INTEGRATED CIRCUITS

DATA SHEET

SAA1500T

State-of-charge indicator for NiMH and NiCd powered applications

Objective specification
File under Integrated Circuits, IC11

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Philips Semiconductors

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FEATURES

- 5-segment state-of-charge indication for LED or LCD displays
- Numerous display facilities to indicate the operational modes
- Designed for constant charge and varying discharge currents
- Large dynamic range of discharge currents
- Independent setting for charge and discharge efficiency
- Battery self-discharge compensation
- Automatic switch-over from fast to trickle charge (to prevent overcharging)
- Low standby current for permanent integration into a battery pack.

APPLICATIONS

- Intelligent battery powered, portable, applications with 'remaining energy' indication and fast charge control.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
V_{CC}	supply voltage		1.8	–	7.0	V
I_{CC}	supply current	V_{CC} = 2.6 V; V_{CI} = 0 V	–	–	90	μA
f_{osc}	fixed frequency	charging	–	4.2	–	kHz
V_{CI}	input sense voltage	discharging	20	–	200	mV
T_{amb}	operating ambient temperature		0	–	+70	°C

ORDERING INFORMATION

EXTENDED TYPE NUMBER	PACKAGE			
	PINS	PIN POSITION	MATERIAL	CODE
SAA1500T	20	SO20L	plastic	SOT163AH

INTRODUCTION

More and more portable appliances are being used because they can operate independently from power sources such as mains or car batteries (see Fig.1). In many cases, NiCd (powerful appliances) and NiMH (environment) rechargeable batteries are used. Because of the constant voltage of these batteries, it is not the energy (Wh) but the charge amount (Ah) that has to be known to enable the state-of-charge indication. In systems with known charge and discharge currents, time is an equivalent for the charge amount in the battery ($t = Q/I$). The charge time can be registered easily on a counter.
The system can be made universal by adapting the counting frequency to the used battery type, thereby making the counter contents a reflection of the energy state of the battery. The requirements of a battery state-of-charge indicator are in many ways similar to those of a fuel gauge for a car.

The SAA1500T is designed for enhanced systems with varying discharge currents. A variety of loads can discharge the battery without disturbing the charge account. If the equivalent of the charge counter contents is known in the SAA1500T, then the following information can be made available:

- The state-of-charge, indicated by LED or LCD displays
- The battery low state, indicated by LED and acoustic alarms
- The full state. A control signal can automatically switch the charge current from a fast to a trickle level to prevent overcharge.

The state-of-charge indication is an important and useful addition to any rechargeable battery pack for a variety of reasons. An underlying problem is the common tendency to recharge batteries many times, in fact more often than actually necessary. People waste time and effort in this way because they are always afraid of being caught out with flat batteries. The state-of-charge indicator helps to overcome this problem and brings other benefits such as:

- Increased battery cycling and consequently improved battery performance and lifetime
- Enhanced customer satisfaction
- Excellent selling feature.

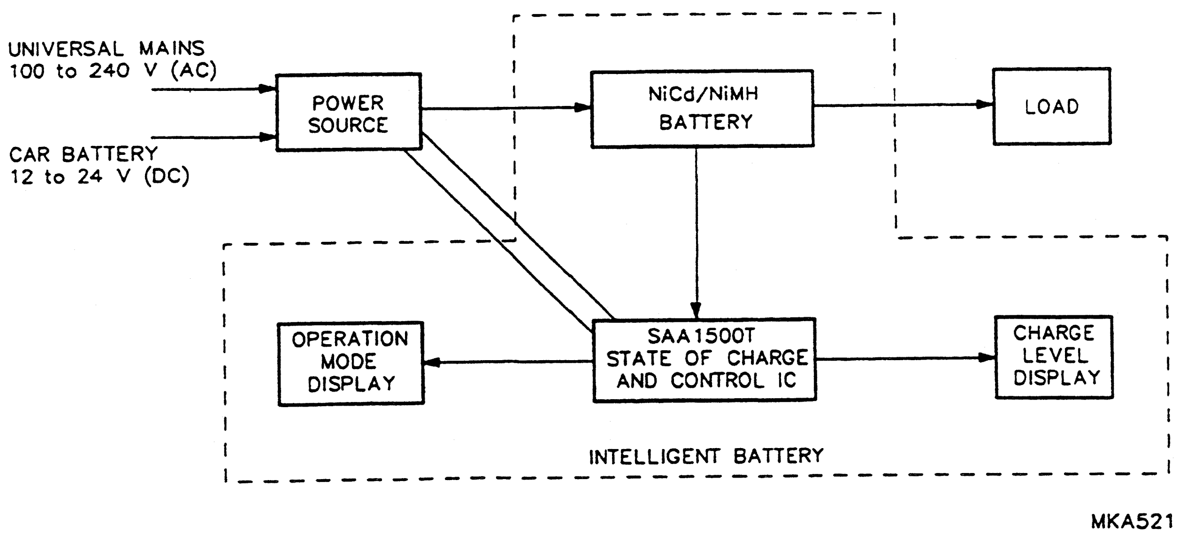


Fig.1 System diagram.

GENERAL DESCRIPTION

The SAA1500T is manufactured in a low voltage SACMOS process and has been designed for use as a battery state-of-charge indicator and as a battery charge controller for rechargeable batteries. In principle only four states exist (but because of two charging levels, fast and trickle charge), six states can be considered for the batteries; fast and trickle charge, fast and trickle charge and discharge at the same time, standby and battery discharge (see Fig.2 State diagram).

During charging, activated by power-on, the charge rate increases linearly with the charge time (assuming constant charge current). During discharge, activated by the 'load switch ON', the charge rate decreases linearly with the discharge time and the discharge current level. During charge/discharge, the charge rate is kept constant. In standby, the charge rate is decreased to compensate for the battery self-discharge.

In the SAA1500T, the known charge current and the measured discharge current are transferred in up/down oscillator pulses. By book-keeping the pulses, an image of the battery charge is created in the counter. The contents of the counter are output via 5 LEDs or a 6 segment LCD bar graph display. Two signal outputs are available to drive the LEDs to indicate whether the batteries are being charged or to indicate the nearly empty state.

