PFM Step-down Single-cell NIZN Battery Charger IC

CN3601

General Description：

CN3601 is a fixed off-time PFM mode step-down battery charge management IC with operating voltage range between 2.7V to 6.5V. It is specially designed for single-cell NIZN battery charge management with fewer external components. CN3601 adopts constant current and maintenance mode to charge battery.

On power up, CN3601 enters constant current charging mode, the on-chip P-channel MOSFET is turned on, inductor current rises. When inductor current reaches upper threshold, the P-channel MOSFET is turned off, a low-side switch is turned on, inductor is discharged, then the P-channel MOSFET is turned on again after 1.5us off time. When battery voltage rises to 1.9V (Typ.), CN3601 enters maintenance mode, in which the inductor current's upper threshold is reduced, in the meantime a timer is started. The charge process will not be terminated until the time out occurs. In termination mode, the P-channel MOSFET is turned off, there is no current flowing into battery. When BAT pin voltage falls below recharge threshold, the CN3601 enters charge mode again. CN3601's switching frequency can be up to 500KHz, which makes a small-profile inductor usable.

The other features include 2 open-drain status indications, chip over temperature protection, inductor current's upper threshold selection, battery temperature monitoring, etc.

CN3601 is available in 10-pin SSOP package.

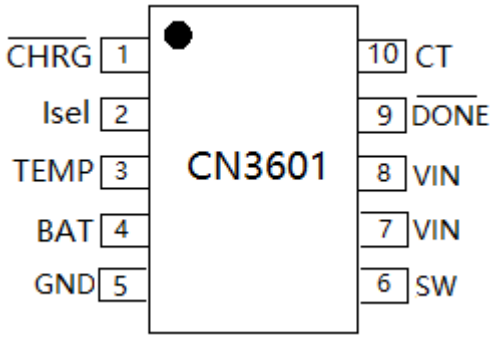
Applications:

- Standalone NIZN Battery Charger
- Car Models
- Toys
- Devices powered by AA or AAA Batteries

Features：

- Input Voltage Range：2.7V to 6.5V
- Operating Current：320uA@VIN=5V
- Switching Frequency up to 500KHz
- Maintenance Charge Mode to Guarantee Fully-charged Battery
- Selectable Upper Threshold of Inductor Current
- Charging terminated by Timer after reaching 1.9V(Typical)
- Automatic Recharge
- Battery Overvoltage Protection
- Chip Over Temperature Protection
- Battery Temperature Monitoring Function with external NTC
- 2 Open-drain Status Indications
- Operating Temperature ：－40℃ to 85℃
- Available in SSOP-10 Package
- Lead-free, rohs-Compliant and Halogen Free

Pin Assignment



Typical Application Circuit:

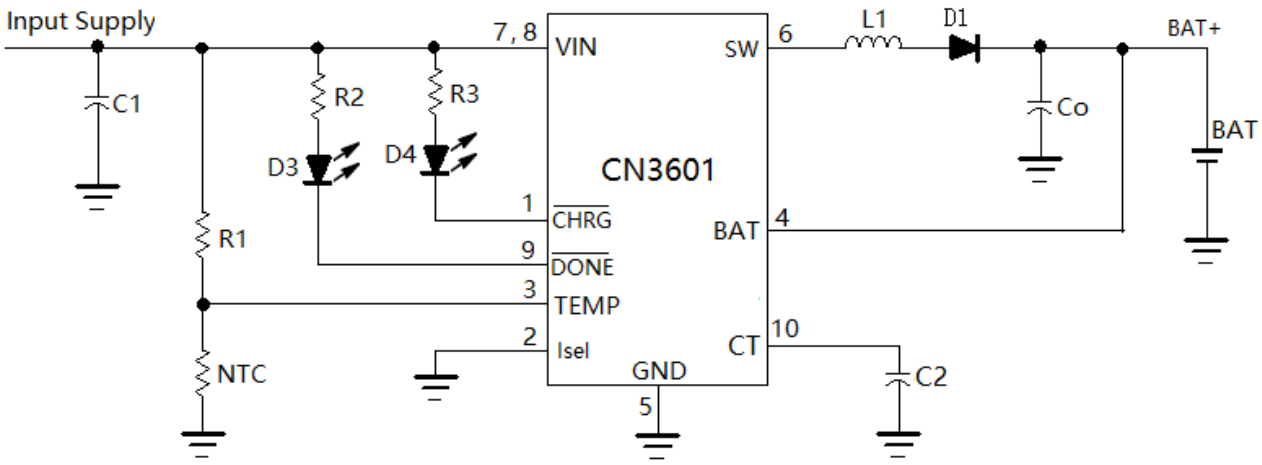


Figure 1 Typical Application Circuit

Ordering Information:

