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Standalone Linear Li-Ion Battery Charger with Thermal Regulation

CE3151 Series

■ INTRODUCTION:

The CE3151 is a complete constant-current/ constant–voltage linear charger for single cell lithium-ion batteries. Its SOT package and low external component count make the CE3151 ideally suited for space limited portable applications. Furthermore, the CE3151 is specifically designed to work within USB power specifications.

No external sense resistor is needed, and no blocking diode is required due to the internal MOSFET architecture. Thermal feedback regulates the charge current to limit the die temperature during high power operation or high ambient temperature. The charge voltage is fixed at V_{FLOAT}, and the charge current can be programmed externally with a single resistor connected between PROG pin and GND. The CE3151 automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached.

When the input supply (wall adapter or USB supply) is removed, the CE3151 automatically enters a low current state, dropping the battery drain current to less than 2µA. The CE3151 can be put into shutdown mode, reducing the supply current to 50µA.

Other features include charge current monitor, undervoltage lockout, automatic recharge and two status pins to indicate charging and charge termination.

■ APPLICATIONS:

- Cellular Telephones, PDAs, MP3 Players
- Digital Still Cameras
- Charging Docks and Cradles
- Bluetooth Applications

■ FEATURES:

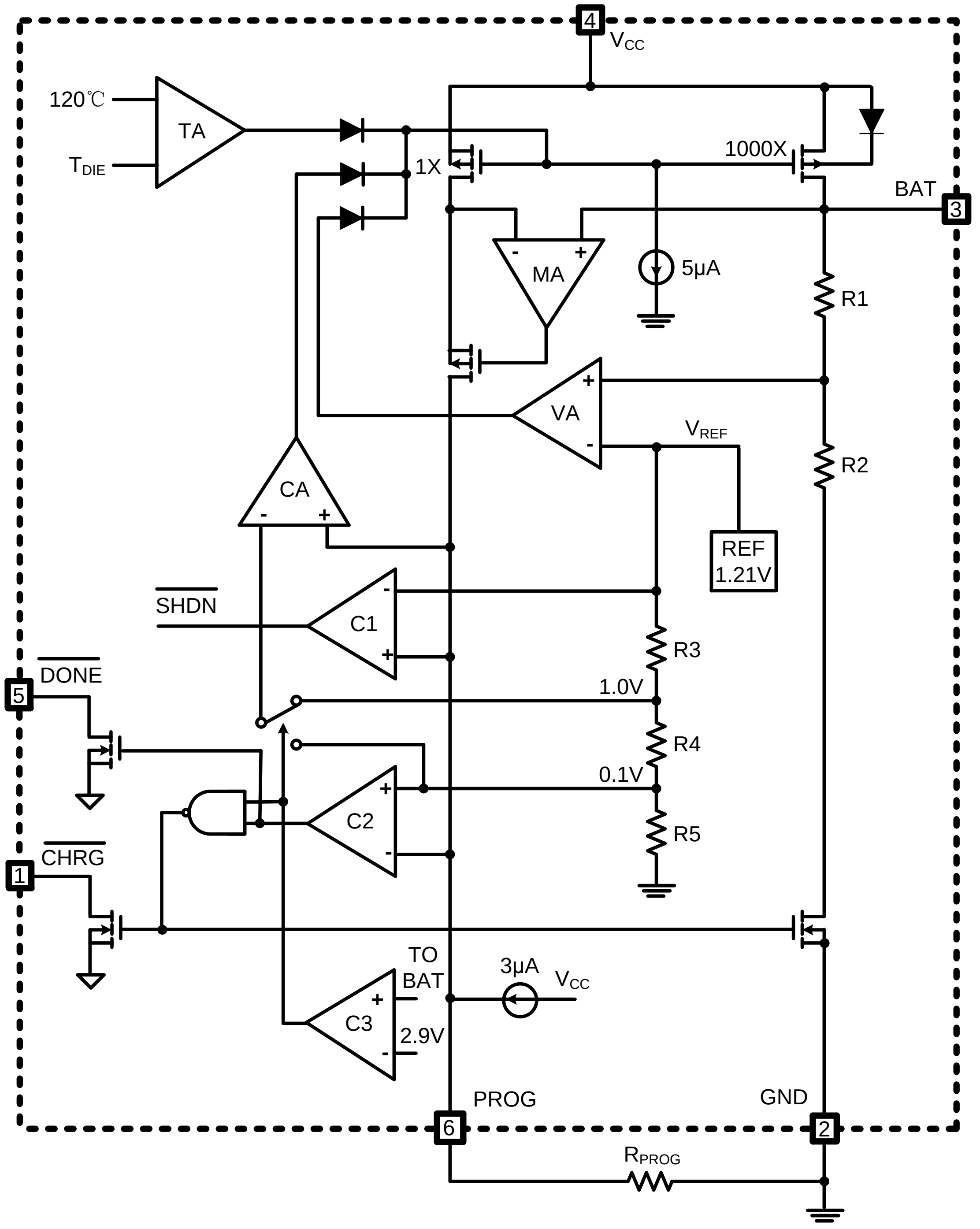
- Small 2.9 mm × 2.8 mm SOT23 Package
- Ideal for Low-Dropout Designs for Single-Cell Li-Ion or Li-Pol Batteries Charge Directly from USB Port or AC Adapter in Space Limited Portable Applications
- Integrated P-ch Power MOSFET and Current Sensor for Up to 800mA Charge Applications
- Reverse Leakage Protection Prevents Battery Drainage
- Pre-charge Conditioning for Reviving Deeply Discharged Cells and Minimizing Heat Dissipation During Initial Stage of Charge
- 2.9V Trickle Charge Threshold
- Constant-Current/Constant-Voltage operation with Thermal Regulation Maximizes Charge Rate Without Risk of Overheating
- Integrated Current and Voltage Regulation
  ±10% Current Regulation Accuracy
  ±1% Voltage Regulation Accuracy
- Charge Current Monitor Output for Gas Gauging
- C/10 Charge Termination
- Automatic Recharge
- Status Output for LEDs or System Interface Indicates Charge and Fault Conditions
- Automatic Sleep Mode for Low-Power Consumption
- 50µA Supply Current in Shutdown
- Battery Short-Circuit Protection
- Soft-Start Limits Inrush Current
- Charge Voltage Options: 4.20V and 4.35V

■ ORDER INFORMATION[1]

Device No.	Battery Float Voltage	Package	Packaging
CE3151A420E	4.20V	SOT23-6	3000 parts per reel
CE3151A435E	4.35V	SOT23-6	3000 parts per reel

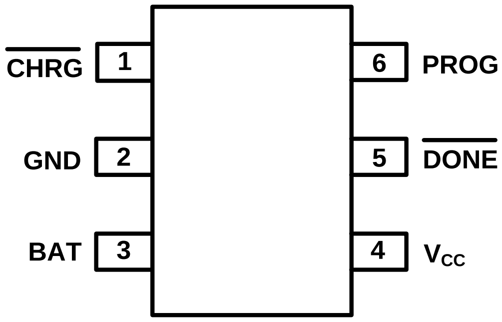
(1)Contact Chipower to check availability of other battery float voltage versions or charge termination current versions.

