Single Cell Lithium-Ion Linear Battery Charger Controllers

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 8-Pin MSOP Package**
- Automatic Sleep Mode When Input Supply is Removed (7µA 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®1731 is a complete constant-current/constant-voltage linear charger controller for single cell 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 (LTC1731-4.1) or 4.2V (LTC1731-4.2).

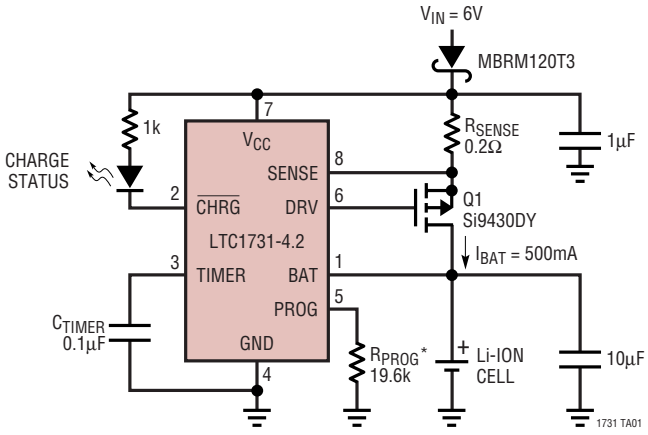
When the input supply is removed, the LTC1731 automatically enters a low current sleep mode, dropping the battery drain current to typically 7µA. An internal comparator detects the end-of-charge (**C**/10) condition while a programmable timer, using an external capacitor, sets the total charge time.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

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

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TYPICAL APPLICATION

500mA Li-Ion Battery Charger

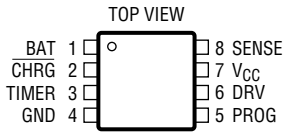


*SHUTDOWN INVOKED BY FLOATING THE PROG PIN

ABSOLUTE MAXIMUM RATINGS (Note 1)

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

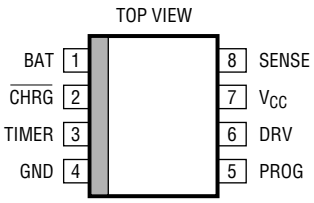
PACKAGE/ORDER INFORMATION



MS8 PACKAGE
8-LEAD PLASTIC MSOP

T_{JMAX} = 150°C, θ_{JA} = 200°C/W

ORDER PART NUMBER
LTC1731EMS8-4.1 LTC1731EMS8-4.2
MS8 PART MARKING
LTJK LTKQ



S8 PACKAGE
8-LEAD PLASTIC SO

T_{JMAX} = 150°C, θ_{JA} = 125°C/W

ORDER PART NUMBER
LTC1731ES8-4.1 LTC1731ES8-4.2
S8 PART MARKING
173141 173142

Consult factory for parts specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS

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

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{CC}	Input Supply Voltage		●	4.5		12	V
I_{CC}	Input Supply Current	Charger On, Current Mode	●		1	3	mA
		Shutdown Mode	●		1	2	mA
		Sleep Mode (Battery Drain Current)			7	20	µA
V_{BAT}	Regulated Output Voltage	LTC1731-4.1 (5V ≤ V_{CC} ≤ 12V)	●	4.059	4.1	4.141	V
		LTC1731-4.2 (5V ≤ V_{CC} ≤ 12V)	●	4.158	4.2	4.242	V
I_{BAT}	Current Mode Charge Current	R_{PROG} = 19.6k, R_{SENSE} = 0.2Ω		465	500	535	mA
		R_{PROG} = 19.6k, R_{SENSE} = 0.2Ω	●	415		585	mA
		R_{PROG} = 97.6k, R_{SENSE} = 0.2Ω		70	100	130	mA
I_{TRIKL}	Trickle Charge Current	V_{BAT} = 2V, R_{PROG} = 19.6k, I_{TRIKL} = (V_{CC} – V_{SENSE})/0.2Ω	●	30	50	100	mA
V_{TRIKL}	Trickle Charge Threshold Voltage	From Low to High	●	2.35	2.457	2.55	V
V_{UV}	V_{CC} Undervoltage Lockout Voltage	From Low to High	●		4.1	4.5	V
ΔV_{UV}	V_{CC} Undervoltage Lockout Hysteresis				200		mV
V_{MSD}	Manual Shutdown Threshold Voltage	PROG Pin Low to High			2.457		V
		PROG Pin High to Low			2.446		V

