TEMIC

TELEFUNKEN Semiconductors

U2402B-C

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

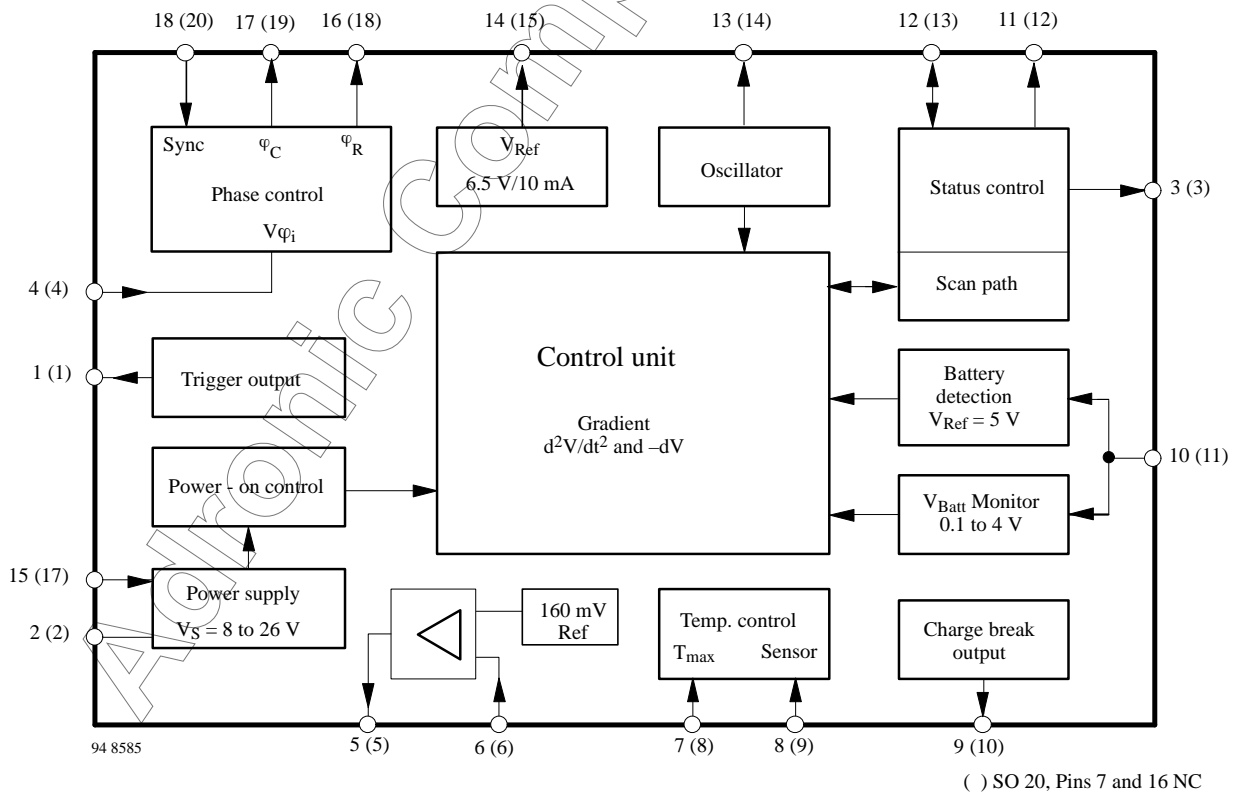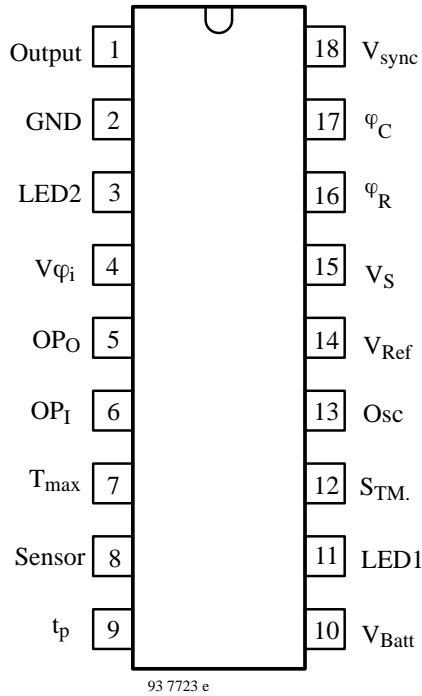- Emergency lighting systems

- Hobby equipment

- Camcorder

94 8585

( ) SO 20, Pins 7 and 16 NC

Figure 1 Block diagram

1

U2402B-C

Pinning

Package: DIP 18

93 7723 e

Pin			Pin
Output	1	18	V_{sync}
GND	2	17	φ_C
LED2	3	16	φ_R
$V\varphi_i$	4	15	V_S
OP_O	5	14	V_{Ref}
OP_I	6	13	Osc
T_{max}	7	12	$S_{TM.}$
Sensor	8	11	LED1
t_p	9	10	V_{Batt}

