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## WATT - HOUR METER

U-2400 NiCd Battery  
Charger

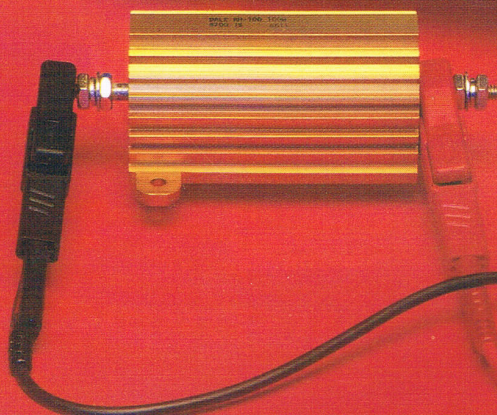
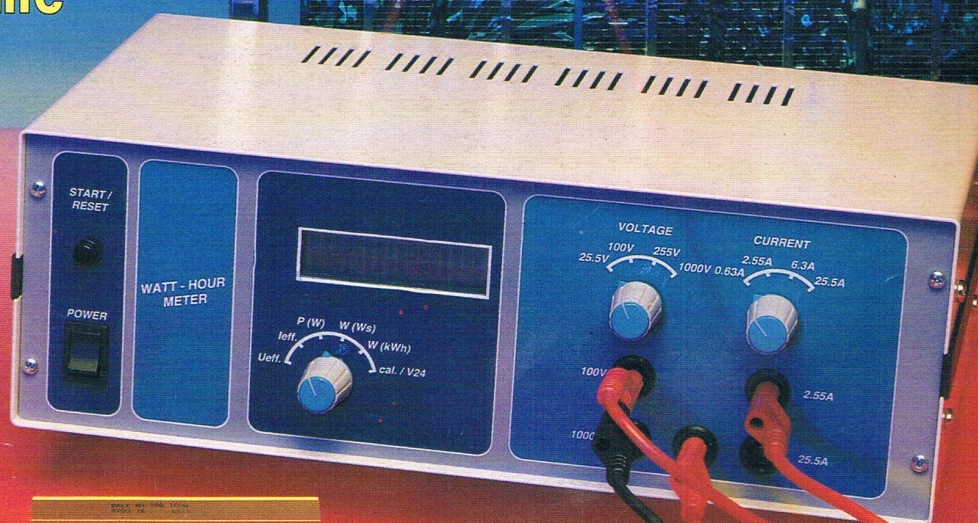
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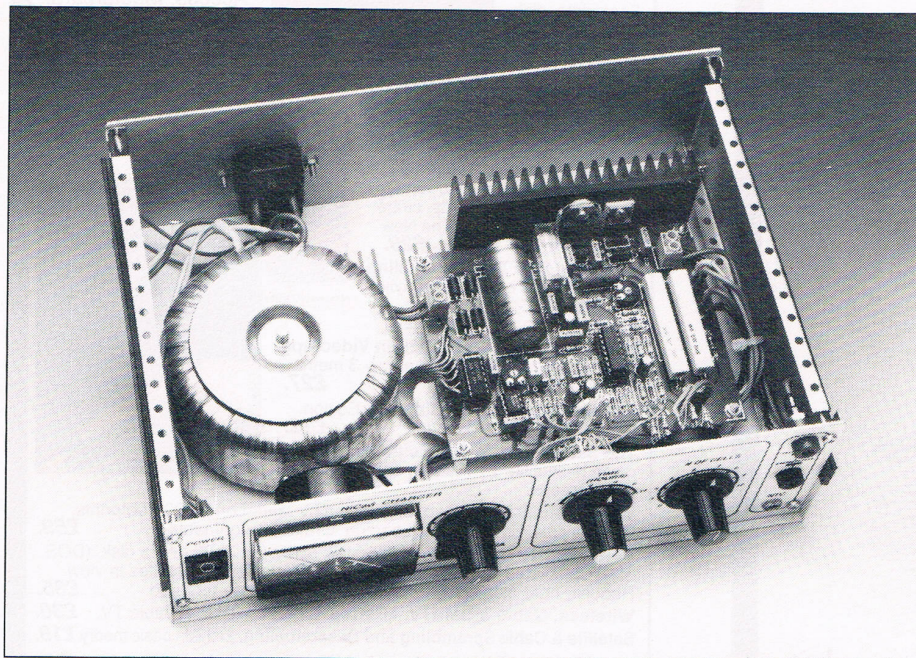
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# U2400B NiCd BATTERY CHARGER

Design by U. Bangert and W. Ernst



The battery charger takes its name from the IC it is based on: the well-known Type U2400B processor. This IC was designed primarily for use in battery chargers and is, therefore, equipped with a number of specific features.