■ BLOCK DIAGRAM



Future 1. Functional Block Diagram

■ PIN CONFIGURATION



SOT23-6 (Top View)

Table 1. Pin Description

PIN		TYPE[1]	DESCRIPTION AND REQUIRED COMPONENTS
No.	**NAME**		
1	$\overline{\text{CHRG}}$	O	**Open Drain Charge Status Output**. When the battery is being charged, the $\overline{\text{CHRG}}$ pin is pulled low by an internal N-channel MOSFET switch. When the CE3151 detects an undervoltage lockout condition, $\overline{\text{CHRG}}$ pin is forced high impedance.
2	GND	I	**Ground Terminal**.
3	BAT	I/O	**Charger Power Stage Current Output and Battery Voltage Sense Input**. BAT pin provides charge current to the battery and regulates the final float voltage. An internal precision resistor divider from this pin sets the float voltage which is disconnected in shutdown mode. Connect the positive terminal of the battery to BAT pin. Bypass BAT to GND with 10µF to 47µF capacitor. BAT pin draws less than 2µA current in shutdown mode (R_{PROG} not connected) or sleep mode .
4	V_{CC}	I	**Charger Positive Input Supply Voltage and Internal Supply**. V_{CC} is the power supply to the internal circuit. V_{CC} can range from 4.5V to 6.5V and should be bypassed with at least a 4.7µF capacitor. When V_{CC} drops to within 80mV of the BAT pin voltage, the CE3151 enters low power sleep mode, dropping BAT pin's current to less than 2µA.
5	$\overline{\text{DONE}}$	O	**Open-Drain Charge termination Status Output**. In charge termination status, $\overline{\text{DONE}}$ is pulled low by an internal switch; Otherwise $\overline{\text{DONE}}$ pin is in high impedance state.
6	PROG	O	**Charge Current Program, Charge Current Monitor and Shutdown Pin**. The charge current is programed by connecting a 1% accuracy metal film resistor R_{PROG} from this pin to GND. When charging in trickle charge mode, the PROG pin voltage is regulated to 0.1V. When charging in constant-current mode, the PROG pin voltage is regulated to 1V.In all modes during charging, the voltage on PROG pin can be used to measure the charge current as the following formula: $I_{BAT}=1000V_{PROG}/R_{PROG}$ The PROG pin can also be used to shut down the charger. Disconnecting the program resistor from ground allows a 3µA current to pull the PROG pin high. When it reaches the 1.21V shutdown threshold voltage, the charger enters shutdown mode, charging stops and the input supply current drops to 50µA. This pin is also clamped to approximately 2.4V. Driving this pin to voltages beyond the clamp voltage will draw currents as high as 1.5mA. Reconnecting R_{PROG} to ground will return the charger to normal operation.

(1) I = input; O = output; P = power

■ ABSOLUTE MAXIMUM RATINGS[1]

(unless otherwise specified , T_A=25°C)

PARAMETER	SYMBOL	RATINGS	UNITS
Input Supply Voltage[2]	V_{CC}	-0.3~10	V
PROG Pin Voltage[2]		-0.3~V_{CC}+0.3	
BAT Pin Voltage[2]		-0.3~8	
$\overline{CHRG}$, $\overline{DONE}$ Pins Voltage[2]		-0.3~10	
BAT Short-Circuit Duration	-	Continuous	-
BAT Pin Output Current (Continuous)	I_{BAT}	800	mA
PROG Pin Current		800	µA
Output sink current	$I_{\overline{CHRG}}$, $I_{\overline{DONE}}$	10	mA
Power dissipation	P_D	400	mW
Operating Ambient Temperature Range[3]	T_A	-40~85	°C
Junction Temperature	T_J	-40~125	°C
Storage Temperature	T_{stg}	-40~125	°C
Lead Temperature (Soldering, 10s)	T_{solder}	260	°C
ESD rating[4]	HBM JESD22-A114A	4000	V
	MM JESD22-A115A	200	V

(1) 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 under *recommended operating conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods my affect device reliability.
(2) All voltages are with respect to network ground terminal.
(3) The CE3151 are guaranteed to meet performance specifications from 0℃ to 70°C. Specifications over the –40°C to 85°C operating temperature range are assured by design, characterization and correlation with statistical process controls.
(4) ESD testing is performed according to the respective JESD22 JEDEC standard.
The human body model is a 100 pF capacitor discharged through a 1.5kΩ resistor into each pin. The machine model is a 200pF capacitor discharged directly into each pin.

■ RECOMMENDED OPERATING CONDITIONS

PARAMETER	SYMBOL	MIN.	MAX.	UNITS
Input voltage range[1]	V_{CC}	4.5	6.5	V
BAT Pin Output Current (Continuous)	I_{BAT}		600[2]	mA
Operating junction temperature range	T_J	0	70	°C
Fast-charge current programming resistor[3]	R_{PROG}	1.66	10	kΩ

(1) If V_{CC} is between UVLO and 4.5V, and above the battery voltage, then the IC is active (can deliver some charge to the battery), but the IC will have limited or degraded performance (some functions may not meet data sheet specifications). The battery may be undercharged (V_{FLOAT} less than in the specification), but will not be overcharged (V_{FLOAT} will not exceed specification).
(2) The thermal regulation feature reduces charge current if the IC's junction temperature reaches 120°C; thus without a good thermal design the maximum programmed charge current may not be reached.
(3) Use a 1% tolerance metal film resistor for R_{PROG} to avoid issues with the R_{PROG} short test when using the maximum charge current setting.

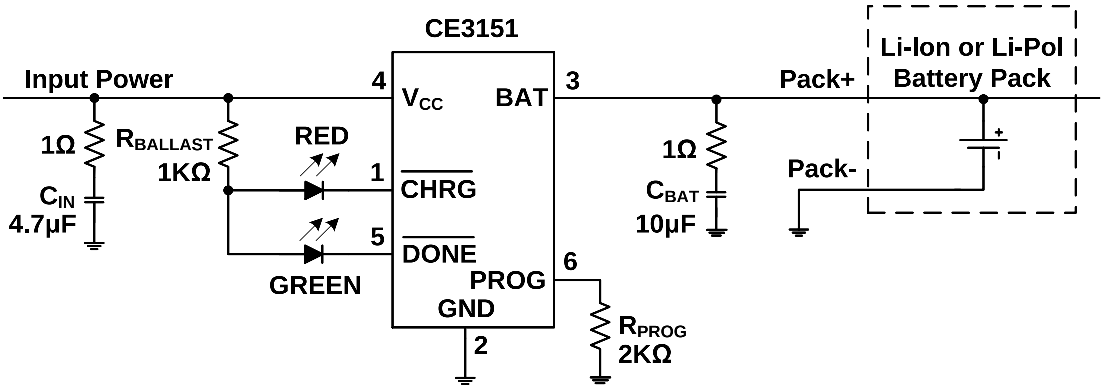
■ ELECTRICAL CHARACTERISTICS

(V_{CC}= 5V, T_A=25℃, Test Circuit Figure 2, unless otherwise specified)