Package: SO 20

94 8594

Pin			Pin
Output	1	20	V_{sync}
GND	2	19	φ_C
LED2	3	18	φ_R
$V\varphi_i$	4	17	V_S
OP_O	5	16	NC
OP_I	6	15	V_{Ref}
NC	7	14	Osc
T_{max}	8	13	$S_{TM.}$
Sensor	9	12	LED1
t_p	10	11	V_{Batt}

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
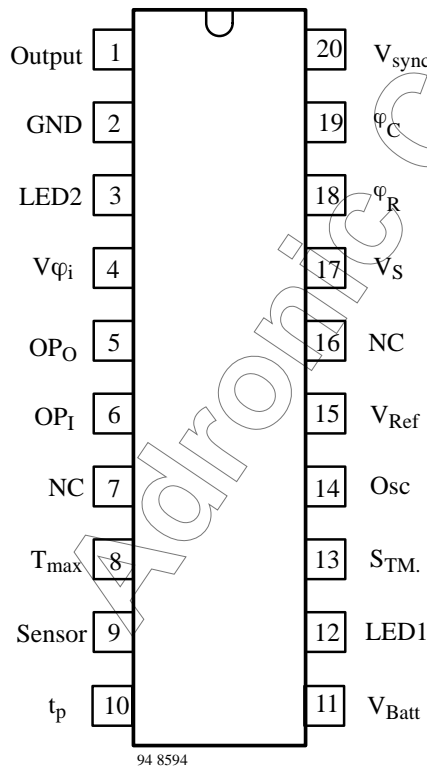
Pin	Symbol	Function
1	Output	Trigger output
2	GND	Ground
3	LED2	Display output "Green"
4	$V\varphi_i$	Phase angle control input voltage
5	OP_O	Operational amplifier output
6	OP_I	Operational amplifier input
7	NC	Not connected
8	T_{max}	Maximum temperature
9	Sensor	Temperature sensor
10	t_p	Charge break 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, 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.
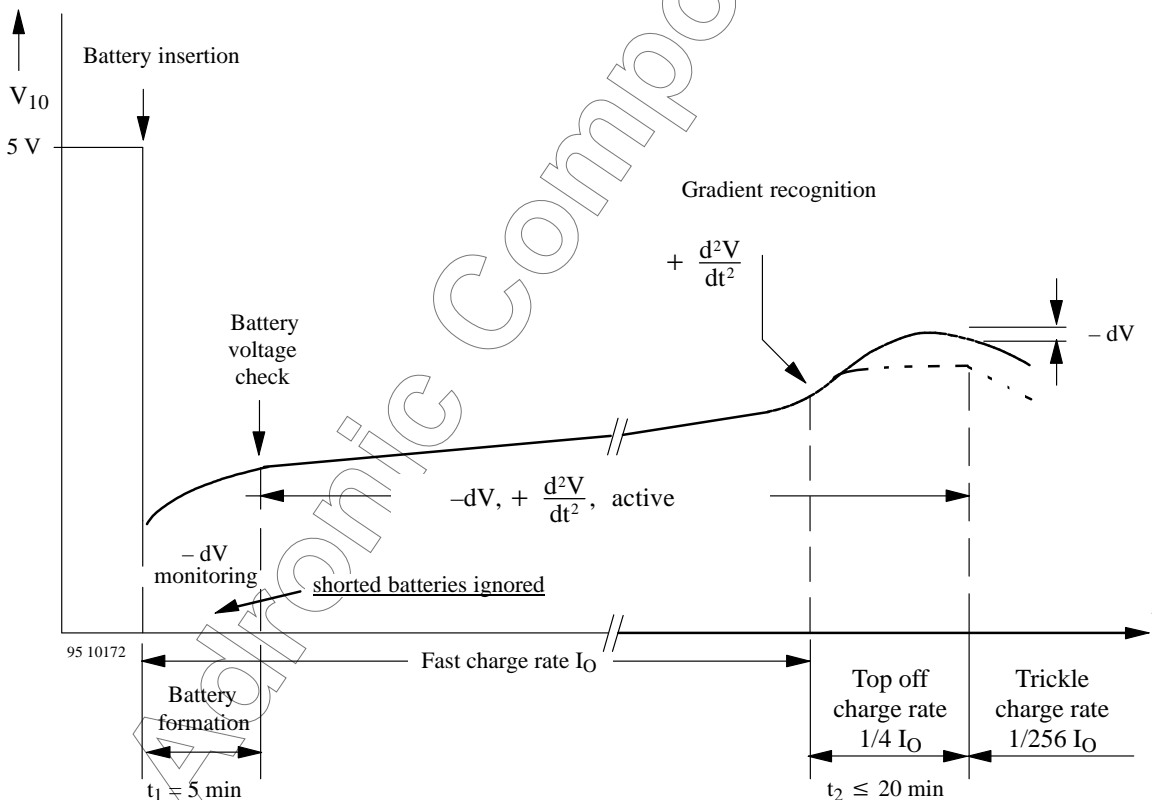