The processor controls the charging for a preset time at constant current, provided, of course, that the battery was fully discharged before charging began. To make certain that this is always so, the operation always starts with discharging the battery entirely. To that end, pin 10 of the device—see Fig. 1—is made logic high. An internal stage connected to this pin causes the battery to be discharged until the voltage at pin 6 has dropped to 0.525 V. At that instant, pin 10, and immediately thereafter pin 12, goes low and charging can begin. The low level at pin 12 serves to actuate charging circuit  $T_2$ - $T_3$ . After charging at full current has taken place for a predetermined time, trickle charging begins. Trickle charging, which may continue for a long period of time, ensures that the battery capacity does not degrade during the life of the battery. It is effected by the processor driving pin 12 low for 100 ms every 16.8 s, which means that effectively the average charging current is reduced to  $6/1000$  of its peak value.

The initial discharge facility may be disabled by connecting pin 6 to earth. This will be reverted to later.

The charging time is predetermined by an external clock at pin 16 or by

an internal clock. The internal timer allows three periods to be preset: 30 m; 1 h; and 12 h. Charging during the 30 m and 1 h periods takes place at full current. During the 12 h period, the charging current is pulsed in a similar manner as in trickle charging but the 100 ms

pulses now occur every 1.2 s. Effectively, therefore, the battery is charged at  $1/12$  of the full current.

The charging current may be altered with  $P_2$ . This preset varies the voltage across it, which changes the duty factor of an internal pulse-width modulator (PWM). This modulator, which drives the charging output, is clocked at a rate of 200 Hz. In this manner, the effective value of the charging current is made continuously variable.

To obviate any possible damage to the battery during fast charging, the processor has an internal failure circuit and two protection circuits: one against overheating of the battery and the other against overcharging the battery.

The battery temperature is monitored via an NTC (negative temperature coefficient) resistor,  $R_8$ , and pin 5. If the level at that pin drops below 0.525 V (equivalent to 40 °C), an error is registered. The NTC sensor must, of course, be in close contact with the battery. Should  $R_8$  itself, or its connections, become defect, the voltage at pin 5 will rise: when this exceeds 2.95 V, an error is signalled.

If the charging voltage per cell rises above 1.6 V, the potential at pin 4 will exceed 0.525 V, whereupon an error is signalled. The voltage of 0.525 V is obtained via a precise potential divider,  $R_{14}$ - $R_{15}$ - $R_{16}$ . The voltage across the

