

# Lithium-Ion Linear Battery Charger Controller

April 2000

## FEATURES

- Complete Linear Charger Controller for 1-Cell Lithium-Ion Batteries
- 1% Voltage Accuracy
- Programmable Charge Current
- C/10 Charge Current Detection Output
- Programmable Charge Termination Timer
- Space Saving, Thin 8-Pin MSOP Package
- Automatic Sleep Mode When Input Supply is Removed (7 $\mu$ A Battery Drain)
- Automatic Trickle Charging of Low Voltage Cells
- Programmable for Constant-Current-Only Mode

## APPLICATIONS

- Cellular Phones
- Handheld Computers
- Charging Docks and Cradles
- Programmable Current Source

## DESCRIPTION

The LTC<sup>®</sup>1731-4.1 is a complete constant-current/constant-voltage linear charge controller for lithium-ion batteries. Nickel-cadmium (NiCd) and nickel-metal-hydride (NiMH) batteries can also be charged with constant current using external termination. The external sense resistor sets the charge current with 5% accuracy. An internal resistor divider and precision reference set the final float potential with 1% accuracy. The output float voltage is set internally to 4.1V.

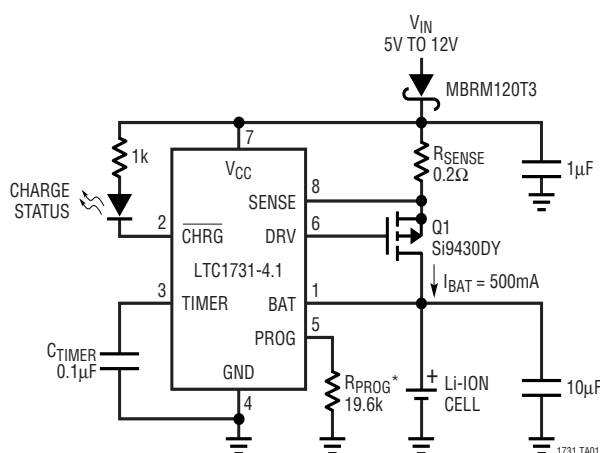
When the input supply is removed, the LTC1731 automatically enters a low current sleep mode, dropping the battery drain current to 7 $\mu$ A typically. An internal comparator detects the end-of-charge (C/10) condition while a programmable timer, using an external capacitor, sets the total charge time. Fully discharged cells are automatically trickle charged at 10% of the programmed current until cell voltage exceeds 2.457V.

The LTC1731-4.1 is available in the 8-pin MSOP and SO packages.

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## TYPICAL APPLICATION

500mA Li-Ion Charger



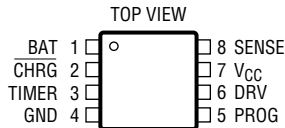
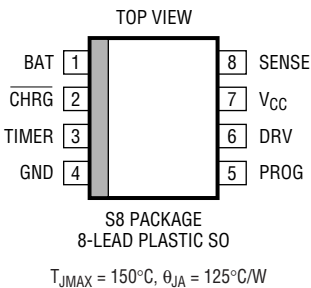
\*SHUTDOWN INVOKED BY FLOATING THE PROG PIN

# LTC1731-4.1

## ABSOLUTE MAXIMUM RATINGS (Note 1)

Input Supply Voltage ( $V_{CC}$ )	13.2V	Operating Temperature Range (Note 2)	–40° to 85°C
Input Voltage (SENSE, DRV, BAT, TIMER, PROG)	–0.3V to ( $V_{CC} + 0.3V$ )	Storage Temperature Range	–65°C to 150°C
Output Voltage (CHRG)	–0.3V to 13.2V	Lead Temperature (Soldering, 10 sec)	300°C

## PACKAGE/ORDER INFORMATION

	ORDER PART NUMBER		ORDER PART NUMBER
	LTC1731EMS8-4.1		LTC1731ES8-4.1
	MS8 PART MARKING		S8 PART MARKING
	LTJK		173141

Consult factory for Industrial and Military grade parts.

