

## Standalone Linear Li-Ion Battery Charger with Thermal Regulation

### Features

- Programmable Charge Current Up to 800mA
- No MOSFET, Sense Resistor or Blocking Diode Required
- Complete Linear Charger for Single Cell Lithium-Ion Batteries
- Constant-Current/Constant-Voltage Operation with Thermal Regulation\* to Maximize Charge Rate
- Without Risk of Overheating
- Charges Single Cell Li-Ion Batteries Directly from USB Port
- Preset 4.2V Charge Voltage with 1% Accuracy
- Automatic Recharge
- 65uA Supply Current in Shutdown
- 2.9V Trickle Charge Threshold
- Available in 5-Lead SOT-23 Package

### Applications

- Charger for Li-Ion Coin Cell Batteries
- Portable MP3 Players, Wireless Headsets
- Bluetooth Applications
- Multifunction Wristwatches

### Order Information

HX6001 - ①, ②:

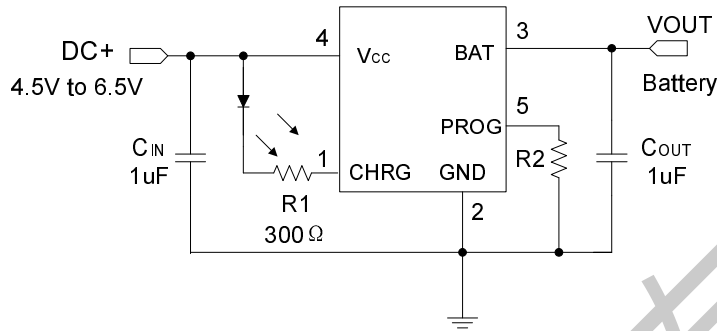
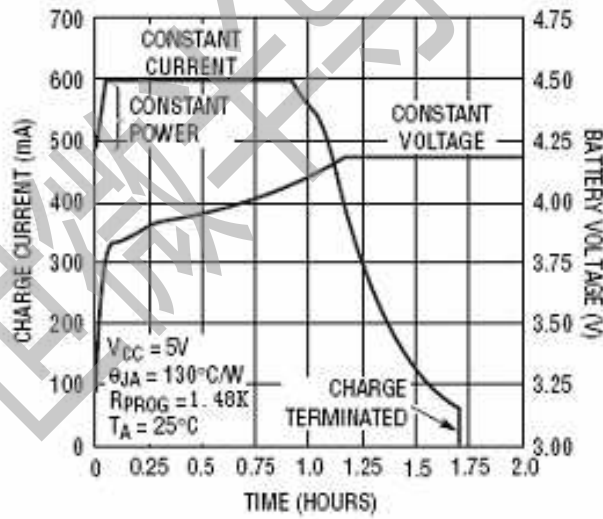
SYMBOL	DESCRIPTION
①	Denotes Output voltage: 4.2V
②	Denotes Package Types: E: SOT-23-5

### Description

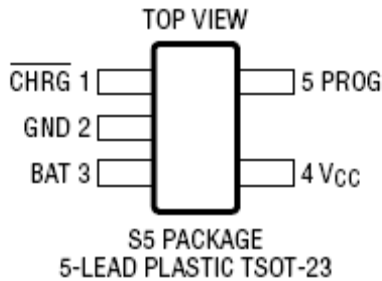
The HX6001 is a complete constant-current/constant voltage linear charger for single cell lithium-ion batteries. Its package and low external component count make the HX6001 ideally suited for portable applications. Furthermore, the HX6001 is specifically designed to work within USB power specifications.

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 4.2V, and the charge current can be programmed externally with a single resistor. The HX6001 automatically terminates the charge cycle when the charge current drops to 1/10<sup>th</sup> the programmed value after the final float voltage is reached.

The HX6001 converters are available in the industry standard SOT-23-5 power packages (or upon request).

**Typical Application**
**600mA Single Cell Li-Lon Charger**

**Complete Charge Cycle (750mAh Battery)**


## Pin Assignment



PIN NUMBER SOT-23- 5	PIN NAME	FUNCTION
1	CHRG	Open-Drain Charge Status Output
2	GND	Ground
3	BAT	Charge Current Output
4	V <sub>CC</sub>	Positive Input Supply Voltage.
5	PROG	Charge Current Program, Charge Current Monitor and Shutdown Pin

