The U240xB Battery Charge IC Family
Design Guide 04.96

TEMIC

Semiconductors

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Introduction

The introduction of the walkman at the end of the 1970s marked the beginning of the trend towards mobile, battery-operated devices in the consumer market. This trend has continued since then and has taken on more importance throughout the last two decades since the introduction of more advanced electronic products requiring longer service lives and faster charging rates. At first, most of the batteries used in rechargeable products were NiCd based and designing battery charge systems was therefore not that complex. Today, the use of NiCd, NiMH and Li-Ion batteries requires more sophisticated charging technology as electronic products face even tougher demands on mobility, flexibility and operating convenience. These demands are not only met by the implementation of NiCd but more advanced battery charge technologies such as NiMH and Li-Ion which optimize the up-time as well as the service life of these energy sources and charge the batteries to the maximum available capacity.

TEMIC's family of battery-charge ICs including the U2400B, U2403B, U2402B-C, U2402B-B, U2405B and U2407B fulfills all today's requirements for slow-, accelerated-, and advanced-charge concepts.

NiCd is still the basic battery technology used in rechargeable battery packs all over the world and has the advantage of being able to withstand various charge rates and even a small amount of overcharging. However, it is a well-known fact that this technology can lead to the so-called memory effect which reduces the service life of the cell, and its main component, Cd, can cause harmful contamination of the environment. The TEMIC devices U2400B and U2403B are used in NiCd rechargeable battery packs for standard and accelerated charge. The U2400B includes a pulsed trickle charge to reduce the appearance of memory effects. The low cost of implementing these devices makes them attractive for use in high-volume markets such as telecommunications, automotive, or consumer electronics.

NiMH and Li-Ion battery technologies are employed more and more often in rechargeable battery packs as they store more energy and can be used for avoiding memory effects. The U2402B-B, U2402B-C, U2405B and U2407B used in NiMH and Li-Ion battery technologies enable advanced charging to the full maximum cell capacity and are all produced in 30-V bipolar technology. They do not require any additional protective circuitry and can detect the start of overcharging before the inflection point of the voltage curve (NiMH). These devices provide the perfect solution for ensuring precise overcharge pro-tection combined with maximum cell capacity. TEMIC's newest IC, the U2407B, introduced at the beginning of 1996, is the optimized solution for external power management, SMPS and linear current regulation.

There are various criteria for enabling current regulation or protecting battery packs against overcharging and memory effects. A timer control combined with a thermal switch-off is a widely used method to terminate standard 15-h charge and accelerated charge cycles of NiCd battery packs. For NiCd and NiMH fast charge as well as advanced charge battery packs, the $-\Delta V$, peak voltage V_{max} detection and the thermal switch-off mode are still the most common methods used to terminate the charge cycle. However, these methods often lead to unnecessary overcharging as well as a reduced service life time of the product. This problem is overcome by using the TEMIC devices U2402B-B, U2402B-C, U2405B and U2407B which are able to detect the start of overcharging at an even earlier stage (before the inflection point of the voltage curve), yet still guarantee optimum service life time (NiCd/NiMH).

This design guide describes the most important circuit functions covering the whole battery charge family and gives examples of applications, providing practical hints for the designer of battery charge subsystems.

Standard and Accelerated Battery Charge

U2400B

General Description

The U2400B is recommended for applications with a 3 – 5 h charge time but can also be used for applications with a 1-h charge time under certain conditions. It includes a timer control, combined with a controlled pre-discharge. A pre-discharge is still the most common solution for avoiding possible memory effects in NiCd. The pulsed trickle charge can also be used to reduce the appearance of memory effects.

In combination with V_{max} and T_{max} switch-off criteria, the 1-C and 0.5-C NiCd battery charge applications can also be recommended. The U2400B is a perfect solution for applications with up to 14 NiCd cells and for rugged applications without any additional periphery. It can also be used for lead battery packs.

In addition, the U2400B is well-suited for low-cost charge control in second-slot applications, telephone base stations and in professional, autonomous desktop charge stations if specific single-type battery packs are used.

Special Features of the U2400B

- Charge-time generation via an internal oscillator (Pin 3), by mains-operated synchronization (Pin 1) or by an external clock (Pin 16)
- Three charging times with fixed oscillator frequency: 0.5 h, 1 h and 12 h (50 Hz synchronization or 200 Hz oscillator frequency)
- Pulse charge with 12-h charge time
- Automatic pre-discharge and automatic start of charging
- Charge and discharge termination in case of overvoltage, overtemperature and sensor discontinuity
- Status output for visual status indication
- **P**ulse-**W**idth **M**odulation (PWM) of the charge and discharge output
- Pulse-trickle charge after the charging time elapses

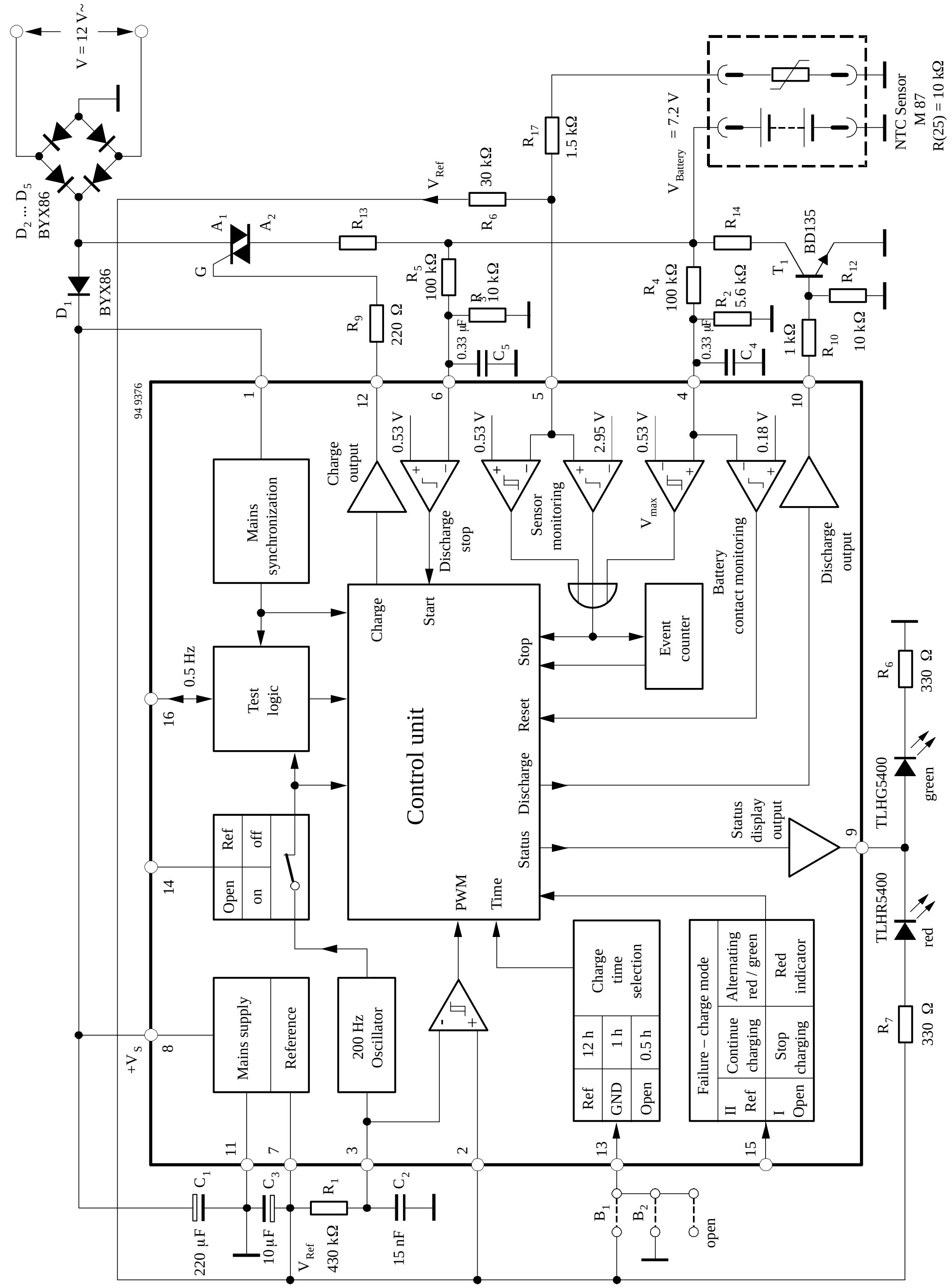


Figure 1. Typical circuit of U2400B

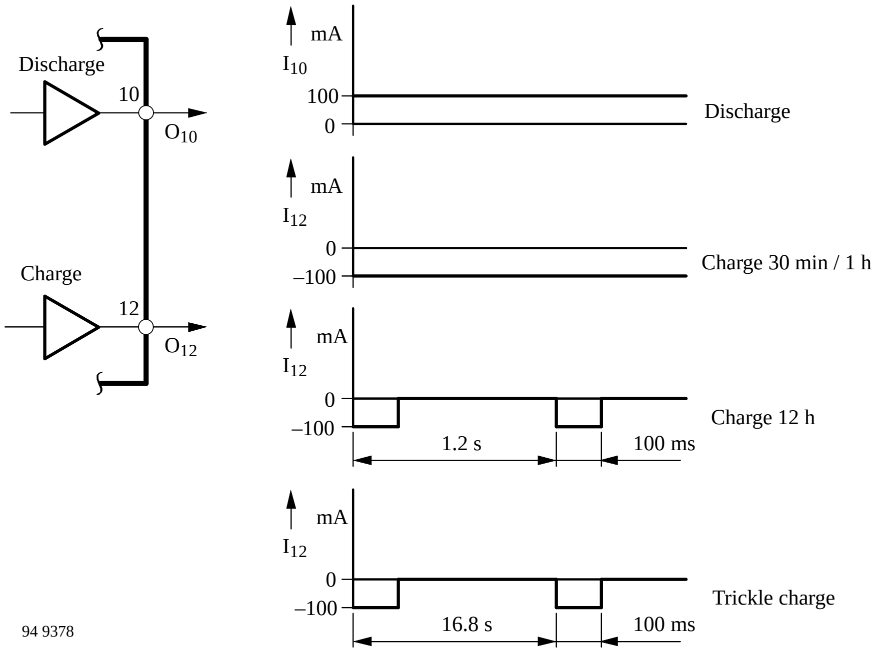


Figure 2. Charge, discharge outputs

Circuit Description

Charge Time Selection for 0.5 h, 1 h and 12 h

Three charge-time selections are available at Pin 13 and are as follows according to the standard system clock.

Pin 13	Charge Time
Open	0.5 h
GND	1.0 h
V_{Ref}	12 h

The 0.5-h and 1-h charge times are for continuous charging, whereas the 12-h charge time offers the user the option of gently charging a battery with 1 C pulsed over the 12 h period. The duty cycle, i.e., ON-OFF (pulse/ pause) ratio is 100 ms/ 1200 ms (see figure 2).

Clock Generator

The system clock required for the charge-time generation can be achieved by using three different methods which are shown in a table below. The following frequencies are used for the standard charge times 0.5 h, 1 h and 12 h at the corresponding inputs:

Clock Generation	Frequency	Pin	Figure
Free-running internal oscillator	200 Hz	3	5
Mains synchronization	50 Hz	1	3
External timer clock input	0.5 Hz	16	4

Double Function of Pin 16

a) IC measurement:
Pin 16 represents a common OR logic output of the divider stages between the mains synchronization (Pin 1) and the oscillator (Pin 3). Also, its output is connected to the input of the following divider. By overwriting Pin 16 with a corresponding input frequency, a fast-charge time sequence for the output at Pin 12 is achievable.

Frequency divider n is as follows:

Divider	Pin 1 –> Pin 16 Pin 3 –> Pin 16	$n_1 = 100$ $n_3 = 400$
Follow-up divider	Pin 16 –> Pin 12	
Programming input	Pin 13 open Pin 13 GND Pin 13 V_{Ref}	$n_{13} = 900$ $n_{13} = 1800$ $n_{13} = 21600$

b) External timer-clock input for various charging times (figure 4):
Additional synchronization with 50 Hz via Pin 1, or with 200 Hz via oscillator Pin 3 must be ensured for generating fixed time conditions such as the blinking frequency and battery detection (see figures 3 and 5).

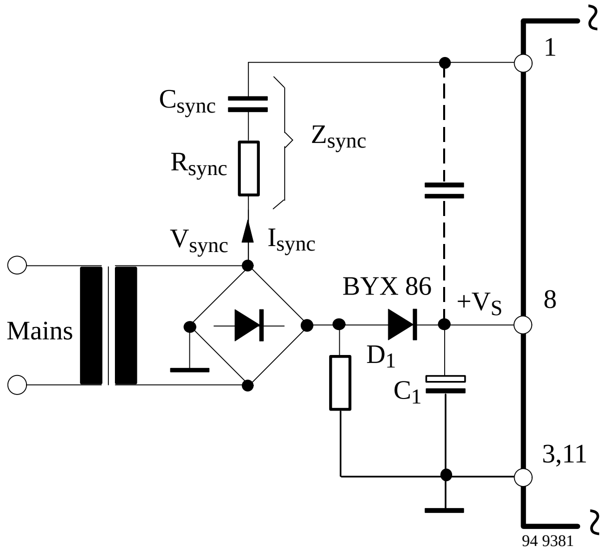
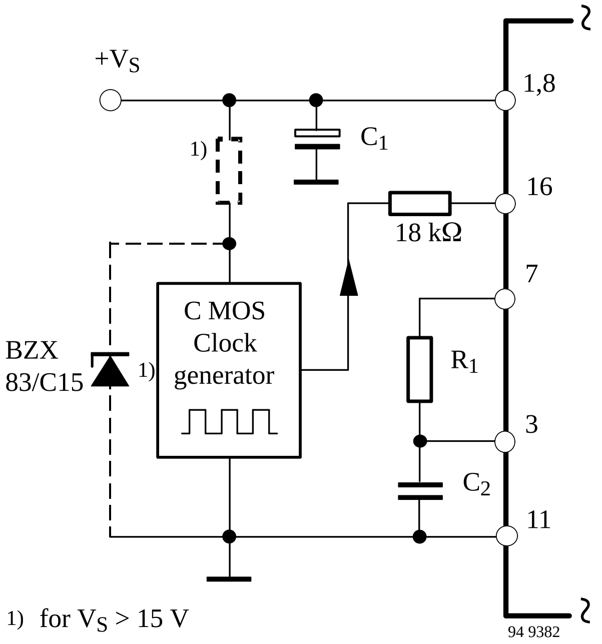


Figure 3. Mains synchronization



1) for $V_S > 15$ V

Figure 4. External timer, clock input

PWM Control

The duty cycle of switching outputs can be controlled by the comparator control input (Pin 2) in conjunction with the internal oscillator (see figure 5).

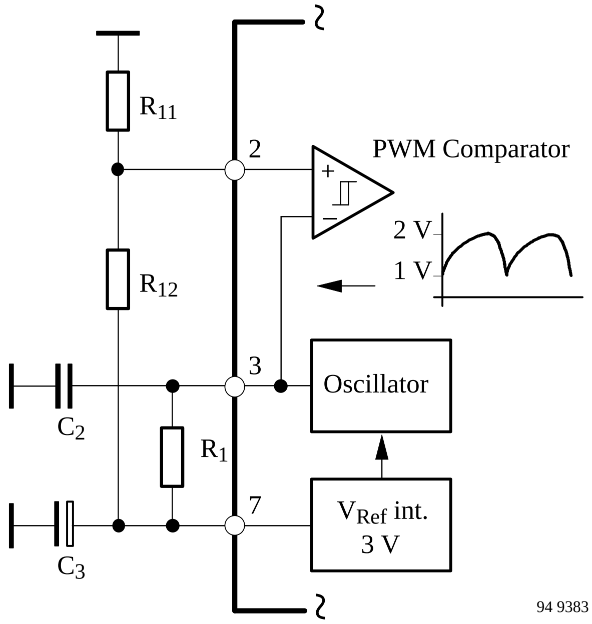


Figure 5. Oscillator/ PWM configuration

This enables the adjustment of the charge and discharge current within certain limits, independent of the actual transformer and battery conditions.

Charge current control by a PWM converter with storage inductance is practical if the internal clock is generated by the mains synchronization input (Pin 1) so that the oscillator can be operated for PWM mode at a high frequency (up to f_{max} = 50 kHz). For further information, please refer to the data sheet U2400B.

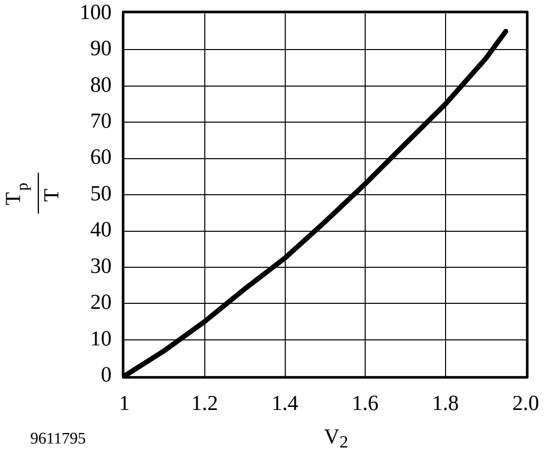


Figure 6. Duty cycle of PWM circuit shown in figure 5

Status Indication

The operating state of the controller can be indicated by means of the status output, Pin 9, as well as the red and green LEDs (see figure 1). The red LED lights after switching on the operating voltage if no battery is inserted.

Contact with the battery is detected if a voltage of 0.18 V occurs at the monitoring input, Pin 4. After a delay of approximately 2 seconds, the output, Pin 10, switches to $+V_S$ potential and enables discharge. Blinking of the red LED indicates this status. The discharge process continues until the voltage at Pin 6 drops below 0.53 V (see figure 1). When this condition has been met, the charging process is automatically activated by applying ground potential to the collector output, Pin 12, and simultaneously starting the charge timer. The green LED indicates the charging status by blinking.

The driver outputs – charge Pin 12 and discharge Pin 10 – will be inactive if voltage temperature cut-off level (Pins 4 and 5) is exceeded.

If an interruption occurs twice, Pin 15 “failure detection” decides whether charging is to be terminated permanently or continued to the end. The status indication (red LED, lighting steadily, or green LED, blinking) shows whether charging is terminated permanently or continued to the end after the interruption.

After the charge time has elapsed, the charge output, Pin 12, reverts to pulse mode for trickle charge. The pulse/ pause ratio (duty cycle) is 0.1 s/ 16.8 s with standard system clocks (see figure 2).

Design Recommendations

Determination of the Charge Time, t

The charge time, t, can be determined as follows:

- Analog to the selected clock source
- A function of the period, T, in conjunction with frequency scaling n_1 or n_3 and n_{13}

Mains Synchronization, Pin 1

$T = 20\text{ ms} @ 50\text{ Hz}$

$n_1 = 100$, $n_{13} = 1800$

$t = T \times n_1 \times n_{13} = 20\text{ ms} \times 100 \times 1800 = 3600\text{ s} = 1\text{ h}$

Clock Oscillator, Pin 3

For the required charge time, t, a period, T, is obtained as follows:

t = 1 h = 3600 s and n 12 = 1800 8 Pin 13 = GND

$$T = \frac{t}{n_3 \times n_{13}} = \frac{3600\text{ s}}{400 \times 1800} = 0.005\text{s} = 5\text{ms} \; (f = 200\text{Hz})$$

In order to determine the oscillator frequency, the values for the RC network of the oscillator can be calculated approximately as follows (value range for R_t 10 kΩ up to 1 MΩ):

$$R_t\ (k\Omega) = \frac{T(s)}{0.7 \times 10^{-6} \times C_t\ (nF)}$$

where $R_t = R_1$, $C_t = C_2$ (see figure 1)

or $T(s) = 0.7\ R_t\,(k\Omega) \times C_t\,(nF) \times 10^{-6}$

External Clock Pre-Selection, Pin 16

A period, T, of an external clock injection is obtained as follows for a charge time:

$t = 4\text{ h} = 14400\text{ s}$ and $n_{13} = 1800$:

$$T = \frac{t}{n_{13}} = \frac{14400\text{ s}}{1800} = 8\text{ s}$$

PWM Charge and Discharge Current Control, Pin 2

The control range for the PWM duty cycle 0 up to 100% corresponds to a voltage V_2 of 1 to 2 V (see figure 6).

A control voltage corresponsing to the PWM and duty cycle can be generated by the voltage divider R_{11}/R_{12} from the reference voltage, Pin 7 (figure 5).

$$R_{11} = R_{12} \frac{V_2}{V_7 - V_2} \qquad \text{e.g., } R_{12} = 100\ \text{k}\Omega$$

V_2 corresponds to the duty cycle as it can be seen in figure 6.

Discharge Stop, Pin 6

The particular cell voltage at which a battery is considered to be discharged mainly depends upon the relevant discharge current. In general, the battery is adequately discharged when the battery drops to a value between 90 and 80% of its nominal value at a discharge current of 1 to 3 C.

The discharge stop comparator terminates the discharge process when $V_6 < V_{T6}$. If pre-discharge is not required, Pin 6 must be connected to GND, Pin 11 (see figure 8).

Determing the voltage divider R_5/R_3:

$$R_3 = R_5 \frac{V_{T6}}{V_{Batt} - V_{T6}}$$

R_5	= 100 kΩ
V_{T6}	internal reference voltage, typical 530 mV
V_{Batt}	final discharge voltage

V_{max} Monitoring, Pin 4

Detection of the battery voltage by the V_{max} comparator is not intended to monitor the charge state of the battery, but merely serves to detect any high impedance battery cell. However, in order to prevent V_{max} cut-off occuring as a result of the rise in cell voltage owing to the charge current, the cut-off threshold should be reasonably higher than the battery's nominal voltage. For example, it is advisable to set the cut-off threshold to at least 1.5 V for a 1-C charge rate.

Determining the voltage divider R_4/R_2:

$$R_2 = R_4 \frac{V_{T4}}{V_{Batt} - V_{T4}}$$

R_4	= 100 kΩ
V_{T4}	internal reference voltage, typical 530 mV
V_{Batt}	overvoltage

Temperature Detection, Pin 5

Thermal cut-off occurs during the charge or discharge phase if the actual voltage at Pin 5 drops below a voltage of 530 mV as a result of a temperature sensor. A grounded NTC sensor is provided in the standard application shown in figure 1. A PTC sensor refferred to as V_{Ref} can also be used.

Determing the voltage divider R_{NTC}/R_6:

$$R_6 = (R_{NTC} + R_{17}) \frac{V_{Ref} \times V_{T5}}{V_{T5}}$$

V_{Ref}	reference voltage Pin 7, typ. 3 V
V_{T5}	internal reference voltage, typical 530 mV
R_{NTC}	NTC sensor
R_{17}	protecting resistance 1.5 kΩ

Applications

A few typical concepts are shown in figure 7 in line with the various economic and functional requirements.

Determining the Charge Current by the Impedance of the Low-Voltage Transformer

Simple and specific chargers do not generally contain any other circuitry for limiting or regulating the charging current, apart from the actual transformer impedance. Such systems require a transformer designed specifically for the relevant battery. This transformer is designed so that the battery cannot be overcharged within the charge time when operating under rated conditions.

Voltage dividers R_4/ R_2 and R_5/ R_3 determine the V_{max} cut-off level and the final discharge voltage (see “Design Recommendations”). Recommended values with regard to the number of cells are given in table 1.

Charge without Pre-Discharge

Economic or design limitations often do not allow pre-discharge of the battery. In the U2400B, there is no power section for the discharge stage. Therefore, the problem of thermal energy when discharging is also solved. However, the system should incorporate a sensor-monitoring function in order to protect the battery against thermal damage when charging partially discharged batteries.

Charging is enabled after inserting the battery or after applying the operating voltage owing to the GND connection of the “discharge-stop input”, Pin 6.

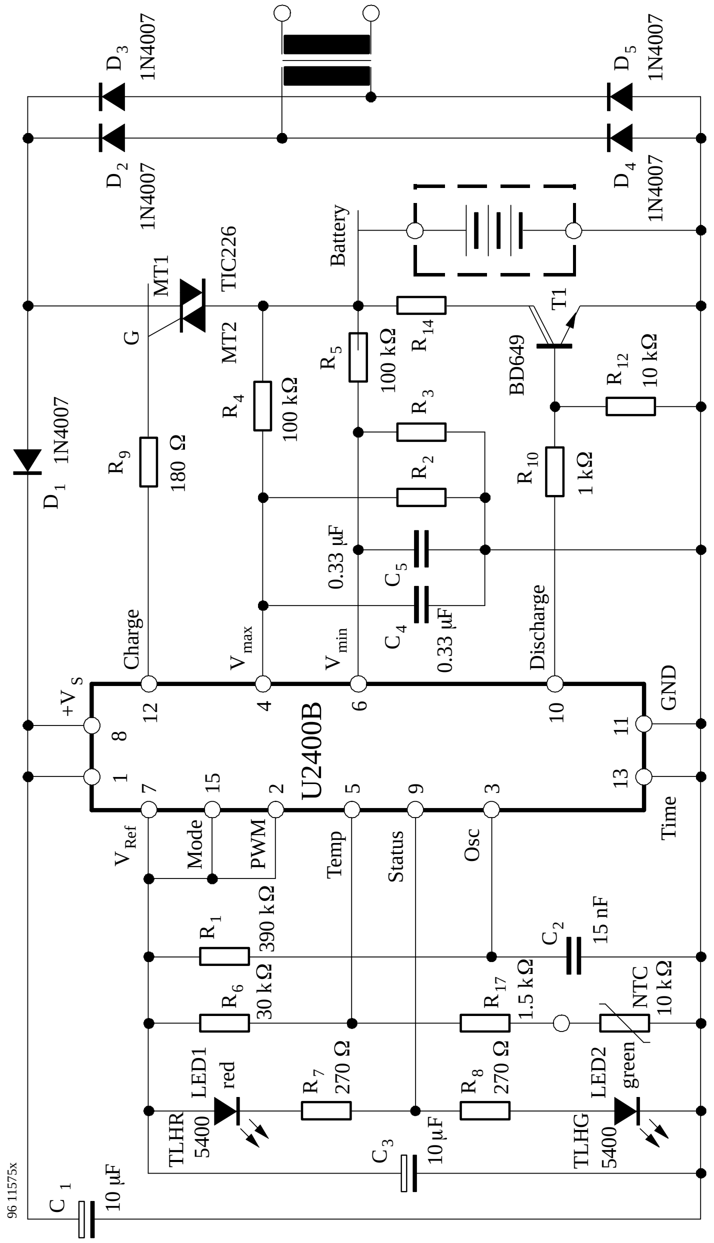


Figure 7. Discharge, charge and trickle-charge of specific batteries

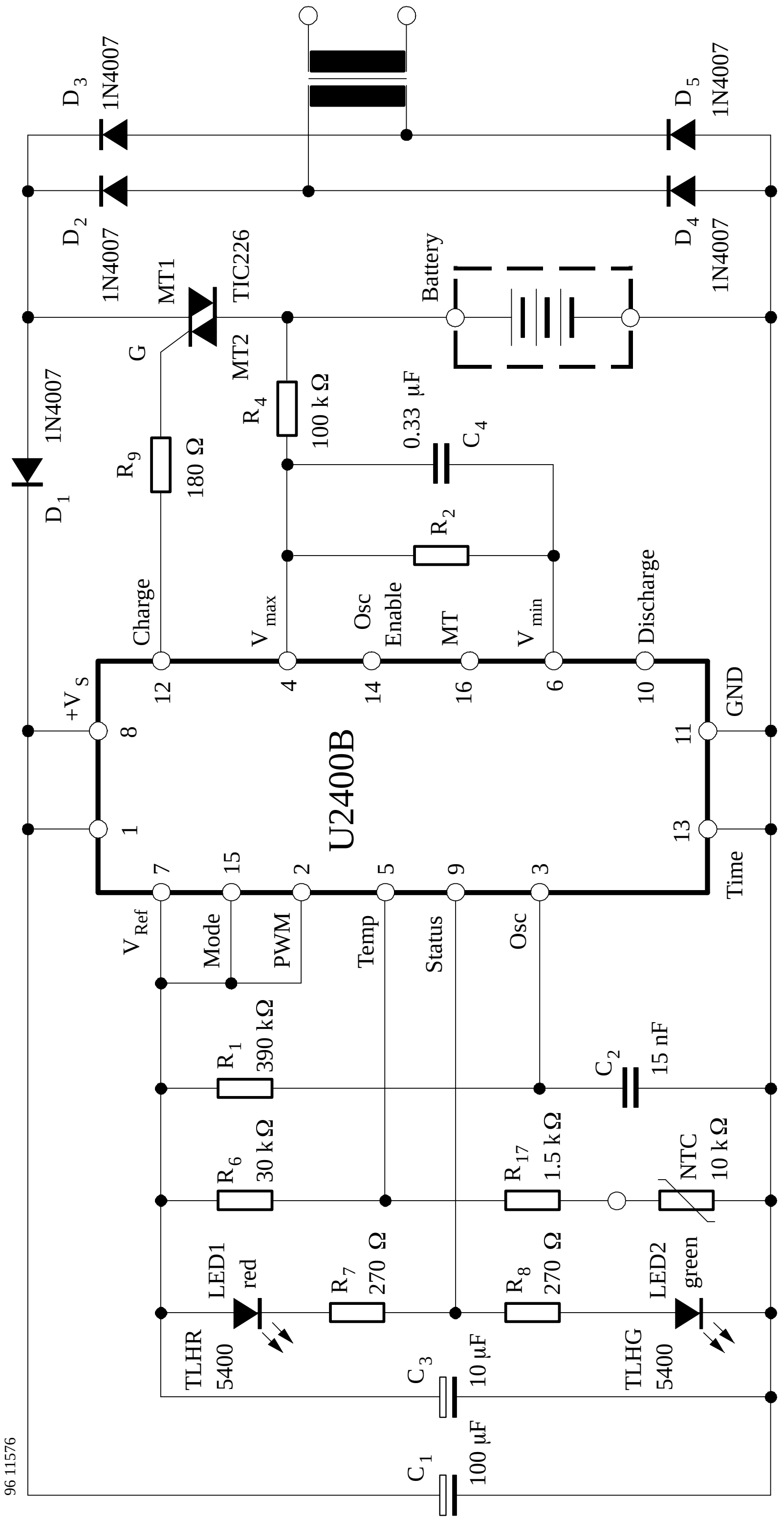


Figure 8. Charge and trickle-charge of specific batteries without pre-discharge

Table 1. Determing the resistances R_2, R_3 as a function of the number of cells

No. of Cells	1	2	3	4	5	6	7	8
R2	47 k	18 k	10 k	8 k2	6 k2	5 k6	4 k7	3 k9
R3	130 k	39 k	24 k	15 k	12 k	10 k	9 k1	8 k2

Power Supply from a DC Source

(e.g., 12-V car battery or 24-V standby power supply)
The aim of the PWM charge-current control application, shown in figure 9, is to limit the charge current. A PNP transistor is required instead of the simple triac switch owing to a lack of self-commutation for dc operation.
A simple limitation function can be implemented with a corresponding series resistor providing the voltage difference between dc source and the nominal voltage of the battery to be charged and the current demand permit this. However, if the power dissipation at the series resistor is passive, a switching principle must be used. The U2400B's controller includes the option of a PWM control function for this purpose. Therefore, the mean value of the required charge current can be set or regulated with relatively little loss for simple applications. The high current pulses which occur in this case are advantageous as far as battery charging is concerned. However, the transistor switch and the charging contacts must be rated appropriately. An additional resistor, R_{11}, in the charging circuit limits the pulse current to an acceptable value.

Battery Contact Monitoring with DC Source

If the battery has to be removed before the termination of the charge time and charging has to be started once again, contact monitoring is required to reset the function at Pin 4. If the voltage at Pin 4 is below 180 mV for a short time, reset is set and the discharge and charge function is started again.
The criterion for the dc voltage from the ac source is fulfilled via zero phase conditions as long as the RC low pass filter allows it. In the case of a dc supplied charge system, where no zero phase is available, the charge voltage must be monitored by maximum control. In figure 10, transistor T switches the circuit of input 4 to ground by withdrawing the battery when the charging voltage exceeds the forward voltage of Z-diode D_2.

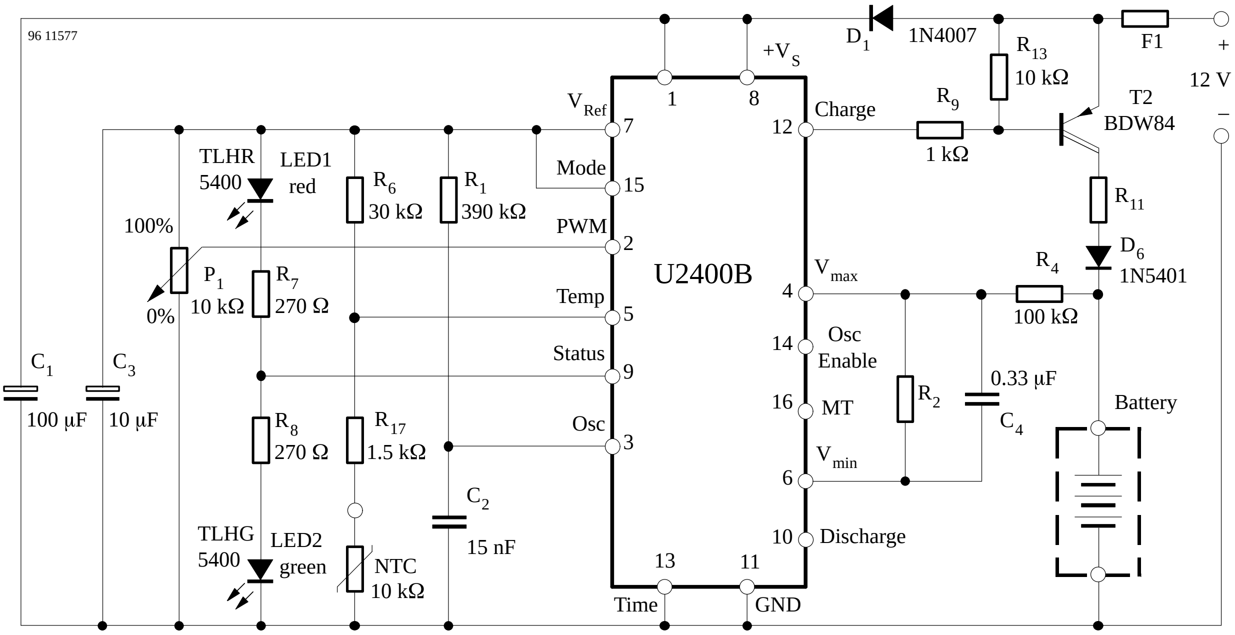


Figure 9. DC-powered charger with PWM charge current control for specific batteries

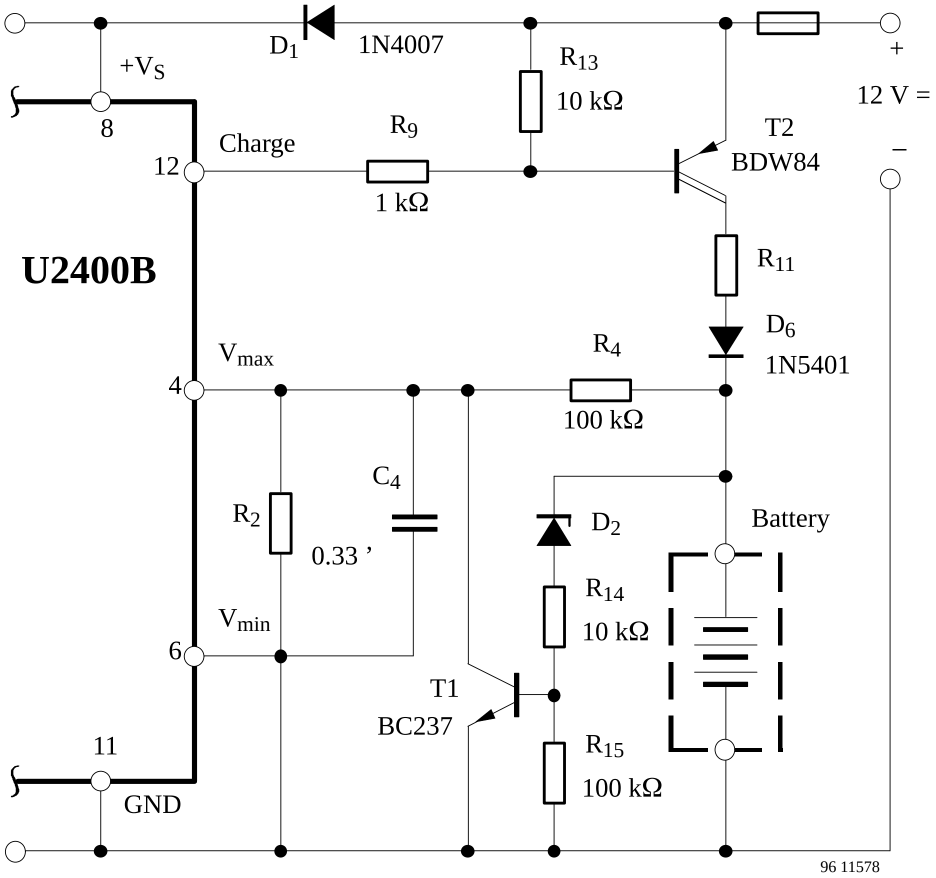


Figure 10. Voltage monitoring with Z-diode

Separate DC-DC Converter for Mulitple Systems

In order to charge individual cells in parallel from one dc supply network (e.g., 24-V standby power supply), it is often practical to use a separate voltage converter in order to adapt the voltage to the battery cells. In figure 11, a multiple charging system with separate charge current via a PWM function, Pin 2, is shown.

To maintain the constant charge current, independent of the charge status of single cells, charge current control can be realized with the help of figure 12.

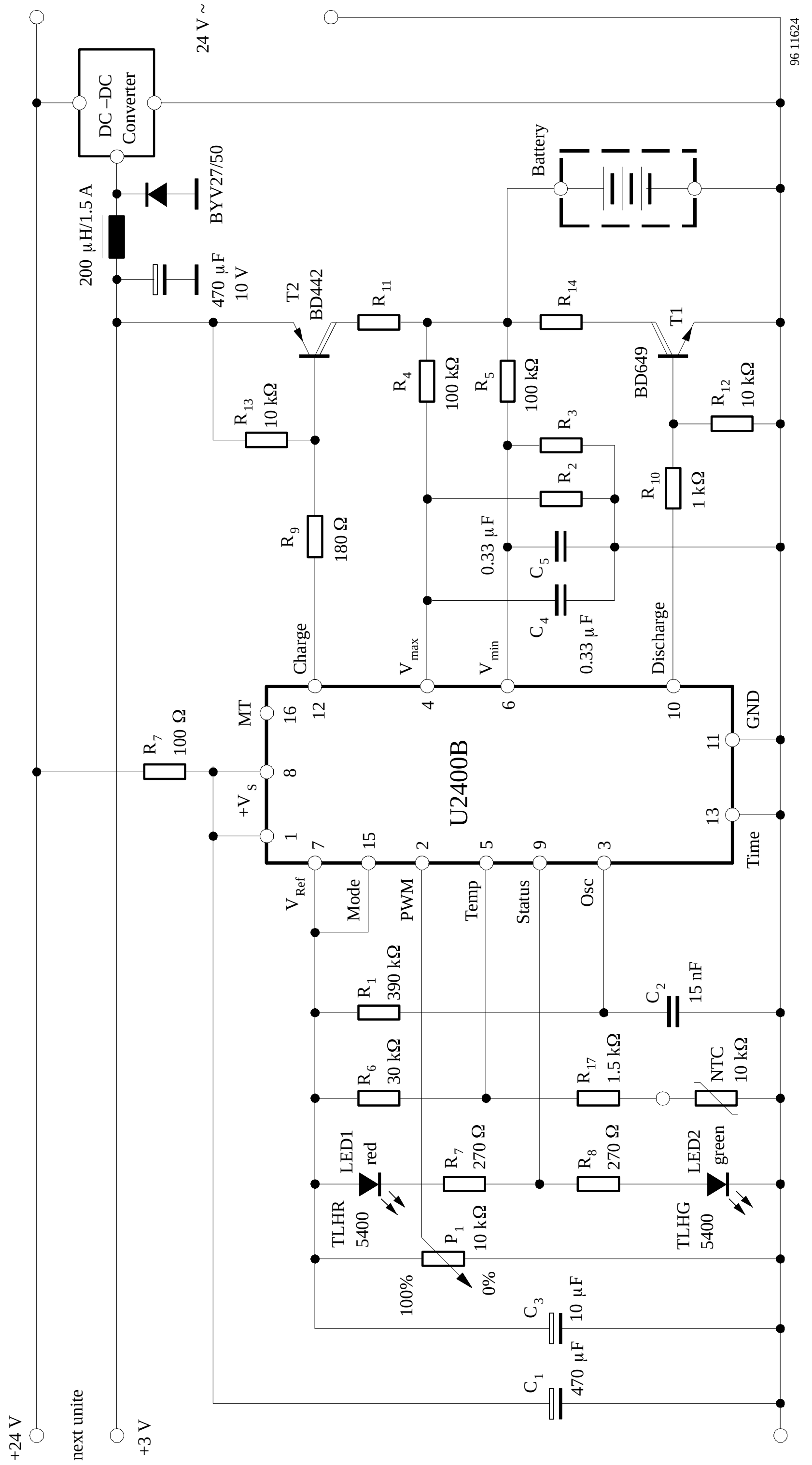


Figure 11. Multiple charger for automomous discharge and charge, connected to a standby dc power supply

Limitation and Regulation of the Charge Current

System-related disadvantages such as high pulse current and current instability (see figure 9) can be avoided by implementing the appropriate circuitry as shown in figure 12.

In contrast to the standard application, the controller is now used in current-controlled PWM step-down mode. The internal oscillator, Pin 3, used for generating the PWM switching frequency of approximately 25 kHz, is employed for limiting and regulating the charge current. The system clock (100 Hz) is obtained from a section of the dual operational amplifier LM358, Pin 7, and is injected at the synchronization input, Pin 1.

The second part of the dual operational amplifier, Pin 1, is wired as an integral action controller and supplies the corresponding voltage for charge and discharge current regulation at the PWM control input, Pin 2. Two separate shunt resistors, R_4 and R_{32}, are used in order to enable current regulation for charge and discharge modes.

During discharge, the PWM control input, Pin 2, detects the actual current value at the shunt R_{32}. The current through R_4 is zero in this case so that GND potential is applied to the setpoint device R_{27}. In charge mode, the current flows through R_4, whereas no current flows through R_{32}. Pin 3 therefore detects the actual current value via R_{27} and the GND potential is applied to Pin 2 via R_{21}. The current is preset by evaluating the actual value at R_{27}.

In this case, the power MOS transistor used is operated actively via clamp voltage by the Z-diode, D_{10}, as a PWM controlled current sink in order to transfer the discharge energy directly to the MOS transistor. This means that heat can be dissipated via a heat sink due to the simple assembly. If pre-discharge can, or must be dispensed with in specific cases, this can be implemented in the same way as described in figure 8 and in the section “Charge without Pre-Discharge”

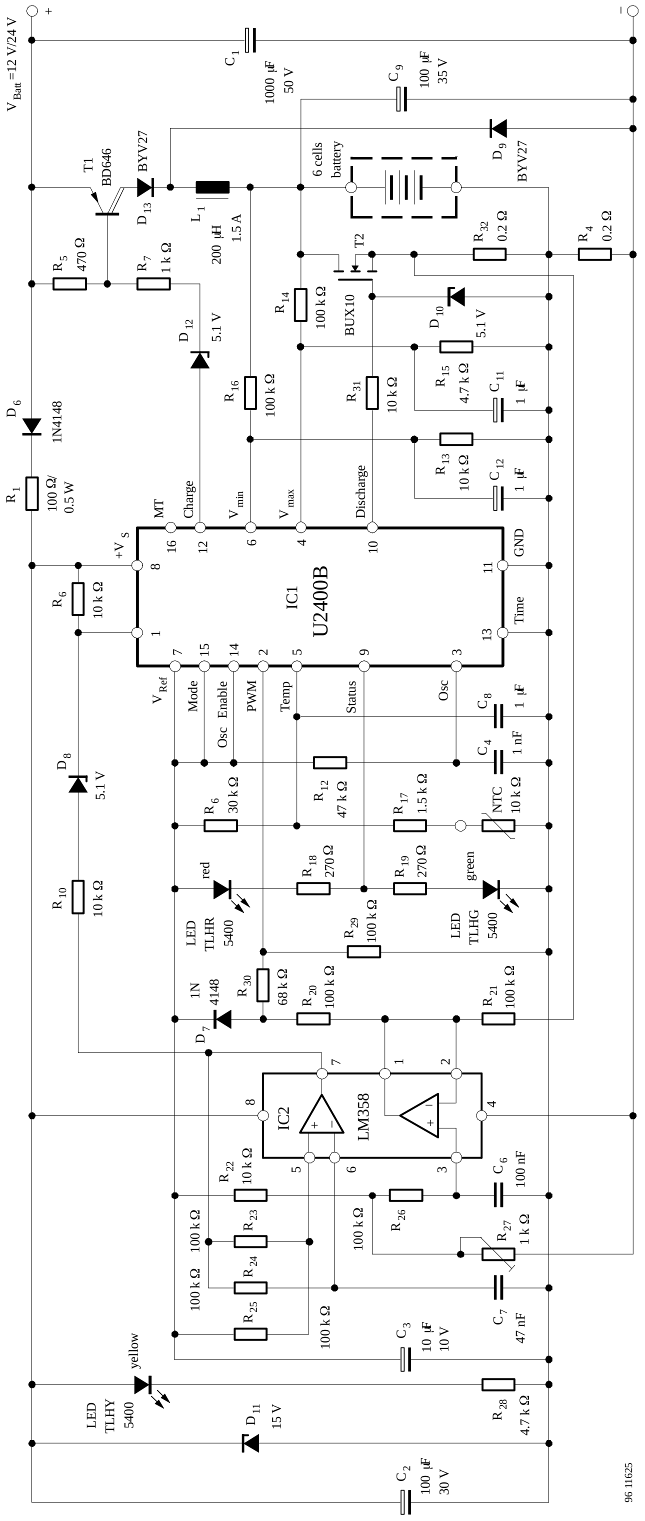


Figure 12. Universal charge and discharge control

U2403B

General Description

The U2403B is recommended as a low-cost solution for standard and accelerated charge and can be used for charging up to 6 cells. With its small periphery, it is recognized as being the most minimized battery charger in the world. It consists of a regulated current source and an adjustable timer. Charge time can be selected in the range of 1 h to 24 h. The charge time can be interrupted depending on the supply voltage and chip temperature of the IC. Furthermore, an extended application for a higher supply voltage and number of cells is available. This circuit is well-suited for NiCd-integrated battery chargers in mobile-phone battery packs as well as for several low-cost car adapters and desk-top chargers.

Applications

Standard Applications

- Minimized system for NiCd and Pb standard charge with current regulation, timer and integrated temperature switch-off
- Minimized NiCd fast charge system (2 h; 500 mA) with timer control
- Accelerated NiCd charge (3 h) with current selection in battery pack (200 mA and 380 mA)
- NiCd fast-charge system (2 h) with timer and external temperature control
- Minimized car adapter

Basic Example

NiCd battery 750 mAh	R_1 = 510 Ω, 1/8 W
Charging time: 3 h	C_1 = 47 µF/ 16 V
Charge current: 240 mA, 1/3 C	R_3 = 6.2 Ω, 1/2 W
Trickle charge: 19 mA < 1/40 C	R_4 = 300 kΩ
	C_4 = 470 pF
	R_5 = 8.2 Ω, 1/2 W

Minimum Supply Voltage

No of Cells	DC Supply Minimum
1	6.8 V
2	8.3 V
3	9.8 V
4	11.3 V
5	12.8 V

Special Requirements for Various Charge Times

R_4, C_4 values for different charging times

	2 h	4 h	6 h	7 h	12 h
R_4	300 kΩ	430 kΩ	470 kΩ	470 kΩ	390 kΩ
C_4	330 pF	470 pF	680 pF	1 nF	2.2 nF

Special Requirements for Various Charge Currents

R_3, R_5 values for different charge current

	240 mA	150 mA	100 mA	50 mA
R_3	6.2 Ω	10 Ω	15 Ω	30 Ω
R_5	8.2 Ω	15 Ω	22 Ω	68 Ω

Basic Equations

$$R_1 = 0.5\ \text{V} / I_S$$
$$I_S = 1.8\ \text{mA}$$
$$R_5 = V_5 / (I_{ch} - 20\ \text{mA})$$

Nominal Charge Current:

$$I_{ch} = V_3/R_3 \text{ where } V_3 = 1.48\ \text{V (typ.)}$$

Trickle Current:

$$I_{ch} = V_3/R_3 + I_8 + I_S$$

Typical values are:

$$V_3 = 100\ \text{mV},\ I_8 = 4.5\ \text{mA}$$

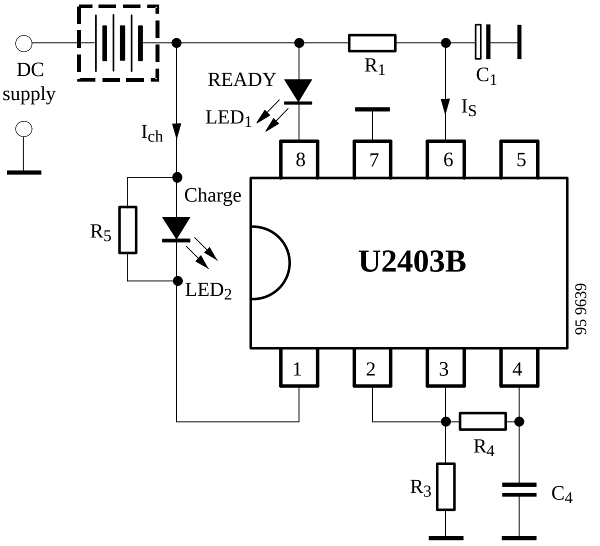


Figure 13. Standard application

Booster and Trickle Charge Reduction

Basic Example

NiCd battery 1000 mAh	R_1 = 510 Ω, 1/8 W
Charging time: 2 h	C_1 = 100 µF/ 16 V
Charge current: 500 mA	R_3 = 3 Ω/ 1 W
Trickle charge: 22 mA < 1/22 C	R_4 = 300 kΩ
	C_4 = 330 pF
	R_5 = 3.9 Ω/ 1 W
	C_2 = 1 µF

Supply Voltage

No of Cells	DC Supply Minimum
1	V_S = 6.5 V
2	8.0 V
3	9.5 V
4	11.0 V
5	12.5 V

Special Requirements for Various Charge Times

R_4, C_4 values for different charge times

	2 h	4 h	6 h	7 h	12 h
R_4	300 kΩ	430 kΩ	470 kΩ	470 kΩ	390 kΩ
C_4	330 pF	470 pF	680 pF	1 nF	2.2 nF

Special Requirements for Various Charge Currents

R_3, R_5 values for different charge currents

	616 mA	493 mA	411 mA	296 mA
R_3	2.4 Ω	3 Ω	3.6 Ω	5 Ω
R_5	3 Ω	3.9 Ω	4.7 Ω	6.8 Ω

R_6 = 560 Ω, reduced trickle charge

Basic Equations

$R_1 = 0.5\ \text{V} / I_S$
$R_5 = V(\text{LED}_2) / (I_{ch} - 20\ \text{mA})$

Nominal Charge Current:

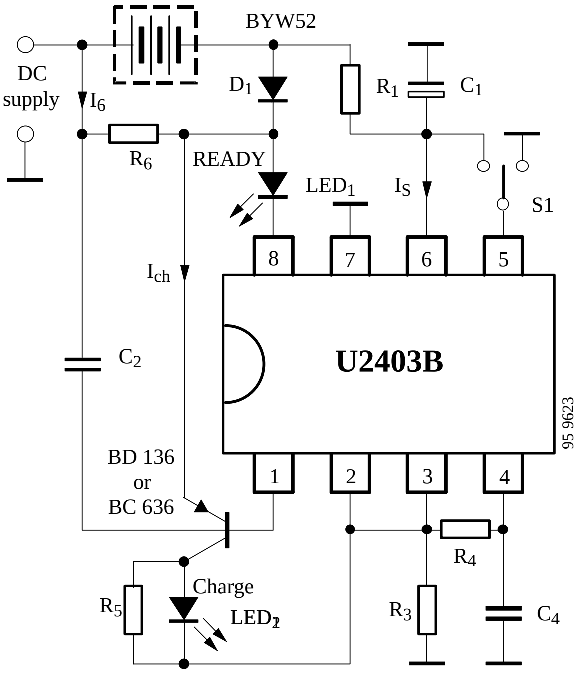
$I_{ch} = V_3 / R_3$
$V_3 = 1.48$ V, typically

Trickle Current:

$I_{ch} = V_3/R_3 + I_{LED1} + I_S - I_6$
Typical values:
$V_3 = 100$ mV
$I_{LED1} = 4.5$ mA
$I_S = 1.8$ mA

Trickle-Charge Reduction (I_6)

$I_6 = (V_{Batt} + V_{D1})/R_6 \quad V_{D1} = 0.75$ V



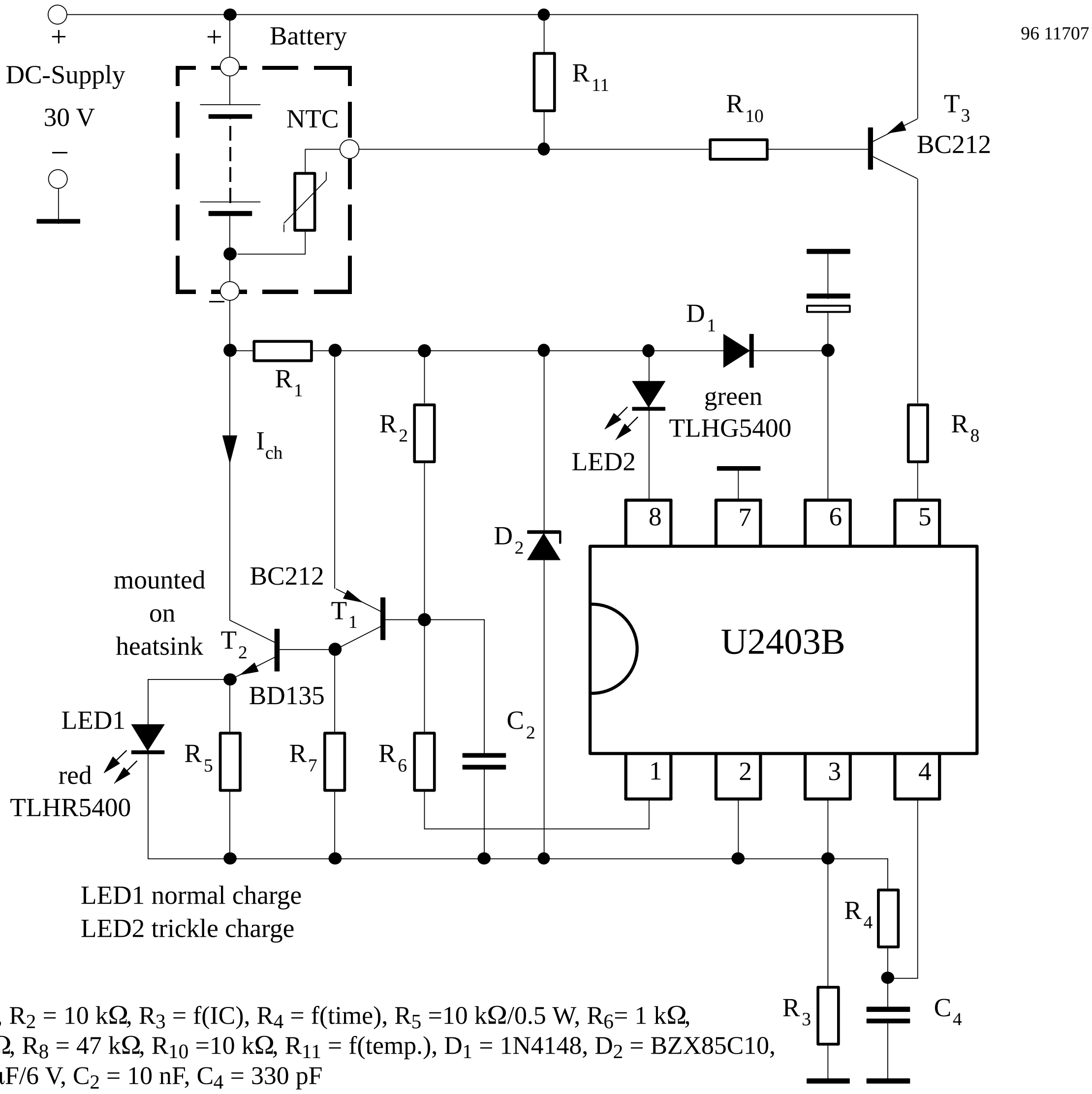
S1: use for test only

Figure 14. Application for charge current > 250 mA

To fulfill requirements of higher charge current an external booster transistor can be used (see figure 7). As the temperature cannot be monitored in this case, a heat sink with a resonable size should be used for safe operation. Test mode switch S_1 can be used for accelerated production check.