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{CC} = 6V$  unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V <sub>CC</sub>	Input Supply Voltage		●	4.5		12	V
I <sub>CC</sub>	Input Supply Current	Charger On, Current Mode Shutdown Mode Sleep Mode (Battery Drain Current)	● ●		1 1 7	3 2 20	mA mA μA
V <sub>BAT</sub>	Regulated Output Voltage	(5V ≤ V <sub>CC</sub> ≤ 12V)	●	4.059	4.1	4.141	V
I <sub>BAT</sub>	Current Mode Charge Current	R <sub>PROG</sub> = 19.6k, R <sub>SENSE</sub> = 0.2Ω R <sub>PROG</sub> = 19.6k, R <sub>SENSE</sub> = 0.2Ω R <sub>PROG</sub> = 97.6k, R <sub>SENSE</sub> = 0.2Ω	●	465 415 70	500  100	535 585 130	mA mA mA
I <sub>TRIKL</sub>	Trickle Charge Current	V <sub>BAT</sub> = 2V, R <sub>PROG</sub> = 19.6k, I <sub>TRIKL</sub> = (V <sub>CC</sub> – V <sub>SENSE</sub> )/0.2Ω	●	30	50	100	mA
V <sub>TRIKL</sub>	Trickle Charge Threshold Voltage	From Low to High	●	2.35	2.457	2.55	V
V <sub>UV</sub>	V <sub>CC</sub> Undervoltage Lockout Voltage	From Low to High	●		4.1	4.5	V
ΔV <sub>UV</sub>	V <sub>CC</sub> Undervoltage Lockout Hysteresis				200		mV
V <sub>MSD</sub>	Manual Shutdown Threshold Voltage	PROG Pin Low to High PROG Pin High to Low			2.457 2.446		V V

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{CC} = 6\text{V}$  unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
$V_{ASD}$	Automatic Shutdown Threshold Voltage	$(V_{CC} - V_{BAT})$ High to Low $(V_{CC} - V_{BAT})$ Low to High	30 40	54 69	90 100	mV mV
$V_{DIS}$	Voltage Mode Disable Threshold Voltage	$V_{TIMER}$	● 5.6			V
$I_{PROG}$	PROG Pin Current	Internal Pull-Up Current, No $R_{PROG}$		2.5		$\mu\text{A}$
	PROG Pin Load Regulation	PROG Pin Source Current, $\Delta V_{PROG} \leq 5\text{mV}$	● 300			$\mu\text{A}$
$V_{PROG}$	PROG Pin Voltage	$R_{PROG} = 19.6\text{k}$		2.457		V
$I_{CHRG}$	$\overline{\text{CHRG}}$ Pin Weak Pull-Down Current	$V_{CHRG} = 1\text{V}$	50	100	150	$\mu\text{A}$
$V_{CHRG}$	$\overline{\text{CHRG}}$ Pin Output Low Voltage	$I_{CHRG} = 5\text{mA}$		0.6	1.2	V
$I_{C/10}$	End of Charge Indication Current Level	$R_{PROG} = 19.6\text{k}$ , $R_{SENSE} = 0.2\Omega$	● 25	50	100	mA
$t_{TIMER}$	TIMER Accuracy	$C_{TIMER} = 0.1\mu\text{F}$		10		%
$V_{CLAMP}$	DRV Pin Clamp Voltage	$V_{CLAMP} = V_{CC} - V_{DRV}$ , $I_{DRIVE} = 50\mu\text{A}$		6.5		V

**Note 1:** Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

**Note 2:** The LTC1731-4.1 is guaranteed to meet performance specifications from  $0^\circ\text{C}$  to  $70^\circ\text{C}$ . Specifications over the  $-40^\circ\text{C}$  to  $85^\circ\text{C}$  operating temperature range are assured by design, characterization and correlation with statistical process controls. Guaranteed I grade parts are available, consult factory.

## PIN FUNCTIONS

**BAT (Pin 1):** Battery Sense Input. A bypass capacitor of at least  $10\mu\text{F}$  is required to keep the loop stable when the battery is not connected. A precision internal resistor divider sets the final float potential on this pin. The resistor divider is disconnected in sleep mode.

