CONSONANCE

PFM buck mode single-cell NiMH battery charge management ICs
CN3600

Overview:

The CN3600 is a fixed off-time PFM mode buck single-cell NiMH battery charge management IC.With an input voltage range of 2.7V to 6.5V, the CN3600 has few external components and is simple to apply, making it ideal for single-cell NiMH battery charge management applications.

The CN3600 uses constant current and maintenance charging modes to charge a single-cell NiMH battery. After power-on, the CN3600 first charges the battery in constant-current mode, and when the battery voltage reaches 1.36V, it enters the maintenance charging mode, and at the same time starts the internal timer. In the maintenance charging mode, the end state is entered only when the timer ends or the battery voltage reaches the maximum voltage (typical value 1.46V). In the end state, no current flows into the battery. When the battery voltage drops below the re-charge threshold, it automatically enters the re-charge mode and starts a new charge cycle.

The CN3600 has a switching frequency of up to 500 KHz, allowing the use of small profile inductors and capacitors.

Other features include two open drain status indication outputs, battery over-voltage protection and chip over-temperature protection.

The CN3600 is available in an 8-pin eSOP package.

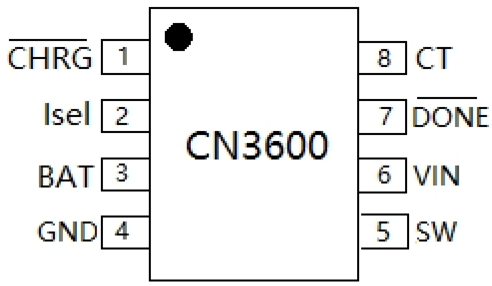
Applications.

- Standalone NiMH battery chargers
- Automotive Models
- Toys
- Devices using #5 or #7 batteries

Features:

- Input voltage range: 2.7V to 6.5V
- Operating current: 320uA@VIN=5V
- Charging current can be automatically adjusted according to the load capacity of the input power supply
- Can be powered by solar panel
- Switching frequency up to 500KHz
- Maintain charge mode ensures full battery capacity
- Selectable peak inductor current (I_{peak})
- Battery voltage up to 1.46V or end of charge by timer
- Automatic re-charge function
- Battery overvoltage protection
- Chip over-temperature protection
- Two open drain status indication outputs
- Operating ambient temperature range: -40°C to 85°C℃
- Adopts eSOP-8 package
- Lead-free, meets rohs, halogen-free