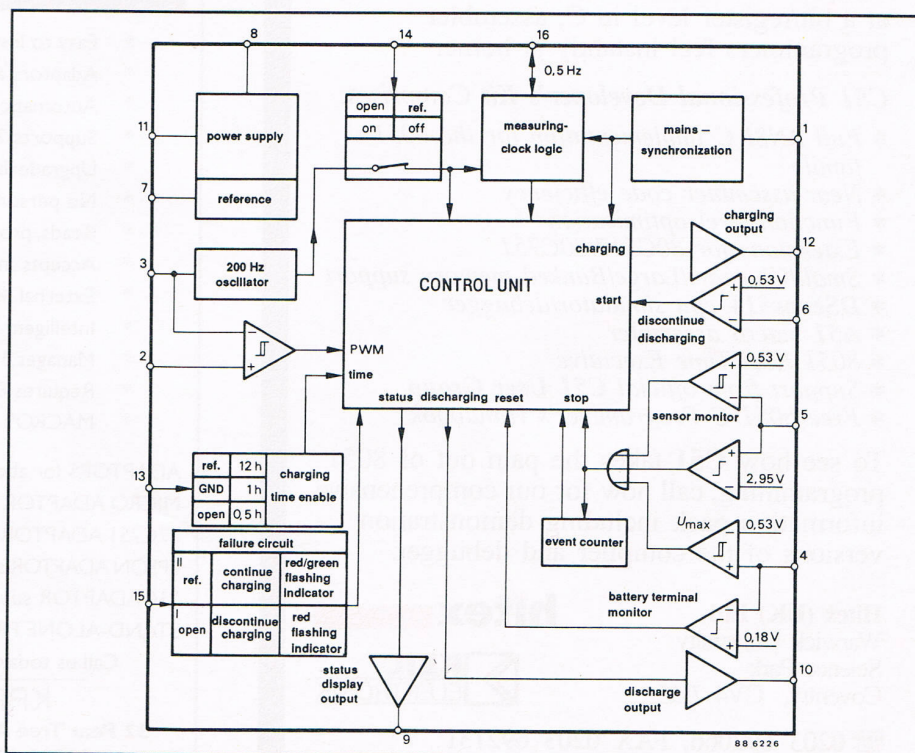


Fig. 1. Block diagram of Telefunken's Type U2400B battery charging processor.



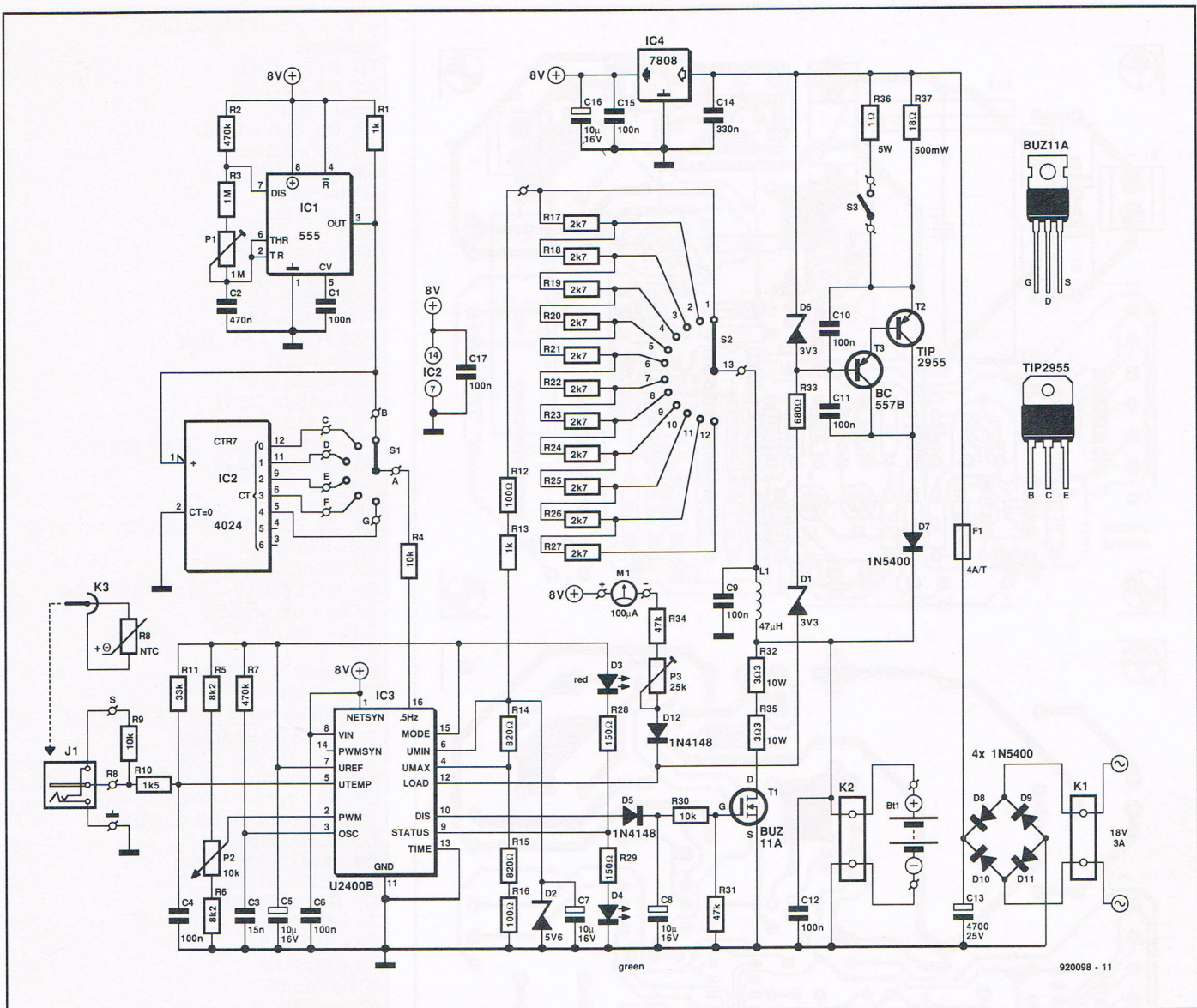


Fig. 2. Circuit diagram of the U2400B NiCd battery charger.

divider is held steady by zener diode  $D_2$ .