**CHRG (Pin 2):** 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. When the charge current drops to 10% of the full-scale current for at least 0.32 seconds, the N-channel MOSFET turns off and a  $100\mu\text{A}$  current source is connected from the  $\overline{\text{CHRG}}$  pin to GND. When the timer runs out or the input supply is removed, the current source will be disconnected and the  $\overline{\text{CHRG}}$  pin is forced into a high impedance state.

**TIMER (Pin 3):** Timer Capacitor and Constant-Voltage Mode Disable Input Pin. The timer period is set by placing a capacitor,  $C_{TIMER}$ , to GND. The timer period is  $t_{TIMER} = (C_{TIMER} \cdot 3 \text{ hours}) / (0.1\mu\text{F})$ . When the TIMER pin is connected to  $V_{CC}$ , the constant-voltage mode is disabled and the charger will operate in constant-current mode only. Short the TIMER pin to GND to disable the internal timer function.

**GND (Pin 4):** Ground.

**PROG (Pin 5):** Charge Current Program and Shutdown Input Pin. The charge current is programmed by connecting a resistor,  $R_{PROG}$  to ground. The charge current is  $I_{BAT} = (V_{PROG} \cdot 800\Omega) / (R_{PROG} \cdot R_{SENSE})$ . The IC can be forced into shutdown by floating the PROG pin and allowing the internal  $2.5\mu\text{A}$  current source to pull the pin above the 2.457V shutdown threshold voltage.

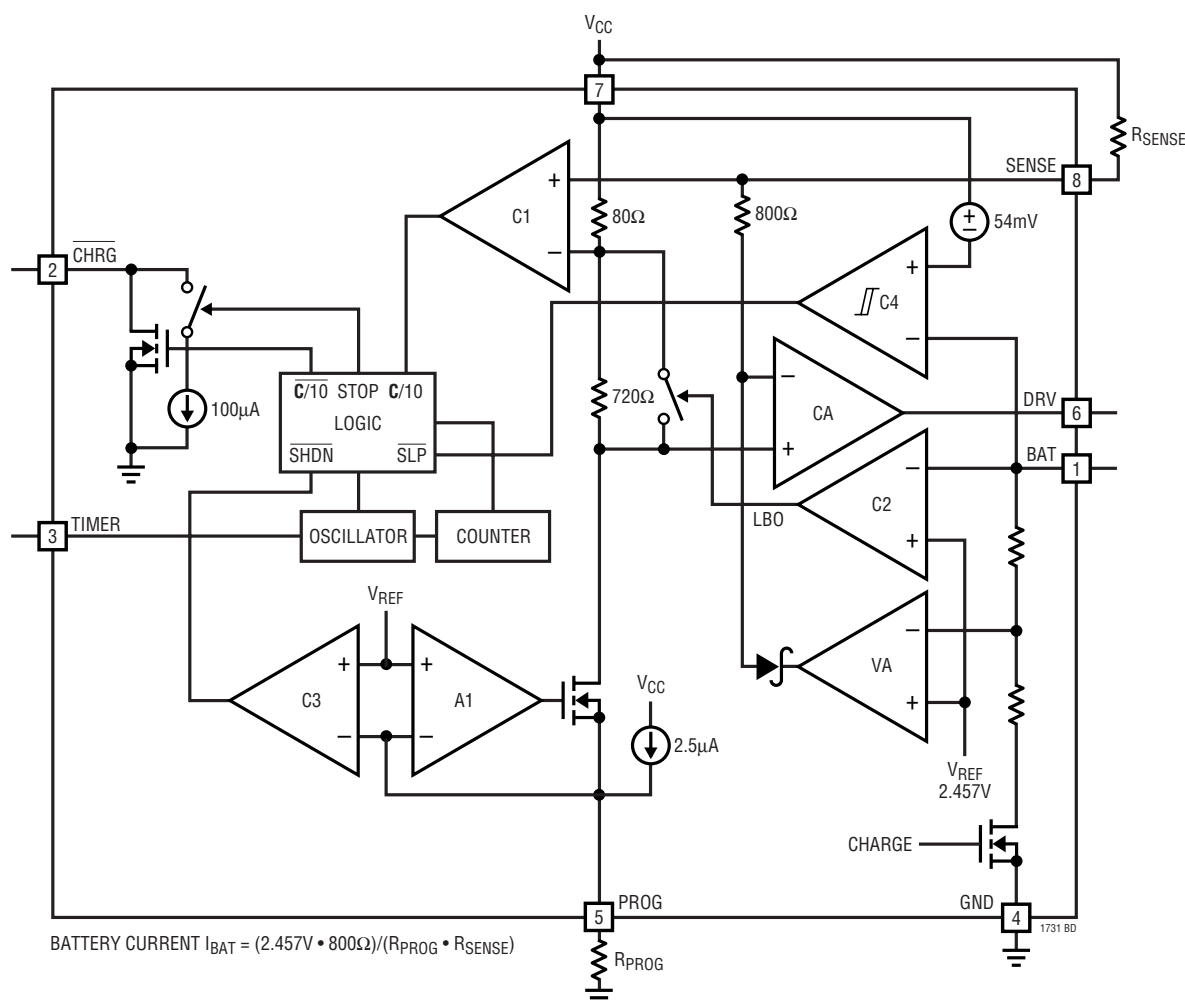
**DRV (Pin 6):** Drive Output Pin for the P-Channel MOSFET or PNP Transistor. The impedance is high at this pin, therefore, a high gain PNP pass transistor should be used. The DRV pin is internally clamped to 6.5V below  $V_{CC}$ .