Part No.	Package	Shipping	Operating Temperature
CN3601	SSOP-10	Tape and Reel, 4000/reel	－40℃ to 85℃

Pin Description:

No.	Symbol	Description
1	$\overline{CHRG}$	**Open-Drain Charge Status Output.** When the battery is being charged (Constant current mode or maintenance mode), this pin is pulled low by an internal switch. Otherwise this pin is in high impedance state.
2	Isel	**The Selection Pin of Upper Threshold of Inductor Current.** A high input will set the upper threshold of inductor current in constant current mode at 1.19A(Typical); A low input will set the upper threshold of inductor current in constant current mode at 0.62A. The Isel pin can be driven by TTL or CMOS logic level.
3	TEMP	**Battery Temperature Sense Input.** Connect this pin to external resistor divider formed by an NTC thermistor and a resistor to sense the battery temperature. If TEMP voltage falls below 44.5% of input voltage, then the charging is suspended, no current flows to battery from input supply. This feature can prevent the battery being charged at high battery temperature. When the voltage at BAT pin is higher than 44.5% of input voltage by 40mV, the charging is resumed.
4	BAT	**Battery Positive Terminal Input.** Battery voltage is feedback to the CN3601 through this pin. The CN3601 determines the charge mode based on the BAT pin voltage.
5	GND	**Ground.** The negative terminal of input supply and battery.
6	SW	**Inductor Connection Pin.** The inductor is tied to this pin. Internally SW pin is connected to a P-Channel MOSFET and an N-Channel MOSFET.
7	VIN	**Positive Terminal of Input Supply.** CN3601's internal circuit is powered by this pin.
8	VIN	
9	$\overline{DONE}$	**Open-Drain Termination Output.** When the charging is terminated, this pin is pulled low by an internal switch. Otherwise this pin is in high impedance state.
10	CT	**Timing Capacitor Connection Input.** The timing capacitor should be connected between CT pin and GND. The timing function is started once CN3601 enters maintenance mode, and the timing time is determined by the following equation: $t_{timing} = 12.18x10^9xC2$ Where C2 is the capacitance of capacitor C2 in Figure.1.

ABSOLUTE MAXIMUM RATINGS

VIN and Isel Voltage……..…－0.3V to 7.0V
BAT Voltage…….....……－0.3V to 7.0V
$\overline{CHRG}$ and $\overline{DONE}$ Voltage…….. －0.3V to VIN
TEMP, SW and CT Voltage…….. －0.3V to VIN

Maximum Junction Temperature.....……...150℃
Operating Temperature Range.....－40℃ to 85℃
Storage Temperature…….....－65℃ to 150℃
Lead Temperature(Soldering, 10s).....…...260℃

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERICS：

(VIN = 5V, T_A＝－40℃ to +85℃, Typical values are at T_A＝+25℃, unless otherwise noted)