Pin Arrangement



Typical Application Circuit: Figure 1

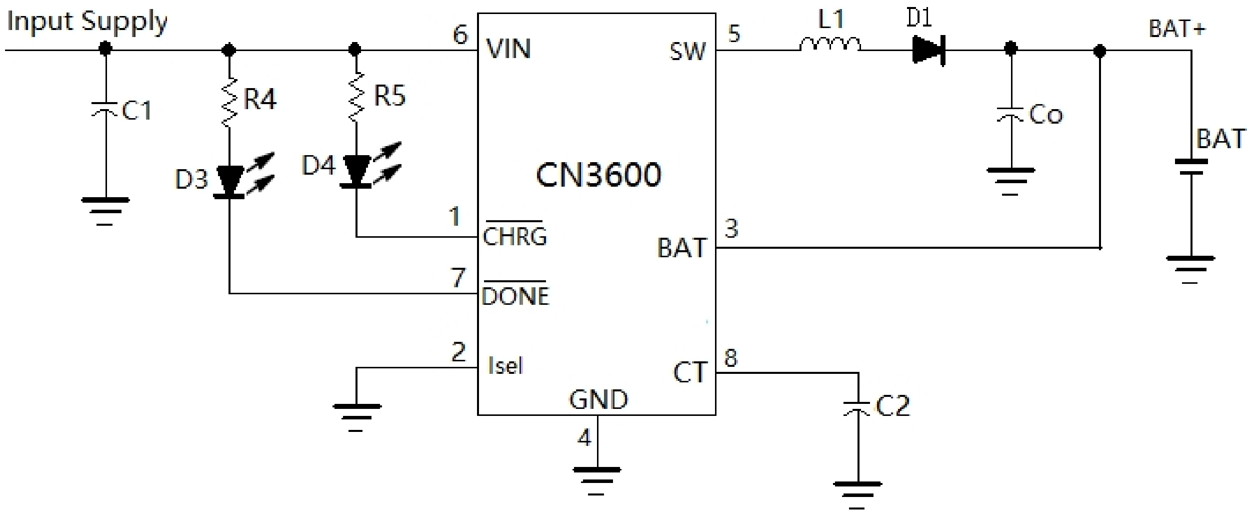


Figure 1 Typical Application Circuit

Ordering Information

Model Number	Package	Package	Operating Temperature
CN3600	SOP-8	Taping, Tray, 4000pcs/tray	-40°C to 85°C°C

Pin Description

Serial Number	Symbol	Symbol
1	$\overline{CHRG}$	**Charge status indication output.** Open drain output. In the charging state (constant current mode or maintain charge mode) this pin is pulled low by the internal N-channel MOSFET. In other states, this pin pin outputs a high resistance state.
2	Isel	**Inductor current peak select input.** When this pin is high, the peak inductor current (i_{peak}) of constant current charging mode is 1.19A (typical); when this pin is low, the peak inductor current of constant current charging mode is 0.62A (typical). The Isel pin accepts TTL logic levels or CMOS logic levels.
3	BAT	**Battery positive connection terminal.** The battery voltage is fed back to the CN3600 through this pin, and the CN3600 determines the charger status based on the voltage at this The CN3600 determines the charger status based on the voltage at this pin.
4 GND	GND	**Ground connection.** Negative connection between input power and battery.
5	SW	The SW pin is connected to an external inductor, and inside the chip, the SW pin is connected to a P-channel MOSFET and an N-channel MOSFET. channel MOSFET and an N-channel MOSFET.
6	VIN	The internal circuitry of the CN3600 is powered through this pin.
7	$\overline{DONE}$	**End-state indication output.** Open drain output. When charging is over, this pin is pulled low by an internal switch; in other states, this pin outputs a high-resistance state. When charging is finished, this pin is pulled low by an internal switch; in other states, this pin outputs a high resistance state.
8	CT	**Timing Capacitor Connection.** The timing capacitor should be connected between the CT pin and ground. When the CN3600 enters the maintain charge state, the timer starts. The timing time is determined by the following formula: $t_{timing} = 12.18 \times 10^9 \times C2$ (seconds) Where C2 is the timing capacitance value in farads.

Limit Parameters

VIN and Isel pin voltages ....-0.3V to 7.0V Maximum Junction Temperature.. 150℃
BAT Pin Voltage ....-0.3V to 7.0V Operating ambient temperature .... -40℃ to 85℃ $\overline{CHRG}$ and $\overline{DONE}$ Pin Voltage .... -0.3V to VIN Storage temperature .... -65℃ to 150℃ SW and CT pin voltages .... 。。。。。 ..... -0.3V to VIN Soldering temperature (10 seconds) .... 260℃

Exceeding the above listed limits may cause permanent damage to the device. The above given are only limit ranges. Working under such limit conditions, the technical specifications of the device will not be guaranteed, and the reliability of the device will also be affected by prolonged exposure to such conditions.

