

JEITA-Compliant 1-Cell Lithium Battery Charger IC for Solar-Powered Systems

CN3166

General Description:

The CN3166 is a complete constant-current /constant voltage linear charger for single cell Li-ion and Li Polymer batteries. The device contains an on-chip power MOSFET and eliminates the need for the external sense resistor and blocking diode. An on-chip adaptive cell can adjust charging current automatically based on the output capability of input power supply, so CN3166 is ideally suited for solar powered system. Thermal feedback regulates the charge current to limit the die temperature at about 132°C during high power operation or high ambient temperature. The regulation voltage is internally fixed at 4.2V with 1% accuracy, it can also be adjusted upwards with an external resistor. The charge current can be set externally with a single resistor. When the input supply is removed, the CN3166 automatically enters a low power sleep mode, dropping the battery drain current to less than 3uA.

Other features include undervoltage lockout, automatic recharge, JEITA-compliant battery temperature monitoring, over charge current protection and charging/termination indicator. The CN3166 is available in 8-pin 2mm × 3mm DFN package.

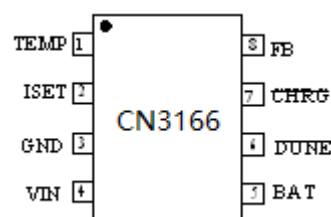
Applications:

- True Wireless Headset
- Wearable Accessories, smart band
- Beauty and Grooming
- Electric Toothbrush
- Medical Endoscope
- Solar Powered System
- Portable Devices

Features:

- Automatic charge current adjustment based on the output capability of input power supply
- Suitable for Solar-Powered System
- No external Blocking Diode or Current Sense Resistors Required
- Preset 4.2V regulation voltage with 1% accuracy, upwards adjustable with a resistor
- Regulation Voltage can be adjusted to 4.35V and 4.4V for ternary lithium battery
- Over Charge Current Protection in case Short Circuit at ISET Pin
- Precharge Conditioning for Reviving Deeply Discharged Cells and Minimizing Heat Dissipation During Initial Stage of Charge
- Continuous Charge Current Up to 950mA
- Constant-Current/Constant-Voltage Operation with Thermal Regulation to Maximize Charge Rate Without Risk of Overheating
- Automatic Low-Power Sleep Mode When Input Supply Voltage is Removed
- Status Indication for LEDs or uP Interface
- C/10 Charge Termination
- Automatic Recharge
- JEITA-Compliant Battery Temperature Monitoring
- Available in 2mm × 3mm DFN-8 Package
- Pb-free, rohs-Compliant and Halogen Free

Pin Assignment



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Typical Application Circuit

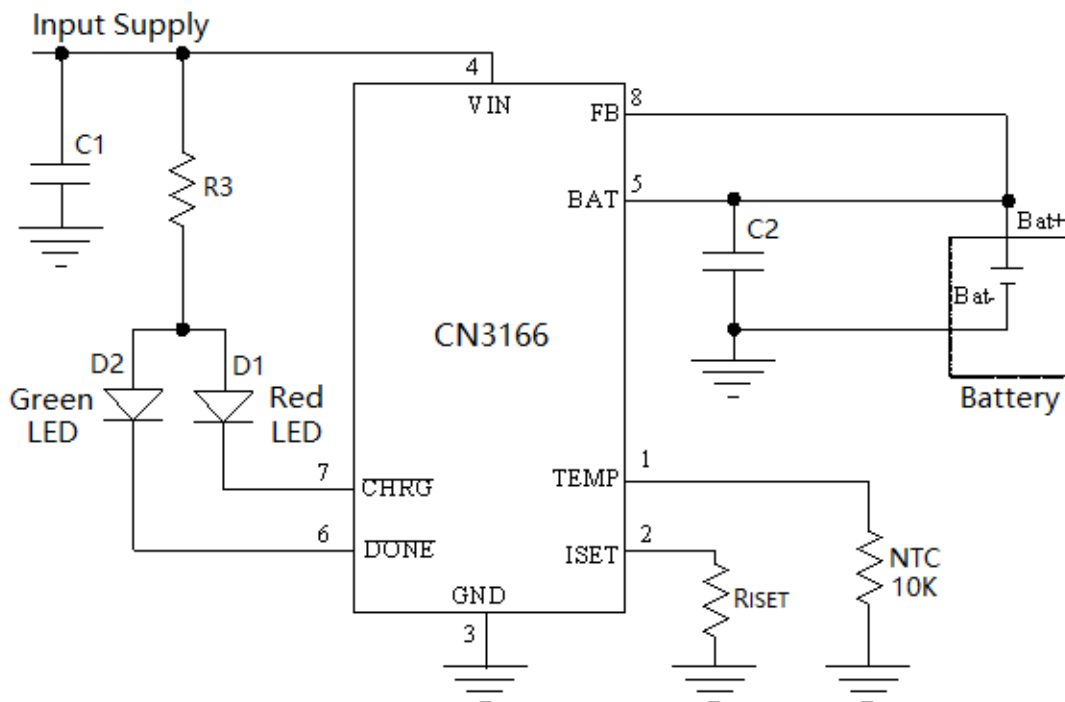


Figure 1 Typical Application Circuit(Constant Voltage Level 4.2V)