ELECTRICAL CHARACTERISTICS

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

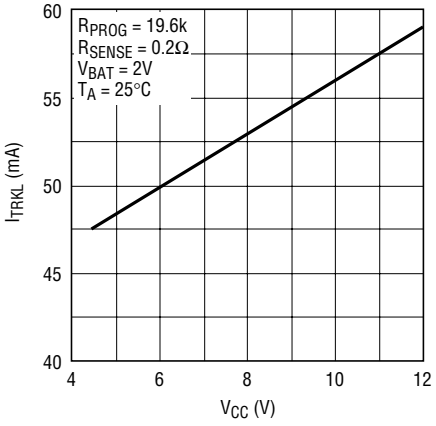
SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{ASD}	Automatic Shutdown Threshold Voltage	(V_{CC} – V_{BAT}) High to Low (V_{CC} – V_{BAT}) Low to High		30 40	54 69	90 100	mV mV
V_{DIS}	Voltage Mode Disable Threshold Voltage	V_{DIS} = V_{CC} – V_{TIMER}	●			0.4	V
I_{PROG}	PROG Pin Current	Internal Pull-Up Current, No R_{PROG}			2.5		µA
	PROG Pin Load Regulation	PROG Pin Source Current, $\Delta V_{PROG} \leq$ 5mV	●	300			µA
V_{PROG}	PROG Pin Voltage	R_{PROG} =19.6k			2.457		V
I_{CHRG}	$\overline{CHRG}$ Pin Weak Pull-Down Current	V_{CHRG} = 1V		50	100	150	µA
V_{CHRG}	$\overline{CHRG}$ Pin Output Low Voltage	I_{CHRG} = 5mA			0.6	1.2	V
$I_{C/10}$	End of Charge Indication Current Level	R_{PROG} = 19.6k, R_{SENSE} = 0.2Ω	●	25	50	100	mA
t_{TIMER}	TIMER Accuracy	C_{TIMER} = 0.1µF			10		%
V_{CLAMP}	DRV Pin Clamp Voltage	V_{CLAMP} = V_{CC} – V_{DRV}, I_{DRIVE} = 50µA			6.5		V

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

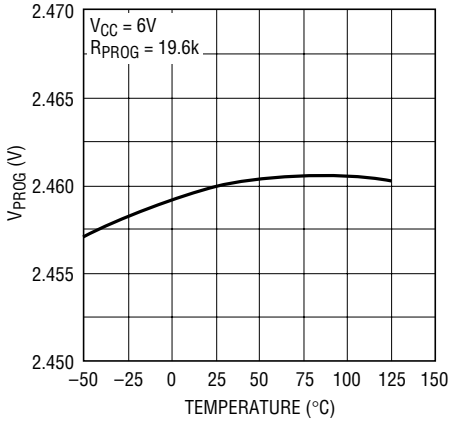
Note 2: The LTC1731E is guaranteed to meet performance specifications from 0°C to 70°C. Specifications over the –40°C to 85°C operating temperature range are assured by design, characterization and correlation with statistical process controls. Guaranteed I grade parts are available, consult factory.