After an error has been signalled to the failure circuit, the processor stops the charging as long as the error persists. Once the error has been removed, charging is recommenced. If, however, a second error is registered, further action depends on the level at pin 15. If that pin is open, trickle-charging is substituted. In that case,  $D_3$  (red) lights. If, however, the reference voltage (3 V, pin 7) is connected to pin 15, as in the present circuit,  $D_3$  and  $D_4$  flash alternately. When the error is removed, continued flashing indicates that the remainder of the charging can be undertaken.

When the supply voltage is switched on, the U2400B is enabled; if no battery is connected, the red LED will light. When a battery is then connected, the potential at pin 4 will be 200–525 mV, provided that the voltage per cell is not lower than 0.6 V. After about 2 s

(during which time the LEDs do not light), the processor will become fully operational. What happens if the cell voltage is below 0.6 V will be discussed later.

During the discharge phase, the red LED flashes; when charging is in progress, the green LED flashes. When the battery is being trickle-charged, the green LED lights continuously.

### Circuit description

The mains transformer for the power supply is not shown in Fig. 2. It provides a secondary voltage of 18 V at a load current of 3 A. After the secondary voltage has been rectified and filtered, it is lowered to 8 V by regulator  $IC_4$ , and used to drive control circuits  $IC_1$ – $IC_3$  and the ammeter. Since the secondary voltage may be as high as 30 V under no-load conditions,  $IC_4$  is mounted on a small heat sink. Also, since the potential at pin 12 of  $IC_3$  must not ex-

ceed 27 V,  $D_1$  is inserted in the line to the charging circuit.

The charging circuit, based on  $T_2$  and  $T_3$ , is a simple constant-current source. When the level at pin 12 of  $IC_3$  is low,  $D_6$  is on, resulting in a constant voltage at the base of  $T_3$ . Since the potential drop across the base-emitter junctions of Darlington pair  $T_2$  and  $T_3$  is a steady 1.5 V, the voltage across  $R_{36}$  and  $R_{37}$  is a constant 1.8 V. When  $S_3$  is open, the current through the transistors, that is, the charging current, is thus 100 mA. When  $S_3$  is closed, the emitter resistors are in parallel, so that the charging current is 2 A. Diode  $D_7$  prevents the battery discharging when the charger is switched off. Since the dissipation of  $T_2$  may be as high as 35 W (one cell and a charging current of 2 A), it is mounted on a suitable heat sink.

Since the discharge output is also controlled by the PWM, the positive pulses at pin 10 of  $IC_3$  charge capaci-