Electrical parameters:

(VIN = 5V, T_A = -40°C to +85°C, typical values measured at T_A = +25°C unless otherwise noted)

Parameter	Symbol	Test Conditions	Minimum	Typical	Maximum	Unit
Input Voltage Range	VIN		2.7		6.5	V
UVLO Threshold	VUVLO				2.65	V
Operating Current	IVIN	VBAT = 2.1V without switching	250	320	390	uA
Fixed Shutdown Time	toff	Charge Mode	1.6	2.0	2.4	uS
Over Temperature Protection Threshold	tOTP			145		°C
Over-temperature protection hysteresis	Hopt			21 °C		Inductance current
Inductive current						
Peak inductive current	ipeak	Constant current charging; Isel High Level		1.19		A
		Maintain Charge; Isel High Level		0.62		
		Constant Current Charge; Isel Low		0.64		
		Maintain Charge; Isel Low		0.44		
BAT Pin						
Maximum Battery Side Voltage	Vhigh	BAT pin voltage rise	1.445	1.445	1.46	V
Constant Current Charge End Voltage	VCCT	BAT pin voltage rise	1.34	1.36	1.38	V
Recharge Threshold	Vrech	BAT pin voltage drop	1.32	1.339	1.36	V
BAT pin current	IBAT	VBAT = 1.5V	4.7	6.3	8	uA
Battery overvoltage protection threshold	VOV	BAT Voltage Rise	1.527	1.557	1.587	V
Battery overvoltage protection release threshold	VOVRLS	BAT voltage drop	1.466	1.496	1.526	
SW Pin						
N-Channel MOSFET Conductance RdsonN	RdsonN	N-channel MOSFET between SW pin and GND		0.3 ohm		ohm
P-channel MOSFET On-resistance Resistance	RdsonP	P-channel MOSFET between SW pin and VIN. VIN		0.4 ohm		ohm
Isel Pin						
Input Low Level	VL	Isel pin voltage drop			0.7 V	VL
Input High Level	VH	Isel pin voltage rise	2.2 V			VH
Input Current	IL	Isel=GND, VIN=6V	-100			nA
	IH	Isel=VIN=6V			100 nA	
$\overline{\text{CHRG}}$ Pin						
Potting Current	ISINK	VCHRG=0.3V, charge mode		10		mA
Leakage Current	ILEAK	VCHRG=6V, end of charge			100	nA
$\overline{\text{DONE}}$ Pin						
Irrigation Current	ISINK	VDONE=0.3V, end of charge		10		mA

Detailed Description:

The CN3600 is a fixed off-time PFM buck mode single-cell NiMH battery charging management IC with an input voltage range of 2.7 V to 6.5 V. The CN3600 includes a voltage reference source, an inductor current detection unit, a battery voltage feedback network, a battery over-voltage protection, an on-chip over-temperature protection, a control unit, and power MOSFET switches, etc. The CN3600 has few peripheral components and is very suitable for single-cell NiMH battery charging applications. With fewer peripheral components and simpler application, it is very suitable for single-cell NiMH battery charging application.

After the input power supply is turned on, CN3600 enters into constant current charging mode, and CHRG pin outputs a low level, indicating that charging is in progress. During the internal P-channel MOSFET conduction, the inductor current rises to the set peak current, the P-channel MOSFET turns off, the other N-channel MOSFET turns on, the inductor current falls, and the energy in the inductor is transferred to the output capacitor and the battery. the P-channel MOSFET's off time is fixed at 2 µs, and at the end of the off time, the N-channel MOSFET turns off and the P-channel MOSFET turns on. P-channel MOSFET turns on and so on. The battery voltage is detected through the BAT pin, and when the BAT pin voltage reaches 1.36V (typical), the CN3600 enters the maintenance charging mode. In the maintenance charging mode, the peak current of the inductor is smaller than the peak current of the constant current charging mode. The timer inside the chip starts at the beginning of the maintenance charging mode, and the charging process ends when the timer ends or the battery voltage reaches the maximum voltage (1.46V typical). In the end-of-charge state, the P-channel MOSFET inside the chip turns off and no current flows to the battery, while the DONE pin outputs a low level to indicate the end of charging. When the voltage at the BAT pin drops to 1.339V (typical), the CN3600 enters the constant current charging mode again to start a new charging cycle.