Charge System at a Higher Voltage of 30 V

Charge systems with higher voltages than V_{Smax} can be realized with the additional expander circuitry, as shown in figure 15. The circuit shown below contains a simple temperature monitoring function. When the temperature level is reached, the transistor, T_3, is switched on. If T_3 is switched on and there is current flow into Pin 5, normal charge is terminated.



R_1 = 1 kΩ, R_2 = 10 kΩ, R_3 = f(IC), R_4 = f(time), R_5 =10 kΩ/0.5 W, R_6= 1 kΩ,
R_7 = 10 kΩ, R_8 = 47 kΩ, R_{10} =10 kΩ, R_{11} = f(temp.), D_1 = 1N4148, D_2 = BZX85C10,
C_1 = 100 µF/6 V, C_2 = 10 nF, C_4 = 330 pF
R_{11} = f(temp.) depends on number of cells

Figure 15. U2403B for higher supply voltage up to 30 V with integrated temperature monitoring

No of Cells	R_{11}
2	13 kΩ
3	8.2 kΩ
4	6.2 kΩ
5	4.7 kΩ

NTC Value	
25°C	6.8 kΩ
40°C	3.9 kΩ
50°C	2.8 kΩ

Advanced Battery Charge

U2402B/ U2405B/ U2407B

General Description

The ICs U2402B, U2405B and U2407B are specifically designed for use in rapid charge, fast charge and very fast charge systems (10 – 180 min.). NiCd, NiMH and Li-Io batteries can be charged quickly and gently. When the capacity limit is reached, fast charging is interrupted using $+d^2V/dt^2$ or $-\Delta V$ gradient detection.

Compared to other charging implementations where the charging is terminated based on $-\Delta V$ or dT/dt identification, the TEMIC battery charge ICs are unique, since they also allow for changes in the positive slope charging curve, based on the second derivative of the voltage with respect to time ($+d^2V/dt^2$). This technique is the safest method of terminating charging before the battery reaches overcharge.

Measurements on a charging battery performed by TEMIC are represented by figures 16 and 17. The temperature curve was measured on the outer surface of a cell. The time delay with respect to the actual inner cell temperature or to the cell voltage must also be considered.

The increase in cell temperature caused by rising pressure indicates incipient overcharge. Progressive loss of capacity and a consequent reduction of the service life of a battery can be expected if this condition occurs frequently.

The design of the ICs ensures that batteries are charged quickly and gently to the maximum capacity. The multiple gradient monitoring ($+d^2V/d^2$ and $-\Delta V$) ensures maximum reliability of switch-off even in the case of critical charging applications for which a less pronounced charge characteristic is expected (e.g., at reduced charge current). An additional temperature control input used for monitoring the battery temperature likewise prevents the charging of a battery whose temperature is outside the specified window.

Reliable detection of the voltage gradient is implemented by a precise and noise-free voltage detection technique. The IC controller supports accurate voltage measurement by interrupting the charge current before and during each measuring phase (currentless phase). This removes any possibility of charge-current-related influences, i.e., voltage drops across contacts and leads. Moreover, a plausibility check function ensures that charging is not interrupted unintentionally by brief voltage irregularities, such as those resulting from chemical reactions in the battery or other external influences.

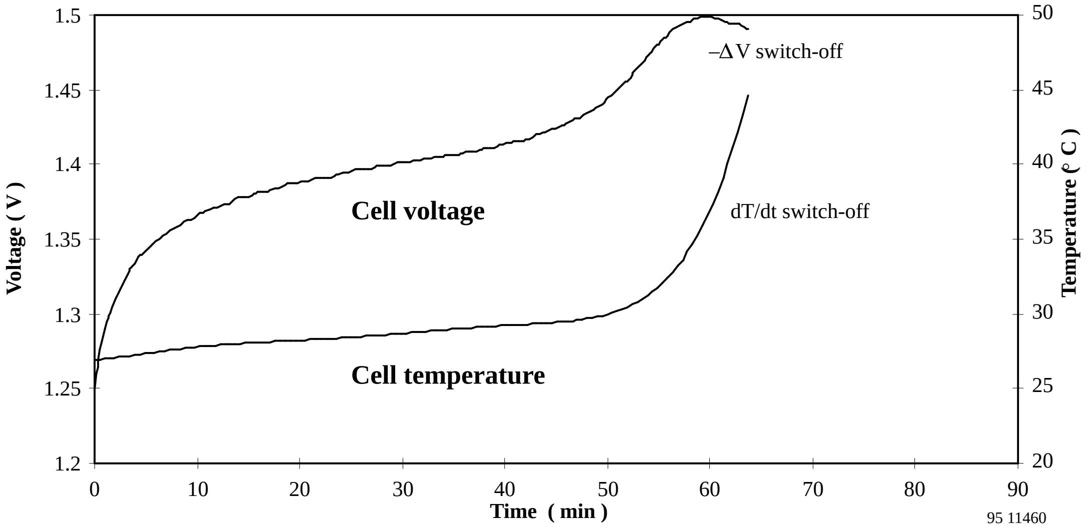


Figure 16. NiMH battery charge termination by conventional switch-off mode ($-\Delta V$:dT/dt)

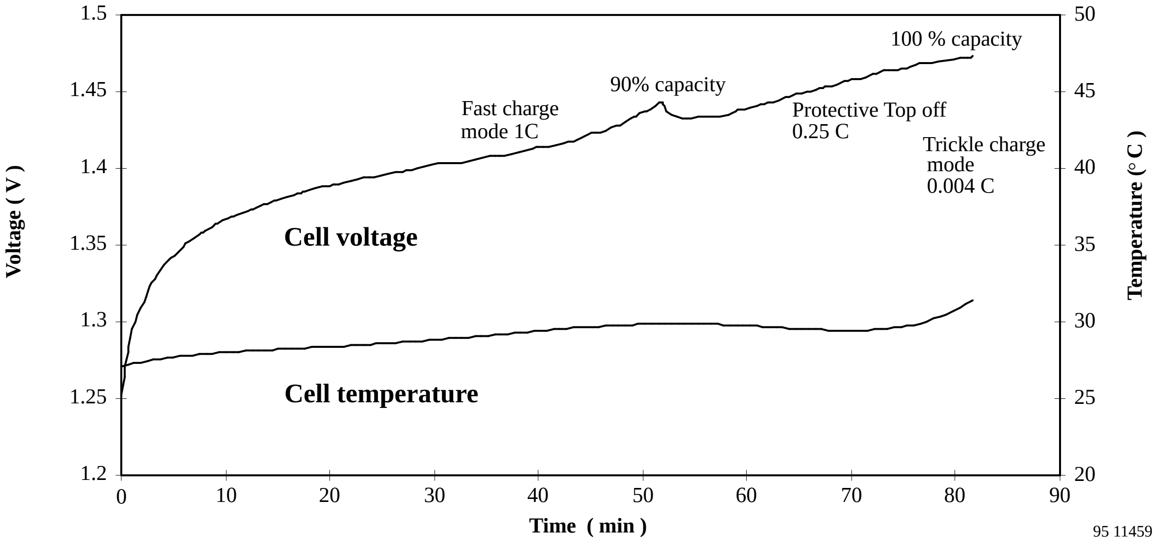


Figure 17. NiMH battery full charge for maximum battery life time (U2402B-C/ U2405B/ U2407B)

A regulated constant charge current is necessary to maintain a continuous charge-voltage characteristic. This constant current regulation is achieved using an internal control amplifier, phase control and simple shunt-current control technique. The phase control circuit utilizes the integrated control amplifier, and provides closed-loop current control. The amplifier, normally used as an integral regulator, generates the output setting voltage corresponding to the deviation between the actual current value (shunt voltage) and the current setpoint value (internal reference voltage).

All battery management functions can be achieved via dc-supply charge systems with a dc-to-dc converter or a linear regulator providing the power supply (U2407B). Additionally, the internal control amplifier can also be used for closed-loop charge control (U2402B, U2405B). This also enables a reduction of the external circuit complexity for dc-powered charge systems.

The main characteristics and differences between the ICs are given in the tables 2 and 3.

In the following, the U2402B-C is used as the basis for describing and comparing the differences between all other ICs of the battery family.

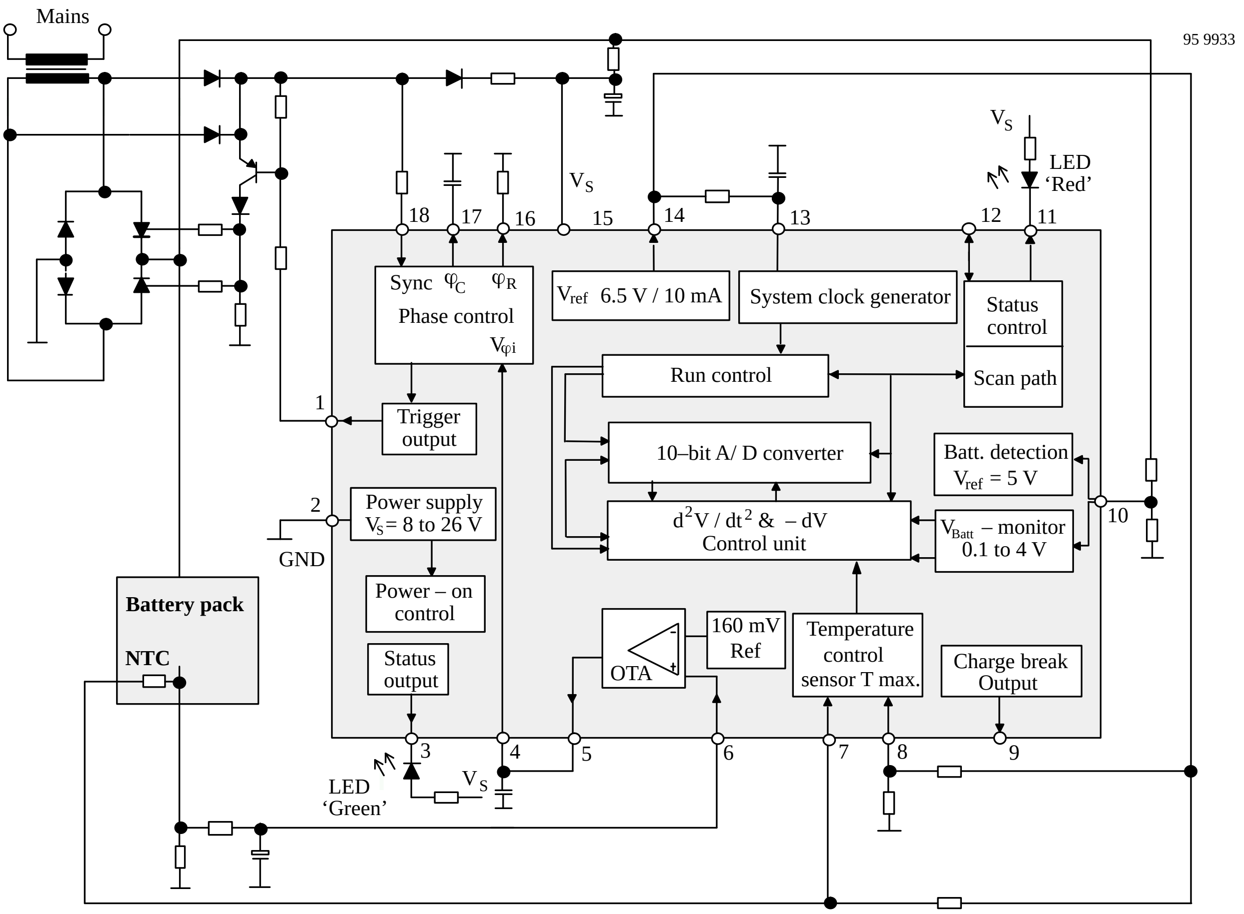


Figure 18. Typical charge application (U2402B/ U2405B)

Table 2. IC selection depending on the application conditions

	IC Version			
	U2402B-B	U2402B-C	U2405B	U2407B
Condition	Charge current control			
Mains supply (AC)	Phase control	Phase control	Phase control	Primary switch
DC-(car) battery	PWM switchmode	PWM switch mode	PWM switch mode	Linear mode
Battery type	NiCd	NiCd/ NiMH/ Li-Ion	NiCd/ NiMh	NiCd/ NiMH

Table 3. Functional differences of the IC versions

	IC Version			
Function	U2402B-B	U2402B-C	U2405B	U2407B
Package	DIP18, SO20	DIP18, SO20	DIP18, SO20	DIP16, SO16
Phase control feature	Yes	Yes	Yes	No
$-\Delta V$ sensibility typ. related to full scale	18 mV	12 mV	12 mV	12 mV
Top-off rate	Not active	$\frac{1}{4} \times I_0$	$\frac{1}{4} \times I_0$	$\frac{1}{4} \times I_0$
Trickle rate	$\frac{1}{16} \times I_0$	$\frac{1}{256} \times I_0$	$\frac{1}{256} \times I_0$	$\frac{1}{256} \times I_0$
Preformation level for drained batteries	No	No	1.6 V related to full scale range	1.6 V related to full scale range
LED status indication	Standard 2 LED outputs	Standard 2 LED outputs	Standard modified 2 LED outputs	All charge states 4 LED outputs
DAC conversion factor V_{Batt} input/ S_{TM} output	0.5	1	1	1
Reset	By battery removing	By battery removing and power-on	By battery removing and power-on	By battery removing and power-on

Feature Comparison

Advanced battery fast-charge systems based on complex voltage curve monitoring are necessary in the following cases:

- Full charge is required by customers with maximum service time of the battery pack
- The customer prefers charge systems for guaranteeing maximum battery life time
- NiCd very fast charge ($\gg$ 1 C) or NiCd/ NiMH fast charge is specified
- Fast charge is specified based on NiMH and Lithium Ion battery packs

TEMIC provides unique fast-charge control ICs with remarkable benefits for reproducable 100% charge and maximum battery life time.

TEMIC battery charge ICs provide best solutions for precise overcharge protection. The ICs offer the following benefits:

- Complete autonomous solution for versatile applications based on few components
- Easy-to-use system: only three system parameters to be fixed (cell number, system frequency, charge current)
- Charge-rate adaption of 0.3 to 6 C
- Optimized system solution for ac and dc applications
- Suitable for telecom and automotive applications
- Suitable for NiMH and Lithium Ion battery-pack applications
- Standard solution for 2 C NiMH charge
- Ready-to-run solution for the automotive industry: car adapters with reduced periphery
- System-cost reduction by integrated power management and reduced NTCs

The control ICs U2402B, U2405B and U2407B are unique solutions for developing efficient and reproducable 0.3 to 6 C battery charge cycles simply and quickly; applications for the combined charge of NiMH and Lithium Ion battery packs are available (1 C). U2402B, U2405B and U2407B can be used in applications for the precise full charge of NiCd in 10 minutes.

Low-cost versions are available for applications with a single-type NiCd battery pack (U2402B-B) and with specific current control concepts (U2407B).

The U2402B, U2405B and the U2407B enable a precise termination of the charge procedure before overcharging starts. This is close to the inflection point of the battery voltage curve. The precise overcharge prevention is combined with a defined top-off charge which follows.

The U2402B and U2405B offer a combination of charge monitoring, phase control and PWM power management and therefore enable smart, gentle and fast charging. The U2407B is a minimized version for external power management concepts and is based on the U2405B. It enables primary switchmode and linear current regulation.

Minimized costs for implementing these designs makes the U2402B family attractive for use in volume markets such as telecommunications, automotive or consumer electronics.

The following paragraphs give a description of the basic U2402B-C version and how it differs to the U2402B-B version, U2405B, U2407B and the U2402B-C.

Characteristical Features of U2402B-C

- The fast-charge cycle switches over to top-off charge mode close to the inflection point of the battery voltage curve due to the + d^2V/dt^2 criteria. At this point, the battery still has about 90% capacity available. The 100% level is achieved during the top-off charge mode. The duration of the top-off charge time is dependent on the frequency.
- The trickle current is fixed at 1/ 256 I_O.
- Various battery packs can be charged by using capacities based on a fixed periphery. The 400 mAh – 1500 mAh range, for example, can be covered with a fixed 950 mA charge current, even in various NiCd and NiMH battery packs. A screen test to ensure optimum frequency is sometimes necessary.
- U2402B-C is recommended for NiMH and mixed NiCd/ NiMH battery charge applications as it is able to accept a wide spectrum of charge capacity.
- A -ΔV switch-off mode is implemented as a safety feature. It has -12 mV for the total DAC range and is therefore suitable both for NiCd and NiMH. The –ΔV sensitivity is 0.30% related to the convertion range. However, the correct values depend on the cell number.
- The slope scanning sequency is selected linear to the charge rate (recommended value for 1-C charge, f = 500 Hz).
- Safe charge termination when measurement input is overdriven.

Comparing the U2402B-B to U2402B-C

The U2402B-B is pin-compatible to the U2402B-C. Application hints and demo boards are valid for both ICs.

- The charge level is aproximately 90% instead of 100% if trickle charge is activated. This is due to a shortened time for the top-off charge mode which means the top-off mode is inactive. The trickle rate is fixed at 1/16 I_O which is essentially higher than that of the C-version. Therefore, by using the B-version, most batteries reach the 100% level after some hours due to the high trickle current.
- 0.5 to 6 C charge cycles are recommend for NiCd batteries. The accepted capacity range is reduced compared to the C-version, e.g., in combined applications with 750-mAh and 1100-mAh battery packs adjusted with 950 mA current.
- –ΔV switch-off criteria: –18 mV for the total DAC range, i.e., 0.45% sensitivity for the conversion range, depending on the cell number.

- The DAC voltage conversion from the measurement input V_{Batt} to the test mode output S_{TM} has half the value compared to the C-version.
- RESET: is only activated by “REMOVING Battery” – not by “Power-ON”

Comparing the U2405B to the U2402B-C

The U2405B is pin-compatible to the U2402B-B and U2402B-C. U2402B demo boards and applications can also be applied to U2405B.

In contrast to the U2402B-C, the U2405B has a slow-charge preformation and specific LED display features.

Preformation Mode for ‘Virgin’ and Drained Batteries

The U2405B offers a preformation procedure for ‘virgin’ and drained batteries. The preformation is carried out when the cell voltage is below a specified level before the fast-charge cycle has been started. To start the fast-charge cycle, a voltage level of more than 0.8 V is necessary. The voltage level of the input conversion range is specified as 1.6 V. By modifying the input voltage divider externally, the cell voltage can be adjusted with regard to the maximum conversion range of typically 4.0 V. The preformation slow charge current can be adjusted by RB1 and starts if the cell voltage condition is met, i.e., 0.1 V – 1.6 V. During the first 10 minutes, the green LED2 is blinking. If the V_{Batt} voltage has not reached the reference level after 10 minutes, the indication changes to RED blinking LED1. The charge therefore continues with preformation rate (RB1). If V_{Batt} reaches the 1.6 V reference level, the fast-charge rate current I_O is switched on and the green LED2 is blinking.

This mode enables fast-charge cycles of ‘virgin’ as well as drained batteries. Premature charge termination – which normally occurs in such cases – is prevented.

LED display: Another difference to the U2402B-C is the standard LED display mode for the following status: “battery disconnection” ($V_{Batt} > 5$ V) and “temperature outside the window before the battery has been inserted” (see status control on page 27).

Comparing the U2407B to U2402B-C and U2405B

The U2407B is a minimized fast-charge control IC which is based on the U2405B.

The U2407B differs from the U2402B-C and the U2405B as external power management is needed to create the complete charge system.

This circuit can be used in most applications primarily for the switchmode and the linear current regulation. The U2407B is used in various devices and in systems with high charge currents. The U2407B has a minimized package compared to the U2402B-C and the U2405B.

The IC is available in DIP16 and SO16 package. If these applications are not requested, the phase angle control or the PWM DC concept should be considered (see U2402B and U2405B).

Preformation algorithm: The preformation algorithm for drained and ‘virgin’ batteries is implemented in the same way as in the U2405B.

Freely-programmable LED status display: In contrast to the U2402B and U2405B, this IC has 4 pins for LED status display which can be programmed in any way. The combination of status display indications is possible with minimum external periphery. A display mode similar to the U2402B and U2405B can be created as well as a typical display mode of telecom OEMs (see data sheet or Technical Data U2407B).

Freely-programmable top-off charge rate: The current amplitude during top-off charge can be reduced by external periphery as shown in the U2407B data sheet and in the section “Technical Data”.

Functional Description

Notes on the following chapter:

- All times refer to the nominal frequency f_{osc} = 800 Hz
- The pins described are based on U2402B/ U2405B
- Values in brackets refer to the U2402B-B

Sequence of a Charge Process

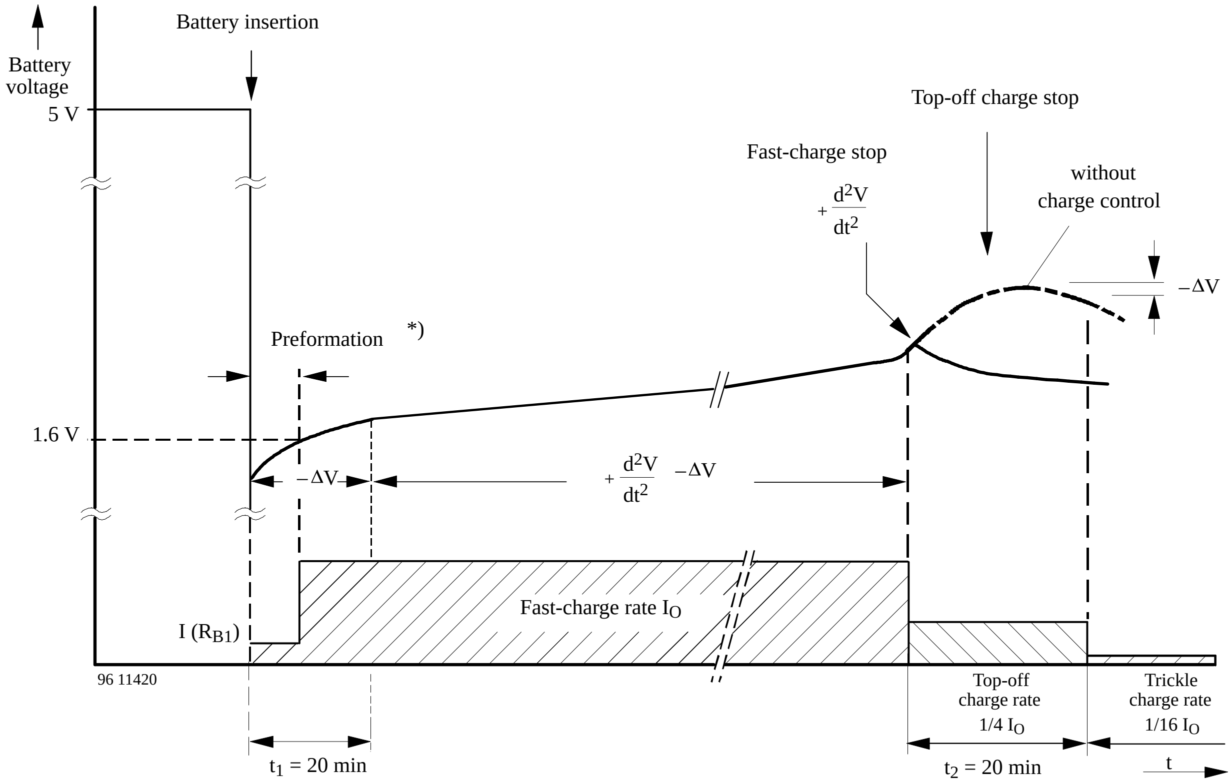


Figure 19. Diagram of the charge function

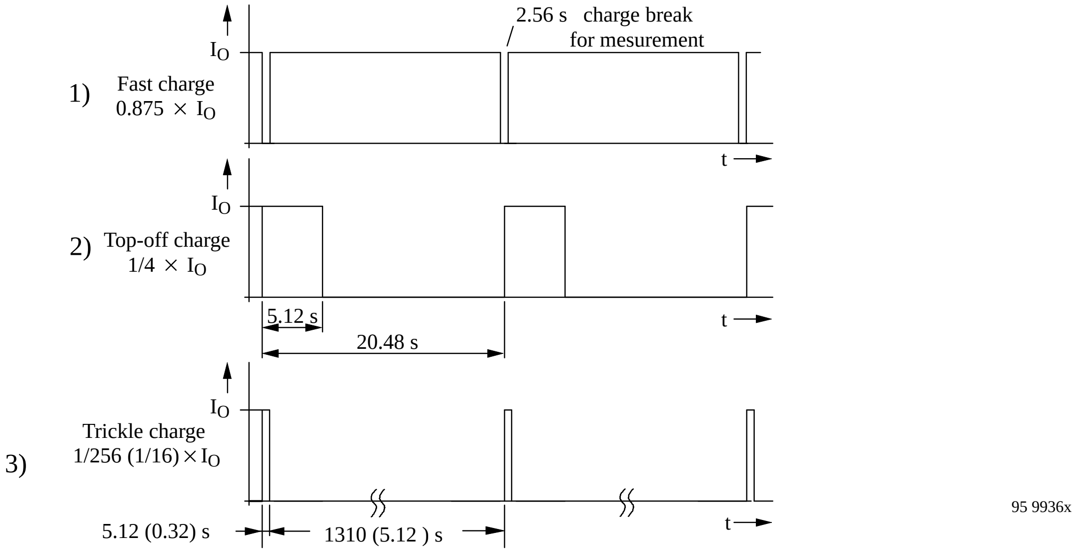


Figure 20. Charge rate for fast charge, top-off charge and trickle charge

After a battery is inserted into the charge unit, fast charge begins at the predetermined charge current I_O if two conditions are met:

- The voltage at the BATT input must be between 0.1 V and 5 V
- The voltage at the sensor input must be in the range of $V(T_{max})$ up to 4 V

The positives slope $(+d^2V/dt^2)$ detection is suppressed during the first five minutes after the start of charging (i.e., during the formation phase) if the frequency has been adjusted to 800 Hz. Only $-\Delta V$ monitoring is active during this phase in order to ensure that charging is interrupted as soon as possible if the battery is already fully charged. Additional external circuit periphery for V_{max} switch-off (peak voltage detection) can be added to avoid overcharging by $-\Delta V$ (see figure 36). Thermal monitoring by the temperature sensor is active during the entire charge time.

The $+d^2V/dt^2$ and the $-\Delta V$ detection functions serve as the switch-off criteria after the formation phase. The typical charge curve in figure 19 shows a steadily increasing voltage characteristic after the formation phase. An accelerated increase of the battery voltage only takes place just before the maximum charging capacity is reached. This accelerated increase in voltage is detected by the $+d^2V / dt^2$ gradient detection function and ensures interruption of fast charging if the result of the plausibility test is positive.

A top-off charge mode automatically follows the fast-charge mode. This operates at a reduced charge current of $1/4 \times I_O$ and provides controlled charging of the battery up to full capacity. A subsequent trickle charge of $1/256 \times I_O$ keeps the battery ready for use at all times. The charge status is indicated by two LEDs.

Functional differences of the various IC versions are given in table 3, page 22.

In the B-version, $-\Delta V$ recognition is active even during top-off mode. The corresponding $-\Delta V$ drop through the reduction of the charge rate can lead to premature cut-off of the top-off charge cycle time. In this case, a relatively high level trickle charge mode $(1/16 \times I_O)$ supplies the necessary incremental charge. In other versions, $-\Delta V$ recognition is disabled after the fast-charge phase. The full top-off charge of 20 minutes with $1/4 \times I_O$ rate is achieved and thus full charge is assumed. This version provides a reduced trickle charge of $1/256 \times I_O$ to compensate for self-discharge.

Status Control

(U2402B-B/ -C)

LED1 (RED)	LED2 (GREEN)	Status
OFF	ON	No battery, top-off charge, trickle charge
OFF	Blinking	Fast charge, temperature out of the window before battery insertion or power-on
ON	OFF	Temperature out of the window
Blinking	OFF	Battery break (interrupt) or short circuit

U2405B

LED1 (RED)	LED2 (GREEN)	Status
OFF	ON	Top-off charge, trickle charge
OFF	Blinking	Fast charge
ON	OFF	Temperature out of the window
Blinking	OFF	Drained battery (0.1 V < V_{Batt} > 1.6 V, if t > 10 min.) Battery break, short circuit
ON	Blinking	Temperature out of window before battery insertion or power-on
OFF	OFF	No battery (V_{Batt} > 5 V)

U2407B

LED1	LED2	LED3	LED4	Status
OFF	OFF	OFF	OFF	No battery (V_{Batt} > 5 V)
OFF	OFF	Blinking	OFF	Fast charge
OFF	ON	OFF	ON	Top-off charge
OFF	ON	OFF	OFF	Trickle charge
Blinking	OFF	OFF	OFF	Failure mode

Measuring Sequence

The system controller carries out a measurement every 20.48 seconds at the standard oscillator frequency of 800 Hz (figure 21). Voltage measurement takes place during a currentless phase of 2.56 seconds. This eliminates the possibility of disturbing influences such as contact resistance or dynamic charge-current fluctuations interfering with the voltage measurement. The actual measuring phase of 1.28 seconds takes place after a delay of 1.28 seconds. This ensures that the battery voltage decays to a stable value after a current interruption and thus permits precise voltage measurement.

To indicate measurement, a trigger pulse lasting 10 ms is applied to the “charge break” output 40 ms after charging is interrupted. This signal can be used for various purposes, e.g., to synchronize a test measurement or to implement a discharge cycle during every charge interruption (see figure 39).

Battery Measuring Input

The battery voltage measurement at Pin 10 (ADC-converter) has a range of typically 0 to 4 V. This means that a battery pack containing two cells can be connected without a voltage divider ($R_{B3} = \infty$; see figure 22).

If the battery voltage exceeds the converter range of 4 V, adjustment at the external voltage divider resistance R_{B2} and R_{B3} is recommended.

If $V_{Batt} > 4$ V, the mode changes immediately from fast charge to trickle charge. This safety feature is not realized in the U2402B-B version.

Values of the resistances R_{B1}, R_{B2}, and R_{B3} are calculated by assuming $R_{B1} = 1\,k\Omega$, $R_{B2} = 10\,k\Omega$ as follows:

$$R_{B3} = R_{B2}\,\frac{V_{10max}}{V_{Bmax} - V_{10max}}$$

The minimum supply voltage, V_{smin}, is calculated for the reset function after removing the inserted battery according to:

$$V_{smin} = \frac{0.03mA \times R_{B3}(R_{B1} + R_{B2}) + 5V(R_{B1} + R_{B2} + R_{B3})}{R_{B3}}$$

Parameters during charge break:
V_{10max} = Maximum voltage at Pin 10
V_{Smin} = Minimum supply voltage at the IC (Pin 15)
V_{Bmax} = Maximum battery voltage

Care should be taken that under specified charge current conditions the final voltage at the input of the converter (Pin 10) does not exceed the threshold voltage level (4.3 V + $V_{BE} \approx$ 5 V) of the reset transistor stage (T_R) in case the divider R_{B3} has to be reduced. When the battery has been removed, the input (Pin 10) is terminated across the pull-up resistance $R_{B1,}$ to the value of 5 V reset-threshold. This guarantees the start of a new charge sequence when a battery is re-inserted.

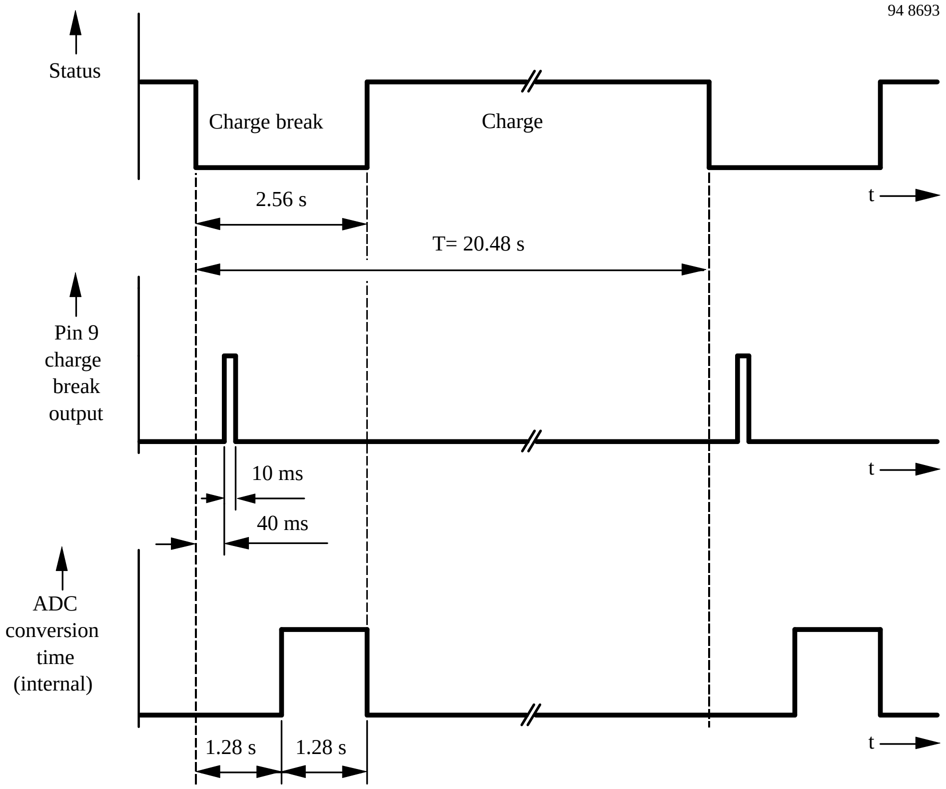


Figure 21. Operating sequence of voltage measurements

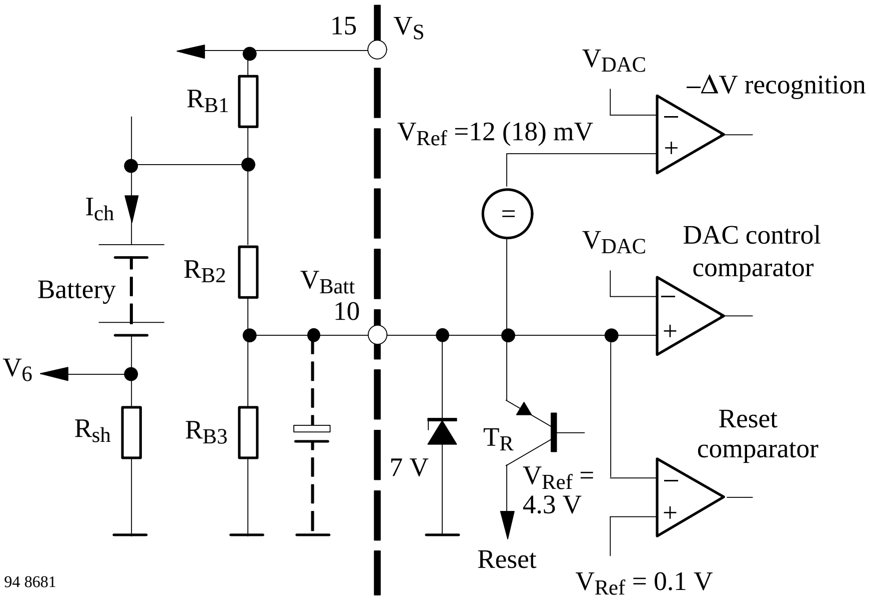


Figure 22. Determination of the input voltage conditions for the battery

Table 4. Adaptation of the current divisor to the cell number

Cell No.	1	2	3	4	5	6	7	8	9	10	11	12
V_{Smin}	8 V	8 V	8 V	9 V	11 V	13 V	15 V	17 V	19 V	21 V	23 V	25 V
R_{B3}	–	–	51 kΩ	16 kΩ	10 kΩ	7.5 kΩ	5.6 kΩ	4.7 kΩ	3.9 kΩ	3.3 kΩ	3 kΩ	2.7 kΩ

Valid when V_{10max} = 3.5 V

Battery Detection and Reset Generation

With the exception of the U2402B-B version, a reset is initialized in all other versions via “power-ON” as well as via battery re-insertion. In the B-version, the battery has to be removed and then re-inserted to enable the reset function. A battery is defined as re-inserted when the voltage at the V_{Batt} input is between 0.1 and 5 V. The charge process is then initialized if the voltage at the sensor input is in the range of V (T_{max}) up to 4 V.

Except for temperature detection, the sensor input is used for recognition of high- and low-impedance batteries (0.1 > V_{Batt} > 5 V). Therefore, high- and low-impedance batteries can be charged with the pull-up method. In the case of damaged batteries, a reset is carried out after the charge start. With batteries that are not damaged, a regular charge process starts after the short formation phase. To ensure a safe charge start, V_{Batt} and the sensor input have to be outside of the voltage window (0.1 V > V_{Batt} > 5 V) for a short time. Battery packs with an integrated sensor achieve this automatically by re-inserting the battery. The requirements for reset generation can be fulfilled for systems without a sensor as described in the section “Charging without Temperature Sensor” (page 32)

It is important to note that under the charge-current condition the resulting voltage at the V_{Batt} input must never reach the 5-V reset-threshold (4.3 V + V_{BE}; see figure 22).

The transistor, T_R, is held at the 5-V reset threshold via pull-up resistor, R_{B1}, after the battery is removed. This enables a further charge when a battery is re-inserted.

The pull-up reset function can be disadvantageous in certain applications, such as battery packs with large cells. V_{Smin} would be too high in this case. In order to prevent this, a pull-down reset function for battery removal, which omits R_{B1}, can be realized. The voltage at input V_{Batt} must be less than 0.1 V. However, the battery cannot be charged if its total voltage is less than 0.1 V.

Analog-Digital-Converter (ADC), Test Sequence

The U2402B-B/C incorporates a special **A**nalog-to-**D**igital **C**onverter (ADC) which consists of a 5-bit coarse and a 5-bit fine converter. This ADC operates by a linear count method which can digitize the measured input voltage of 4 V at V_{Batt}, Pin 10, in 6.5-mV steps of sensitivity.

The ADC system is comprised of a **D**igital-to-**A**nalog **C**onverter (DAC) combined with a comparator. When a charge cycle has been started, the coarse counter of the DAC carries out a fast tracking to the actual V_{Batt} voltage. The counter is stopped by the input comparator (see figure 22) when the DAC voltage reaches the V_{Batt} voltage up to 10 mV. One pulse for the fine counter of the DAC is generated subsequently.

During the charge process, only one pulse (fine tracking) for the following measuring cycles is produced.

Fast-Charge Termination

There are two criteria considered for charge interruption reasonability:

– ΔV Cut-Off

When the signal at Pin 10 of the DA converter is 12 mV below the actual value, the comparator identifies it as a voltage drop of –ΔV. The validity of –ΔV cut-off is considered only if the actual value is below 12 mV for three consecutive cycles of measurement. In contrast to this, the U2402B-B has a -ΔV sensitivity of 18 mV.

+d^2V/dt^2 Cut-Off

A four-bit forward/ backward counter is used to register the slope change ($+d^2V/dt^2$, V_{Batt} – slope). This counter is clocked by each tracking phase of the fine DAC counter. Starting at its initial value, the counter counts the first eight cycles in forward direction and the next eight cycles in reverse direction. At the end of 16 cycles, the actual value is compared with the initial value. If there is a difference of more than two LSB bits (13.5 mV) from the actual (counter) value, then there is an identification of a positive slope change which leads to normal charge cut-off. A second counter in the same configuration operates in parallel with eight clock cycles delay to reduce the total cut-off delay from 16 test cycles to eight test cycles.

Charge Current Control

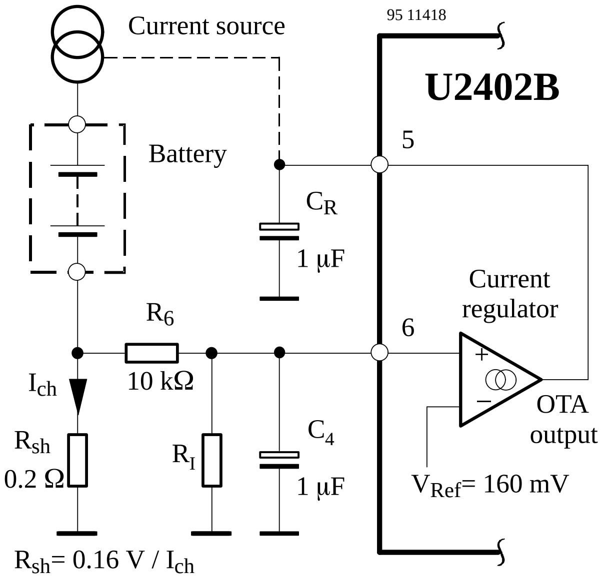


Figure 23. Detail schematic for charge current control

The charge current is measured by the shunt resistor, R_{sh}. The internal OTA-compares the voltage drop on R_{sh} with an internal voltage reference of 160 mV. Corresponding to the deviation of the voltage values, the OTA provides an output current at Pin 5 into the external smooth capacitor, C_R. Depending on the application, the resulting voltage is used to control either an external power stage or the internal power management when using U2402B/ U2405B.

If no voltage divider R_I is used, the shunt resistor R_{sh} determines the charge current I_{Ch}. The shunt resistor can be calculated as follows:

$$R_{sh}(\Omega) = \frac{160}{I_{Ch}(mA)}$$

Based on this value, the current can be increased by inserting an apropriate divider resistor R_I. For determining R_I, use the following formula:

$$R_I(k\Omega) = \frac{160 \times 10}{I_{ch}(mA) \times R_{sh}(\Omega) - 160}$$

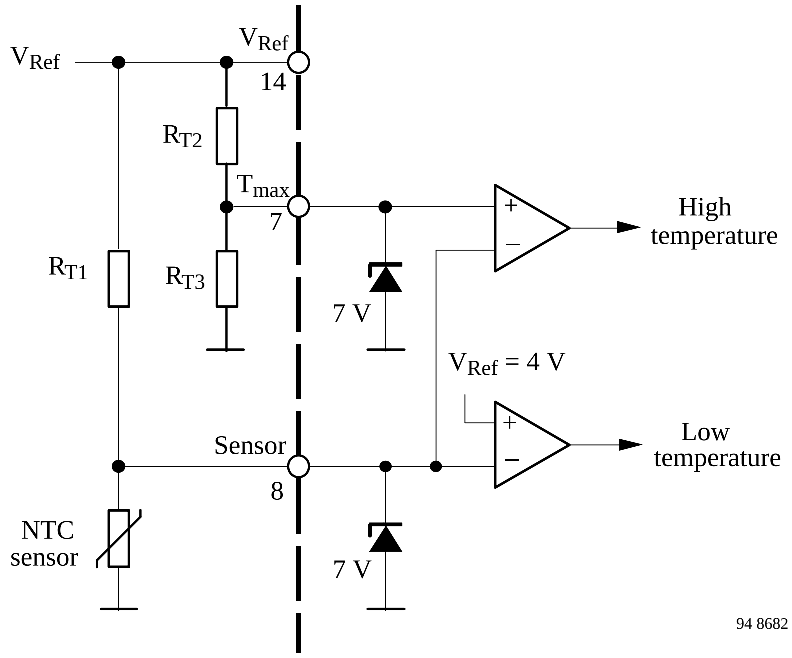


Figure 24. Temperature window

Temperature Control

When the battery temperature is outside the specified **temperature window**, the overall temperature control will not allow the charging process to continue. A short circuit or interruption of the sensor charge also leads to charge switch-off.

A differentiation is made whether the battery exceeds the maximum allowable temperature, T_{max}, during the charge phase or the battery temperature is outside the temperature window range before battery connection.

A permanent switch-off follows after a measurement period of 20.48 s if the temperature exceeds a specified level. A charge sequence will start only when the specified window temperature range is attained (see the section “Status Control” on page 27).

The temperature window is specified between two voltage transitions. The upper voltage transition is specified by the internal reference voltage of 4 V, and the lower voltage transition is represented by the external voltage divider resistances R_{T2} and R_{T3}.

NTC sensors are normally used to control the temperature of the battery pack. If the resistance values of NTC are known for maximum and minimum conditions of allowable temperature, then the other resistance values, R_{T1}, R_{T2} and R_{T3}, are calculated as follows:

Suppose R_{T2} = 100 kΩ, then

$$R_{T1} = R_{NTCmax} \frac{V_{Ref} - 4V}{4V}$$

$$R_{T3} = R_{NTCmin} \frac{R_{T2}}{R_{T1}}$$

If NTC sensors are not used, the circuit configuration shown in figure 25 and figure 26 should be selected.

Charging Without Temperature Sensor

A defined reset condition is fulfilled when:

- Voltage V_{Batt} is higher than 5 V and the voltage V_{sensor} is greater than 4 V (pull-up method)
- Voltage V_{Batt} is lower than 0.1 V and the voltage V_{sensor} is smaller than V_{Tmax} (pull-down method)

This can be achieved by linking the sensor input with the V_{Batt} input (see figures 25 and 26).

Pull-up: $V_{Batt} > 5$ V –> $V_{sensor} > 4$ V

Pull-down: $V_{Batt} < 0.1$ V –> $V_{sensor} < V_{Tmax}$

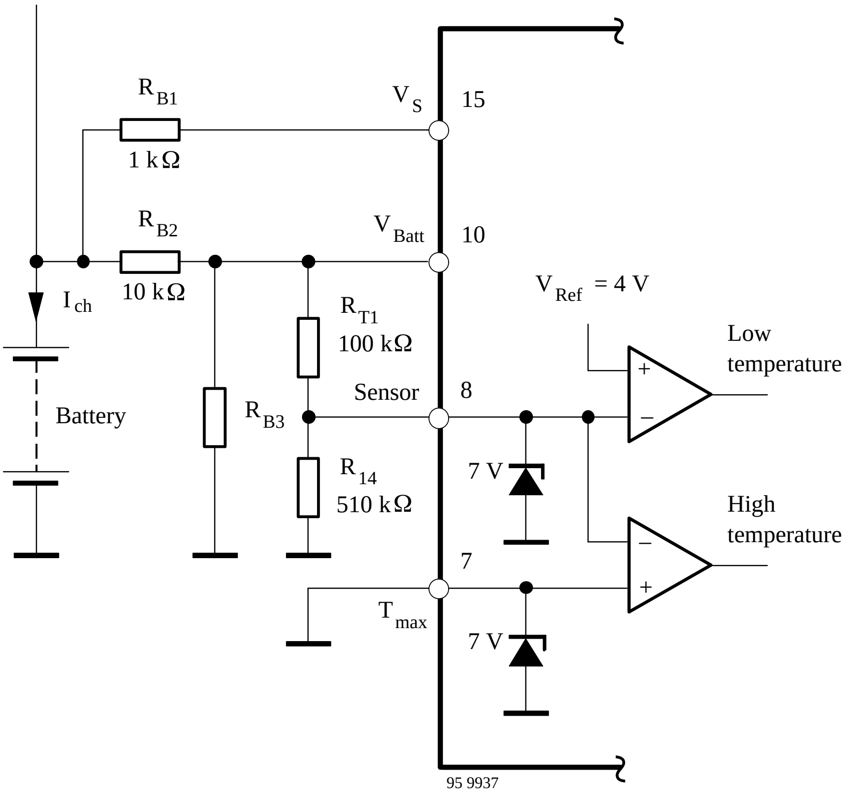


Figure 25. Charge reset with pull-up method

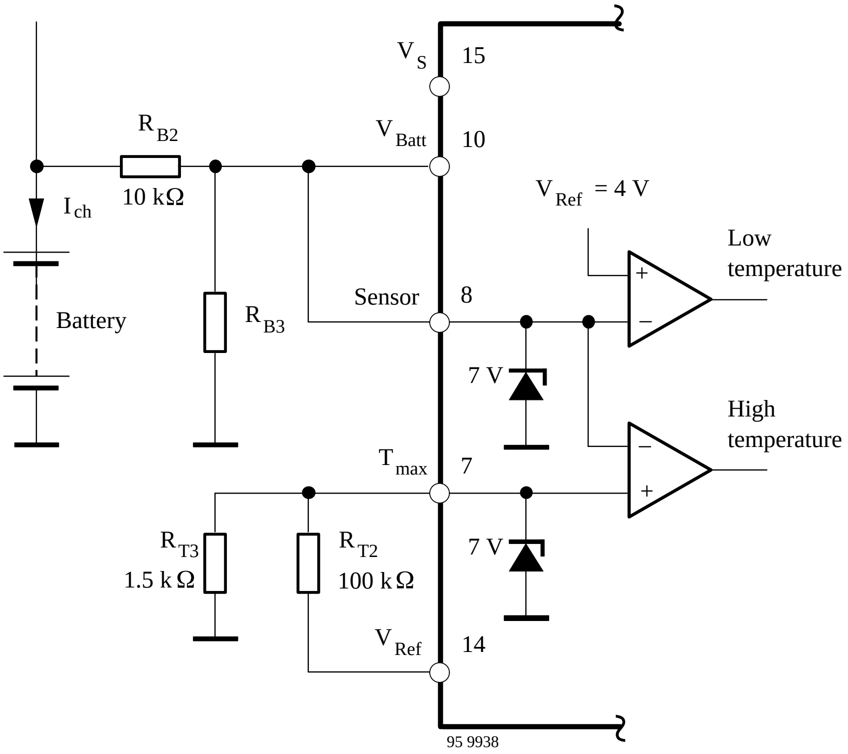


Figure 26. Charge reset with pull-down method

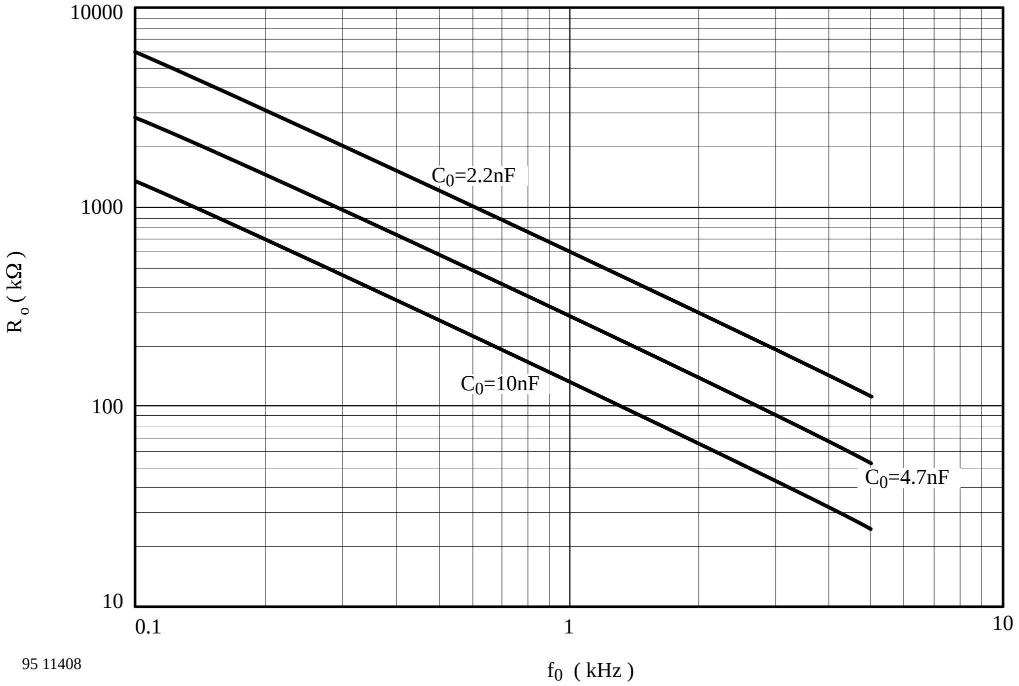


Figure 27. Frequency versus resistance for different capacitance values

Oscillator

Time sequences regarding measurement scanning and evaluation are determined by the system oscillator. All the technical data given in the description are when operating at the standard frequency of 800 Hz.

Oscillator Frequency Adjustment

To ensure a secure charge termination by slope detection, the measurement scan sequence has to match the oscillator frequency respectively. The required oscillator frequency, f_O, depends on the battery charge rate. The following settings are recommended for starting the application:

0.5 C charge	0.5	×	500 Hz	=	250 Hz
1 C charge					500 Hz
2 C charge	2	×	500 Hz	=	1000 Hz
3 C charge	3	×	500 Hz	=	1500 Hz

Figure 27 shows the frequency versus resistance curves with different capacitance values. The blink frequency of LED outputs can be calculated as follows:

$$f_{LED} = \frac{\text{Oscillator frequency } f_O}{1024}$$

Power Supply

The charge controller enables the direct power supply of 8 to 26 V at Pin 15. Internal regulation limits higher input voltages. Series resistance, R_1, limits the supply current, $I_{S,}$ to a maximum value of 25 mA. Series resistance is recommended to suppress the noise signal, even below 26-V upward limit. It is calculated as follows:

$$R_{1min} \geq \frac{V_{max} - 26\ V}{25\ mA}$$

$$R_{1max} \leq \frac{V_{min} - 8\ V}{I_{tot}}$$

where

I_{tot} = $I_S + I_{RB1} + I_1$

V_{max}, V_{min} = Rectified voltage

I_S = Current consumption (IC) without load

I_{RB1} = Current through resistance, R_{B1}

I_1 = Trigger current at Pin 1

Application Examples

Standard Charge Application

The integration of smart battery charge control combined with phase angle power management make the U2402B and U2405B ideal for mains-powered battery charging designs in the power range up to approximately 20 W. By using these ICs, circuit perphery and system costs can be reduced and EMC problems avoided. However, in a power range of over 20 W, this application is limited by transformer size and weight. Switchmode peripheries would therefore be more suitable.