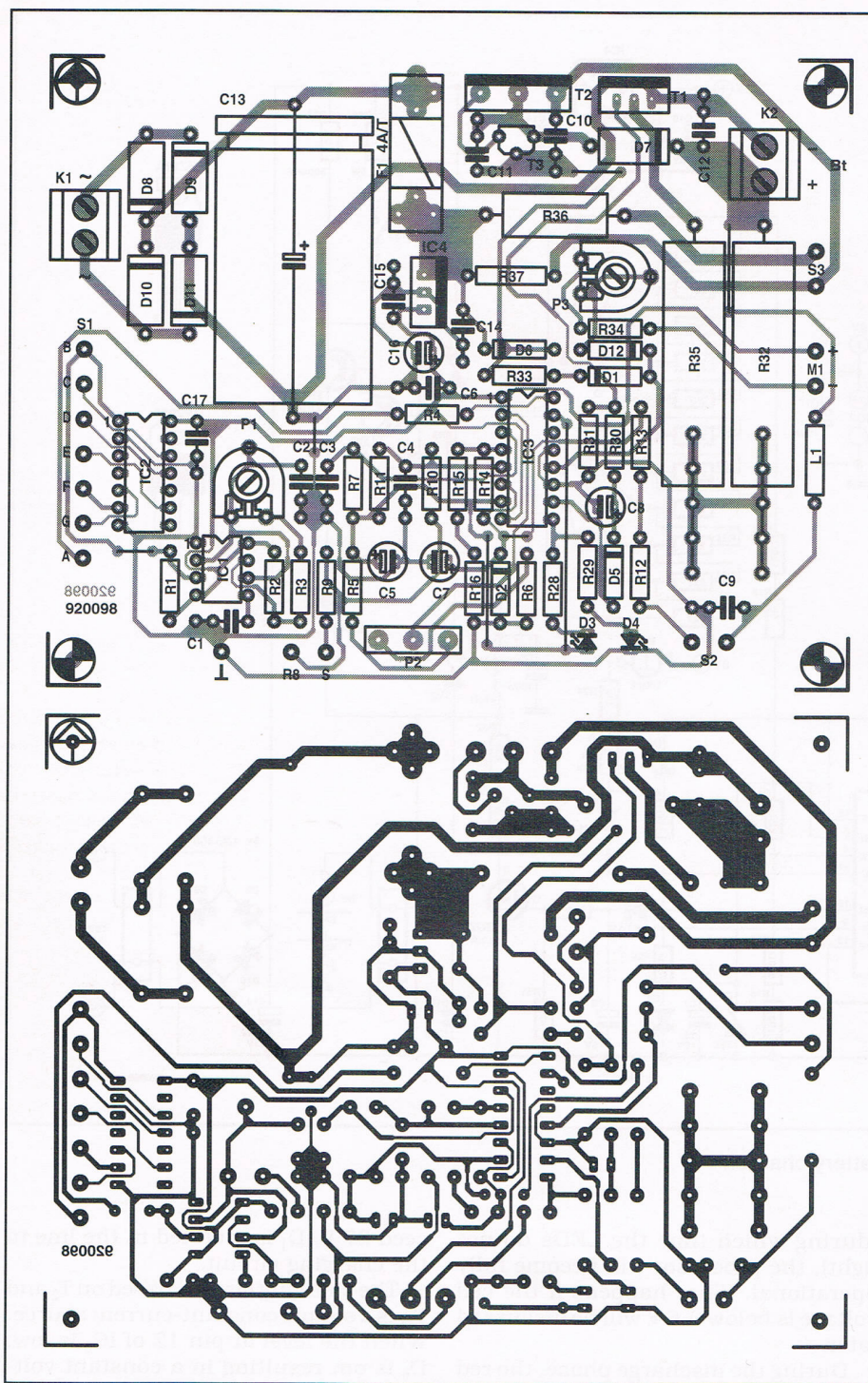


Fig. 3. Printed-circuit board for the U2400B NiCd battery charger.

tor  $C_8$ . The resulting voltage across this capacitor switches on  $T_1$ . This is always providing that a current of  $>0$  A has been preset. Since  $T_1$  is a power MOSFET, which has a very low on resistance, the discharge load is formed almost entirely by  $R_{32}$  and  $R_{35}$ . Although the discharge current depends on the battery voltage,  $IC_3$  ensures that all types of battery are discharged correctly.

Twelve-way rotary switch  $S_2$  ensures that the overvoltage monitoring is adapted to the number of cells contained in the battery. Zener diode  $D_2$  protects

pins 4 and 6 of  $IC_3$  from too high a voltage if, for example,  $S_2$  is set to the position for a single cell and a 12-cell battery is connected to the charging terminals. The potential at either of these pins must not exceed 6 V. This switch is a make-before-break type to minimize voltage surges during switching.

Rotary switch  $S_1$  links the U2400B to the external clock, an astable multivibrator (AMV) based on the well-known Type NE555 timer IC. The clock rate is set to 1 Hz, that is, a period of 1 s, with  $P_1$  (this is, by the way, the

only calibration required). This switch is a break-before-make type to prevent short-circuiting of IC outputs. The outputs of scaler  $IC_2$  provide six frequencies, corresponding to six different charging times—see Fig. 5.

The voltage set with  $P_2$  controls the PWM and thus the charging current. The voltage range is extended by  $R_6$  and  $R_9$ , so that at the two extreme settings of  $P_2$  a narrow 'dead zone' exists. This ensures that the charging current can be set correctly between zero and maximum.