Figure 3 Charge function diagram, f_{osc} = 800 Hz

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

$I_{tot} = I_S + I_{RB1} + I_1$
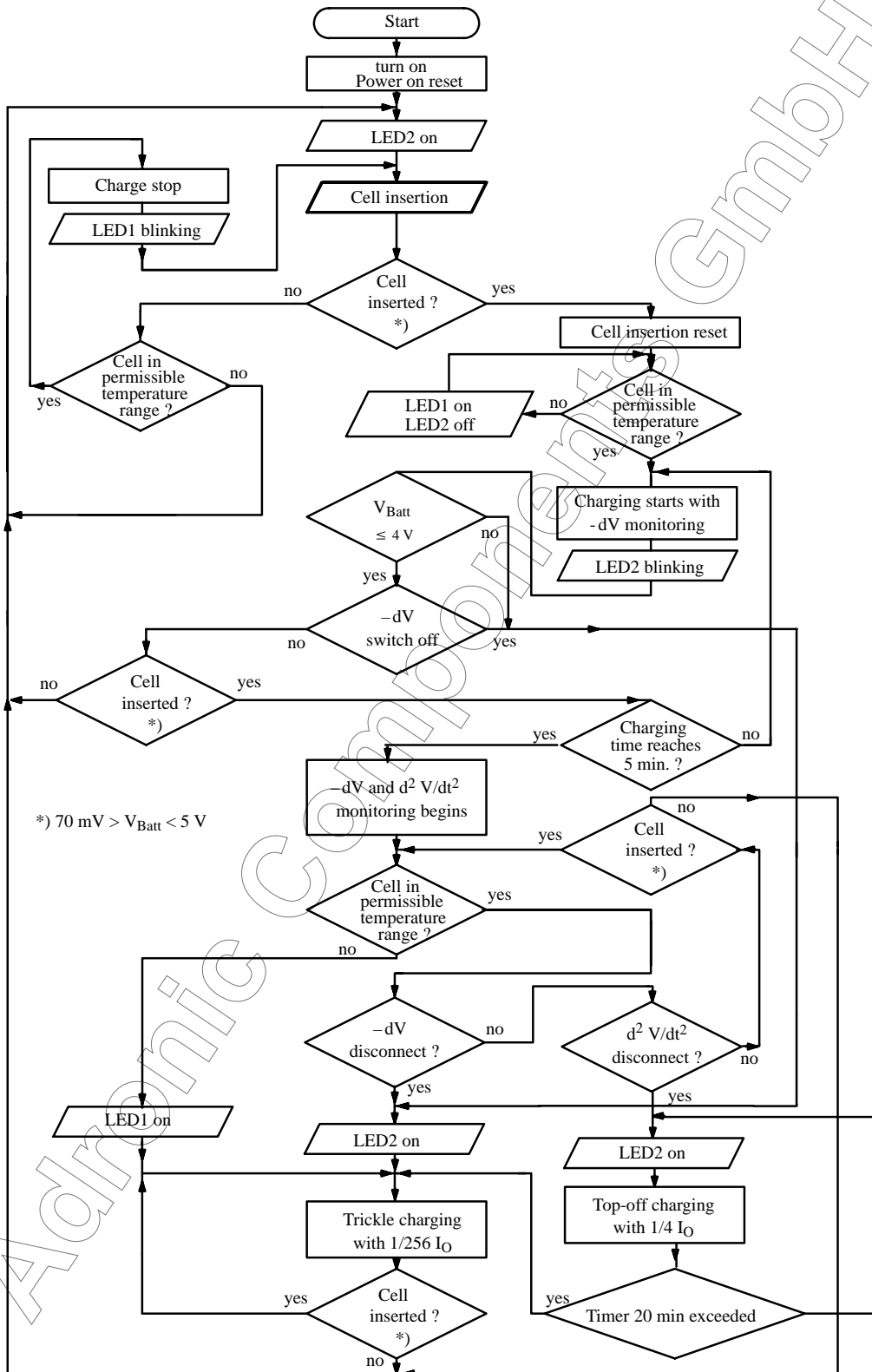
V_{max}, V_{min} = Rectified voltage

I_S = Current consumption (IC) without load

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

I_1 = Trigger current at Pin 1

Start

turn on
Power on reset

LED2 on

Charge stop

LED1 blinking

Cell insertion

Cell inserted ?
*)

no / yes

Cell insertion reset

Cell in permissible temperature range ?

yes / no

LED1 on
LED2 off

no

Cell in permissible temperature range ?

yes / no

Charging starts with - dV monitoring

LED2 blinking

$V_{Batt} \le 4\,V$

yes / no

- dV switch off

no / yes

Cell inserted ?
*)

no / yes

Charging time reaches 5 min. ?

yes / no

Cell inserted ?
*)

no / yes

- dV and $d^2 V/dt^2$ monitoring begins

Cell in permissible temperature range ?

yes / no

*) 70 mV > V_{Batt} < 5 V

- dV disconnect ?

no / yes

$d^2 V/dt^2$ disconnect ?

no / yes

LED1 on

LED2 on

LED2 on

Trickle charging with 1/256 I_O

Top-off charging with 1/4 I_O

Cell inserted ?
*)

yes / no

Timer 20 min exceeded

yes / no

93 7696 e

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.