TYPICAL PERFORMANCE CHARACTERISTICS

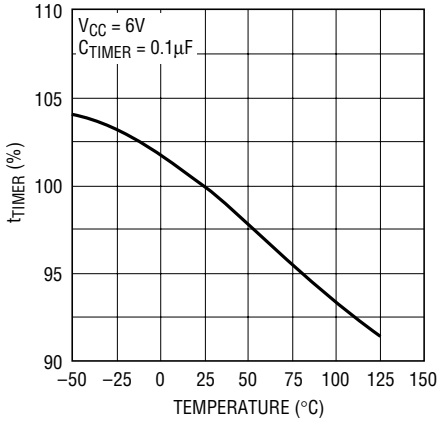
Trickle Charge Current vs Input Supply



Program Pin Voltage vs Temperature

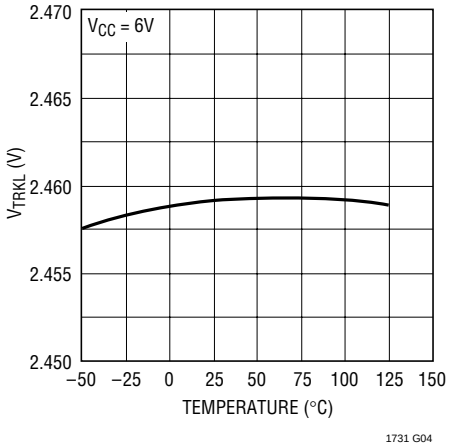


Timer Accuracy vs Temperature

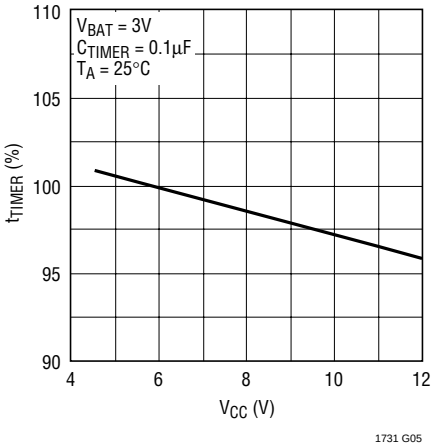


TYPICAL PERFORMANCE CHARACTERISTICS

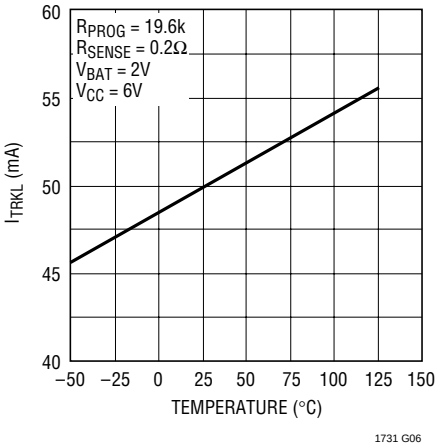
Trickle Charge Threshold Voltage vs Temperature