## Absolute Maximum Ratings

- Input Supply Voltage (VCC) ..... -0.3V to 7V
- PROG..... - 0.3V to VCC + 0.3V
- BAT ..... -0.3V to 7V
- CHRG..... -0.3V to 7V
- BAT Short-Circuit Duration ..... Continuous
- BAT Pin Current ..... 800mA
- Maximum Junction Temperature ..... 125°C
- Operating Ambient Temperature Range..... -40°C to 85°C
- Storage Temperature Range ..... -65 °C to 125°C
- Lead Temperature (Soldering, 10 sec)..... 300°C

## Electrical Characteristics

Operating Conditions:  $T_A=25^{\circ}\text{C}$ ,  $V_{CC}=5\text{V}$  unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
$V_{CC}$	Input Supply Voltage		4.5	5.0	6.5	V
$I_{CC}$	Input Supply Current	Charge Mode, $R_{PROG} = 10\text{k}$ Standby Mode (Charge Terminated) I Shutdown Mode ( $R_{PROG}$ Not Connected, $V_{CC} < V_{BAT}$ , or $V_{CC} < V_{UV}$ )		70 45 65		$\mu\text{A}$ $\mu\text{A}$ $\mu\text{A}$
$V_{FLOAT}$	Regulated Output (Float) Voltage	$0^{\circ}\text{C} \leq T_A \leq 85^{\circ}\text{C}$ , $I_{BAT} = 50\text{mA}$	4.15	4.2	4.24	V
$I_{BAT}$	BAT Pin Current	$R_{PROG} = 10\text{k}$ , Current Mode $R_{PROG} = 2\text{k}$ , Current Mode Standby Mode, $V_{BAT} = 4.2\text{V}$ Shutdown Mode ( $R_{PROG}$ Not Connected) Sleep Mode, $V_{CC} = 0\text{V}$	83 410	89 445 7.3 7.2 0.3	97 470	$\text{mA}$ $\text{mA}$ $\mu\text{A}$ $\mu\text{A}$ $\mu\text{A}$
$I_{TRIKL}$	Trickle Charge Current	$V_{BAT} < V_{TRIKL}$ , $R_{PROG} = 2\text{k}$	15	39	65	$\text{mA}$
$V_{ASD}$	$V_{CC} - V_{BAT}$ Lockout Threshold Voltage	$V_{CC}$ from Low to High $V_{CC}$ from High to Low		5 18		$\text{mV}$
$I_{TERM}$	C/10 Termination Current Threshold	$R_{PROG} = 2\text{k}$		45		$\text{mA}$
$V_{PROG}$	PROG Pin Voltage	$R_{PROG} = 10\text{k}$ , Current Mode	0.94	1.02	1.08	V
$R_{ON}$	Efficiency	Power FET "ON" Resistance (Between $V_{CC}$ and $BAT$ )		660		$\text{m}\Omega$

## Application Information

### PIN ASSIGNMENT

CHRG (Pin 1): Open-Drain Charge Status Output. When the battery is charging, the CHRG pin is pulled low by an internal N-channel MOSFET. When the charge cycle is completed or reverse battery lockout / No AC is detected, CHRG is forced high impedance.

GND (Pin 2): Ground.

BAT (Pin 3): Charge Current Output. It should be bypassed with at least a 1uF capacitor. It Provides charge current to the battery and regulates the final float voltage to 4.2V. An internal precision resistor divider from this pin sets the float voltage which is disconnected in shutdown mode.

VCC (Pin 4): Positive Input Supply Voltage. It Provides power to the charger VCC can range from 4.30V to 6.5V and should be bypassed with at least a 1uF capacitor. When VCC drops to within 20mV of the BAT pin voltage, the HX6001 enters shutdown mode, dropping IBAT to less than 1 uA.

PROG (Pin 5): Charge Current Program, Charge Current Monitor and Shutdown Pin. The charge current is programmed by connecting a 1% resistor, RPROG, to ground. When charging in constant-current mode, this pin servos to 1V. In all modes, the voltage on this pin can be used to measure the charge current using the following formula:  $IBAT = (V_{PROG}/R_{PROG}) * 890$ , The PROG pin can also be used to shut down the charger. Disconnecting the program resistor from ground allows a weak 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 65uA. Reconnecting RPROG to ground will return the charger to .normal operation.

## Operation

The HX6001 is a single cell lithium-ion battery charger using a constant-current/constant-voltage algorithm. It can deliver up to 800mA of charge current (using a good thermal PCB layout) with a final float voltage accuracy of  $\pm 1\%$ . The HX6001 includes an internal P-channel power MOSFET and thermal regulation circuitry. No blocking diode or external current sense resistor is required; thus, the basic charger circuit requires only two external components. Furthermore, the HX6001 is capable of operating from a USB power source.