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

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

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)
$V_{Battmax}$ = Max battery voltage

The voltage conditions mentioned above are measured during charge current break (switch-off condition).
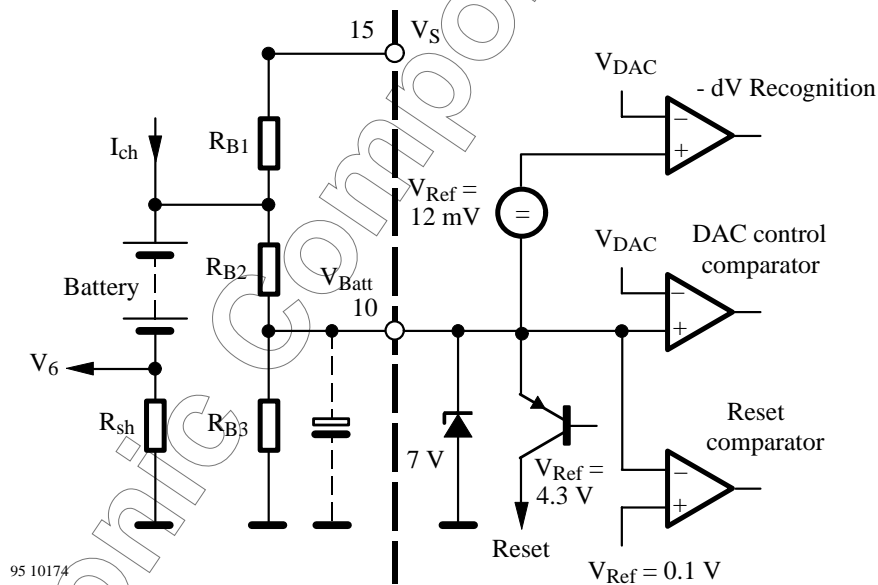
Figure 5 Input configuration for the battery voltage measurement

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.

94 8693
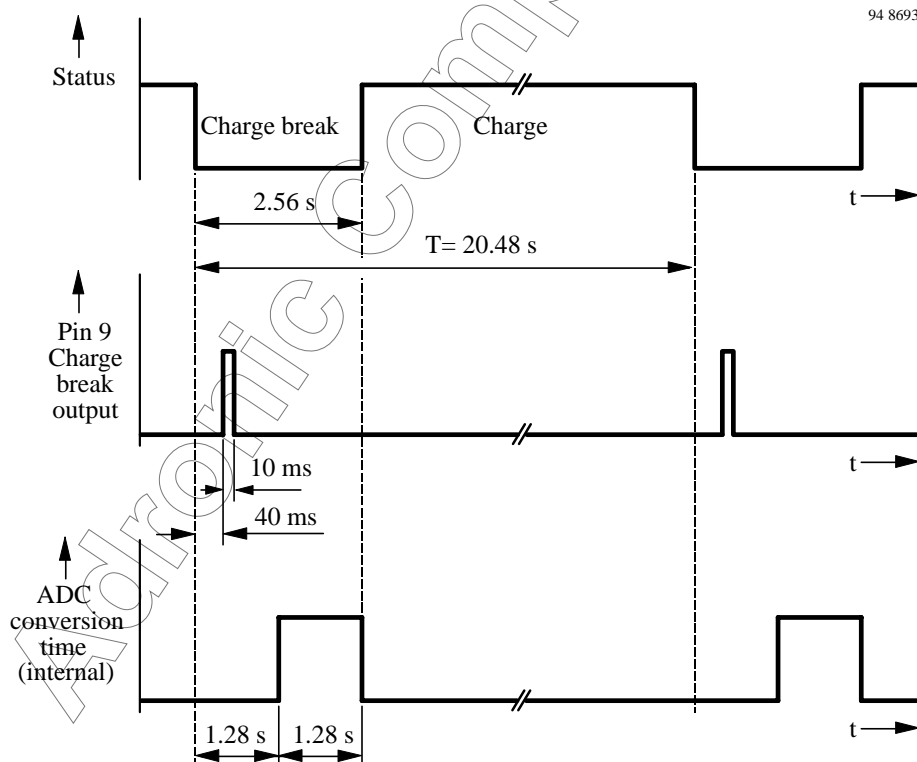
Figure 6 Operating sequence of voltage measurements

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.
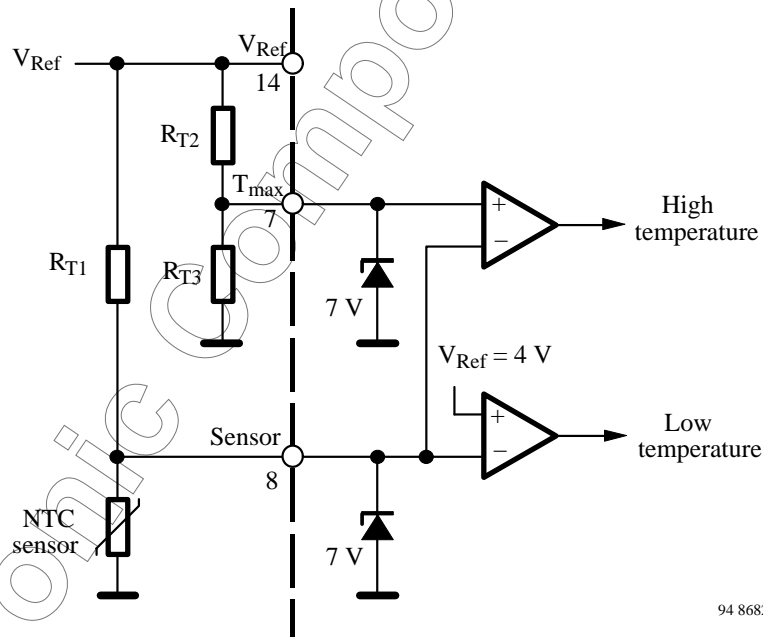
Figure 7 Temperature window