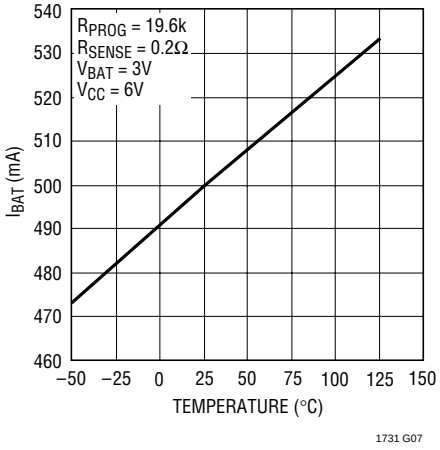
Timer Accuracy vs Input Supply



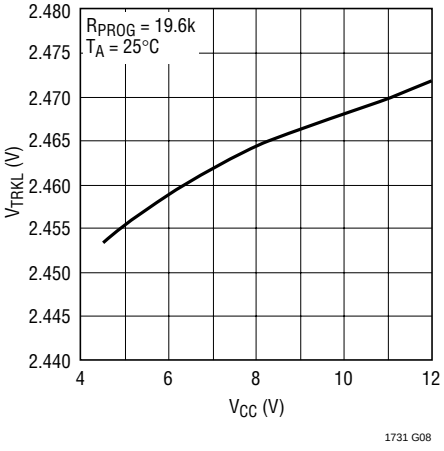
Trickle Charge Current vs Temperature



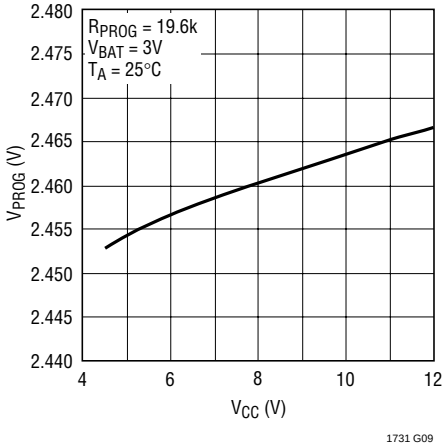
Battery Charge Current vs Temperature



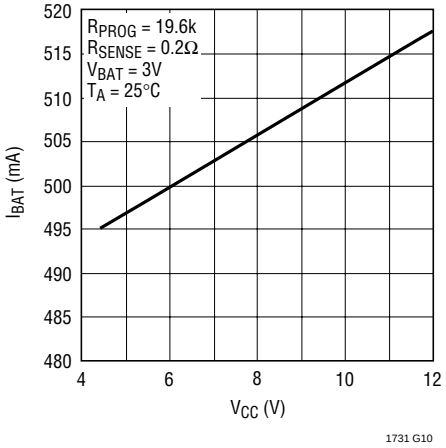
Trickle Charge Threshold Voltage vs Input Supply



Program Pin Voltage vs Input Supply



Battery Charge Current vs Input Supply



PIN FUNCTIONS

BAT (Pin 1): Battery Sense Input. A bypass capacitor of at least 10µF 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.

$\overline{\text{CHRG}}$ (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 100µA 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 $t_{TIMER} = (C_{TIMER} \bullet 3 \text{ hours})/(0.1\mu F)$. When the TIMER pin is connected to V_{CC}, the constant-voltage mode and the timer are disabled, the chip will operate in constant-current mode only. Short the TIMER pin to GND to disable the internal timer function and the **C**/10 function.

GND (Pin 4): Ground Connection.

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 $I_{BAT} = (V_{PROG} \bullet 800\Omega)/(R_{PROG} \bullet R_{SENSE})$. The IC can be forced into shutdown by floating the PROG pin. An internal 2.5µA current source will pull the pin above the shutdown threshold voltage when the program resistor (R_{PROG}) is disconnected.