**$V_{CC}$  (Pin 7):** Positive Input Supply Voltage. When  $V_{BAT}$  is within 54mV of  $V_{CC}$ , the LTC1731 is forced into sleep mode, dropping  $I_{CC}$  to  $7\mu\text{A}$ .  $V_{CC}$  ranges from 4.5V to 12V (LTC1731-4.1). Bypass this pin with a  $1\mu\text{F}$  capacitor.

**SENSE (Pin 8):** Current Sense Input. A sense resistor,  $R_{SENSE}$ , must be connected from  $V_{CC}$  to the SENSE pin. This resistor is chosen using the following equation:

$$R_{SENSE} = (V_{PROG} \cdot 800\Omega) / (R_{PROG} \cdot I_{BAT})$$

## BLOCK DIAGRAM



## OPERATION

The LTC1731 is a linear battery charger controller. The charge current is programmed by the combination of a program resistor ( $R_{\text{PROG}}$ ) from the PROG pin to ground and a sense resistor ( $R_{\text{SENSE}}$ ) between the  $V_{\text{CC}}$  and SENSE pins.  $R_{\text{PROG}}$  sets a program current through an internal trimmed  $800\Omega$  resistor setting up a voltage drop from  $V_{\text{CC}}$  to the input of the current amplifier (CA). The current amplifier servos the gate of the external P-channel MOSFET to force the same voltage drop across  $R_{\text{SENSE}}$  which sets the charge current. When the potential at the BAT pin approaches the preset float voltage, the voltage amplifier (VA) will start sinking current which reduces the voltage drop across  $R_{\text{SENSE}}$ , thus reducing the charge current.

Charging begins when the potential at V<sub>CC</sub> pin rises above the UVLO level and a program resistor is connected from the PROG pin to ground. At the beginning of the charge cycle, if the cell voltage is below 2.457V, the charger goes into trickle charge mode. The trickle charge current is 10% of the full-scale current. If the cell voltage stays low for one quarter of the total charge time, the charge sequence will be terminated immediately.

The charger goes into the fast charge constant-current mode after the voltage on the BAT pin rises above 2.457V. In constant-current mode, the charge current is set by the combination of  $R_{SENSE}$  and  $R_{PROG}$ .

## OPERATION

When the battery approaches the final float voltage, the charge current will begin to decrease. When the current drops to 10% of the full-scale charge current, an internal comparator will turn off the pull-down N-channel MOSFET at the  $\overline{\text{CHRG}}$  pin and connect a weak current source to ground to indicate an end-of-charge (C/10) condition.