The NTC sensor is connected to the

## PARTS LIST

### Resistors:

R1, R13 = 1 k $\Omega$   
 R2, R7 = 470 k $\Omega$   
 R3 = 1 M $\Omega$   
 R4, R9, R30 = 10 k $\Omega$   
 R5, R6 = 8.2 k $\Omega$   
 R8 = 10 k $\Omega$ , NTC  
 R10 = 1.5 k $\Omega$   
 R11 = 33 k $\Omega$   
 R12, R16 = 100  $\Omega$   
 R14, R15 = 820  $\Omega$   
 R17–R27 = 12.7 k $\Omega$   
 R28, R29 = 150  $\Omega$   
 R31, R34 = 47 k $\Omega$   
 R32, R35 = 3.3  $\Omega$ , 9 W  
 R33 = 680  $\Omega$   
 R36 = 1  $\Omega$ , 5 W  
 R37 = 18  $\Omega$ , 0.5 W  
 P1 = 1 M $\Omega$  preset  
 P2 = potentiometer, 10 k $\Omega$ , linear  
 P3 = 25 k $\Omega$  preset

### Capacitors:

C1, C4, C6, C9–C12, C15, C17 = 100 nF  
 C2 = 470 nF  
 C3 = 15 nF  
 C5, C7, C8, C16 = 10  $\mu$ F, 16 V, radial  
 C13 = 4700  $\mu$ F, 25 V  
 C14 = 330 nF

### Inductors:

L1 = 47  $\mu$ H  
 Tr1 (not shown) = mains transformer, 18 V, 3 A secondary

### Semiconductors:

D1, D6 = zener diode 3.3 V, 400 mW  
 D2 = zener diode 5.6 V, 400 mW  
 D3 = LED, 3mm, red  
 D4 = LED, 3 mm, green  
 D5, D12 = 1N4148  
 D7–D11 = 1N5400  
 T1 = BUZ11A  
 T2 = TIP2955  
 T3 = BC557B  
 IC1 = NE555  
 IC2 = 4024  
 IC3 = U2400B  
 IC4 = 7808

### Miscellaneous:

F1 = fuse, 4 A, with holder for PCB  
 K1, K2 = 2-way terminal block, pitch 5 mm  
 M1 = moving coil meter, 100  $\mu$ A  
 S1 = 1-pole, 6-position rotary switch  
 S2 = 1-pole, 12-position rotat switch  
 S3 = single-pole on-off switch  
 Heat sink Type SK81 (1.5 K W $^{-1}$ )  
 PCB Type 920098: see page 70.



charger via a switched jack socket,  $J_1$ . In this way, the resistor may be removed when a sealed battery is being charged. Since the sensor cannot come into close thermal contact with such a battery, temperature monitoring is impossible and it is, therefore, better removed. Resistor  $R_9$  then simulates a 'cool' sensor, whereupon charging can commence.

The many 100 nF capacitors and inductor  $L_1$  serve to decouple any incoming RF radiation and spurious voltage peaks on the mains supply.

## Construction

The charger is best built on the PCB shown in Fig. 3. This board has been designed so that the operating controls,  $S_1$ – $S_3$  and the LEDs are mounted on one side and the power transistors on the other side. The power transistors must be fixed with the use of insulating washers and plenty of heat conducting paste. A heat sink rated at  $1.5 \text{ KW}^{-1}$  is then fitted behind the transistors (again with plenty of heat conducting paste)—see Fig. 4. It is also possible to fit the power transistor to the inside rear panel of the enclosure and the heat sink to the outside (again, use plenty of heat conducting paste and insulating washers and bushes). If the heat sink is fitted inside the enclosure, make sure that there is adequate ventilation (drill a number of small holes in the top panel or fit a small extractor fan).

Commence the populating of the board with fitting the wire links. Load resistors must be mounted at least 10 mm ( $7/16$  in) above the board's surface. Resistors  $R_{17}$ – $R_{27}$  must be soldered direct to the relevant terminals of  $S_2$ —see Fig. 2. Only two wires then link the switch to the board.

Preset  $P_1$  is adjusted by using either an oscilloscope or a frequency counter between terminal B of  $S_1$  and earth.