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.
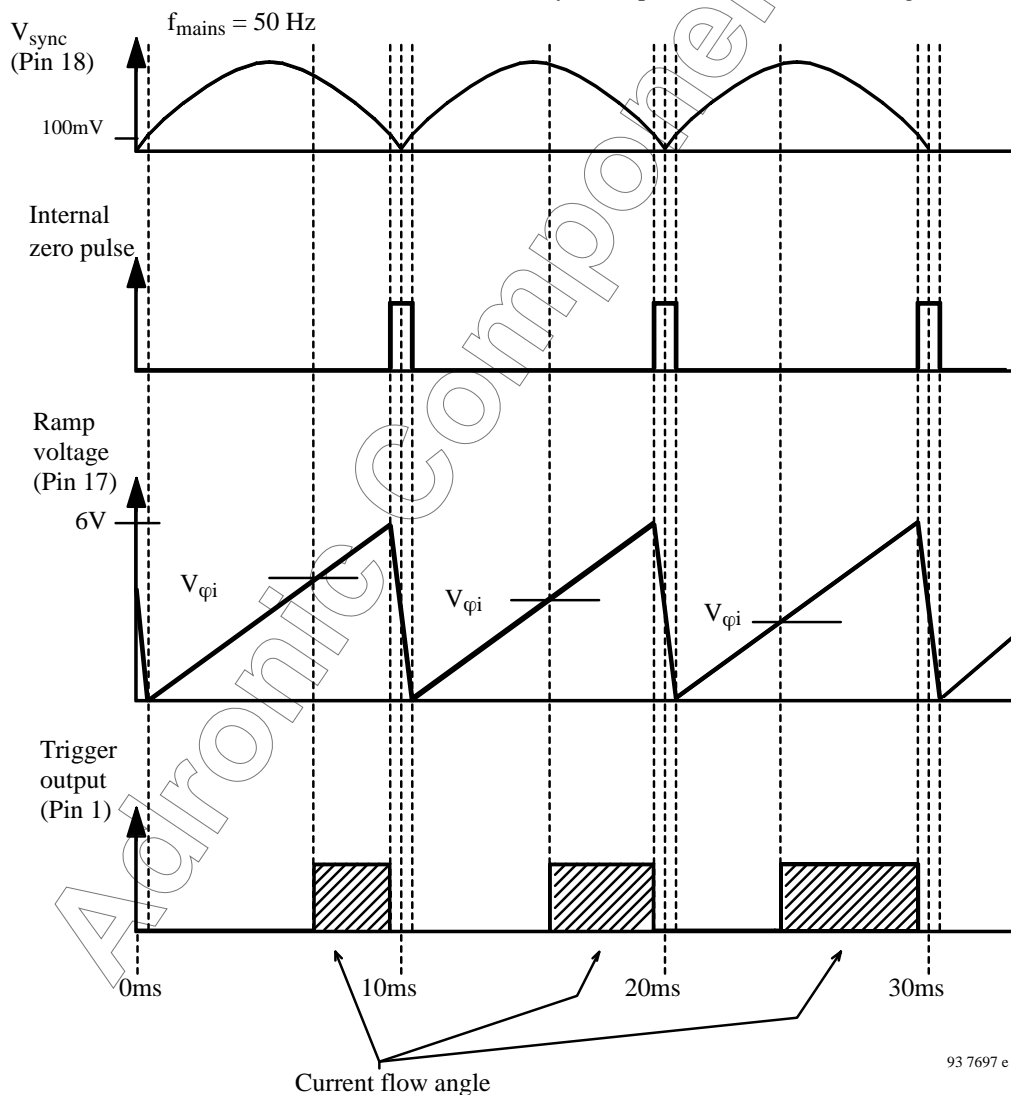
Figure 8 Phase control function diagram

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

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.
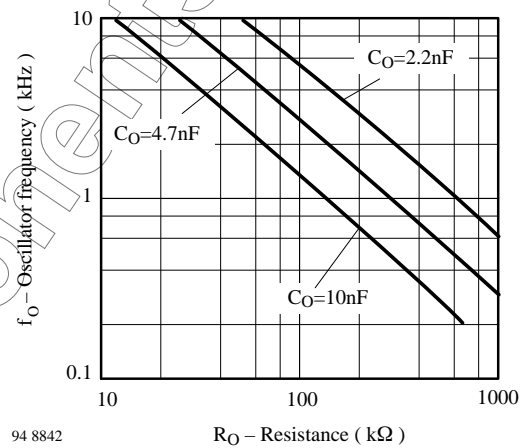
Figure 9 Frequency versus resistance for different capacitance values