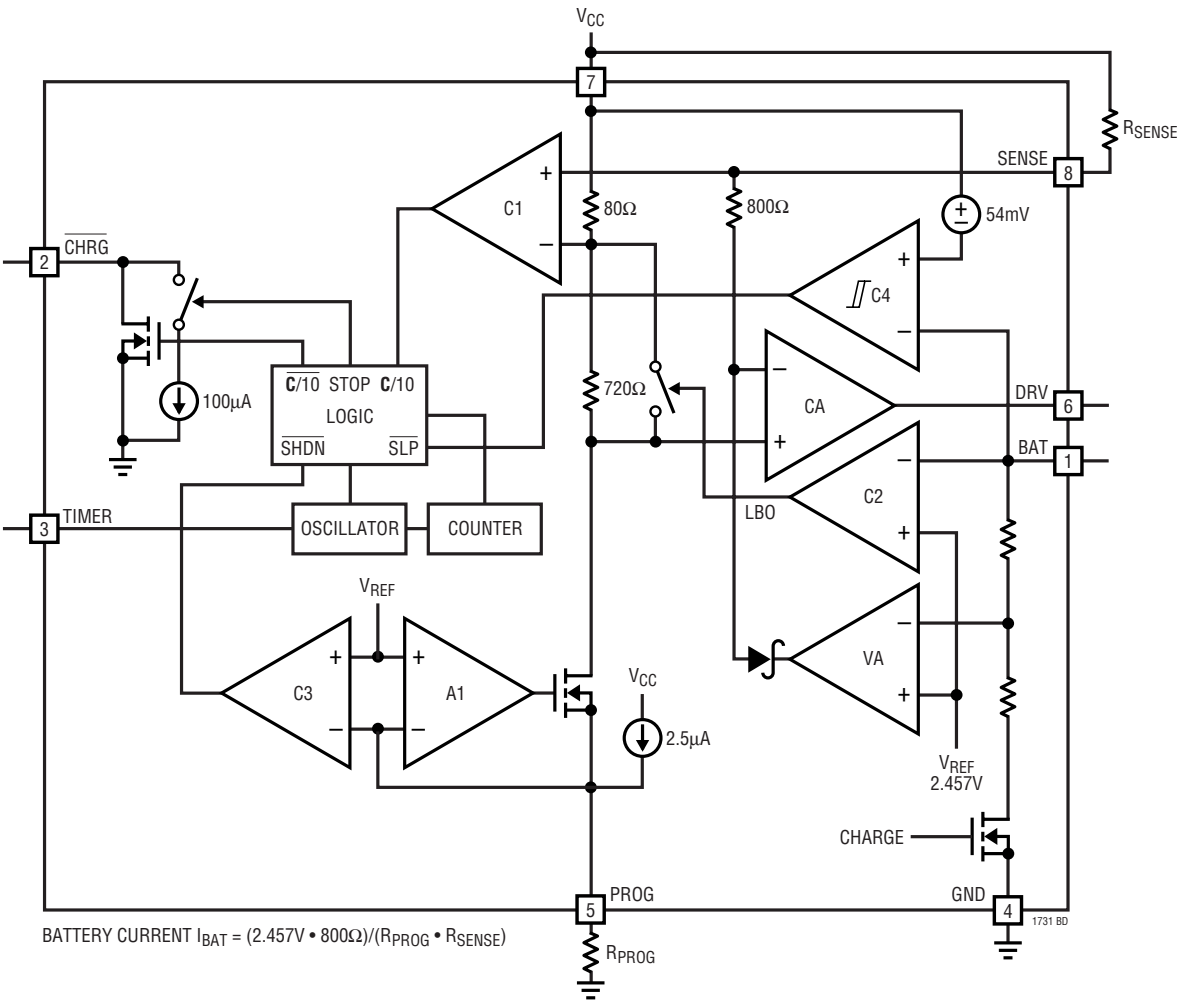
DRV (Pin 6): Drive Output Pin for the P-Channel MOSFET or PNP Transistor. The impedance is high at this pin, therefore, a high beta PNP pass transistor should be used. The DRV pin is internally clamped to 6.5V below V_{CC}.

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 7µA. V_{CC} ranges from 4.5V to 12V. Bypass this pin with a 1µF 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:

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

BLOCK DIAGRAM



OPERATION

The LTC1731 is a linear battery charger controller for single cell lithium-ion batteries. The charge current is programmed by the combination of a program resistor (R_{PROG}) from the PROG pin to ground and a sense resistor (R_{SENSE}) between the V_{CC} and SENSE pins. R_{PROG} sets a program current through an internal trimmed 800Ω resistor setting up a voltage drop from V_{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_{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 shrinks the voltage drop across R_{SENSE}, thus reducing the charge current.

Charging begins when the potential at V_{CC} 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 battery 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.

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}.

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 $\overline{CHRG}$ pin and connect a weak current source to ground to indicate an end-of-charge (**C**/10) condition.

An external capacitor on the TIMER pin sets the total charge time. After a time-out occurs, the charging will be terminated and the $\overline{CHRG}$ pin is forced to a high impedance state. To restart the charge cycle, simply remove the input voltage and reapply it, or float the 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 ±1% (max) accuracy. For NiMH and NiCd batteries, the LTC1731 can be turned into a current source by pulling the TIMER pin to V_{CC}. When in the constant-current only mode, the voltage amplifier, timer and the trickle charge function are all disabled.

The charger can be shut down by floating the PROG pin (I_{CC} = 1mA). An internal current source will pull it high and clamp at 3.5V. When the input voltage is not present, the charger goes into a sleep mode, dropping I_{CC} to 7μA. This greatly reduces the current drain on the battery and increases the standby time.

APPLICATIONS INFORMATION

Charge Termination

The charger is off when any of the following conditions exist: the voltage at the V_{CC} pin is below 4.1V, the voltage at the V_{CC} pin is higher than 4.1V but is less than 54mV above V_{BAT}, or the PROG pin is floating. The DRV pin will be pulled to V_{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_{CC} rises above 4.1V. To prevent oscillation around V_{CC} = 4.1V, 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 charge mode. The charge current is set 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, charging will be terminated and the $\overline{CHRG}$ pin output is forced to a high impedance state.