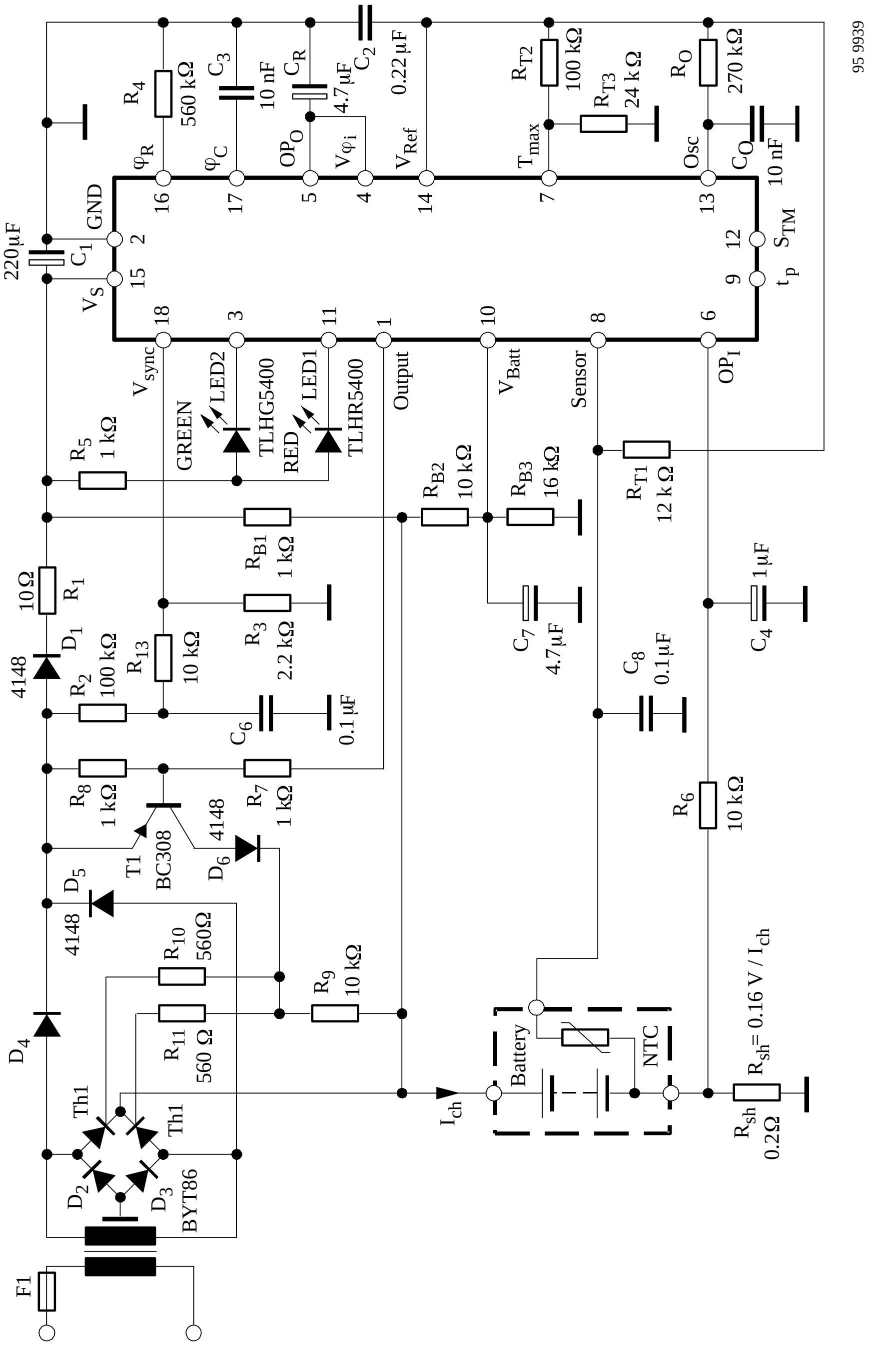


Figure 28. Standard application suitable for 4 cells NiCd/ NiMH, 800 mA (U2402B/U2405B)

A thyristor half bridge used in the standard application is especially recommended for higher charge currents to achieve minimum overall power dissipation. However, another configuration with a rectifier and triac can also be selected for smaller currents (figure 29). As thyristors need a positive gate control, an additional PNP transistor driver stage is required.

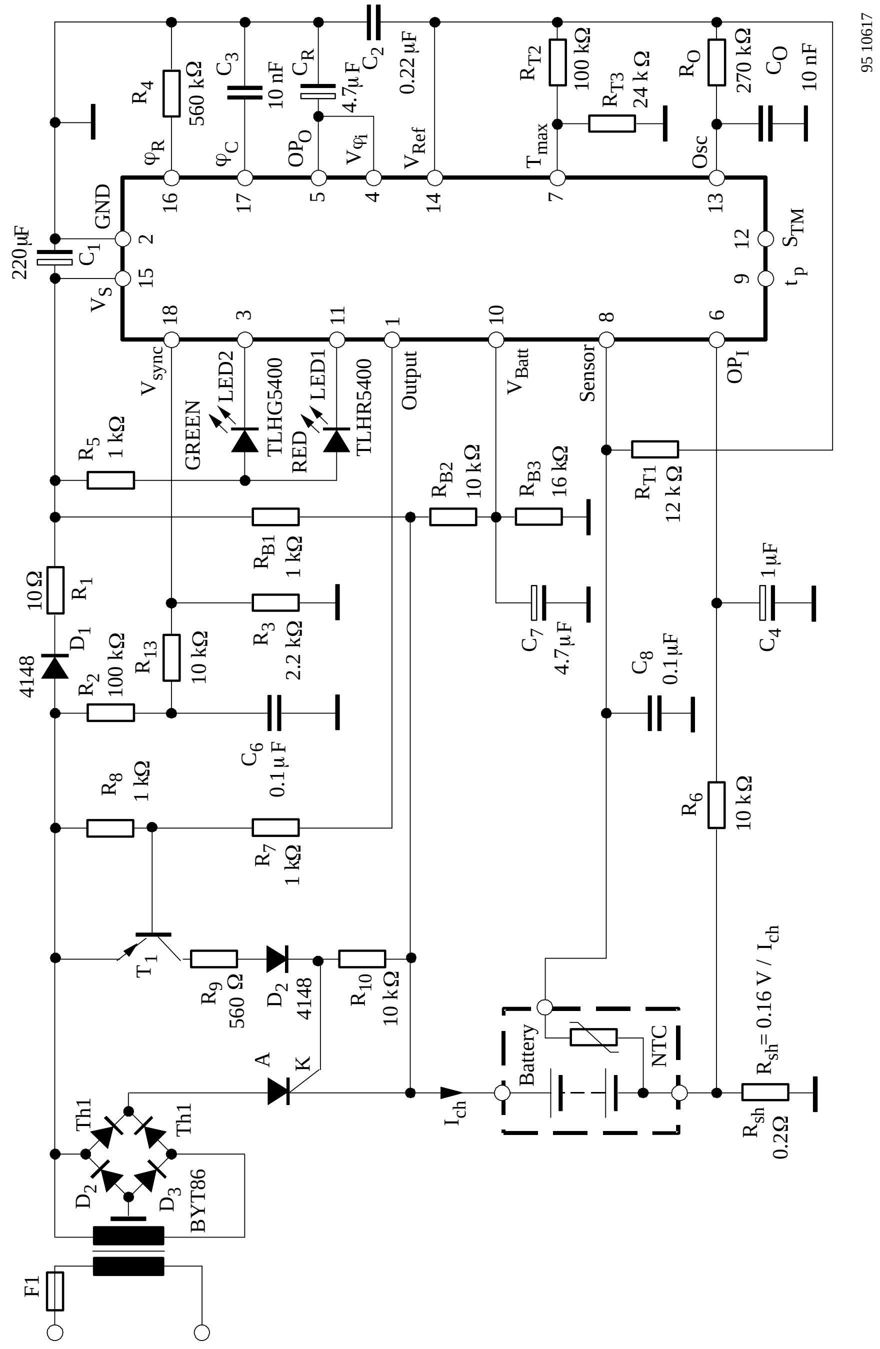


Figure 29. Minimized standard application for 4 NiCd/ NiMH cells 800 mA (U2402B/U2405B)

The phase control of the U2402B/ U2405B is based on the well-known principle of a mains-synchronized ramp which corresponds to the periphery of Pins 16, 17 and 18.

A comparator compares the ramp voltage with the control voltage at Pin 4. The trigger output, Pin 1, switches to “active low” during the time when the ramp voltage exceeds the control voltage. Therefore, the control voltage at Pin 4 determines the trigger position throughout the mains half wave. This affects the arithmetical average of the charge current flow angle.

The charge current flowing into the battery is measured via a shunt resistor, R_{sh}. The internal control amplifier with transmitter output (OTA) compares the shunt voltage at Pin 6 with an internal reference voltage of 160 mV. The resulting set voltage of Pin 5 at the integration capacitor, C_R, forms the control voltage for Pin 5 which is required to perform the phase control function.

The secondary coil of the transformer supplies the charge current over the thyristor bridge. During the thyristor reverse mode, the capacitor C_1 is recharged through the bridge rectifier $D_2 – D_5$. The IC is supplied by each half wave of mains during this time.

Transformer Adjustment to the System

Choice of Transformer

The design of the transformer is not critical. However, the output impedance of the transformer should not be measured too low in order to limit the pulse load.

To guarantee the specified constant current under worst-case conditions (mains undervoltage and fully charged battery), the output voltage of the transformer has to be measured so that the required current can flow into the battery. In special cases, this application can be done under laboratory conditions.

Charge Current Adjustment

The charge current, I_{ch}, is adjusted via the shunt resistor R_{sh}:

$$R_{sh} = \frac{0.16}{I_{ch}\ (A)}$$

Adjustment of Cell Number

The cell number of the battery pack is adjusted via resistor R_{B3}:

$$R_{B3}\ (k\Omega) = \frac{35}{V_{Bmax}\ (V)\ -3.5}$$

V_{Bmax} = maximum battery voltage without charge current

Voltage Measurement Interval

The measurement interval can be adjusted through the oscillator frequency, f_o, with R_o and C_o.

Charge Rate	Frequency	R_o	C_o
0.5 CA	250 – 300	470 – 600	10 nF
1 CA	500 – 600	240 – 300	10 nF
2 CA	1000 – 1200	120 – 150	10 nF

Parallel Multicharge System

Charge systems for single battery cells need autonomous cell management in most cases, allowing each cell to be inserted into the charge box at any time. Charge time control runs independently. This parallel multicharge system is implemented with n-times of the standard system (figure 30). For supply and synchronization of single systems, a separate transformer winding with a rectifier bridge is used.

Every single charge box is parallel and equal to the others. During the mains half-wave, only one system admits charge current. Due to the autonomous current regulation via phase control, the charge unit that needs the earliest firing point is activated. The other charge units remain currentless during the mains half-wave. For the rest of the time, the switched thyristor clamps the dc-voltage to cell current, so no other system can be activated.

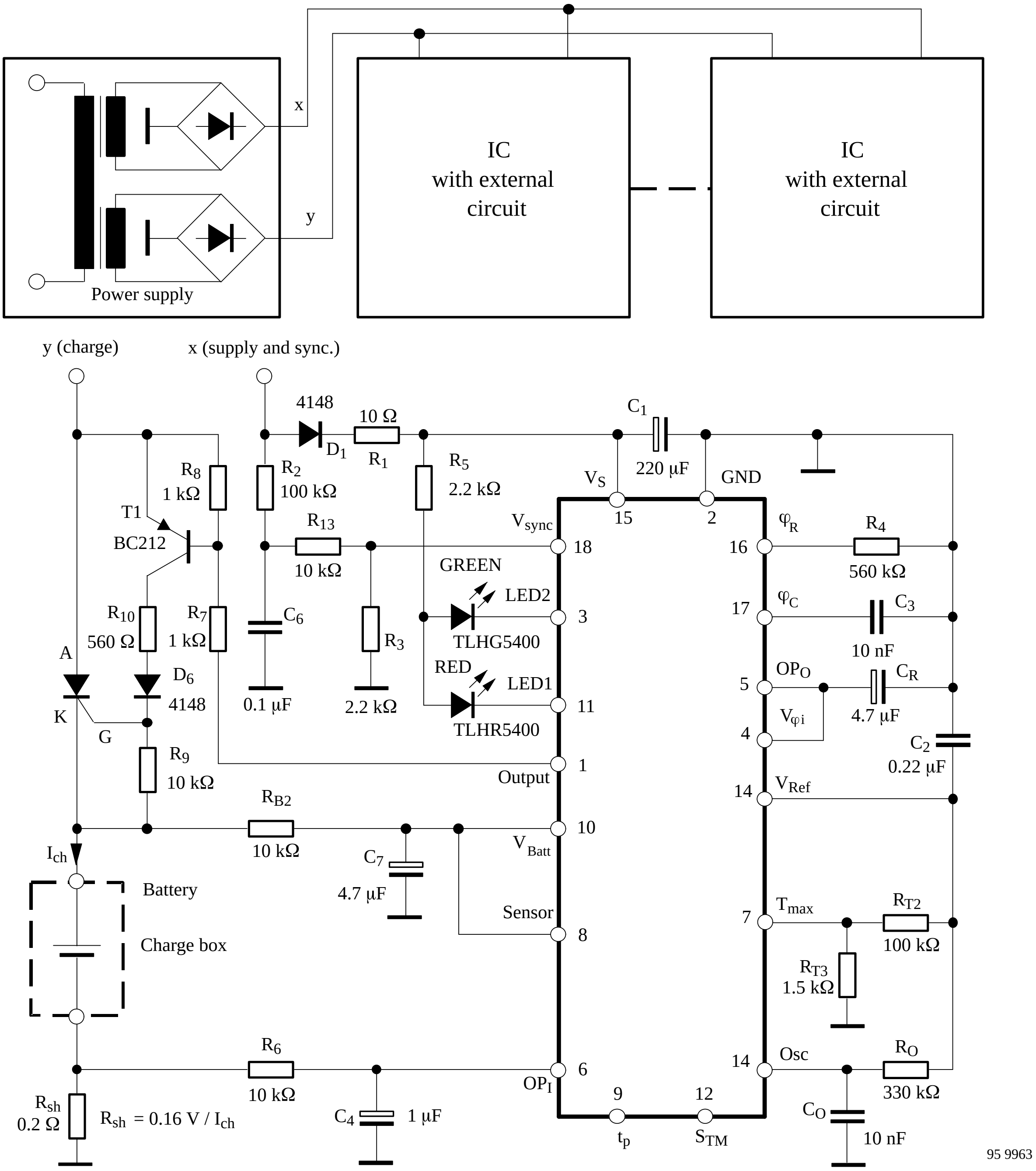


Figure 30. Parallel multicharge system for n × 1 NiCd/ NiMH cell 800 mA (U2402B/U2405B)

Linear Controller

Charge facilities powered from a dc source, such as a 12-V car battery or a 24-V auxiliary power supply system, require either a linear or a switch-mode controller to regulate the charge current.

The linear controller method is usually the least expensive, provided the higher power dissipation of the linear controller permits its use. This method does not require any expensive magnetic components such as smoothing or interference suppression chokes.

Figure 31 shows such an application which requires an additional NPN transistor (T_2) for inverting and level shifting. The internal phase control of the U2407B is not connected in this case, while the charge current detection and the internal error amplifier are used for current control in exactly the same way as in the standard application.

Battery detection with the pull-down method is possible in addition to the described method (see the section “Charging without Temperature Sensor”).

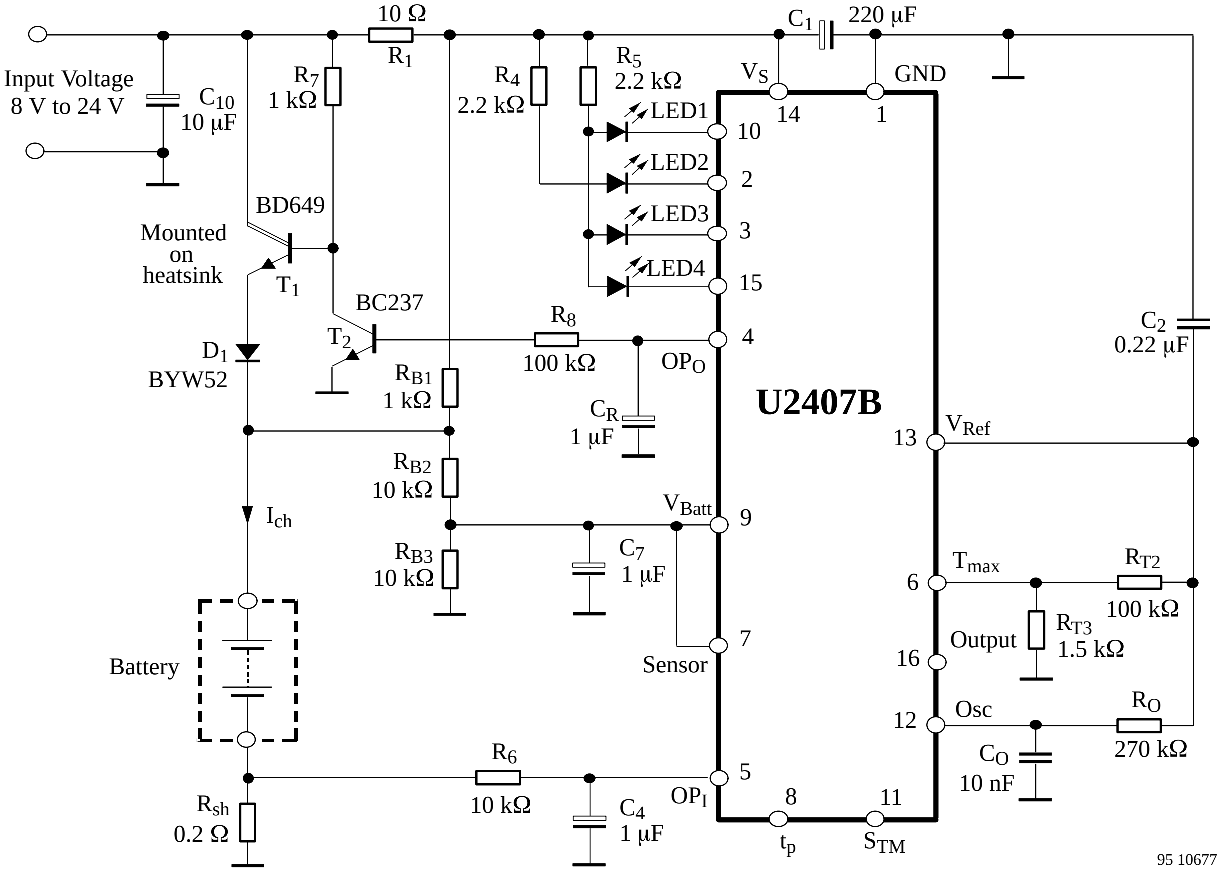


Figure 31. Linear charge controller for dc power supply without temperature sensor valid for 4 NiCd/ NiMH cells 800 mA

Switchmode Controller in Step-Down Conversion

High charge currents combined with a large voltage difference between the dc power supply and the battery to be charged demand the use of a switchmode IC to reduce the resulting power dissipation to a reasonable level. However, it should always be kept in mind that this approach is more expensive and may also cause more problems with regard to troubleshooting and certification.

The inductance of the required smoothing choke can be calculated with the following formula:

$$L = \frac{(V_{in} - V_{out}) \times V_{out}}{V_{in} \times dI_{out} \times f}$$

L (H)	Inductance
V_{in}(V)	Input voltage
V_{out}(V)	Output voltage
dI_{out}(A)	Ripple of the output current
f(Hz)	Switching frequency

Samples from “Pikatron” (Germany) have been used for internal tests in the following applications. If the switching frequency is kept below 20 kHz, the internal standard phase-control function component U2402B/ U2405B can be used in a switchmode design with little extra expense.

Figure 32 shows how simple chargers for the lower current range can be realized inexpensively. The components R_4 and C_3 determine the switching frequency. The maximum possible switching frequency is limited to approximately 20 kHz due to the internal circuitry of the U2402B/ U2405B, which is not primarily designed for switchmode applications.

Special charge applications for mobile phones in cars often require charge-current detection in the +lead of the battery due to the charge compartment design (see figure 32). An operational amplifier configured as a differential amplifier for charge-current detection is used especially for this purpose.

Charge systems for higher currents (> 2 A) require a significantly higher switching frequency to reduce the size of the choke and thus the costs (see figure 33). The LT1074 switchmode controller (step-down converter) or similar components are available in a TO220 package and permit an output current of 5 A with an internally fixed frequency of 100 kHz.

The U2402B/U2405B enables both charge-current detection and charge-current control. Charge monitoring is also included.

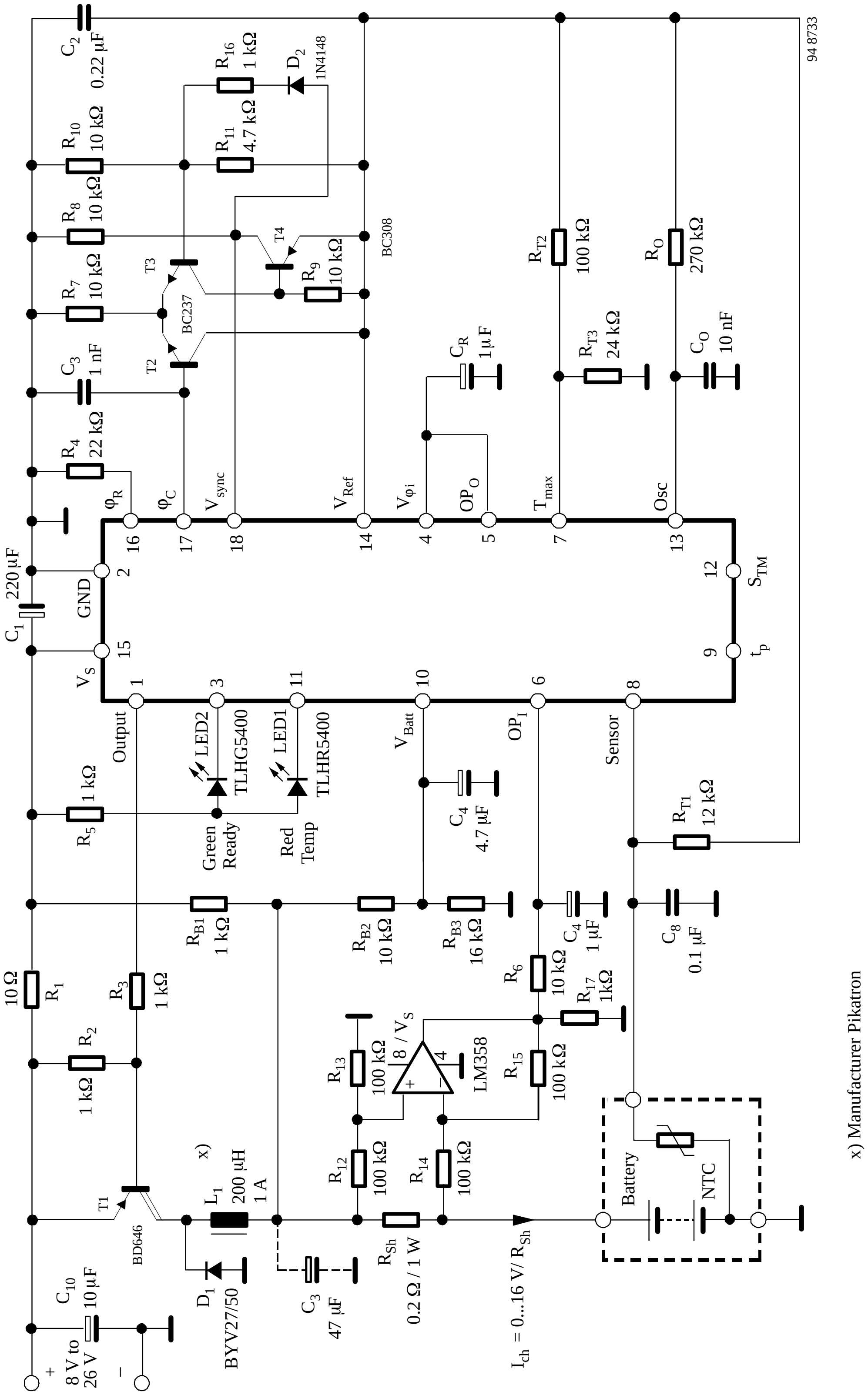


Figure 32. PWM switchmode charge concept for dc power supply in automotive applications with high-side current detection (U2402B/U2405B)

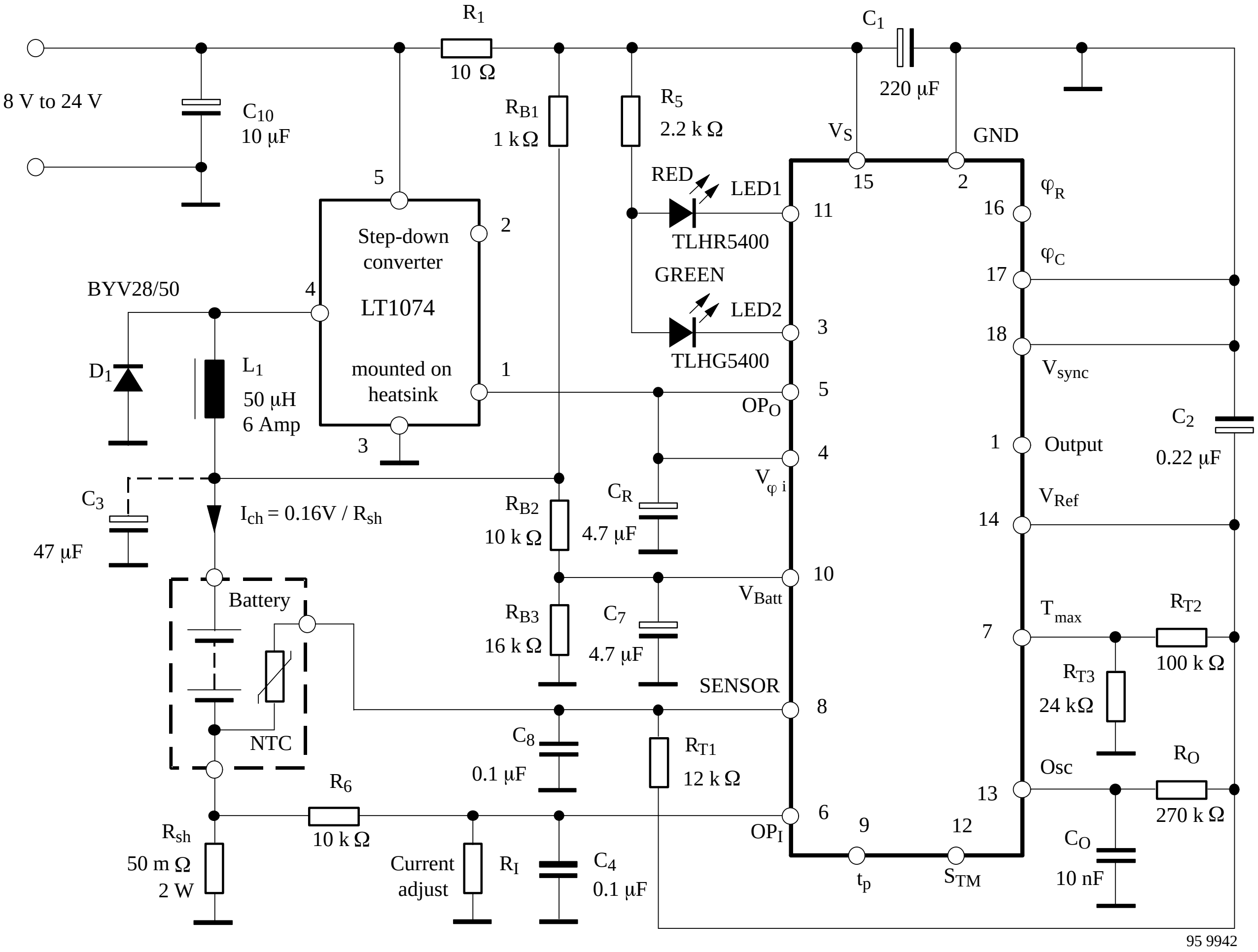


Figure 33. Charge concept with external switchmode controller valued for 4 NiCd/ NiMH cells (U2402B/U2405B)

Charge Systems with Safety Cut–Off

Universal chargers for various battery types often need a time-dependent forced cut-off. In addition, such a cut-off makes it possible to charge lead batteries with a time-controlled dc current.

An external standard CMOS timer 4060 controls the maximum charge time. At each charge start (power-on or battery detection), the timer is started again from RESET mode. If the cut-off criteria of the U2402B/ U2405B are invalid, the timer stops the charge process after 150% of the nominal charge time.

Short Functional Description

Timer reset starts when Pin 12 is logic “1”

- Dynamic reset via C_{10} at power-on
- Static reset via T_2 and D_7 when battery is removed

The charge cut-off by timer is given when the timer output Q_{13} changes to logic “1.” Q_{13} causes a phase shift via D_8 at input T_{max} of the U2402B-B, U2402B-C and U2405B. As a result, a charge cut-off with latch is initiated.

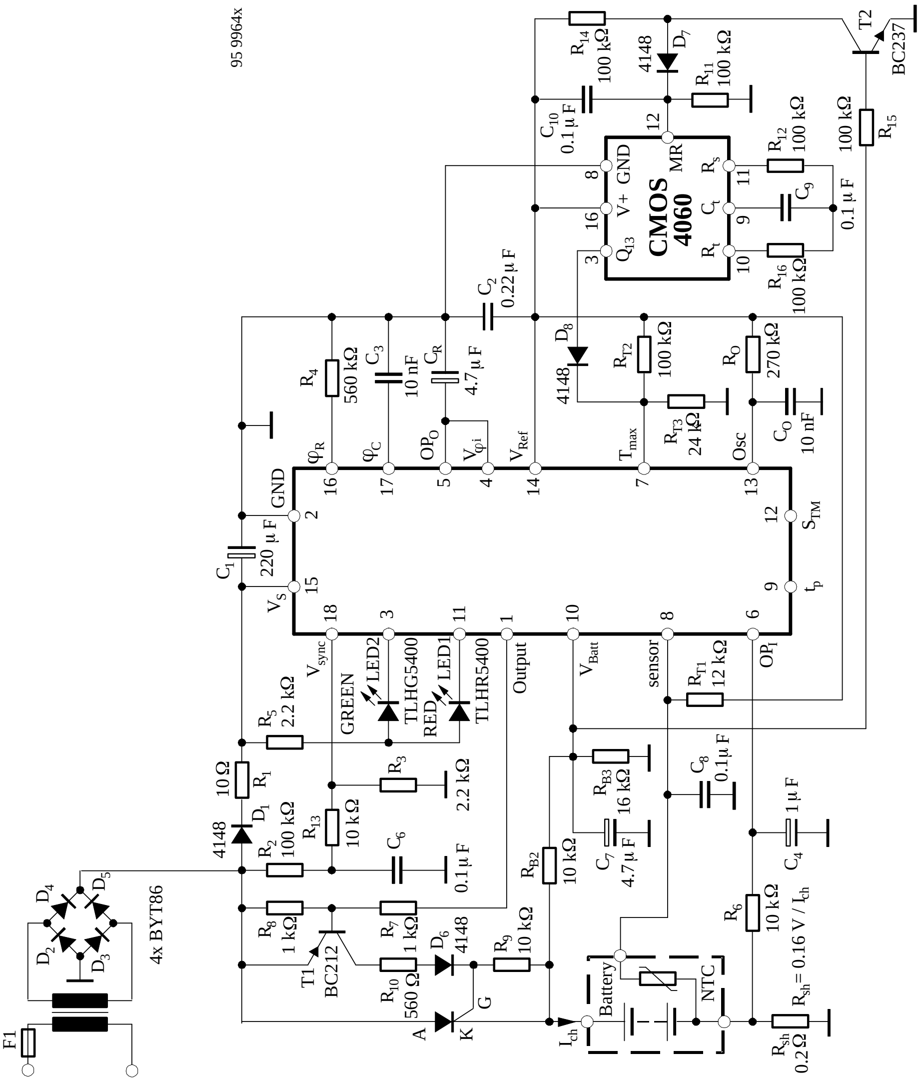


Figure 34. Standard application with safety cut-off (U2402B/U2405B)

Optional Battery Pre-Discharge

Normally, there is no direct necessity for active discharge in fast chargers with intelligent charge-interruption detection (as supported by the U2402B-B, U2402B-C and U2405B). Nevertheless, some customers occasionally require a “pre-discharge on demand” function to avoid a “memory effect”, or to reactivate the battery. As shown in figure 35, this requirement can be fulfilled with additional circuitry. The discharge circuit is activated by pressing the button S_1 and remains stored by the thyristor function T_6/ T_3. This switches on the discharge circuit T_2/ R_{20}, and the battery is charged at the current determined by R_{20}. T5 is conductive during the discharge phase and thereby keeps the controller in reset state via the V_{Batt} input. Discharging is interrupted when the voltage at divider R_{24}/ R_{25} is less than the sum of the voltages

V_{BE} (T_3) + V_{CE} (T4) + V(D_{10}) + V(D_{11}).

This cancels the reset state and starts the charge process automatically.

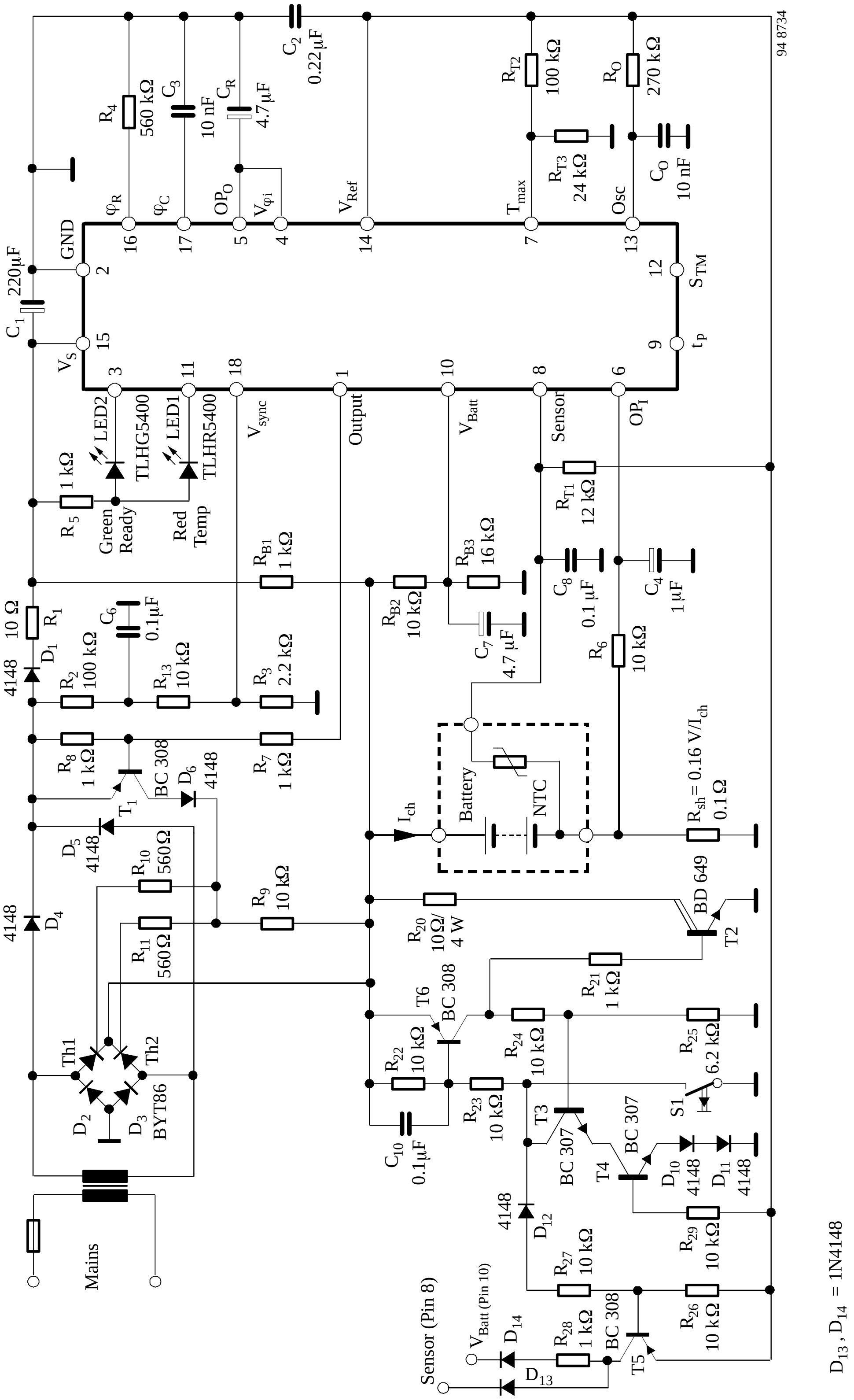


Figure 35. Standard charge application with discharging option (U2402B, U2405B)

Charge Disabling for Full Batteries

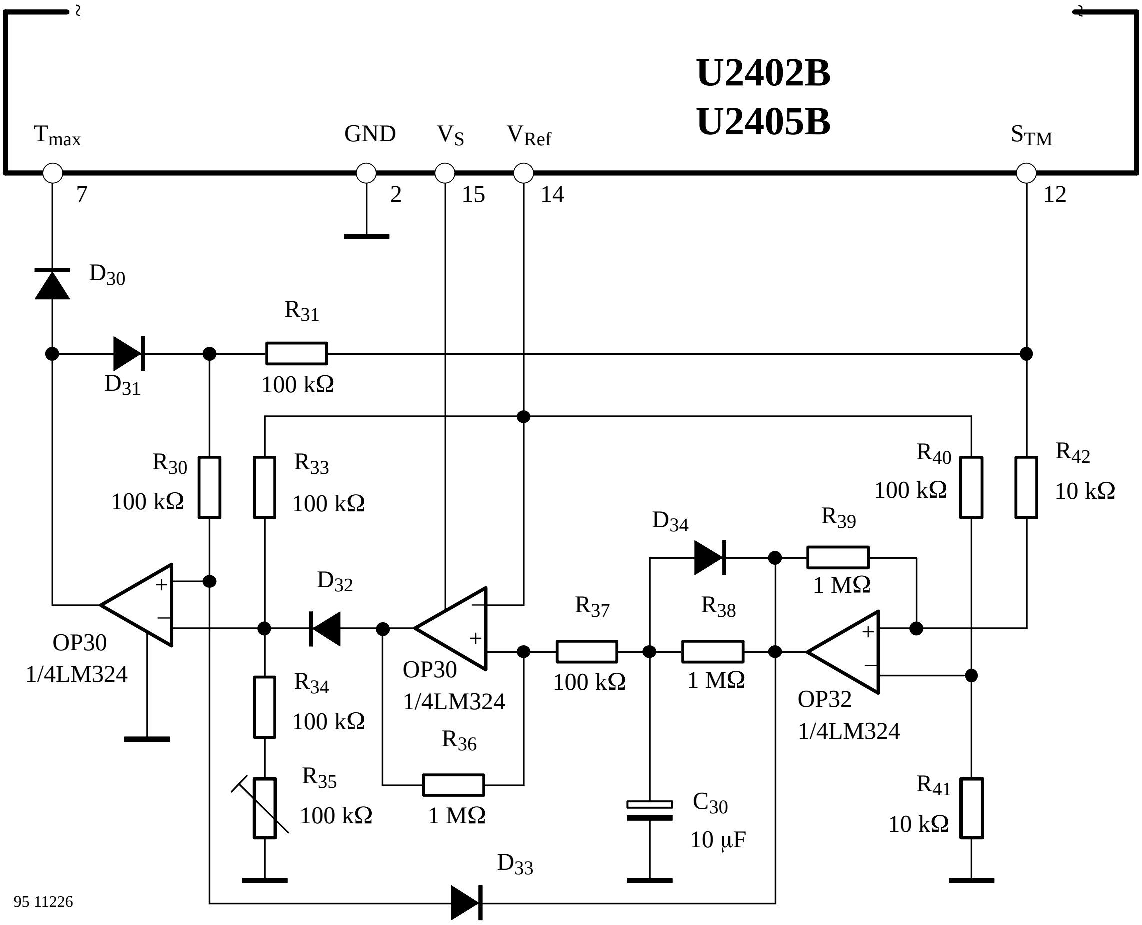


Figure 36.

This circuit, combined with the standard periphery of U2402B/ U2405B, prevents a re-start of the charge cycle if the battery is still in fully charged status. The battery voltage is monitored during a short time (ca. 10 s) after “battery insertion” or “power-on”. If the battery voltage is higher than a specified level during this time, the charge cycle will not start.

Function Description

When a battey has been inserted or power-on is present, the internal DA converter (TEST output Pin 12) increases according to the sampled V_{Batt} voltage Pin 10.

The comparator output OP32 switches to high level when the output crosses over the reference level R_{40}/ R_{41}. Capacitor C_{30} will be charged by time constant R_{38}/ C_{30}. Comparator OP31 compares the increasing capacitor voltage to the reference voltage at Pin 14. The delay time to reach the comparator threshold level defines the time window for the battery voltage check. As long as this reference level is not reached, the OP31 output is in a low state. It enables a battery voltage check which compares the adjusted reference level R_{33}/ (R_{34}, R_{35}) with the transmitted voltage from output by means of OP30. If the battery voltage represented by Pin 12 becomes higher than the reference voltage, the OP30 latches into high state. Charge termination is completed after the reset measurement cycle, which is caused by high state transmission to T_{max} Pin 7 by D_{30}. The charge disable is displayed through the red LED.

When the time window (10 s) is over, OP32 is switched to high state and overwrites the reference divider R_{33}/ (R_{34}, R_{35}) with D_{32} so that the battery voltage can never reach this level. This means the normal charge process will not be stopped by level indication.

Combined Charge System for NiCd/ NiMH and Li-Ion Batteries

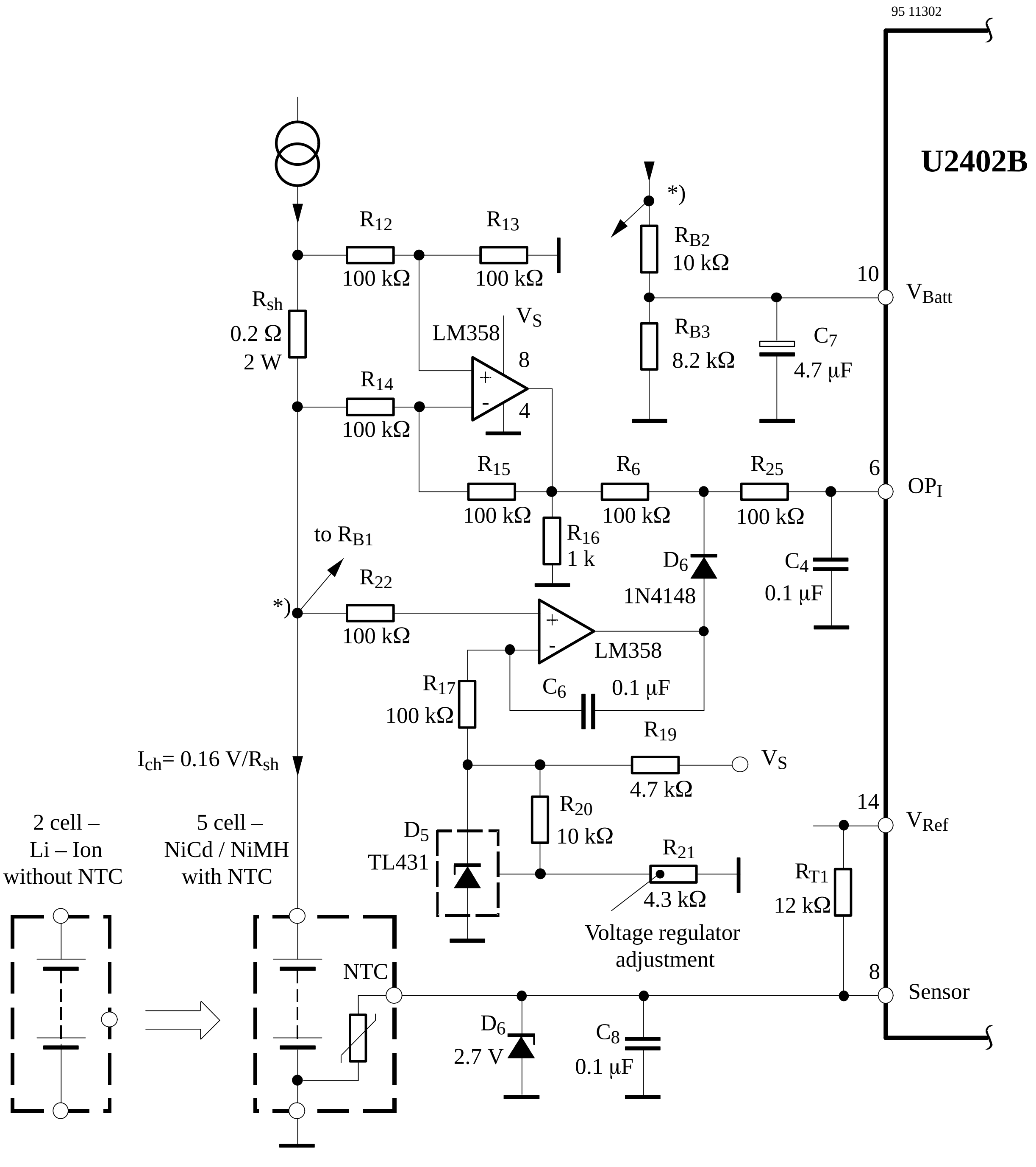


Figure 37.

The configuration of this application is for using the U2402B which is suitable for the fast charging of either 5 cell (NiCd/ NiMH) or 2 cell (Li-Ion) batteries respectively. An additional OP amp is used to control the maximum voltage (8.2 V) of the 2 cells Li-Ion battery. The system switches from current regulation to voltage regulation if the maximum voltage is reached during the charge procedure. Type detection is not necessary as long as the charge voltage of the NiCd/ NiMH-battery is lower than that of the Li-Ion battery. According to this condition the charge termination by slope detection is not attached if NiCd/ NiMH batteries are being charged.

When the Li-Ion battery is in charge status, the NTC contact is not connected. The Z-diode, D_4, is used to clamp the voltage at the SENSOR input, Pin 8, below the upper level of the temperature window. The reset function of the SENSOR input is fulfilled by the transistor, T_5, if the battery has been removed. In open mode, the voltage regulator output is in high level. This effects the on-state of T_5. Subsequently the SENSOR input is pulled down below the temperature level, whereas the reset function is achieved.

In the voltage regulation mode, the OP amp is configured as an integration regulator which compares the measured battery voltage with the corresponding setpoint. This is represented by a precise reference device D_5. The output of the operational amplifier dominantly influences the actual value of current detection by D_6. This means the charge control turns from current regulation mode to voltage regulation mode. In continuous charge, the regulator keeps the battery voltage constant, whereby the charge current drops below a minimum level or when the specified time has elapsed.

Charge Level Indication

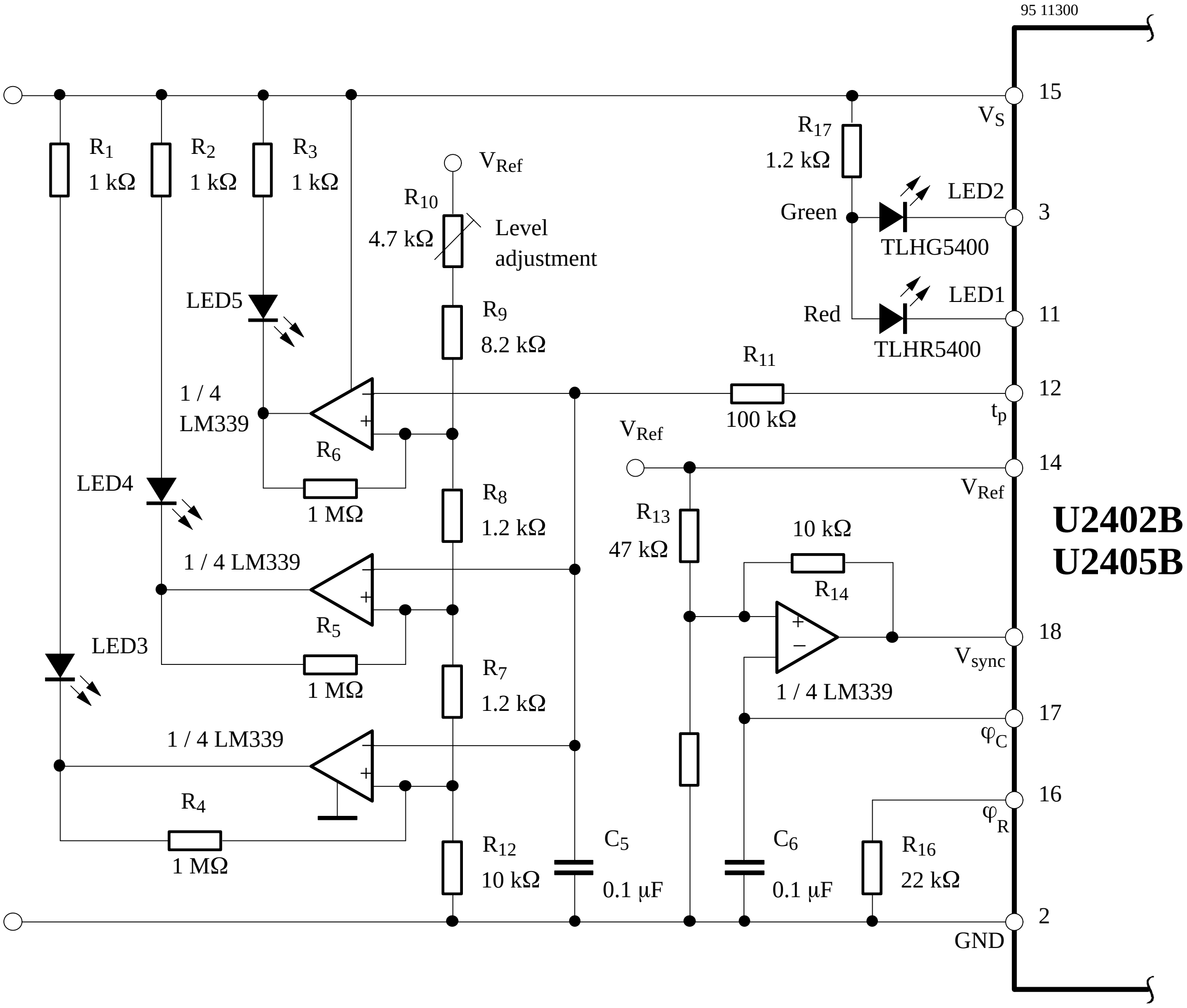


Figure 38.

This is an application for the U2402B and U2405B which enables the level indication of the capacity status during the charge cycle. As the resulting cell voltage is also affected by the charge current, the cell voltage measurement is performed without current to avoid a cell voltage modulation. The existing DA output (Pin 12) represents the measured voltage concerning this condition.

Circuit Proposal

- 100% level indication is displayed by steady on-state of green LED2 (Pin 3) when battery is inserted
- 25% level displays LED3, 4 and 5 inserted

A total adjustment for the common levels is achieved by R_{23}. The voltage step width, which indicates the 25%, 50% and 75% level, can be adjusted through R_{19}, R_{20}, R_{21}.

Cycled Discharge

Cycled discharging, I_{dis}, with a periodic negative pulse mode during the fast-charge cycle is sometimes used as a way of improving the capacity of NiCd/NiMH cells. TEMIC's measurements, as well as measurements by acknowledged experts, have shown that this function prooves to be of little value. Should it be required for any reasons at all, it can be simply implemented as shown in figure 39.

By using Pin 9 (charge break), a negative pulse is provided to implement this function. This configuration is shown in figure 39. It is up to the customer to create an optimum charge design.

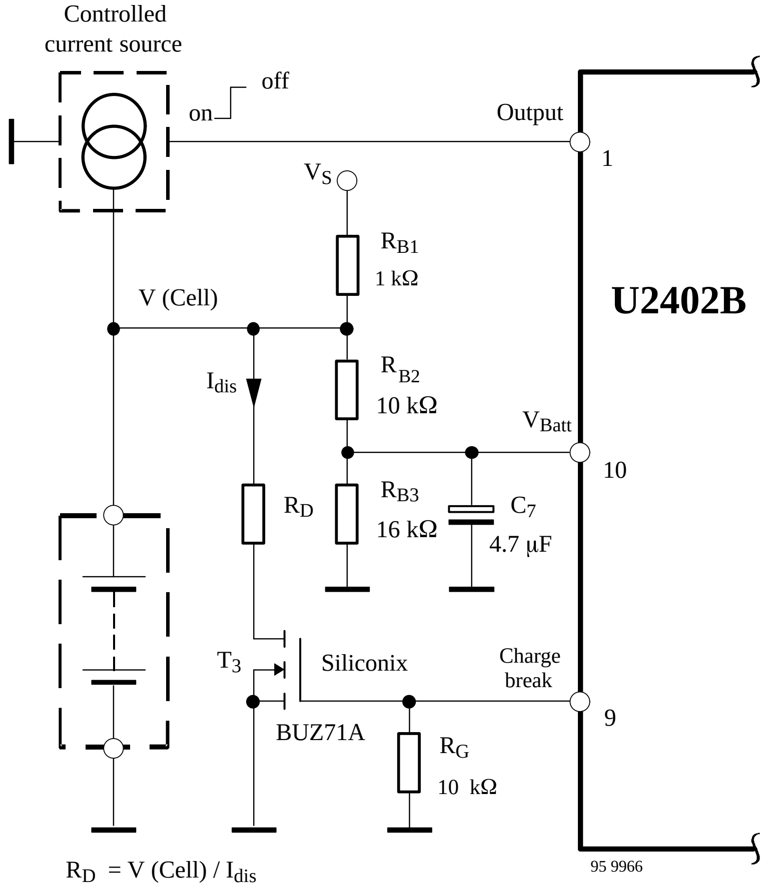


Figure 39. Application with cycled discharge

External Charge Current Source

If a constant charge is provided from an external source, such as a plug-in power supply unit, the U2407B-B is also responsible for switching off the power source during the measurement phase in addition to monitoring the batteries.

Figure 40 shows such a minimum solution without temperature sensor.