PARAMETER	SYMBOL	CONDITIONS	MIN.	TYP.	MAX.	UNITS
Under voltage Lockout Threshold[1]	V_{UVL}	V_{CC} from Low to High		3.9		V
Under voltage Lockout Hysteresis	ΔV_{UVL}			150		mV
Input Supply Current	I_{CC}	Charge Mode[2], R_{PROG}=10K		150	500	µA
		Standby Mode (Charge Terminated)		50	100	
		Shutdown Mode: R_{PROG} Not Connected, V_{CC}<V_{BAT}, or V_{CC}<V_{UVL}		50	100	
CE "High" Level Voltage	V_{CEH}		1.5		V_{CC}	V
CE "Low" Level Voltage	V_{CEL}				0.4	V
Trickle Charge Threshold	V_{TRIKL}	R_{PROG}=10K, V_{BAT} Rising		2.9		V
Trickle Charge Hysteresis	ΔV_{TRIKL}	R_{PROG}=10K		100		mV
Trickle Charge Current	I_{TRIKL}	R_{PROG}=2K	45	50	550	mA
BAT Pin Current	I_{BAT}	R_{PROG}=2K, Current Mode (V_{BAT}=4.0V)	450	500	550	
		Standby Mode, V_{BAT}=V_{FLOAT}	0	-2.5	-6.0	µA
		Shutdown Mode (R_{PROG} Not Connected)		±1	±2	
		Sleep Mode, V_{CC}=0V		-1	-2	
PROG Pin Voltage	V_{PROG}	R_{PROG}=1K, Current Mode	0.9	1.0	1.1	V
PROG Pin Pull-Up Current	I_{PROG}			3		µA
Regulated Output (Float) Voltage	V_{FLOAT}	0°C ≤ T_A ≤ 85°C, I_{BAT}=20mA, R_{PROG}=10K	4.158	4.200	4.250	V
			4.300	4.350	4.400	V
C/10 Termination Current Threshold	I_{TERM}[3]	R_{PROG}=2K		0.1		mA/mA
Termination Comparator Filter Time	t_{TERM}	I_{BAT} Falling Below I_{TERM}	0.8	1.8	4.0	mS
Recharge Battery Threshold	ΔV_{RECHRG}	$V_{FLOAT}-V_{RECHRG}$		150		mV
Recharge Comparator Filter Time	$t_{RECHARGE}$	V_{BAT} High to Low	0.8	1.8	4.0	mS
V_{CC} – V_{BAT} Lockout Threshold	A_{MSD}	V_{CC} from Low to High		100		mV
		V_{CC} from High to Low		80		mV
$\overline{CHRG}$ Pin Voltage	$V_{\overline{CHRG}}$	$I_{\overline{CHRG}}$=5mA		0.3	0.6	V
$\overline{DONE}$ Pin Voltage	$V_{\overline{DONE}}$	$I_{\overline{DONE}}$=5mA		0.3	0.6	V
Soft-Start Time	t_{SS}	I_{BAT}=0 to I_{BAT}=1000V/R_{PROG}		20		mS
Power FET "ON" Resistance (Between V_{CC} and BAT)	R_{ON}	I_{BAT}=600mA		400		mΩ
Junction Temperature in Constant Temperature Mode	$T_{J(REG)}$			120		°C

(1) Specified by design, not production tested.
(2) Supply current includes PROG pin current (approximately 100µA) but does not include any current delivered to the battery through the BAT pin (approximately 100mA).
(3) I_{TERM} is expressed as a fraction of measured full charge current with indicated PROG resistor.

■ TYPICAL APPLICATION CIRCUIT



Typical Application for Charging Between 100mA and 500mA

Figure 2. Standard Application Circuit

■ OPERATION

Power Down (Undervoltage Lockout, UVLO)

An internal undervoltage lockout circuit monitors the input voltage, the CE3151 is in a power-down mode when the input power voltage (V_{CC}) is below the power-down threshold (Undervoltage Lockout threshold) V_{UVL}. The UVLO circuit has a built-in hysteresis of 150mV.

During the power down mode, all IC functions are off. The integrated power MOSFET connected between V_{CC} and BAT pins is off, the status output pin $\overline{CHRG}$ is set to the high impedance state.

Sleep Mode

The CE3151 enters the low-power sleep mode when the input power voltage (V_{CC}) is above the power down threshold (Undervoltage Lockout threshold) V_{UVL} but still lower than the Sleep mode exit threshold, $V_{UVL}<V_{CC}<V_{BAT}+V_{(SLP\_EXIT)}$. During the sleep mode, the charger is off. The integrated power MOSFET connected between V_{CC} and BAT pins is off, the status output pin $\overline{CHRG}$ is set to the high impedance state.

The sleep mode is entered from any other state, if the input power (V_{CC}) is not detected. This feature prevents draining the battery during the absence of $V_{CC.}$

The backgate control circuit prevents any reverse current flowing from the battery to the adapter terminal during the charger off delay time.

Note that the $\overline{CHRG}$ pin is not deglitched, and it indicates input power loss immediately after the input voltage falls below the BAT pin voltage. If the input source frequently drops below the BAT pin voltage and recovers, a small capacitor can be used from $\overline{CHRG}$ to GND to prevent $\overline{CHRG}$ flashing events.

Begin Charge Mode

All blocks in the IC are powered up, and the CE3151 is ready to start charging the battery. A new charge cycle is started when the control logic decides that all conditions required to enable a new charge cycle are met.

Normal Charge Cycle

A charge cycle begins when the voltage at the V_{CC} pin rises above the UVLO threshold level and a 1% program resistor is connected from the PROG pin to ground or when a battery is connected to the charger BAT pin. If the BAT pin voltage is less than the V_{TRIKL} threshold (2.9V typical), the charger enters trickle charge mode. In this mode, the CE3151 applies approximately 1/10th of the programmed fast-charge current value in current regulation mode to bring the battery voltage up to a safe level for full current charging.

When the BAT pin voltage rises above the V_{TRIKL} threshold (2.9V typical), the charger enters current regulation mode, where the programmed fast-charge current is applied to the battery. When the BAT pin approaches the final float voltage (V_{FLOAT}), the CE3151 enters voltage regulation mode and the charge current begins to decrease. When the charge current drops to 1/10th of the programmed fast-charge current value in current regulation mode, the charge cycle ends.