Shutdown

The LTC1731 can be forced into shutdown by floating the PROG pin and allowing the internal 2.5μA current source to pull the pin above the 2.457V shutdown threshold

APPLICATIONS INFORMATION

voltage. The DRV pin will then be pulled up to V_{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:

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

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

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

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

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

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:

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

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 $\overline{CHRG}$ output will turn into a high impedance state to indicate that the charging has stopped. Connecting the TIMER pin to V_{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.

$\overline{CHRG}$ Status Output Pin

When the charge cycle starts, the $\overline{CHRG}$ pin is pulled down to ground by an internal N-channel MOSFET that can drive an LED. When the battery current drops to 10% of the full-scale current (**C**/10), the N-channel MOSFET is turned off and a weak 100µA current source to ground is connected to the $\overline{CHRG}$ 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.

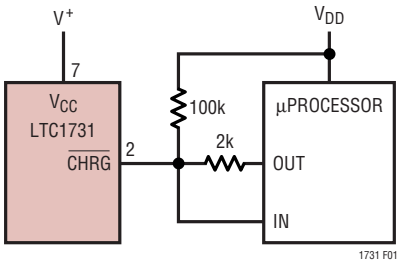


Figure 1. Microprocessor Interface

When the LTC1731 is in charge mode, the $\overline{CHRG}$ 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 $\overline{CHRG}$ pin. The N-channel MOSFET will pull the pin low even with a 2k 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 100µA current source is connected to the $\overline{CHRG}$ pin. The IN pin will then be pulled high by the 2k pull-up. 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 $\overline{CHRG}$ pin will change to high impedance state and the 100k resistor will then pull the pin high to indicate the charging has stopped. Refer to Table 1 for the summary.

Table 1. $\overline{CHRG}$ Pin Interface with Microprocessor

IN	OUT	STATUS
Low	High	Charging
Low	Hi-Z	Charging
High	High	**C**/10
Low	Hi-Z	**C**/10
High	Hi-Z	Stop Charging

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 $\overline{CHRG}$ pin and switches in a 100µA current source to ground.

APPLICATIONS INFORMATION

After an internal time delay of 320ms, 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_{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 0.6µA/mV. For every 1µA of base current, a 1.6mV of gain error shows up at the inputs of CA. With R_{PROG} = 19.6k (100mV across R_{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_{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.

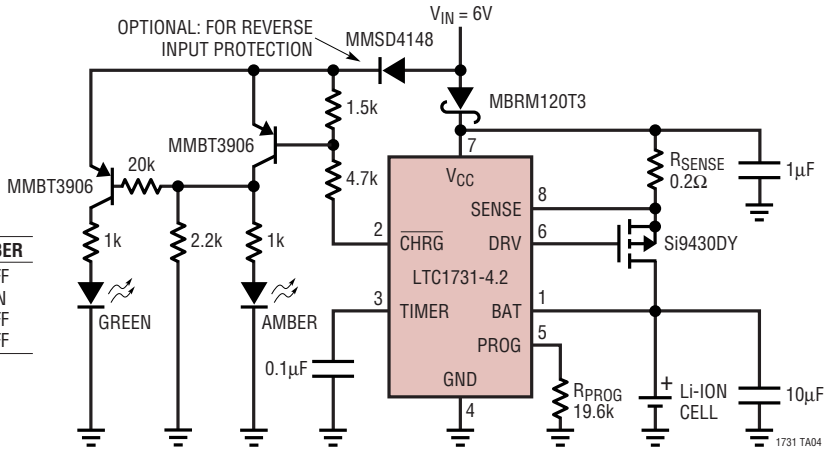
Stability

The charger is stable without any compensation when a P-channel MOSFET is used as the pass transistor. However, a 10µF 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_{CC}. This capacitor is needed to help stablize the voltage loop. A 10µF capacitor at the BAT pin is also recommended when a battery is not present.