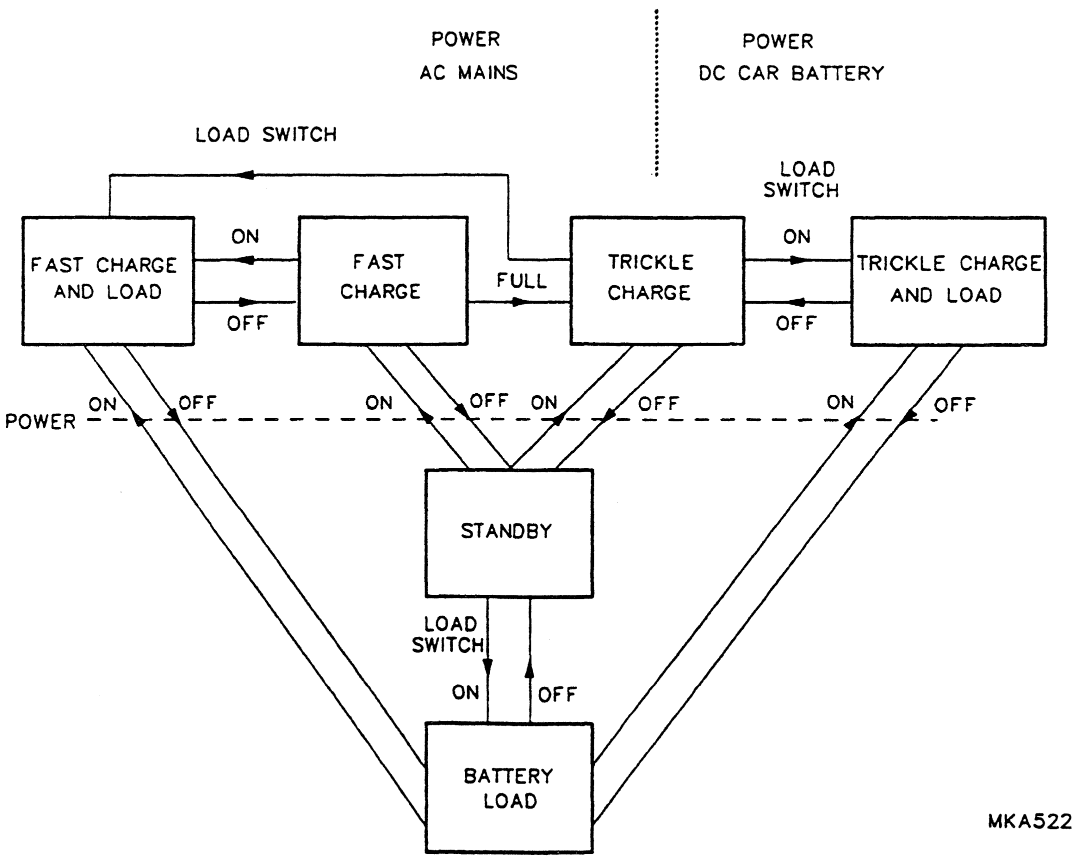


Fig.2 State diagram.

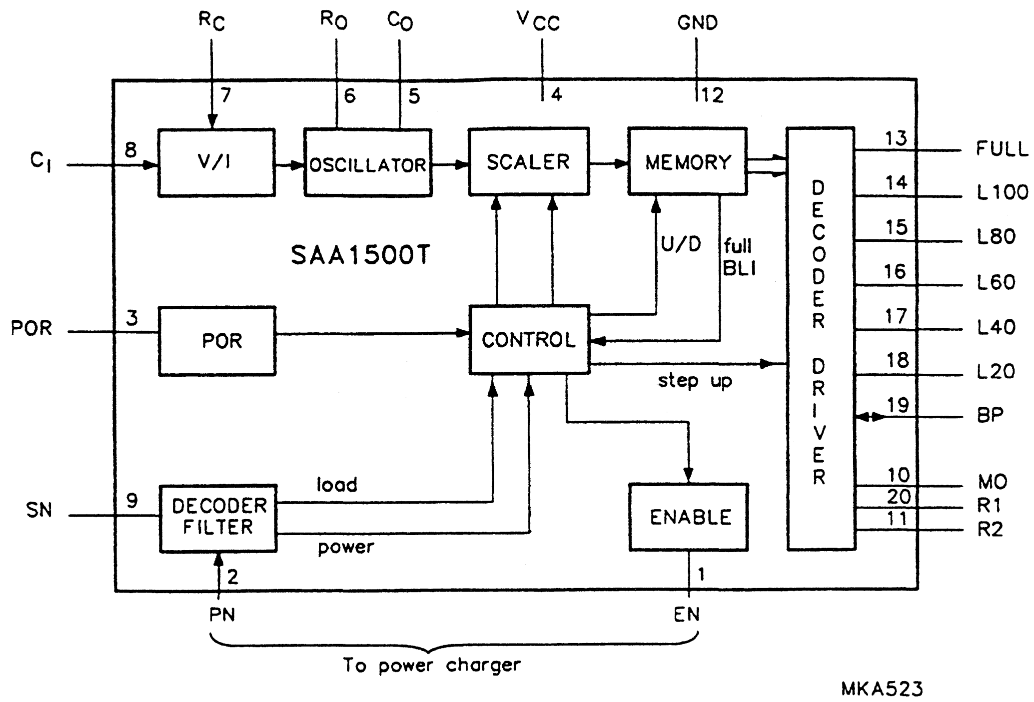


Fig.3 Block diagram.

PINNING

SYMBOL	PIN	DESCRIPTION
EN	1	enable control signal for battery charge unit
PN	2	power NOT mode detection
POR	3	power-on-reset, reset at LOW battery voltage
V_{CC}	4	supply voltage
C_O	5	capacitor for oscillator frequency
R_O	6	resistor for charge or self-discharge oscillator frequency
R_C	7	resistor to convert sense input voltage
C_I	8	discharge current sense input
SN	9	switch NOT, load switch ON detection
MO	10	mains ON state indication
R2	11	battery LOW drive signal for external buzzer
GND	12	ground
FULL	13	battery FULL indication, only LCD
L100	14	100% indication, LCD or LED driven
L80	15	80% indication, LCD or LED driven
L60	16	60% indication, LCD or LED driven
L40	17	40% indication, LCD or LED driven
L20	18	20% indication, LCD or LED driven
BP	19	backplane, (LCD), LCD/LED mode detection input
R1	20	battery LOW indicator, LOW drive

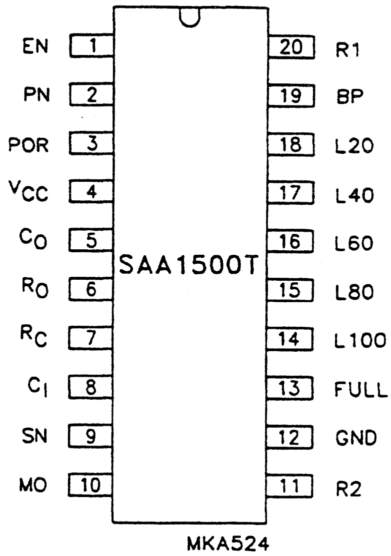


Fig.4 Pin configuration.