Parameters	Symbol	Test Conditions		Min	Typ.	Max	Unit
Input Voltage Range	VIN			2.7		6.5	V
UVLO Threshold	V_{UVLO}					2.65	V
Operating Current	I_{VIN}	V_{BAT}＝2.1V，No Switching		250	320	390	uA
Fixed Off-Time	t_{off}	Charge mode		1.2	1.5	1.8	uS
Over Temperature Protection	t_{OTP}				145		℃
Hysteresis of Over Temperature Protection	H_{opt}				21		℃
Inductor Current							
Upper Threshold	I_{peak}	CC	Isel is high		1.19		A
		Maintenance			0.62		
		CC	Isel is low		0.64		
		Maintenance			0.44		
BAT Pin							
Constant Charge Termination Voltage	V_{CCT}	BAT voltage rises		1.881	1.9	1.919	V
Recharge Threshold	V_{rech}	BAT voltage falls		1.722	1.742	1.762	V
BAT Pin Current	I_{BAT}	V_{BAT}＝1.9V		4.7	6	8	uA
Over Voltage Threshold	V_{OV}	BAT voltage rises		1.967	1.997	2.027	V
Over Voltage Release Threshold	V_{OVRLS}	BAT voltage falls		1.906	1.936	1.966	
SW Pin							
On-resistance of N-channel MOSFET	RdsonN	N-channel MOSFET is between SW pin and GND			0.3		ohm
On-resistance of P-channel MOSFET	RdsonP	P-channel MOSFET is between SW pin and VIN			0.4		ohm
TEMP Pin							
Input Current	I_{TEMP}			-100		+100	nA
TEMP Comparator Threshold	V_{TEMP}	TEMP voltage falls		42.5	44.5	46.5	%VIN
TEMP Comparator Hysteresis	H_{TEMP}				40		mV
Isel Pin							
Input Low Voltage	V_L	Isel voltage falls				0.7	V
Input High Voltage	V_H	Isel voltage rises		2.2			V
Input Current	I_L	Isel=GND，VIN=6V		－100			nA
	I_H	Isel=VIN=6V				100	

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Parameters	Symbol	Test Conditions	Min	Typ.	Max	Unit
$\overline{CHRG}$ **Pin**						
Sink Current	I_{SINK}	V_{CHRG}=0.3V，charge mode		10		mA
Leakage Current	I_{LEAK}	V_{CHRG}=6V，termination mode			100	nA
$\overline{DONE}$ **Pin**						
Sink Current	I_{SINK}	V_{DONE}=0.3V，termination mode		10		mA
Leakage Current	I_{LEAK}	V_{DONE}=6V，charge mode			100	nA

Detailed Description：

The CN3601 is a fixed off-time PFM mode step-down charge management IC for single-cell NIZN battery with input voltage range from 2.7V to 6.5V.

The CN3601 is composed of reference voltage, inductor current sensing circuit, battery voltage detection circuit, battery over voltage protection circuit, chip over temperature protection, battery temperature monitoring circuit, logic control block and MOSFET switch, etc. The CN3601 is ideally suitable for single-cell NIZN battery charging application with fewer external components.

After power-on, CN3601 enters constant current charging mode, $\overline{CHRG}$ pin outputs low to indicate that the charging is ongoing, the on-chip P-channel MOSFET is turned on, the inductor current rises. When the inductor current rises to the upper threshold, the P-channel MOSFET is turned off, the internal N-channel MOSFET is turned on, the inductor current begins to fall, the energy stored in the inductor is transferred to the battery and the output capacitor. The P-channel MOSFET's off time is fixed at 1.5us, and after the off time, the external P-channel MOSFET is turned on again, and so forth. The battery voltage is sensed through BAT pin. When the BAT pin voltage reaches 1.9V(Typical), CN3601 enters maintenance mode. In maintenance mode, the upper threshold of inductor current is reduced. Once CN3601 is in maintenance mode, an on-chip timer is started, and the charging will not be terminated until the time out occurs. In termination mode, the on-chip P-channel MOSFET is turned off, there is no current flowing to the battery, $\overline{DONE}$ pin outputs low to indicate the termination mode. When the battery voltage falls below 1.742V(Typical), CN3601 enters constant current charge mode to start a new charge cycle.

The highest switching frequency of CN3601 can be up to 500KHz, which makes the low-profile inductor usable.

The other functions include selectable upper threshold of inductor current, battery over voltage protection, the chip over temperature protection, and the battery temperature monitoring, etc..

The charge profile is illustrated in Figure 2.