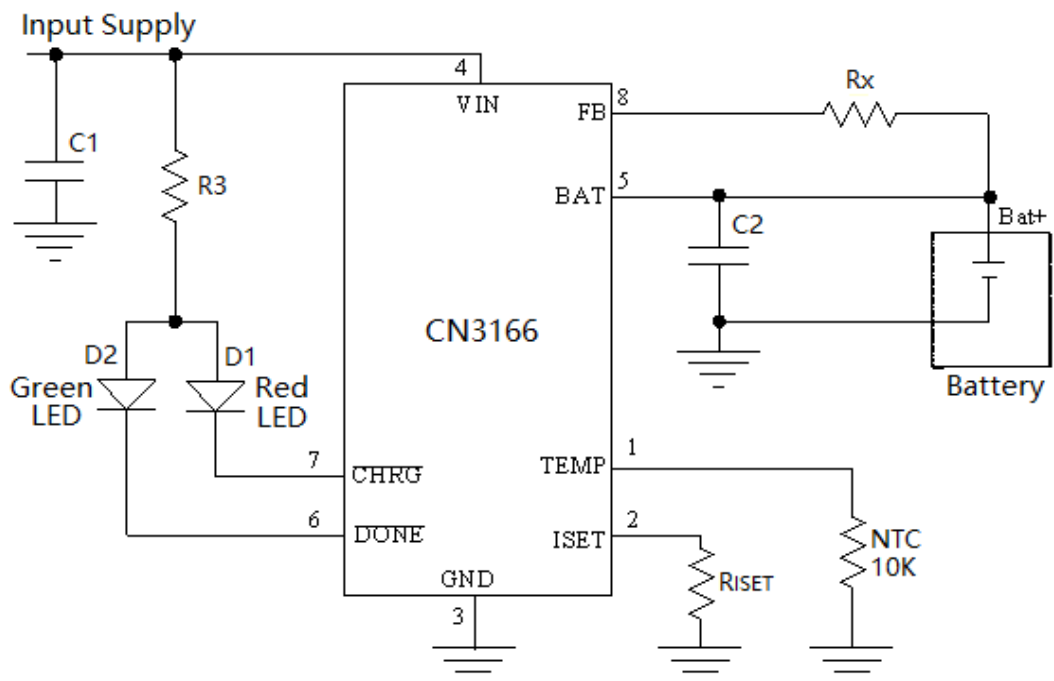


Figure 2 Application Circuit(Adjust Constant Voltage Level with Rx)

In Figure 2, the BAT pin's voltage in constant voltage mode is given by the following equation:

$$V_{REG} = 4.2 + 3.707 \times 10^{-6} \times R_x$$

Where, V_{REG} is in volt

R_x is in ohm

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Ordering Information:

Part No.	Package	Shipping	Marking	Operating Temperature Range
CN3166	DFN-8	Tape&Reel, 5000/Reel	LNG	-40°C to +85°C