FUNCTIONAL DESCRIPTION

Power-on-reset

The POR circuit resets all counters if the supply voltage rises from 0 to V_{CC}. Reset is performed before V_{CC} = 1.8 V.
If the rise time of V_{CC} is fast, an external resistor and capacitor ensure the minimum pulse width of the internal reset pulse. If the rise time of V_{CC} is slow, the POR circuit acts as a level detector. The counters are also reset before V_{CC} = 1.8 V.

Oscillator (see Fig.5)

An RC type oscillator is used in the SAA1500T. The HIGH and LOW switching levels, and thus the voltage swing of the oscillator, are derived from V_{CC}. The timing components are designed so that the oscillator frequency is at V_{CC} and temperature independent.

The rise and fall times of the oscillator period are:

$t_r = R_O \times C_O \times \ln2$; $t_f = R_O//10\ k\Omega \times C_O \times \ln2$;
$t_u \approx 15\ \mu s$ (9.1)

t_u is the undershoot time. The timings given in the specification are referenced to a fixed frequency of 4.2 kHz. Table 1 gives the modes at which the fixed frequency is active.

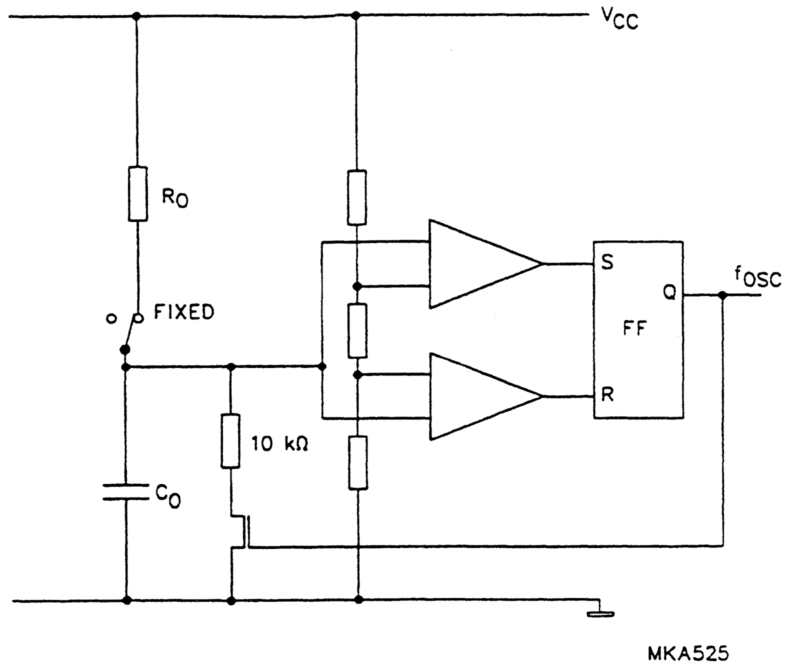


Fig.5 Fixed oscillator frequency.

V/I convertor (variable frequency)

The discharge current is sensed over a low ohmic (less dissipation) resistor R_{sense} (70 mΩ). In the voltage-to-current block (V/I), the sense voltage is converted into a current and this current is used to charge the oscillator capacitor C_O, (see Fig.6).

The period time can be calculated using the following equation:

$t_r = (C_O \times V_{CC} \times R_{conv})/(3 \times I_{load} \times R_{sense})$;
$t_f \approx 10\ k\Omega \times C_O \times \ln 2$; $t_u \approx 15\ \mu s$ (9.2)

The rise time is the dominating factor, and so it is clear that the countdown frequency is proportional to the discharge current .
In the discharge mode the frequency is V_{CC} dependent. However, as the battery voltage is rather insensitive to the battery charge, this influence is low.
The input voltage to the V/I block ranges from 20 mV to 200 mV. Outside of this range it is less accurate (see Fig.7).

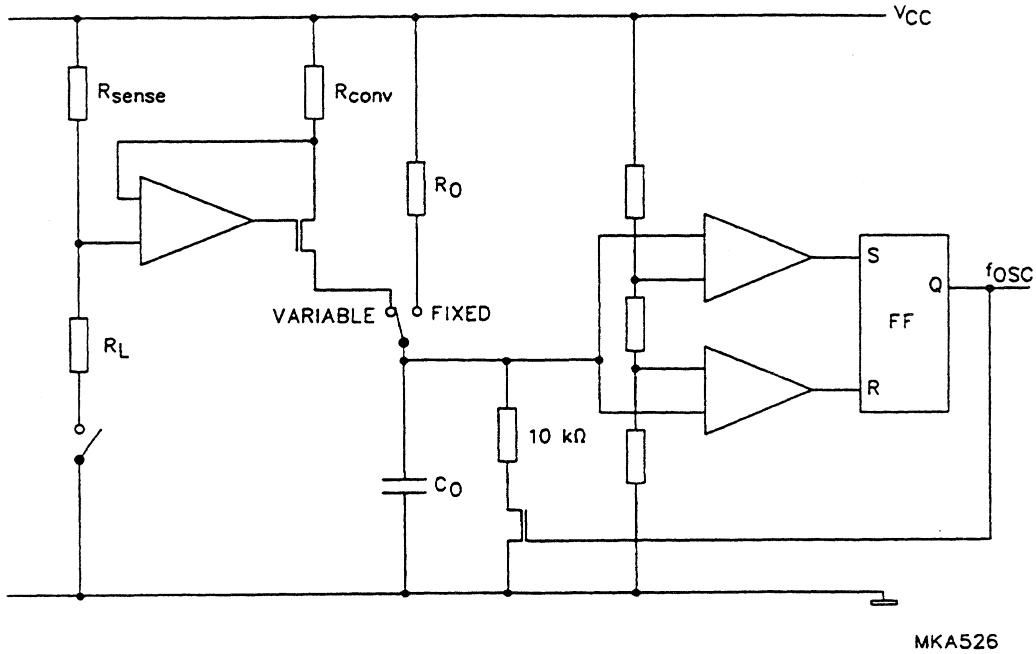


Fig.6 Variable oscillator frequency.