TYPICAL APPLICATION

Using $\overline{CHRG}$ Pin to Indicate Charge Status

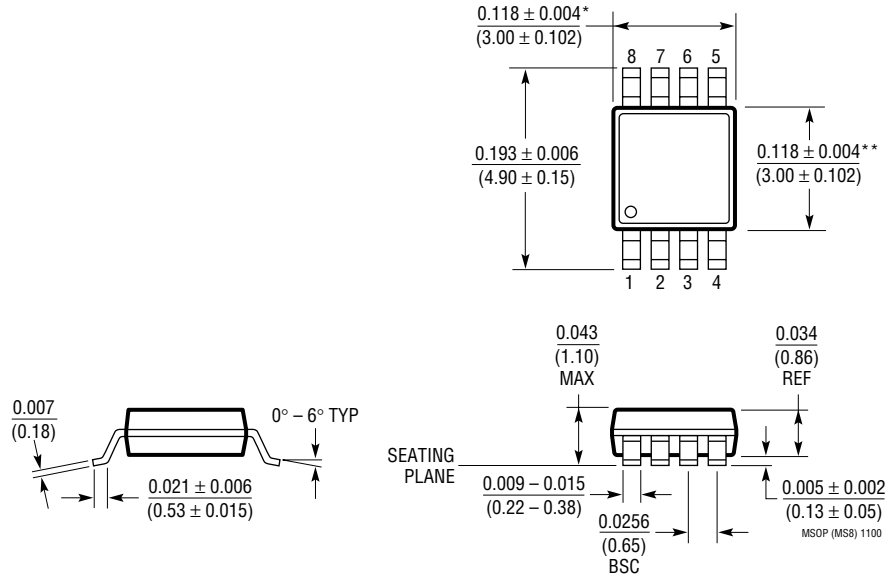


CONDITION	GREEN	AMBER
NO WALL ADAPTER	OFF	OFF
CHARGING (I > C/10)	OFF	ON
CHARGING (I < C/10)	ON	OFF
TIMER EXPIRED	ON	OFF

PACKAGE DESCRIPTION

Dimensions in inches (millimeters) unless otherwise noted.

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



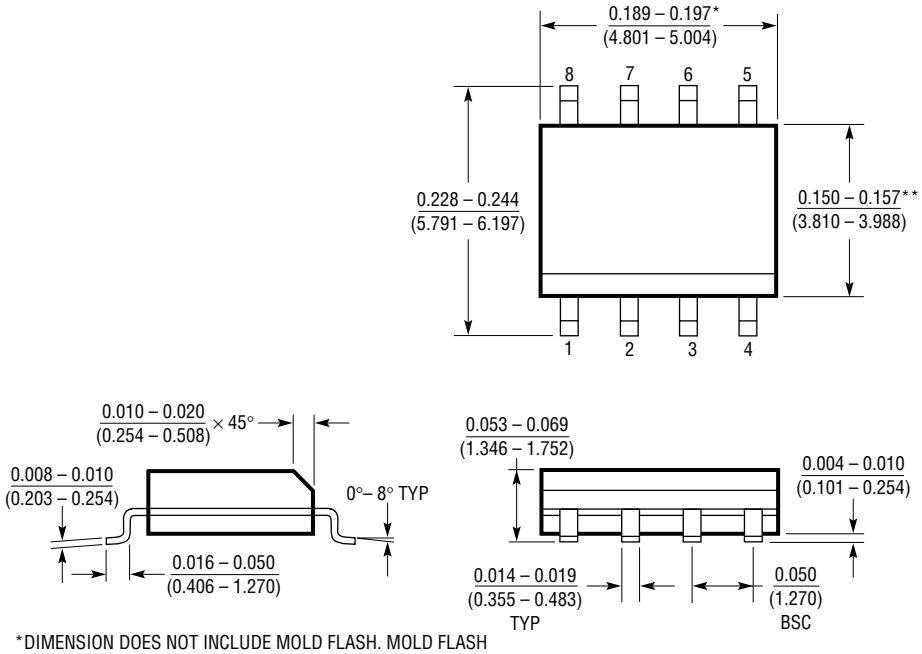
* DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

** DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS. INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

PACKAGE DESCRIPTION

Dimensions in inches (millimeters) unless otherwise noted.