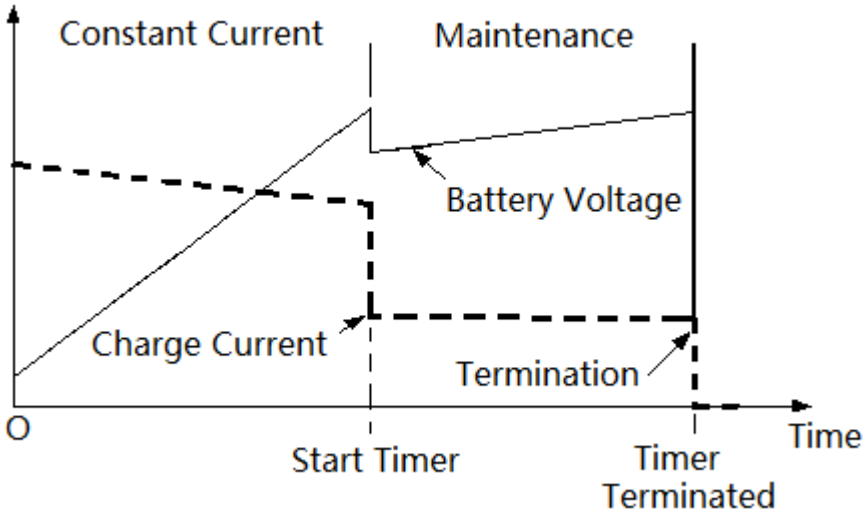


Figure 2 Charging Profile

The charging flow is illustrated in Figure 3.

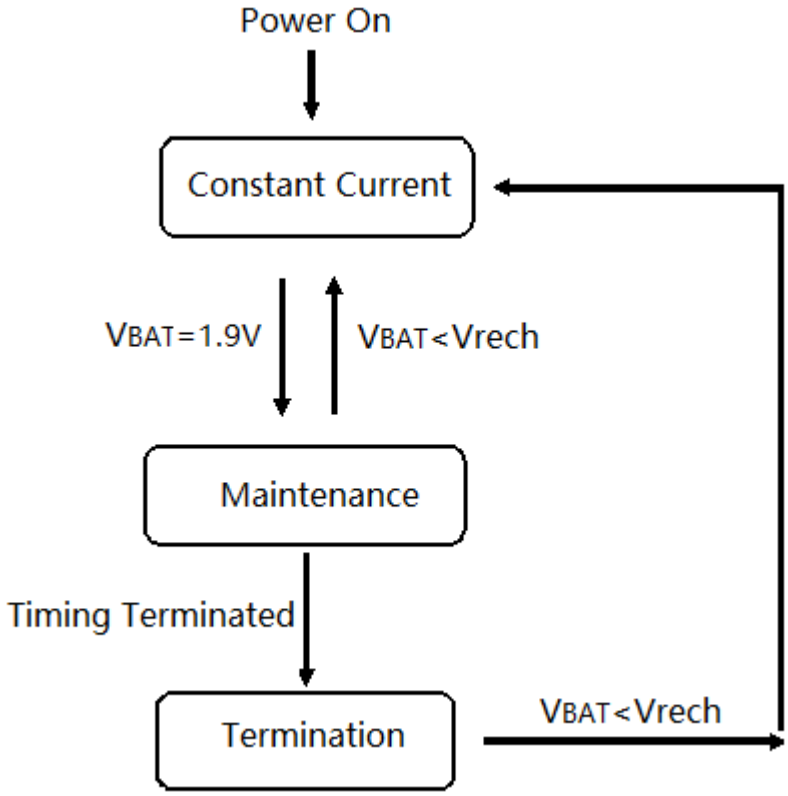


Figure 3 Charging Flow

Application Information:

Input Voltage Range

The CN3601 functions well when the input voltage is between 2.7V to 6.5V. On-chip UVLO circuit will shut down the CN3601 if input voltage falls below UVLO threshold (2.65V Max.).

The Selection of Upper Threshold of Inductor Current (i_{peak})

The pin Isel is used to select the inductor peak current. During the on time of on-chip P-channel MOSFET, inductor current rises, and the P-channel MOSFET is turned off when inductor current reaches its upper threshold set by Isel pin, the upper threshold is also named i_{peak}

The upper threshold of inductor current(i_{peak}) is listed in the Table 1.

Isel	Charging State	Upper Threshold (i_{peak})
High	Constant Current	1.19A
	Maintenance	0.62A
Low	Constant Current	0.64A
	Maintenance	0.44A

Table 1 Upper Threshold of Inductor Current(i_{peak})

Do not apply a voltage between 0.7V and 2.2V on Isel pin, otherwise the upper threshold of inductor current may be uncertain.