Block Diagram

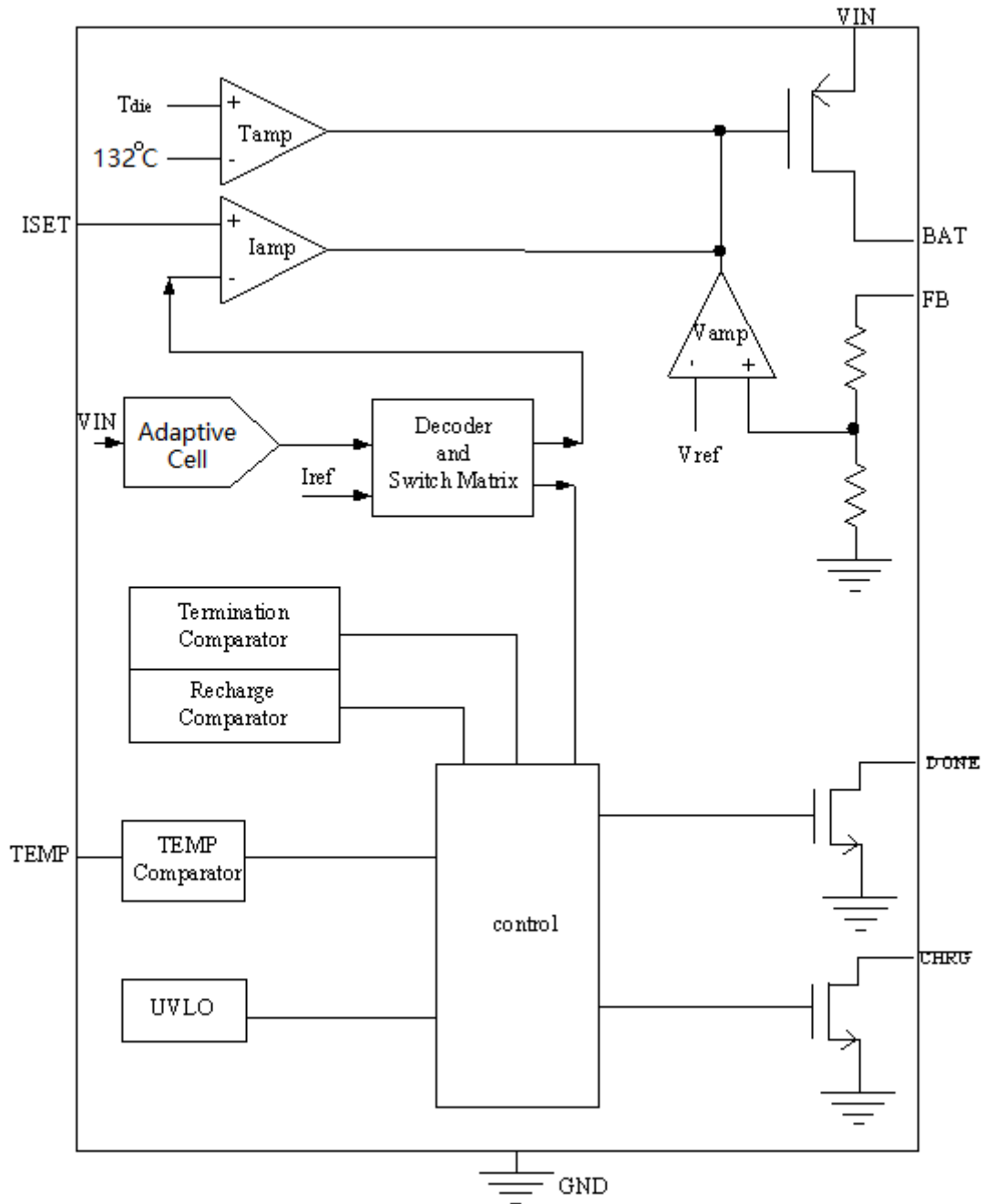


Figure 3 Block Diagram

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Pin Description

Pin No.	Name	Function Description
1	TEMP	<p>Battery Temperature Monitoring Input. Connecting a 10K ohm NTC thermistor between TEMP pin and GND.</p> <ul style="list-style-type: none"> ● If TEMP pin's voltage is below 0.1V or above 0.85V, which means battery is too hot or too cold, charging is suspended. ● If TEMP's voltage is between 0.1V and 0.135V, which means battery is warm, charge current is reduced to 50% of full-scale current set by resistor at ISET pin and regulation voltage is reduced to $97.25\% \cdot V_{REG}$. ● If TEMP's voltage is between 0.135V and 0.55V, CN3166 functions normally. ● If TEMP's voltage is between 0.55V and 0.85V, which means battery is cool, charge current is reduced to 25% of full-scale current set by resistor at ISET pin. <p>If battery temperature monitoring function is not needed, connect a fixed 10K ohm resistor from TEMP pin to GND.</p>
2	ISET	<p>Constant Charge Current Setting and Charge Current Monitor Pin. The charge current is set by connecting a resistor R_{ISET} from this pin to GND. When in precharge mode, the ISET pin's voltage is regulated to 0.135V. When in constant charge current mode, the ISET pin's voltage is regulated to 1.205V. In all modes during charging, the voltage on ISET pin can be used to measure the charge current as follows:</p> $I_{CH} = (V_{ISET} / R_{ISET}) \times 981$
3	GND	Ground Terminal (Ground).
4	VIN	Positive Input Supply Voltage. VIN is the power supply to the internal circuit. When VIN drops to within 10mv of the BAT pin voltage, CN3166 enters low power sleep mode, dropping BAT pin's current to less than 3uA.
5	BAT	Battery Connection Pin. Connect the positive terminal of the battery to BAT pin. BAT pin draws less than 3uA current in sleep mode. BAT pin provides charge current to the battery and provides regulation voltage.
6	\overline{DONE}	Open-Drain Charge termination Status Output. In charge termination status, \overline{DONE} is pulled low by an internal switch; Otherwise \overline{DONE} pin is in high impedance state.
7	\overline{CHRG}	Open Drain Charge Status Output. When the battery is being charged, the \overline{CHRG} pin is pulled low by an internal switch, otherwise \overline{CHRG} pin is in high impedance state.
8	FB	Battery Voltage Sense Input. This Pin can sense the battery voltage; Also the regulation voltage in constant voltage mode can be adjusted by connecting an external resistor between FB pin and BAT pin.
9	Thermal PAD	Exposed pad beneath the IC for heat dissipation. Solder thermal pad to the board with vias connecting to solid GND plane.

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Absolute Maximum Ratings

All Terminal Voltage..... -0.3V to 6.5V
 BAT Short-Circuit Duration.....Continuous
 Storage Temperature..... -65°C to 150°C
 Lead Temperature(Soldering, 10s).....260°C

Maximum Junction Temperature.....150°C
 Operating Temperature..... -40°C to 85°C
 Thermal Resistance (DFN-8).....TBD

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 above 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 Characteristics

(VIN=5V, TA=-40°C to 85°C, Typical Values are measured at TA=25°C, unless otherwise noted)