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



*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

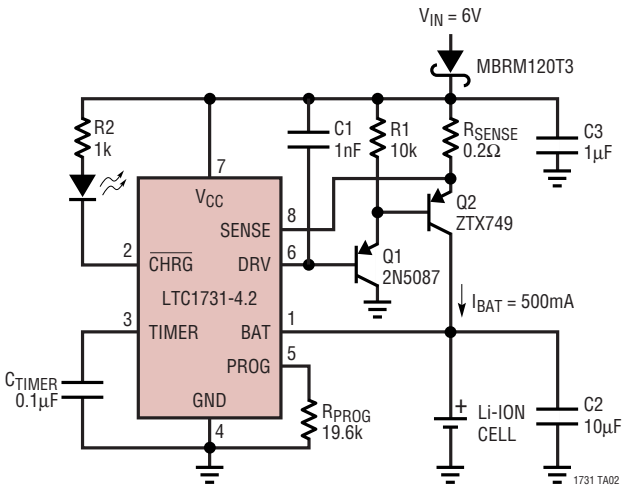
**DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

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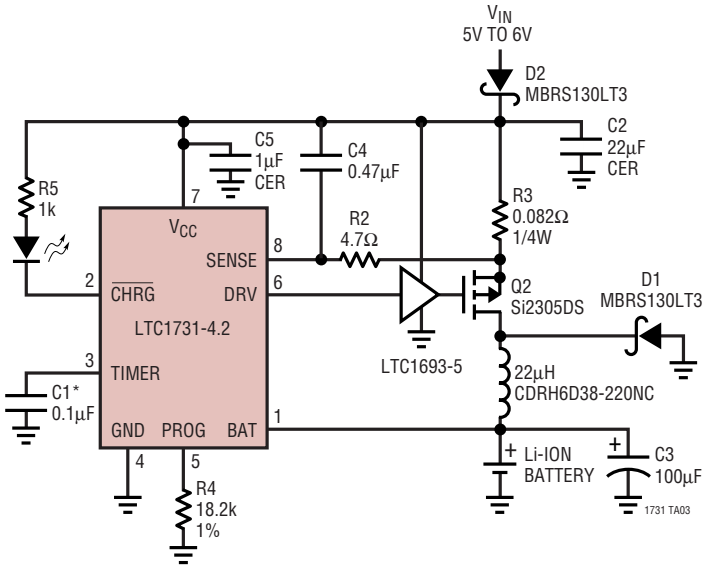
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TYPICAL APPLICATIONS

Linear Charger Using a PNP Transistor



1.5A Single Cell Switching Battery Charger



*AVX 0603ZC104KAT1A

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_{IN} Can Be Higher or Lower Than Battery Voltage, 1.5A Switch
LT1571-1/LT1571-2 LT1571-5	200kHz/500kHz Constant-Current/Constant-Voltage Battery Charger Family	Up to 1.5A Charge Current for 1- or 2-Cell Li-Ion Batteries, Preset and Adjustable Battery Voltages, **C**/10 Charge Detection
LT1620/LT1621	Rail-to-Rail Current Sense Amplifier	Precise Output Current Programming, Up to 32V V_{OUT}
LTC1730	Integrated Pulse Charger for 1-Cell Li-Ion Battery	0.35Ω Internal N-FET Requires No Blocking Diode
LTC1729	Termination Controller for Li-Ion	Time or Charge Current Termination, Automatic Charger/Battery Detection, Status Output, Preconditioning, 8-Lead MSOP
LTC1732	Constant-Current/Constant-Voltage Li-Ion Linear Battery Charger	Stand Alone Battery, No µC or Firmware Required, Auto Recharge of Low Battery, 10-Pin MSOP, Input Supply Detection
LTC1734	SOT-23 Li-Ion Battery Charger	Needs Only Two External Components, Monitors Charge Current, No Reverse Diode or Sense Resistor Required

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408)432-1900 • FAX: (408) 434-0507 • www.linear-tech.com
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