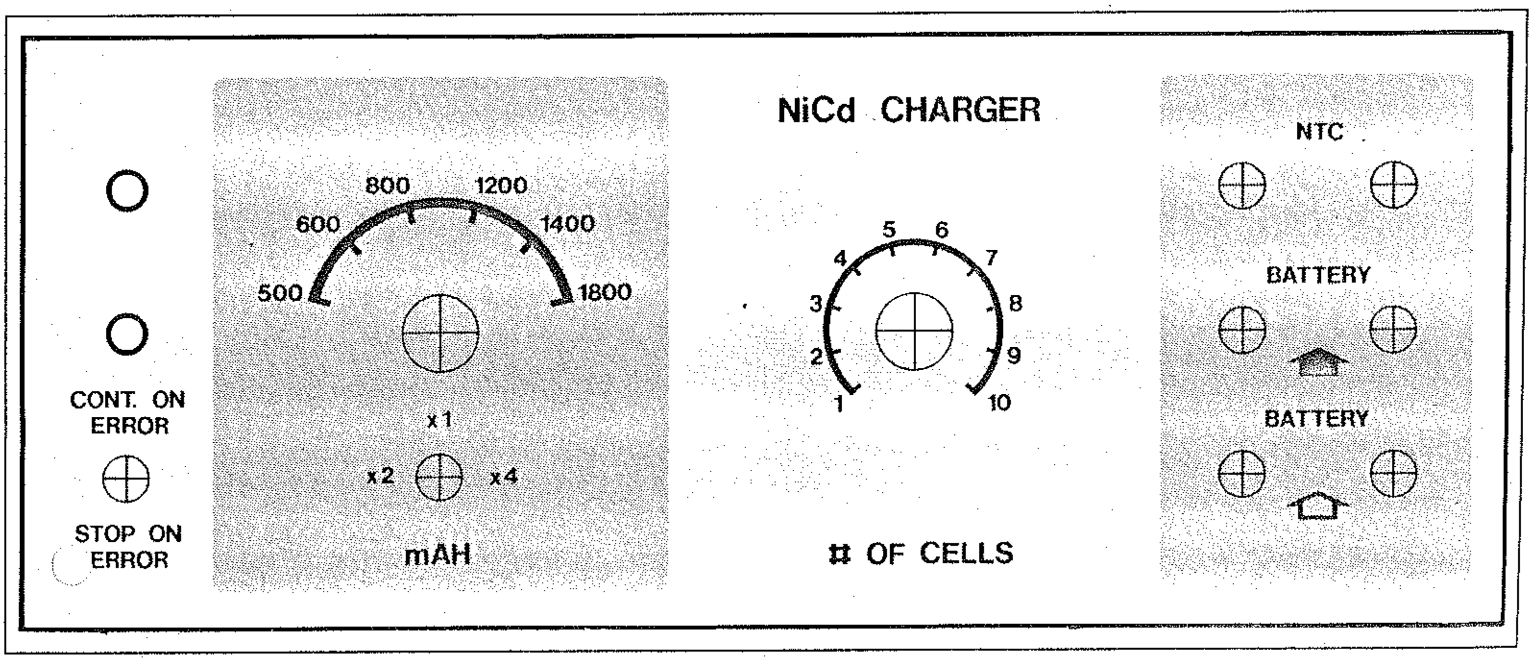


Fig. 10. A front panel foil for the battery charger (196×77 mm) is available through our Readers' Services.

ranged at 1:179, which reduces the average charging current of 1800 mA to 10 mA.

The level of the discharge and charging currents is independent of the selected charging period and may be set to six fixed values with S_4. If it is required for a battery to be charged completely in 30 minutes, the charging current selected must have twice the value of the battery capacity. The charging current in mA corresponds to the capacities shown on the front panel—see Fig. 10. That is, in position 500 mAh, the charging current is 500 mA. Independent of this, the charging current may be doubled by shunting R_{22} with a second 0.1 Ω, 1 W, resistor. This may, however, be done only if the total consumption, $I_{load} \times U_{load}$ does not exceed 25 W, otherwise the switched-mode power supply may become overloaded. Furthermore, the maximum current through the inductor, the fuse rating (max. 8 A), and the maximum discharge current (max. 10 A) must be observed.

Construction

The battery charger is best constructed on the printed-circuit board shown in Fig. 9.

Pay good attention to the polarity of a number of components and make sure that firm solder connections are made where large currents are likely to flow.

The components that need cooling, i.e., IC_5, D_5, and T_8, are located at the edge of the board to enable them to be fitted direct to a suitable heat sink (≥3.2 K W^{-1} at a consumption of ≤25 W).

Make sure that the rear of the LT1070 is electrically bonded to the earth connection specially provided between the supply connections for C_7 and IC_5.

All presets are conveniently grouped at one side of the board.

Resistors R_{23}–R_{43} are not located on the board, but are soldered direct to the rotary switches. These switches are intended to be fitted to the front panel. Their sections that must be connected to the board are marked G/H, K/L, and M/N.