Parameters	Symbol	Test Conditions	Min	Typ	Max	Unit
Input Supply Voltage	VIN		4.4		6	V
Operating Current	IVIN	Charge Termination Mode	350	500	660	uA
Undervoltage Lockout	Vuvlo	VIN falling		2.4	2.65	V
Undervoltage Lockout Hysteresis	Huvlo			0.12		V
Soft Start Time	tss		100	160	220	uS
Regulation Voltage	VREG	Constant Voltage Mode	4.158	4.2	4.242	V
BAT pin Current	ICC	RISSET=1.24K, VBAT=3.6V	860	950	1040	mA
	IPRE	RISSET=1.24K, VBAT=2.4V	70	95	120	
	ISDBY	VBAT=VREG, standby mode	1.8	3.7	7	uA
	ISLP	VIN=0V, sleep mode			3	
Precharge Threshold						
Precharge Threshold	VPRE	Voltage at BAT pin rising	63	66.7	70	%VREG
Precharge Threshold Hysteresis	HPRE			1.6		%VREG
Charge Termination Threshold						
Charge Termination Threshold	Vterm	Measure voltage at ISET pin	110	135	160	mV
Recharge Threshold						
Recharge Threshold	IRECH	Charge current rises	28	33	38	%ICC
	VRECH	Battery voltage falls	93.3	95.8	98.3	%VREG
Sleep Mode						
Sleep Mode Threshold	VSLP	VIN from high to low, measures the voltage (VIN-VBAT)		10		mV
Sleep mode Release Threshold	VSLPR	VIN from low to high, measures the voltage (VIN-VBAT)		60		mV

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Parameters	Symbol	Test Conditions	Min	Typ	Max	Unit
Over Charge Current Protection						
Over Charge Current Threshold	I_{OCP}		1.0	1.25	1.5	A
Deglitch Time	t_{OCP_DGL}	Deglitch time for over charge current protection	1.2	2	2.7	ms
ISET Pin						
ISET Pin Voltage	V_{ISET}	Precharge mode	0.11	0.135	0.16	V
		Constant current mode	1.12	1.205	1.29	
TEMP Pin						
TEMP Source Current	I_{TEMP}		27	30	33	uA
Cold Threshold	V_{COLD}	V_{TEMP} rises, cool to cold	800	850	900	mV
Cold Release Threshold	V_{COLDR}	V_{TEMP} falls, cold to cool	755	805	855	mV
Cool Threshold	V_{COOL}	V_{TEMP} rises, normal to cool	510	550	590	mV
Cool Release Threshold	V_{COOLR}	V_{TEMP} falls, cool to normal	465	505	545	mV
Warm Threshold	V_{WARM}	V_{TEMP} falls, normal to warm	120	135	150	mV
Warm Release Threshold	V_{WARMR}	V_{TEMP} rises, warm to normal	138	155	172	mV
Hot Threshold	V_{HOT}	V_{TEMP} falls, warm to hot	85	100	115	mV
Hot Release Threshold	V_{HOTR}	V_{TEMP} rises, hot to warm	105	120	135	mV
FB Pin						
FB Input Current 1	I_{FB1}	$V_{FB}=3.6V$, normal operation	1.8	3	5	uA
FB Input Current 2	I_{FB2}	$V_{IN}<V_{UVLO}$ or $V_{IN}<V_{BAT}$			1	uA
\overline{DONE} Pin						
\overline{DONE} Sink Current	I_{DONE}	$V_{DONE}=0.3V$, termination mode		10		mA
\overline{DONE} Leakage Current		$V_{DONE}=6V$, charge mode			1	uA
\overline{CHRG} Pin						
\overline{CHRG} Sink Current	I_{CHRG}	$V_{CHRG}=0.3V$, Charge status		10		mA
\overline{CHRG} Leakage Current		$V_{CHRG}=6V$, termination mode			1	uA

Note: V_{REG} is the battery regulation voltage

I_{CC} is the full-scale charge current set by the resistor at ISET pin.

Detailed Description

The CN3166 is a linear battery charger IC designed primarily for charging single cell lithium-ion or lithium-polymer or ternary lithium battery. Featuring an internal P-channel power MOSFET, the charger uses a constant-current/constant-voltage to charge the battery. Continuous charge current can be set up to 950mA with an external resistor. No blocking diode or sense resistor is required. The on-chip adaptive cell can adjust charging current automatically based on the output capability of input power supply, so CN3166 is ideally suited for the solar-powered systems, or the applications that need to charge a battery with an input power supply whose output capability is limited. The open-drain output \overline{DONE} and \overline{CHRG} indicates the charger's status. The internal thermal regulation circuit reduces the programmed charge current if the die temperature attempts to rise above a preset value of approximately 132°C. This feature protects the CN3166 from excessive temperature, and allows the user to push the limits of the power handling capability of a given circuit board without risk of damaging the CN3166 or the external components. Another benefit of adopting thermal regulation is that charge

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current can be set according to typical, not worst-case, ambient temperatures for a given application with the assurance that the charger will automatically reduce the current in worst-case conditions.

The charge cycle begins when the voltage at the VIN pin rises above 4.4V, a current set resistor is connected from the ISET pin to ground. The $\overline{\text{CHRG}}$ pin outputs a logic low to indicate that the charge cycle is ongoing. At the beginning of the charge cycle, if the voltage at FB pin is below 66.7% of the regulation voltage, the charger is in precharge mode to bring the cell voltage up to a safe level for charging. The charger goes into the fast charge constant-current mode once the voltage on the FB pin rises above 66.7% of the regulation voltage. In constant current mode, the charge current is set by R_{ISET} . When the battery approaches the regulation voltage, the charge current begins to decrease as the CN3166 enters the constant-voltage mode. When the current drops to charge termination threshold, $\overline{\text{DONE}}$ is pulled low by an internal switch and $\overline{\text{CHRG}}$ pin assumes a high impedance state to indicate that the charge cycle is terminated. The charge termination threshold is 11.2% of the current in constant current mode. To restart the charge cycle, just remove the input voltage and reapply it. The charge cycle can also be automatically restarted if the charge current rises above the recharge threshold. The on-chip reference voltage, error amplifier and the resistor divider provide regulation voltage with 1% accuracy which can meet the requirement of lithium-ion and lithium polymer batteries. When the input voltage is not present, the charger goes into a sleep mode, dropping battery drain current to less than 3uA. This greatly reduces the current drain on the battery and increases the standby time.