The CN3600's switching frequency can reach 500KHz, allowing the use of small form factor inductors and capacitors. Other features include peak inductor current selectable via the Isel pin, battery over-voltage protection, and chip over-temperature protection. The charging current/voltage curve is shown in Figure 2:

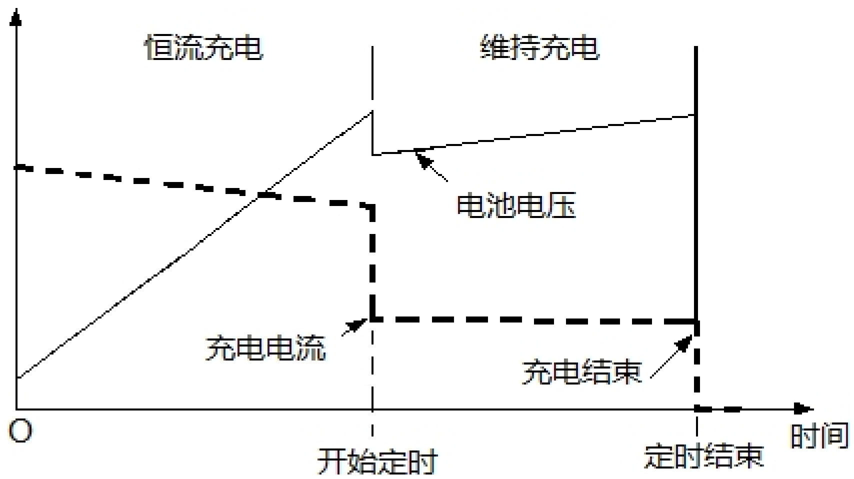


Figure 2 Charging current/voltage curve

The charging flow is shown in Figure 3:

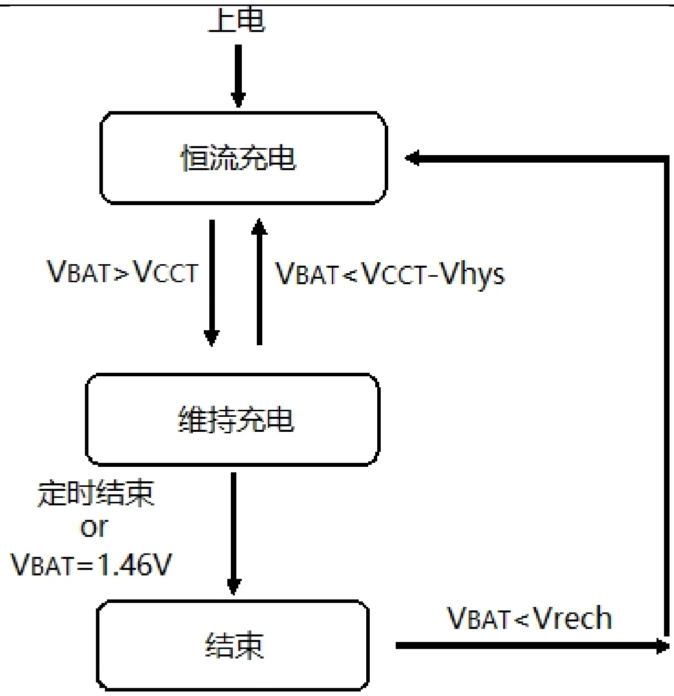


Figure 3 Charging flow

Application Information.

Input Voltage Range

The CN3600 operates from 2.7V to 6.5V. The UVLO unit inside the chip shuts down the internal circuits when the input voltage falls below the low voltage latch threshold (max. 2.65V).

The internal UVLO unit shuts down the internal circuit when the input voltage falls below the low voltage latch threshold (maximum 2.65V).

Inductor Current Peak (ipeak) Selection

The Isel pin is used to select the inductor current peak. The inductor current rises when the internal P-channel MOSFET is energized and reaches the peak value set by the Isel pin.

When the inductor current reaches the peak value set by the Isel pin, the internal P-channel MOSFET is turned off. The peak inductor current (ipeak) is shown in Table 1:

Isel	State	Peak Inductor Current (ipeak)
High Level	Constant current charging mode	1.19A
	Maintenance charging mode	0.62A
Low Level	Constant Current Charge Mode	0.64A
	Maintain Charge Mode	0.44A

Table 1 Inductance Current Peak (ipeak) Selection

Do not apply voltages from 0.7V to 2.2V to the Isel pin as this will leave the peak inductor current selection uncertain.