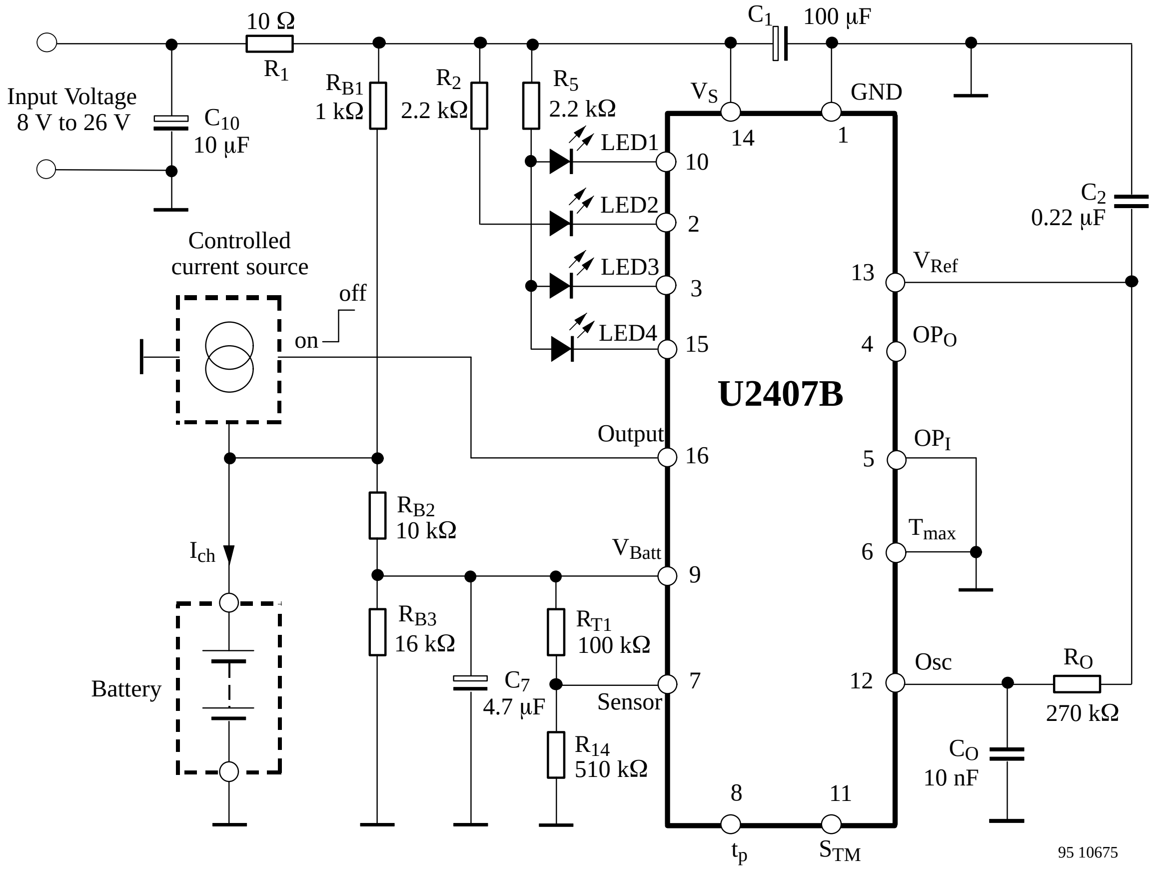


Figure 40. Minimum dc charge system with external power source

Charge-Discharge Mode for Mobile Phones

When using the U2402B/ U2405B in mobile applications requiring a charge-discharge mode, a specific circuit is necessary. Parallel operation during the charging is not allowed. However, if this were the case, the ac load caused by transmission mode would lead to an undesired charge termination during the running charge cycle.

The U2402B/ U2405B application circuit described in the following paragraphs is designed to be used for mobile phone applications where a Restart mode is initiated when the system transferes from Standby mode into Traffic mode (i.e., active mode) of the system. There are no switch criteria available to indicate the transmission from the Standby into the Traffic mode. For this reason, the related voltage drop-down effect of the battery voltage is used as a criteria to initiate the Reset function. A restart initiated by the Reset function is also achieved when the battery discharge end voltage has been reached.

Circuit Function

Comp1 compares V_{Batt} at Pin 10 with the last sample value of the DAC output (Pin 12). As the battery voltage at Pin 10 drops down below the voltage of the DAC caused by the load during transmission mode, Comp1 switches to “1” and generates a reset function.

To avoid noise interference generated by the charge current, the output of Comp1 is open for the duration of the charge-break indicator signal only. Therefore, Comp2 monitors the charge-break signal of Pin 9 – creating a logical AND-function together with Comp1.

Comp3 monitors the battery voltage of Pin 10 with regard to discharge shortage. It provides a “1” signal for reset generation in case of falling below the reference value. The dynamic pulse created by C_1 and the output of Comp1 are connected by T_1 and D_1 to a logical OR function. The dynamic pulse signal is sampled by C_2 as the peak value and discharged by R_2 in a defined way. Comp3 generates a charge reset at the V_{Batt} input Pin 10 for a defined time duration.

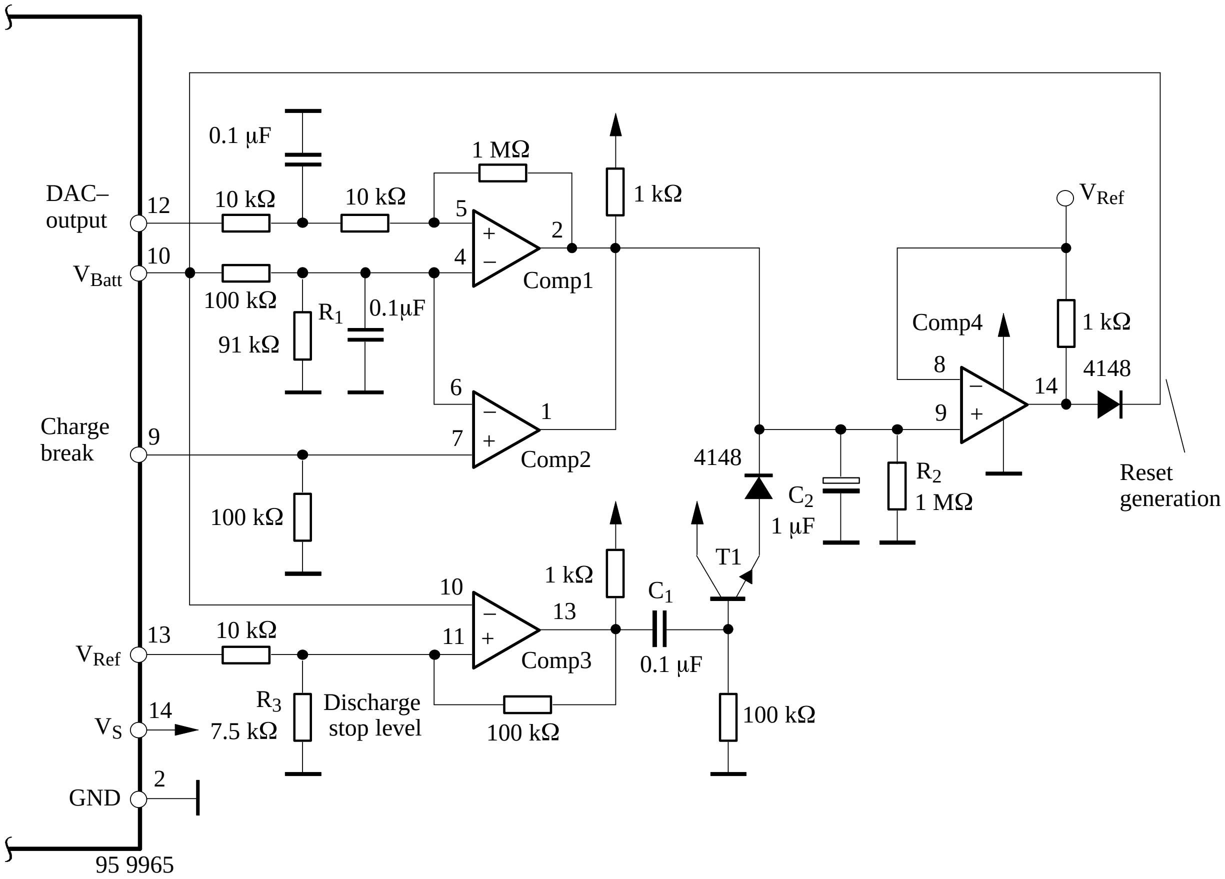


Figure 41. Traffic mode circuit

Primary Switchmode Systems

In conventional charge systems, 50-Hz to 60-Hz power transformers are normally used for power transformation and for galvanic isolation between the mains and the charge circuit. Due to the volume- and weight ratio, power transformers are applicable up to 20 VA.

In the case of higher power ranges, such as for 10-minute chargers or for space-saving units such as power plugs, only primary switchmode power supplies are used.

Energy conversion as well as galvanic isolation are realized by a special ferromagnetic transformer. Samples from “Pikatron” (Germany) have been used for internal tests. Figure 42 shows the simplest example, a single-ended flyback converter. In this application, the phase-control function is not used. The control IC has to monitor the charge process, as well as to detect and regulate the charge current. All designs that do not use the phase control of U2402B can utilize the less expensive U2407B-B (SO16).

Power regulation for the charge current supply is managed by a standard primary switchmode power supply with PWM “current mode” IC Si9120 from Siliconix. In corresponding configurations, other PWM circuits, such as the MC3843 can be used.

The set point for PWM power control Pin 15 is a result of the control amplifier output (Pin 5) of the charge controller. This value is transmitted via the optocoupler. For the measurement of currentless battery voltage, Opam cuts off the Si9120 during the necessary time duration.

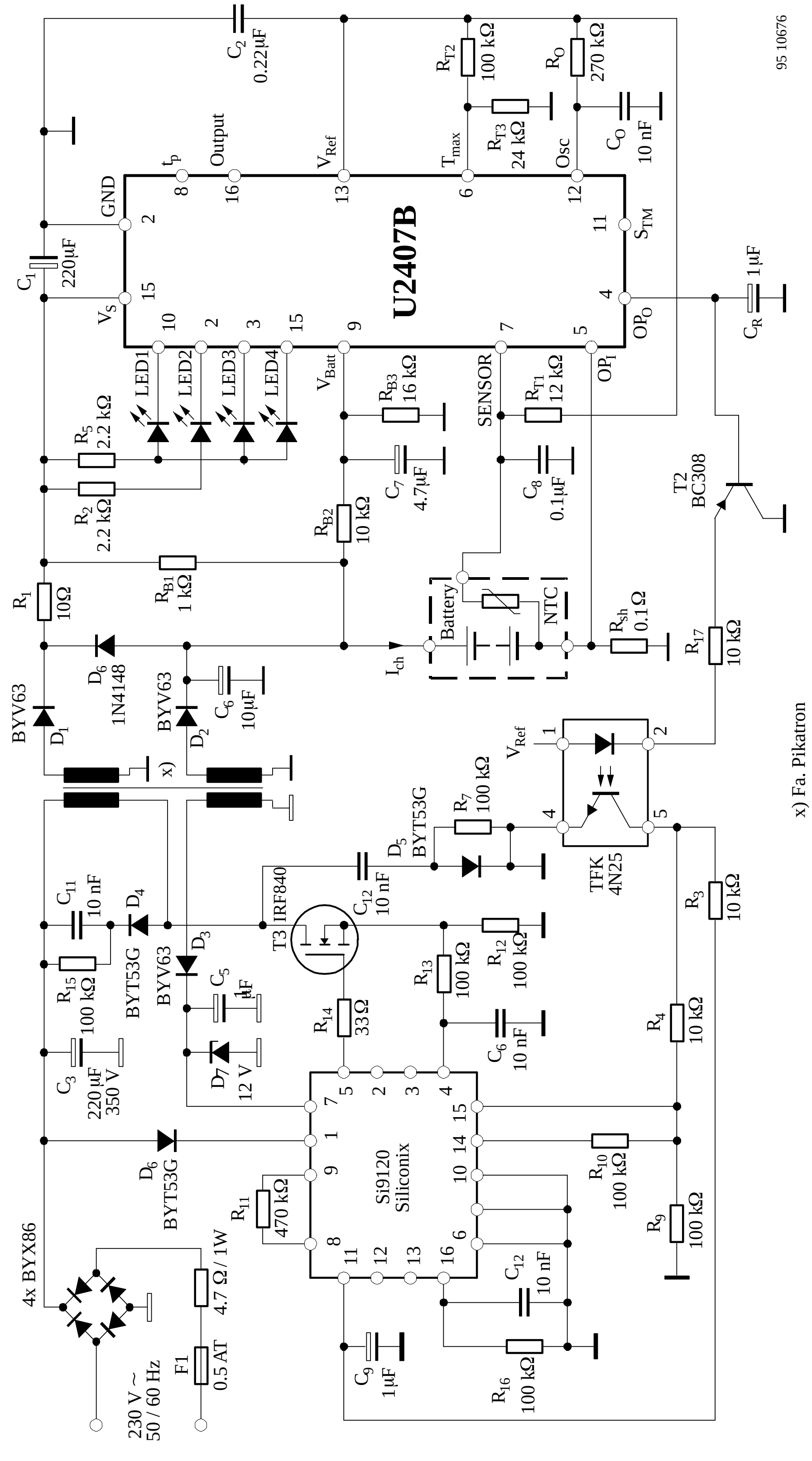


Figure 42. Primary switchmode system

Charging of Batteries with Automatic Pre-Discharge

Description

The monolithic integrated circuit, U2400B, is a bipolar circuit, designed for automatic recharging of NiCd/ NiMH batteries. It has controlled and defined charging characteristics for different charging sequence with subsequent trickle charge operation. The long life – Memory Effect – of the recharging cell remains intact.

Features

- Three time selections:
  0.5 h, 1 h or 12 h with subsequent trickle charge operation
- Battery temperature and contact monitoring
- Charging interrupt for overvoltage or excessive temperature
- Automatic pre-discharge possible
- Separate charge- and discharge outputs
- Pulse-width modulation facility of charge- and discharge current for matching to transformer or battery data
- Timer clock via mains or internal oscillator
- Reference voltage source
- LED-status output for mode indication

Case: DIP 16, SO 16

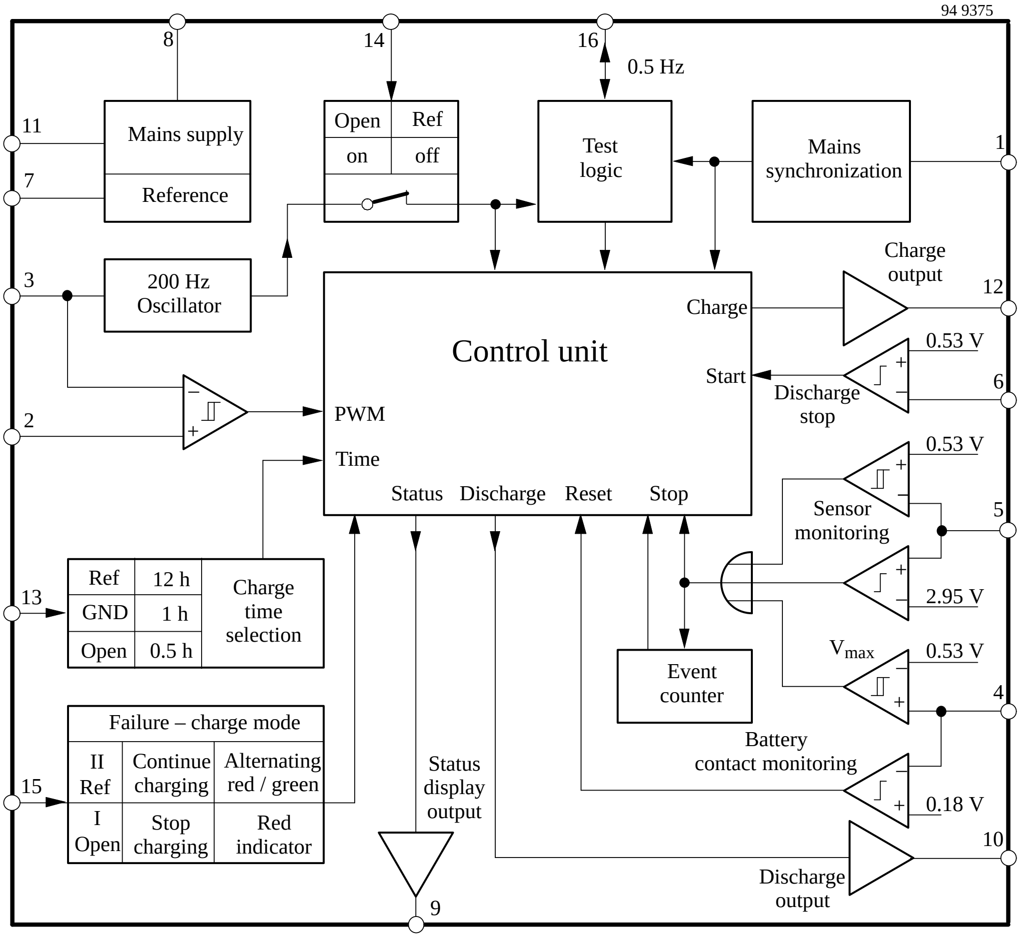


Figure 1. Block diagram

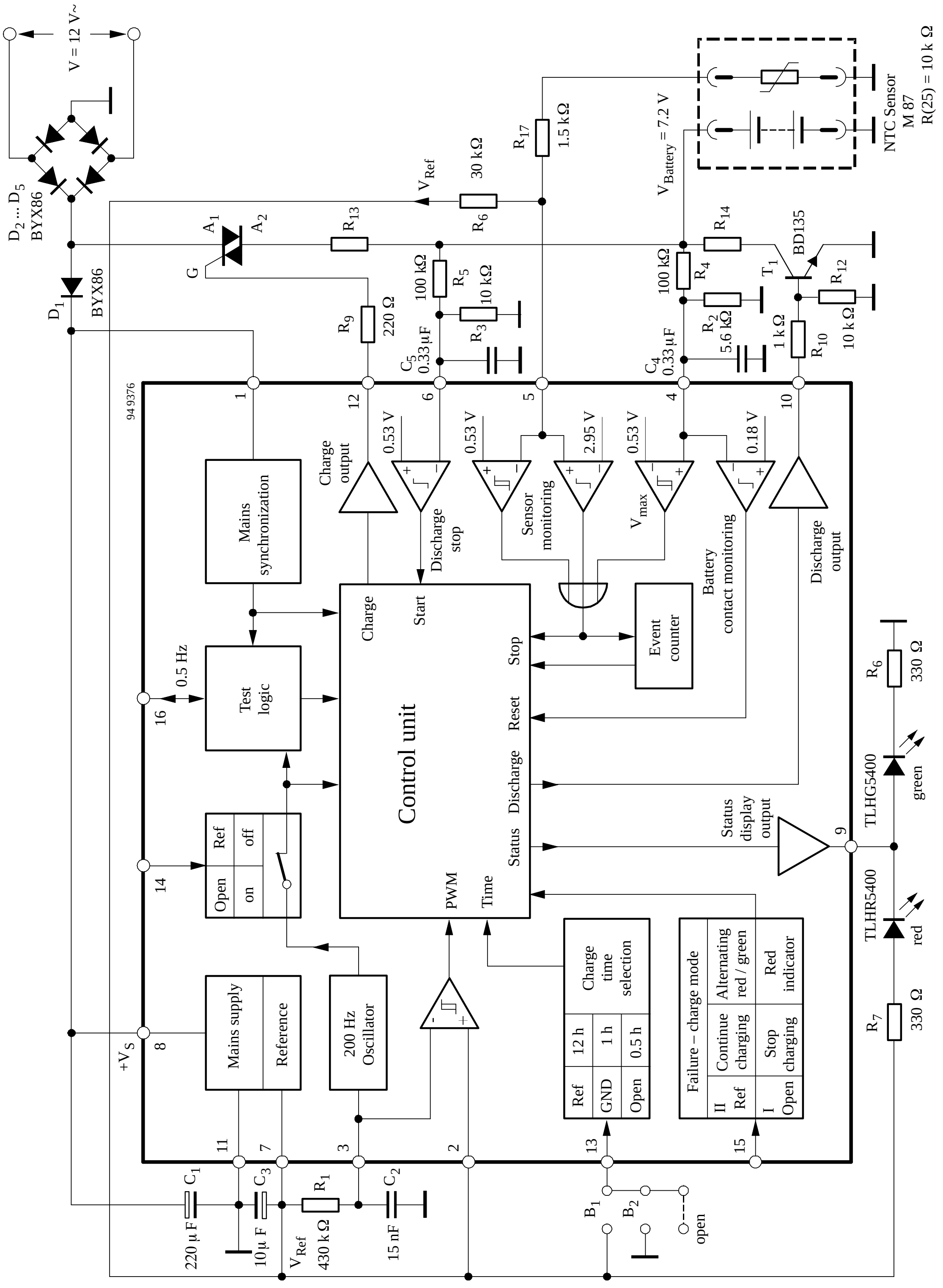

V = 12 V~
$D_2 ... D_5$
BYX86
D_1
BYX86
A_1
A_2
G
R_{13}
R_9
220 Ω
V_{Ref}
R_6
30 kΩ
R_{17}
1.5 kΩ
R_5
100 kΩ
R_3
10 kΩ
C_5
0.33 µF
$V_{Battery}$ = 7.2 V
NTC Sensor
M 87
R(25) = 10 k Ω
R_{14}
BD135
T_1
R_{12}
R_4
100 kΩ
R_2
5.6 kΩ
C_4
0.33 µF
R_{10}
1 kΩ
10 kΩ
94 9376
1
12
6
5
4
10
Mains synchronization
Charge output
0.53 V
Discharge stop
0.53 V
Sensor monitoring
2.95 V
0.53 V
V_{max}
0.18 V
Battery contact monitoring
Discharge output
Event counter
Charge
Start
Stop
Reset
Discharge
Status
Control unit
PWM
Time
16
0.5 Hz
Test logic
14
Open
on
Ref
off
+V_S
8
Mains supply
Reference
200 Hz Oscillator
Charge time selection
Ref 12 h
GND 1 h
Open 0.5 h
Failure – charge mode
II Ref Continue charging Alternating red / green
I Open Stop charging Red indicator
Status display output
9
R_6
330 Ω
TLHG5400
green
TLHR5400
red
R_7
330 Ω
11
7
3
2
13
15
C_1
220 µ F
C_3
10 µ F
V_{Ref}
R_1
430 k Ω
C_2
15 nF
B_1
B_2
open

Figure 2.

General Description, Figures 2 and 3

The integrated circuit, U2400B, supports specially the controlled and defined charging of fast NiCd cells. Varieties of charging time selections i.e., standard charge (12 h), quick charge (1 h) or fast charge (0.5 h) are possible.

Before the charging begins, cell is discharged completely. In this way, the long life − Memory Effect − of the recharging cell remains intact. Surveillance is taken over by control unit for time, thermal and voltage during the charging and switch-off when the specified capacity is attained. When switched on, the red LED connected to the display output (Pin 9) is activated if no battery is connected. When a battery is inserted with a minimum voltage of approximately 180 mV at Pin 4, the pre-discharge phase is then started with a 2 seconds delay. Discharge output at Pin 10 is activated, which is indicated by the flashing red LED, shown in figure 5. The discharge procedure is stopped with a voltage less than 530 mV (at Pin 6). The following charge phase (charge output Pin 12 active) is indicated by the flashing green LED (Pin 9).

After the programmed charging period (Pin 13: 0.5 or 1 h continuous charge, or 12 h pulsed charge) the trickle charge phase is reached (figure 4). This trickle charge mode is indicated by the constant green LED. This means, the battery has stored the maximum possible amount of energy. The outputs − display, discharge and charge − will be set inactive (by temperature, overvoltage), and the timer clock is interrupted during all two phases and in each mode, when a limit value (Pins 4 and 5) is exceeded.

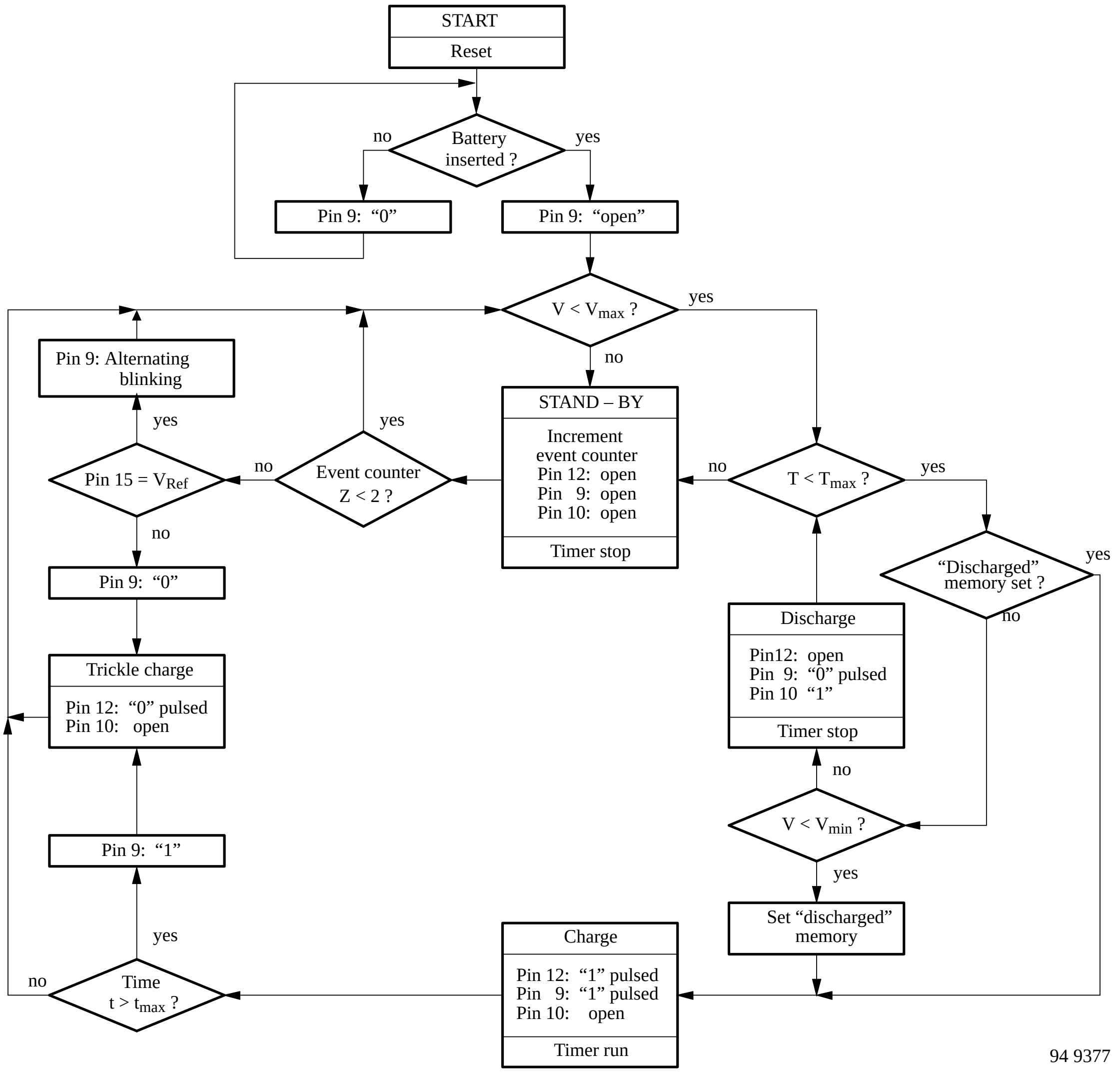


Figure 3. Flow chart

A two-stage event counter will be incremented with each limit value violation. If the event counter stores two interruptions, subsequent behaviour is determined by the programming at Pin 15:

- An open circuit at Pin 15 means that the actual mode has to be cancelled after 2 limit value violations. This is indicated by a flashing red display.
- If the IC's internal reference voltage (Pin 7) is connected to Pin 15, only the display mode changes: alternating red-green flashing. After the limit value violation has elapsed, the IC attempts to make up for the remaining charging period so that the maximum possible residual capacity will be made available even if a battery is already damaged.

The timer clock for programmable charging period and other internal clocks is obtained either from the internal 200 Hz oscillator, figure 6, or from the external mains synchronization (figure 7). Figure 8 shows that an external timer clock (via Pin 16) for deviating charging periods is possible. In this case the internal oscillator or mains synchronization must be activated to clock the control unit.

The negative input of a pulse-width modulator (PWM) is connected to the ramp oscillator (Pin 3). Pin 2 provides the positive input for this comparator (figure 9).

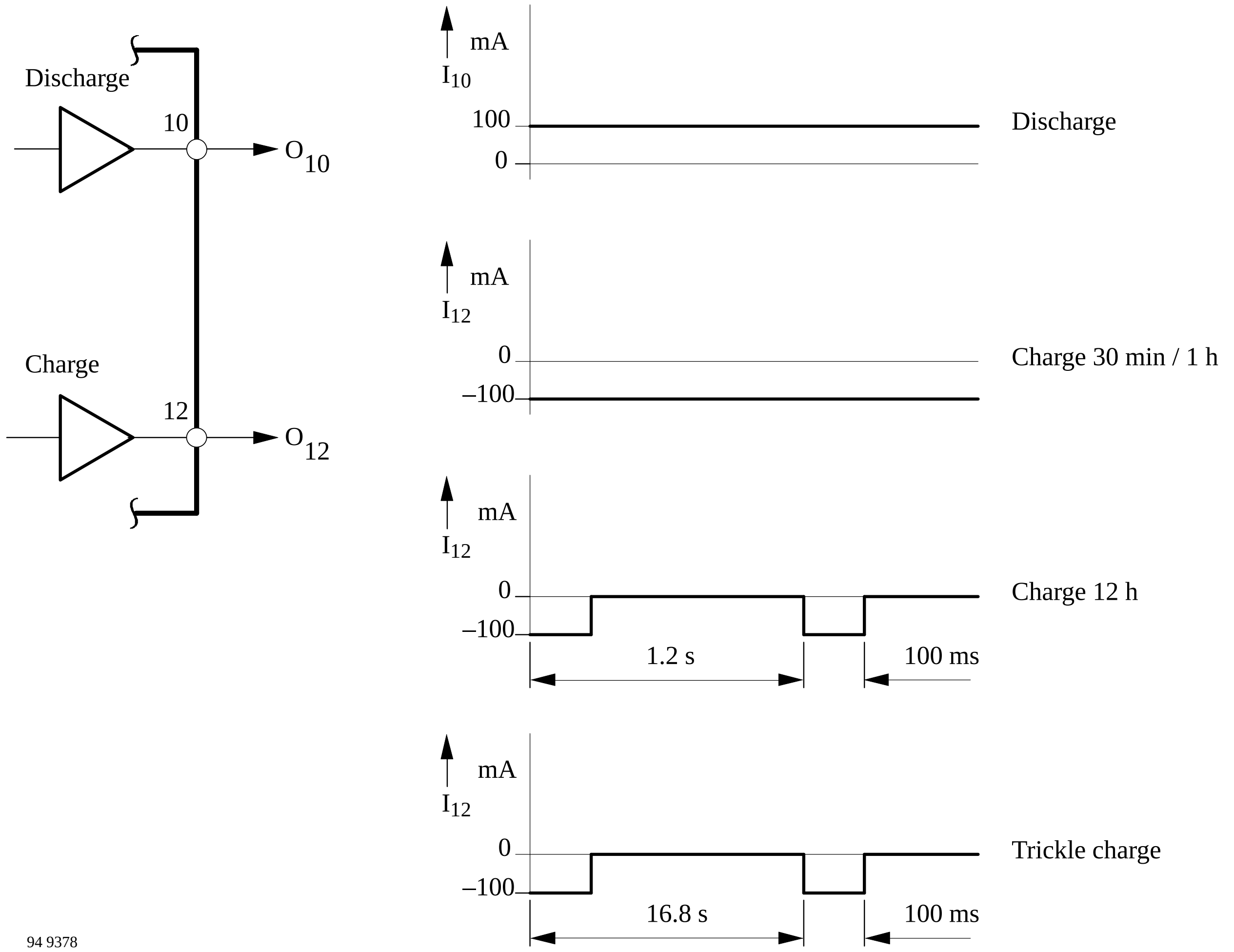


Figure 4. Discharge, charge outputs

If a dc voltage in the range of 0.9 to 2.1 V is supplied to comparator positive input (Pin 2), the discharge and charge outputs are deactivated as soon as the oscillator’s saw-tooth voltage (Pin 3) exceeds the dc voltage at Pin 2 (figures 9, 10 and 11). This pulse-width modulation effects the active discharge and charge output in each mode – discharge, charge or trickle charge. This offers the possibility of matching the r.m.s. current to various battery capacities by means of a switchable voltage divider.

Pin 14 must be connected to reference voltage Pin 7, if the internal clock signals are derived from the mains synchronization input Pin 1 with simultaneous pulse-width modulation. The oscillator can then be used deviating from 200 Hz.

As soon as a battery is removed, the red LED is active (= no contact). A total pause of approximately 2 seconds must be given between removing the charged battery and inserting a new battery to inform the IC that the inserted battery is to be charged.

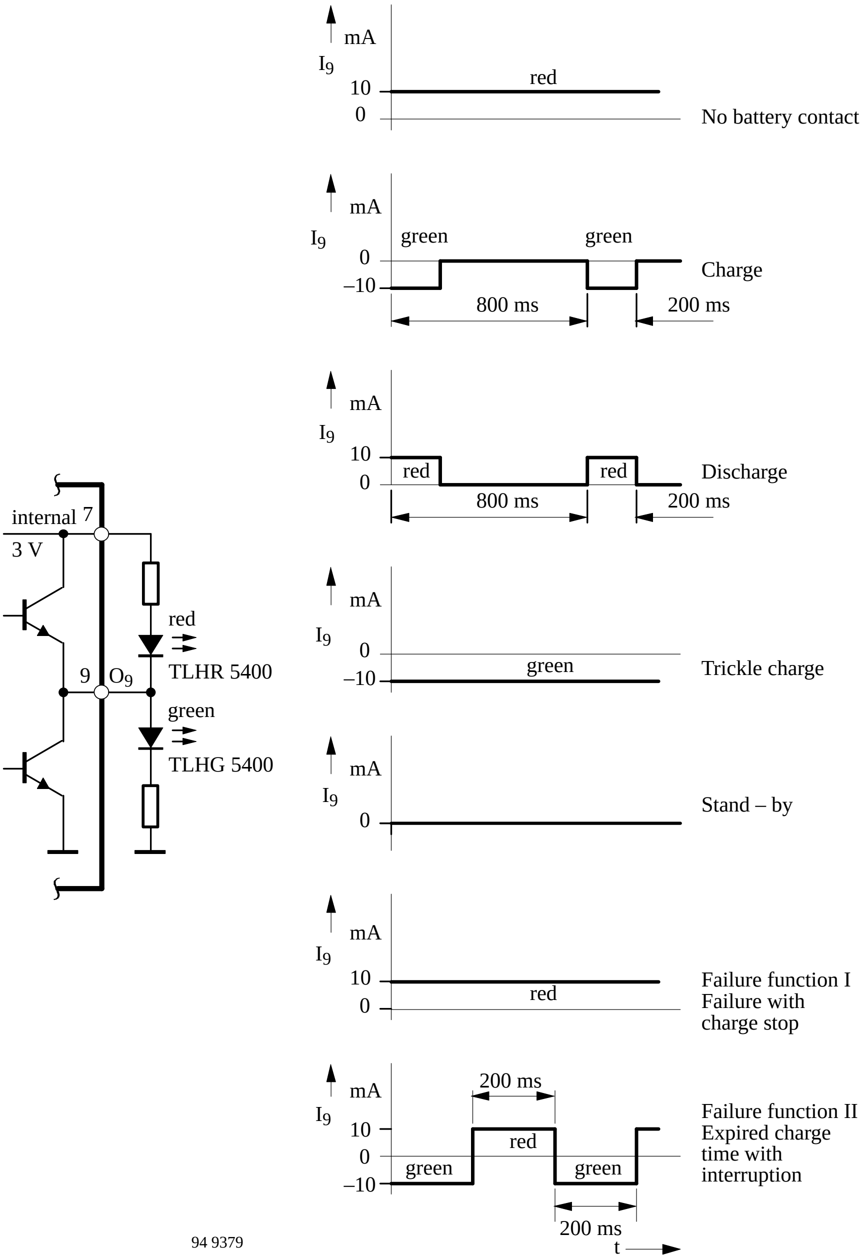


Figure 5. Status display output

Clock generator

Timer clock can be realised either by the internal 200 Hz oscillator or with mains sync. of 50 Hz. In addition to that, there is a possibility of external timer clock input via Pin 16 (figure 8).

a) 200-Hz oscillator

Figure 6 shows the typical circuit for 200 Hz oscillator. C_1 is meant for ripple smoothing of the mains supply.

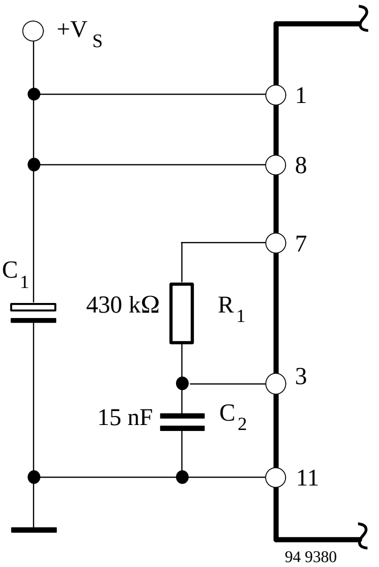


Figure 6. 200-Hz oscillator

b) Mains synchronisation

Mains synchronisation is shown in figure 7.

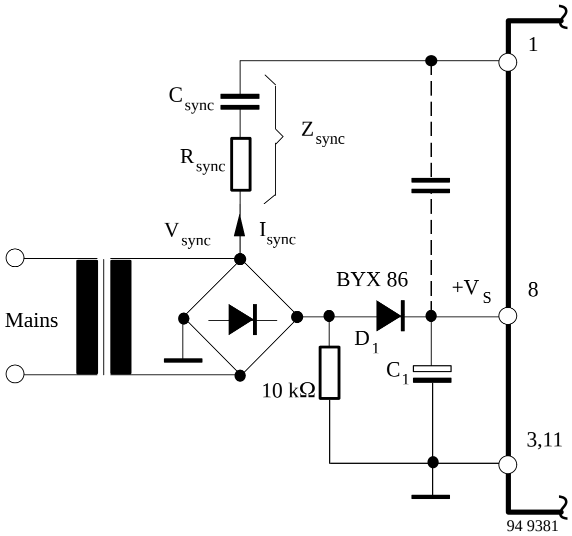


Figure 7. Mains synchronisation

Given below is the dimensioning of the circuit.

$$Z_{sync} = \sqrt{\left(\frac{1}{2 \cdot \pi \cdot f \cdot C_{sync}}\right)^2 + R^2_{sync}}$$

where f = mains frequency

$$Z_{sync(min)} \geq \frac{2 \cdot \hat{V}_{sync}}{I_{sync(max)}} = \frac{2 \cdot V_{sync\,(peak)}}{10\ mA}$$

$$Z_{sync(max)} \leq \frac{0.8\ V}{I_{sync(min)}} = \frac{0.8\ V}{30\ \mu A}$$

$$\text{i.e.,}\ \ C_{sync} = 0.15\ \mu F;\ \ R_{sync} = 15\ k\Omega$$

c) External timer clock input

For a fixed internal timing (battery contact monitoring, flashing frequency red/ green), an oscillator frequency of 200 Hz is necessary. There is a possibility of mains synchronisation via Pin 1. In case of mains synchronisation, the oscillator must be separated from the clock logic (Pin 14 connected to V_{Ref}).

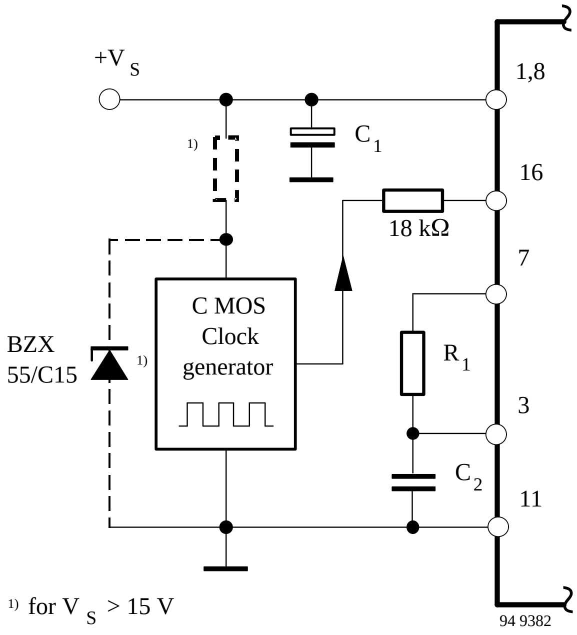


Figure 8. External timer clock input, Pin 16 for different charging times

Pulse Width Modulation (PWM)

There are two separate inputs to PWM comparator. Positive lead is available at Pin 2, whereas negative lead is connected directly to the oscillator as shown in figure 9.

A dc voltage in the range of 0.9 to 2.1 V at the comparator input Pin 2, switches-off the charge and discharge outputs, when the oscillator ramp voltage at Pin 3 has a higher value than the applied voltage at Pin 2.

PWM is operating independent of discharge, charge or trickle mode. The effective current requirement for the different battery types of same voltage can be maintained by voltage ratio given below:

$$R_{11} = R_{12} \cdot \frac{V_2}{V_7 - V_2}$$

Recommended current range is 20 to 200 µA.

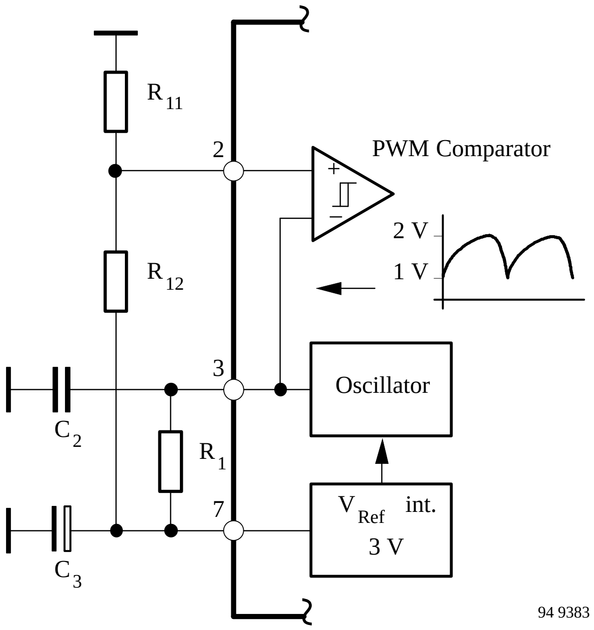


Figure 9. PWM comparator input voltage circuit for different cell capacities

In case, the internal clock signal is generated via mains synchronisation at Pin 1, then Pin 14 should be connected to Pin 7. The oscillator circuit frequency at Pin 3 can be selected now deviating from 200 Hz.

Figure 10 shows pulse diagram of PWM with respect to discharge and charge output currents, whereas figure 11 represents its ratio respecting voltage at Pin 2.

Programming Inputs

Pin 14

The internal clock signal can be derived either from the mains sync. circuit or from the autonomous oscillator. Internal oscillator clock disconnection is achieved with Pin 14 (figure 7).

Oscillator clock disconnected, when Pin 14 is connected to Pin 7 (ref.).

Oscillator clock connected, when Pin 14 is grounded (Pin 11) or open.

When oscillator clock is connected, then it is the timer clock.

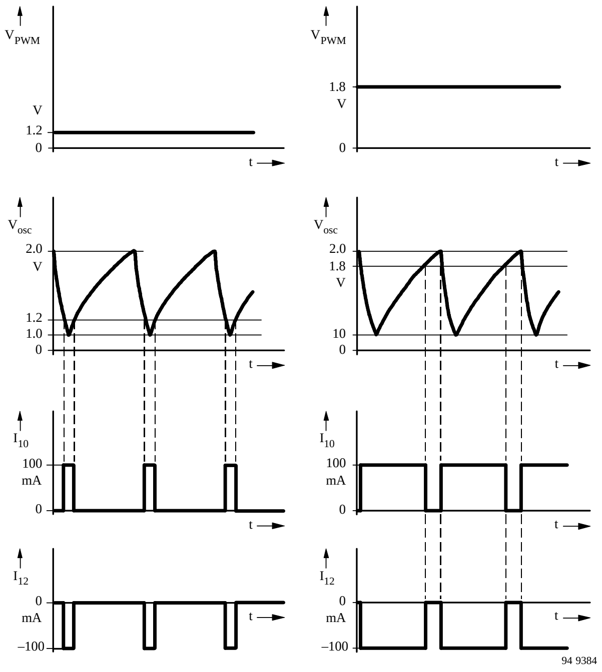


Figure 10. Pulse sequence for PWM circuit of figure 9

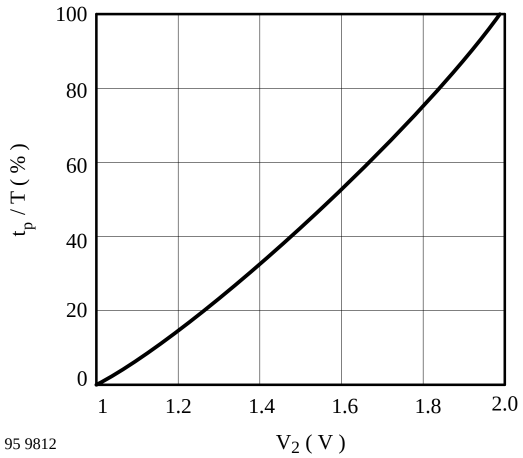


Figure 11. Duty cycle of PWM circuit of figure 9

Pin 15

There are two failure-function-possibilities.

Failure Function I I_{15} = 0 or 0 to 0.8 V

Trickle charge function comes into operation, if two events have occured (temperature and/ or overvoltage).

Display mode: red blinking.

Failure Function II V_{15} = 2.4 to 3.0 V

The display mode will be changed after two events. Charging time will continue after each failure event.

Display mode: alternating red/ green flashing

Discharge Stop Comparator figure 12

Comparator turns off the discharge process when $V_6 \leq V_{T6}$, i.e., the specified discharge voltage of the cell is attained.

The following realtaionship is valid:

$$R_3 = R_5 \cdot \frac{V_{T6}}{V_B - V_{T6}}$$

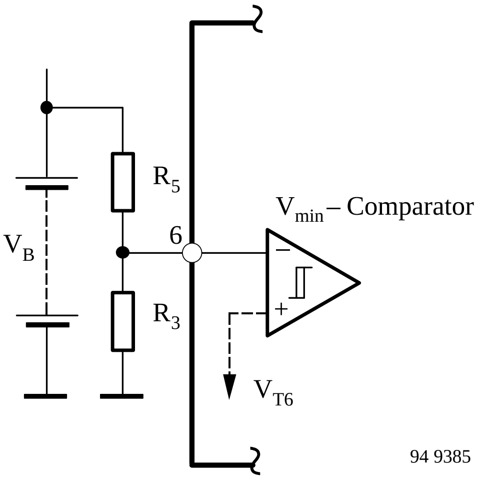


Figure 12. Comparator threshold dimensioning circuit

V_{max}-Comparator figure 13

Comparator interrupts the discharge and charge outputs when $V_4 \geq V_{T4max}$.

The following relationship is valid:

$$R_2 = R_4 \cdot \frac{V_{T4max}}{V_B - V_{T4max}}$$

Current flow for voltage divider (R_4, R_2) should be selected so that the trickle charge (1/180 of one hour charge) should not lead to the discharge of the battery. Take care that the input stand-by current of the comparator is less than one-tenth of divider current.

Recommended idle divider current ≥ 20 µA.

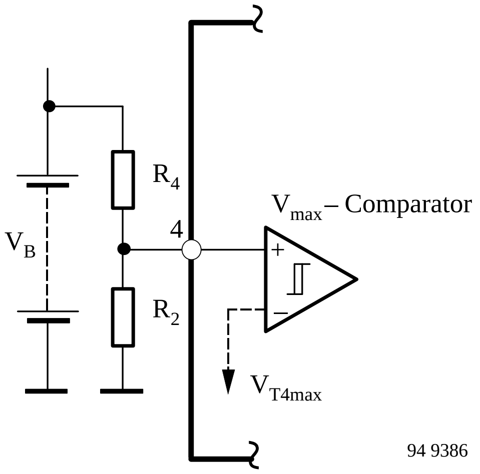


Figure 13. V_{max}-comparator circuit

Temperature comparator figure 14

This comparator interrupts the discharge and charge outputs when $V_5 \leq V_{T5min}$.

The following relationship is valid:

$$R_6 = \frac{V_{Ref} - V_{T5min}}{V_{T5min}} (R_{NTC} + R_{17})$$

R_{NTC} is calculated at 45°C.

To avoid the necessary loading of the internal reference source voltage, idle current is recommended in the range of 20 µA to 2 mA.

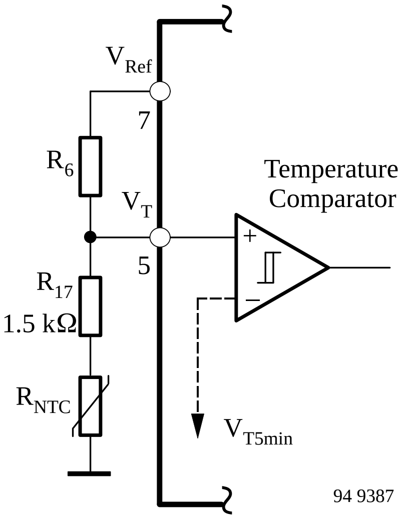


Figure 14. Temperature comparator

Absolute Maximum Ratings

Reference point Pin 11, unless otherwise specified

Parameters		Symbol	Value	Unit
Current requirement	Pin 8 t ≤ 10 µs	I_S	30 150	mA
Supply voltage	Pin 8	V_S	26.5	V
Output voltages				
Charge output	Pin 12	V_{12}	27	V
Discharge output	Pin 10	V_{10}	$V_S + 0.5$	V
Display output	Pin 9	V_9	6	V
Synchronisation:	Pin 1			
V_{sync}		V_1	$V_S \pm 2$	V
$\pm I_{sync}$		I_1	10	mA
Input voltages:	Pin 2 to 6 Pin 14 to 16	v_i	6 6	V
Reference output current	Pin 7	$-I_{Ref}$	20	mA
Time selection voltage	Pin 13	V_{13}	3	V
Power dissipation	T_{amb} = 45°C T_{amb} = 85°C	P_{tot}	0.8 0.4	W
Storage temperature range		T_{stg}	– 40 to +125	°C
Ambient temperature range		T_{amb}	–10 to +85	°C

Thermal Resistance

Parameters	Symbol	Value	Unit
Junction ambient			
DIP 16	R_{thJA}	120	K/W
SO 16 on PC board		180	
SO 16 on ceramic		100	

Electrical Characteristics

V_S = 5 V, T_{amb} = 25°C, reference point Pin 11, unless otherwise specified

Parameters	Test Conditions / Pins		Symbol	Min.	Typ.	Max.	Unit
Supply							
Current consumption	without load	Pin 8	I_S	1.5		5.0	mA
Voltage range		Pin 8	V_S	5.0		25.0	V
Voltage limitation	I_S = 10 mA	Pin 8	V_S	26.5		29.5	
Reference voltage	I_7 = 0 to 5 mA	Pin 7	V_{Ref}	2.82	3.0	3.18	V
Max. reference current		Pin 7	$-I_{Ref}$			10	mA
Control outputs							
Discharge current		Pin 10	$-I_{10}$	100		135	mA
Charge current		Pin 12	$+I_{12}$	100		135	
Saturation voltage							
Charge output, I_{12} = 100 mA		Pin 12-11	V_{sat}	0.8		2.5	V
Discharge output, I_{10} = –100 mA		Pin 10–8		0.8		2.5	

Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Oscillator	Pin 3					
Oscillator frequency	$C_2 = C_{osc}$ = 15 nF $R_1 = R_{osc}$ = 430 kΩ	f_{osc}		200		Hz
Low saw-tooth threshold		V_{T3min}		1.0		V
Upper saw-tooth threshold		V_{T3max}		2.0		V
Comparators						
Discharge stop	Pin 6	V_{T6}		525±5%		mV
Overvoltage	Pin 4	V_{T4max}		525±5%		
Hysteresis	Pin 4	V_{hyst}		15		mV
Battery contact monitoring	Pin 4	V_{T4min}	140		200	mV
Sensor temperature voltage	Pin 5	V_{T5min}		525±5%		mV
Hysteresis	Pin 5	V_{hyst}		15		mV
Open wire voltage	Pin 5	V_{T5max}	V_7–0.25		V_7–0.02	V
PWM-Comparator input voltage range	Pin 2	V_2	0.9		3.0	V
PWM-Comparator-Hysteresis	Pin 2	$V_{2\ hyst}$	18		40	mV
Charge time f = 50 Hz (mains) or 200 Hz (oscillator)	Pin 13 = open Pin 13 = ground Pin 13 = +3 V	t		30 1 12		min h h
Status output						
Output current	Pin 9	$\pm I_0$	8		15	mA
Saturation voltage	Pin 9–11 Pin 9–7	V_{sat} $-V_{sat}$			0.5 0.5	V

Applications

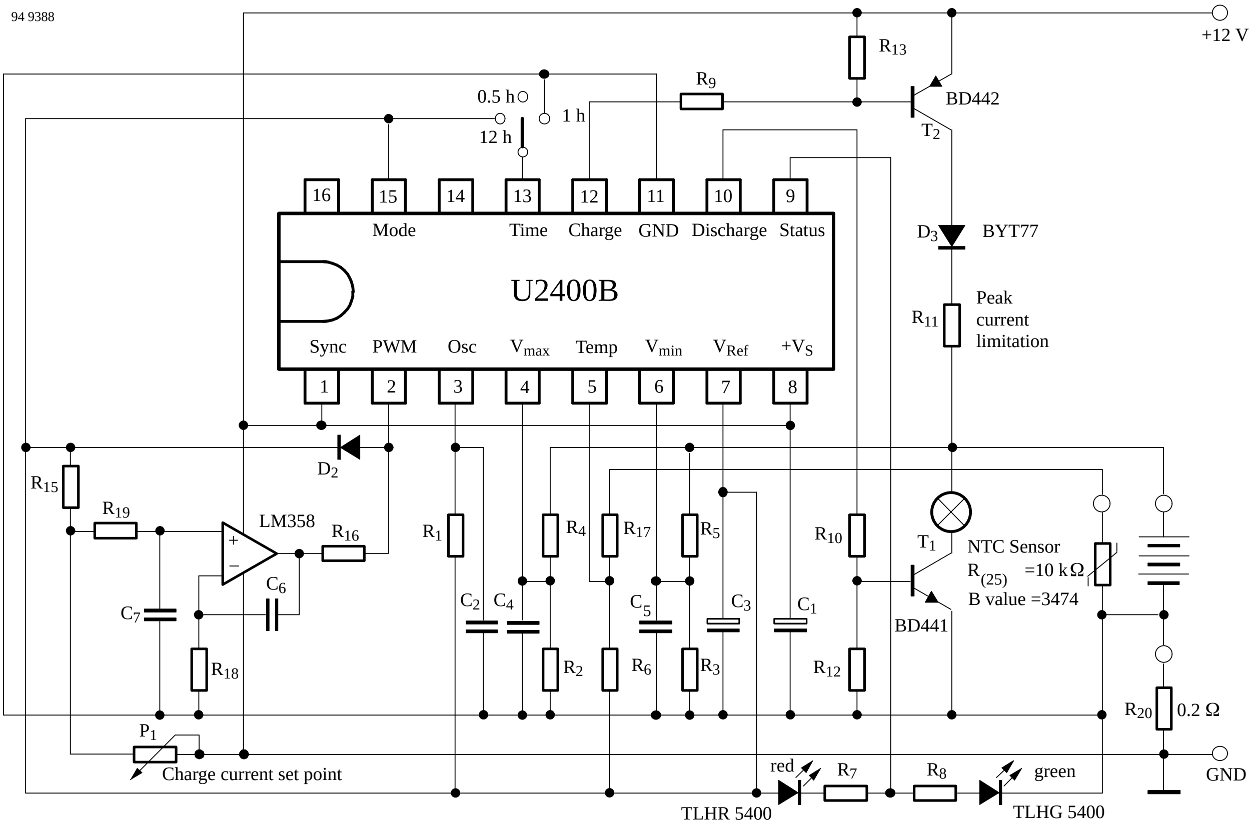
Quick charge for NiCd-batteries with PWM method

Figure 15 describe the current regulations with PWM. Mean value of the charge current for the battery which is created across power transistor T_2 is so dimensioned that it is independent of supply and battery voltage. For the purpose of regulation, load current is obtained via resistor $R_{20} = 0.2\ \Omega$, whose voltage drop serves as actual value for the operation amplifier. It is however recommended to use PNP-differential input stage due to its relatively low loss of power across the shunt resistance (P = 0.2 W, @ 200 mV with 1 A charge current).