During charging, battery temperature is continuously monitored in cooperation with an NTC thermistor connected between TEMP pin and GND. The battery temperature monitoring function provided by CN3166 is designed to follow JEITA temperature standard for lithium batteries.

The charging profile is shown in the following figure:

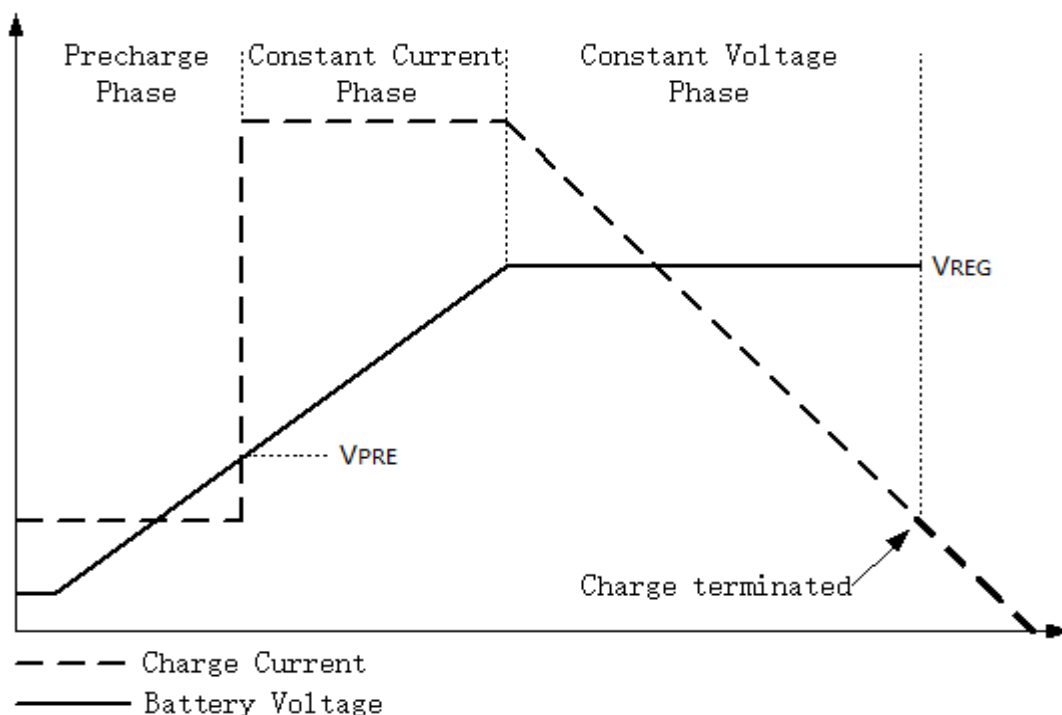


Figure 4 Charging Profile

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Application Information

Undervoltage Lockout (UVLO)

An internal undervoltage lockout circuit monitors the input voltage and keeps the charger in shutdown mode until VIN rises above the undervoltage lockout voltage. The UVLO circuit has a built-in hysteresis of 0.12V.

Sleep mode

There is an on-chip sleep comparator. The comparator keeps the charger in sleep mode if VIN falls below sleep mode threshold (VBAT+10mv). Once in sleep mode, the charger will not come out of sleep mode until VIN rises 60mv above the battery voltage.

Precharge mode

At the beginning of a charge cycle, if the battery voltage is below 66.7% of the regulation voltage, the charger goes into precharge mode or trickle charge mode, and the charge current is 11.2% of fast charge current in constant current mode.

Charging Current limited by the Output capability of Input Power Supply

If the output capability of input power supply is less than the charging current set by the resistor at ISET pin, then the on-chip adaptive cell will begin to function to adjust the charging current based on the output capability of input power supply. In this case, the actual charging current may be less than the value set by the resistor at ISET pin, but it is maximized to the output capability of input power supply on the condition that the input voltage at VIN pin is no less than 4.4V, which is the minimum operating voltage of CN3166. So the charging current can be set according to the maximum output capability of input power supply, not the worst case.

Adjusting the regulation voltage in constant voltage mode

The regulation voltage in constant voltage mode can be adjusted upwards by an external resistor connecting between FB pin and BAT pin as shown in Figure 5. This feature is especially meaningful for ternary lithium batteries.