Battery Side (BAT Pin) Maximum Voltage

The maximum voltage at the battery terminal is the highest voltage that may be reached at the battery terminal (BAT pin) during charging. The maximum voltage at the battery terminal is set at 1.46V (typical) inside the CN3600. Since the battery voltage drops slightly when the NiMH battery is close to being full, the battery voltage may not always reach the maximum voltage set. If the battery voltage reaches the maximum voltage, the charging process will end immediately. This is a protection mechanism for the battery. If the battery is not connected to the charger, the CN3600 will charge the output capacitor as if it were a battery to the overvoltage protection voltage.

Battery Overvoltage Protection

The battery overvoltage protection unit inside the CN3600 continuously monitors the BAT pin voltage. When the BAT pin voltage rises and exceeds 1.557V (typical), the internal P-channel MOSFET is turned off, no current flows to the battery, and CHRG outputs a high-resistance state, and if in the maintain charge state, then the maintain charge timer is cleared. When the BAT pin voltage drops below 1.496V (typical), the CN3600 is released from the overvoltage protection state and the charging process is restarted.

The charging process is restarted.

The BAT pin voltage may reach the overvoltage protection threshold in the following three situations:

- Battery is not connected
- Battery load is suddenly disconnected
- Maintain charge time set too long

Maintain Charge Mode

When the BAT pin voltage rises to 1.36V (typical), the CN3600 enters the maintenance charge mode. The peak inductor current decreases as shown in Table 1. The internal maintenance charging timer is activated. This timer determines the upper limit of the maintenance charging time. The timing time is set with a capacitor on the CT pin. When the timing ends, the entire charging cycle ends and the CN3600 enters the end state.

In maintain charging mode, the timing time is determined by the following formula:

$$T = 12.18 \times 10^9 \times C2 \quad \text{(seconds)}$$

Where:

- T is the timing time in seconds
- C2 is the capacitance value of capacitor C2 in Figure 1 in farads.

The C2 capacitance value should be greater than 100pF or the timing accuracy will be affected. If a SMD ceramic capacitor is used, then the capacitance value should preferably be a 1uF

or 2.2uF capacitor or multiple in parallel, size 0805 or 1206.

In maintenance charging mode, when the BAT pin voltage drops to 1.339V (typical), the CN3600 enters constant current mode and the maintenance charging timer clears to zero. The maintenance charge timer is also cleared to zero in the battery overvoltage protection state and the chip over temperature protection state.

Inductor Current and Charging Current Estimation

When the P-channel MOSFET inside the CN3600 conducts, the inductor current rises, and when it reaches the set peak (i_{peak}), the P-channel MOSFET turns off, and the turn-off time is fixed at 2 microseconds (typical), so the minimum value of the inductor current i_b is determined by the following equation:

$$i_b = i_{peak} - \frac{V_D + V_{BAT}}{L} t_{off}$$

In normal operation, to minimize electromagnetic emissions, the inductance value should be chosen such that the converter operates in continuous current mode, CCM, meaning that the inductor current minimum i_b must be greater than zero. Even in the maintenance charging mode, the inductor current minimum i_b should be greater than zero.