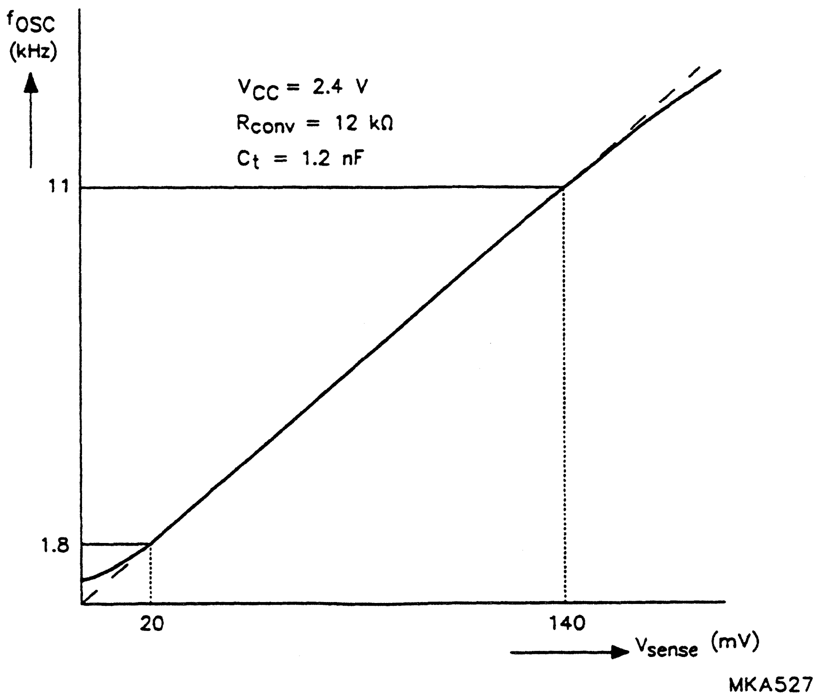


Fig.7 Voltage to frequency conversion.

Decoder filter

In the decoder filter block, the two inputs PN (power NOT) and SN (switch NOT) are tested. SN is tested on two logic states (HIGH and LOW) and PN on four states (HIGH, LOW, >5Ffixed and <3Ffixed). The inputs are digitally filtered to make them insensitive to external interference caused by motor commutation currents. The PN input informs the SAA1500T about the power charge unit state. The most important states are; fast charge, trickle charge and no power.
The SN input informs the SAA1500 about the load state. Two states are possible, load or no load. The load switch is sensed for that information.

Memory

The memory has a fixed volume of ten times. The memory contents (= battery charge) will be output via the decoder/driver block.

Scaler

In the scaler, a scale factor is introduced to scale down the memory counting frequency. In the trickle and standby modes, the battery current is adapted and so the memory counting frequency is changed accordingly. For the following modes, fixed scale factors are programmed:

- fast charge = 7.37×10^5
- trickle charge = 32 x fast charge
- standby = 150 x trickle charge
- discharge mode = 8.85×10^5.

Control

In the control block, in co-operation with the decoder/filter, six user modes and two test modes are provided together with appropriate signals to select the correct scale factors. The pin control signals, the different modes of operation, the oscillator frequency and scale factors are given in Table 1. The direction of the scale factor, up or down, is dependent on the mode, and thus determined in the control block. Four user modes have been explained previously.

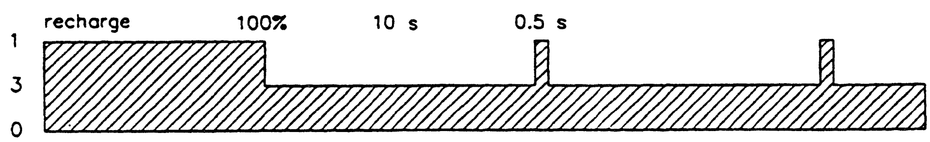
In the 'trickle charge and load mode', the discharge current is nearly always much higher than the trickle charge level, consequently the scale factor is chosen to be the same as in the discharge mode.
In many cases a motor is driven in the 'fast charge and load mode'. The control pin EN switches the system from a current source to a voltage source regulation to keep the motor speed constant. This ensures that only the current demanded by the motor will be delivered and the batteries will remain unaffected. For this reason a scale factor of zero is selected in this mode.
During the two test modes the scale factor is set at 1 to speed up the counter checks.
Step-up means that LEDs are switched on successively at the beginning of an LED display. If the LEDs are already active, there will be no step-up. Only those LEDs that are concerned with the charge status are activated. The step up frequency is $2 \times 10^{-3} \times f_{OSC}$ (see appendix B).
The LED and LCD display, during charge and discharge, is illustrated in Fig.12 (Appendix A) and in Fig.13 (Appendix B).
The memory block passes information to the control unit concerning the extreme states of the battery charge. At batteries FULL, a signal is sent to the enable block to terminate the fast charge session. At batteries almost empty, a Battery Low Indication (BLI) signal is sent to the decoder/driver (see also appendix A).

Table 1 Modes of operation.

INPUTS		MODES OF OPERATION	INDEX	OSCILLATOR FREQUENCY	SCALE FACTOR
PN	SN				
L	L	test, very fast down count	TD	fixed	512
<3Ffix	L	trickle charge and load, count down	TCL	variable	885k
>5Ffix	L	fast charge and load, no count	FCL	fixed	0
H	L	battery load, count down	BL	variable	885k
L	H	test, very fast up count	TU	fixed	512
<3Ffix	H	trickle charge, slow up count	TC	fixed	23M6
>5Ffix	H	fast charge, fast up count	FC	fixed	737k
H	H	standby, self discharge, POR active	SB	fixed	7G1
H	H	standby, self discharge, after POR	SB	fixed	3G5

Enable

It is possible to use the enable output (EN) to control the fast charge on the batteries. The EN signal is HIGH when the indicator shows not full. When an LED bar-graph is used and it shows FULL, then the EN signal will pulsate between HIGH and OPEN states. This provides a pulsating trickle charge waveform with a 5% duty factor for a 10 second period to compensate for the LED currents. If an LCD bar-graph is used, then at the full state, the EN output goes into a continuous high impedance state (see Fig.8).



0 = V_{SS}

1 = V_{CC}

3 = 3–state; high impedance

EN signal with LED bar graph applied.

With LCD bar graph, the signal is continuously 3–state after 100%.

MKA528

Fig.8 Waveform of enable signal with full batteries.

Decoder driver

The SAA1500T is intended to display the charge of the batteries in a six segment LCD bar graph or five segment LED display. LED indication is also given for batteries nearly empty, batteries on recharge and batteries full during recharge. Outputs L100, L80, L60, L40, L20 and FULL are designed to drive an LCD bar-graph with output BP connected to the backplane of the LCD. The LCD segment is active if the segment voltage is in antiphase with the BP voltage. If, however, BP is connected to ground (V_{SS}), then outputs L100, L80, L60, L40 and L20 may drive the LEDs directly with their anodes connected to the positive supply (V_{CC}). Outputs MO and R1 can drive LEDs directly. Output MO indicates batteries on recharge (LED constantly ON) and batteries full while recharging (LED flashes). Output R1 indicates that the battery is nearly empty. Output R2 provides a second battery nearly empty signal which can be used to drive a simple electroacoustic transducer with an audio tone via an external transistor. Circuit waveforms are illustrated in Fig.9.