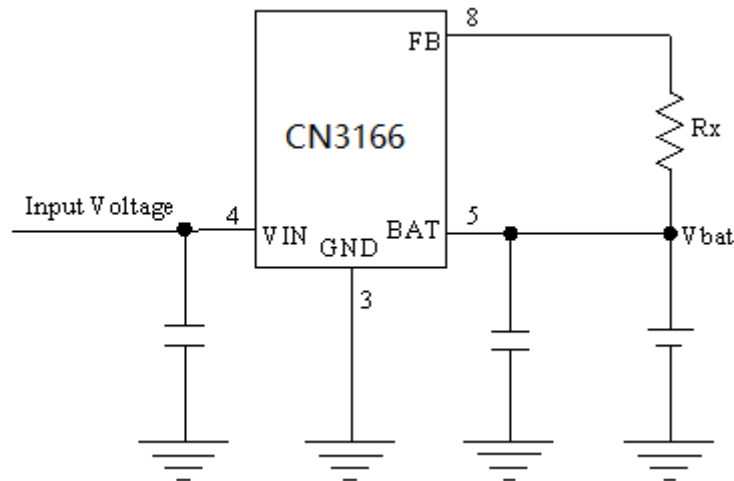


Figure 5 Adjusting Regulation Voltage in Constant Voltage Mode

In Figure 5, the regulation voltage in constant voltage mode will be given by the following equation:

$$V_{REG} = 4.2 + 3.707 \times 10^{-6} \times R_x$$

Where,

V_{REG} is in volt

R_x is in ohm

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Setting Charge Current

The formula for the battery charge current in constant current mode is:

$$I_{CH} = 1182V / R_{ISET}$$

Where:

I_{CH} is the charge current in ampere

R_{ISET} is the total resistance from the ISET pin to ground in ohm

For example, if 950mA charge current is required, calculate:

$$R_{ISET} = 1182V / 0.95A = 1.244k \Omega$$

For best stability over temperature and time, 1% metal film resistors are recommended. If the charger is in constant-temperature or constant voltage mode, the charge current can be monitored by measuring the ISET pin voltage, and the charge current is calculated as the following equation:

$$I_{CH} = (V_{ISET} / R_{ISET}) \times 981$$

Combine Two Power Inputs

Although the CN3166 allows charging from a solar power supply, a wall adapter or a USB port can also be used to charge Li-Ion/Li-polymer batteries. Figure 6 shows an example of how to combine 2 power inputs. A P-channel MOSFET, M1, is used to prevent back conducting into the 2nd power supply when the 1st power supply is present and Schottky diode, D1, is used to prevent 2nd power supply loss through the 1k Ω pull-down resistor.

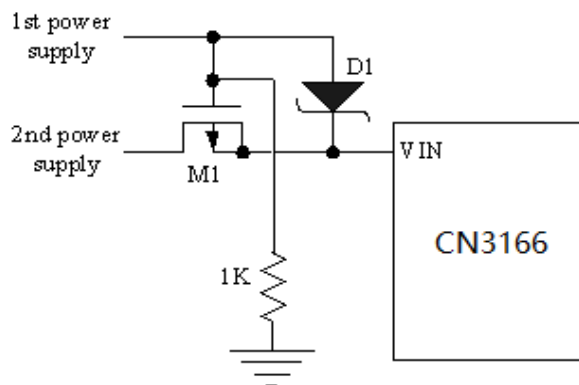


Figure 6 Combining 2 Input Power Supply

Battery Temperature Monitoring

To prevent the damage caused by the very high or very low temperature done to the battery, the CN3166 continuously monitors battery temperature by measuring the voltage at TEMP pin which is determined by TEMP pin's source current (30uA typical) and a negative temperature coefficient (NTC) thermistor connected between TEMP pin and GND as shown in Figure 1 and Figure 2.

If battery temperature monitoring function is not needed, connect a fixed 10Kohm resistor from TEMP to GND. The battery temperature monitoring function for CN3166 is designed to follow the JEITA temperature standard for Li-Ion and Li-Poly batteries; charge current and regulation voltage (V_{REG}) are reduced based on battery temperature ranges.

There are totally five battery temperature ranges for CN3166:

- Hot: Above 55°C,
- Warm: 45°C to 55°C,
- Normal: 10°C to 45°C
- Cool: 0°C to 10°C,
- Cold: Below 0°C.

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Normal operation occurs when battery temperature is between 10°C and 45°C, charge current and voltage will be the normal values.

When battery is in the Cool temperature range, which is between 0°C and 10°C, the charge current is 25% of full-scale charge current and regulation voltage is not changed.

When the battery is in the Warm temperature range, which is between 45°C and 55°C, the charge current is reduced to 50% of full-scale charge current and regulation voltage is reduced to 97.25% of the regulation voltage designed.

Charging is suspended if battery temperature is below Cold temp of 0°C or above Hot temp of 55°C. When charging is suspended, both $\overline{\text{CHRG}}$ pin and $\overline{\text{DONE}}$ pin become high impedance state.

Once battery temperature is not in hot range and cold range, charging resumes automatically.

TEMP pin voltage is the product of its source current and NTC's resistance, so the selection of NTC should make sure TEMP pin voltage meet the requirements of hot, warm, cool and cold threshold. An NTC of nominal resistance 10K ohm at room temperature may be suitable for CN3166.

A resistor of small resistance in series with NTC thermistor and a resistor of large resistance in parallel with NTC thermistor can fine tune CN3166's temperature range.

The following table lists TEMP pin voltage, charge current and regulation voltage in the above-mentioned 5 battery temperature range.