### Normal Charge Cycle

A charge cycle begins when the voltage at the VCC 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 output. If the BAT pin is less than 2.9V, the charger enters trickle charge mode.

In this mode, the HX6001 supplies approximately 1/10 the programmed charge current to bring the battery voltage up to a safe level for full current charging. When the BAT pin voltage rises above 2.9V, the charger enters constant-current mode, where the programmed charge current is supplied to the battery. When the BAT pin approaches the final float voltage (4.2V), the HX6001 enters constant-voltage mode and the charge current begins to decrease. When the charge current drops to 1/10 of the programmed value, the charge cycle ends.

### Programming Charge Current

The charge current 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 are calculated using the following equations:

$$R_{\text{PROG}} = \frac{1000V}{I_{\text{CHG}}}, \quad I_{\text{CHG}} = \frac{1000V}{R_{\text{PROG}}}$$

The charge current out of the BAT pin can be determined at any time by monitoring the PROG pin voltage using the following equation:

$$I_{\text{BAT}} = \frac{V_{\text{PROG}}}{R_{\text{PROG}}} \cdot 1000$$

### Charge Termination

A charge cycle is terminated when the charge current falls to 1/10th the programmed 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 for longer than  $t_{\text{TERM}}$  (typically 1ms), charging is terminated. The charge current is latched off and the HX6001 enters standby mode, where the input supply current drops to 200mA. (Note: C/10 termination is disabled in trickle charging and thermal limiting 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 the programmed value. The 1ms filter time ( $t_{TERM}$ ) on the termination comparator ensures that transient loads of this nature do not result in premature charge cycle termination.

Once the average charge current drops below 1/10th the programmed value, the HX6001 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 HX6001 constantly monitors the BAT pin voltage in standby mode. If this voltage drops below the 4.05V 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 1 shows the state diagram of a typical charge cycle.

### **Charge Status Indicator (CHRG)**

The charge status output has three different states: strong pull-down (~10mA), weak pull-down (~20mA) and high impedance. The strong pull-down state indicates that the

HX6001 is in a charge cycle. Once the charge cycle has terminated, the pin state is determined by undervoltage lockout conditions. A weak pull-down indicates that VCC meets the UVLO conditions and the HX6001 is ready to charge. High impedance indicates that the HX6001 is in undervoltage lockout mode: either VCC is less than 100mV above the BAT pin voltage or insufficient voltage is applied to the VCC pin. A microprocessor can be used to distinguish between these three states—this method is discussed in the Applications Information section.

### **Thermal Limiting**

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 HX6001 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 HX6001. The charge current can be set according to typical (not worst-case) ambient temperature with the assurance that the charger will automatically reduce the current in worst-case conditions. ThinSOT power considerations are discussed further in the Applications Information section.

### **Undervoltage Lockout (UVLO)**

An internal undervoltage lockout circuit monitors the input voltage and keeps the charger in shutdown mode until VCC rises above the undervoltage lockout threshold. The UVLO circuit has a built-in hysteresis of 200mV. Furthermore, to protect against reverse current in the power MOSFET, the

UVLO circuit keeps the charger in shutdown mode if VCC falls to within 30mV of the battery voltage. If the UVLO comparator is tripped, the charger will not come out of shutdown mode until VCC rises 100mV above the battery voltage.

## Manual Shutdown

At any point in the charge cycle, the HX6001 can be put into shutdown mode by removing RPROG thus floating the PROG pin. This reduces the battery drain current to less than 2mA and the supply current to less than 50mA. A new charge cycle can be initiated by reconnecting the program resistor.

In manual shutdown, the CHRG pin is in a weak pull-down state as long as VCC is high enough to exceed the UVLO conditions. The CHRG pin is in a high impedance state if the HX6001 is in undervoltage lockout mode: either VCC is within 100mV of the BAT pin voltage or insufficient voltage is applied to the VCC pin.

## Automatic Recharge

Once the charge cycle is terminated, the HX6001 continuously monitors the voltage on the BAT pin using a comparator with a 2ms filter time ( $t_{RECHARGE}$ ). A charge cycle restarts when the battery voltage falls below 4.05V (which corresponds to approximately 80% to 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. CHRG output enters a strong pull down state during recharge cycles.