The waveform of inductor current is shown in Fig. 4:

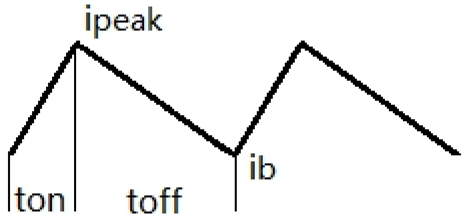


Fig. 4 Inductor current waveform

The charging current, i.e., the average value of inductor current is determined by the following equation:

$$I_{CH} = I_L = i_{peak} - \frac{V_D + V_{BAT}}{2L} * \frac{2(V_D + V_{BAT}) + V_{IN}}{V_{IN}} t_{off}$$

In the above two equations:

i_{peak} is the peak inductor current, as shown in Table 1, in amps V_D is the forward conduction voltage drop of the diode, in volts V_{BAT} is the battery voltage, in volts

VIN is the input voltage in volts

L is the inductance of inductor L in Figure 1 in henries

t_{off} is the turn-off time of the P-channel MOSFET, typical $2 \times 10^{(-)(6)}$ (seconds)

Calculating the Switching Frequency

In the typical application circuit shown in Figure 1, the CN3600 internal P-channel MOSFET has an on-time:

$$ton = \frac{V_{BAT}+V_D}{VIN - V_{BAT} - V_D}\ toff$$

The turn-off time of the internal P-channel MOSFET is 2 microseconds (typical). So the switching frequency of the CN3600 is:

$$f_{sw} = \frac{1}{ton + toff}$$

It can be seen that the switching frequency is related to the input voltage and battery voltage.

End of Charge

In maintenance charging mode, if the timing ends or the BAT pin voltage reaches the set maximum voltage (typical value 1.46V), the whole charging process ends and the internal P-channel MOSFET of the chip is turned off and no current flows to the battery.

Recharge

At the end of the charging state, when the voltage at the BAT pin drops to the typical value of 1.339V, the CN3600 enters the constant current charging mode and restarts the charging cycle.

Inductance Selection

In order to minimize electromagnetic radiation, the inductance value should be selected so that the converter operates in Continuous Current Mode (CCM) in all cases. Particular attention should be paid to the maintenance charging mode, where the inductor current peak is small.

Table 2 lists the recommended inductance values:

Condition	Inductance Value
Isel always high	10uH or 15uH
Isel is low	15uH or 22uH

Table 2 Recommended Inductance Values

The saturation current of the inductor should be greater than 1.5A.

Diode Selection

In the circuit shown in Figure 1, diode D1 is used to prevent current from flowing backwards from the battery. In order to achieve high conversion efficiency, the forward conduction voltage of the diode should be as small as possible.

voltage should be as small as possible. A Schottky diode is a good choice. The rated forward conduction current of the diode should be greater than 1.5A.

Input Filter Capacitor

Power input and ground need to be connected to a minimum of 4.7 microfarads chip ceramic filter capacitor (Figure 1, C1), if the input power supply output impedance is relatively large, or the input power supply connecting wire is relatively long, the capacitance value should be increased accordingly; capacitor withstand voltage should be higher than the maximum input voltage. Generally, the input capacitance value is between 4.7uF and 22uF, which has a relatively low impedance at a frequency of 1MHz. It is recommended to use X5R or X7R chip ceramic capacitors with low series equivalent resistance (ESR).

Output Filter Capacitors

A filter capacitor (C_o in Figure 1) is required between the positive terminal of the battery and ground, and this capacitor also supplies energy to the battery during the shutdown of the internal P-channel MOSFET.

Typically, a 10uF to 22uF capacitor will suffice, and the ESR of the output filter capacitor should be as small as possible. It is recommended to use series equivalent resistance

(ESR) is relatively low X5R or X7R chip ceramic capacitors.

Chip over-temperature protection

The CN3600 has a chip over-temperature protection function. When the junction temperature of the chip exceeds 145 degrees, the internal P-channel MOSFET is turned off and no energy is transferred to the battery. When the junction temperature drops below 124 degrees, the CN3600 resumes normal operation.

In the chip over-temperature protection state, the maintain charge timer is cleared and the $\overline{CHRG}$ pin outputs a high resistance state.

Battery not connected

If the battery is not connected to the charger, the CN3600 charges the output capacitor as if it were a battery. the BAT pin voltage is rapidly charged to the overvoltage protection threshold, then the BAT pin voltage is slowly discharged to the overvoltage protection release threshold by the current drawn by the internal feedback resistor, and then it is rapidly recharged to the overvoltage protection threshold, and so on and so forth, creating a sawtooth wave at the BAT pin.