Battery Temperature Range	TEMP Pin Voltage	Charge Current	Regulation Voltage
Hot: above 55°C	$V_{\text{TEMP}} < V_{\text{HOT}}$	Charge Suspended	Charge Suspended
Warm: 45°C to 55°C	$V_{\text{HOTR}} < V_{\text{TEMP}} < V_{\text{WARM}}$	50% * I _{CC}	97.25 * V _{REG}
Normal: 10°C to 45°C	$V_{\text{WARMR}} < V_{\text{TEMP}} < V_{\text{COOLR}}$	Normal Value	Normal Value
Cool: 0°C to 10°C	$V_{\text{COOL}} < V_{\text{TEMP}} < V_{\text{COLDR}}$	25% * I _{CC}	Normal Value
Cold: below 0°C	$V_{\text{TEMP}} > V_{\text{COLD}}$	Charge Suspended	Charge Suspended

Recharge

After a charge cycle has terminated, if the charge current rises above 30% of the constant charge current, or battery voltage falls below 95.8% of regulation voltage, a new charge cycle will begin automatically.

Constant-Current/Constant-Voltage/Constant-Temperature

The CN3166 use a unique architecture to charge a battery in a constant-current, constant-voltage, constant temperature fashion as shown in Figure 3. Amplifiers Iamp, Vamp, and Tamp are used in three separate feedback loops to force the charger into constant-current, constant-voltage, or constant-temperature mode, respectively. In constant current mode the charge current delivered to the battery equal to $1182V/R_{\text{ISET}}$. If the power dissipation of the CN3166 results in the junction temperature approaching 132°C, the amplifier Tamp will begin decreasing the charge current to limit the die temperature to approximately 132°C. As the battery voltage rises, the CN3166 either returns to constant-current mode or it enters constant voltage mode straight from constant-temperature mode.

Over Charge Current Protection

During normal operation, the charge current should be regulated to the value set by the resistor at ISET pin. However, if a short circuit or a misuse of abnormally small resistance occurs on ISET pin, the charge current may rise to unintended level. If the charge current exceeds over charge current threshold I_{OC}, the CN3166 is turned off after a deglitch time of t_{OCP_DGL}.

The CN3166 remains latched off, and will not restart operation until the input supply is removed and re-applied.

Open-Drain Status Outputs

The CN3166 have 2 open-drain status outputs: $\overline{\text{CHRG}}$ and $\overline{\text{DONE}}$. $\overline{\text{CHRG}}$ is pulled low when the charger is in charging status, otherwise $\overline{\text{CHRG}}$ becomes high impedance. $\overline{\text{DONE}}$ is pulled low if the charger is in termination

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status, otherwise \overline{DONE} becomes high impedance.

If battery temperature is in hot and cold range, both \overline{CHRG} and \overline{DONE} become high impedance.

The open drain status output that is not used should be tied to ground.

VIN Bypass Capacitor

Many types of capacitors can be used for input bypassing(C1 in Figure 1 and 2), Generally, a 1uF to 10uF (Case:0805) 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.

If the ceramic capacitor is used as the input supply bypassing purpose, a voltage spike may be created when the input voltage is applied to the CN3166 via a cable. If the cable is a bit long, the circuit shown in Figure 7 or a TVS diode from VIN pin to GND should be considered to use to prevent the CN3166 from being damaged by the voltage spike.