GND is the negative supply for operational amplifier whereas the reference point for other components of the IC is different i.e., positive shunt drop voltage. Current set point is given across the voltage divider R_{15}/P_1 whereas the actual value across R_{18} with a common point, the resistance R_{20}.

The output voltage of operational amplifier delivers the voltage for PWM-control at Pin 2. Current regulation acts only on charge current, whereas discharge current is specified by R_{14}.

Maximum and minimum voltage adjustment for variety of cells (batteries) can be calculated with R_4/R_2 and R_5/R_3 ratios.



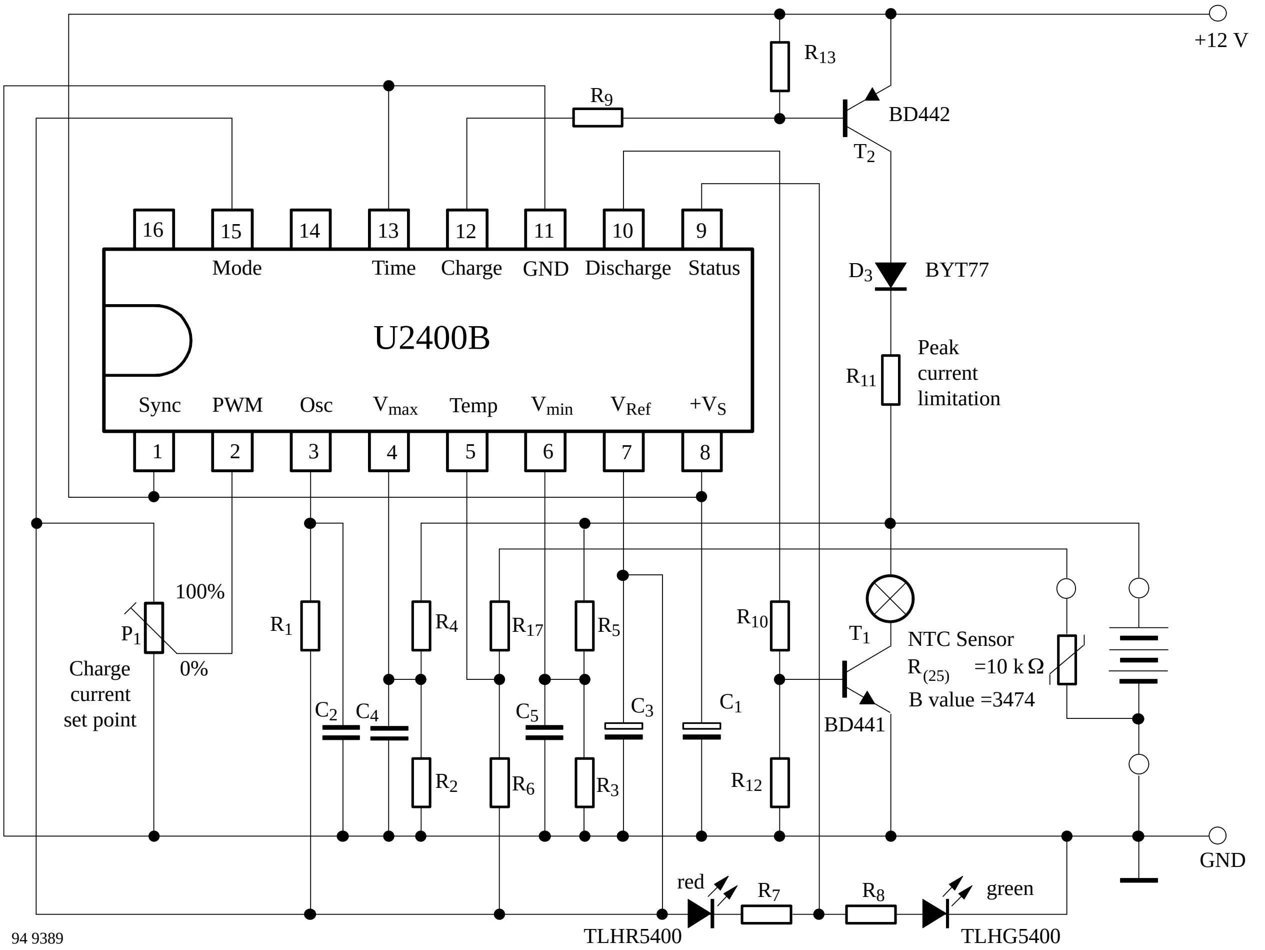
$R_1 = 390\ k\Omega$
R_2, R_3 = see table 1, under figure 16
$R_4, R_5, R_{16}, R_{18}, R_{19} = 100\ k\Omega$
$R_6 = 30\ k\Omega$
$R_7, R_8 = 270\ \Omega$

$R_9, R_{10} = 180\ \Omega$
$R_{12}, R_{13}, R_{15} = 10\ k\Omega$
$R_{17} = 1.5\ k\Omega$
$R_{20} = 0.2\ \Omega$
$P_1 = 1\ k\Omega$

$C_1, C_7 = 100\ \mu F$
$C_2 = 15\ nF$
$C_3 = 10\ \mu F$
$C_4, C_5, C_6 = 0.33\ \mu F$
D_2 = IN4148

Figure 15.

- Charge current regulation
- Automatic pre-discharge
- Charge time: 0.5 h, 1 h, 12 h
- Temperature monitoring
- Status indication



R_1 = 390 kΩ
R_2, R_3 = see table 1
R_4, R_5 = 100 kΩ
R_6 = 30 kΩ
R_7, R_8 = 270 Ω

R_9, R_{10} = 180 Ω
R_{12}, R_{13} = 10 kΩ
R_{17} = 1.5 kΩ
P_1 = 10 kΩ

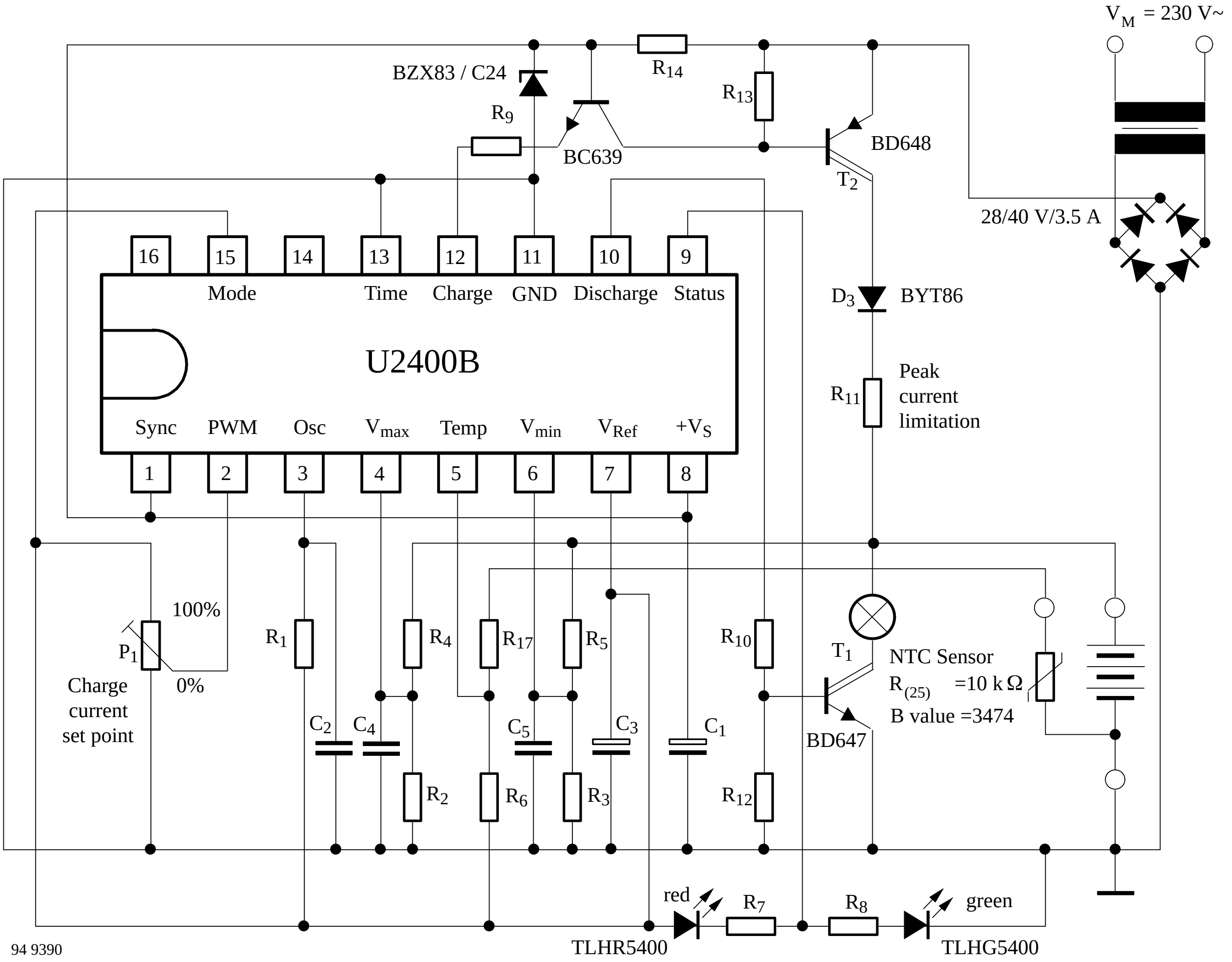
C_1 = 100 µF
C_2 = 15 nF
C_3 = 10 µF
C_4, C_5 = 0.33 µF

Figure 16.

- Automatic pre-discharge
- Charge time 1 h
- Temperature monitoring
- Status indication

Table 1. Resistances R_2 and R_3 dimensioning for figures 15 and 16

Cell Quantity	1	2	3	4	5	6	7
R_2	47 kΩ	18 kΩ	10 kΩ	8.2 kΩ	6.2 kΩ	5.6 kΩ	4.7 kΩ
R_3	130 kΩ	39 kΩ	24 kΩ	15 kΩ	12 kΩ	10 kΩ	8.2 kΩ



R$_1$ = 510 kΩ
R$_2$, R$_3$ = see table 2
R$_4$, R$_5$ = 100 kΩ
R$_6$ = 30 kΩ
R$_7$, R$_8$ = 270 Ω

R$_9$, R$_{10}$ = 2.2 kΩ / 0.5 W
R$_{12}$, R$_{13}$ = 10 kΩ
P$_1$ = 10 kΩ
R$_{14}$ = 220 Ω / 1 W
R$_{17}$ = 1.5 kΩ

C$_1$ = 470 µF
C$_2$ = 22 nF
C$_3$ = 10 µF
C$_4$, C$_5$ = 0.33 µF

Figure 17.

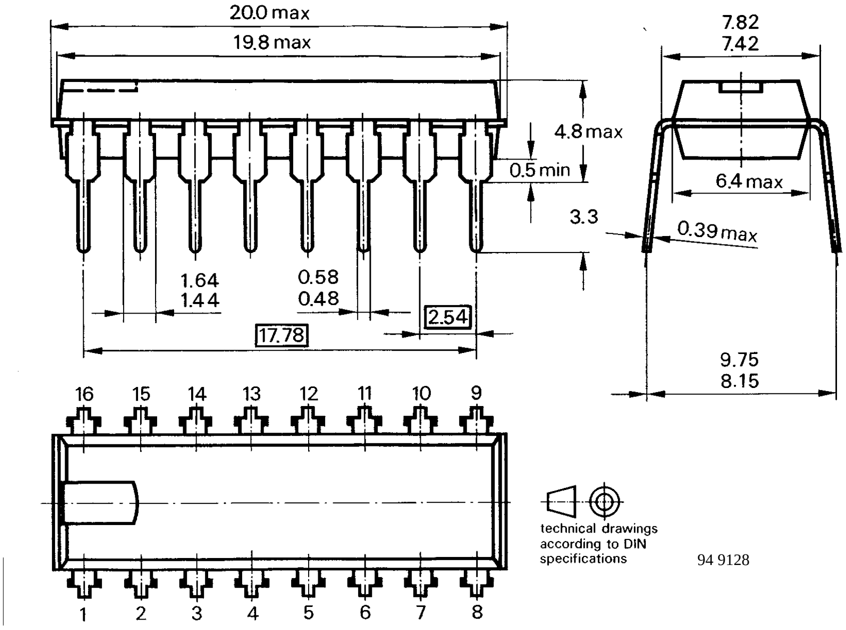
- Charge voltage higher than IC supply
- Charge time 2 h
- Pre-discharge function
- Temperature monitoring

Table 2. Resistances R$_2$ and R$_3$ dimensioning

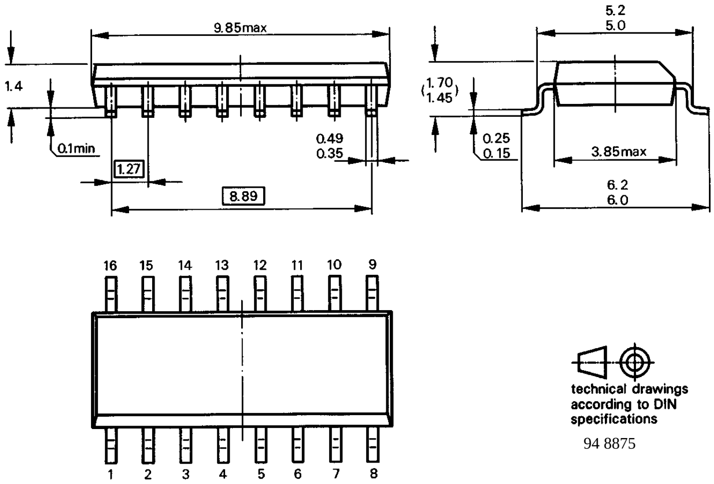
Cell quantity	20	30
R$_2$	1.5 kΩ	1.0 kΩ
R$_3$	2.2 kΩ	1.5 kΩ

Dimensions in mm

Package: DIP 16



Package: SO 16



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It is the policy of **TEMIC TELEFUNKEN microelectronic GmbH** to

1. Meet all present and future national and international statutory requirements.
2. Regularly and continuously improve the performance of our products, processes, distribution and operating systems with respect to their impact on the health and safety of our employees and the public, as well as their impact on the environment.

It is particular concern to control or eliminate releases of those substances into the atmosphere which are known as ozone depleting substances (ODSs).

The Montreal Protocol (1987) and its London Amendments (1990) intend to severely restrict the use of ODSs and forbid their use within the next ten years. Various national and international initiatives are pressing for an earlier ban on these substances.

TEMIC TELEFUNKEN microelectronic GmbH semiconductor division has been able to use its policy of continuous improvements to eliminate the use of ODSs listed in the following documents.

1. Annex A, B and list of transitional substances of the Montreal Protocol and the London Amendments respectively
2. Class I and II ozone depleting substances in the Clean Air Act Amendments of 1990 by the Environmental Protection Agency (EPA) in the USA
3. Council Decision 88/540/EEC and 91/690/EEC Annex A, B and C (transitional substances) respectively.

TEMIC can certify that our semiconductors are not manufactured with ozone depleting substances and do not contain such substances.

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Telephone: 49 (0)7131 67 2831, Fax number: 49 (0)7131 67 2423

Charge Timer

Description

The U2403B is a monolithic, integrated-bipolar circuit which can be used in applications for time-controlled, constant-current charge. Selection of charge current versus timing is carried out by using the external circuit at Pins 2, 3 and 4. For high current requirement, an external transistor is recommended in series with the battery. To protect the IC against high power loss (typically > 140°C), the oscillator is shut down when the reference voltage is switched off (0 V). The same thing happens when there is a saturation caused by collector voltage at Pin 1. When the overtemperature has disappeared and the collector voltage at Pin 1 has exceeded the supply voltage ($V_1 > V_S$), charge time operation continues (see flow chart in figure 3).

Features

- Easy-to-run autonomous dual rate charger
- Constant charge current
- 3 h – 24 h charge time programmable
- Low cost dc regulator
- Overtemperature protection
- Charge-mode indication
- Operation starts at the moment of battery insertion
- Fast charge time-test mode

Applications

- Cordless telephones
- Low-cost battery-charge timer
- Entertainment

Package: DIP8, SO8

Block Diagram

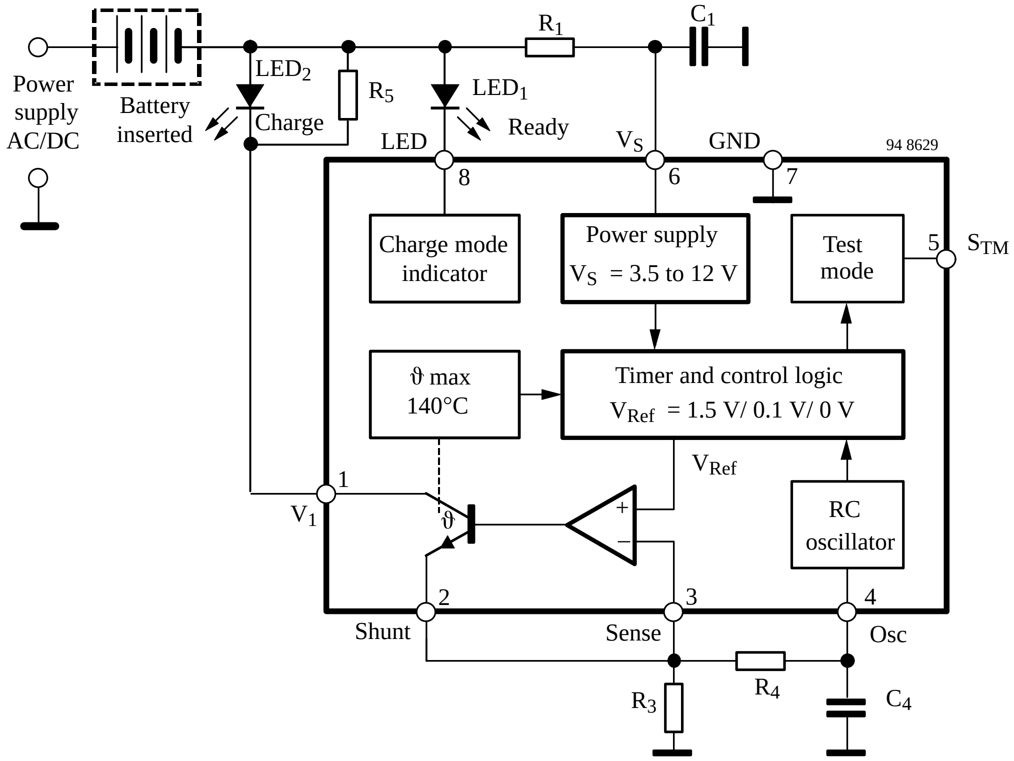
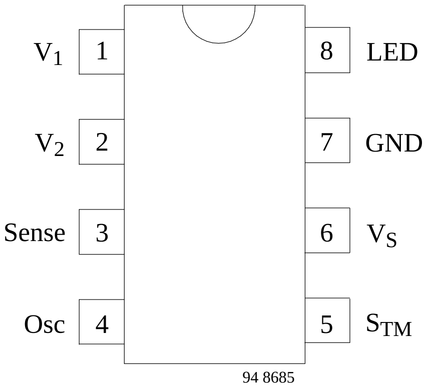


Figure 1. Block diagram with external circuit

Pin Description



Pin	Symbol	Function
1	V_1	Collector terminal
2	V_2	Shunt emitter terminal
3	V_3	Amplifier sense input
4	Osc	Oscillator input
5	S_{TM}	Test mode switch
6	V_S	Supply voltage
7	GND	Reference point, GND
8	LED	Charge mode indicator

Pin 1, Collector Voltage V_1

Pin 1 is an open collector output. When $V_1 \leq 3$ V, the charge cycle is switched off until it is above the supply voltage, as shown in figure 6.

Pin 2, Shunt Emitter

The constant current source is supplied by the internal operational amplifier. The voltage across R_3 is determined via the internal reference source.

$I_{ch} = V_3/R_3 \quad (V_3 = V_{sense})$

Pin 3, Amplifier Sense Input (Inverted)

The voltage-regulated current source has a closed loop at Pin 2, Pin 3, and resistor R_3.

Pin 4, Oscillator Input R_4, C_4

Selection of current charge versus timing is carried out by using the external circuit at Pins 2, 3, and 4. Typical values are given in charge characteristics (see table on page 3).

Pin 5, Test-Mode Switch for Charging Time

Charging time, $t_{ch,}$ is given by the equation.

$$t_{ch} = \frac{1}{f_{osc}} \cdot 2^n$$

where:

f_{osc} = oscillator frequency (see figure 2)

n = frequency divider
= 26, if S_{TM} open
= 17, if S_{TM} = GND
= 8, if $S_{TM} = V_S$

The first eight divider stages can be tested directly. 256 input tact signals at Pin 4 create one tact signal at Pin 5.

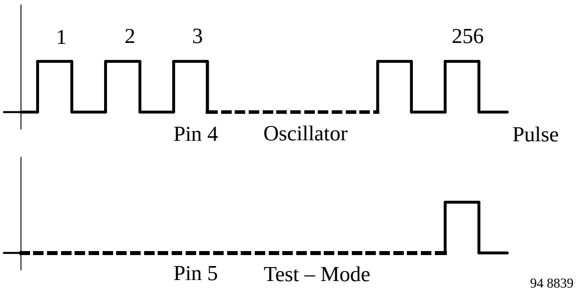


Figure 2. Quick test timer 1/3

Example

Assume a charge time of 6 h.
Select the values of R_4 and C_4 from the tables on page 3.

For example:	$R_4 = 470$ kΩ
	$C_4 = 680$ pF

There is a frequency of approximately 3100 Hz at Pin 4. It is possible to test the charge time of 6 h by running through the charge cycle for a very short time. By connecting Pin 5 with GND, the test time is 42 s. By connecting Pin 5 with Pin 1 (V_1), the test time is reduced to about 82.4 ms. R_5 is connected in parallel to the LED_2 and provides a protective bypass function for the LED (see figure 1).

Pin 6, Supply Voltage, V_S

$V_S \approx 3.1$ V	power-on reset release (turn-on)
$V_S \approx 2.9$ V	under-voltage reset
$V_S \approx 13$ V	supply voltage limitation

Pin 7, Ground

Pin 8, Charge Mode Indicator

An open-collector output supplies constant current to LED$_1$ after the active charge phase has been terminated. ϑ_{max} controls the function temperature for the final stage range. This is when the temperature is above 140°C and the charge function is therefore switched off.

Trickle Charge

The trickle charge starts after the charge has been terminated. In this case, the internal reference voltage is reduced from 1.5 V to approximately 0.1 V. This means the charge current is decreased by the factor:

$K = 1.5\ V / 0.1\ V = 15.$

Trickle current = I_{ch} / 15 + I_6 (supply current) + I_8

It is possible to reduce the trickle charge with resistor R_6, as shown in figures 6 and 7.

Charge Characteristics

Charge Time

Test time/ Test-Mode Switch S_{TM}			Oscillator Components		Frequency
Open	V_S	GND	R_4 (KΩ)	C_4 (pF)	f_{osc} (Hz)
3 h	41.2 ms	21 s	510 430 300	270 330 470	6213
4 h	54.9 ms	28 s	620 430 300	330 470 680	4660
5 h	68.6 ms	35 s	510 390 300	470 680 1000	3728
6 h	82.4 ms	42 s	620 470 360	470 680 1000	3105
7 h	96.1 ms	49 s	560 430 220	680 1000 2200	2663
8 h	109.8 ms	56 s	620 470 200	680 1000 2200	2330
9 h	123.6 ms	1 min 3 s	750 510 240	680 1000 2200	2071
10 h	137.3 ms	1 min 10 s	620 270 130	820 2200 4700	1864
12 h	164.8 ms	1 min 24 s	390 150	2200 4700	1553
16 h	219.7 ms	1 min 56 s	470 200	2200 4700	1165

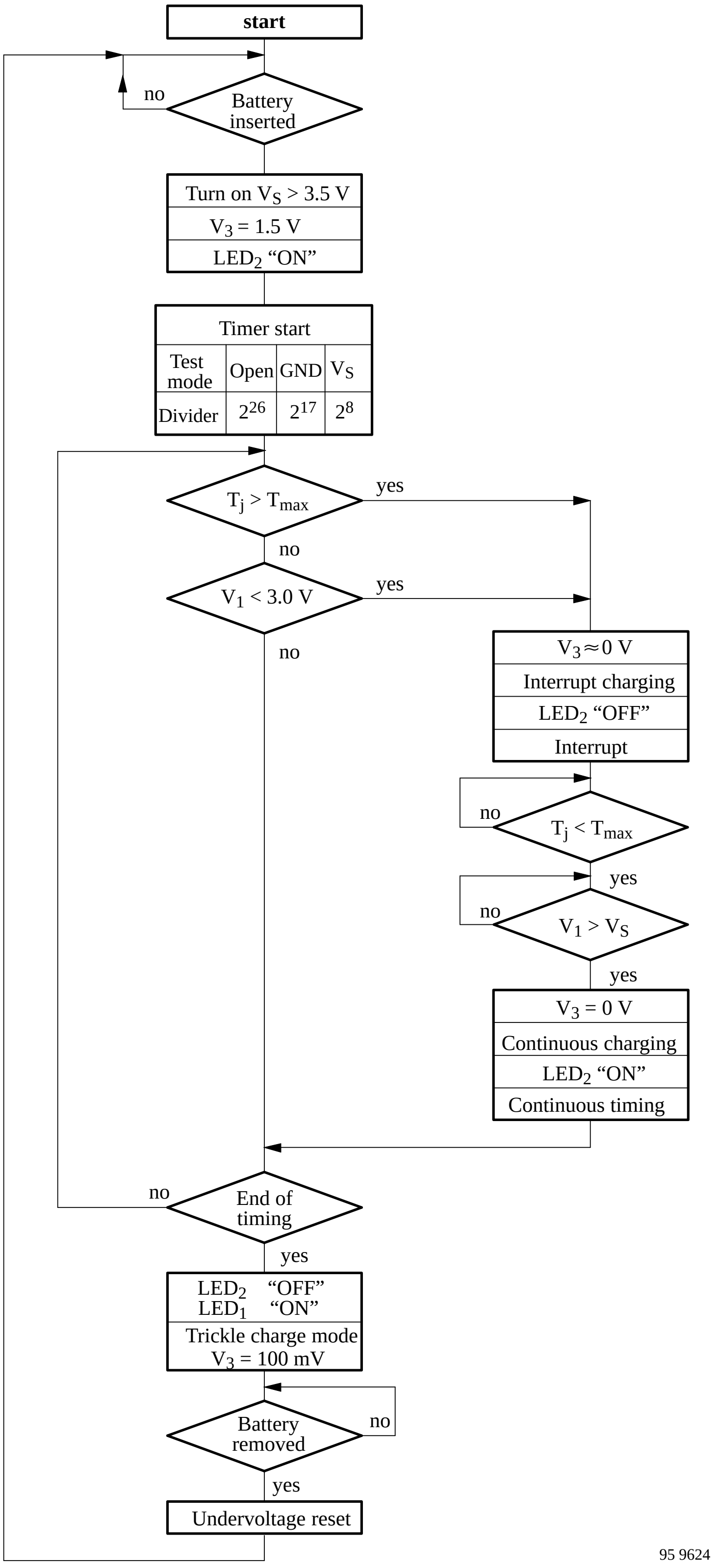


Figure 3. Flow chart

Absolute Maximum Ratings

Reference point Pin 7 (GND), unless otherwise specified.

Parameters		Symbol	Value	Unit
Supply current	Pin 6	I_S	20	mA
t ≤ 100 µs		i_s	100	mA
Currents	Pin 1	I_1	300	mA
	Pin 2	$-I_2$	310	mA
	Pin 3	I_3	1	µA
	Pin 4	I_4	15	mA
	Pin 5	I_5	–75 to +120	µA
	Pin 8	I_8	8	mA
Voltages	Pins 1, 3, 5, 6 and 8	V	13.5	V
	Pin 2	V_2	1.6	
	Pin 4	V_4	1.5	
Junction temperature		T_j	150	°C
Ambient temperature		T_{amb}	10 to 85	°C
Storage temperature range		T_{stg}	–50 to +150	°C

Thermal Resistance

Parameters	Symbol	Value	Unit
Junction ambient	R_{thJA}		
DIP8		120	K/W
SO8 on PC-board		220	
SO8 on ceramic		140	
SO8 on ceramic with thermal compound		80	

Electrical Characteristics

V_S = 6 V, T_{amb} = 25°C, reference point Pin 7 (GND), unless otherwise specified.

Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Supply voltage limitation	Pin 6 I_S = 4 mA I_S = 20 mA	V_S	 12.5 12.6		 13.5 13.7	V
Supply current	V_S = 6 V	I_S	1.4		2.2	mA
Voltage monitoring	Pin 6					
Turn-on threshold		V_{TON}	2.8		3.5	V
Turn-off threshold		V_{TOFF}	2.5		3.2	
Charge-mode indicator (LED)	Pin 8					
LED current		I_8	3.0		6.0	mA
LED saturation voltage	I_8 = 3.7 mA	V_8			960	mV
Leakage current		I_{lkg}	–0.35		1.1	µA
Collector terminal, Figure 5	Pin 1					
Open collector current		I_{CO}	15		55	µA
Saturation threshold	V_S = 6 V	V_{TON} V_{TOFF}	2.55 V_S–1V	3.0 V_S	3.35 V_S–0.4V	V
Shunt emitter current	$R_3 = 5.6\ \Omega$ Pin 2	I_2	250		285	mA
Operational sense amplifier, Figure 1	Pin 3					
Input current	V_3 = 0 V	I_3	–0.6		0.08	µA
Input voltage	V_{Ref} = 1.5 V V_{Ref} = 100 mV V_{Ref} = 0 V	V_3	1.42 40 –0.4	1.5 70	1.58 100 40	V mV mV
Oscillator	Pin 4					
Leakage current	V_4 = 0 to 0.85 V	I_{lkg}	–0.5		0.1	µA
Threshold voltage	Upper	$V_{T(u)}$	875		985	mV
Oscillator frequency	$R_4 = 160\ k\Omega$, C_4 = 2.2 nF $R_4 = 680\ k\Omega$, C_4 = 4.7 nF	f_{osc}	2700 305		3050 345	Hz
Test mode switch (S_{TM})	Pin 5					
Input current	V_5 = 6 V V_5 = 0 V	I_5	40 –75		120 –20	µA
Output voltage	High Low	$V_{0(H)}$ $V_{0(L)}$	1.7 0.5		2.5 1.0	V

Internal Temperature Switch

The internal temperature monitoring is active if the chip temperature rises above 140°C. Above this temperature the voltage at Pin 3 goes to zero. Similarly, the charge current, I_{ch}, reduces according to the equation:

$I_{ch} = V_3 / R_3$

where I_{ch} = 1 to 2 mA (IC supply current)

The oscillator is connected to GND via Pin 3 (V_3) which holds the present time status. When the chip temperature decreases below the transition value, all functions are released and the charge time is continued. The process is reversible. If there is a higher power dissipation in the circuit ($T_j > 140°C$), the temperature monitoring remains permanently activated (ON). The total cycle time is prolonged according to the interrupt-time duration, see figure 4.

Automatic Control Protection

To reduce the design costs, it is possible to select the transformer which requires minimum power supply.

The output stage of the control is selected so that it is switched off before saturation is achieved (V_{CEsat} = 3.0 V). In this case, the voltage at Pin 3 is kept at a value of zero. The charge current is also zero and the transformer is now an open circuit impedance. The system becomes active again if $V_1 \geq V_S$.

The advantage of the system is that if sags of short duration appear on the mains voltage or if the transformers used are too small, the charge duration is increased, but the charge capacity remains the same (see figure 5).

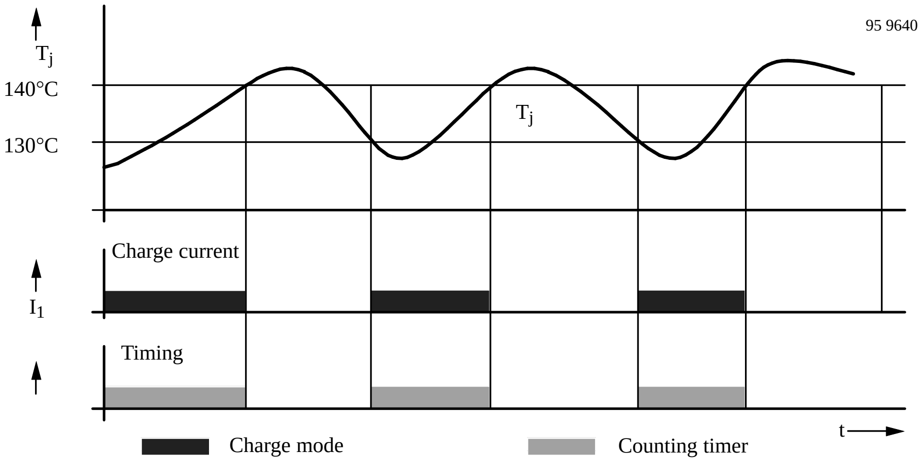


Figure 4. Charge duration – overtemperature

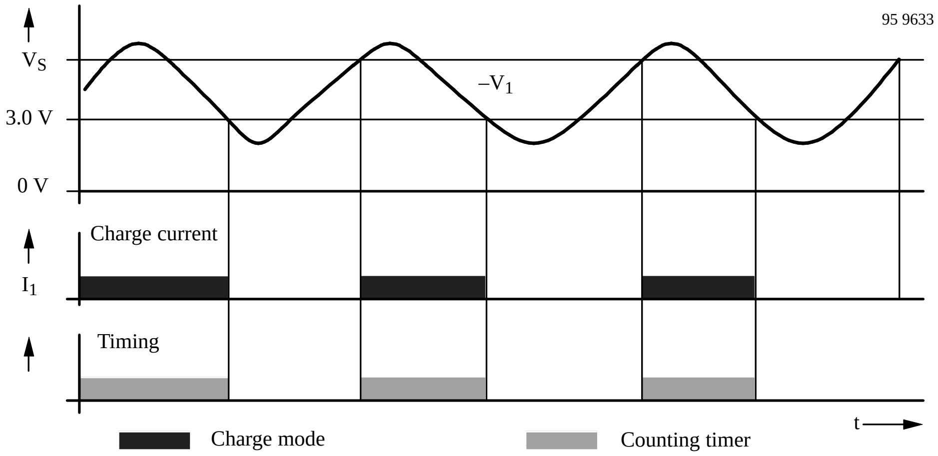


Figure 5. Charge duration – V_1

Standard Applications

Basic Example

NiCd battery 750 mAh Charging time: 3 h Charge current: 240 mA, 1/3 C Trickle charge: 19 mA < 1/40 C	R_1 = 510 Ω, 1/8 W C_1 = 47 µF/ 16 V R_3 = 6.2 Ω, 1/2 W R_4 = 300 kΩ C_4 = 470 pF R_5 = 8.2 Ω, 1/2 W

Minimum Supply Voltage

No of Cells	DC Supply Minimum
1	6.8 V
2	8.3 V
3	9.8 V
4	11.3 V
5	12.8 V

Special Requirements of Different Charge Times

R_4, C_4 values for different charging times

	2 h	4 h	6 h	7 h	12 h
R_4	300 kΩ	430 kΩ	470 kΩ	470 kΩ	390 kΩ
C_4	330 pF	470 pF	680 pF	1 nF	2.2 nF

Special Requirements for Different Charge Current

R_3, R_5 values for different charge current

	240 mA	150 mA	100 mA	50 mA
R_3	6.2 Ω	10 Ω	15 Ω	30 Ω
R_5	8.2 Ω	15 Ω	22 Ω	68 Ω

Basic Equations

$R_1 = 0.5\ V / I_S$
$I_S = 1.8\ mA$
$R_5 = V_5 / (I_{ch} - 20\ mA)$

Nominal Charge Current:
$I_{ch} = V_3/R_3$ where $V_3 = 1.48\ V$ (typ.)

Trickle Current:
$I_{ch} = V_3/R_3 + I_8 + I_S$
Typical values are:
$V_3 = 100\ mV$, $I_8 = 4.5\ mA$

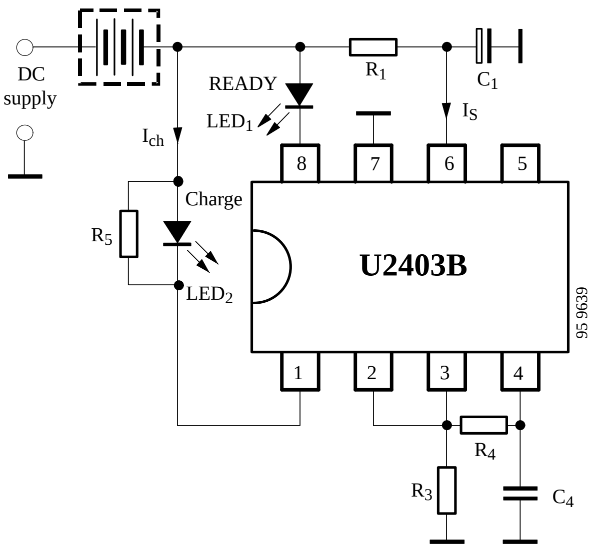


Figure 6. Standard application

Booster and Trickle Charge Reduction

Basic Example

NiCd battery 1000 mAh	R_1 = 510 Ω, 1/8 W
Charging time: 2 h	C_1 = 100 µF/ 16 V
Charge current: 500 mA	R_3 = 3 Ω/ 1 W
Trickle charge: 22 mA < 1/22 C	R_4 = 300 kΩ
	C_4 = 330 pF
	R_5 = 3.9 Ω/ 1 W
	C_2 = 1 µF

Supply Voltage

No of Cells	DC Supply Minimum
1	V_S = 6.5 V
2	8.0 V
3	9.5 V
4	11.0 V
5	12.5 V

Special Requirements for Different Charge Times

R_4, C_4 values for different charge times

	2 h	4 h	6 h	7 h	12 h
R_4	300 kΩ	430 kΩ	470 kΩ	470 kΩ	390 kΩ
C_4	330 pF	470 pF	680 pF	1 nF	2.2 nF

Special Requirements for Different Charge Current

R_3, R_5 values for different charge currents

	616 mA	493 mA	411 mA	296 mA
R_3	2.4 Ω	3 Ω	3.6 Ω	5 Ω
R_5	3 Ω	3.9 Ω	4.7 Ω	6.8 Ω

R_6 = 560 Ω, reduced trickle charge

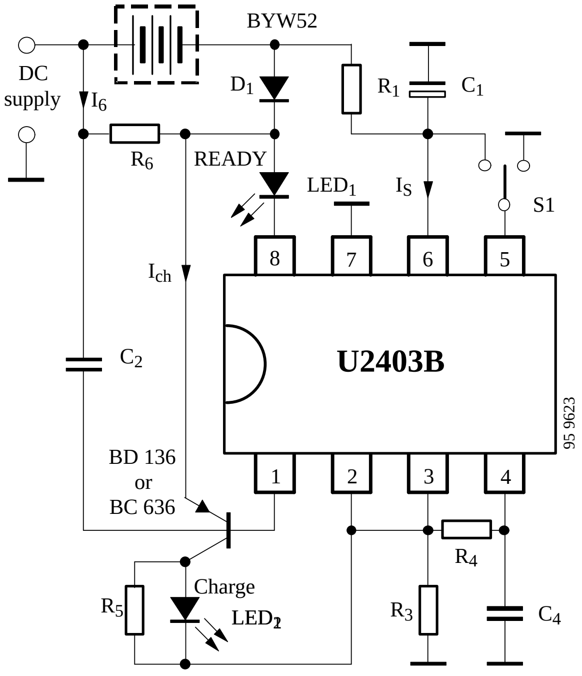
Basic Equations

$R_1 = 0.5\ \text{V} / I_S$
$R_5 = V(\text{LED}_2)/ (I_{ch} - 20\ \text{mA})$

Nominal Charge Current:
$I_{ch} = V_3/ R_3$
$V_3 = 1.48\ \text{V}$, typically

Trickle Current:
$I_{ch} = V_3/R_3 + I_{LED1} + I_S - I_6$
Typical values:
$V_3 = 100\ \text{mV}$
$I_{LED1} = 4.5\ \text{mA}$
$I_S = 1.8\ \text{mA}$

Trickle-Charge Reduction (I_6)
$I_6 = (V_{Batt} + V_{D1})/R_6$ $\qquad V_{D1} = 0.75\ \text{V}$



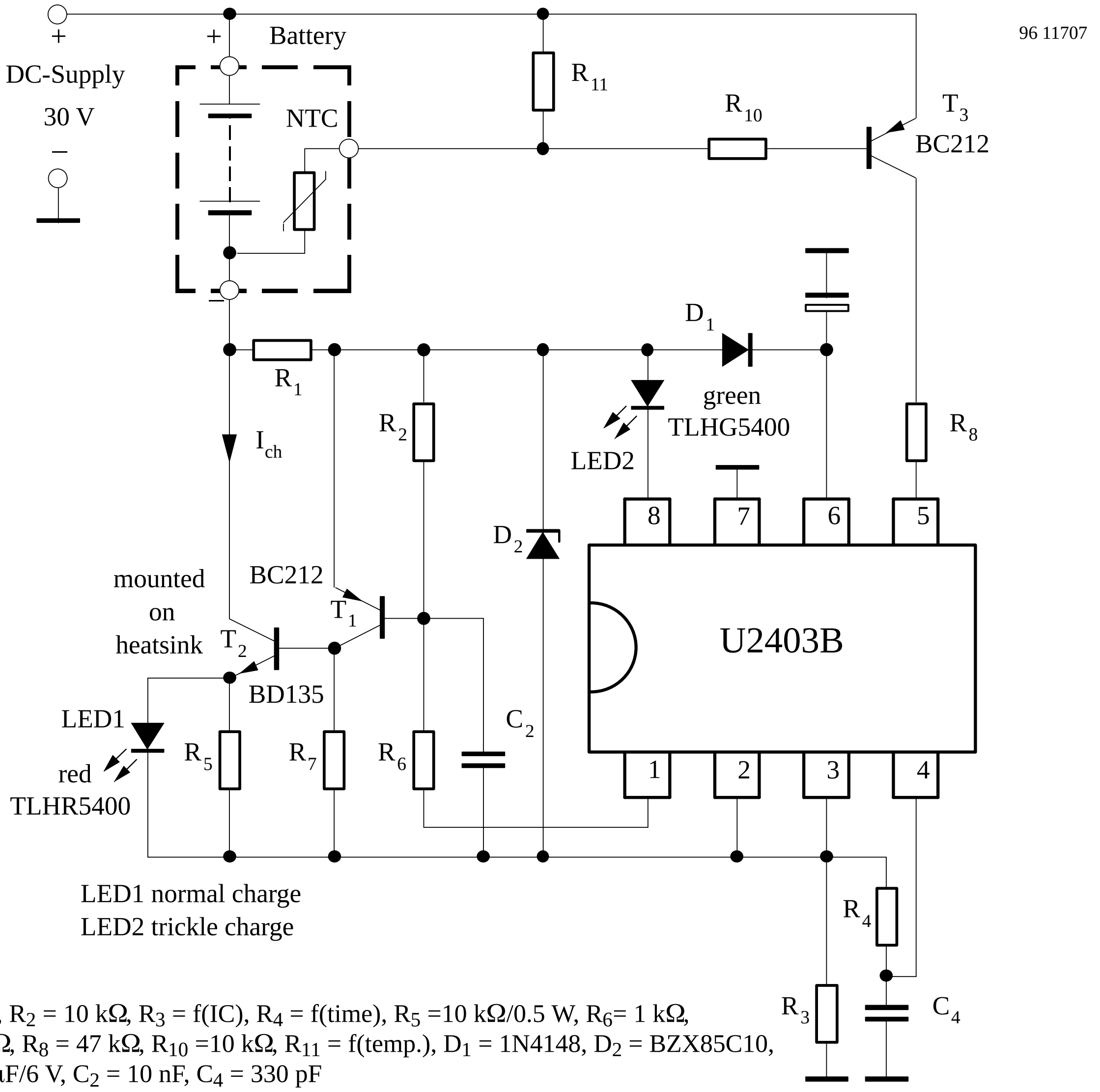
S1: use for test only

Figure 7. Application for charge current > 250 mA

To fulfill requirements of higher charge current an external booster transistor can be used (see figure 7). As the temperature cannot be monitored in this case a heat sink with a resonable size should be used for safe operation. Test mode switch S_1 can be used for accelerated production check.

Charge System at Higher Voltage of 30 V

Charge systems with higher voltages than V_{Smax} can be realized with the additional expander circuitry, as shown in figure 8. This circuit contains a simple temperature monitoring function. When the temperature level is reached, the transistor, T_3, is switched on. If T_3 is switched on and there is current flow into Pin 5, normal charge is terminated.



R_1 = 1 kΩ, R_2 = 10 kΩ, R_3 = f(IC), R_4 = f(time), R_5 =10 kΩ/0.5 W, R_6= 1 kΩ,
R_7 = 10 kΩ, R_8 = 47 kΩ, R_{10} =10 kΩ, R_{11} = f(temp.), D_1 = 1N4148, D_2 = BZX85C10,
C_1 = 100 µF/6 V, C_2 = 10 nF, C_4 = 330 pF
R_{11} = f(temp.) depends on number of cells

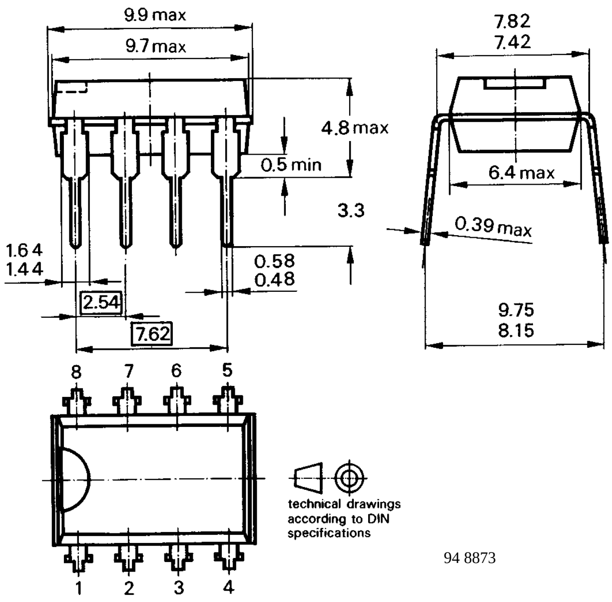
Figure 8. U2403B for higher supply voltage up to 30 V with integrated temperature monitoring

No of Cells	R_{11}
2	13 kΩ
3	8.2 kΩ
4	6.2 kΩ
5	4.7 kΩ

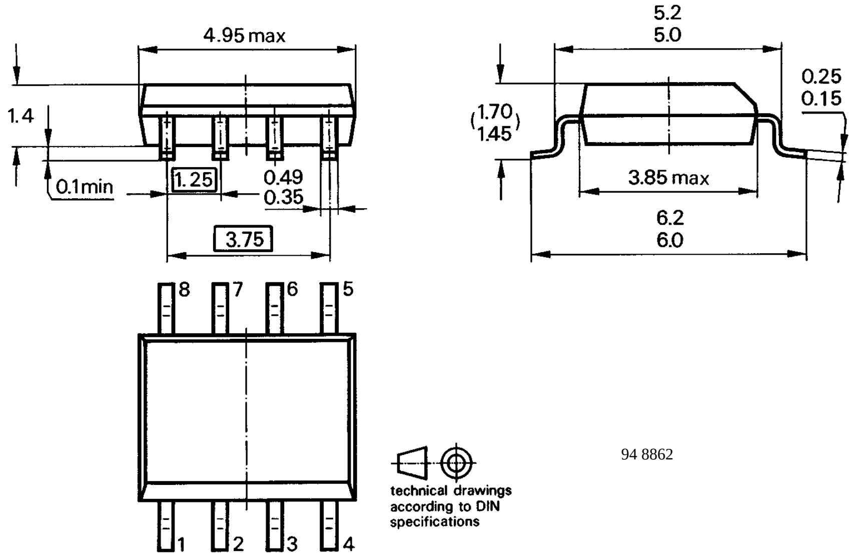
NTC Value	
25°C	6.8 kΩ
40°C	3.9 kΩ
50°C	2.8 kΩ

Dimensions in mm

Package: DIP8



Package: SO8



Ozone Depleting Substances Policy Statement

It is the policy of **TEMIC TELEFUNKEN microelectronic GmbH** to

1. Meet all present and future national and international statutory requirements.

2. Regularly and continuously improve the performance of our products, processes, distribution and operating systems with respect to their impact on the health and safety of our employees and the public, as well as their impact on the environment.

It is particular concern to control or eliminate releases of those substances into the atmosphere which are known as ozone depleting substances (ODSs).

The Montreal Protocol (1987) and its London Amendments (1990) intend to severely restrict the use of ODSs and forbid their use within the next ten years. Various national and international initiatives are pressing for an earlier ban on these substances.

TEMIC TELEFUNKEN microelectronic GmbH semiconductor division has been able to use its policy of continuous improvements to eliminate the use of ODSs listed in the following documents.

1. Annex A, B and list of transitional substances of the Montreal Protocol and the London Amendments respectively

2. Class I and II ozone depleting substances in the Clean Air Act Amendments of 1990 by the Environmental Protection Agency (EPA) in the USA

3. Council Decision 88/540/EEC and 91/690/EEC Annex A, B and C (transitional substances) respectively.

TEMIC can certify that our semiconductors are not manufactured with ozone depleting substances and do not contain such substances.

TEMIC TELEFUNKEN microelectronic GmbH, P.O.B. 3535, D-74025 Heilbronn, Germany
Telephone: 49 (0)7131 67 2831, Fax number: 49 (0)7131 67 2423

Fast Charge Controller for NiCd/NiMH Batteries

Description

The fast charge battery controller circuit, U2402B-B, uses bipolar technology. It enables an efficient and economic charge system. It incorporates intelligent multiple gradient battery voltage monitoring and mains phase control for power management. With automatic top-off charging, the integrated circuit enables the charge device to stop regular charging, before the critical stage of overcharging can occur. It has two LED driver indications for charge and temperature status.