Programming Charge Current

The charge current delivered to the battery from USB bus or wall adapter supply is programmed using a single resistor from the PROG pin to ground. The battery charge current is 1000 times the current out of the PROG pin. The program resistor and the charge current (I_{CHG}) are calculated using the equations:

$I_{CHG}=1000V/R_{PORG}$, $R_{PORG}=1000V/I_{CHG}$

Monitoring Charge Current

When the charge function is enabled internal circuits generate a current proportional to the charge current at the PROG pin. This current, when applied to the external charge current programming resistor R_{PROG} generates an analog voltage that can be monitored by an external host to calculate the current sourced from the BAT pin. Charge current out of the BAT pin can be determined at any time by monitoring the PROG pin voltage and using the following equations:

$V_{PROG}=(I_{BAT} \times R_{PROG})/1000$

Charge Termination Detection

The charging current is monitored during the voltage regulation phase. Charge termination is indicated at the $\overline{CHRG}$ pin ($\overline{CHRG}$=High-Z) once the charge current falls to 1/10th of the programmed fast-charge current value after the final float voltage is reached. This condition is detected by using an internal, filtered comparator to monitor the PROG pin. When the PROG pin voltage falls below 100mV **(Note: Any external sources that hold the PROG pin above 100mV will prevent the CE3151 from terminating a**

charge cycle.) for longer than t_{TERM} (1.8ms typical), charging is terminated. The charge current is latched off and the CE3151 enters charge done mode, where the input supply current drops to 50µA. **(Note: C/10 charge termination is disabled in trickle charging and thermal regulation modes.)**

When charging, transient loads on the BAT pin can cause the PROG pin to fall below 100mV for short periods of time before the DC charge current has dropped to 1/10th of the programmed fast-charge current value in current regulation mode. The 1.8ms deglitch period t_{TERM} on the termination comparator ensures that transient loads of this nature do not result in premature charge cycle termination and false termination indication. Once the average charge current drops below 1/10th the programmed fast-charge current value in current regulation mode, the CE3151 terminates the charge cycle and ceases to provide any current through the BAT pin. In this state, all loads on the BAT pin must be supplied by the battery.

The CE3151 constantly monitors the BAT pin voltage in standby mode. If this voltage drops below the recharge threshold (V_{RECHRG}), another charge cycle begins and current is once again supplied to the battery. To manually restart a charge cycle, when in standby mode, the input voltage must be removed and reapplied, or the charger must be shut down and restarted using the PROG pin. Figure 3 shows the state diagram of a typical charge cycle.

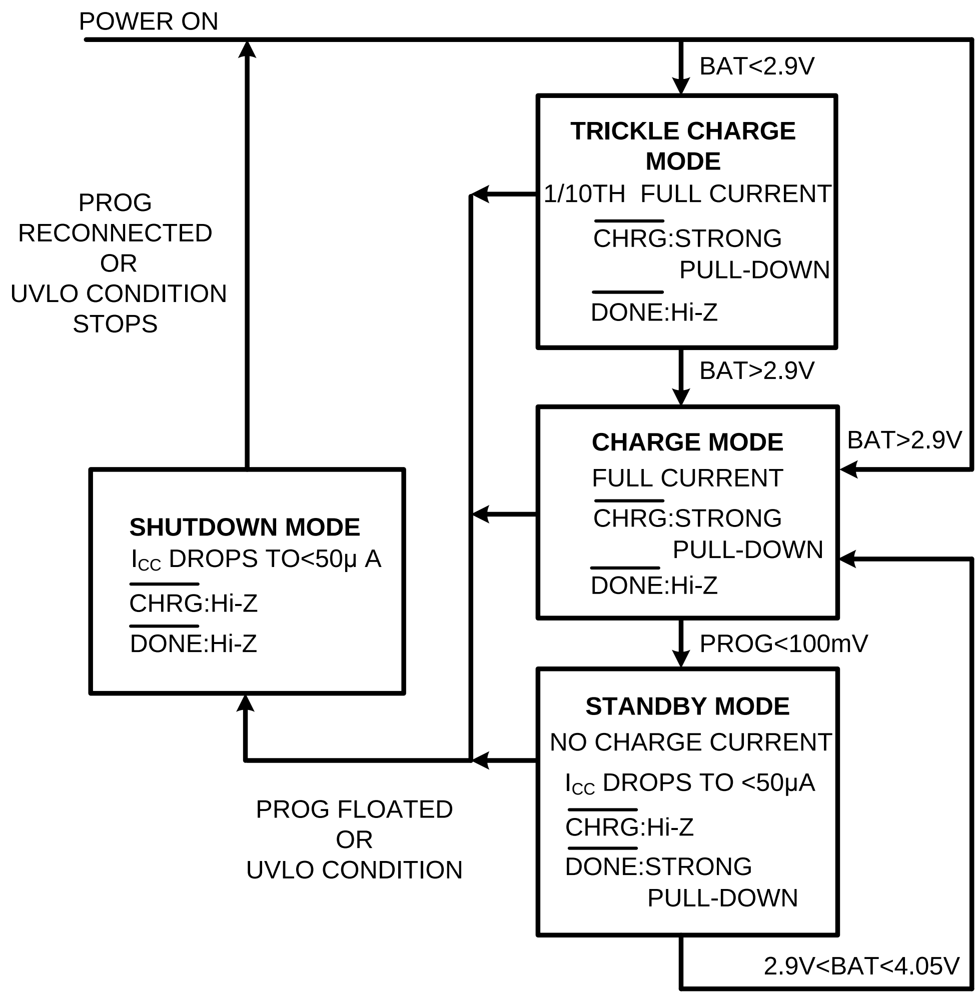


Figure 3. State Diagram of a Typical Charge Cycle

Recharge

Once the charge cycle is terminated, the charger sits idle and continuously monitors the voltage on the BAT pin using a comparator with a 1.8ms filter time, $t_{RECHARGE}$. A charge cycle automatically restarts when the battery voltage falls below V_{RECHRG} threshold (which corresponds to approximately 80%-90% battery capacity). This ensures that the battery is kept at, or near, a fully charged condition and eliminates the need for periodic charge cycle initiations. $\overline{\text{CHRG}}$ output enters a strong pull-down state during recharge cycles.

If the battery is removed from the charger, a sawtooth waveform of approximately 100mV appears at the battery output. This is caused by the repeated cycling between termination and recharge events.

This cycling results in pulsing at the $\overline{CHRG}$ output; an LED connected to this pin will exhibit a blinking pattern, indicating to the user that a battery is not present. The frequency of the sawtooth is dependent on the amount of output capacitance. See the Battery Absent Detection section for additional details.

Manual Shutdown

At any point in the charge cycle, the CE3151 can be put into shutdown mode by removing R_{PROG} thus floating the PROG pin. This reduces the battery drain current to less than 2µA and the supply current to less than 50µA. A new charge cycle can be initiated by reconnecting the program resistor.

In manual shutdown, The $\overline{CHRG}$ pin is in a high impedance state.