U2402B-C

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
Supply current	Pin 15	I_S	100	mA
Current limitation $t < 100$ 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	I_5	– 80		+ 80	μA
Output pause current		Pin 5	I_{pause}	– 130		– 100	μA
Non-inverting input voltage		Pin 6	V_6	0		5	V
Non-inverting input current		Pin 6	I_6	– 0.5		0.5	μA
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

TEMIC

TELEFUNKEN Semiconductors

U2402B-C

| Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Charge break output	**Pin 9**					
Output voltage	I = 0	V_9	0		8.4	V
Output current		I_9			10	mA
Battery input **Pin 10**						
Input voltage for ADC		V_{Batt}	0		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
Test mode switch	**Pin 12**					
Input voltage		V_{12}	2.8		3.2	V
Input resistance		r_{12}		$12 \pm 20\%$		kΩ
Sync. oscillator	**Pin 13**					
Frequency	R = 750 kΩ C = 2200 pF	f_{osc}		800		Hz
Threshold voltage	High level Low level	$V_{T(H)}$ $V_{T(L)}$		$4.3\ \pm3\%$ $2.2\ \pm3\%$		V
Input current		I_{13}	-0.5		0.5	µA
Phase control						
Ramp voltage	$R_\varphi = 270\ k\Omega$ 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/min²
– dV-turn-off threshold		$-dV$		12		mV
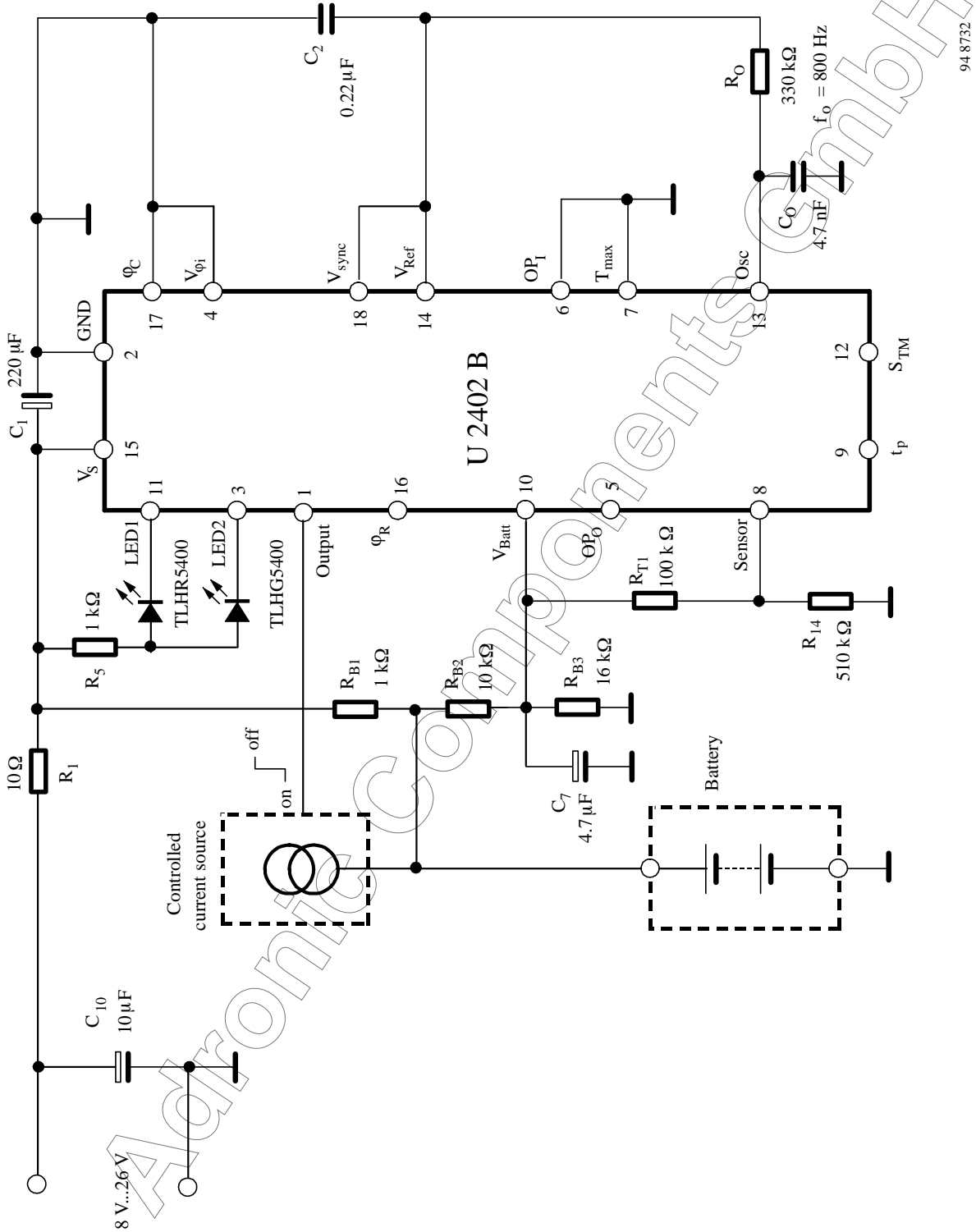
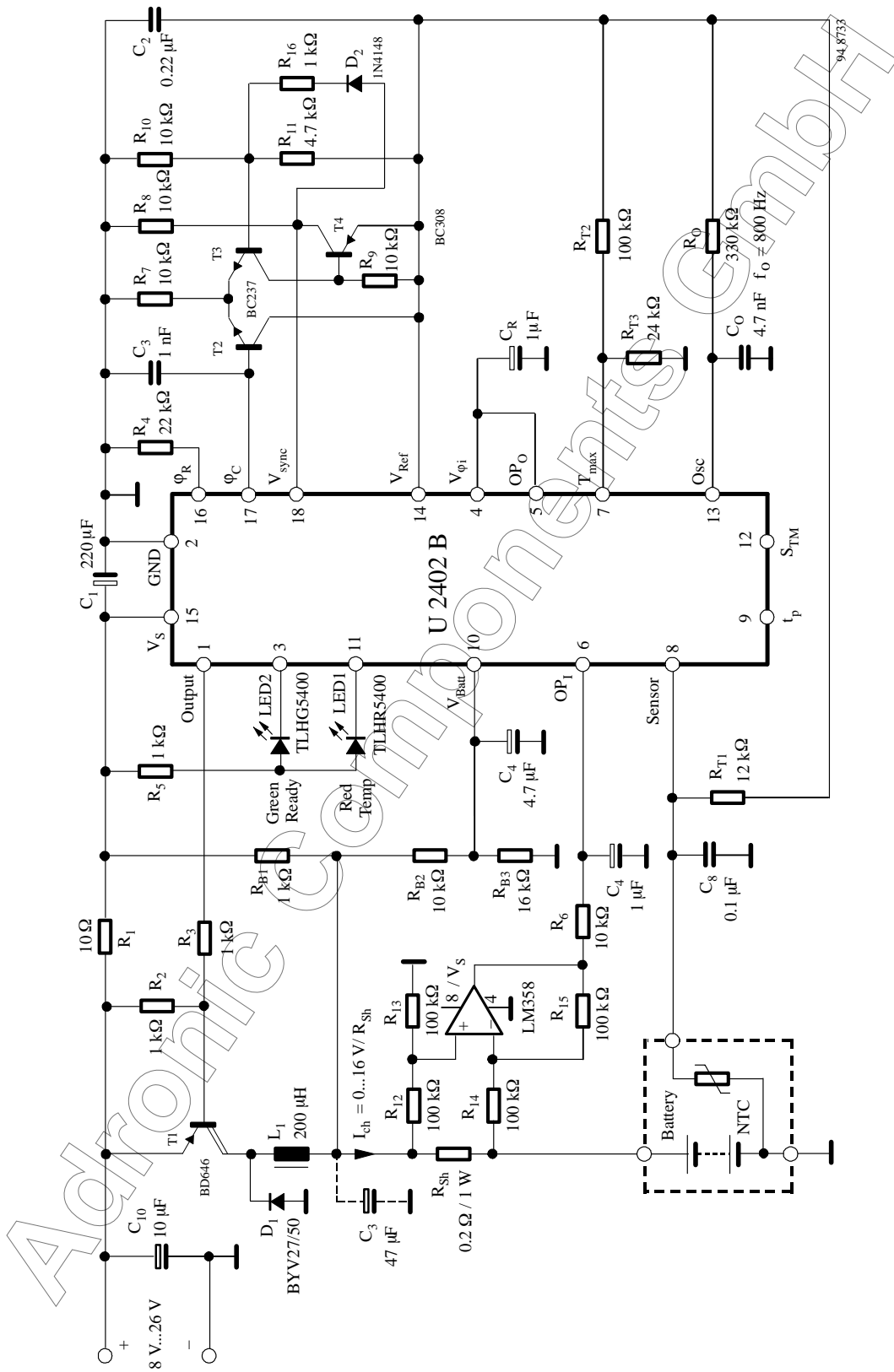Figure 10 Minimum charge system with external current source for 4 NiCd/NiMH cells