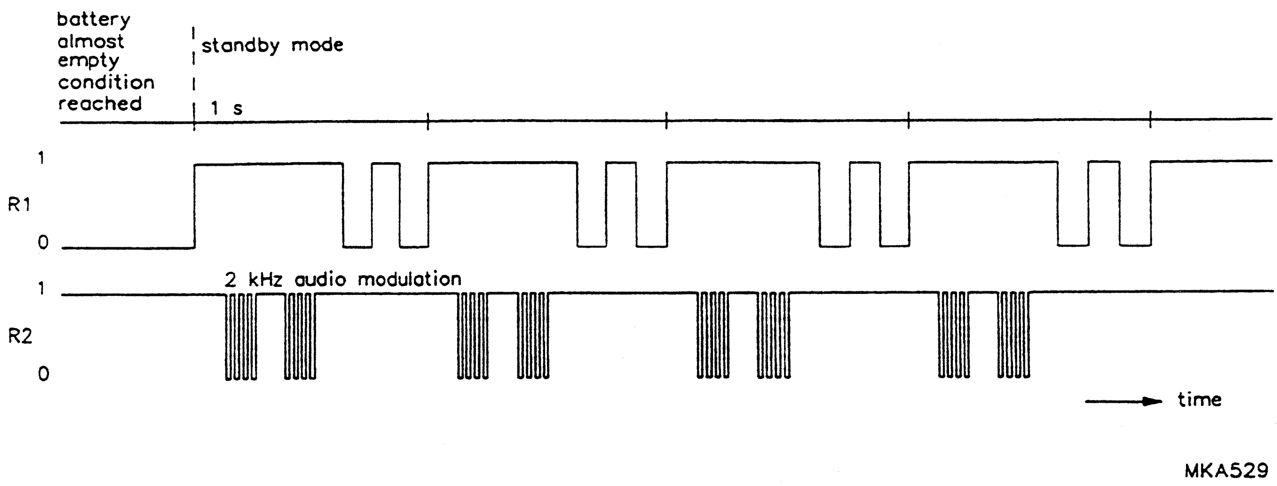


Fig.9 Waveform of R1 and R2 signalling empty batteries.

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CC}	supply voltage		−0.5	7.0	V
V_I	input voltage	note 1	−0.5	V_{CC}+0.5	V
V_O	output voltage	note 1	−0.5	V_{CC}+0.5	V
I_{CC}	supply current		–	40	mA
I_{SS}	supply current		–	−120	mA
I_I	input current		–	±10	mA
I_O	output current		–	±20	mA
T_{amb}	operating ambient temperature		0	+70	°C
T_{stg}	storage temperature		−65	+150	°C

Note

1. V_{CC} + 0.5 V must not exceed 7.0 V.

DC CHARACTERISTICS

T_{amb} – 25 °C; unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
V_{OH}	HIGH level output voltage (pins 13 and 19)	V_{CC} = 2.4 V; I_O = –650 µA	2.0	–	–	V
V_{OH}	HIGH level output voltage (pins 1 and 11)	V_{CC} = 2.4 V; I_O = –1 mA	2.0	–	–	V
V_{OH}	HIGH level output voltage (pins 10, 14 to 18 and 20)	V_{CC} = 2.4 V; I_O = –300 µA	2.0	–	–	V
V_{OL}	LOW level output voltage (pins 13 and 19)	V_{CC} = 2.4 V; I_O = 650 µA	–	–	0.4	V
V_{OL}	LOW level output voltage (pin 11)	V_{CC} = 2.4 V; I_O = 1 mA	–	–	0.4	V
V_{OL}	LOW level output voltage (pins 10 14 to 18 and 20)	V_{CC} = 3.8 V; I_O = 15 mA	1.8	–	–	V
		V_{CC} = 2.4 V; I_O = 5 mA	–	–	0.55	V
$\|I_{LO}\|$	output leakage current (pins 1 and 19)	V_{CC} = 3.8 V; V_O = V_{CC} or 0 V	–	–	±1	µA
$\|I_{LI}\|$	input leakage current (pin 3)	V_{CC} = 3.8 V; V_3 = 0 V	–	–	1	µA
$\|I_{LI}\|$	input leakage current (pin 2)	V_{CC} = 3.8 V	–	–	1	µA
I_9	input current (pin 9)	V_{CC} = 2.4 V	30	–	80	µA
V_{ihs}	Schmitt trigger HIGH (pins 2, 9 and 19)	V_{CC} = 2 V	1.6	–	–	V
		V_{CC} = 4 V	2.2	–	–	V
V_{ils}	Schmitt trigger LOW (pins 2, 9 and 19)	V_{CC} = 2 V	–	–	0.4	V
		V_{CC} = 4 V	–	–	0.18	V
V_{hys}	hysteresis voltage (pins 2, 9 and 19)	V_{CC} = 2 V	0.4	–	–	V
		V_{CC} = 4 V	0.5	–	–	V
V_{IH}	HIGH level input voltage (pin 3)	V_{CC} = 3.8 V; I_3 = 1 µA	0.8	–	1.5	V
		V_{CC} = 1.8 V; I_3 = 1 µA	–	–	1.55	V
V_{IL}	LOW level input voltage (pin 3)	V_{CC} = 1.8 V; I_3 = 1 µA	–	–	1.55	V
I_5	input current (pin 5)	V_{CC} = 2.4 V; V_5 = 2.4 V	150	–	360	µA
I_{CC}	supply current	V_{CC} = 2.6 V; V_3 = V_8 = 0 V; V_5 = V_7 = 0 V	–	–	90	µA

AC CHARACTERISTICS

T_{amb} = 25 °C; unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
f_{OSC}	fixed oscillator frequency	V_{CC} = 2.4 V; R_6 = 260 kΩ C_5 = 1.2 nF; $V_8 = V_2 = V_9$ = 0 V	3.81	4.24	4.67	kHz
Δf_{OSC}	variable oscillator frequency	V_{CC} = 2.4 V; V_8 = 56 mV; R_7 = 12 kΩ C_5 = 1.2 nF; PN = 1; SN = 0	4.04	4.65	5.02	kHz
		V_{CC} = 2.4 V; V_8 = 35 mV; R_7 = 12 kΩ C_5 = 1.2 nF; PN = 1; SN = 0	2.47	2.94	3.24	kHz
SVRR	supply voltage ripple rejection	V_{CC} = 2.2 to 2.6 V; V_8 = 49 mV	–	–	5	%/0.1V

QUALITY SPECIFICATION

General quality specification for integrated circuits: UZW - BO/FQ - 601.