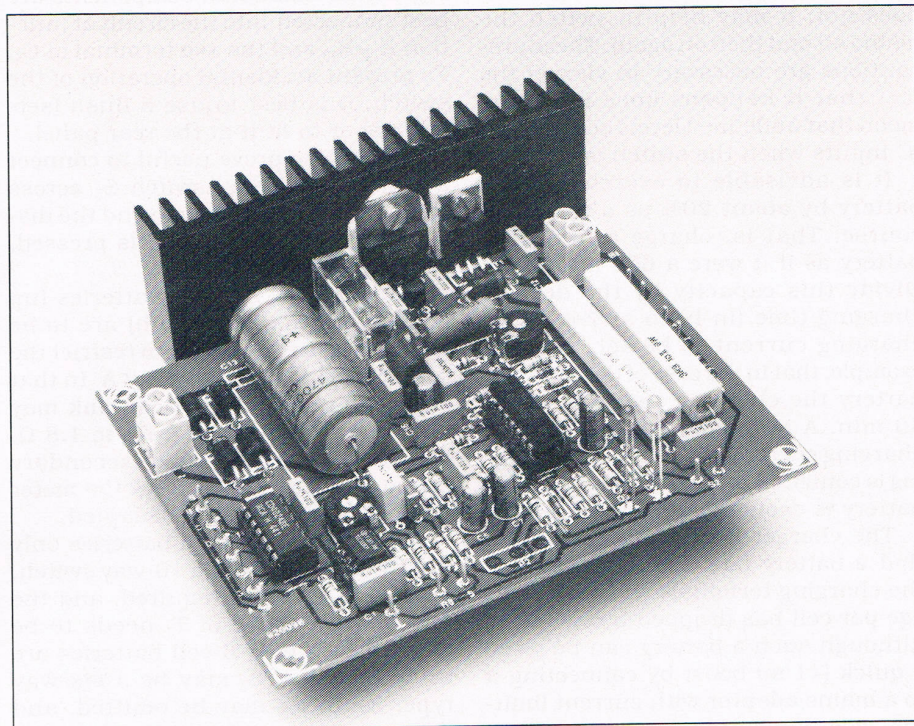


Fig. 4. The completed printed-circuit board showing the position of the heat sink.

In the first case, set  $P_1$  to obtain a period of 1 s; in the second case, adjust it to obtain a frequency of 1.0 Hz.

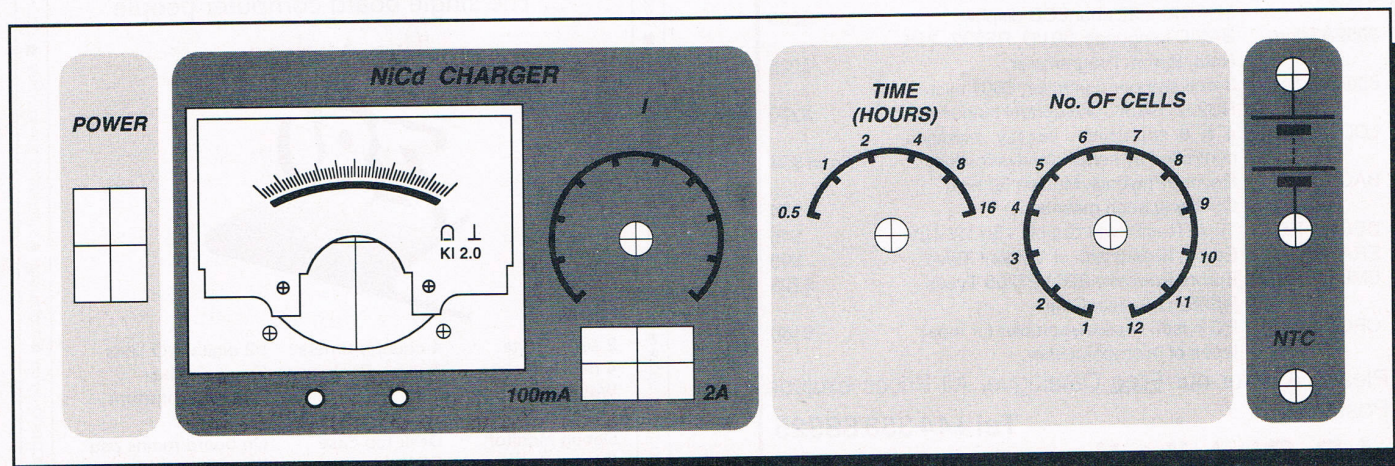
If neither of these instruments is available, set  $P_1$  to the centre of its travel and  $S_1$  to position 30 min (B). Select the number of cells ( $S_2$ ) and the required charging current ( $S_3$  and  $P_2$ ). Switch on the mains, whereupon the red LED should light (do not insert the NTC sensor). Connect a battery to the charging terminals, when after two seconds the red LED should begin to flash, indicating that discharging has commenced. Shortly thereafter, charging begins and the green LED starts flashing. Note the time during which the LED continues to flash. Any deviation from 30 min should be corrected

with  $P_1$ . This method may require the calibration to be repeated several times before the length of the period is right.