An external capacitor on the  $\text{TIMER}$  pin sets the total charge time. After a time-out occurs, the charging will be terminated immediately and the  $\overline{\text{CHRG}}$  pin is forced to a high impedance state. To restart the charge cycle, simply remove the input voltage and reapply it, or float the  $\text{PROG}$  pin momentarily.

For batteries like lithium-ion that require accurate final float potential, the internal 2.457V reference, voltage amplifier and the resistor divider provide regulation with  $\pm 1\%$  (max) accuracy. For NiMH and NiCd batteries, the LTC1731 can be turned into a current source by pulling the  $\text{TIMER}$  pin to  $V_{\text{CC}}$ . When in the constant-current only mode, the voltage amplifier, timer and the trickle charge function are all disabled.

When the input voltage is not present, the charger goes into a sleep mode, dropping  $I_{\text{CC}}$  to  $7\mu\text{A}$ . This greatly reduces the current drain on the battery and increases the standby time. The charger can be shut down by floating the  $\text{PROG}$  pin. An internal current source will pull it high and clamp at 3.5V.

## APPLICATIONS INFORMATION

### Charge Termination

The charger is off when any of the following conditions exist: the voltage at the  $V_{\text{CC}}$  pin is below 4.1V, the voltage at the  $V_{\text{CC}}$  pin is higher than 4.1V but is less than 54mV above  $V_{\text{BAT}}$ , or the  $\text{PROG}$  pin is floating. The  $\text{DRV}$  pin will be pulled to  $V_{\text{CC}}$  and the internal resistor divider is disconnected to reduce the current drain on the battery.

### Undervoltage Lockout (UVLO)

An internal undervoltage lockout circuit monitors the input voltage and keeps the charger in shutdown mode until  $V_{\text{CC}}$  rises above 4.1V. To prevent oscillation around  $V_{\text{CC}} = 4.1\text{V}$ , the UVLO circuit has built-in hysteresis.

### Trickle Charge and Defective Battery Detection

At the beginning of the charging sequence, if the battery voltage is low (below 2.457V) the charger goes into trickle mode. The charge current is dropped to 10% of the full-scale current. If the low cell voltage persists for one quarter of the total charging time, the battery is considered defective, the charging will be terminated and the  $\overline{\text{CHRG}}$  pin output is forced to a high impedance state.

### Shutdown

The LTC1731 can be forced into shutdown by floating the  $\text{PROG}$  pin thus allowing the internal  $2.5\mu\text{A}$  current source to pull the pin above the 2.457V shutdown threshold voltage. The  $\text{DRV}$  pin will then be pulled up to  $V_{\text{CC}}$  and turn off the external P-channel MOSFET. The internal timer is reset in the shutdown mode.

### Programming Charge Current

The formula for the battery charge current (see Block Diagram) is:

$$I_{\text{BAT}} = (I_{\text{PROG}})(800\Omega/R_{\text{SENSE}}) \\ = (2.457\text{V}/R_{\text{PROG}})(800\Omega/R_{\text{SENSE}})$$

where  $R_{\text{PROG}}$  is the total resistance from the  $\text{PROG}$  pin to ground.

For example, if 0.5A charge current is needed, select a value for  $R_{\text{SENSE}}$  that will drop 100mV at the maximum charge current.  $R_{\text{SENSE}} = 0.1\text{V}/0.5\text{A} = 0.2\Omega$ , then calculate:

$$R_{\text{PROG}} = (2.457\text{V}/500\text{mA})(800\Omega/0.2\Omega) = 19.656\text{k}$$

For best stability over temperature and time, 1% resistors are recommended. The closest 1% resistor value is 19.6k.