APPLICATION INFORMATION

The SAA1500T can be used in many applications with different types and sizes of rechargeable batteries. In the Introduction it is stated that the discharge/charge time is the equivalent of the battery charge.
The formula of the elapsed discharge/charge time and thus the collected charge is (see Fig.3):

discharge/charge time = t_{OSC} x scale factor x memory

(1) The fixed time period of the oscillator during charging is given in the following equation:

t_{OSC} = (Charge Time) / (scale factor x 10)

Where: the Charge Time (CT) is the time taken to fully charge empty batteries.

Therefore: f_{OSC} = 7370 / (3600 x CT [h]) [kHz]; (exclusive efficiency corrections) (13.1)

From formula (13.1) it is clear that the fixed oscillator frequency is dependent on the charge time (and so the charge current) and not on the battery size.
If the charge time and the oscillator frequency are fixed, the external components C_O and R_O can be calculated with formula (9.1). Some examples are given in Table 2.

(2) Many timing functions are related to the fixed oscillator frequency. The most important are the trickle charge and the self-discharge times (see also Table 2).

(3) The variable time period of the oscillator during discharge is given in the following equation:

t_{OSC} = (discharge time) / (scale factor x 10)

Therefore: f_{OSC} = 8850 / (3600 x DT) [kHz] (13.2)

Furthermore, formulas (9.1) and (9.2) are valid and, combining them with formula (13.2), the external components R_{conv}, and R_{sense} can be calculated:

R_{conv}/R_{sense} ' 500 x 10^3 x Q [Ah] / C_O [nF]; (V_{CC} = 2.4 V) (13.3)

As can be seen from formula (13.3), it is the battery size that is of importance and not the discharge time. Some examples are given in Table 3.

Table 2 Charge components.

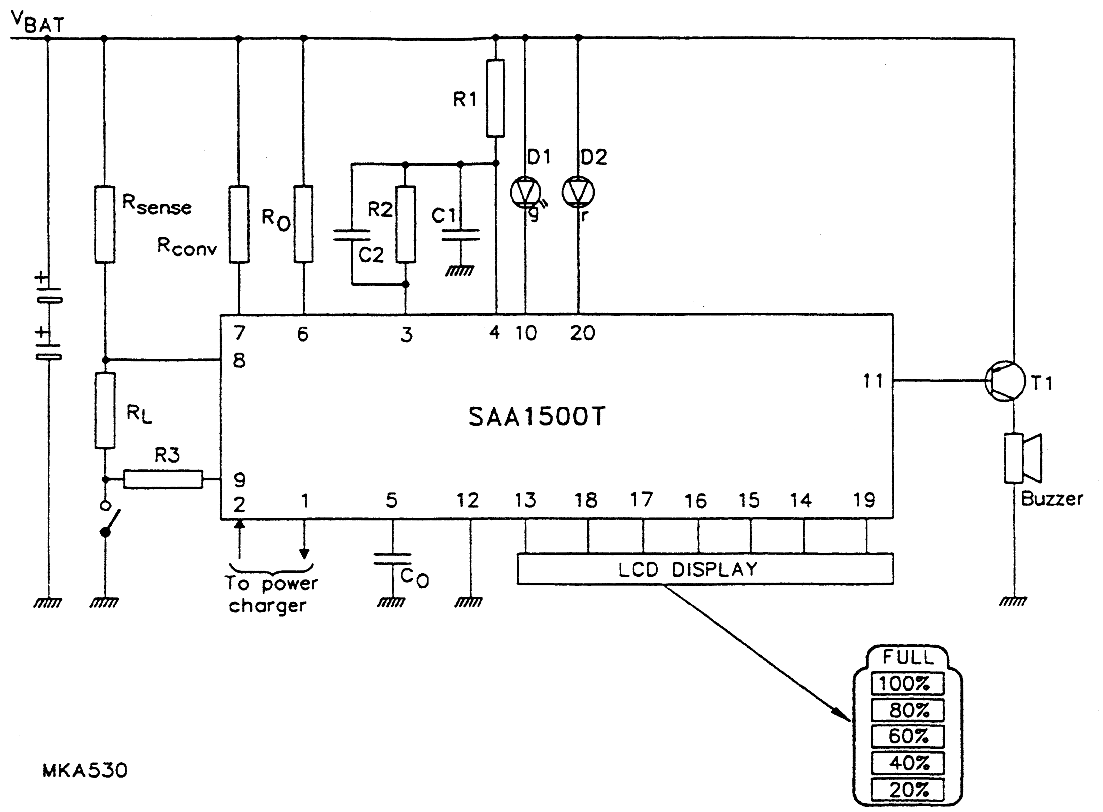
NiXX / xxAh				
charge time (h)	1/3	1/2	1	
charge current (CA)	3	2	1	
fixed frequency (kHz)	6.1	4.1	2.05	formula 13.1
R_O (kΩ) (C_O = 1.2 nF); note 1	180	264	556	formula 9.1
R_O (kΩ) (C_O = 2.4 nF); note 1	90	132	277	
trickle charge current (CA)	1/32 x I_{charge}			
self-discharge current (CA)	1/150 x $I_{trickle}$			

Note

1. C_O > 1.2 nF because of the parasitic capacitance influence on the printed-circuit board.

Table 3 Discharge components.

	NiCd		NiMH	
	AA(600mAh)	**Sub C(1.2Ah)**	**AA(1.1Ah)**	**AA(1.7Ah)**
R_{conv}/R_{sense}(C_O = 1.2 nF)	252k	499k	459k	706k
R_{conv}/R_{sense}(C_O = 2.4 nF)	126k	252k	229k	352k
R_{conv} (C_O = 1.2 nF) (R_{sense} = 70 mΩ)	17k6	34k8	32k	49k3
R_{conv} (C_O = 2.4 nF) (R_{sense} = 70 mΩ)	8k8	17k4	16k	24k6



R1 = 100 Ω; R2 = 1.5 MΩ; R3 = 5.1 kΩ; C1 = 100; C2 = 1.2 nF.

Fig.10 Application diagram for LCD display.