Figure 11 Car battery supplied charge system with high side current detection for four NiCd/NiMH cells @ 800 mA
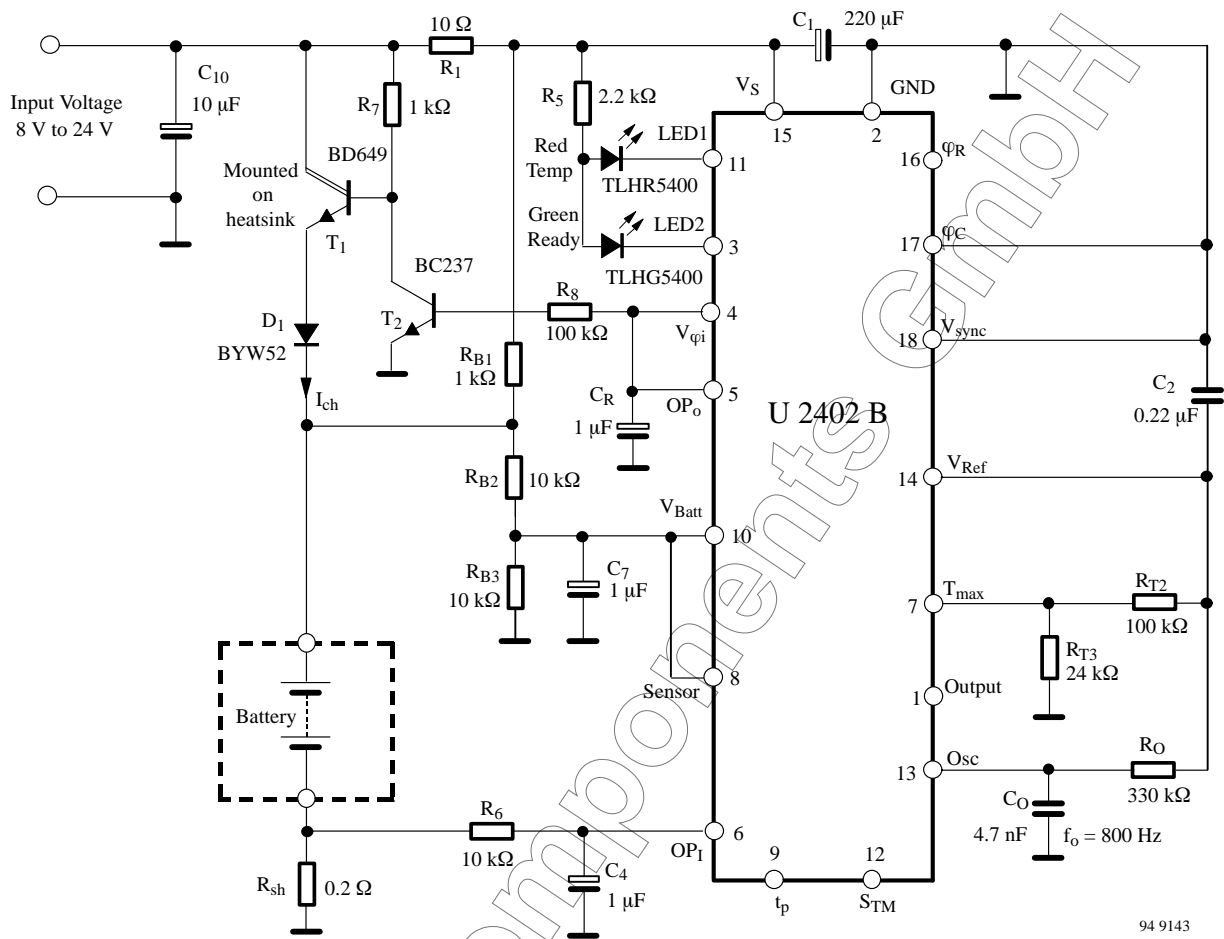
Figure 12 Standard application with predischarge for eight NiCd/NiMH cells @ 1600 mA

Figure 13 Battery charger for 12 V DC supply
linear current regulation
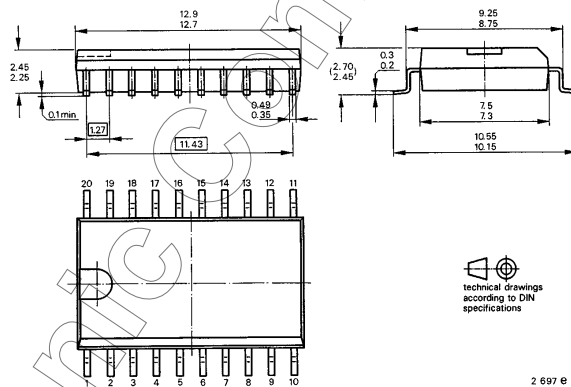
Dimensions in mm

Package: DIP 18
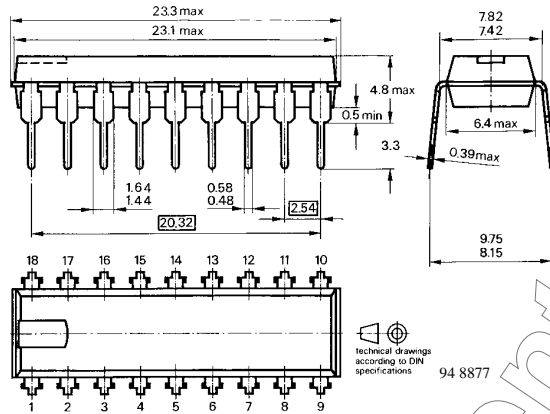
Package: SO 20

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 and

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.

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

The Montreal Protocol (1987) and its London Amendments (1990) will soon 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 any 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 and

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 and do not contain ozone depleting substances.