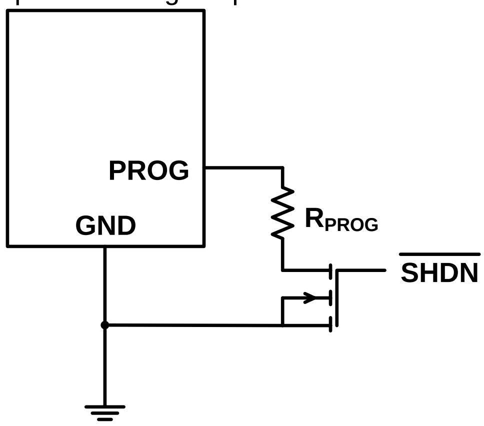


Figure 4. Shutdown Operation

Startup With Deeply Depleted Battery Connected

The CE3151 charger furnishes the programmed charge current if a battery is detected. If no battery is connected the CE3151 operates as follows:

- The output current is regulated to the programmed pre-charge current if $V_{BAT}<V_{TRIKL}$.
- The output current is regulated to the programmed fast-charge current If $V_{BAT}>V_{TRIKL}$ and voltage regulation is not reached.

Thermal Regulation Loop

An internal thermal feedback loop reduces the programmed charge current if the die temperature attempts to rise above a preset value of approximately 120°C. This feature protects the CE3151 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 CE3151. The charge current can be set according to typical (not worst-case) ambient temperatures with the assurance that the charger will automatically reduce the current in worst-case conditions.

Over-Current Protection

Over-current protection is provided in all modes of operation, including voltage regulation. The output current is limited to either the programmed pre-charge current limit value or the fast-charge current limit value, depending on the voltage at the output.

Charge Status Indicator ($\overline{CHRG}$, $\overline{DONE}$)

The CE3151 family provides battery charge status via two status pins: $\overline{CHRG}$ and $\overline{DONE}$. $\overline{CHRG}$ and $\overline{DONE}$ pins are internally connected to an N-channel open drain MOSFET. $\overline{CHRG}$ is pulled low when the charger is in charging status, otherwise $\overline{CHRG}$ becomes high impedance. $\overline{DONE}$ is pulled low if the charger is in charge termination status, otherwise $\overline{DONE}$ becomes high impedance.

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

A microprocessor can be used to distinguish between the two states—this method is discussed in the Applications Information section.

The following table lists the two indicator status and its corresponding charging state.

Table 2. Charge Status Indicator[1]

Charge State Description	$\overline{\text{CHRG}}$	$\overline{\text{DONE}}$
Preconditioning-Current Mode (Trickle) Charge	ON	HI-Z
Constant-Current Mode (Fast) Charge	ON	HI-Z
Constant-Voltage Mode (Taper) Charge, $I_{BAT}>I_{TERM}$	ON	HI-Z
Charge Temination ($I_{BAT}<I_{TERM}$, Charge Done)	HI-Z	ON
Power Down (Undervoltage Lockout) Mode	HI-Z	HI-Z
Sleep Mode ($V_{UVL}<V_{CC}<V_{BAT}+V_{(SLP\_EXIT)}$, or the V_{CC} is removed)	HI-Z	HI-Z
Shutdown Mode(PROG pin floating)	HI-Z	HI-Z
No battery with Charge Enabled	FLASH Rate depends on C_{BAT}	ON
Fault Condition (Battery Short Circuit)	ON	HI-Z
Fault Condition (Battery Overvoltage)	HI-Z	HI-Z

(1) Pulse loading on the BAT pin may cause the IC to cycle between Done and charging states (LEDs Flashing)

The two status pins can be used to communicate to the host processor or drive LEDs.
It is supposed that red LED is connected to $\overline{\text{CHRG}}$ pin and green LED is connected to $\overline{\text{DONE}}$ pin.
The LEDs should be biased with as little current as necessary to create reasonable illumination, therefore, a ballast resistor should be placed between the LED cathode and the status pin. LED current consumption will add to the overall thermal power budget for the device package, hence it is good to keep the LED drive current to a minimum 2mA should be sufficient to drive most low cost red or green LEDs. It is not recommended to exceed 10mA for driving an individual status LED. The required ballast resistor values can be estimated using following formula:

$R_{BALLAST} = [V_{CC} - V_{F(LED)}] / I_{LED}$

Example:

$R_{BALLAST} = [5.0V - 2.0V] / 2mA = 1.5k\Omega$

Note: Red LED forward voltage (V_F) is typically 2.0V@ 2mA.

■ APPLICATION INFORMATIONS

Stability Considerations

The constant-voltage mode feedback loop is stable without an output capacitor provided a battery is connected to the charger output. With no battery present, an output capacitor is recommended to reduce ripple voltage. When using high value, low ESR ceramic capacitors, it is recommended to add a 1Ω resistor in series with the capacitor. No series resistor is needed if tantalum capacitors are used.

In constant-current mode, the PROG pin is in the feedback loop, not the battery. The constant-current mode stability is affected by the impedance at the PROG pin. With no additional capacitance on the PROG pin, the charger is stable with program resistor values as high as 20k. However, additional capacitance on this node reduces the maximum allowed program resistor. The pole frequency at the PROG pin should be kept above 100kHz. Therefore, if the PROG pin is loaded with a capacitance, C_{PROG}, the following equation can be used to calculate the maximum resistance value for R_{PROG}:

$$R_{PROG} \le \frac{1}{2\pi \times 10^5 \times C_{PROG}}$$

Average, rather than instantaneous, charge current may be of interest to the user. For example, if a switching power supply operating in low current mode is connected in parallel with the battery, the average current being pulled out of the BAT pin is typically of more interest than the instantaneous current pulses.

In such a case, a simple RC filter can be used on the PROG pin to measure the average battery current as shown in Figure 5. A 10k resistor has been added between the PROG pin and the filter capacitor to ensure stability.