## APPLICATIONS INFORMATION

### Programming the Timer

The programmable timer is used to terminate the charge. The length of the timer is programmed by an external capacitor at the TIMER pin. The total charge time is:

$$\text{Time} = (3 \text{ Hours})(C_{\text{TIMER}}/0.1\mu\text{F})$$

The timer starts when the input voltage greater than 4.1V is applied and the program resistor is connected to ground. After a time-out occurs, the  $\overline{\text{CHRG}}$  output will turn into a high impedance state to indicate that the charging has stopped. Connecting the TIMER pin to  $V_{\text{CC}}$  disables the timer and also puts the charger into a constant-current mode. To only disable the timer function, short the TIMER pin to GND.

### $\overline{\text{CHRG}}$ Status Output Pin

When the charge cycle starts, the  $\overline{\text{CHRG}}$  pin is pulled down to ground by an internal N-channel MOSFET that can drive an LED. When the charge current drops to 10% of the full-scale current (**C/10**), the N-channel MOSFET is turned off and a weak 100 $\mu\text{A}$  current source to ground is connected to the  $\overline{\text{CHRG}}$  pin. After a time-out occurs, the pin will go into a high impedance state. By using two different value pull-up resistors, a microprocessor can detect three states from this pin (charging, **C/10** and stop charging). See Figure 1.

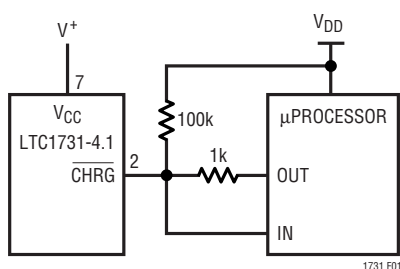


Figure 1. Microprocessor Interface

When the LTC1731 is in charge mode, the  $\overline{\text{CHRG}}$  pin is pulled down by an internal N-channel MOSFET. To detect this mode, force the digital output pin, OUT, high and measure the voltage at the  $\overline{\text{CHRG}}$  pin. The N-channel MOSFET will pull the pin low even with a 1k pull-up resistor. Once the charge current drops to 10% of the full scale current (**C/10**), the N-channel MOSFET is turned off

and a 100 $\mu\text{A}$  current source is connected to the  $\overline{\text{CHRG}}$  pin. By forcing the OUT pin into a high impedance state, the current source will pull the pin low through the 100k resistor. When the internal timer has expired, the  $\overline{\text{CHRG}}$  pin will change to high impedance state and the 100k resistor will then pull the pin high to indicate the charging has stopped.

### End of Charge (C/10)

The LTC1731 includes a comparator to monitor the charge current to detect an end-of-charge condition. When the battery current falls below 10% of full scale, the comparator trips and turns off the N-channel MOSFET at the  $\overline{\text{CHRG}}$  pin and switches in a 100 $\mu\text{A}$  current source to ground. After an internal time delay of at least 300ms, this state is then latched. This delay will help prevent false triggering due to transient currents. The end-of-charge comparator is disabled in trickle charge mode.

### Gate Drive

Typically the LTC1731 controls an external P-channel MOSFET to supply current to the battery. The DRV pin is internally clamped to 6.5V below  $V_{\text{CC}}$ . This feature allows low voltage P-channel MOSFETs with gate to source breakdown voltage rated at 8V to be used.

An external PNP transistor can also be used as the pass transistor instead of the P-channel MOSFET. Due to the low current gain of the current amplifier (CA), a high gain Darlington PNP transistor is required to avoid excessive charge current error. The gain of the current amplifier is around 0.6 $\mu\text{A}/\text{mV}$ . For every 1 $\mu\text{A}$  of base current, a 1.6mV of gain error shows up at the inputs of CA. With  $R_{\text{PROG}} = 19.6\text{k}$  (100mV across  $R_{\text{SENSE}}$ ), it represents 1.67% of error in charging current.

### Constant-Current Only Mode

The LTC1731 can be used as a programmable current source by forcing the TIMER pin to  $V_{\text{CC}}$ . This is particularly useful for charging NiMH or NiCd batteries. In the constant-current only mode, the timer and voltage amplifier are both disabled. An external termination method is required to properly terminate the charge.