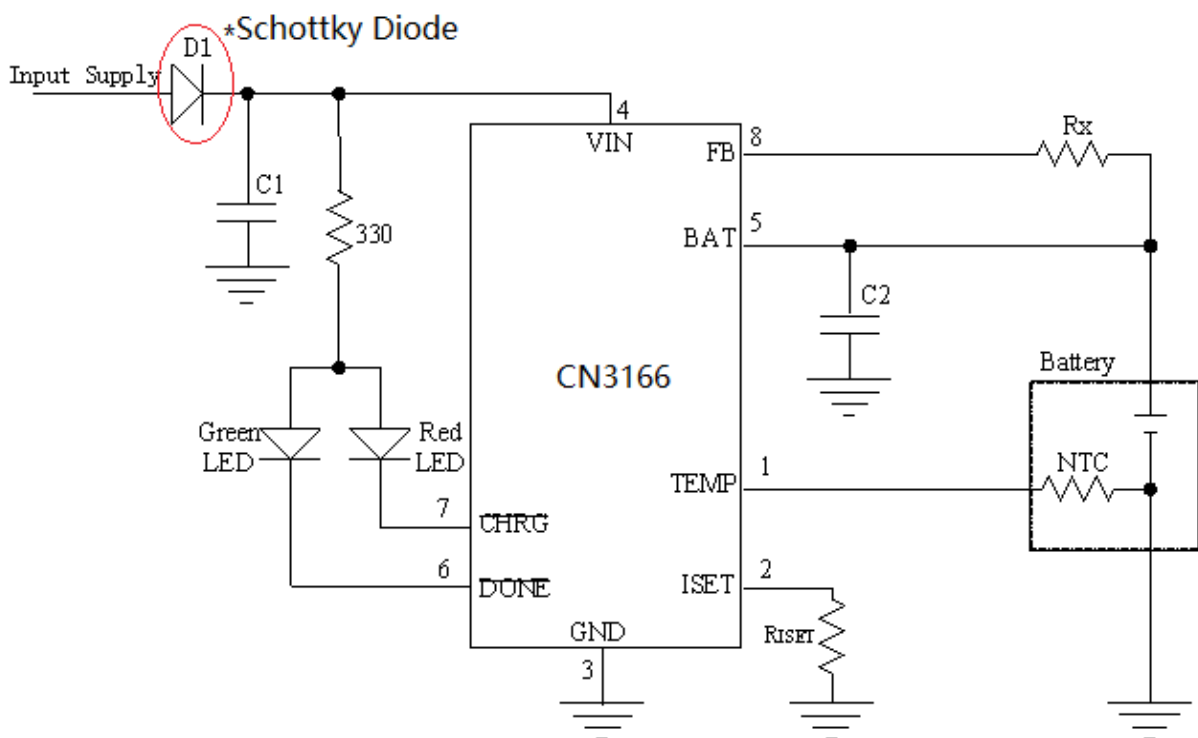


Figure 7 Adding Diode D1 to Suppress Voltage Spike

Stability

A capacitor from BAT pin to GND is required to stabilize the feedback loop, generally the feedback loop is stable with an 1uF to 22uF ceramic capacitor. If electrolytic capacitor is used, the capacitance can be as high as 100uF.

In constant current mode, the stability is also affected by the impedance at the ISET pin. With no additional capacitance on the ISET pin, the loop is stable with current set resistors values as high as 50K Ω . However, additional capacitance on ISET pin reduces the maximum allowed current set resistor. The pole frequency at ISET pin should be kept above 200KHz. Therefore, if ISET pin is loaded with a capacitance C, the following equation should be used to calculate the maximum resistance value for R_{ISET} :

$$R_{ISET} < 1 / (6.28 \times 2 \times 10^5 \times C)$$

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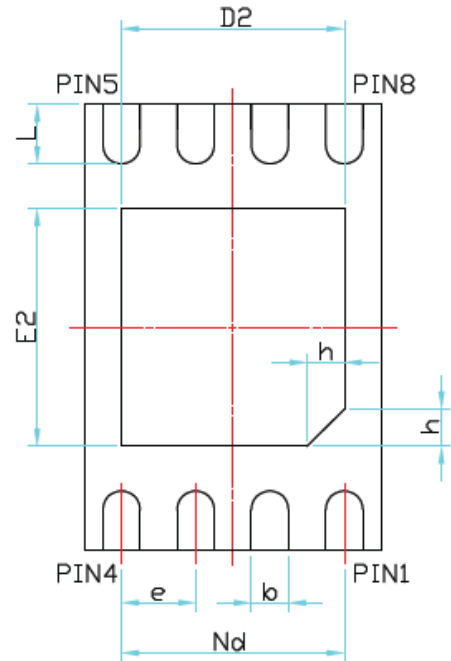
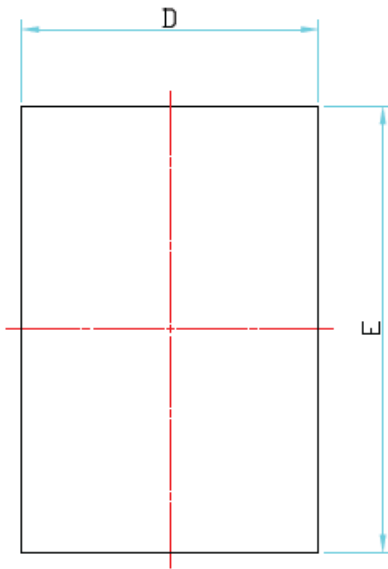
Board Layout Considerations

1. R_{ISET} at ISET pin should be as close to CN3166 as possible, also the parasitic capacitance at ISET pin should be kept as small as possible.
2. The capacitance at VIN pin and BAT pin should be as close to CN3166 as possible.
3. During charging, CN3166's temperature may be high, the NTC thermistor should be placed far enough to CN3166 so that the thermistor can reflect the battery's temperature correctly.
4. It is very important to use a good thermal PC board layout to maximize charging current. The thermal path for the heat generated by the IC is from the die to the copper lead frame through the package lead (especially the ground lead) to the PC board copper, the PC board copper is the heat sink. The footprint copper pads should be as wide as possible and expand out to larger copper areas to spread and dissipate the heat to the surrounding ambient. Feedthrough vias to inner or backside copper layers are also useful in improving the overall thermal performance of the charger. Other heat sources on the board, not related to the charger, must also be considered when designing a PC board layout because they will affect overall temperature rise and the maximum charge current.

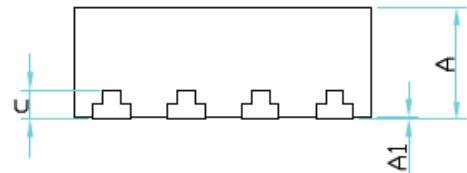
The ability to deliver maximum charge current under all conditions requires that the exposed metal pad on the back side of the CN3166 package be soldered to the PC board ground. Failure to make the thermal contact between the exposed pad on the backside of the package and the copper board will result in larger thermal resistance.

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Package Information



SYMBOL	MILLMETER		
	MIN	NOM	MAX
A	0.70	0.75	0.80
A1	0.00	0.02	0.05
b	0.18	0.25	0.30
c	0.18	0.20	0.25
D	1.90	2.00	2.10
D2	1.40	1.50	1.60
e	0.50 BSC		
Nd	1.50 BSC		
E	2.90	3.00	3.10
E2	1.50	1.60	1.70
L	0.30	0.40	0.50
h	0.20	0.25	0.30



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