The Battery Over Voltage Protection

In CN3601, there is a battery over voltage protection block that continuously monitors the voltage at BAT pin. If the battery voltage rises above 1.997V(Typical), the P-channel MOSFET is turned off, no current flows to battery, $\overline{CHRG}$ outputs high impedance. When the voltage at BAT pin falls below 1.936V(Typical), CN3601 is released from over voltage protection status, the charging resumes.

The voltage at BAT pin may reach over voltage protection level when battery is absent, or the load is removed suddenly, or the timing time in maintenance mode is set too long.

Maintenance Charge Mode

If the voltage at BAT pin rises above 1.9V (Typical), the CN3601 goes into the maintenance charge mode. The upper threshold of inductor current in maintenance mode is reduced as shown in Table 1. An internal timer is started once the CN3601 is in the maintenance mode, this puts a time limit on the maintenance charge mode, the time limit is programmed by a capacitor at the CT pin as shown in Figure 1. After the time out occurs, the whole charge cycle is terminated, the CN3601 enters termination mode.

In maintenance mode, the time limit is determined by the following equation:

$$T = 12.18 \times 10^9 \times C2$$

Where:

- T is the time limit in second
- C2 is the capacitance of C2 in Figure 1, the unit is Farad, C2 should be greater than 100pF, otherwise the timer's accuracy may be affected. If multi-layer ceramic capacitor is used as the timing capacitor, it is better to use 1uF or 2.2uF capacitor whose package size is 0805 or 1206.

In maintenance mode, if voltage at BAT pin falls below 1.742V(typical), CN3601 goes back to constant current charge mode。

The timer in maintenance mode is suspended if the battery temperature is too high or the CN3601's silicon temperature is over 145℃. The timer resumes once the battery temperature or CN3601's silicon temperature is back to normal range.

The timer in maintenance mode is reset when the battery over voltage protection is asserted.

Inductor Current and Charge Current Estimation

When the on-chip P-channel MOSFET is on, inductor current rises, when it reaches the upper threshold i_{peak}, the P-channel MOSFET is turned off, the off-time is fixed at 1.5us (Typical). So the lowest inductor current i_b is decided by the following equation:

$$ib = ipeak - \frac{VD+VBAT}{L} toff$$

In normal operation, for less EMI emission, inductor L's value should be chosen so that the converter operates in continuous conduction mode in any case, namely i_b must be greater than 0A, especially in maintenance mode. The waveform of inductor current is shown in Figure 4:

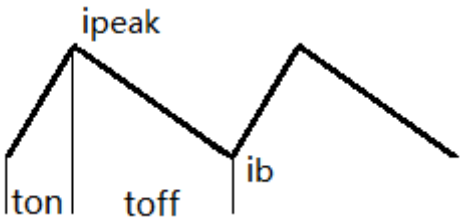


Figure 4 Waveform of Inductor Current

The charge current, also the average inductor current is determined by the following equation:

$$ICH = IL = ipeak - \frac{VD+VBAT}{2L} * \frac{2(VD+VBAT)+VIN}{VIN} toff$$

In the above 2 equations about i_b and I_{CH},

i_{peak} is inductor's peak current as listed in Table 1

V_D is the forward voltage drop of diode D1 in Figure 1

V_{BAT} is the battery voltage

VIN is the input voltage

L is the inductance of the inductor L1 in Figure 1

t_{off} is the off time of on-chip P-channel MOSFET, and is fixed at 1.5us Typical

Calculate Switching Frequency

In the application circuit shown in Figure 1, the on-time of on-chip P-channel MOSFET is:

$$ton = \frac{VBAT+VD}{VIN-VBAT-VD} toff$$

The off-time t_{off} of the P-channel MOSFET is fixed at 1.5us

So the switching frequency is:

$$fsw = \frac{1}{ton+toff}$$

The switching frequency varies with input voltage and battery voltage

Charge Termination

If the time out occurs in maintenance mode, the charge cycle is terminated, the on-chip P-channel MOSFET is turned off, no current flows to battery.

Recharge

In termination mode, if voltage at BAT pin falls below 1.742V(Typical), CN3601 enters constant current charge mode again.