## APPLICATIONS INFORMATION

### Stability

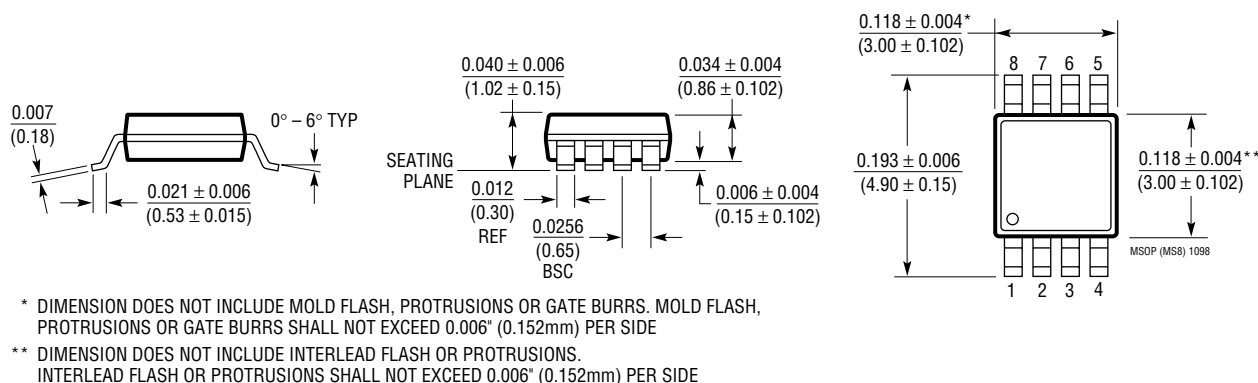
The charger is stable without any compensation when a P-channel MOSFET is used as the pass transistor. However, a 10 $\mu$ F capacitor is recommended at the BAT pin to keep the ripple voltage low when the battery is disconnected.

When a PNP transistor is chosen as the pass transistor, a 1000pF capacitor is required from the DRV pin to V<sub>CC</sub>. This capacitor is needed to help stabilize the voltage loop. A 10 $\mu$ F capacitor at the BAT pin is also recommended when a battery is not present.

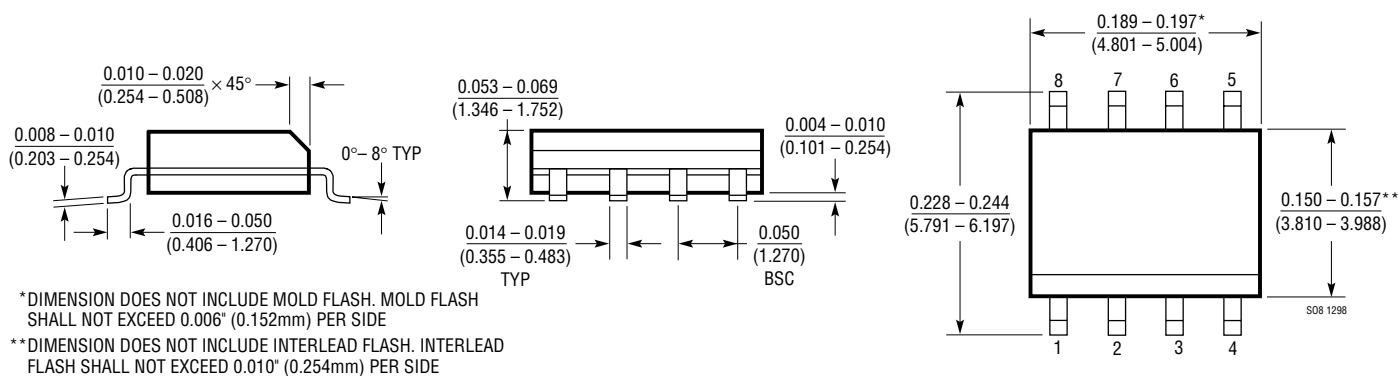
## PACKAGE DESCRIPTION

Dimensions in inches (millimeters) unless otherwise noted.