Open Drain Status Indication Outputs

The CN3600 provides two open drain status indication outputs: $\overline{DONE}$ and $\overline{CHRG}$. In constant current charging mode and maintenance charging mode, the $\overline{CHRG}$ pin is pulled low by the internal switch, and in other states the $\overline{CHRG}$ pin outputs a high resistance state.

In the end-of-charge state, the $\overline{DONE}$ pin is pulled low by the internal switch, and in the other states, the $\overline{DONE}$ pin outputs a high-resistance state. If the CN3600 is in the chip over-temperature protection or battery over-voltage protection state, $\overline{CHRG}$ outputs high resistance state.

When the battery is not connected to the charger, $\overline{CHRG}$ pin and $\overline{DONE}$ pin output high resistance.

About Input Power Adaptive Function

The CN3600's input voltage range is between 2.7V and 6.5V. When the input power supply's carrying capacity is less than the input current for which the CN3600 is designed, the input voltage is controlled to be pulled down to a minimum of 2.68V (typical) to adapt to the input power supply's carrying capacity.

In the input power adaptive mode, the input voltage may drop to 2.68V (typical) so make sure that the selected MOS transistor is fully conductive around 2.4V.

This feature allows the CN3600 to be used with an input power supply that is fully energized at around 2.4V.

This feature allows the CN3600 to be powered by solar panels.

Design Flow

To determine the component parameters in the circuit shown in Figure 1, the following design flow can be followed:

(1) Select the inductance value according to Table 2.

(2) Determine the constant current charging current and the maintenance charging current according to the battery capacity and charging time requirements. Select the two peak inductor currents by connecting the Isel pin to a high or low level, which in turn determines the charging current.

(3) Determining the Maintenance Charge Timing Time

Based on experience, at least 55% of the battery capacity should be replenished in the maintenance charging mode to ensure a full battery. Assuming the battery capacity is C, the maintenance charge timing time is:

$$T = 0.55C / I_{CH}$$

Where I_{CH} is the charging current for the maintenance charging mode.

It should be noted that the energy required to replenish the battery in the maintenance charging mode is related to the internal resistance of the battery, the parasitic resistance of the battery connecting wires and other factors, so the accurate maintenance charging timing time should be determined by the test of the specific conditions of the application, rather than based on the above empirical data.

(4) Determine the capacitance value of timing capacitor C2 according to the timing time.

$$\text{Timing time} \quad T = 12.18 \times 10^9 \times C2 \qquad \text{(seconds)}$$

(5) Determine the input filter capacitance value based on the input power supply characteristics, input power supply lead length and input current.

(6) Select the diode. Preferably Schottky diode.

(7) Select the output filter capacitor. Generally 10uF to 22uF chip ceramic capacitors can meet the requirements.