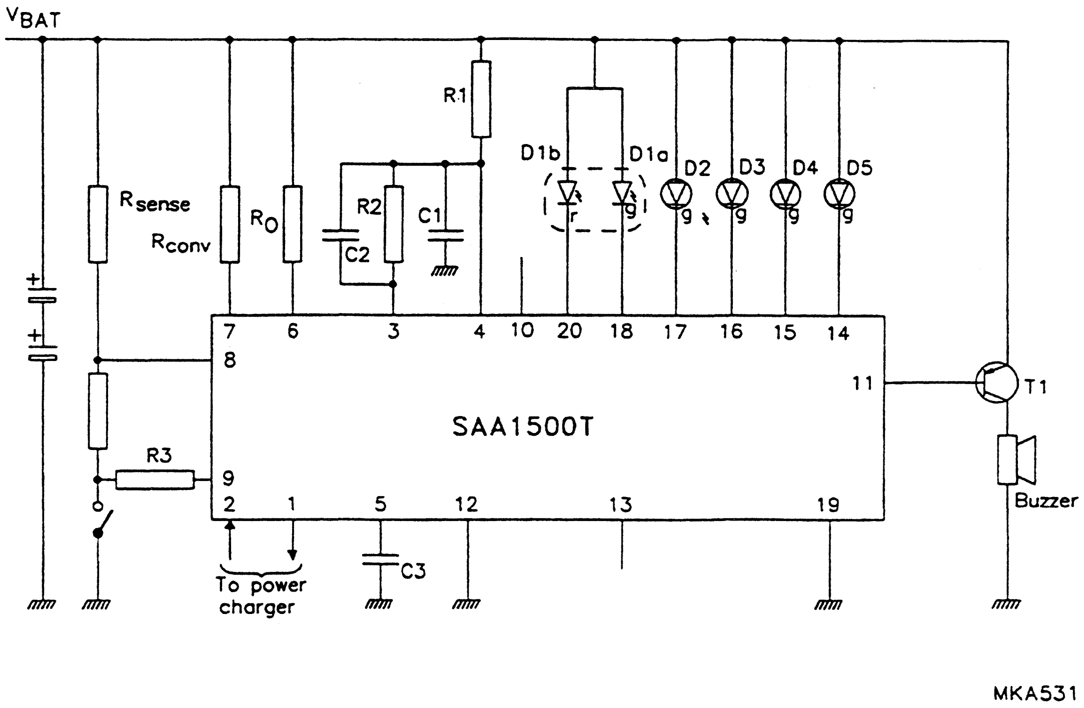


Fig.11 Application diagram for LED display.

APPENDIX A

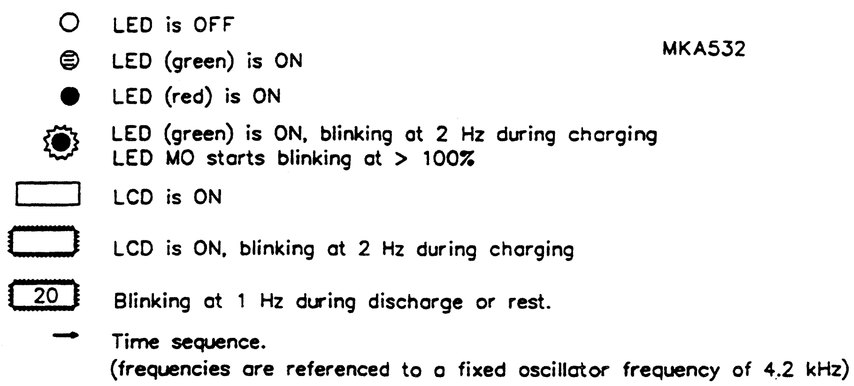


Fig.12 Legend for figure 13.

APPENDIX B

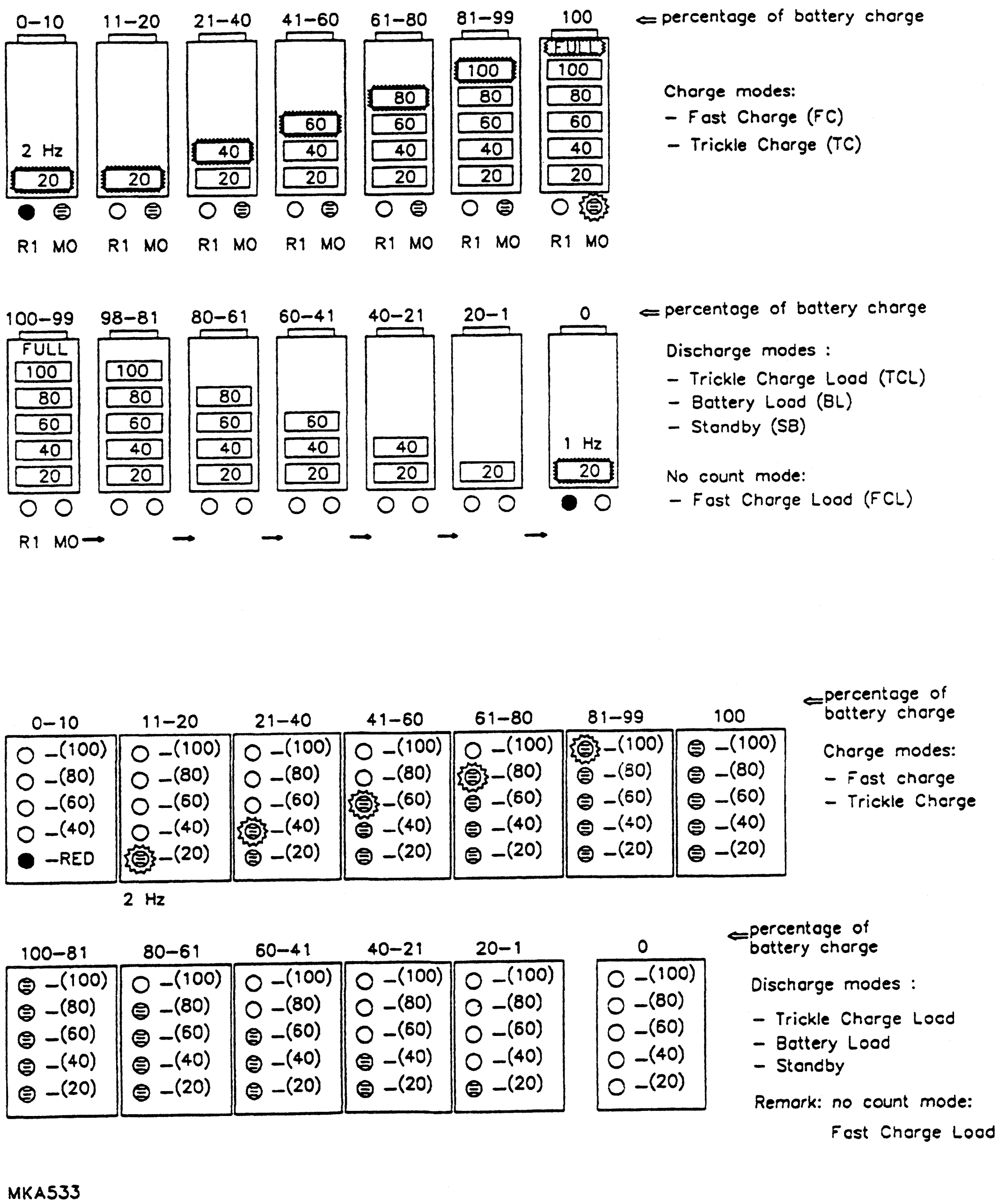


Fig.13 Battery charge displayed by LCD and LED.