### MS8 Package 8-Lead Plastic MSOP (LTC DWG # 05-08-1660)

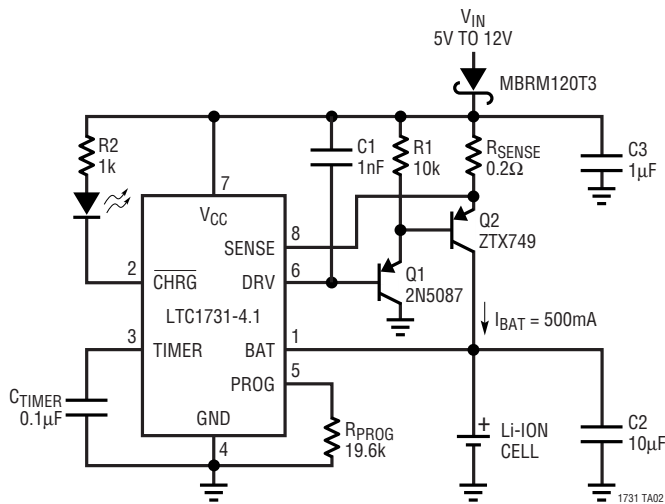


### S8 Package 8-Lead Plastic Small Outline (Narrow 0.150) (LTC DWG # 05-08-1610)

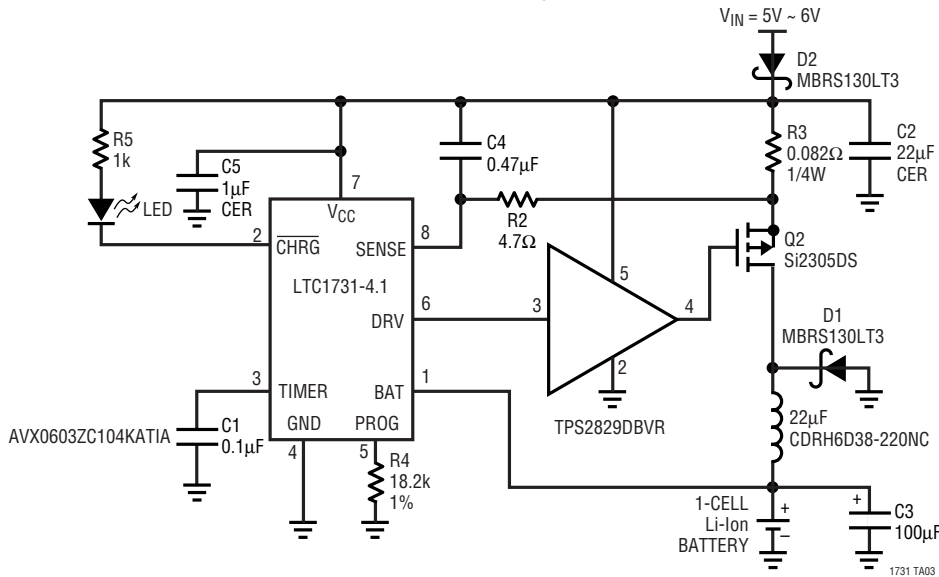


TYPICAL APPLICATIONS

Linear Charger Using a PNP Transistor



1.5A Single-Cell Battery Charger



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT®1510-5	500kHz Constant-Voltage/Constant-Current Battery Charger	Most Compact, Up to 1.5A, Charges NiCd, NiMH, Li-Ion Cells
LT1512	SEPIC Battery Charger	V <sub>IN</sub> Can Be Higher or Lower Than Battery Voltage, 1.5A Switch
LT1571	Battery Charger with Preset Voltage and Termination Flag	Up to 1.5A; Preset Voltages: 4.1V, 4.2V, 8.2V, 8.4V
LT1620	Rail-to-Rail Current Sense Amplifier	Precise Output Current Programming, Up to 32V V <sub>OUT</sub> , Up to 10A I <sub>OUT</sub>
LTC1729	Termination Controller for Li-Ion	Time or Charge Current Termination, Automatic Charger/Battery Detection, Status Output, Preconditioning, 8-Lead MSOP
LTC1731-4.2	Li-Ion Linear Battery Charge Controller	Fast Charge 4.2V Li-Ion Batteries with Constant-Voltage/Constant-Current Linear Charger