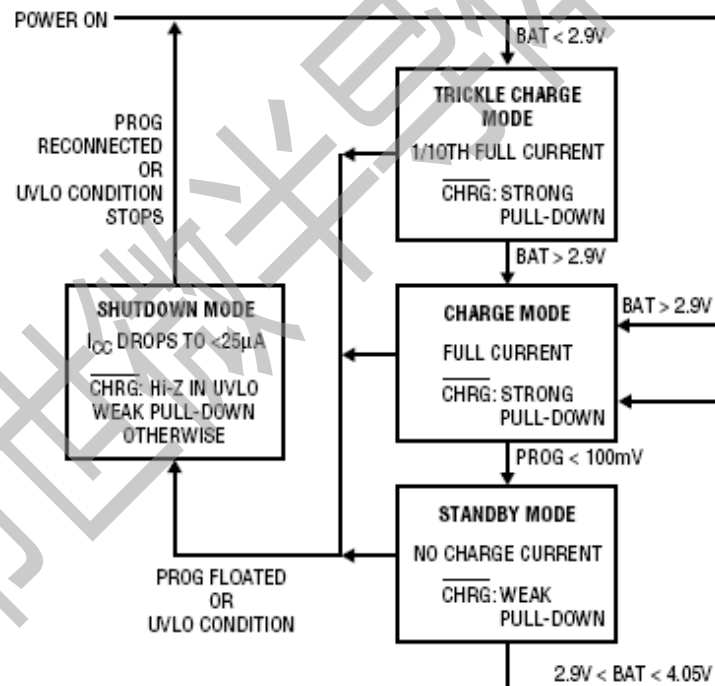


Figure 1. State Diagram of a Typical Charge Cycle



**V<sub>CC</sub> Bypass Capacitor**

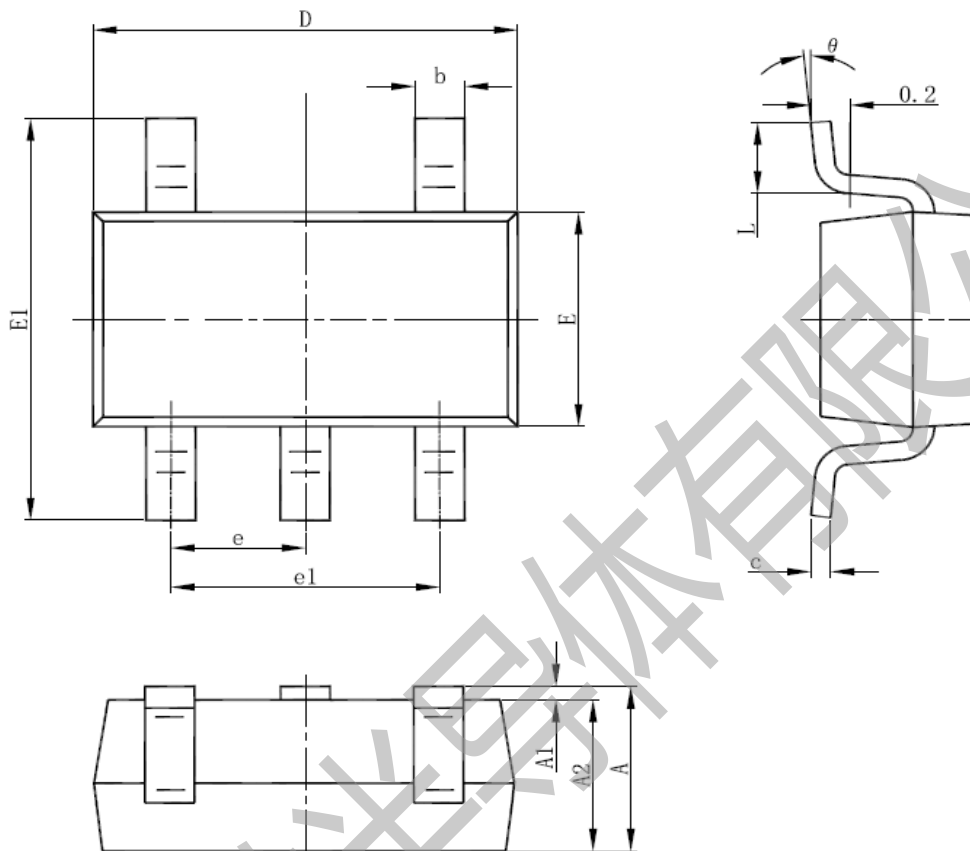
Many types of capacitors can be used for input bypassing, however, caution must be exercised when using multilayer ceramic capacitors. Because of the self-resonant and high Q characteristics of some types of ceramic capacitors, high voltage transients can be generated under some start-up conditions, such as connecting the charger input to a live power source. Adding a 1.5W resistor in series with an X5R ceramic capacitor will minimize start-up voltage transients.

**Charge Current Soft-Start**

The HX6001 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 100ms. This has the effect of minimizing the transient current load on the power supply during start-up.

## Packaging Information

### SOT-23-5 Package Outline Dimension



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