Remarks to figure 13

LED mode

The LEDs are activated at every operational mode change. If the LEDs were already active before the mode change, the display will not be changed. If the LEDs were not active before the mode change, a step-up pattern is generated. Step up means that the LEDs are activated successively recording the charge status every 1/8 second. In the Battery Load, Trickle Charge Load and Standby modes, the LEDs are switched off after 8 second. In the Fast Charge, Trickle Charge and Fast Charge Load modes, the LEDs remain on.

Battery Low Indication is active if;

The charging (FC,TC) is stopped (==> standby) before 10% charge is reached.
The discharging (BL, TCL) is started below 10% and stopped (==> SB) above 0%.
The discharging is stopped (==>) at 0%.
For BLI waveforms (see Fig.9) R1 is active before the mode is switched over to standby.

Battery Low Indication is not active if;

Discharging is started above 10% and stopped 10-1%. Instead, the green L20 LED will be active for 8 seconds. If recharging is started during 1-10%. The L20 LED is blinking at 2 Hz, the red LED is not active.

LCD mode

The LCD display, as against the LED mode, is always visible.

Battery Low Indication is active if:

The charging (FC, TC) is stopped (==> standby) before 10% charge is reached.
The discharging (BL, TCL) is stopped (==> SB) at 0% charge.

PACKAGE OUTLINE

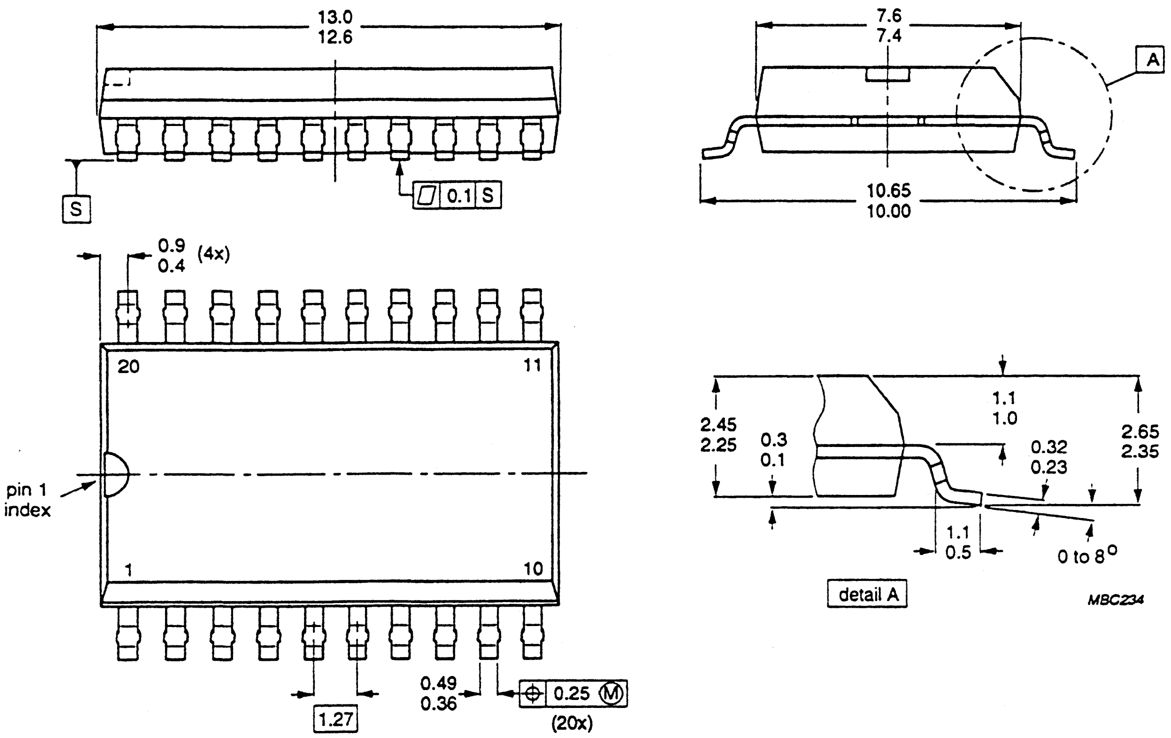


Fig.14 20-lead mini-pack; plastic (SO20L; SOT163AH).

SOLDERING

Plastic mini-packs

BY WAVE

During placement and before soldering, the component must be fixed with a droplet of adhesive. After curing the adhesive, the component can be soldered. The adhesive can be applied by screen printing, pin transfer or syringe dispensing.

Maximum permissible solder temperature is 260 °C, and maximum duration of package immersion in solder bath is 10 s, if allowed to cool to less than 150 °C within 6 s. Typical dwell time is 4 s at 250 °C.

A modified wave soldering technique is recommended using two solder waves (dual-wave), in which a turbulent wave with high upward pressure is followed by a smooth laminar wave. Using a mildly-activated flux eliminates the need for removal of corrosive residues in most applications.

BY SOLDER PASTE REFLOW

Reflow soldering requires the solder paste (a suspension of fine solder particles, flux and binding agent) to be applied to the substrate by screen printing, stencilling or pressure-syringe dispensing before device placement.

Several techniques exist for reflowing; for example, thermal conduction by heated belt, infrared, and vapour-phase reflow. Dwell times vary between 50 and 300 s according to method. Typical reflow temperatures range from 215 to 250 °C.

Preheating is necessary to dry the paste and evaporate the binding agent. Preheating duration: 45 min at 45 °C.

REPAIRING SOLDERED JOINTS (BY HAND-HELD SOLDERING IRON OR PULSE-HEATED SOLDER TOOL)

Fix the component by first soldering two, diagonally opposite, end pins. Apply the heating tool to the flat part of the pin only. Contact time must be limited to 10 s at up to 300 °C. When using proper tools, all other pins can be soldered in one operation within 2 to 5 s at between 270 and 320 °C. (Pulse-heated soldering is not recommended for SO packages.)

For pulse-heated solder tool (resistance) soldering of VSO packages, solder is applied to the substrate by dipping or by an extra thick tin/lead plating before package placement.

DEFINITIONS

Data sheet status	
Objective specification	This data sheet contains target or goal specifications for product development.
Preliminary specification	This data sheet contains preliminary data; supplementary data may be published later.
Product specification	This data sheet contains final product specifications.
Limiting values	
Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.	
Application information	
Where application information is given, it is advisory and does not form part of the specification.	

LIFE SUPPORT APPLICATIONS

These products are not designed for use in life support appliances, devices, or systems where malfunction of these products can reasonably be expected to result in personal injury. Philips customers using or selling these products for use in such applications do so at their own risk and agree to fully indemnify Philips for any damages resulting from such improper use or sale.

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