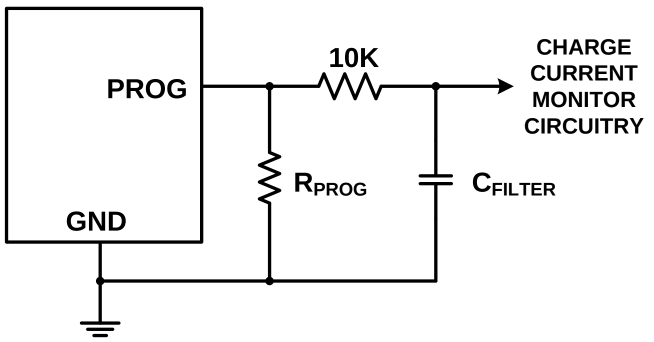


Figure 5. Isolating Capacitive Load on PROG Pin and Filtering

Power Dissipation

The conditions that cause the CE3151 to reduce charge current through thermal feedback can be approximated by considering the power dissipated in the IC. Nearly all of this power dissipation is generated by the internal MOSFET—this is calculated to be approximately:

$P_D = (V_{CC} – V_{BAT}) \cdot I_{BAT}$

where P_D is the power dissipated, V_{CC} is the input supply voltage, V_{BAT} is the battery voltage and I_{BAT} is the charge current. The approximate ambient temperature at which the thermal feedback begins to protect the IC is:

$T_A = 120°C – P_D\theta_{JA}$

$T_A = 120°C – (V_{CC} – V_{BAT}) \cdot I_{BAT} \cdot \theta_{JA}$

Example: An CE3151 operating from a 5V USB supply is programmed to supply 400mA full-scale current to a discharged Li-Ion battery with a voltage of 3.75V. Assuming θ_{JA} is 150°C/W (see Board Layout Considerations), the ambient temperature at which the CE3151 will begin to reduce the charge current is approximately:

$T_A = 120°C – (5V – 3.75V) \cdot 400mA \cdot 150°C/W$

$T_A = 120°C – 0.5W \cdot 150°C/W = 120°C –75°C$

$T_A = 45°C$

The CE3151 can be used above 45°C ambient, but the charge current will be reduced from 400mA. The approximate current at a given ambient temperature can be approximated by:

$$I_{BAT} = \frac{120°C - T_A}{(V_{CC} - V_{BAT}) \times \theta_{JA}}$$

Using the previous example with an ambient temperature of 60°C, the charge current will be reduced to approximately:

$$I_{BAT} = \frac{120℃ - 60℃}{(5V - 3.75V) \times 150℃/W} = \frac{60℃}{187.5℃/A}$$

$$I_{BAT} = 320mA$$

Moreover, when thermal feedback reduces the charge current, the voltage at the PROG pin is also reduced proportionally as discussed in the Operation section.

It is important to remember that CE3151 applications do not need to be designed for worst-case thermal conditions since the IC will automatically reduce power dissipation when the junction temperature reaches approximately 120°C.

Thermal Considerations

Because of the small size of the SOT package, it is very important to use a good thermal PC board layout to maximize the available charge current. The thermal path for the heat generated by the IC is from the die to the copper lead frame, through the package leads, **(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 following table lists thermal resistance for several different board sizes and copper areas. All measurements were taken in still air on 3/32" FR-4 board with the device mounted on topside.

Table 3. Measured Thermal Resistance (2-Layer Board*)

COPPER AREA		BOARD AREA	THERMAL RESISTANCE
TOPSIDE	BACKSIDE		JUNCTION-TO-AMBIENT
2500mm^2	2500mm^2	2500mm^2	125°C/W
1000mm^2	2500mm^2	2500mm^2	125°C/W
225mm^2	2500mm^2	2500mm^2	130°C/W
100mm^2	2500mm^2	2500mm^2	135°C/W
50mm^2	2500mm^2	2500mm^2	150°C/W

***Each layer uses one ounce copper**

Table 4. Measured Thermal Resistance (4-Layer Board)**

COPPER AREA (EACH SIDE)	BOARD AREA	THERMAL RESISTANCE JUNCTION-TO-AMBIENT
2500mm^2	2500mm^2	80°C/W

***Top and bottom layers use two ounce copper, inner layers use one ounce copper.**
****10,000mm2 total copper area**

Increasing Thermal Regulation Current

Reducing the voltage drop across the internal MOSFET can significantly decrease the power dissipation in the IC. This has the effect of increasing the current delivered to the battery during thermal regulation. One method is by dissipating some of the power through an external component, such as a resistor or diode.

Example: An CE3151 operating from a 5V wall adapter is programmed to supply 800mA full-scale current to a discharged Li-Ion battery with a voltage of 3.75V. Assuming θ_{JA} is 125°C/W, the approximate charge current at an ambient temperature of 25°C is:

$$I_{BAT} = \frac{120℃ - 25℃}{(5V - 3.75V) \times 125℃/W} = 608mA$$

By dropping voltage across a resistor in series with a 5V wall adapter (shown in Figure 6), the on-chip power dissipation can be decreased, thus increasing the thermally regulated charge current

$$I_{BAT} = \frac{120℃ - 25℃}{(V_S - I_{BAT} R_{CC} - V_{BAT}) \times \theta_{JA}}$$

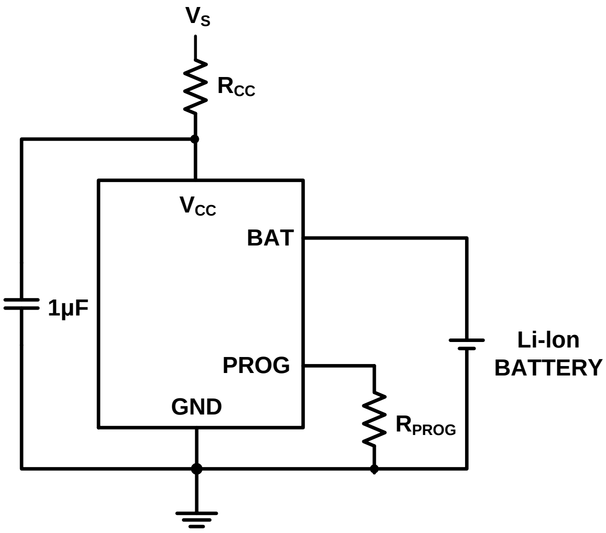


Figure 6. A Circuit to Maximize Thermal Mode Charge Current

Solving for I_{BAT} using the quadratic formula **(Note: Large values of R_{CC} will result in no solution for I_{BAT}. This indicates that the CE3151 will not generate enough heat to require thermal regulation)**.

$$I_{BAT} = \frac{(V_S - V_{BAT}) - \sqrt{(V_S - V_{BAT})^2 - \frac{4R_{CC}(120°C - T_A)}{\theta_{JA}}}}{2R_{CC}}$$

Using R_{CC}=0.25Ω, V_S=5V, V_{BAT}=3.75V, T_A=25°C and θ_{JA}=125°C/W we can calculate the thermally regulated charge current to be: I_{BAT}=708.4mA

While this application delivers more energy to the battery and reduces charge time in thermal mode, it may actually lengthen charge time in voltage mode if V_{CC} becomes low enough to put the CE3151 into dropout.

This technique works best when R_{CC} values are minimized to keep component size small and avoid dropout. Remember to choose a resistor with adequate power handling capability.

Selecting Input V_{CC} Bypass Capacitor

Many types of capacitors can be used for input bypassing, however, caution must be exercised when using multilayer ceramic capacitors. Because of the self-resonant and high Q characteristics of some types of ceramic capacitors, high voltage transients can be generated under some start-up conditions, such as connecting the charger input to a live power source. Adding a 1Ω resistor in series with an X5R ceramic capacitor will minimize start-up voltage transients.