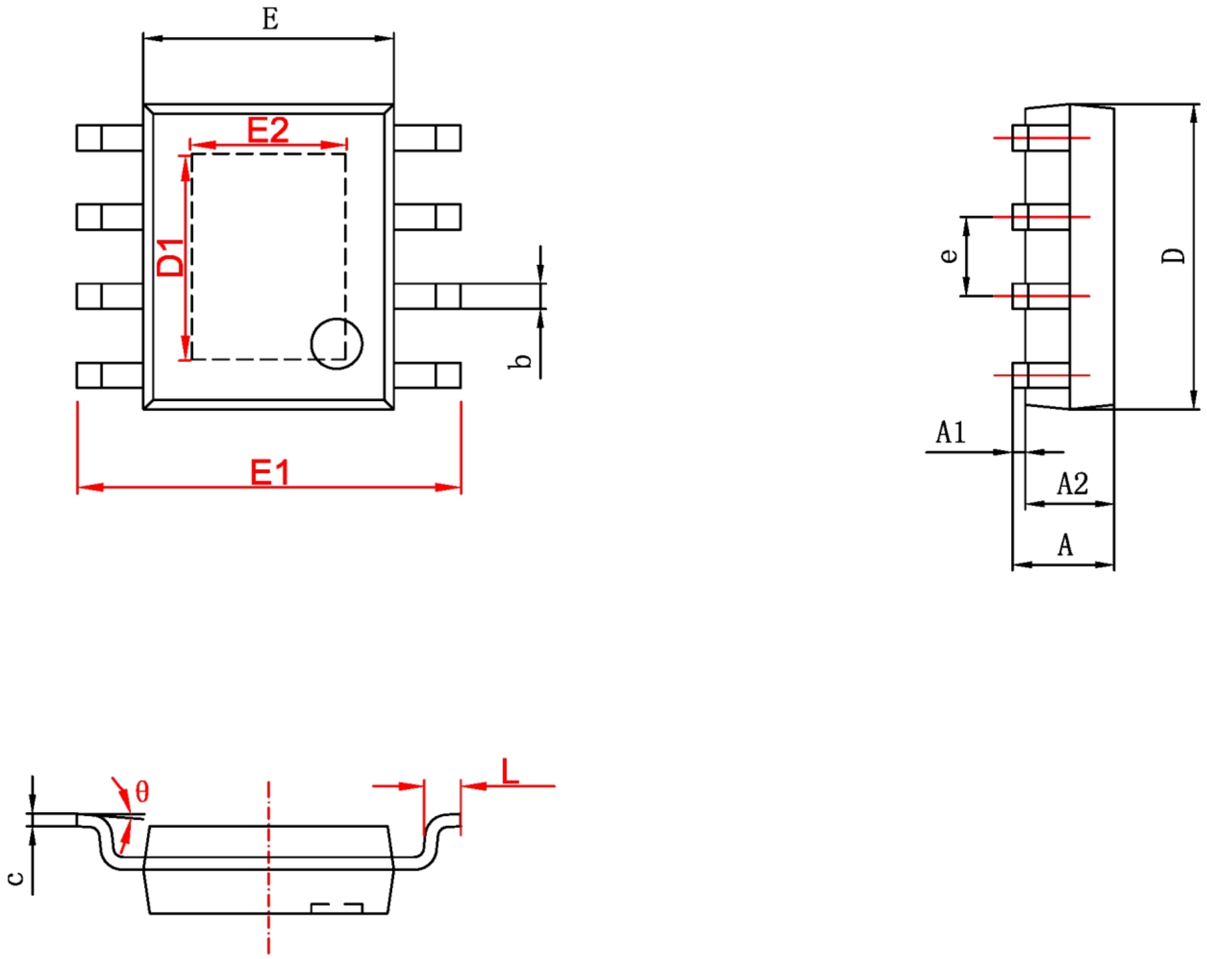
PCB Design Considerations

A well-designed PCB is important for converter efficiency and performance. The following three suggestions are important for PCB design.

- Use a double-layer PCB.
- The output capacitor ground terminal, the GND pin of the CN3600 is connected to the input capacitor ground terminal through the same copper skin, and then connected together to the input power supply ground (system ground). The copper skin connecting these nodes should be as wide as possible.
- To minimize electromagnetic radiation, the copper skins connecting the diode, inductor, input capacitor and output capacitor should be as short as possible and wide enough.

Package Information

CONSONANCE



字符	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.350	1.750	0.053	0.069
A1	0.050	0.150	0.004	0.010
A2	1.350	1.550	0.053	0.061
b	0.330	0.510	0.013	0.020
c	0.170	0.250	0.006	0.010
D	4.700	5.100	0.185	0.200
D1	3.202	3.402	0.126	0.134
E	3.800	4.000	0.150	0.157
E1	5.800	6.200	0.228	0.244
E2	2.313	2.513	0.091	0.099
e	1.270(BSC)		0.050(BSC)	
L	0.400	1.270	0.016	0.050
θ	0°	8°	0°	8°