The ammeter is calibrated simply by measuring the voltage across  $R_{37}$ , preferably with a standard analogue voltmeter, setting  $S_3$  to position 100 mA, and adjusting  $P_2$  for maximum current. When the voltage across  $R_{37}$  is 1.8 V, adjust  $P_3$  for full-scale deflection (FSD) of the meter. This calibration should, of course, be carried out in the charging mode.

## Hints and modifications

Before connecting a battery to the charger, make sure that the switches are set as required and that the red LED lights



920098 - F

Fig. 5. A front panel foil for the charger (here shown reduced to 75%) is available ready made – see page 70.



when the charger is switched on. If it does not, it may help to switch the mains off and then on again. These precautions are necessary in view of the fact that it happens once in a blue moon that undefined levels occur at the IC inputs when the switch is turned.

It is advisable to overcharge the battery by about 20% as a matter of course. That is, charge a 500 mAh battery as if it were a 600 mAh type. Divide this capacity by the desired charging time (in h) to arrive at the charging current to be set. Say, for example, that in the case of the 500 mAh battery the charging time should be 30 min. A quick calculation gives a charging current of 1.2 A. If fast charging is contemplated, make sure that the battery is designed to cope with it.

The charger is not able to register that a battery has been connected to the charging terminals when the voltage per cell has dropped below 0.6 V. Although such a battery can be given a quick (<1 m) boost by connecting it to a mains adaptor with current limiting, it is far better to use the additional circuit shown in Fig. 6 to cope with flat batteries. Spring-loaded switch  $S_4$  connects a 10 k $\Omega$  resistor,  $R_{38}$ , between pins 4 and 7 of IC<sub>3</sub>, thereby 'tricking' the circuit into starting charg-

ing. These additional components are best connected into the circuit at junction  $R_{14}$ - $R_{15}$  and the +ve terminal of  $C_5$ . To prevent accidental operation of the switch, it is best to use a flush (set-in) type or to fit it at the rear panel.

It may also prove useful to connect a flush spring-loaded switch,  $S_5$ , across capacitor  $C_7$  with which to end the discharge. When this switch is pressed, charging will commence.

If only small cells or batteries (up to no more than 600 mAh) are to be charged, it may be useful to restrict the peak charging current to 1.2 A. In that case, the rating of the heat sink may be reduced to 2.5 K W<sup>-1</sup>,  $R_{36}$  to 1.8  $\Omega$ , 4 W, and the transformer secondary rating to 1.8 A. The scale of the meter must, of course, also be adapted.

If charging of 10-cell batteries only is foreseen,  $S_2$  may be a 10-way switch,  $R_{26}$  and  $R_{27}$  are not required, and the secondary voltage of  $T_1$  needs to be only 15 V. If only 6-cell batteries are to be charged,  $S_2$  may be a six-way type,  $R_{22}$  to  $R_{27}$  may be omitted, and the secondary transformer voltage needs to be 10-12 V only. In both cases, smaller heat sinks will suffice. ■

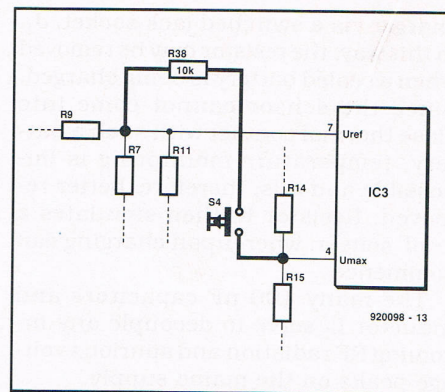


Fig. 6. If charging flat batteries is a frequent requirement, a simple switch and a 10 k $\Omega$  resistor are a worthwhile extra.

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