In most applications, all that is needed is a bypass capacitor, typically a 4.7μF capacitor placed in close proximity to V_{CC} and GND pins, works well. The CE3151 is designed to work with both regulated and unregulated external dc supplies. If a non-regulated supply is chosen, the supply unit should have enough capacitance to hold up the supply voltage to the minimum required input voltage at maximum load. If not, more capacitance has to be added to the input of the charger.

USB Inrush Limiting

When a USB cable is plugged into a portable product, the inductance of the cable and the high-Q ceramic input capacitor form an L-C resonant circuit. If the cable does not have adequate mutual coupling or if there is not much impedance in the cable, it is possible for the voltage at the input of the product to reach as high as twice the USB voltage (~10V) before it settles out. In fact, due to the high voltage coefficient of many ceramic capacitors (a nonlinearity), the voltage may even exceed twice the USB voltage. To prevent excessive voltage from damaging the CE3151 during a hot insertion, it is best to have a low voltage coefficient capacitor at the V_{CC} pin to the CE3151 family. This is achievable by selecting an MLCC capacitor that has a higher voltage rating than that required for the application. For example, a 16V, X5R, 10μF capacitor in a 1206 case would be a better choice than a 6.3V, X5R, 10μF capacitor in a smaller 0805 case.

Alternatively, the following soft connect circuit in Figure 7 can be employed. In this circuit, capacitor C2 holds MN1 off when the cable is first connected. Eventually C2 begins to charge up to the USB input voltage applying increasing gate support to MN1. The long time constant of R1 and C2 prevent the current from building up in the cable too fast thus dampening out any resonant overshoot.

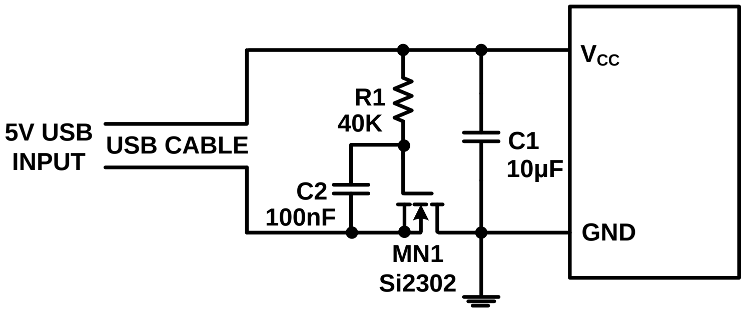


Figure 7. USB Soft Connect Circuit

Charge Current Soft-Start

The CE3151 includes a soft-start circuit to minimize the inrush current at the start of a charge cycle. When a charge cycle is initiated, the charge current ramps from zero to the full-scale current over a period of approximately 20mS. This has the effect of minimizing the transient current load on the power supply during start-up.

$\overline{CHRG}$ Status Output Pin

When a discharged battery is connected to the charger, the constant current portion of the charge cycle begins and the $\overline{CHRG}$ pin pulls to ground. The $\overline{CHRG}$ pin can sink up to 10mA to drive an LED that indicates that a charge cycle is in progress.

When the battery is nearing full charge, the charger enters the constant-voltage portion of the charge cycle and the charge current begins to drop. When the charge current drops below 1/10 of the programmed current, the charge cycle ends and the strong pull-down is replaced by the high impedance, indicating that the charge cycle has ended. If the input voltage is removed or drops below the undervoltage lockout threshold, the $\overline{CHRG}$ pin becomes high impedance. Figure 8 shows that by using a pull-up resistor, a microprocessor can detect all two states from this pin.

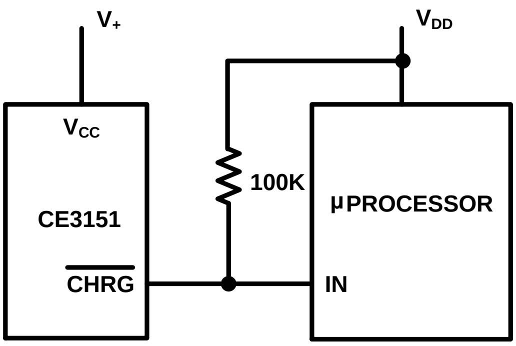


Figure 8. Using a Microprocessor to Determine $\overline{CHRG}$ State

Reverse Polarity Input Voltage Protection

In some applications, protection from reverse polarity voltage on V_{CC} is desired. If the supply voltage is high enough, a series blocking diode can be used. In other cases, where the voltage drop must be kept low a P-channel MOSFET can be used (as shown in Figure 9).

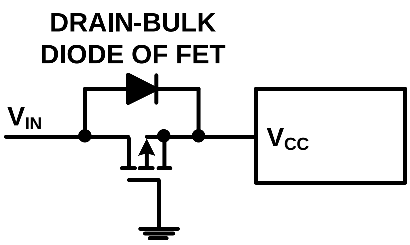


Figure 9. Low Loss Input Reverse Polarity Protection

Dynamically Selectable Charge Current

The PROG resistance can be altered dynamically under processor control by switching a second PROG pin resistor. When the higher current is required, the switch is turned on, making the effective programming resistance equal to the parallel combination of the two resistors. The external circuit is illustrated in Figure 10.

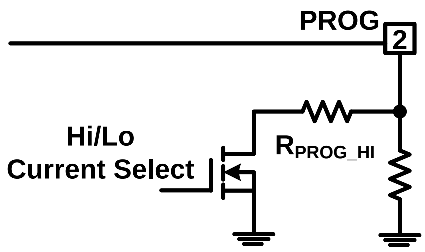


Figure 10. Dynamic selection of low and high charge currents

Note that the PROG pin resistor programs the fast-charge, pre-charge, and termination currents, so all will be modified by a change in the PROG pin resistor.

An open-drain GPIO can be used directly to engage the parallel resistor R_{PROG_HI}. Care must be taken to ensure that the R_{DS-ON} of the GPIO is considered in the selection of R_{PROG_HI}. Also important is the part-to-part and temperature variation of the GPIO R_{DS-ON}, and their contribution to the High Current charge current tolerance. A small amount of current could, potentially, flow from PROG into the GPIO ESD structure through R_{PROG_HI} during this event. While unlikely to do any harm, this effect must also be considered.

USB and Wall Adapter Power

The CE3151 family allows charging from both a wall adapter and a USB port. Figure 11 shows an example of how to combine wall adapter and USB power inputs. A P-channel MOSFET, MP1, is used to prevent back conducting into the USB port when a wall adapter is present and a Schottky diode, D1, is used to prevent USB power loss through the 1k pull-down resistor.

Typically a wall adapter can supply more current than the 500mA-limited USB port. Therefore, an N-channel MOSFET, MN1, and an extra 10k program resistor are used to increase the charge current to 600mA when the wall adapter is present.