Selection of Inductor

The inductor value should be chosen so that the converter operates in continuous conduction mode(CCM) in any case for less EMI emission.

Table 2 lists the recommended inductor value:

Conditions	Inductor Value
Isel is always high	15uH or 22uH
Isel being low may be the case	22uH or 33uH

Table 2 Inductor Value

The inductor's saturation current should be greater than 1.5A.

Selection of Diode

The diode D1 in Figure 1 is used to prevent battery current from flowing backwards. The forward voltage of the diode should be as low as possible for better efficiency. A Schottky diode is a good choice. The forward current rating of the diode must be at least 1.5A.

Input Capacitor

In most applications, a bypass capacitor at VIN is needed. An at least 4.7uF ceramic capacitor, placed in close proximity to VIN and GND pins, works well. In some applications depending on the power supply characteristics and cable length, it may be necessary to increase the capacitor's value. The capacitor's breakdown voltage should be higher than the maximum input voltage.

Generally a capacitor between 4.7uF and 20uF works well, ceramic capacitor of X5R or X7R is highly recommended.

Output Capacitor

A filter capacitor (Co in Figure 1) is needed between battery positive terminal and ground, the capacitor also supply energy to battery when the P-channel MOSFET is in off state.

Generally a capacitor of 10uF~22uF works well, the ESR of the output capacitor should be as small as possible, X5R or X7R capacitors are recommended.

Over Temperature Protection

The CN3601 adopts on-chip over temperature protection function. If the silicon temperature is over 145℃, the P-channel MOSFET is turned off, no energy is transferred to inductor or battery until the silicon temperature falls below 124℃ again.

In over temperature protection state, the timer of maintenance mode is stopped, and $\overline{CHRG}$ outputs high impedance.

Battery Absence

When the battery is not present, the CN3601 takes the output capacitor as battery and charges it quickly to over voltage protection level, then the battery voltage decays slowly to over voltage release threshold because of low battery current, so the CN3601 will toggle between charge and over voltage protection mode, which results in a sawtooth waveform at battery positive terminal.

Open-Drain Status Outputs

The CN3601 has 2 open-drain status outputs: $\overline{DONE}$ and $\overline{CHRG}$. $\overline{CHRG}$ is pulled low when the charger is in constant current charge mode or maintenance mode, otherwise $\overline{CHRG}$ becomes high impedance.

$\overline{DONE}$ is pulled low if the charger is in termination status, otherwise $\overline{DONE}$ becomes high impedance.

If CN3601's over temperature state or over voltage protection is asserted, $\overline{CHRG}$ outputs high impedance.

If the voltage at TEMP pin is lower than 44.5%*VIN, which means battery temperature is too high, $\overline{CHRG}$ outputs high impedance.

If battery is not present, both $\overline{CHRG}$ and $\overline{DONE}$ output high impedance.

Battery Temperature Monitoring

To prevent the damage caused by the very high temperature done to the battery, the CN3601 continuously senses battery temperature by measuring the voltage at TEMP pin which is connected to an external resistor divider formed by an NTC thermistor and a resistor.

If V_{TEMP}<(44.5%×VIN), it indicates that the battery temperature is too high and the charge cycle is suspended, no current flows to battery.

If V_{TEMP} is greater than (44.5%×VIN) by 40mV, the charge cycle resumes.

If battery temperature monitoring function is not needed, just connect TEMP pin to VIN pin.

Design Procedures

The following design procedures can be followed to design the parameters of CN3601 application circuit:

（1） To select inductor value according to Table 2

（2） To determine the charge current according to the battery capacity and the requirement of charge time. There are only 2 choices of charge current by pulling Isel pin to high or low.

（3） To determine the timing time in maintenance mode

In maintenance mode, empirically an amount of energy of 25% of battery capacity should be charged into battery. Suppose battery capacity is C, so the timing time should be:

$$T = 0.25C / I_{CH}$$

Where, I_{CH} is the charge current in maintenance mode

Please be noted that to guarantee a fully-charged battery, the amount of energy that need to be charged in maintenance mode is related to the factors such as battery internal resistance and cable's parasitic resistance, etc. So the timing time should be decided through experiments, not just the above empirical data.

（4） To decide the capacitor C2 based on the timing time.