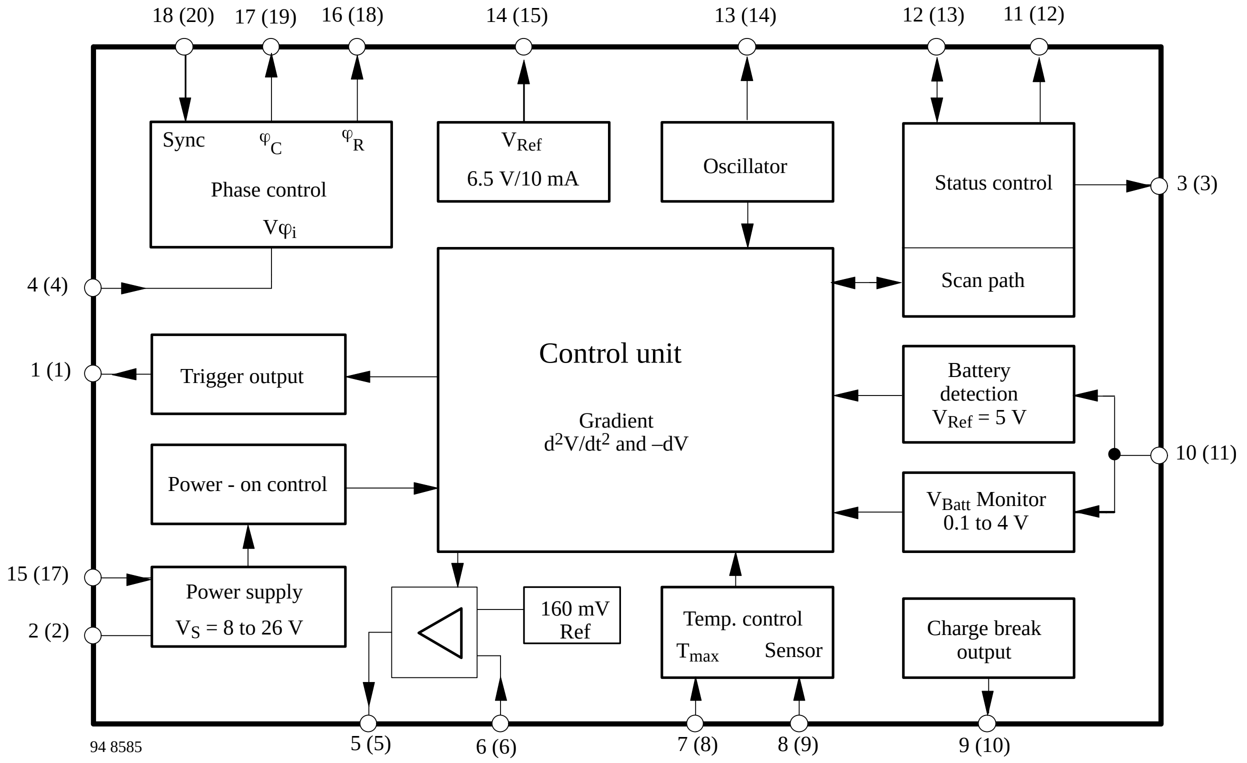
Features

- Multiple gradient monitoring
- Temperature window (T_{min}/T_{max})
- Exact battery voltage measurement without charge
- Phase control for charge current regulation
- Top off and trickle charge function
- Two LED outputs for charge status indication
- Disabling of d^2V/dt^2 switch-off criteria during battery formation
- Battery voltage check

Applications

- Portable power tools
- Laptop/notebook personal computer
- Cellular/cordless phones
- Emergency lighting systems
- Hobby equipment
- Camcorder

Package: DIP18, SO20

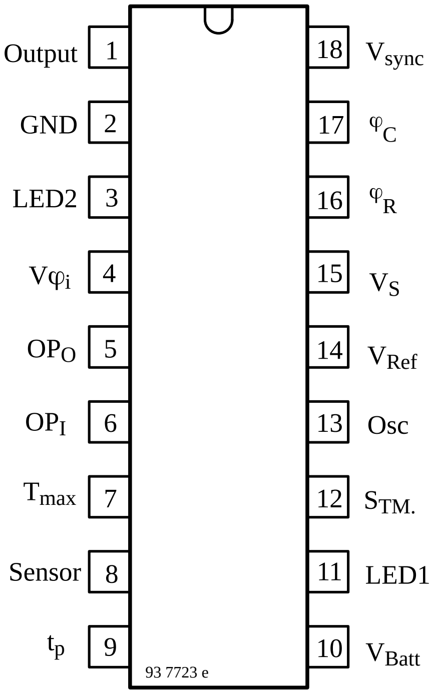


( ) SO 20, Pins 7 and 16 NC

Figure 1. Block diagram

Pinning

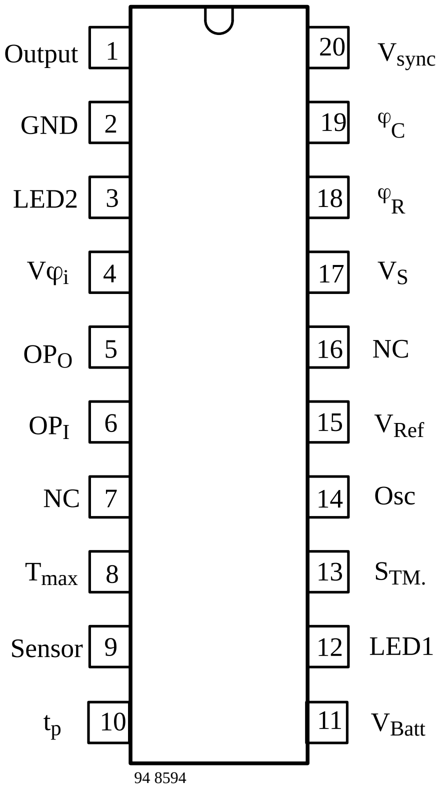
Package: DIP18



Pin Description

Pin	Symbol	Function
1	Output	Trigger output
2	GND	Ground
3	LED2	Display output “Green”
4	$V\varphi_i$	Phase angle control input voltage
5	OP_O	Operational amplifier output
6	OP_I	Operational amplifier input
7	T_{max}	Maximum temperature
8	Sensor	Temperature sensor
9	t_p	Charge break output
10	V_{Batt}	Battery voltage
11	LED1	LED display output “Red”
12	$S_{TM.}$	Test mode switch (status control)
13	Osc	Oscillator
14	V_{Ref}	Reference output voltage
15	V_S	Supply voltage
16	φ_R	Ramp current adjustment – resistance
17	φ_C	Ramp voltage – capacitance
18	$V_{sync.}$	Mains synchronisation input

Package: SO20



Pin	Symbol	Function
1	Output	Trigger output
2	GND	Ground
3	LED2	Display output “Green”
4	$V\varphi_i$	Phase angle control input voltage
5	OP_O	Operational amplifier output
6	OP_I	Operational amplifier input
7	NC	Not connected
8	T_{max}	Maximum temperature
9	Sensor	Temperature sensor
10	t_p	Charge break output
11	V_{Batt}	Battery voltage
12	LED1	LED display output “Red”
13	$S_{TM.}$	Test mode switch (status control)
14	Osc	Oscillator
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17	V_S	Supply voltage
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19	φ_C	Ramp voltage – capacitance
20	$V_{sync.}$	Mains synchronisation input

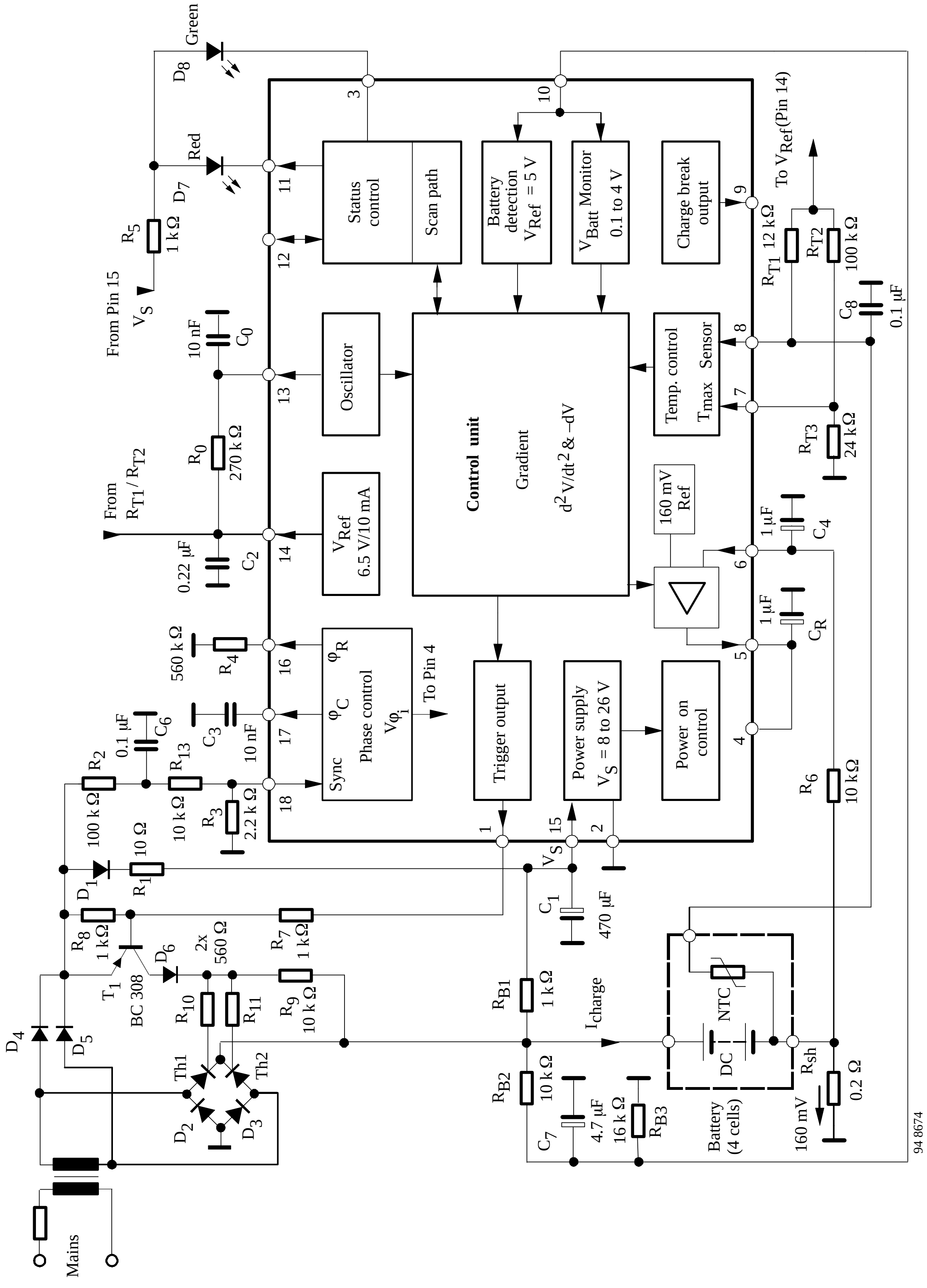


Figure 2. Block diagram with external circuit (DIP pinning)

General Description

The integrated circuit, U2402B-B, is designed for charging Nickel-Cadmium (NiCd) and Nickel-Metal-Hydride (NiMH) batteries. Fast charging results in voltage lobes when fully charged (figure 3). It supplies two identifications (i.e., + d^2V/dt^2, and – dV) to end the charge operation at the proper time.

As compared to the existing charge concepts where the charge is terminated – after voltage lobes – according to – dV and temperature gradient identification, the U2402B takes into consideration the additional changes in positive charge curves, according to the second derivative of the voltage with respect to time (d^2V/dt^2). The charge identification is the sure method of switching off the fast charge before overcharging the battery. This helps to give the battery a long life by hindering any marked increase in cell pressure and temperature.

Even in critical charge applications, such as a reduced charge current or with NiMH batteries where weaker charge characteristics are present multiple gradient control results in very efficient switch-off.

An additional temperature control input increases not only the performances of the charge switching characteristics but also prevents the general charging of a battery whose temperature is outside the specified window.

A constant charge current is necessary for continued charge-voltage characteristic. This constant current regulation is achieved with the help of internal amplifier phase control and a simple shunt-current control technique.

All functions relating to battery management can be achieved with dc-supply charge systems. A dc-dc-converter or linear regulator should take over the function of power supply. For further information please refer to the applications.

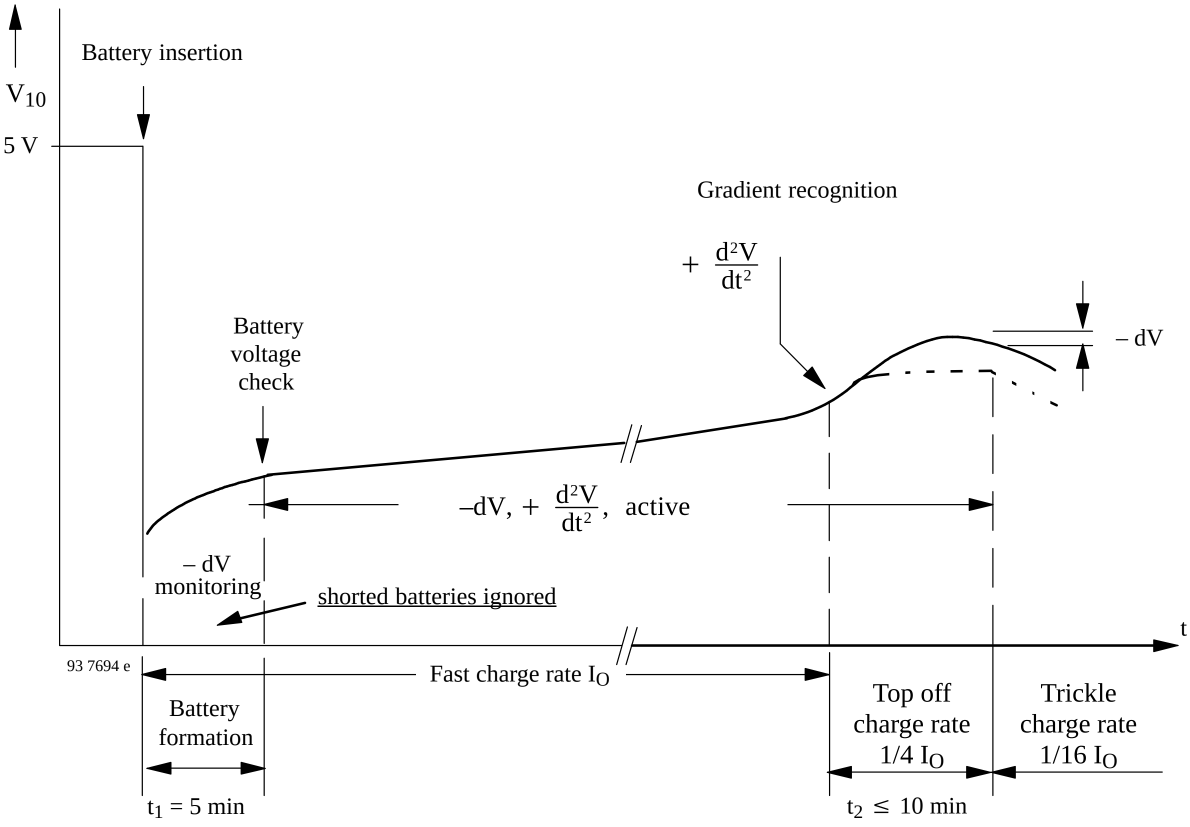


Figure 3. Charge function diagram, f_{osc} = 800 Hz

Flow Chart Explanation, f_{osc} = 800 Hz (Figures 2, 3 and 4)

Battery pack insertion disables the voltage lock at battery detection input Pin 10. All functions in the integrated circuit are reset. For further description, DIP-pinning is taken into consideration.

Battery Insertion and –dV Monitoring

The charging procedure will be carried out if battery insertion is recognised. If the polarity of the inserted battery is not according to the specification, the fast charge rate will stop immediately. After the polarity test, if positive, the defined fast charge rate, I_O, begins for the first 5 minutes according to –dV monitoring. After 5 minutes of charging, the first identification control is executed.

If the inserted battery has a signal across its terminal of less than 0.1 V, then the charging procedure is interrupted. This means that the battery is defective i.e., it is not a rechargeable battery – “shorted batteries ignored”.

Voltage and temperature measurements across the battery are carried out during charge break interval (see figure 6), i.e., currentless or idle measurements.

If the inserted battery is *fully charged*, the –dV control will signal a charge stop after six measurements (approximately 110 seconds). All the above mentioned functions are recognised during the first 5 minutes according to –dV method. During this time, $+d^2V/dt^2$ remains inactive. In this way the battery is protected from unnecessary damage.

d^2V/dt^2-Gradient

If there is no charge stop within the first 5 minutes after battery insertion, then d^2V/dt^2 monitoring will be active. In this actual charge stage, all stop-charge criteria are active.

When close to the battery’s capacity limit, the battery voltage curve will typically rise. As long as the $+d^2V/dt^2$ stop-charging criteria are met, the device will stop the fast charge activities.

Top-Off Charge Stage

By charge disconnection through the $+d^2V/dt^2$ mode, the device switches automatically to a defined protective top-off charge with a pulse rate of 1/4 I_O (pulse time, t_p = 5.12 s, period, T = 20.48 s).

The top-off charge time is specified for a maximum time of 10 minutes @ 800 Hz. A voltage drop during top-off charge leads to the –dV switch-off.

Trickle Charge Stage

When top-off charge is terminated, the device switches automatically to trickle charge with 1/16 I_O (t_p = 320 ms, period = 5.12 s). The trickle continues until the battery pack is removed.

Basic Description

Power Supply, Figure 2

The charge controller allows the direct power supply of 8 V to 26 V at Pin 15.Internal regulation limits higher input voltages. Series resistance, R_1, regulates the supply current, I_S, to a maximum value of 25 mA. Series resistance is recommended to suppress the noise signal, even below 26 V limitation. It is calculated as follows.

$$R_{1min} \geq \frac{V_{max} - 26\ V}{25\ mA}$$

$$R_{1max} \leq \frac{V_{min} - 8\ V}{I_{tot}}$$

where

$I_{tot} = I_S + I_{RB1} + I_1$

V_{max}, V_{min} = Rectified voltage

I_S = Current consumption (IC) without load

I_{RB1} = Current through resistance, R_{B1}

I_1 = Trigger current at Pin 1

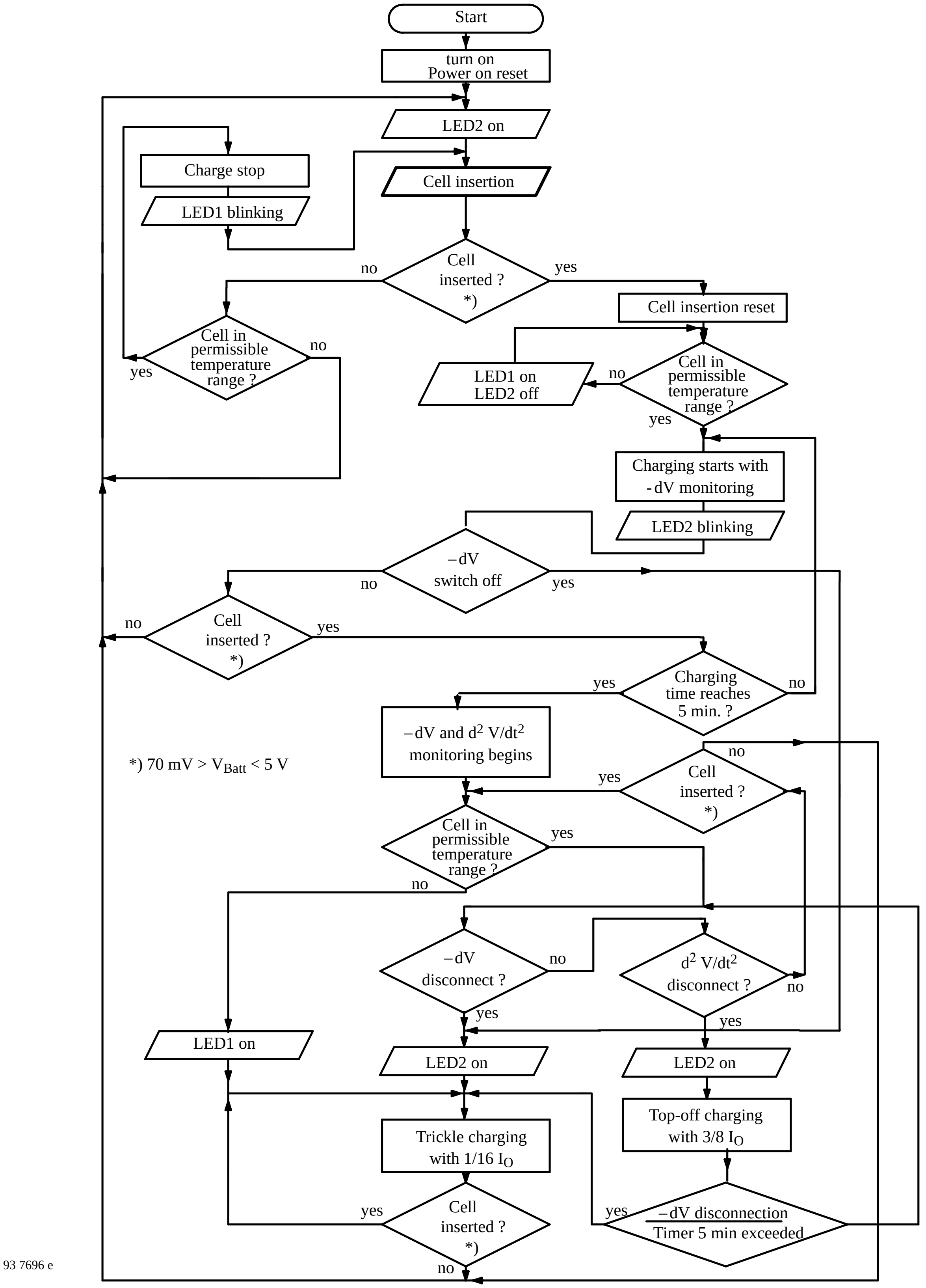


Figure 4. Flow chart

Battery Voltage Measurement

The battery voltage measurement at Pin 10 (ADC-converter) has a range of 0 V to 4 V, which means a battery pack containing two cells can be connected without a voltage divider.

Precaution should be taken that under specified charge current conditions, the final voltage at the input of the converter, Pin 10, should not exceed the threshold voltage level of the reset comparator, which is 5 V. When the battery is removed, the input (Pin 10) is terminated across the pulled-up resistance, $R_{B1,}$ to the value of 5 V-reset-threshold. In this way, the start of a new charge sequence is guaranteed when a battery is reinserted.

If the battery voltage exceeds the converter range of 4 V, adjusting it by the external voltage divider resistance, R_{B2} and R_{B3} is recommended.

Value of the resistance, R_{B3} is calculated by assuming R_{B1} = 1 kΩ, R_{B2} = 10 kΩ, as follows:

$$R_{B3} = R_{B2}\,\frac{V_{10max}}{V_{Bmax} - V_{10max}}$$

The minimum supply voltage, V_{smin}, is calculated for reset function after removing the inserted battery according to:

$$V_{smin} = \frac{0.03mA \cdot R_{B3}(R_{B1} + R_{B2}) + 5V\ (R_{B1} + R_{B2} + R_{B3}}{R_{B3}}$$

where:

V_{10max} = Max voltage at Pin 10
V_{Smin} = Min supply voltage at the IC (Pin 15)
V_{Bmax} = Max battery voltage

The voltage conditions mentioned above are measured during charge current break (switch-off condition).

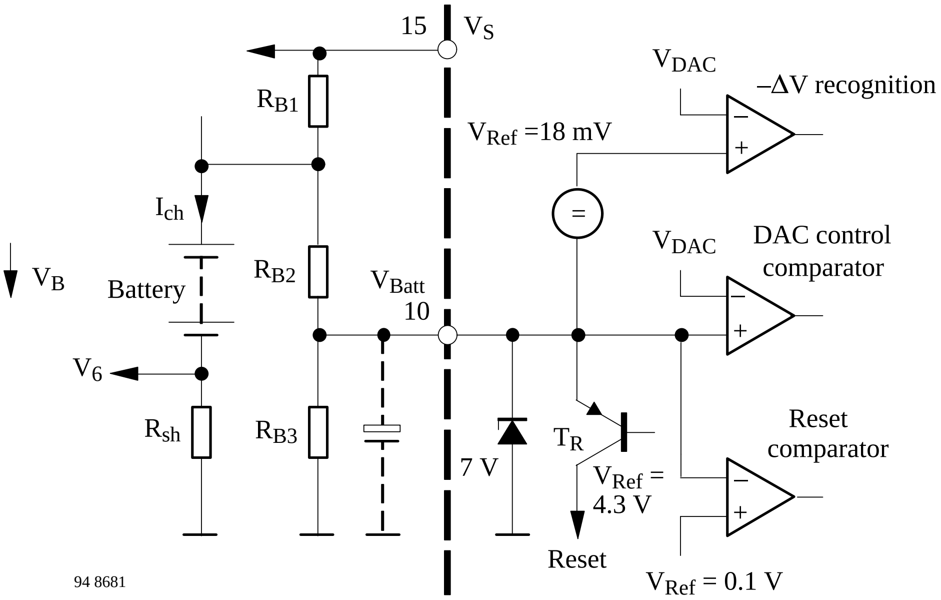


Figure 5. Input configuration for the battery voltage measurement

Table 1. valid when V_{10max} = 3.5 V

Cell No.	1	2	3	4	5	6	7	8	9	10	11	12
V_{Smin} (V)	8	8	8	9	11	13	15	17	19	21	23	25
R_{B3} (kΩ)	–	–	51	16	10	7.5	5.6	4.7	3.9	3.3	3	2.7

Analog-Digital-Converter (ADC), Test Sequence

A special analog-digital-converter consists of a five-bit coarse and a five-bit fine converter . It operates by a linear count method which can digitalize a battery voltage of 4 V at Pin 10 in 6.5 mV steps of sensitivity.

In a duty cycle, T, of 20.48 s, the converter executes the measurement from a standard oscillation frequency of f_{osc} = 800 Hz. The voltage measurement is during the charge break time of 2.56 s (see figure 6), i.e., no-load voltage (or currentless phase). Therefore it has optimum measurement accuracy because all interferences are cut-off during this period (e.g., terminal resistances or dynamic load current fluctuations).

After a delay of 1.28 s the actual measurement phase of 1.28 s follows. During this idle interval of cut-off conditions, battery voltage is stabilized and hence measurement is possible.

An output pulse of 10 ms appears at Pin 9 during charge break after a delay of 40 ms. The output signal can be used in a variety of way, e.g., synchronising the test control (reference measurement).

Plausibility for Charge Break

There are two criterian considered for charge break plausibility:

– dV Cut-Off

When the signal at Pin 10 of the DA converter is 18 mV below the actual value, the comparator identifies it as a voltage drop of – dV. The validity of – dV cutt-off is considered only if the actual value is below 18 mV for three consective cycles of measurement.

d^2V/dt^2 Cut-Off

A four bit forward/ backward counter is used to register the slope change (d^2V/dt^2, V_{Batt} – slope). This counter is clocked by each tracking phase of the fine AD-counter. Beginning from its initial value, the counter counts the first eight cycles in forward direction and the next eight cycles in reverse direction. At the end of 16 cycles, the actual value is compared with the initial value. If there is a difference of more than two LSB-bit (13.5 mV) from the actual counter value, then there is an identification of slope change which leads to normal charge cut-off. A second counter in the same configuration is operating in parallel with eight clock cycles delay, to reduce the total cut-off delay, from 16 test cycles to eight test cycles.

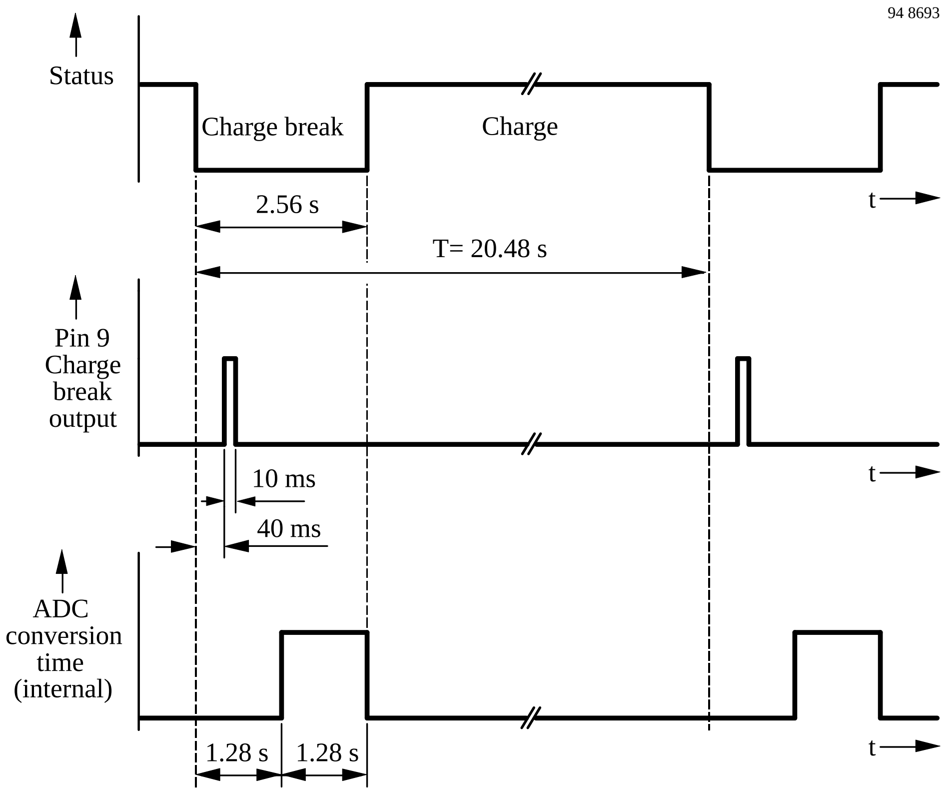


Figure 6. Operating sequence of voltage measurements

Temperature Control, Figure 7

When the battery temperature is not inside the specified *temperature windows*, the overal temperature control will not allow the charge process. Sensor short circuit or interruption also leads to switch-off.

Differentiation is made whether the battery exceeds the maximum allowable temperature, T_{max}, during the charge phase or the battery temperature is outside the temperature window range before battery connection.

A permanent switch-off follows after a measurement period of 20.48 s, if the temperature exceeds a specified level, which is denoted by a status of a red LED_1. A charge sequence will start only when the specified window temperature range is attained. In such a case, the green LED_2 starts blinking immediately showing a quasi *charge readiness*, even though there is no charge current flow.

The temperature window is specified between two voltage transitions. The upper voltage transition is specified by the internal reference voltage of 4 V, and the lower voltage transition is represented by the external voltage divider resistances R_{T2} and R_{T3}.

NTC sensors are normally used to control the temperature of the battery pack. If the resistance values of NTC are known for maximum and minimum conditions of allowable temperature, then other resistance values, R_{T1}, R_{T2} and R_{T3} are calculated as follows:

suppose R_{T2} = 100 kΩ, then

$$R_{T1} = R_{NTCmax}\,\frac{V_{Ref} - 4V}{4V}$$

$$R_{T3} = R_{NTCmin}\,\frac{R_{T2}}{R_{T1}}$$

If NTC sensors are not used, then select the circuit configuration according to figure 10.

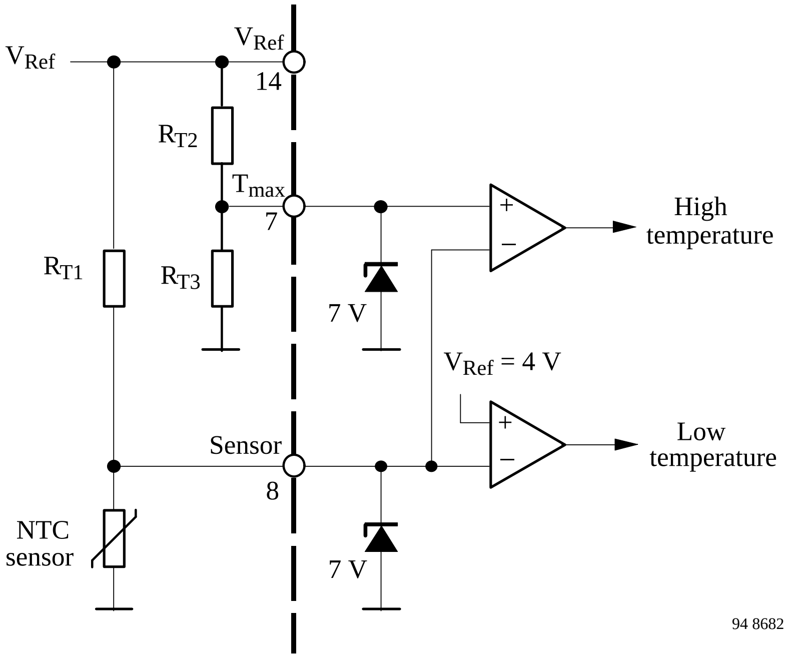


Figure 7. Temperature window

Current Regulation Via Phase Control (Figure 8)

Phase Control

An internal phase control monitors the angle of current flow through the external thyristors as shown in figure 2. The phase control block represents a ramp generator synchronised by mains zero cross over and a comparator.

The comparator will isolate the trigger output, Pin 1, until the end of the half wave (figure 8) when the ramp voltage, V_{ramp}, reaches the control voltage level, $V\varphi_i$, within a mains half wave.

Charge Current Regulation (Figure 2)

According to figure 2 the operational amplifier (OpAmp) regulates the charge current, I_{ch} (= 160 mV / R_{sh}), average value. The OpAmp detects the voltage drop across the shunt resistor (R_{sh}) at input Pin 6 as an actual value. The actual value will then be compared with an internal reference value (rated value of 160 mV).

The regulator’s output signal, V_5, is at the same time the control signal of the phase control, $V\varphi_i$ (Pin 4). In the adjusted state, the OpAmp regulates the current flow angle through the phase control until the average value at the shunt resistor reaches the rated value of 160 mV.

The corresponding evaluation of capacitor C_R at the operational amplifier (regulator) output determines the dynamic performance of current regulation.

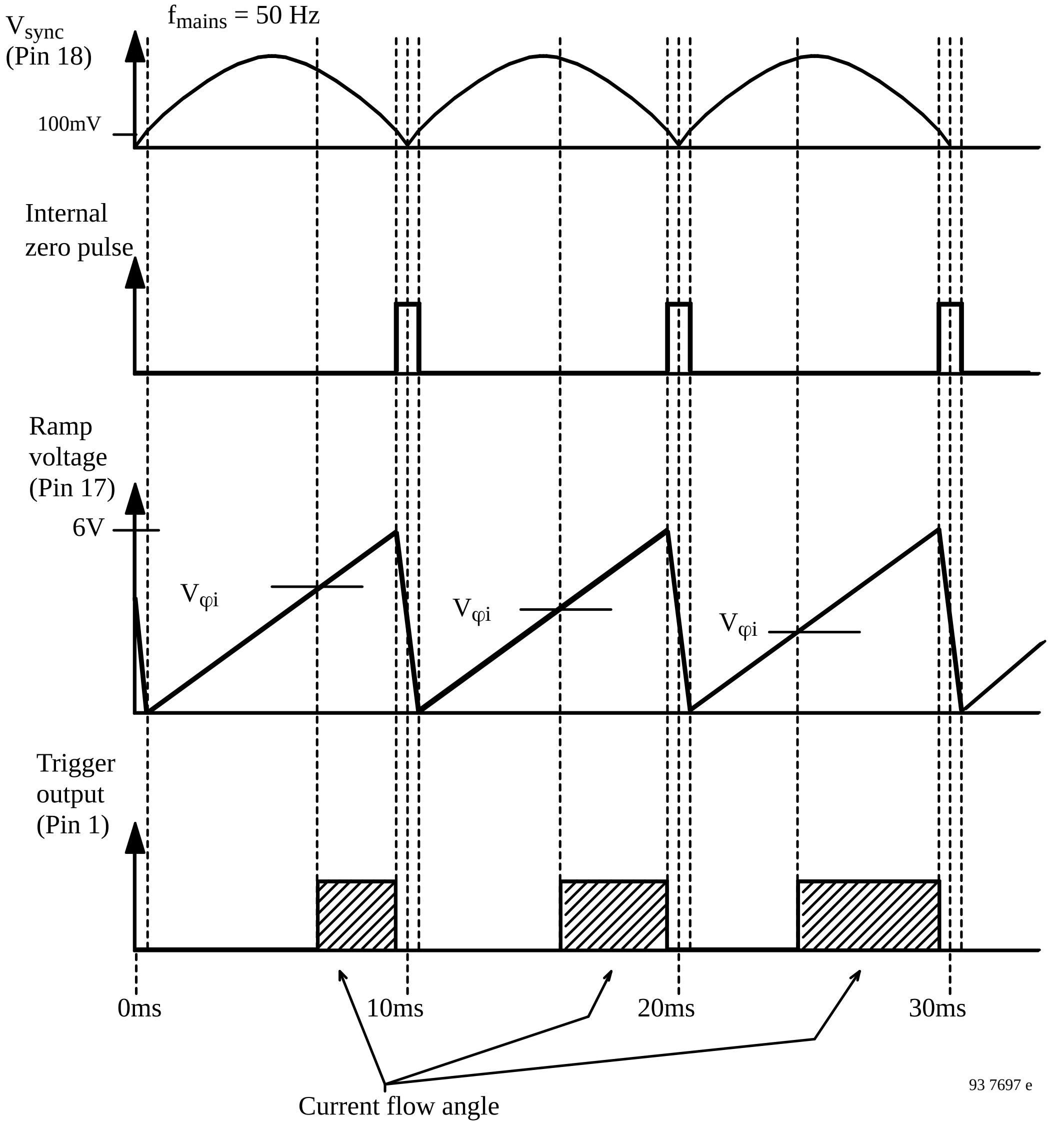


Figure 8. Phase control function diagram

Status Control

Status control inside and outside the charging process are designated by LED_1 and LED_2 outputs given in the table below:

LED1 (red)	LED2 (green)	Status
OFF	ON	No battery, top off charge, trickle charge
OFF	Blinking	Quick charge, temperature out of the window before battery insertion or power on
ON	OFF	Temperature out of the window
Blinking	OFF	Battery break (interrupt) or short circuit

The blink frequency of LED outputs can be calculated as follows:

$$f_{(LED)} = \frac{\text{Oscillator frequency, } f_{osc}}{1024}$$

Oscillator

Time sequences regarding measured values and evaluation are determined by the system oscillator. All the technical data given in the description are with the standard frequency 800 Hz.

It is possibe to alter the frequency range in a certain limitation. Figure 9 shows the frequency versus resistance curves with different capacitance values.

Oscillation Frequency Adjustment

Recommendations:

0.5C charge	0.5 × 500 Hz =	250 Hz
1C charge		500 Hz
2C charge	2 × 500 Hz =	1000 Hz
3C charge	3 × 500 Hz =	1500 Hz

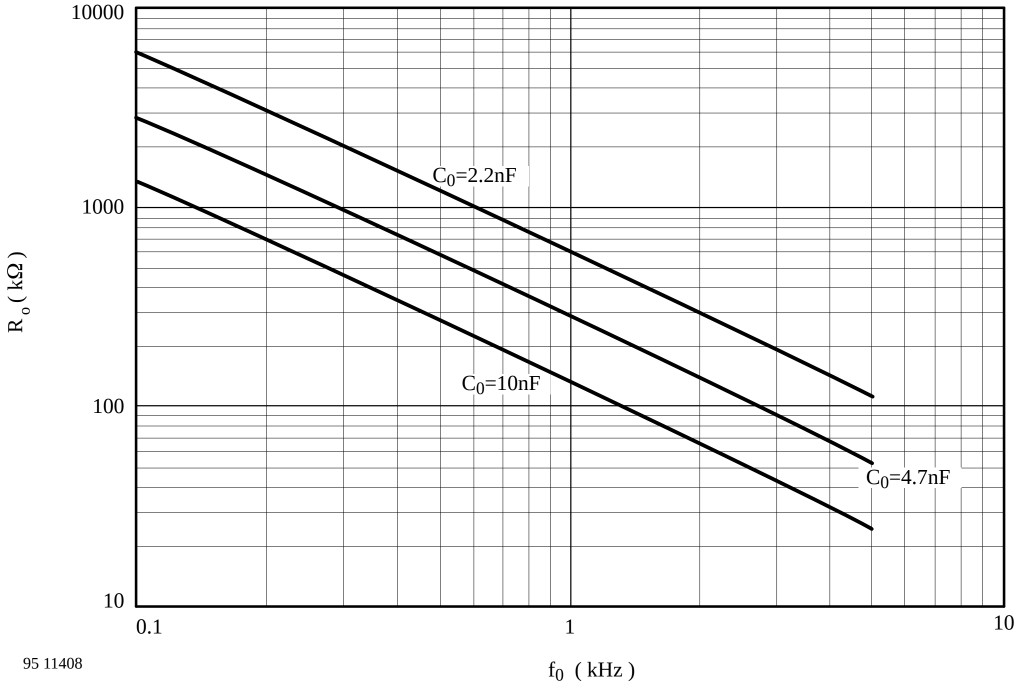


Figure 9. Frequency versus resistance for different capacitance values

Absolute Maximum Ratings

Reference point Pin 2 (GND), unless otherwise specified

Parameters		Symbol	Value	Unit
Supply voltage	Pin 15	V_S	26	V
Voltage limitation	I_S = 10 mA	V_S	31	V
Current limitation t < 100 µs	Pin 15	I_S	25 100	mA
Voltages at different pins	Pins 1, 3 and 11 Pins 4 to 10, 12 to 14 and 16 to 18	V	26 7	V
Currents at different pins	Pin 1 Pins 3 to 14 and 16 to 18	I	25 10	mA
Power dissipation	T_{amb} = 60°C	P_{tot}	650	mW
Ambient temperature range		T_{amb}	– 10 to 85	°C
Junction temperature		T_j	125	°C
Storage temperature range		T_{stg}	– 40 to 125	°C

Thermal Resistance

Parameters	Symbol	Maximum	Unit
Junction ambient	R_{thJA}	100	K/W

Electrical Characteristics

V_S = 12 V, T_{amb} = 25°C, reference point Pin 2 (GND), unless otherwise specified.

Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Power supply	Pin 15					
Voltage range		V_S	8		26	V
Power-on threshold	ON OFF	V_S	3.0 4.7		3.8 5.7	V V
Current consumption	without load	I_S	3.9		9.1	mA
Reference	Pin 14					
Reference voltage	I_{Ref} = 5 mA I_{Ref} = 10 mA	V_{Ref}	6.19 6.14	6.5 6.5	6.71 6.77	V V
Reference current		$-I_{Ref}$			10	mA
Temperature coefficient		TC		– 0.7		mV/K
Operational amplifier OP						
Output voltage range	I_5 = 0 Pin 5	V_5	0.15		5.8	V
Output current range	V_5 = 3.25 V Pin 5	$\pm I_5$	80			µA
Output pause current	Pin 5	$\pm I_{pause}$	100			µA
Non-inverting input voltage	Pin 6	V_6	0		5	V
Non-inverting input current	Pin 6	$\pm I_6$			0.5	µA

Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Comparator or Temperature control						
Input current	Pin 7, 8	$I_{7,\,8}$	– 0.5		0.5	µA
Input voltage range	Pin 7, 8	$V_{7,\,8}$	0		5	V
Threshold voltage	Pin 8	V_8	3.85		4.15	V
Charge break output	Pin 9					
Output voltage	High, I_9 = 4 mA Low, I_9 = 0 mA	V_9	8.4		 100	V mV
Output current	V_9 = 1 V	I_9	10			mA
Battery detection Pin 10						
Analog-digital converter	Conversion range Full scale level	V_{Batt}	0 3.85		4.0	V
Input current	0.1 V $\leq$ V_{Batt} $\leq$ 4.5 V	– I_{Batt}			0.5	µA
Input voltage for reset		V_{Batt}	4.8	5.0	5.3	V
Input current for reset	V_{Batt} $\geqq$ 5 V	I_{Batt}	8		35	µA
Battery detection	Maximum voltage	Δ V_{Batt}	80		120	mV
Hysteresis	Maximum voltage	V_{hys}		15		mV
Mode select	Pin 12					
Threshold voltage	Test mode	V_{12}			4.7	V
Input current	Normal mode Open	I_{12}	20 0			µA
Sync. oscillator	Pin 13					
Frequency	R = 150 kΩ C = 10 nF	f_{osc}		800		Hz
Threshold voltage	High level Low level	$V_{T(H)}$ $V_{T(L)}$		4.3 ±3% 2.2 ±3%		V
Input current		I_{13}	– 0.5		0.5	µA
Phase control						
Ramp voltage	R_{φ} = 270 kΩ Pin 16	V_{16}	2.9		3.9	V
Ramp current		I_{16}	0		100	µA
Ramp voltage range		V_{17}	0		5	V
Ramp discharge current		I_{17}	3.3		8	mA
Synchronisation	Pin 18					
Minimum current	V_{sync} $\leq$ 80 mV	– I_{sync}	10		2	µA
Maximum current	V_{sync} = 0 V	– I_{sync}	15		30	µA
Zero voltage detection		V_{sync}	83	100	135	mV
Hysteresis		V_{hys}		15		mV
Charge stop criteria (function)	Pin 10					
Positive gradient-turn-off threshold	f_{osc} = 800 Hz	d^2V/dt^2		4.8		mV/ min^2
– dV-turn-off threshold		– dV		18		mV

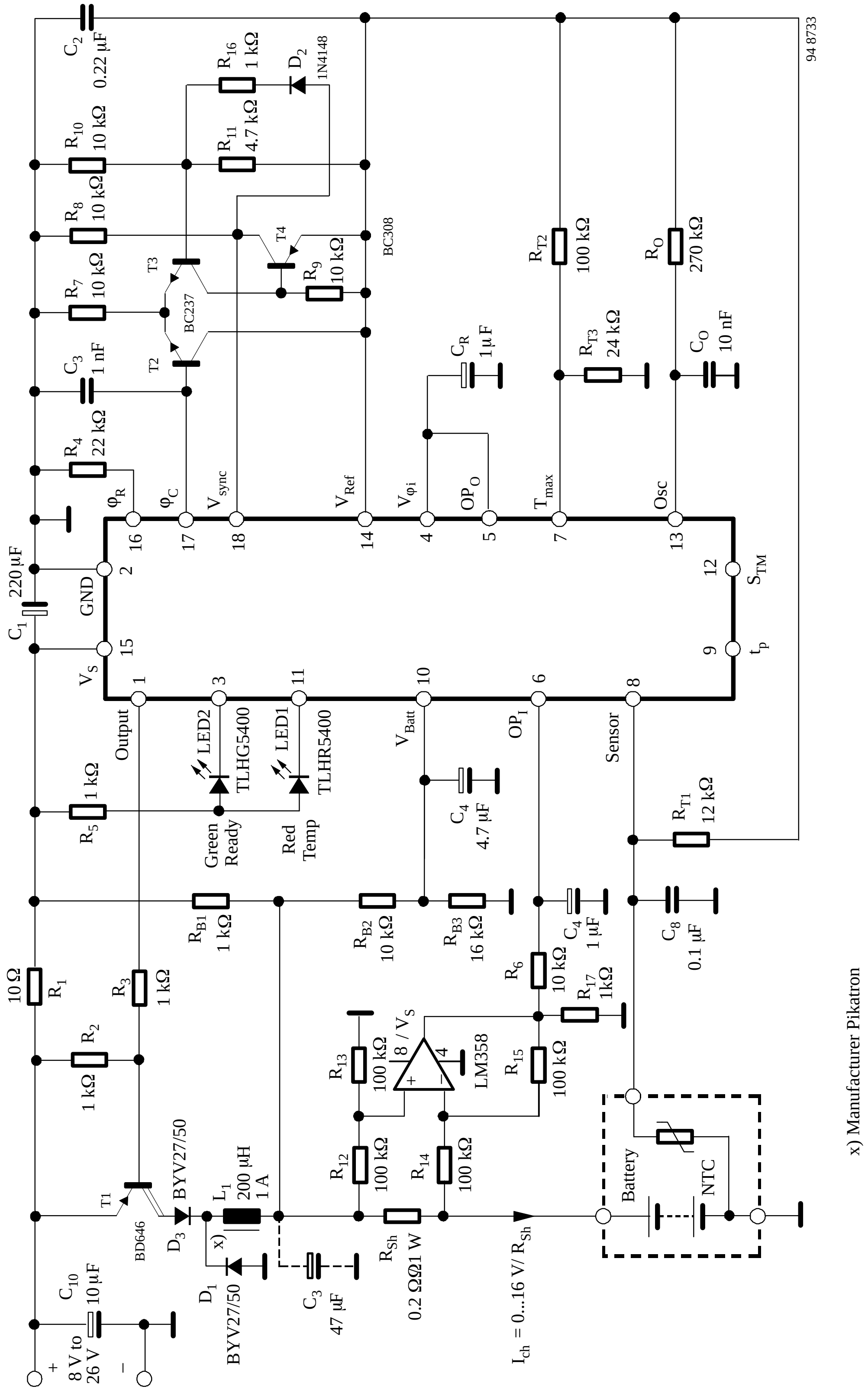


Figure 10. Car battery supplied charge system with high side current detection for four NiCd/NiMH cells @ 800 mA

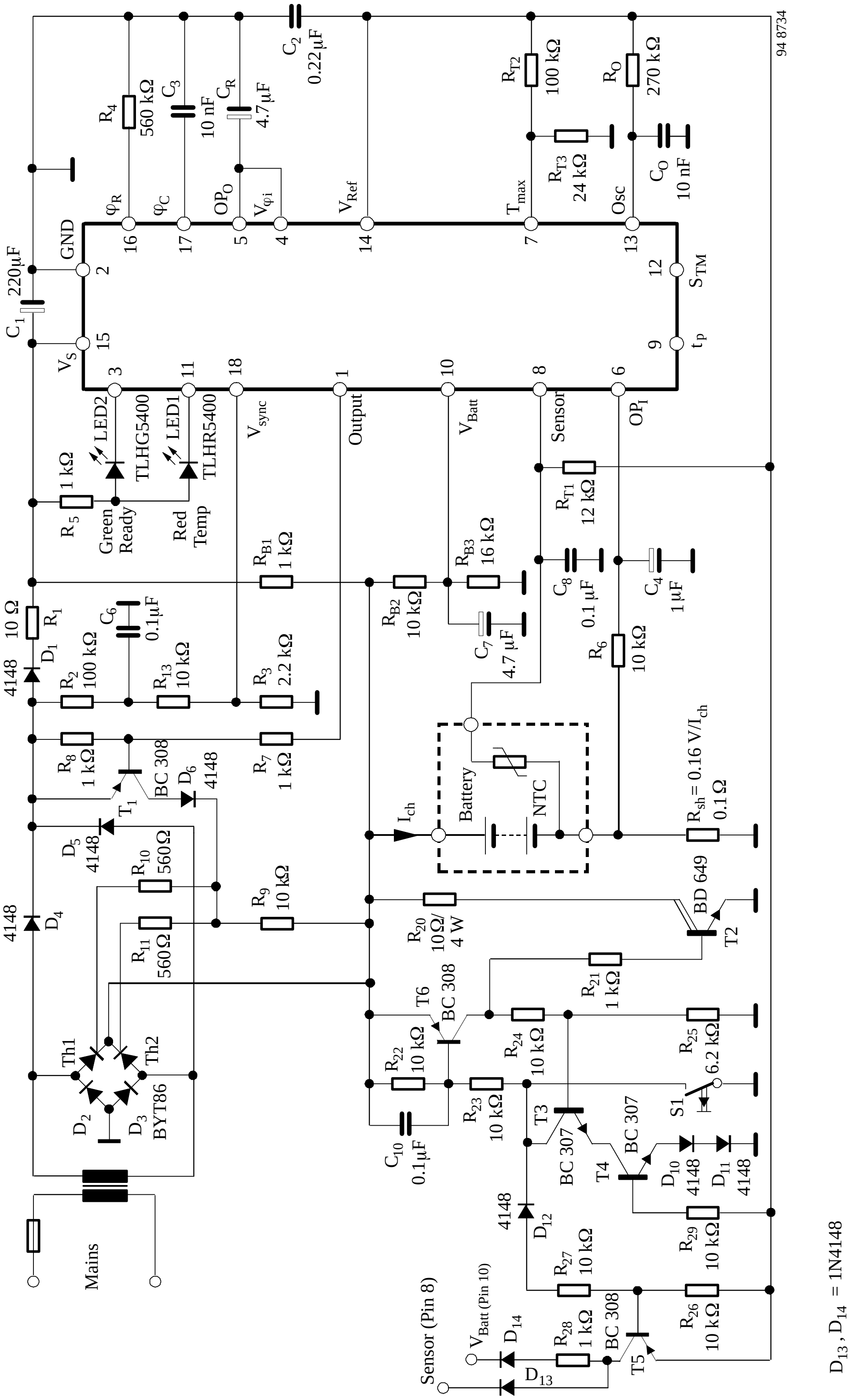
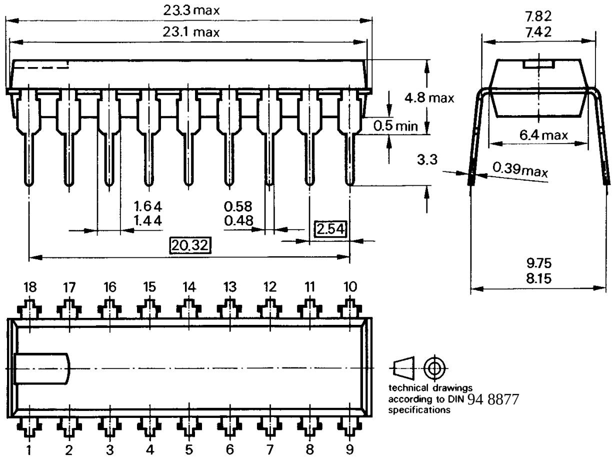


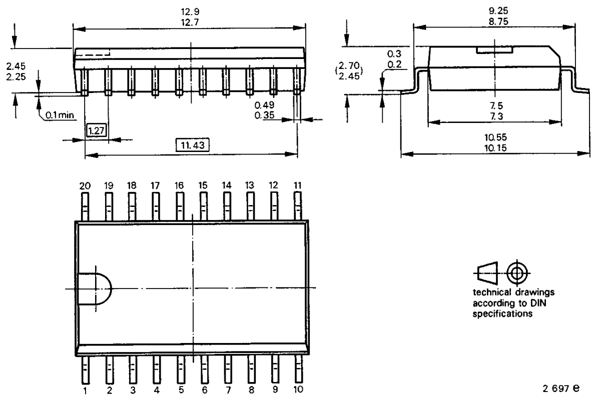
Figure 11. Standard application with predischarge for 8 NiCd/NiMH cells @ 1600 mA

Dimensions in mm

Package: DIP18



Package: SO20



Ozone Depleting Substances Policy Statement

It is the policy of **TEMIC TELEFUNKEN microelectronic GmbH** to

1. Meet all present and future national and international statutory requirements.

2. Regularly and continuously improve the performance of our products, processes, distribution and operating systems with respect to their impact on the health and safety of our employees and the public, as well as their impact on the environment.

It is particular concern to control or eliminate releases of those substances into the atmosphere which are known as ozone depleting substances (ODSs).

The Montreal Protocol (1987) and its London Amendments (1990) intend to severely restrict the use of ODSs and forbid their use within the next ten years. Various national and international initiatives are pressing for an earlier ban on these substances.

TEMIC TELEFUNKEN microelectronic GmbH semiconductor division has been able to use its policy of continuous improvements to eliminate the use of ODSs listed in the following documents.

1. Annex A, B and list of transitional substances of the Montreal Protocol and the London Amendments respectively

2. Class I and II ozone depleting substances in the Clean Air Act Amendments of 1990 by the Environmental Protection Agency (EPA) in the USA

3. Council Decision 88/540/EEC and 91/690/EEC Annex A, B and C (transitional substances) respectively.

TEMIC can certify that our semiconductors are not manufactured with ozone depleting substances and do not contain such substances.

We reserve the right to make changes to improve technical design and may do so without further notice. Parameters can vary in different applications. All operating parameters must be validated for each customer application by the customer. Should the buyer use TEMIC products for any unintended or unauthorized application, the buyer shall indemnify TEMIC against all claims, costs, damages, and expenses, arising out of, directly or indirectly, any claim of personal damage, injury or death associated with such unintended or unauthorized use.

TEMIC TELEFUNKEN microelectronic GmbH, P.O.B. 3535, D-74025 Heilbronn, Germany
Telephone: 49 (0)7131 67 2831, Fax number: 49 (0)7131 67 2423

Fast Charge Controller for NiCd/NiMH Batteries

Description

The fast charge battery controller circuit, U2402B-C, uses bipolar technology. It enables an efficient and economic charge system. It incorporates intelligent multiple gradient battery voltage monitoring and mains phase control for power management. With automatic top-off charging, the integrated circuit enables the charge device to stop regular charging, before the critical stage of overcharging can occur. It has two LED driver indications for charge and temperature status.