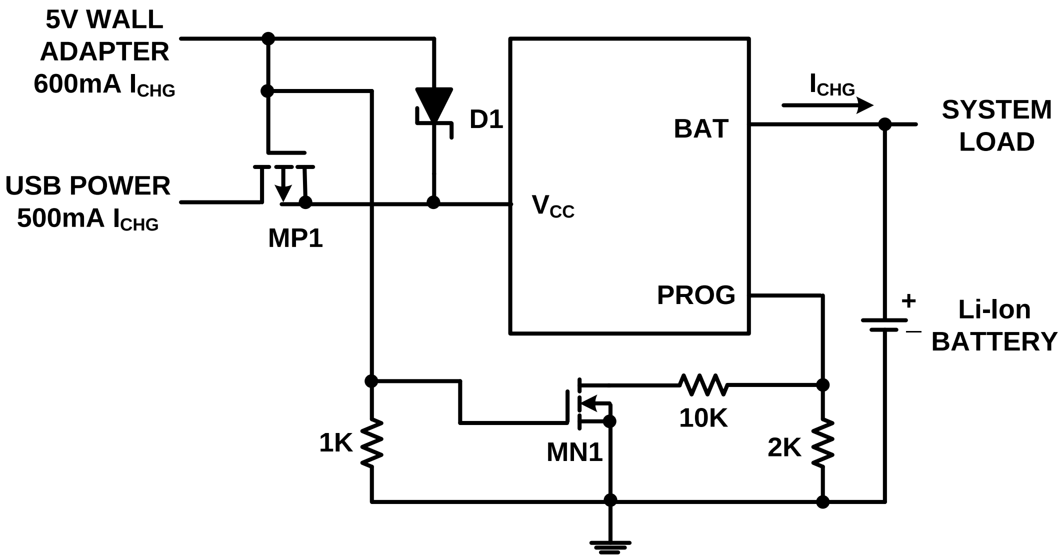


Figure 11. Combining Wall Adapter and USB Power

PCB Layout Considerations

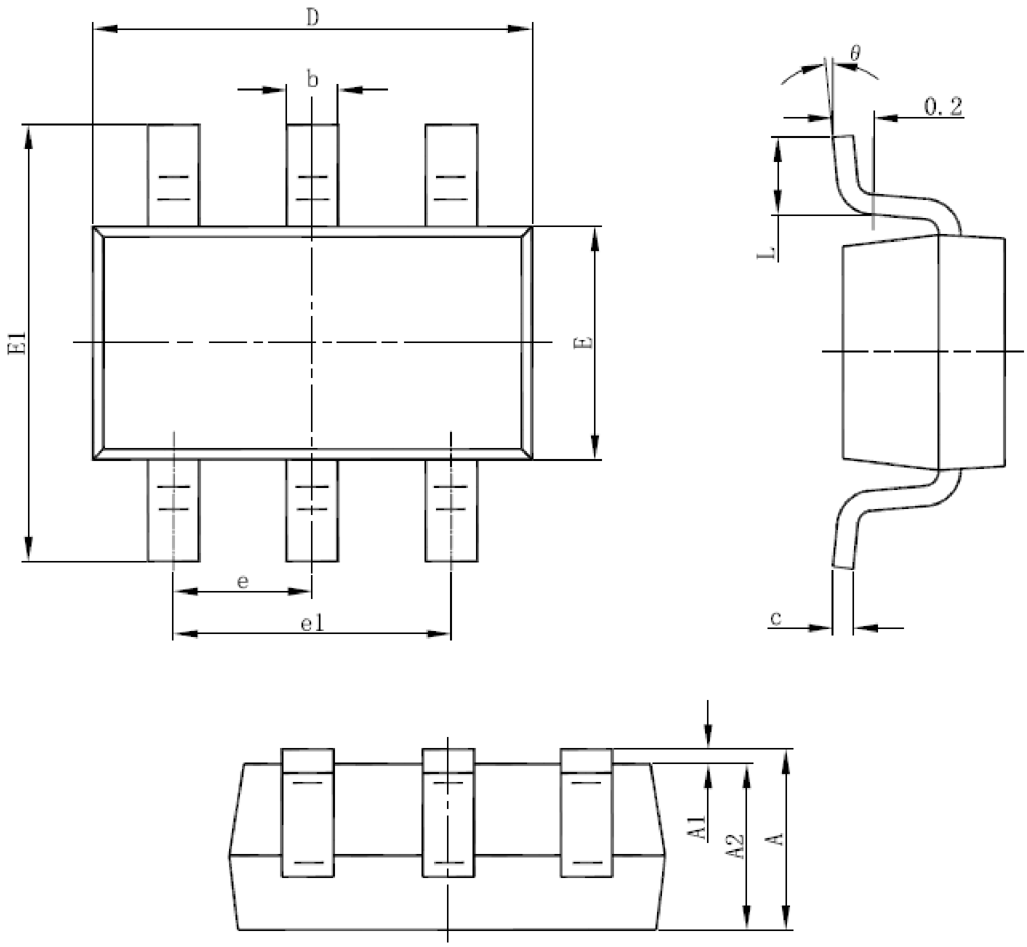
The CE3151 series are fully integrated single-chip low cost single-cell Li-Ion or Li-Pol battery chargers ideal for portable applications. Careful PCB layout is necessary. For optimal performance, place all peripheral components as close to the IC as possible. A short connection is highly recommended.

Several layout tips are listed below for the best electric and thermal performance.

* Input bypass capacitor from V_{CC} to GND should be placed as close as possible to CE3151, with short trace runs to both V_{CC} and GND pins, and connected to ground plane. The trace of input in the PCB should be placed far away the sensitive devices or shielded by the ground.
* The GND should be connected to a strong ground plane for heat sinking and noise protection.
* Output bypass capacitors from BAT to GND should be placed as close as possible to CE3151, with short trace runs to both BAT and GND pins, and connected to ground plane to reduce noise coupling.
* The BAT pin is the voltage feedback to the device and should be connected with its trace as close to the battery pack as possible.
* The high current charge paths into V_{CC} pin and from the BAT pin must be sized appropriately for the maximum charge current in order to avoid voltage drops in these traces.
* The connection of R_{PROG} should be isolated from other noisy traces. The short wire is recommended to prevent EMI and noise coupling.
* All low-current GND connections should be kept separate from the high-current charge or discharge paths from the battery. Use a single-point ground technique incorporating both the small signal ground path and the power ground path.

■ PACKAGING INFORMATION

- **SOT23-6 Package Outline Dimensions**



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.050	1.250	0.041	0.049
A1	0.000	0.100	0.000	0.004
A2	1.050	1.150	0.041	0.045
b	0.300	0.500	0.012	0.020
c	0.100	0.200	0.004	0.008
D	2.820	3.020	0.111	0.119
E	1.500	1.700	0.059	0.067
E1	2.650	2.950	0.104	0.116
e	0.950(BSC)		0.037(BSC)	
e1	1.800	2.000	0.071	0.079
L	0.300	0.600	0.012	0.024
θ	0°	8°	0°	8°