The sockets for connecting the NTC resistor, R_6, the supply (K_1) and the batteries (K_2) are located at the right-hand side of the front panel.

Calibration

There are quite a few calibrations to be carried out, but fortunately they are not very critical. In the first place, do not yet fit IC_1.

1. Set S_4 to 500 (mA), S_3 to 8 (batteries), S_2 to its centre position, and all presets to the centre of their travel.
2. Connect a 12 V, 2 A supply to K_1 (observe polarity!).
3. Connect an auxiliary supply of 8 V to K_2 (observe polarity!).
4. Connect a multimeter between the ⊕ pin of K_2 and point G on the board, and adjust P_4 until the measured voltage is *exactly* the same as that between the pins of K_2.
5. Set S_3 to position 10 and adjust P_2 until with an auxiliary voltage of 8–8.5 V on K_2, a voltage of 0.53 V is measured between junction P_2–R_3–C_{12} and earth. This ensures that all batteries are first discharged to an e.m.f. of 0.8–0.85 V.
6. Set S_3 to position 10 and adjust P_1 until with an auxiliary voltage of 10× the maximum specified (by manufacturer) cell voltage on K_2, a potential of 0.53 V is measured between junction P_1–R_2–C_{11} and earth. The maximum cell voltage is normally about 1.65 V, but may vary from 1.55 V to 1.7 V.
7. The external clock is adjusted with the aid of P_3 and this is best done on an oscilloscope. The frequency of the signal at pin 6 of IC_2 must be 1 Hz. If you have no oscilloscope, use a logic tester with LED indication: the flashing of the LED may be compared with the second hand of a watch.
8. Remove the auxiliary voltage from K_2, switch off the supply voltage, and fit IC_1 and R_6. In an emergency, a normal 1 kΩ resistor may be used for R_6.
9. Connect a partially discharged 500 mAh battery to K_2, set S_4 to 500 and S_3 to 1.
10. Reconnect the 12 V supply to K_1, whereupon the red LED will come on.
11. Connect a digital multimeter (set to 1–2 A d.c.) in series with the battery. About 2 seconds after the connection with the battery is made, the red LED goes out and discharging of the battery begins. Adjust P_5 till the multimeter reads 500 mA.
12. After a little while, the battery will be discharged and charging will commence, indicated by the coming on of the green LED. The current through the multimeter will then change direction: adjust P_6 until it has a value of 500 mA.
13. The battery charger is now ready for use.

Finally

Before charging is begun, always set the various switches to the correct position. The charger can then be switched on and the batteries connected to it. When a different set of batteries or battery is connected to the charger, reset the processor by briefly switching off the supply. ■

PARTS LIST

Resistors:
R1, R19 = 1.2 kΩ
R2, R3, R13, R18 = 10 kΩ
R4 = 390 kΩ
R5 = 2.2 kΩ
R6 = 1 kΩ NTC
R7 = 82 Ω
R8, R15 = 270 Ω
R9 = 18 kΩ
R10 = 200 Ω
R11 = 100 kΩ
R12 = 1 MΩ
R14 = 2.7 kΩ
R16, R25, R31 = 56 Ω
R17 = 1.5 kΩ
R20 = 33 kΩ
R21 = 560 Ω
R22 = 0.1 Ω, 1 W
R23, R29 = 22 Ω
R24, R30 = 39 Ω
R26, R32 = 100 Ω
R27, R33 = 120 Ω
R28, R34 = 150 Ω
R35–R43 = 1 kΩ
P1 = 10 kΩ preset
P2 = 25 kΩ preset
P3 = 50 kΩ preset
P4 = 2.5 kΩ preset
P5, P6 = 50 Ω preset.

Capacitors:
C1, C11, C12, C13 = 100 nF
C2 = 15 nF
C3, C9, C10 = 470 µF, 25 V
C4 = 22 nF
C5, C6 = 47 µF, 25 V
C7 = 200 µF, 25 V
C8 = 1 µF

Inductors:
L1 = choke 200 µH, 5 A

Semiconductors:
D1 = LED, red
D2 = LED, green
D3 = zener, 2.7 V, 400 mW
D4 = 1N5408
D5 = BYW 29/100
D6 = zener, 18 V, 400 mW
T1, T2, T3, T5, T6 = BC560B
T4 = BS170
T7 = BC547B
T8 = TIP147
IC1 = U2400B
IC2 = 4060
IC3 = TLC271
IC4 = 7808
IC5 = LT1070

Miscellaneous:
S1 = miniature C/O switch
S2 = miniature C/O switch with centre position
S3 = rotary switch, 1 pole, 12 positions
S4 = rotary switch, 2 poles, 6 positions
F1 = fuse, 5 A, complete with holder
K1, K2 = 2-way terminal block
Heat sink, 100×38×15 mm
PCB 900134
Front panel foil 900134-F

Estimated cost: £45–£55