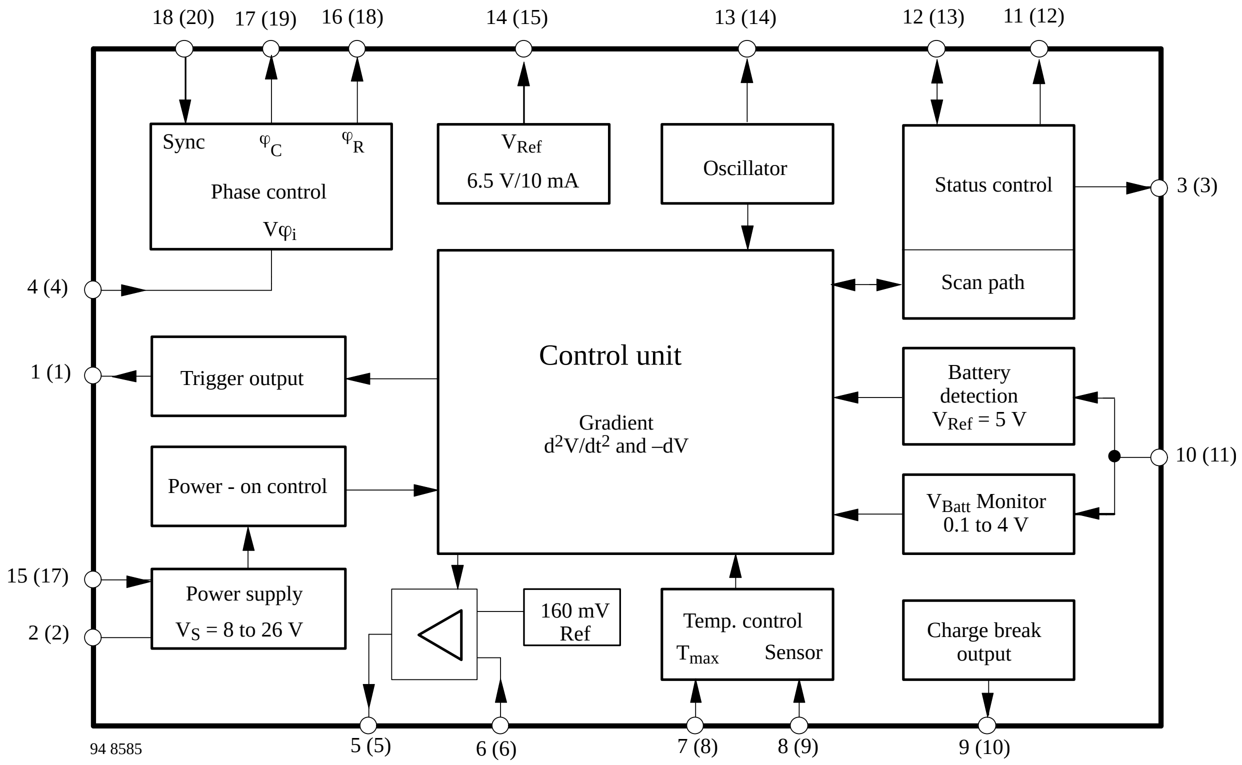
Features

- Multiple gradient monitoring
- Temperature window (T_{min}/T_{max})
- Exact battery voltage measurement without charge
- Phase control for charge current regulation
- Top off and trickle charge function
- Two LED outputs for charge status indication
- Disabling of d^2V/dt^2 switch-off criteria during battery formation
- Battery voltage check

Applications

- Portable power tools
- Laptop/notebook personal computer
- Cellular/cordless phones
- Emergency lighting systems
- Hobby equipment
- Camcorder

Package: DIP18, SO20

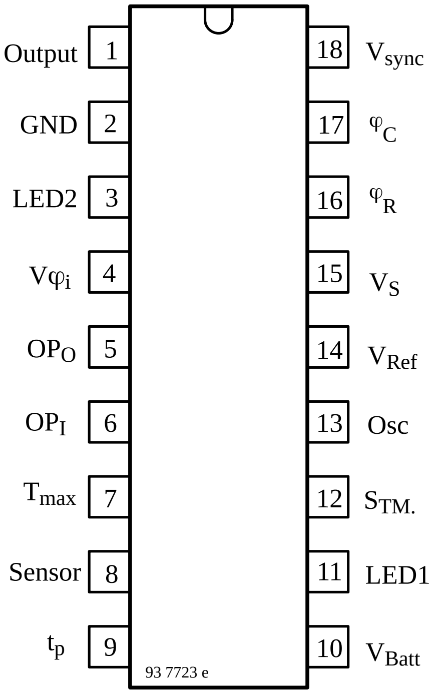


( ) SO 20, Pins 7 and 16 NC

Figure 1. Block diagram

Pinning

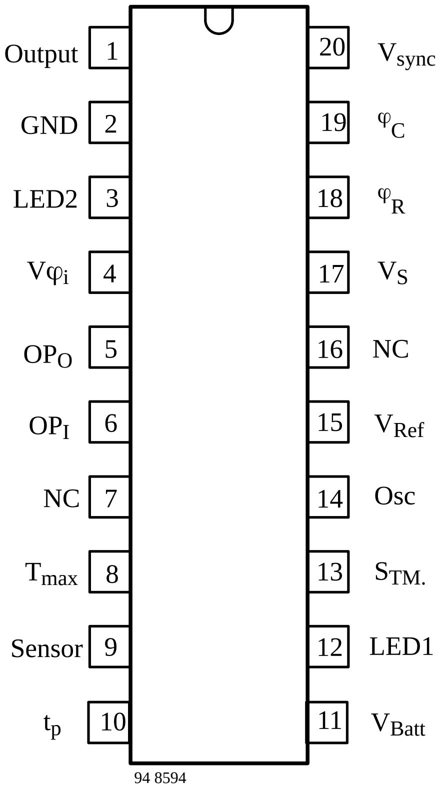
Package: DIP18



Pin Description

Pin	Symbol	Function
1	Output	Trigger output
2	GND	Ground
3	LED2	Display output “Green”
4	$V\varphi_i$	Phase angle control input voltage
5	OP_O	Operational amplifier output
6	OP_I	Operational amplifier input
7	T_{max}	Maximum temperature
8	Sensor	Temperature sensor
9	t_p	Charge break output
10	V_{Batt}	Battery voltage
11	LED1	LED display output “Red”
12	$S_{TM.}$	Test mode switch (status control)
13	Osc	Oscillator
14	V_{Ref}	Reference output voltage
15	V_S	Supply voltage
16	φ_R	Ramp current adjustment – resistance
17	φ_C	Ramp voltage – capacitance
18	$V_{sync.}$	Mains synchronisation input

Package: SO20



Pin	Symbol	Function
1	Output	Trigger output
2	GND	Ground
3	LED2	Display output “Green”
4	$V\varphi_i$	Phase angle control input voltage
5	OP_O	Operational amplifier output
6	OP_I	Operational amplifier input
7	NC	Not connected
8	T_{max}	Maximum temperature
9	Sensor	Temperature sensor
10	t_p	Charge break output
11	V_{Batt}	Battery voltage
12	LED1	LED display output “Red”
13	$S_{TM.}$	Test mode switch (status control)
14	Osc	Oscillator
15	V_{Ref}	Reference output voltage
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17	V_S	Supply voltage
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19	φ_C	Ramp voltage – capacitance
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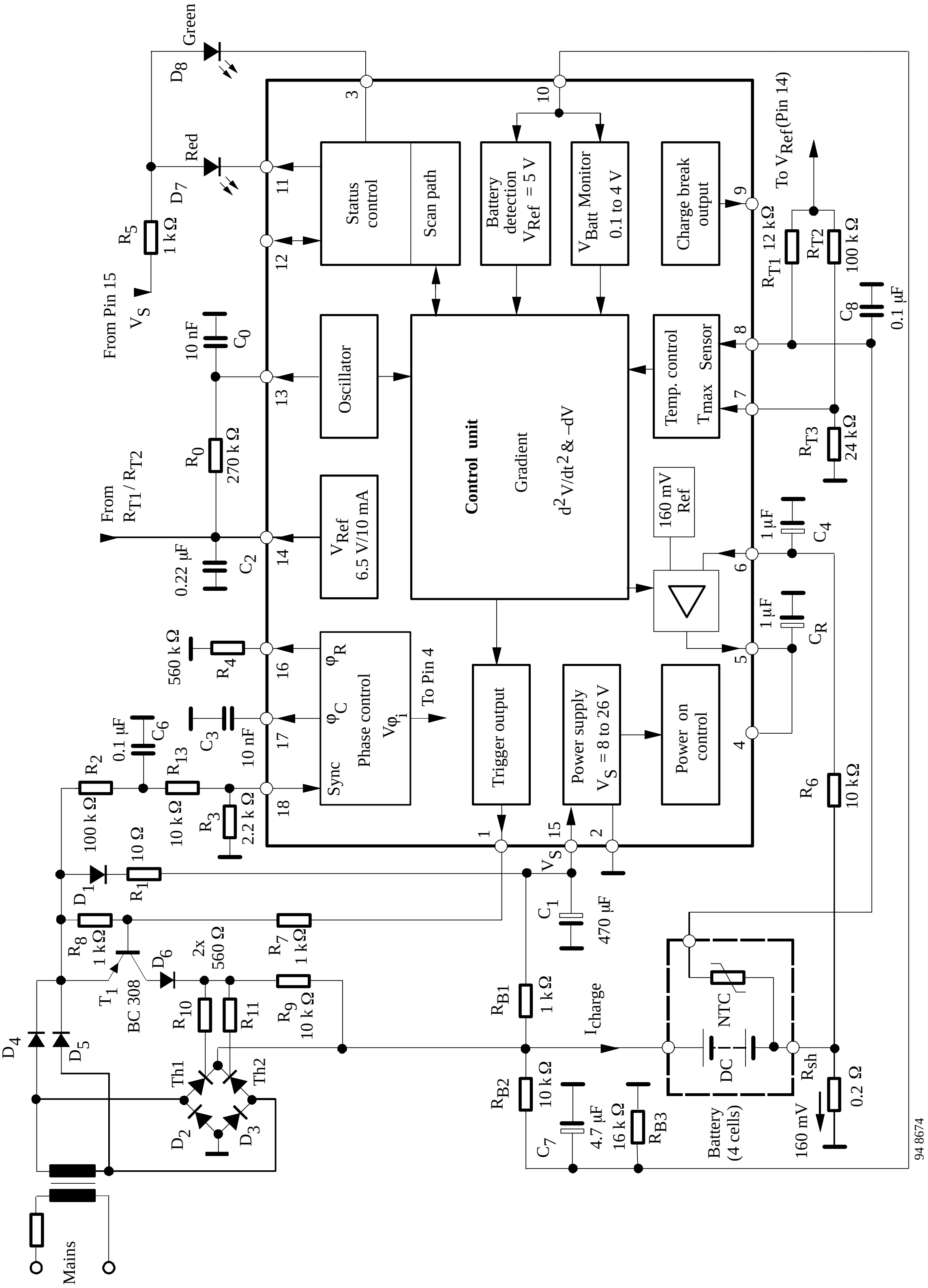


Figure 2. Block diagram with external circuit (DIP pinning)

General Description

The integrated circuit, U2402B-C, is designed for charging Nickel-Cadmium (NiCd) and Nickel-Metal-Hydride (NiMH) batteries. Fast charging results in voltage lobes when fully charged (figure 3). It supplies two identifications (i.e., + d^2V/dt^2, and – dV) to end the charge operation at the proper time.

As compared to the existing charge concepts where the charge is terminated – after voltage lobes – according to – dV and temperature gradient identification, the U2402B-C takes into consideration the additional changes in positive charge curves, according to the second derivative of the voltage with respect to time (d^2V/dt^2). The charge identification is the sure method of switching off the fast charge before overcharging the battery. This helps to give the battery a long life by hindering any marked increase in cell pressure and temperature.

Even in critical charge applications, such as a reduced charge current or with NiMH batteries where weaker charge characteristics are present multiple gradient control results in very efficient switch-off.

An additional temperature control input increases not only the performances of the charge switching characteristics but also prevents the general charging of a battery whose temperature is outside the specified window.

A constant charge current is necessary for continued charge-voltage characteristic. This constant current regulation is achieved with the help of internal amplifier phase control and a simple shunt-current control technique.

All functions relating to battery management can be achieved with dc-supply charge systems. A dc-dc-converter or linear regulator should take over the function of power supply. For further information please refer to the applications.

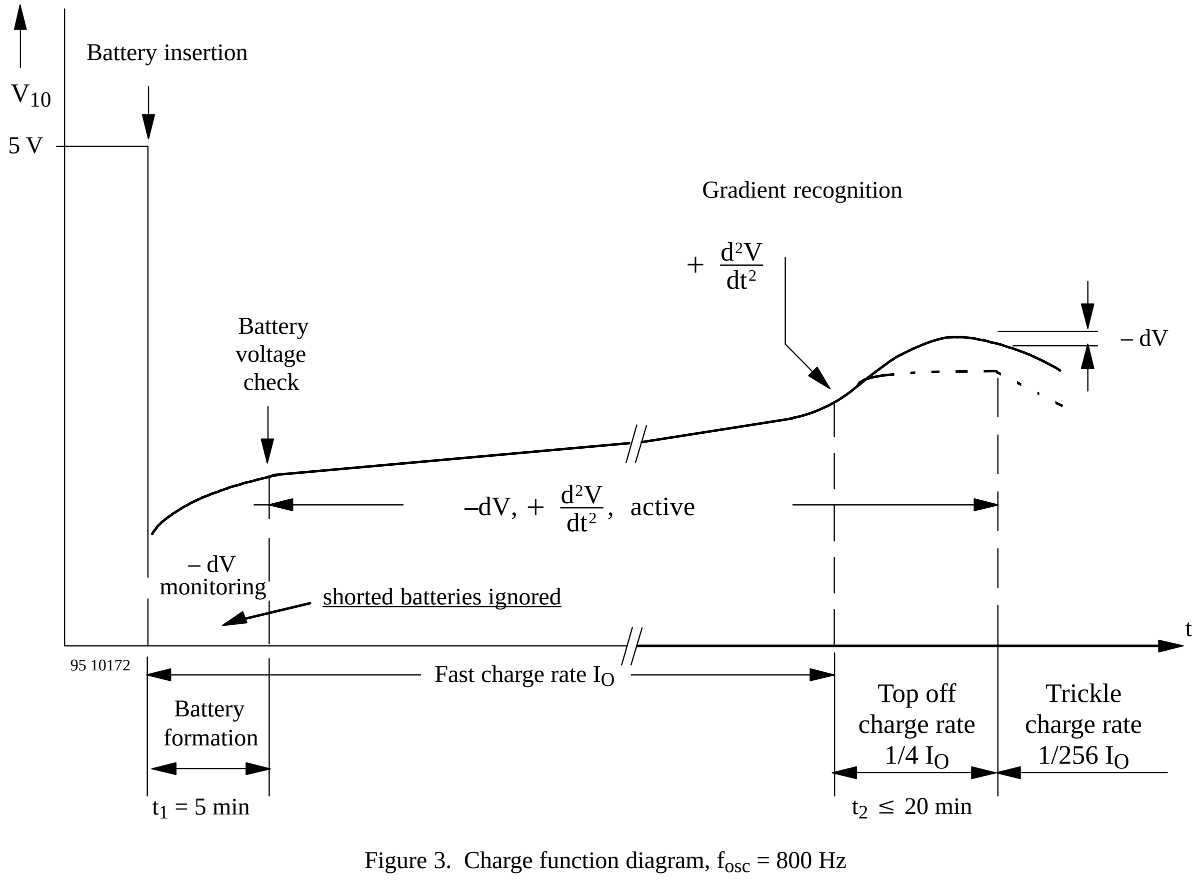


Figure 3. Charge function diagram, f_{osc} = 800 Hz

Flow Chart Explanation, f_{osc} = 800 Hz (Figures 2, 3 and 4)

Battery pack insertion disables the voltage lock at battery detection input Pin 10. All functions in the integrated circuit are reset. For further description, DIP-pinning is taken into consideration.

Battery Insertion and –dV Monitoring

The charging procedure will be carried out if battery insertion is recognised. If the polarity of the inserted battery is not according to the specification, the fast charge rate will stop immediately. After the polarity test, if positive, the defined fast charge rate, I_O, begins for the first 5 minutes according to –dV monitoring. After 5 minutes of charging, the first identification control is executed.

If the inserted battery has a signal across its terminal of less than 0.1 V, then the charging procedure is interrupted. This means that the battery is defective i.e., it is not a rechargeable battery – “shorted batteries ignored”.

Voltage and temperature measurements across the battery are carried out during charge break interval (see figure 6), i.e., currentless or idle measurements.

If the inserted battery is *fully charged*, the –dV control will signal a charge stop after six measurements (approximately 110 seconds). All the above mentioned functions are recognised during the first 5 minutes according to –dV method. During this time, $+d^2V/dt^2$ remains inactive. In this way the battery is protected from unnecessary damage.

d^2V/dt^2-Gradient

If there is no charge stop within the first 5 minutes after battery insertion, then d^2V/dt^2 monitoring will be active. In this actual charge stage, all stop-charge criteria are active.

When close to the battery’s capacity limit, the battery voltage curve will typically rise. As long as the $+d^2V/dt^2$ stop-charging criteria are met, the device will stop the fast charge activities.

Top-Off Charge Stage

By charge disconnection through the $+d^2V/dt^2$ mode, the device switches automatically to a defined protective top-off charge with a pulse rate of 1/4 I_O (pulse time, t_p = 5.12 s, period, T = 20.48 s).

The top-off charge time is specified for a time of 20 minutes @ 800 Hz.

Trickle Charge Stage

When top-off charge is terminated, the device switches automatically to trickle charge with 1/256 I_O (t_p = 5.12 s, period = 1310.72 s). The trickle continues until the battery pack is removed.

Basic Description

Power Supply, Figure 2

The charge controller allows the direct power supply of 8 V to 26 V at Pin 15. Internal regulation limits higher input voltages. Series resistance, R_1, regulates the supply current, I_S, to a maximum value of 25 mA. Series resistance is recommended to suppress the noise signal, even below 26 V limitation. It is calculated as follows.

$$R_{1min} \geq \frac{V_{max} - 26\ V}{25\ mA}$$

$$R_{1max} \leq \frac{V_{min} - 8\ V}{I_{tot}}$$

where

$I_{tot} = I_S + I_{RB1} + I_1$

V_{max}, V_{min} = Rectified voltage

I_S = Current consumption (IC) without load

I_{RB1} = Current through resistance, R_{B1}

I_1 = Trigger current at Pin 1

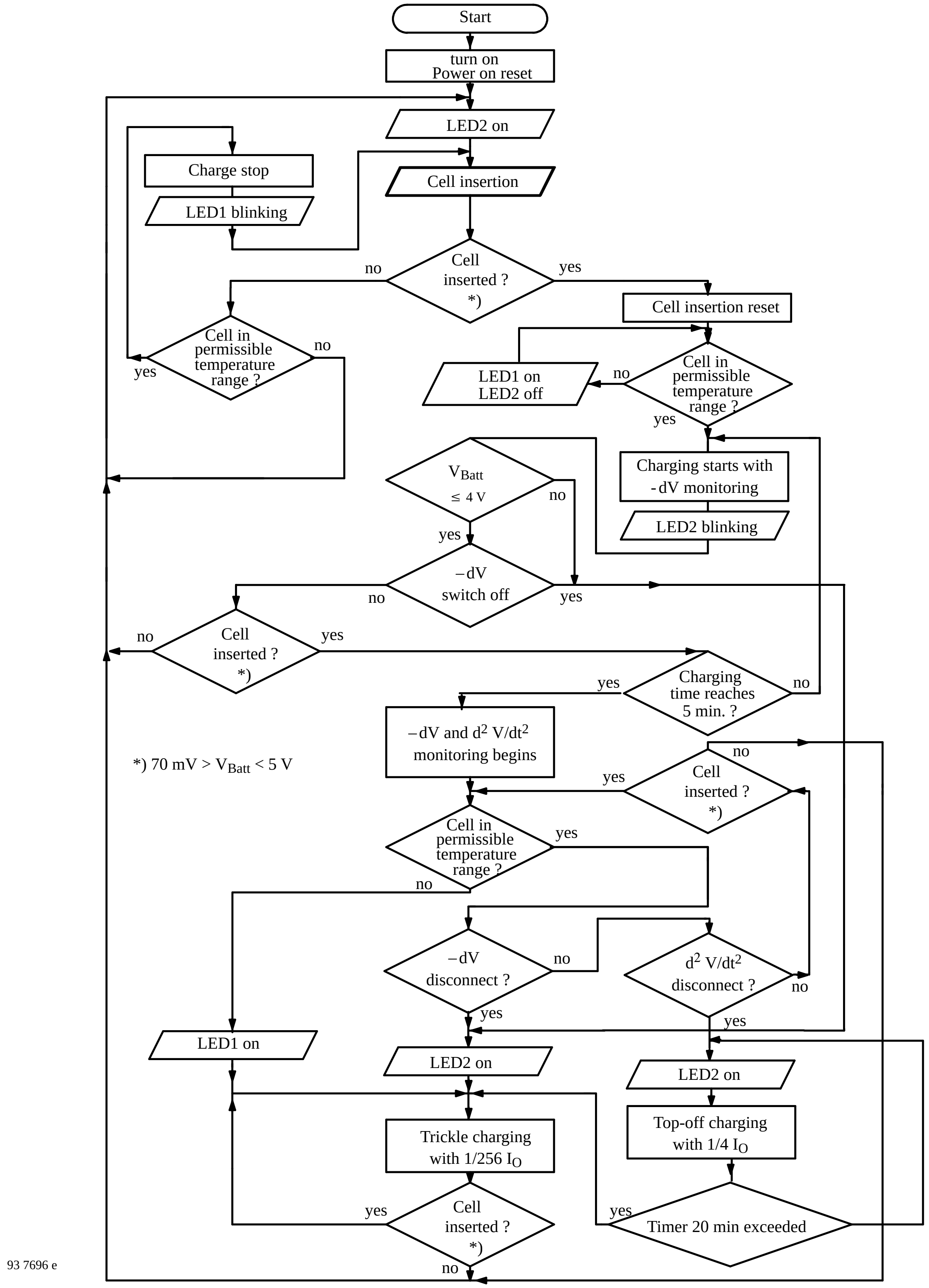


Figure 4. Flow chart

Battery Voltage Measurement

The battery voltage measurement at Pin 10 (ADC-converter) has a range of 0 V to 4 V, which means a battery pack containing two cells can be connected without a voltage divider.

If the AD converter is overloaded ($V_{Batt} \geq 4$ V) a safety switch off occurs. The fast charge cycle is terminated by automatically changing to the trickle charge.

Precaution should be taken that under specified charge current conditions, the final voltage at the input of the converter, Pin 10, should not exceed the threshold voltage level of the reset comparator, which is 5 V. When the battery is removed, the input (Pin 10) is terminated across the pulled-up resistance, R_{B1}, to the value of 5 V-reset-threshold. In this way, the start of a new charge sequence is guaranteed when a battery is reinserted.

If the battery voltage exceeds the converter range of 4 V, adjusting it by the external voltage divider resistance, R_{B2} and R_{B3} is recommended.

Value of the resistance, R_{B3} is calculated by assuming $R_{B1} = 1$ kΩ, $R_{B2} = 10$ kΩ, as follows:

$$R_{B3} = R_{B2} \frac{V_{10max}}{V_{Bmax} - V_{10max}}$$

The minimum supply voltage, V_{smin}, is calculated for reset function after removing the inserted battery according to:

$$V_{smin} = \frac{0.03mA \cdot R_{B3}(R_{B1} + R_{B2}) + 5V\ (R_{B1} + R_{B2} + R_{B3}}{R_{B3}}$$

where:

V_{10max} = Max voltage at Pin 10
V_{Smin} = Min supply voltage at the IC (Pin 15)
V_{Bmax} = Max battery voltage

The voltage conditions mentioned above are measured during charge current break (switch-off condition).

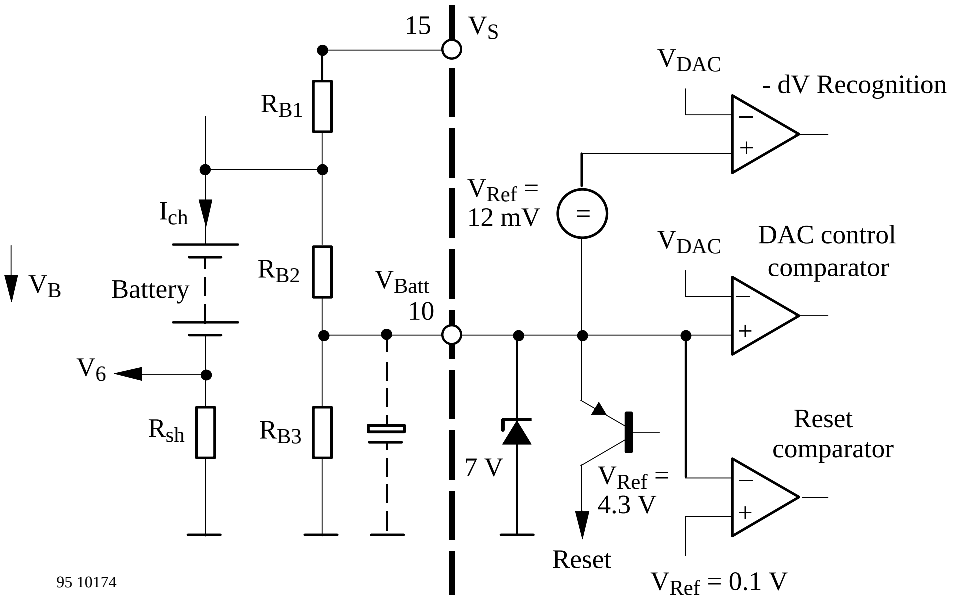


Figure 5. Input configuration for the battery voltage measurement

Table 1. valid when $V_{10max} = 3.5$ V

Cell No.	1	2	3	4	5	6	7	8	9	10	11	12
V_{Smin} (V)	8	8	8	9	11	13	15	17	19	21	23	25
R_{B3} (kΩ)	–	–	51	16	10	7.5	5.6	4.7	3.9	3.3	3	2.7

Analog-Digital-Converter (ADC), Test Sequence

A special analog-digital-converter consists of a five-bit coarse and a five-bit fine converter . It operates by a linear count method which can digitalize a battery voltage of 4 V at Pin 10 in 6.5 mV steps of sensitivity.

In a duty cycle, T, of 20.48 s, the converter executes the measurement from a standard oscillation frequency of f_{osc} = 800 Hz. The voltage measurement is during the charge break time of 2.56 s (see figure 6), i.e., no-load voltage (or currentless phase). Therefore it has optimum measurement accuracy because all interferences are cut-off during this period (e.g., terminal resistances or dynamic load current fluctuations).

After a delay of 1.28 s the actual measurement phase of 1.28 s follows. During this idle interval of cut-off conditions, battery voltage is stabilized and hence measurement is possible.

An output pulse of 10 ms appears at Pin 9 during charge break after a delay of 40 ms. The output signal can be used in a variety of way, e.g., synchronising the test control (reference measurement).

Plausibility for Charge Break

There are two criterian considered for charge break plausibility:

– dV Cut-Off

When the signal at Pin 10 of the DA converter is 12 mV below the actual value, the comparator identifies it as a voltage drop of – dV. The validity of – dV cutt-off is considered only if the actual value is below 12 mV for three consective cycles of measurement.

d^2V/dt^2 Cut-Off

A four bit forward/ backward counter is used to register the slope change (d^2V/dt^2, V_{Batt} – slope). This counter is clocked by each tracking phase of the fine AD-counter. Beginning from its initial value, the counter counts the first eight cycles in forward direction and the next eight cycles in reverse direction. At the end of 16 cycles, the actual value is compared with the initial value. If there is a difference of more than two LSB-bit (13.5 mV) from the actual counter value, then there is an identification of slope change which leads to normal charge cut-off. A second counter in the same configuration is operating in parallel with eight clock cycles delay, to reduce the total cut-off delay, from 16 test cycles to eight test cycles.

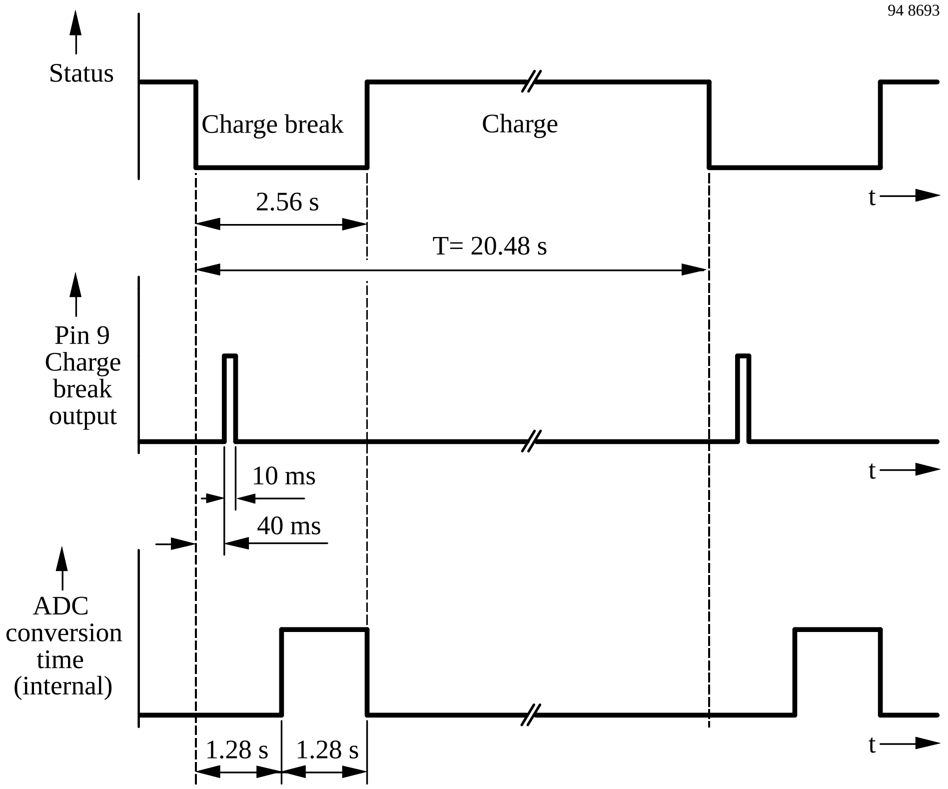


Figure 6. Operating sequence of voltage measurements

Temperature Control, Figure 7

When the battery temperature is not inside the specified *temperature windows*, the overal temperature control will not allow the charge process. Sensor short circuit or interruption also leads to switch-off.

Differentiation is made whether the battery exceeds the maximum allowable temperature, T_{max}, during the charge phase or the battery temperature is outside the temperature window range before battery connection.

A permanent switch-off follows after a measurement period of 20.48 s, if the temperature exceeds a specified level, which is denoted by a status of a red LED_1. A charge sequence will start only when the specified window temperature range is attained. In such a case, the green LED_2 starts blinking immediately showing a quasi *charge readiness*, even though there is no charge current flow.

The temperature window is specified between two voltage transitions. The upper voltage transition is specified by the internal reference voltage of 4 V, and the lower voltage transition is represented by the external voltage divider resistances R_{T2} and R_{T3}.

NTC sensors are normally used to control the temperature of the battery pack. If the resistance values of NTC are known for maximum and minimum conditions of allowable temperature, then other resistance values, R_{T1}, R_{T2} and R_{T3} are calculated as follows:

suppose R_{T2} = 100 kΩ, then

$$R_{T1} = R_{NTCmax} \frac{V_{Ref} - 4V}{4V}$$

$$R_{T3} = R_{NTCmin} \frac{R_{T2}}{R_{T1}}$$

If NTC sensors are not used, then select the circuit configuration according to figure 10.

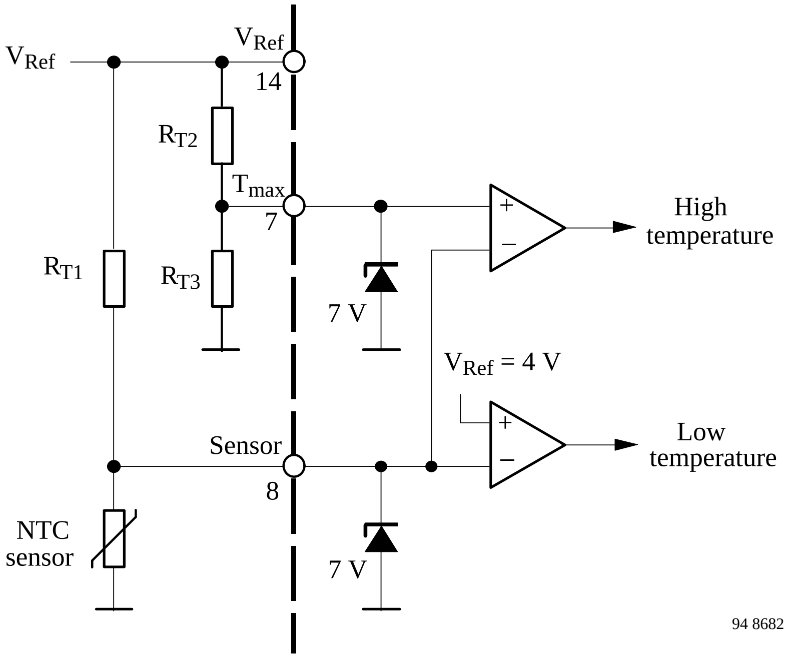


Figure 7. Temperature window

Current Regulation Via Phase Control (Figure 8)

Phase Control

An internal phase control monitors the angle of current flow through the external thyristors as shown in figure 2. The phase control block represents a ramp generator synchronised by mains zero cross over and a comparator.

The comparator will isolate the trigger output, Pin 1, until the end of the half wave (figure 8) when the ramp voltage, $V_{ramp,}$ reaches the control voltage level, $V\varphi_{i,}$ within a mains half wave.

Charge Current Regulation (Figure 2)

According to figure 2 the operational amplifier (OpAmp) regulates the charge current, I_{ch} (= 160 mV / R_{sh}), average value. The OpAmp detects the voltage drop across the shunt resistor (R_{sh}) at input Pin 6 as an actual value. The actual value will then be compared with an internal reference value (rated value of 160 mV).

The regulator's output signal, $V_{5,}$ is at the same time the control signal of the phase control, $V\varphi_i$ (Pin 4). In the adjusted state, the OpAmp regulates the current flow angle through the phase control until the average value at the shunt resistor reaches the rated value of 160 mV.
The corresponding evaluation of capacitor C_R at the operational amplifier (regulator) output determines the dynamic performance of current regulation.

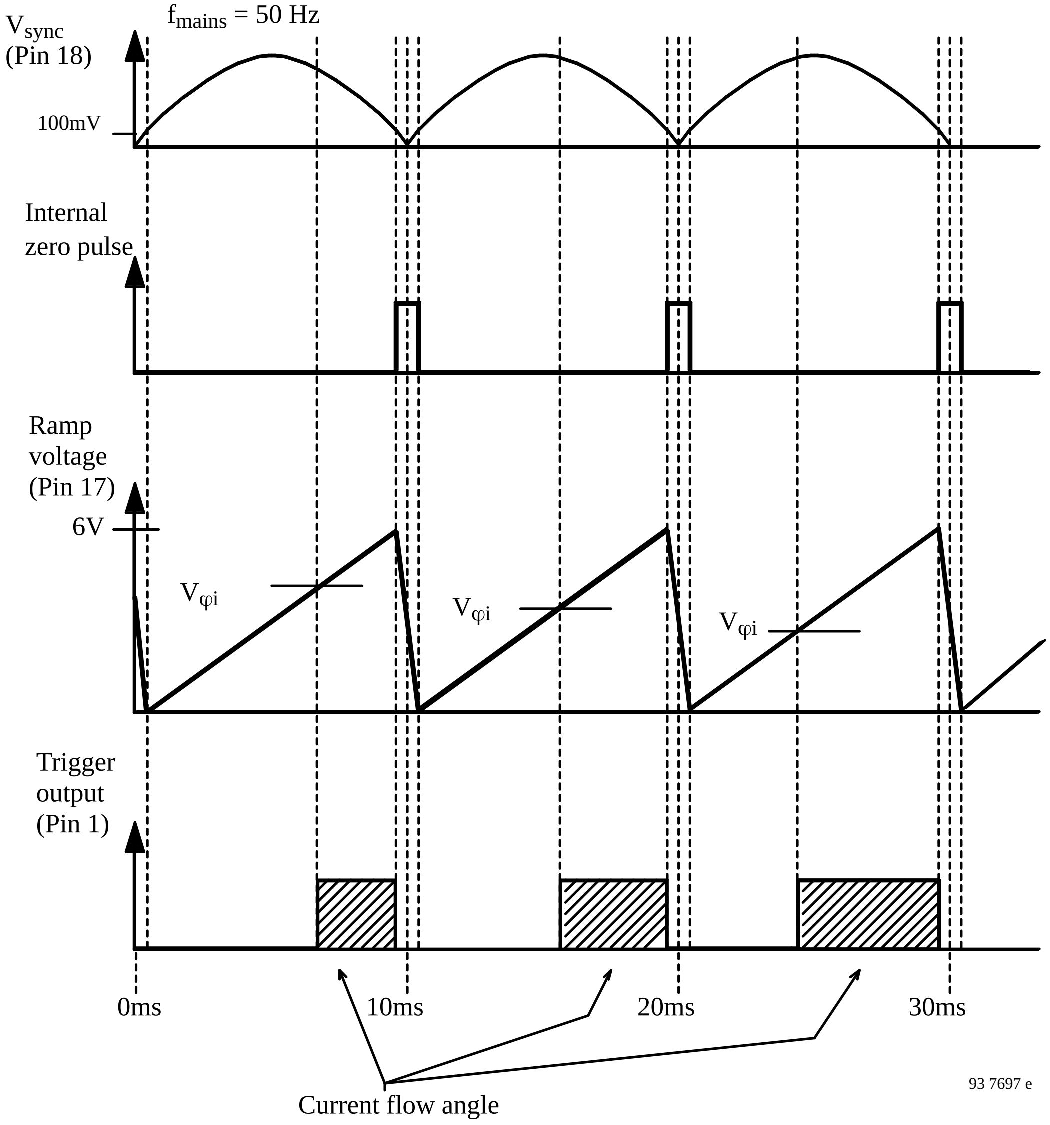


Figure 8. Phase control function diagram

Status Control

Status control inside and outside the charging process are designated by LED_1 and LED_2 outputs given in the table below:

LED1 (red)	LED2 (green)	Status
OFF	ON	No battery, top off charge, trickle charge
OFF	Blinking	Quick charge, temperature out of the window before battery insertion or power on
ON	OFF	Temperature out of the window
Blinking	OFF	Battery break (interrupt) or short circuit

The blink frequency of LED outputs can be calculated as follows:

$$f_{(LED)} = \frac{\text{Oscillator frequency, } f_{osc}}{1024}$$

Oscillator

Time sequences regarding measured values and evaluation are determined by the system oscillator. All the technical data given in the description are with the standard frequency 800 Hz.

It is possibe to alter the frequency range in a certain limitation. Figure 9 shows the frequency versus resistance curves with different capacitance values.

Oscillation Frequency Adjustment

Recommendations:

0.5C charge	0.5 × 500 Hz =	250 Hz
1C charge		500 Hz
2C charge	2 × 500 Hz =	1000 Hz
3C charge	3 × 500 Hz =	1500 Hz

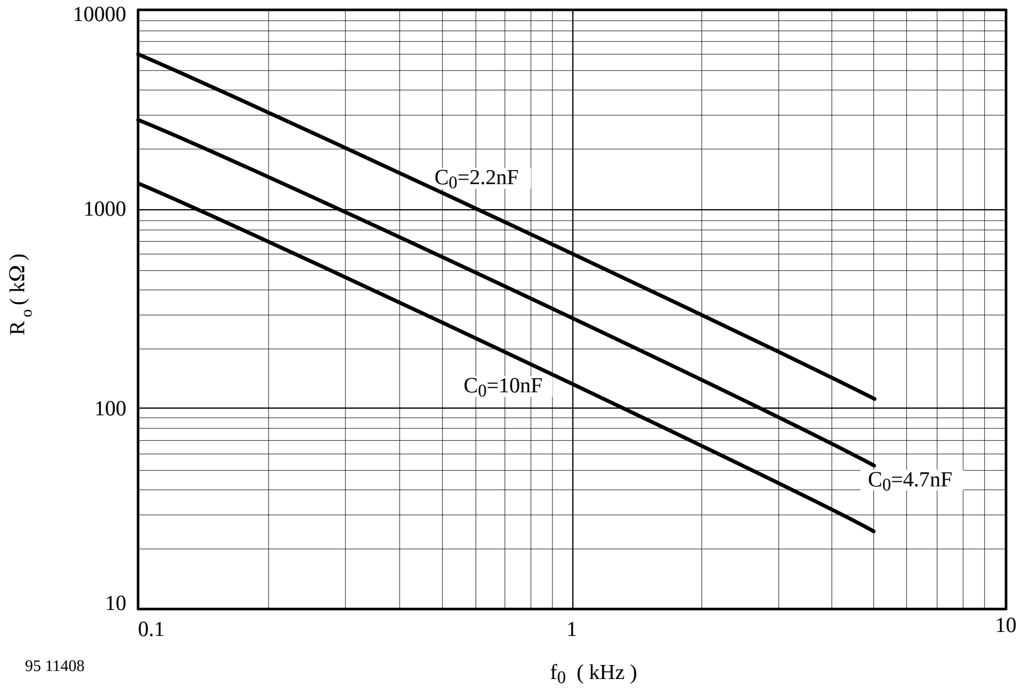


Figure 9. Frequency versus resistance for different capacitance values

Absolute Maximum Ratings

Reference point Pin 2 (GND), unless otherwise specified

Parameters	Symbol	Value	Unit
Supply voltage Pin 15 Voltage limitation $I_S = 10$ mA	V_S	26 31	V
Current limitation Pin 15 t < 100 µs	I_S	25 100	mA
Voltages at different pins Pins 1, 3 and 11 Pins 4 to 10, 12 to 14 and 16 to 18	V	26 7	V
Currents at different pins Pin 1 Pins 3 to 14 and 16 to 18	I	25 10	mA
Power dissipation $T_{amb} = 60°C$	P_{tot}	650	mW
Ambient temperature range	T_{amb}	– 10 to 85	°C
Junction temperature	T_j	125	°C
Storage temperature range	T_{stg}	– 40 to 125	°C

Thermal Resistance

Parameters	Symbol	Maximum	Unit
Junction ambient	R_{thJA}	100	K/W

Electrical Characteristics

$V_S = 12$ V, $T_{amb} = 25°C$, reference point Pin 2 (GND), unless otherwise specified.

Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Power supply	Pin 15					
Voltage range		V_S	8		26	V
Power-on threshold	ON OFF	V_S	3.0 4.7		3.8 5.7	V V
Current consumption	without load	I_S	3.9		9.1	mA
Reference	Pin 14					
Reference voltage	$I_{Ref} = 5$ mA $I_{Ref} = 10$ mA	V_{Ref}	6.19 6.14	6.5 6.5	6.71 6.77	V V
Reference current		$-I_{Ref}$			10	mA
Temperature coefficient		TC		– 0.7		mV/K
Operational amplifier OP						
Output voltage range	$I_5 = 0$ Pin 5	V_5	0.15		5.8	V
Output current range	$V_5 = 3.25$ V Pin 5	$\pm I_5$	80			µA
Output pause current	Pin 5	$-I_{pause}$	100			µA
Non-inverting input voltage	Pin 6	V_6	0		5	V
Non-inverting input current	Pin 6	$\pm I_6$			0.5	µA

Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Comparator or Temperature control						
Input current	Pin 7, 8	$I_{7,\,8}$	– 0.5		0.5	µA
Input voltage range	Pin 7, 8	$V_{7,\,8}$	0		5	V
Threshold voltage	Pin 8	V_8	3.85		4.15	V
Charge break output	Pin 9					
Output voltage	High, I_9 = 4 mA Low, I_9 = 0 mA	V_9	8.4		 100	V mV
Output current	V_9 = 1 V	I_9	10			mA
Battery detection	Pin 10					
Analog-digital converter	Conversion range Full scale level	V_{Batt}	0 3.85		4.0	V
Input current	0.1 V $\leq V_{Batt} \leq$ 4.5 V	$-I_{Batt}$			0.5	µA
Input voltage for reset		V_{Batt}	4.8	5.0	5.3	V
Input current for reset	$V_{Batt} \geqq$ 5 V	I_{Batt}	8		35	µA
Battery detection	Maximum voltage	ΔV_{Batt}	80		120	mV
Hysteresis	Maximum voltage	V_{hys}		15		mV
Mode select	Pin 12					
Threshold voltage	Test mode	V_{12}			4.7	V
Input current	Normal mode Open	I_{12}	20 0			µA
Sync. oscillator	Pin 13					
Frequency	R = 150 kΩ C = 10 nF	f_{osc}		800		Hz
Threshold voltage	High level Low level	$V_{T(H)}$ $V_{T(L)}$		4.3 ± 3% 2.2 ± 3%		V
Input current		I_{13}	– 0.5		0.5	µA
Phase control						
Ramp voltage	R_{φ} = 270 kΩ Pin 16	V_{16}	2.9		3.9	V
Ramp current		I_{16}	0		100	µA
Ramp voltage range		V_{17}	0		5	V
Ramp discharge current		I_{17}	3.3		8	mA
Synchronisation	Pin 18					
Minimum current	$V_{sync} \leq$ 80 mV	$-I_{sync}$	10		2	µA
Maximum current	V_{sync} = 0 V	$-I_{sync}$	15		30	µA
Zero voltage detection		V_{sync}	83	100	135	mV
Hysteresis		V_{hys}		15		mV
Charge stop criteria (function)	Pin 10					
Positive gradient-turn-off threshold	f_{osc} = 800 Hz	d^2V/dt^2		4.8		mV/min^2
– dV-turn-off threshold		– dV		12		mV

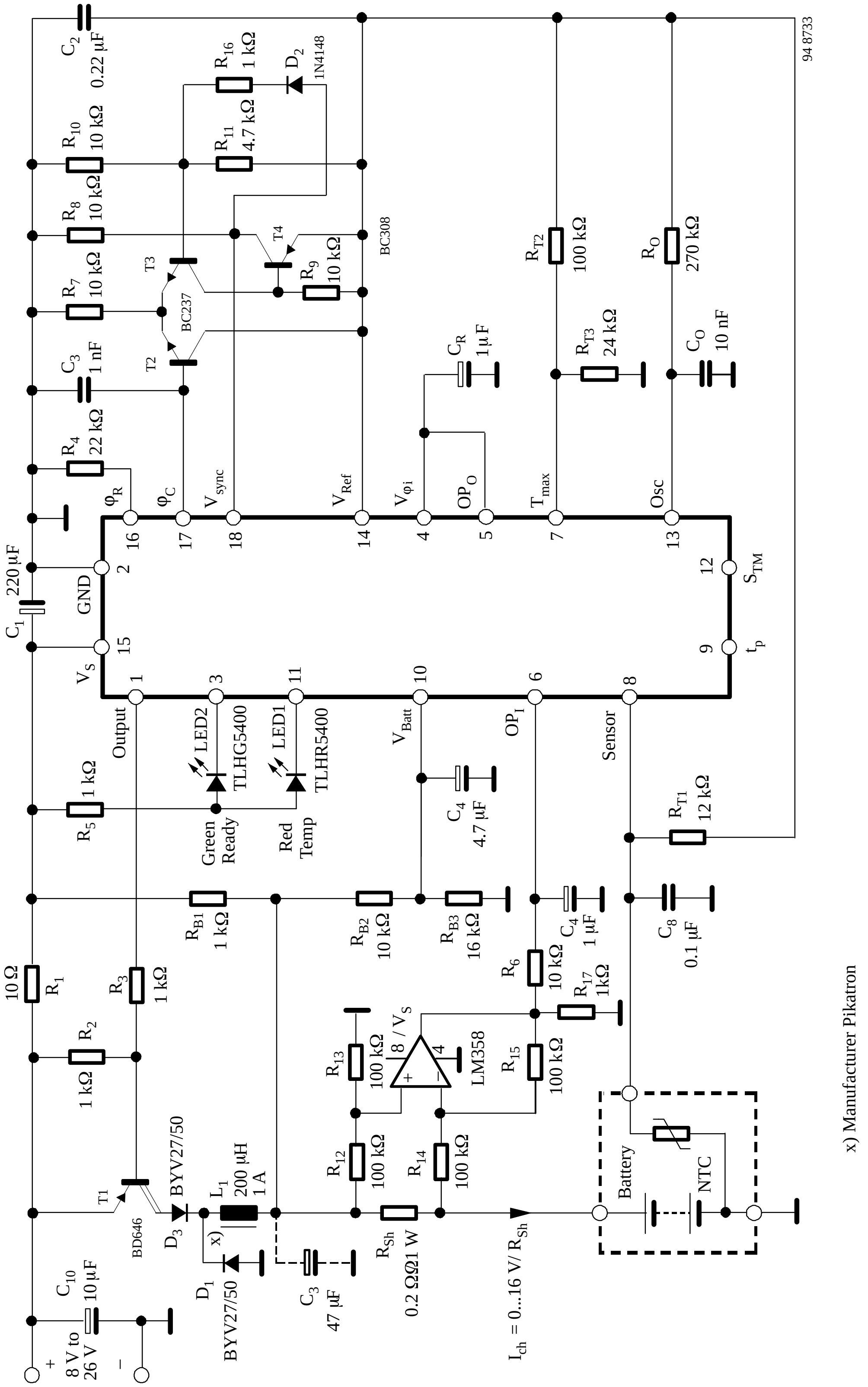


Figure 10. Car battery supplied charge system with high side current detection for four NiCd/NiMH cells @ 800 mA

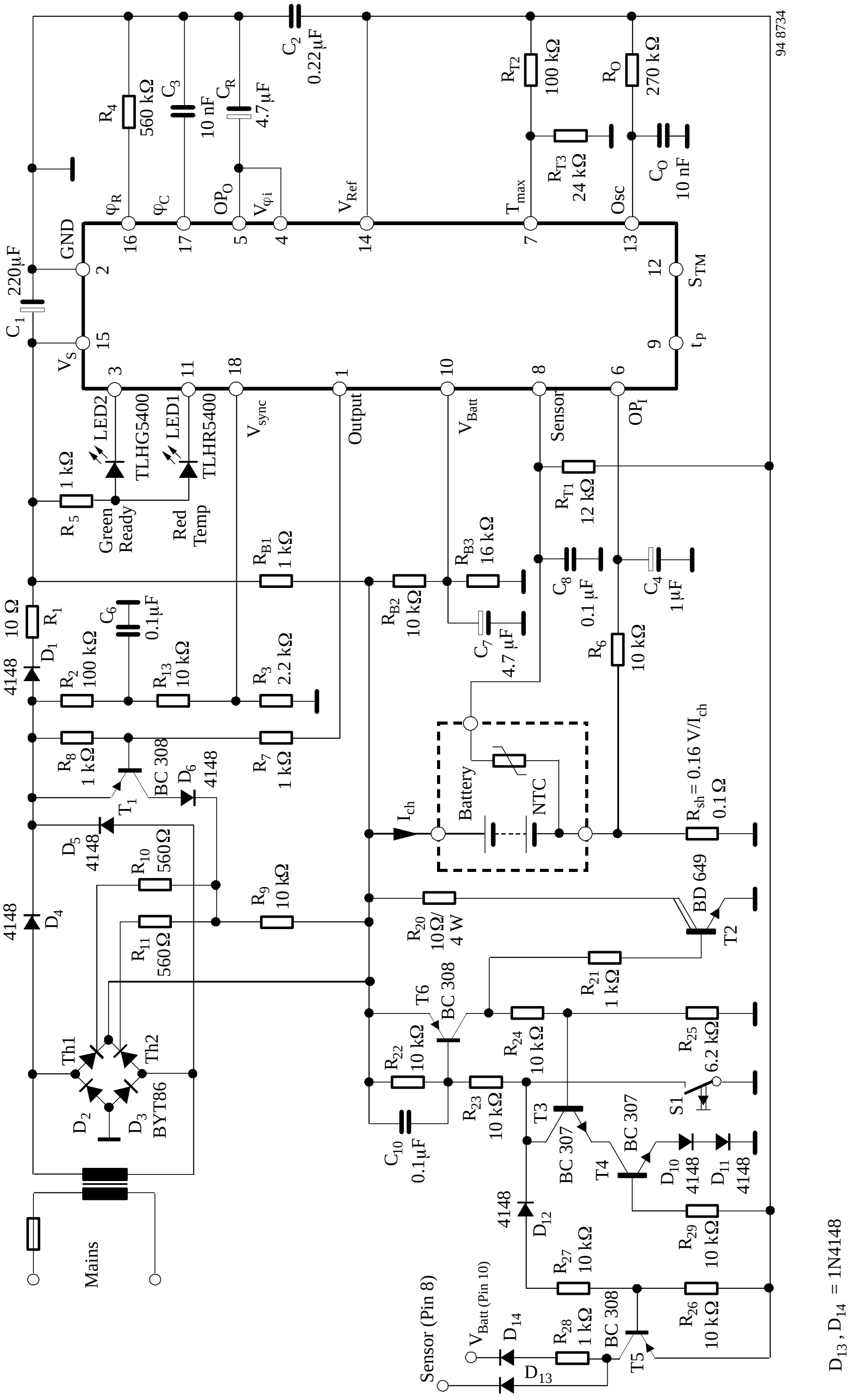
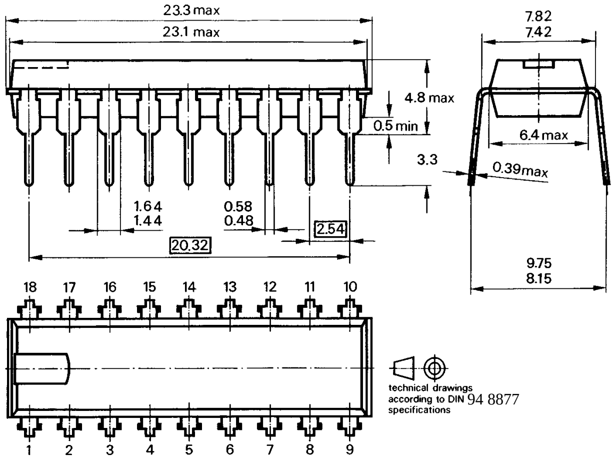


Figure 11. Standard application with predischarge for eight NiCd/NiMH cells @ 1600 mA

Dimensions in mm

Package: DIP18



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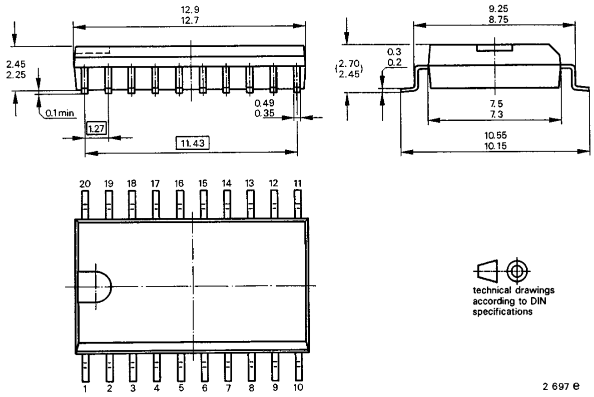


Ozone Depleting Substances Policy Statement

It is the policy of **TEMIC TELEFUNKEN microelectronic GmbH** to

1. Meet all present and future national and international statutory requirements.
2. Regularly and continuously improve the performance of our products, processes, distribution and operating systems with respect to their impact on the health and safety of our employees and the public, as well as their impact on the environment.

It is particular concern to control or eliminate releases of those substances into the atmosphere which are known as ozone depleting substances (ODSs).

The Montreal Protocol (1987) and its London Amendments (1990) intend to severely restrict the use of ODSs and forbid their use within the next ten years. Various national and international initiatives are pressing for an earlier ban on these substances.

TEMIC TELEFUNKEN microelectronic GmbH semiconductor division has been able to use its policy of continuous improvements to eliminate the use of ODSs listed in the following documents.

1. Annex A, B and list of transitional substances of the Montreal Protocol and the London Amendments respectively
2. Class I and II ozone depleting substances in the Clean Air Act Amendments of 1990 by the Environmental Protection Agency (EPA) in the USA
3. Council Decision 88/540/EEC and 91/690/EEC Annex A, B and C (transitional substances) respectively.

TEMIC can certify that our semiconductors are not manufactured with ozone depleting substances and do not contain such substances.

TEMIC TELEFUNKEN microelectronic GmbH, P.O.B. 3535, D-74025 Heilbronn, Germany
Telephone: 49 (0)7131 67 2831, Fax number: 49 (0)7131 67 2423

Fast Charge Controller for Drained NiCd/NiMH Batteries

Description

The fast charge battery controller circuit, U2405B, uses bipolar technology. It enables an efficient and economic charge system. It incorporates intelligent multiple gradient battery voltage monitoring and mains phase control for power management. With automatic top-off charging, the integrated circuit enables the charge device to stop regular charging, before the critical stage of overcharging can occur. It incorporates an additional algorithm for reactivating fully drained batteries especially after long time storage. It has two LED driver indications for charge and temperature status.