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

（5） To decide the input capacitor based on the input supply's characteristics, input supply's cable length and input current.

（6） To select diode. A schottky diode is a good choice.

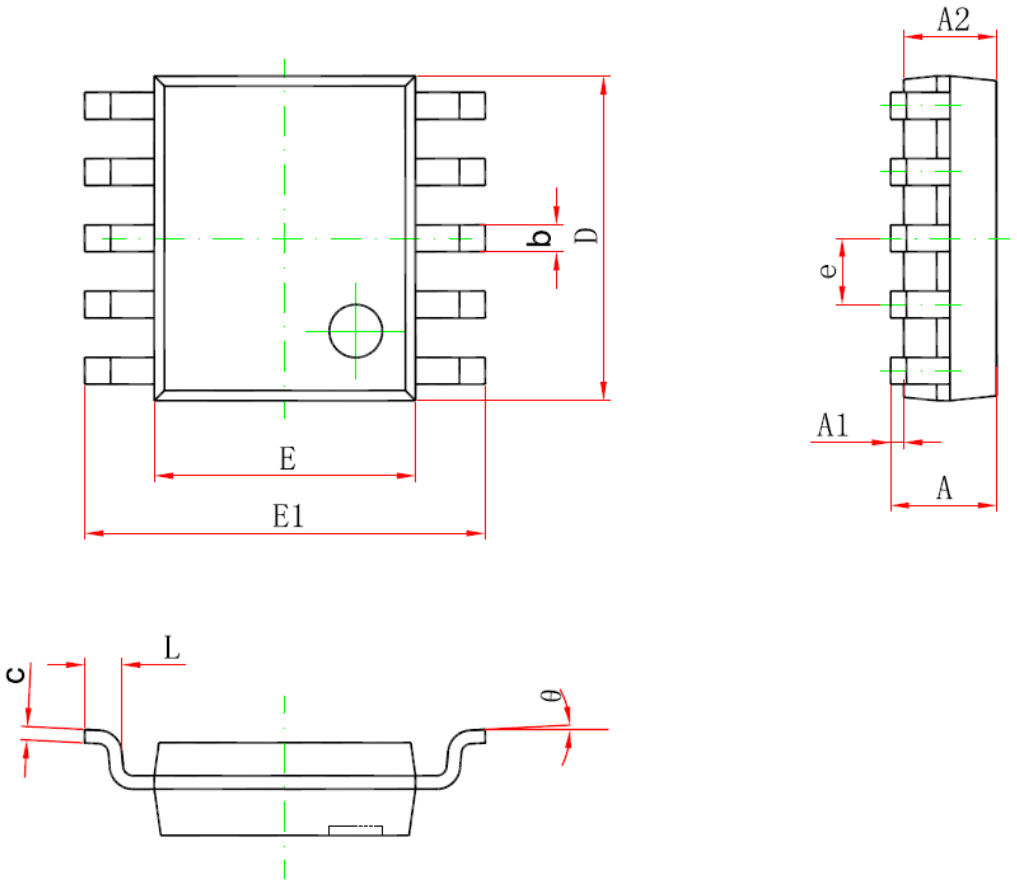
（7） To select the output capacitor. A 10uF to 22uF ceramic capacitor works well for the purpose.

PCB Considerations

A good PCB design is very important to efficiency and performance. When laying out the printed circuit board, the following considerations should be taken to ensure proper operation of the IC.

- Use double-layer PCB for better performance.
- The ground connections of output capacitor, CN3601 GND need to feed into same copper that connects to the input capacitor ground before tying back into system ground. This copper should be as wide as possible, and back to system ground separately.
- To minimize radiation, the diode, inductor and the input bypass capacitor traces should be kept as short as possible.

Package Information



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.350	1.750	0.053	0.069
A1	0.100	0.250	0.004	0.010
A2	1.350	1.550	0.053	0.061
b	0.300	0.450	0.012	0.018
c	0.170	0.250	0.007	0.010
D	4.700	5.100	0.185	0.201
E	3.800	4.000	0.150	0.157
E1	5.800	6.200	0.228	0.244
e	1.000(BSC)		0.039(BSC)	
L	0.400	1.270	0.016	0.050
θ	0°	8°	1°	8°