Features

- Preformation algorithm for drained batteries
- Multiple gradient monitoring
- Temperature window (T_{min}/T_{max})
- Exact battery voltage measurement without charge
- Phase control for charge current regulation
- Top off and trickle charge function
- Two LED outputs for charge status indication
- Disabling of d^2V/dt^2 switch-off criteria during battery formation
- Battery voltage check

Applications

- Portable power tools
- Laptop/notebook personal computer
- Cellular/cordless phones
- Emergency lighting systems
- Hobby equipment
- Camcorder

Package: DIP18, SO20

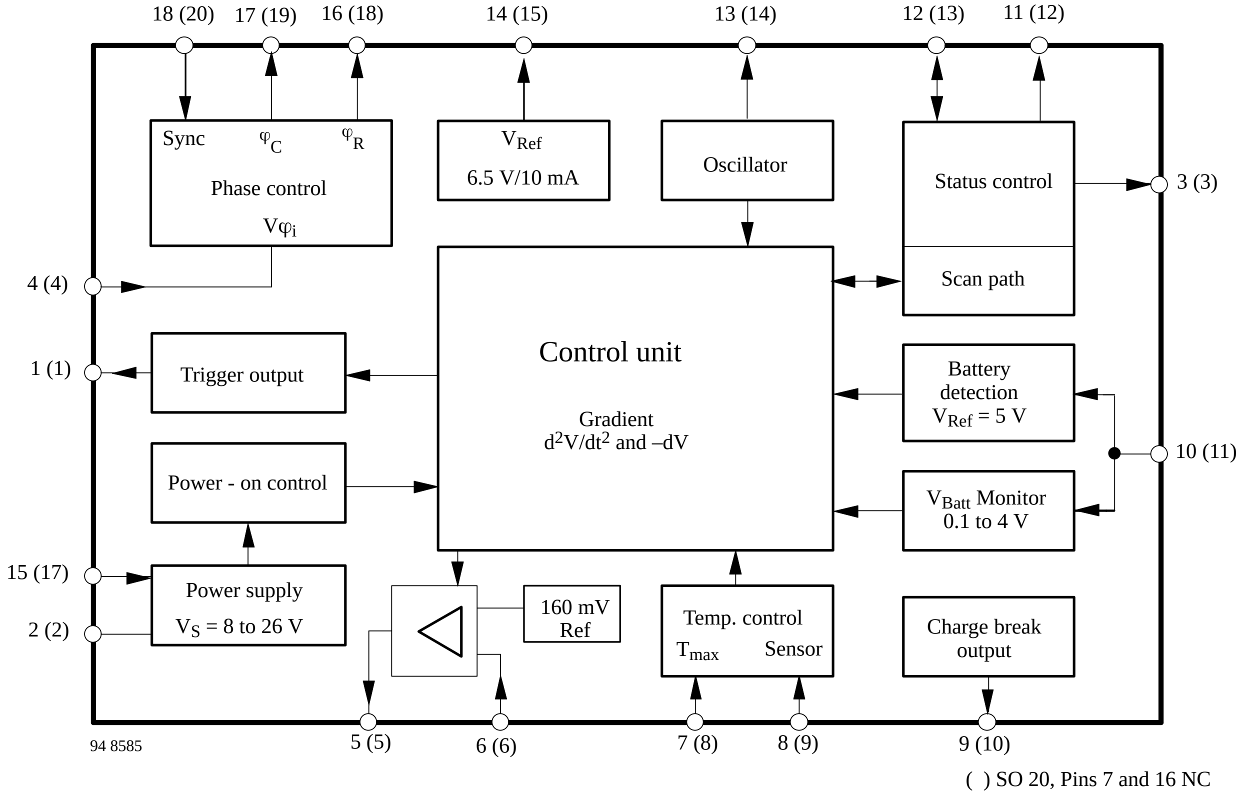
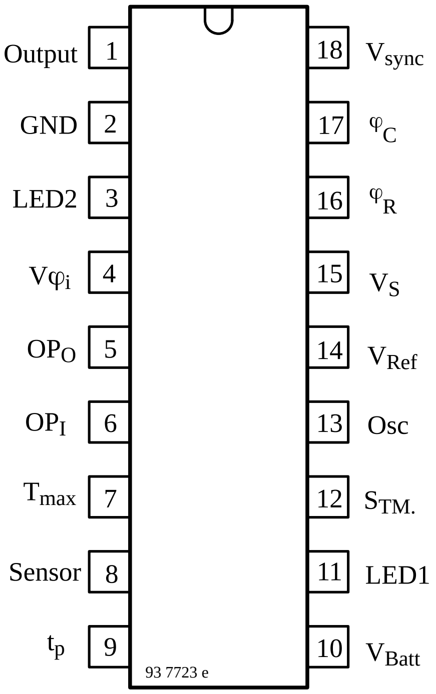


Figure 1. Block diagram

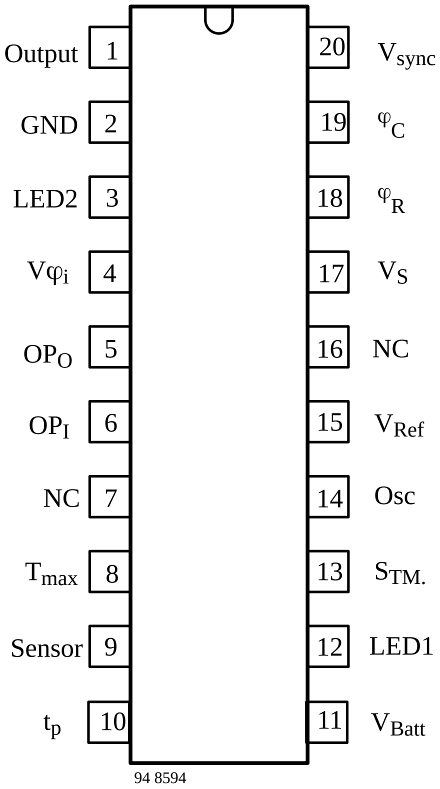
Pin Description

Package: DIP18



Pin	Symbol	Function
1	Output	Trigger output
2	GND	Ground
3	LED2	Display output “Green”
4	$V\varphi_i$	Phase angle control input voltage
5	OP_O	Operational amplifier output
6	OP_I	Operational amplifier input
7	T_{max}	Maximum temperature
8	Sensor	Temperature sensor
9	t_p	Charge break output
10	V_{Batt}	Battery voltage
11	LED1	LED display output “Red”
12	$S_{TM.}$	Test mode switch (status control)
13	Osc	Oscillator
14	V_{Ref}	Reference output voltage
15	V_S	Supply voltage
16	φ_R	Ramp current adjustment – resistance
17	φ_C	Ramp voltage – capacitance
18	$V_{sync.}$	Mains synchronisation input

Package: SO20



Pin	Symbol	Function
1	Output	Trigger output
2	GND	Ground
3	LED2	Display output “Green”
4	$V\varphi_i$	Phase angle control input voltage
5	OP_O	Operational amplifier output
6	OP_I	Operational amplifier input
7	NC	Not connected
8	T_{max}	Maximum temperature
9	Sensor	Temperature sensor
10	t_p	Charge break output
11	V_{Batt}	Battery voltage
12	LED1	LED display output “Red”
13	$S_{TM.}$	Test mode switch (status control)
14	Osc	Oscillator
15	V_{Ref}	Reference output voltage
16	NC	Not connected
17	V_S	Supply voltage
18	φ_R	Ramp current adjustment – resistance
19	φ_C	Ramp voltage – capacitance
20	$V_{sync.}$	Mains synchronisation input

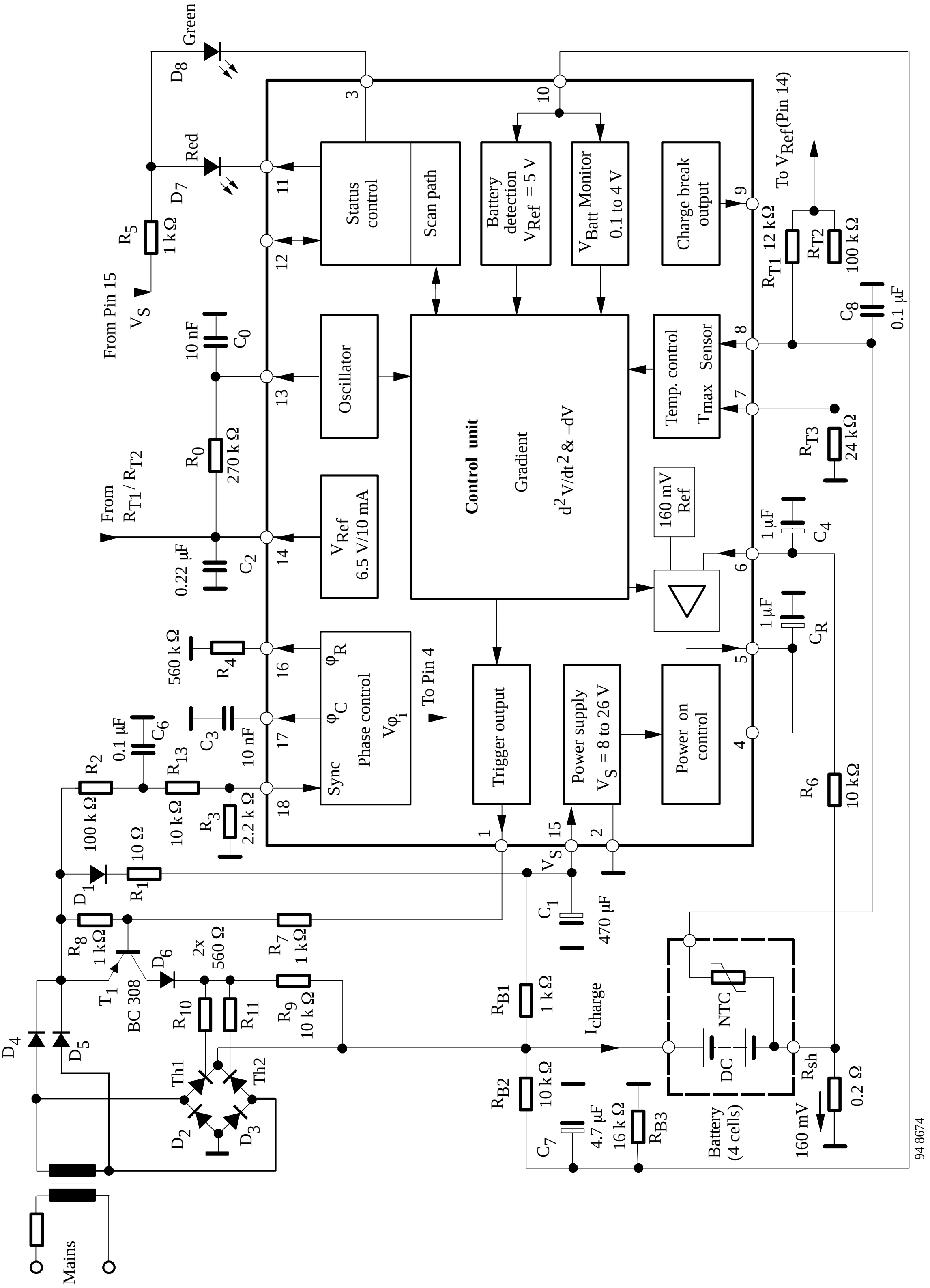


Figure 2. Block diagram with external circuit (DIP pinning)

General Description

The integrated circuit, U2405B, is designed for charging Nickel-Cadmium (NiCd) and Nickel-Metal-Hydride (NiMH) batteries. Fast charging results in voltage lobes when fully charged (figure 3). It supplies two identifications (i.e., + d^2V/dt^2, and – dV) to end the charge operation at the proper time.

As compared to the existing charge concepts where the charge is terminated − after voltage lobes − according to – dV and temperature gradient identification, the U2405B takes into consideration the additional changes in positive charge curves, according to the second derivative of the voltage with respect to time (d^2V/dt^2). The charge identification is the sure method of switching off the fast charge before overcharging the battery. This helps to give the battery a long life by hindering any marked increase in cell pressure and temperature.

Even in critical charge applications, such as a reduced charge current or with NiMH batteries where weaker charge characteristics are present multiple gradient control results in very efficient switch-off.

An additional temperature control input increases not only the performances of the charge switching characteristics but also prevents the general charging of a battery whose temperature is outside the specified window.

A specific preformation algorithm is implemented for reactivating fully drained batteries especially in the case of batteries that have been stored for a long time.

A constant charge current is necessary for continued charge-voltage characteristic. This constant current regulation is achieved with the help of internal amplifier phase control and a simple shunt-current control technique.

All functions relating to battery management can be achieved with dc-supply charge systems. A dc-dc-converter or linear regulator should take over the function of power supply. For further information please refer to the applications.

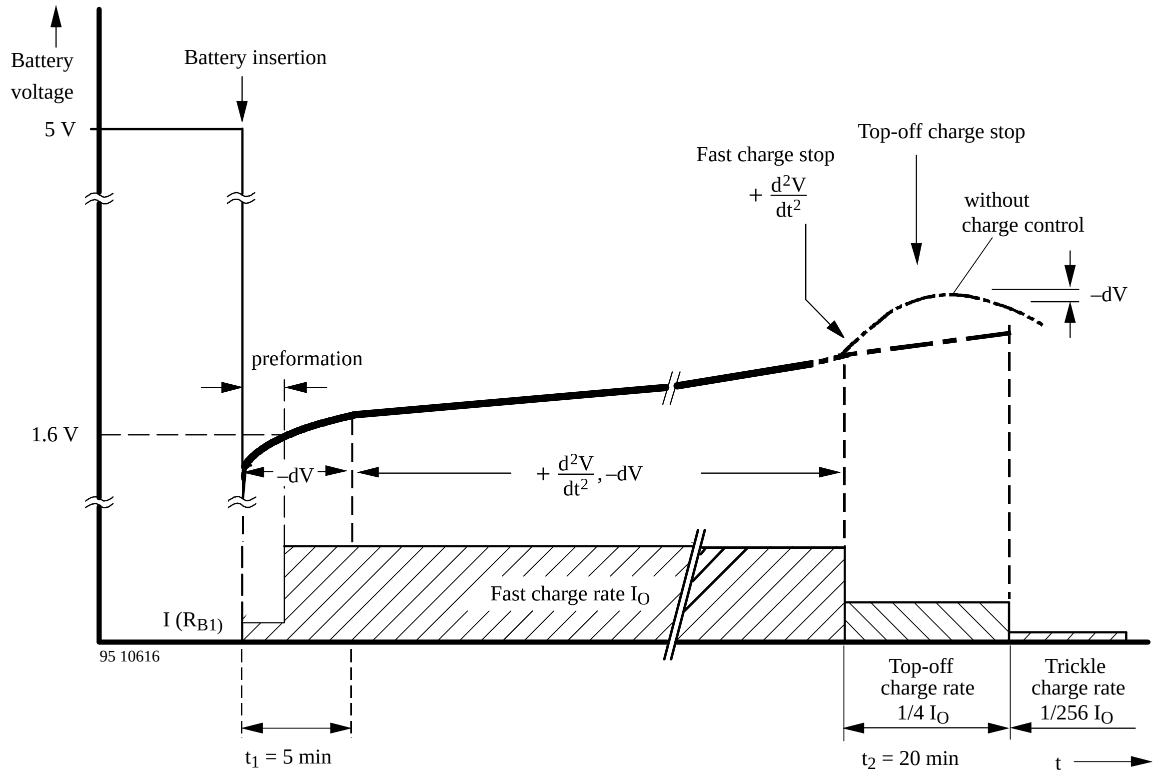


Figure 3. Charge function diagram, f_{osc} = 800 Hz

Flow Chart Explanation, f_{osc} = 800 Hz (Figures 2, 3 and 4)

Battery pack insertion disables the voltage lock at battery detection input Pin 10. All functions in the integrated circuit are reset. For further description, DIP-pinning is taken into consideration.

Battery Insertion and –dV Monitoring

After battery insertion fast charge I_o begins normally when the input voltage V_{Batt} is higher than 1.6 V. For the first 5 minutes the d^2V/dt^2-gradient recognition is suppressed, –dV monitoring is activated. In case the detected V_{Batt} voltage is less then 1.6 V the special preformation procedure will be activated. The reference level with respect to the cell voltage can be adjusted by the resistor R_{B3} (see figure 2).

Preformation Procedure

Before fast charge of fully drained or long time stored batteries begin, a reactivation of it is necessary. The preformation current is dependent on pull-up resistor R_{B1}. The fast charge starts only after the V_{Batt} is higher than 1.6 V level. During the first 10 minutes the green LED2 is blinking. If after 10 minutes, V_{Batt} voltage has not reached the reference level, the indication changes to red blinking LED1. The charge will continue with preformation rate I (R_{B1}). In case V_{Batt} increases to 1.6 V reference level, the fast charge rate current I_o is switched-on and the green LED2 is blinking.

–dV Cut-Off (Monitoring)

When the signal at Pin 10 of the DA converter is 12 mV below the actual value, the comparator identifies it as a voltage drop of –dV. The validity of –dV cut-off is considered only if the actual value is below 12 mV for three consecutive cycles of measurement.

d^2V/dt^2-Gradient

If there is no charge stop within the first 5 minutes after battery insertion, then d^2V/dt^2 monitoring will be active. In this actual charge stage, all stop-charge criteria are active.

When close to the battery’s capacity limit, the battery voltage curve will typically rise. As long as the $+d^2V/dt^2$ stop-charging criteria are met, the device will stop the fast charge activities.

Top-Off Charge Stage

By charge disconnection through the $+d^2V/dt^2$ mode, the device switches automatically to a defined protective top-off charge with a pulse rate of 1/4 I_O (pulse time, t_p = 5.12 s, period, T = 20.48 s).

The top-off charge time is specified for a time of 20 minutes @ 800 Hz.

Trickle Charge Stage

When top-off charge is terminated, the device switches automatically to trickle charge with 1/256 I_O (t_p = 5.12 s, period = 1310.72 s). The trickle continues until the battery pack is removed.

Basic Description

Power Supply, Figure 2

The charge controller allows the direct power supply of 8 V to 26 V at Pin 15. Internal regulation limits higher input voltages. Series resistance, R_1, regulates the supply current, I_S, to a maximum value of 25 mA. Series resistance is recommended to suppress the noise signal, even below 26 V limitation. It is calculated as follows.

$$R_{1min} \geq \frac{V_{max} - 26\ V}{25\ mA}$$

$$R_{1max} \leq \frac{V_{min} - 8\ V}{I_{tot}}$$

where

$I_{tot} = I_S + I_{RB1} + I_1$

V_{max}, V_{min} = Rectified voltage

I_S = Current consumption (IC) without load

I_{RB1} = Current through resistance, R_{B1}

I_1 = Trigger current at Pin 1

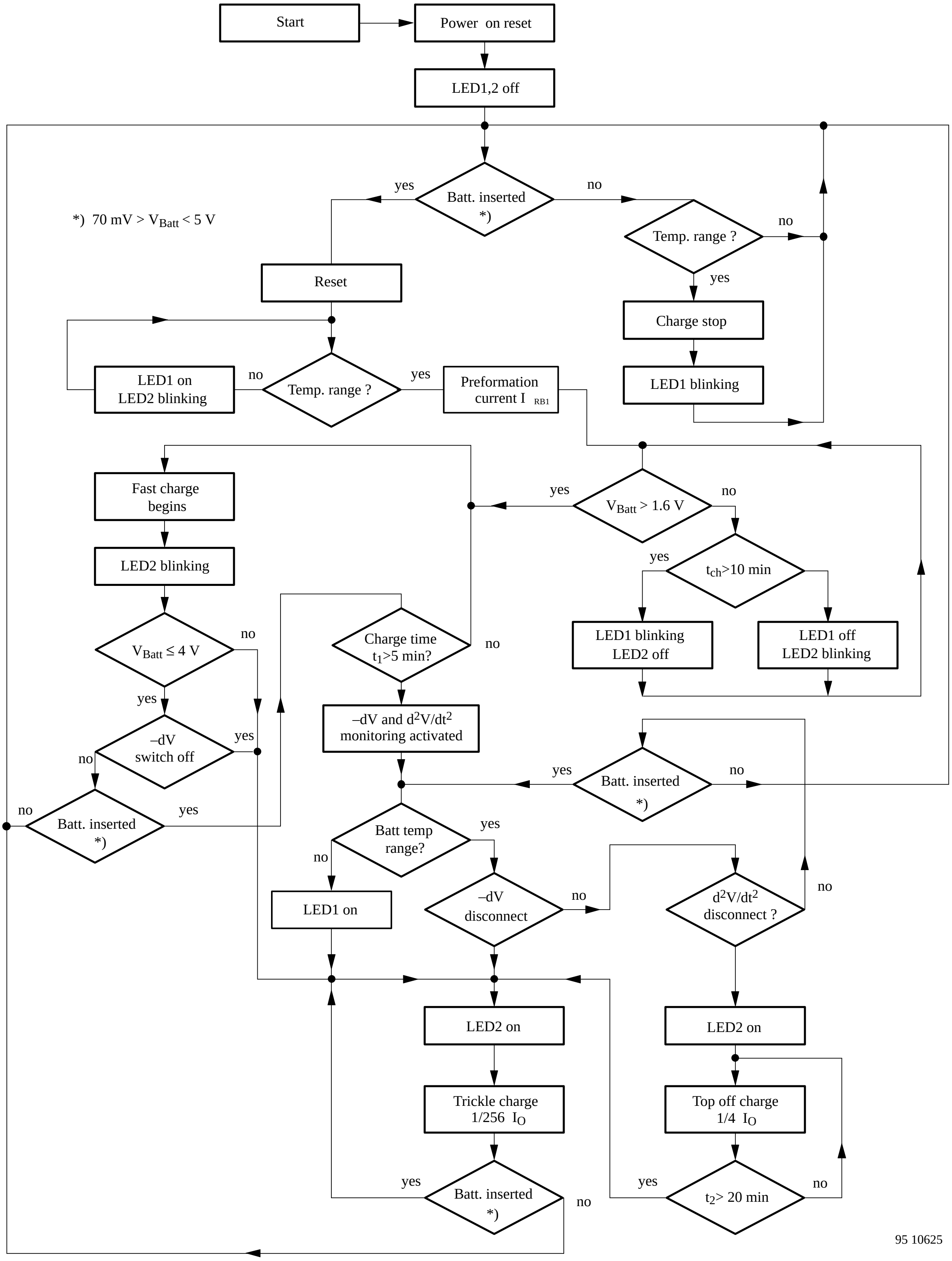


Figure 4. Flow chart

Battery Voltage Measurement

The battery voltage measurement at Pin 10 (ADC-converter) has a range of 0 V to 4 V, which means a battery pack containing two cells can be connected without a voltage divider.

If the AD converter is overloaded ($V_{Batt} \geq 4$ V) a safety switch off occurs. The fast charge cycle is terminated by automatically changing to the trickle charge.

Precaution should be taken that under specified charge current conditions, the final voltage at the input of the converter, Pin 10, should not exceed the threshold voltage level of the reset comparator, which is 5 V. When the battery is removed, the input (Pin 10) is terminated across the pulled-up resistance, $R_{B1,}$ to the value of 5 V-reset-threshold. In this way, the start of a new charge sequence is guaranteed when a battery is reinserted.

If the battery voltage exceeds the converter range of 4 V, adjusting it by the external voltage divider resistance, R_{B2} and R_{B3} is recommended.

Value of the resistance, R_{B3} is calculated by assuming $R_{B1} = 1$ kΩ, $R_{B2} = 10$ kΩ, as follows:

$$R_{B3} = R_{B2} \frac{V_{10max}}{V_{Bmax} - V_{10max}}$$

The minimum supply voltage, V_{smin}, is calculated for reset function after removing the inserted battery according to:

$$V_{smin} = \frac{0.03mA \cdot R_{B3}\left(R_{B1} + R_{B2}\right) + 5V\left(R_{B1} + R_{B2} + R_{B3}\right)}{R_{B3}}$$

where:

V_{10max} = Max voltage at Pin 10
V_{Smin} = Min supply voltage at the IC (Pin 15)
V_{Bmax} = Max battery voltage

The voltage conditions mentioned above are measured during charge current break (switch-off condition).

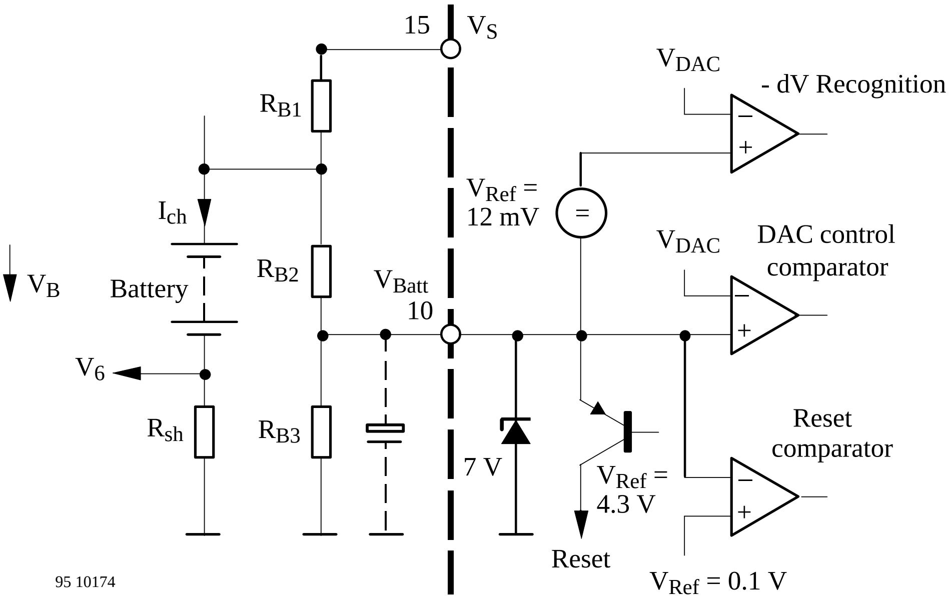


Figure 5. Input configuration for the battery voltage measurement

Table 1. valid when $V_{10max} = 3.5$ V

Cell No.	1	2	3	4	5	6	7	8	9	10	11	12
V_{Smin} (V)	8	8	8	9	11	13	15	17	19	21	23	25
R_{B3} (kΩ)	–	–	51	16	10	7.5	5.6	4.7	3.9	3.3	3	2.7

Analog-Digital-Converter (ADC), Test Sequence

A special analog-digital-converter consists of a five-bit coarse and a five-bit fine converter . It operates by a linear count method which can digitalize a battery voltage of 4 V at Pin 10 in 6.5 mV steps of sensitivity.

In a duty cycle, T, of 20.48 s, the converter executes the measurement from a standard oscillation frequency of f_{osc} = 800 Hz. The voltage measurement is during the charge break time of 2.56 s (see figure 6), i.e., no-load voltage (or currentless phase). Therefore it has optimum measurement accuracy because all interferences are cut-off during this period (e.g., terminal resistances or dynamic load current fluctuations).

After a delay of 1.28 s the actual measurement phase of 1.28 s follows. During this idle interval of cut-off conditions, battery voltage is stabilized and hence measurement is possible.

An output pulse of 10 ms appears at Pin 9 during charge break after a delay of 40 ms. The output signal can be used in a variety of way, e.g., synchronising the test control (reference measurement).

Plausibility for Charge Break

There are two criterian considered for charge break plausibility:

– dV Cut-Off

When the signal at Pin 10 of the DA converter is 12 mV below the actual value, the comparator identifies it as a voltage drop of – dV. The validity of – dV cutt-off is considered only if the actual value is below 12 mV for three consective cycles of measurement.

d^2V/dt^2 Cut-Off

A four bit forward/ backward counter is used to register the slope change (d^2V/dt^2, V_{Batt} – slope). This counter is clocked by each tracking phase of the fine AD-counter. Beginning from its initial value, the counter counts the first eight cycles in forward direction and the next eight cycles in reverse direction. At the end of 16 cycles, the actual value is compared with the initial value. If there is a difference of more than two LSB-bit (13.5 mV) from the actual counter value, then there is an identification of slope change which leads to normal charge cut-off. A second counter in the same configuration is operating in parallel with eight clock cycles delay, to reduce the total cut-off delay, from 16 test cycles to eight test cycles.

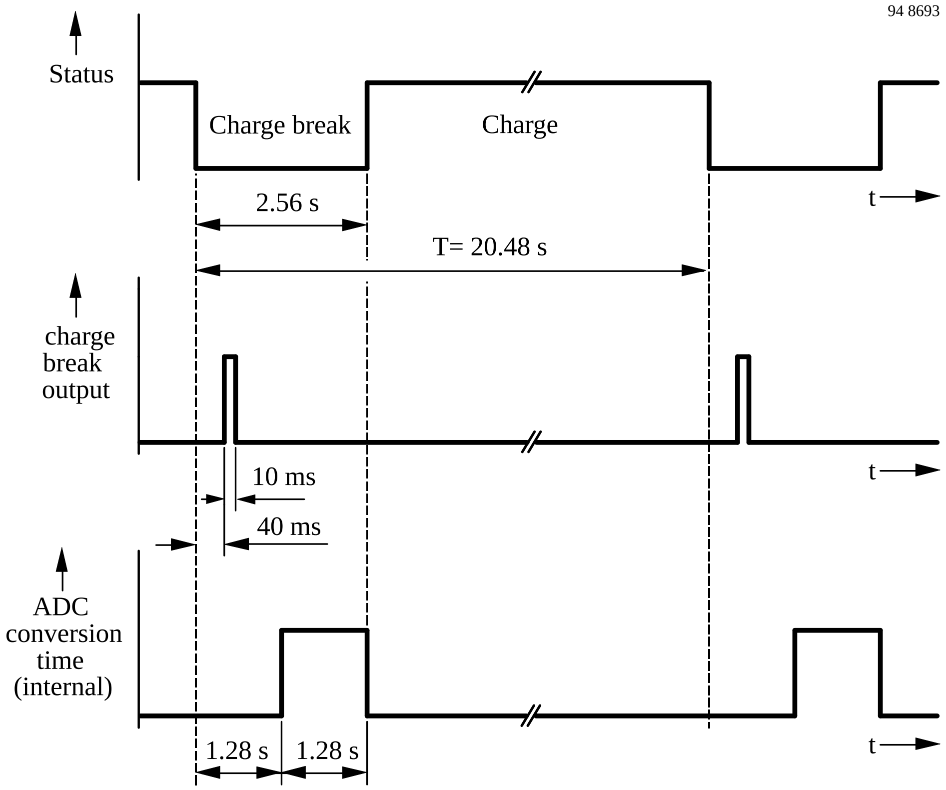


Figure 6. Operating sequence of voltage measurements

Temperature Control, Figure 7

When the battery temperature is not inside the specified *temperature windows,* the overal temperature control will not allow the charge process. Sensor short circuit or interruption also leads to switch-off.

Differentiation is made whether the battery exceeds the maximum allowable temperature, T_{max}, during the charge phase or the battery temperature is outside the temperature window range before battery connection.

A permanent switch-off follows after a measurement period of 20.48 s, if the temperature exceeds a specified level, which is denoted by a status of a red LED_1. A charge sequence will start only when the specified window temperature range is attained. In such a case, the green LED_2 starts blinking immediately showing a quasi charge readiness, even though there is no charge current flow.

The temperature window is specified between two voltage transitions. The upper voltage transition is specified by the internal reference voltage of 4 V, and the lower voltage transition is represented by the external voltage divider resistances R_{T2} and R_{T3}.

NTC sensors are normally used to control the temperature of the battery pack. If the resistance values of NTC are known for maximum and minimum conditions of allowable temperature, then other resistance values, R_{T1}, R_{T2} and R_{T3} are calculated as follows:

suppose R_{T2} = 100 kΩ, then

$$R_{T1} = R_{NTCmax} \frac{V_{Ref} - 4V}{4V}$$

$$R_{T3} = R_{NTCmin} \frac{R_{T2}}{R_{T1}}$$

If NTC sensors are not used, then select the circuit configuration according to figure 10.

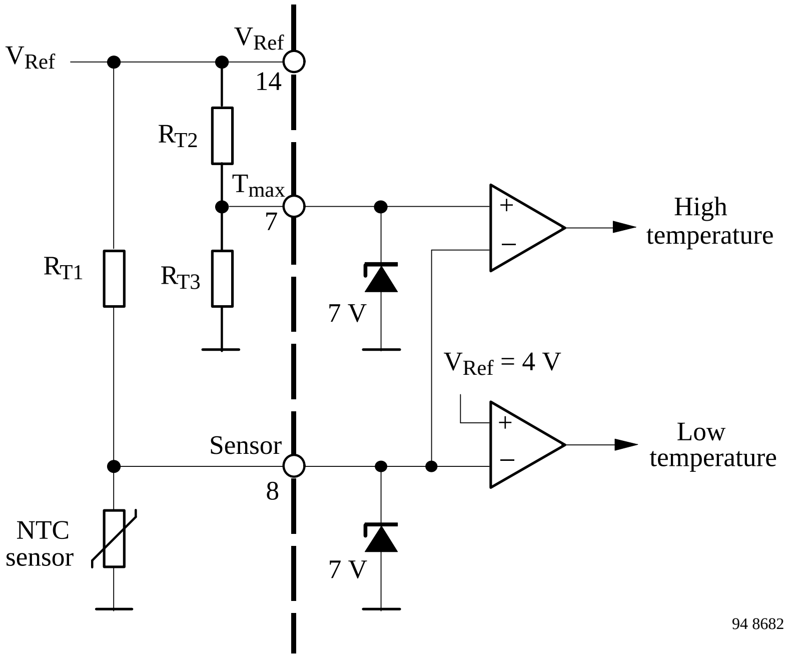


Figure 7. Temperature window

Current Regulation Via Phase Control (Figure 8)

Phase Control

An internal phase control monitors the angle of current flow through the external thyristors as shown in figure 2. The phase control block represents a ramp generator synchronised by mains zero cross over and a comparator.

The comparator will isolate the trigger output, Pin 1, until the end of the half wave (figure 8) when the ramp voltage, V_{ramp}, reaches the control voltage level, $V\varphi_i$, within a mains half wave.

Charge Current Regulation (Figure 2)

According to figure 2 the operational amplifier (OpAmp) regulates the charge current, I_{ch} (= 160 mV / R_{sh}), average value. The OpAmp detects the voltage drop across the shunt resistor (R_{sh}) at input Pin 6 as an actual value. The actual value will then be compared with an internal reference value (rated value of 160 mV).
The regulator's output signal, V_5, is at the same time the control signal of the phase control, $V\varphi_i$ (Pin 4). In the adjusted state, the OpAmp regulates the current flow angle through the phase control until the average value at the shunt resistor reaches the rated value of 160 mV.
The corresponding evaluation of capacitor C_R at the operational amplifier (regulator) output determines the dynamic performance of current regulation.

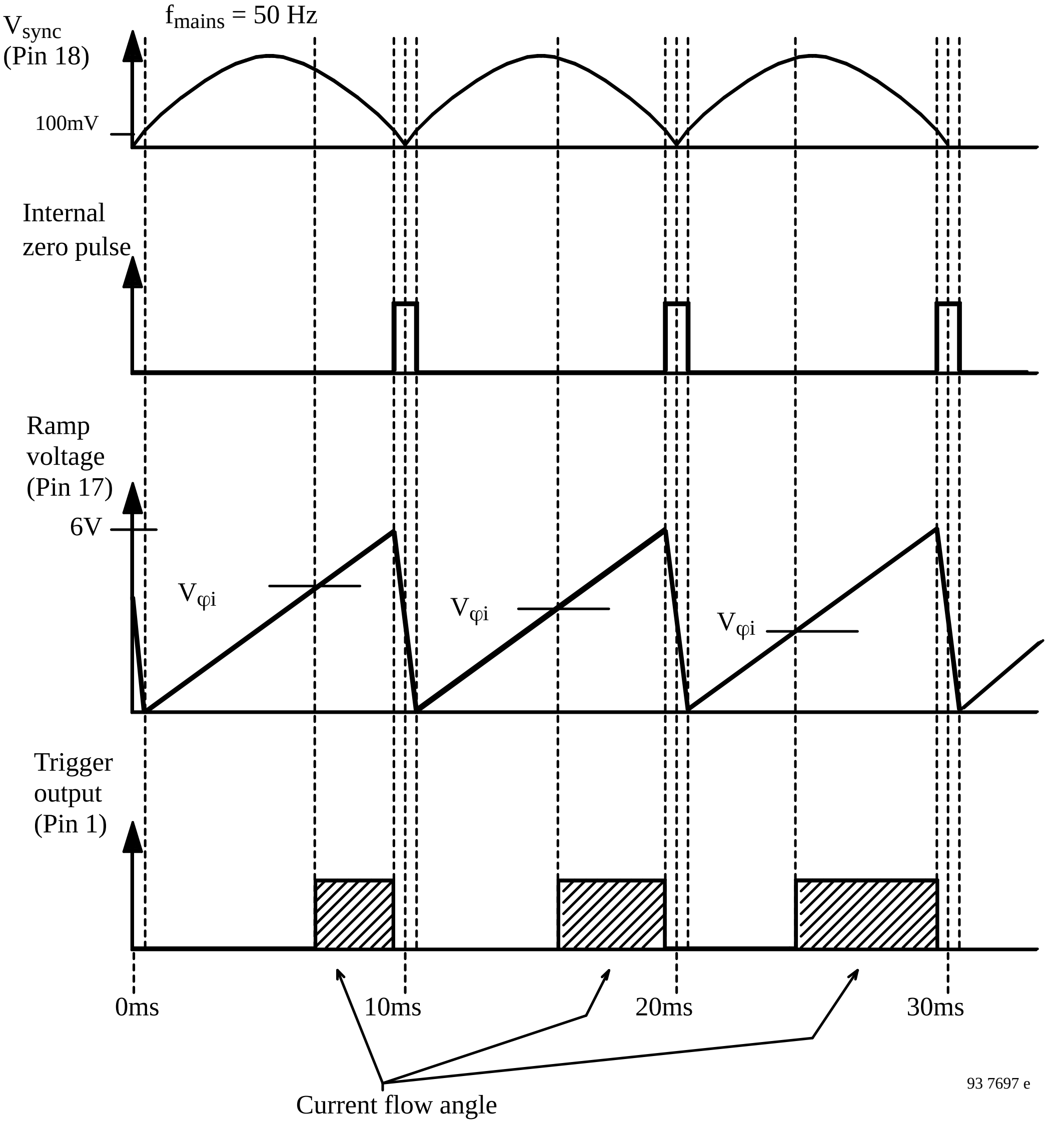


Figure 8. Phase control function diagram

Status Control

Status control inside and outside the charging process are designated by LED_1 and LED_2 outputs given in the table below:

LED1 (red)	LED2 (green)	Status
OFF	ON	Top off charge, trickle charge
OFF	Blinking	Quick charge
ON	OFF	Temperature out of the window
Blinking	OFF	Drained battery (0.1 V < V_{Batt} > 1.6 V, if t > 10 min.) Battery break, short circuit
ON	Blinking	Temperature out of window before battery insertion or power on
OFF	OFF	No battery (V_{Batt} > 5 V)

The blink frequency of LED outputs can be calculated as follows:

$$f_{(LED)} = \frac{\text{Oscillator frequency, } f_{osc}}{1024}$$

Oscillator

Time sequences regarding measured values and evaluation are determined by the system oscillator. All the technical data given in the description are with the standard frequency 800 Hz.

It is possibe to alter the frequency range in a certain limitation. Figure 9 shows the frequency versus resistance curves with different capacitance values.

Oscillation Frequency Adjustment

Recommendations:

0.5C charge	0.5 × 500 Hz =	250 Hz
1C charge		500 Hz
2C charge	2 × 500 Hz =	1000 Hz
3C charge	3 × 500 Hz =	1500 Hz

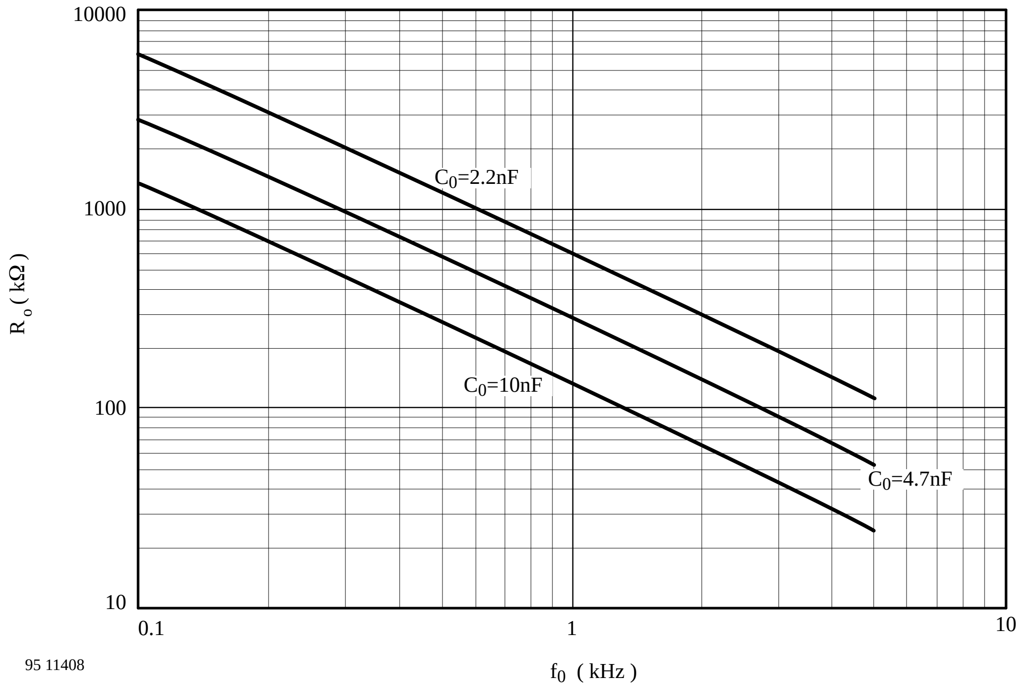


Figure 9. Frequency versus resistance for different capacitance values

Absolute Maximum Ratings

Reference point Pin 2 (GND), unless otherwise specified

Parameters	Symbol	Value	Unit
Supply voltage Pin 15	V_S	26	V
Voltage limitation $I_S = 10$ mA		31	
Current limitation Pin 15 t < 100 µs	I_S	25 100	mA
Voltages at different pins Pins 1, 3 and 11 Pins 4 to 10, 12 to 14 and 16 to 18	V	26 7	V
Currents at different pins Pin 1 Pins 3 to 14 and 16 to 18	I	25 10	mA
Power dissipation $T_{amb} = 60°C$	P_{tot}	650	mW
Ambient temperature range	T_{amb}	– 10 to 85	°C
Junction temperature	T_j	125	°C
Storage temperature range	T_{stg}	– 40 to 125	°C

Thermal Resistance

Parameters	Symbol	Maximum	Unit
Junction ambient	R_{thJA}	100	K/W

Electrical Characteristics

$V_S = 12$ V, $T_{amb} = 25°C$, reference point Pin 2 (GND), unless otherwise specified

Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Power supply	Pin 15					
Voltage range		V_S	8		26	V
Power-on threshold	ON OFF	V_S	3.0 4.7		3.8 5.7	V V
Current consumption	without load	I_S	3.9		9.1	mA
Reference	Pin 14					
Reference voltage	$I_{Ref} = 5$ mA $I_{Ref} = 10$ mA	V_{Ref}	6.19 6.14	6.5 6.5	6.71 6.77	V V
Reference current		$-I_{Ref}$			10	mA
Temperature coefficient		TC		– 0.7		mV/K
Operational amplifier OP						
Output voltage range	$I_5 = 0$ Pin 5	V_5	0.15		5.8	V
Output current range	$V_5 = 3.25$ V Pin 5	$\pm I_5$	80			µA
Output pause current	Pin 5	$-I_{pause}$	100			µA
Non-inverting input voltage	Pin 6	V_6	0		5	V
Non-inverting input current	Pin 6	$\pm I_6$			0.5	µA
Comparator or temperature control						
Input current	Pin 7, 8	$\pm I_{7, 8}$			0.5	µA
Input voltage range	Pin 7, 8	$V_{7, 8}$	0		5	V
Threshold voltage	Pin 8	V_8	3.85		4.15	V

Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Charge break output	Pin 9					
Output voltage	High, I_9 = 4 mA Low, I_9 = 0 mA	V_9	8.4		 100	V mV
Output current	V_9 = 1 V	I_9	10			mA
Battery detection	Pin 10					
Analog-digital converter	Conversion range Full scale level	V_{Batt}	0 3.85		4.0	V
Input current	0.1 V $\leq$ V_{Batt} $\leq$ 4.5 V	$-I_{Batt}$			0.5	µA
Input voltage for reset		V_{Batt}	4.8	5.0	5.3	V
Input current for reset	V_{Batt} $\geqq$ 5 V	I_{Batt}	8		35	µA
Battery detection	Maximum voltage	ΔV_{Batt}	80		120	mV
Hysteresis	Maximum voltage	V_{hys}		15		mV
Mode select	Pin 12					
Treshold voltage	Testmode	V_{12}			4.7	V
Input current		I_{12}	20			µA
Input current	Normal mode Pin 12 open		0			
Sync. oscillator	Pin 13					
Frequency	R = 150 kΩ C = 10 nF	f_{osc}		800		Hz
Threshold voltage	High level Low level	$V_{T(H)}$ $V_{T(L)}$		4.3 ±3 % 2.2 ±3 %		V
Input current		I_{13}	– 0.5		0.5	µA
Phase control						
Ramp voltage	R_{φ} = 270 kΩ Pin 16	V_{16}	2.9		3.9	V
Ramp current		I_{16}	0		100	µA
Ramp voltage range		V_{17}	0		5	V
Ramp discharge current		I_{17}	3.3		8	mA
Synchronisation	Pin 18					
Minimum current	V_{sync} $\leq$ 80 mV	$-I_{sync}$	10		2	µA
Maximum current	V_{sync} = 0 V	$-I_{sync}$	15		30	µA
Zero voltage detection		V_{sync}	83	100	135	mV
Hysteresis		V_{hys}		15		mV
Charge stop criteria (function)	Pin 10					
Positive gradient-turn-off threshold	f_{osc} = 800 Hz	d^2V/dt^2		4.8		mV/ min^2
– dV-turn-off threshold		– dV		12		mV

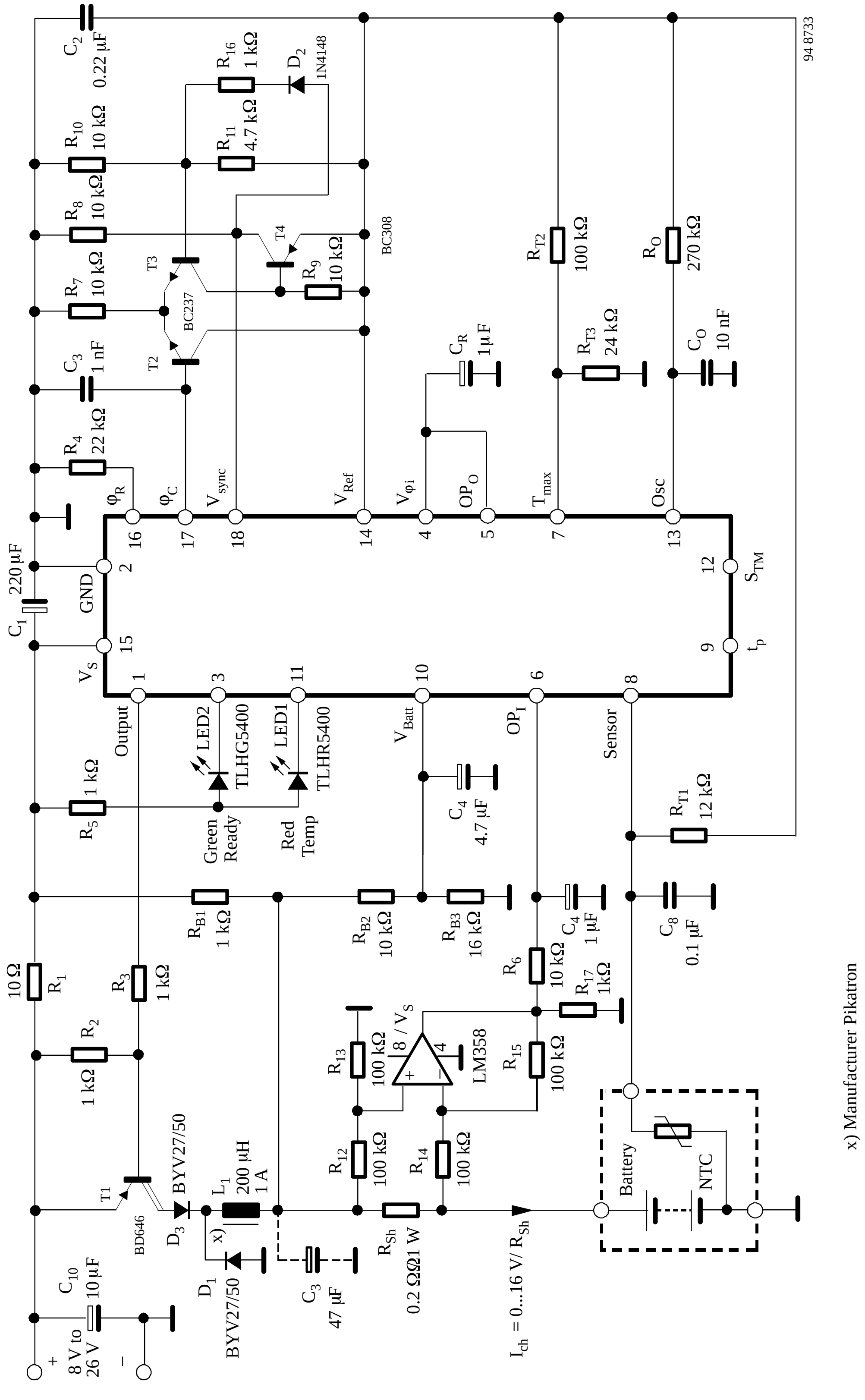


Figure 10. Car battery supplied charge system with high side current detection for 4 NiCd/NiMH cells @ 800 mA

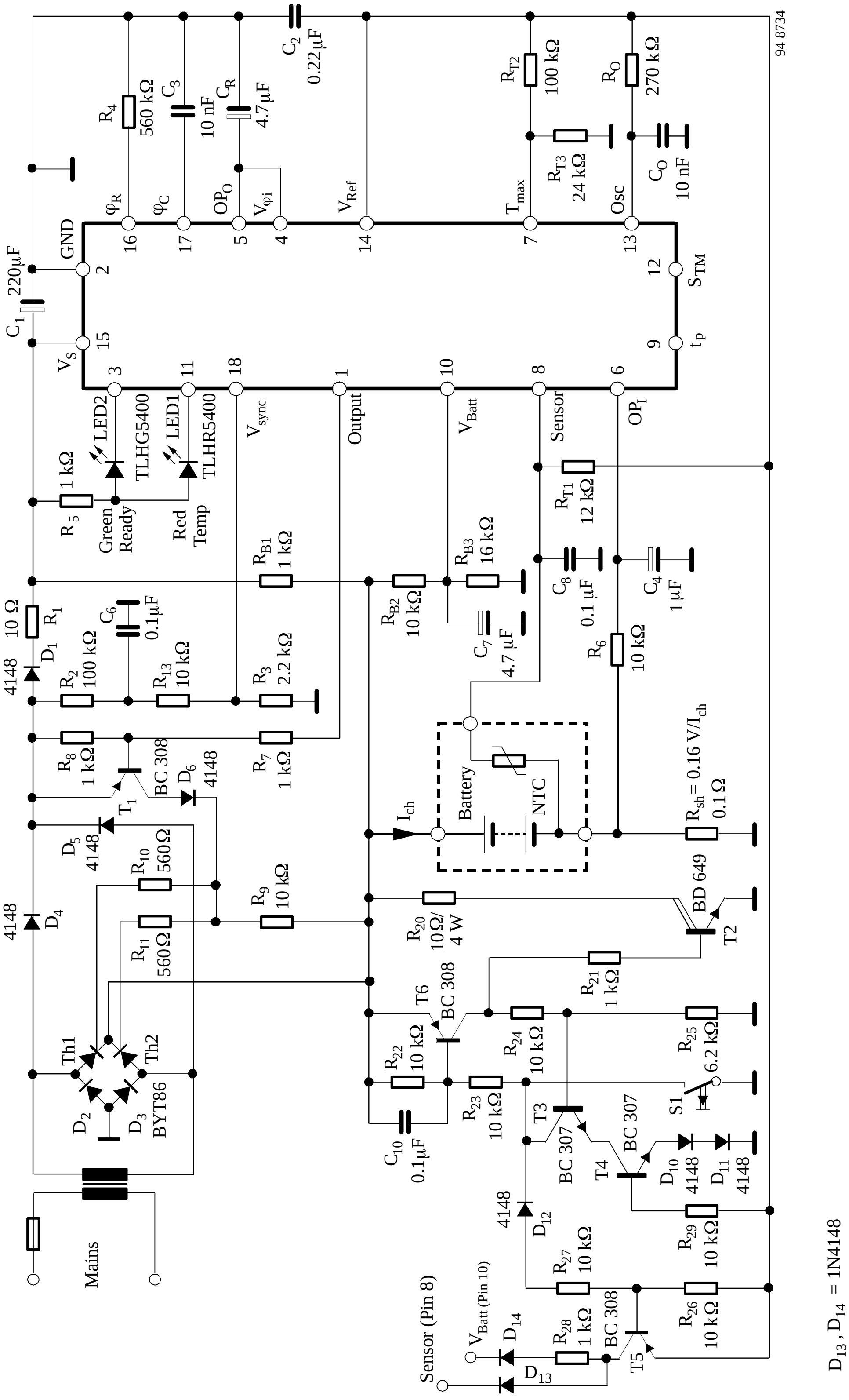
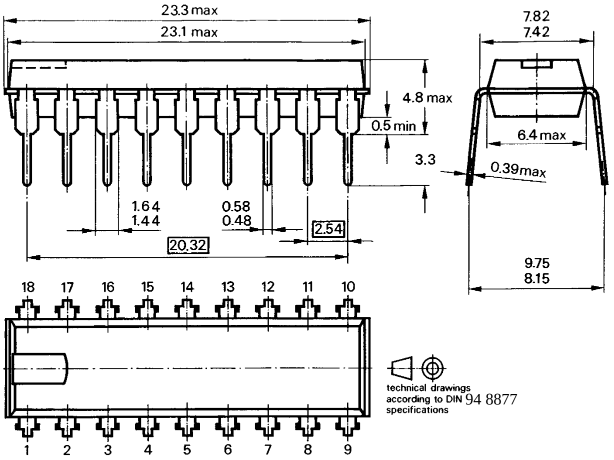


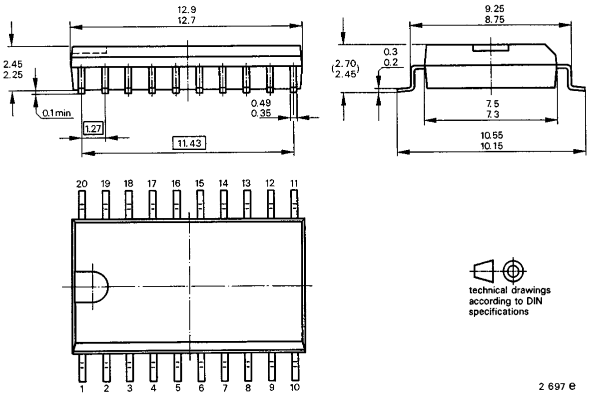
Figure 11. Standard application with predischarge for 8 NiCd/NiMH cells @ 1600 mA

Dimensions in mm

Package: DIP18



Package: SO20



Ozone Depleting Substances Policy Statement

It is the policy of **TEMIC TELEFUNKEN microelectronic GmbH** to

1. Meet all present and future national and international statutory requirements.

2. Regularly and continuously improve the performance of our products, processes, distribution and operating systems with respect to their impact on the health and safety of our employees and the public, as well as their impact on the environment.

It is particular concern to control or eliminate releases of those substances into the atmosphere which are known as ozone depleting substances (ODSs).

The Montreal Protocol (1987) and its London Amendments (1990) intend to severely restrict the use of ODSs and forbid their use within the next ten years. Various national and international initiatives are pressing for an earlier ban on these substances.

TEMIC TELEFUNKEN microelectronic GmbH semiconductor division has been able to use its policy of continuous improvements to eliminate the use of ODSs listed in the following documents.

1. Annex A, B and list of transitional substances of the Montreal Protocol and the London Amendments respectively

2. Class I and II ozone depleting substances in the Clean Air Act Amendments of 1990 by the Environmental Protection Agency (EPA) in the USA

3. Council Decision 88/540/EEC and 91/690/EEC Annex A, B and C (transitional substances) respectively.

TEMIC can certify that our semiconductors are not manufactured with ozone depleting substances and do not contain such substances.

TEMIC TELEFUNKEN microelectronic GmbH, P.O.B. 3535, D-74025 Heilbronn, Germany
Telephone: 49 (0)7131 67 2831, Fax number: 49 (0)7131 67 2423