# LTC1732-4/LTC1732-4.2

## Lithium-Ion Linear Battery Charger Controller

October 2000

## FEATURES

- **Complete Linear Charger Controller for 1-Cell Lithium-Ion Batteries**
- **Preset Charge Voltage with 1% Accuracy**
- 4.5V to 12V Input Voltage Range
- **Programmable Charge Current**
- **C/10 Charge Current Detection Output**
- **Programmable Charge Termination Timer**
- **Small, Thin 10-Pin MSOP Package**
- **Select Pin to Charge Either 4.1V or 4.2V Cells (LTC1732-4)**
- Automatic Sleep Mode When Input Supply is Removed (Only 7μA Battery Drain)
- Automatic Trickle Charge of Low Voltage Cells
- Programmable for Constant-Current-Only Mode
- Battery Insertion Detect and Automatic Charging of Low-Battery Cell
- **Input Supply (Wall Adapter) Detection Output**
- 4.05V Recharge Threshold for 4.2V Cells (LTC1732-4.2)
- 3.8V Recharge Threshold for 4.1V or 4.2V Cells (LTC1732-4)

## APPLICATIONS

- Cellular Phones
- Handheld Computers
- Charging Docks and Cradles

## DESCRIPTION

The LTC®1732 is a complete constant-current/constant-voltage linear charge controller for lithium-ion (Li-Ion) batteries. Nickel-cadmium (NiCd) and nickel metal-hydride (NiMH) batteries can also be charged with constant current using external termination. Charge current can be programmed with 7% (max) accuracy using external sense and program resistors. An internal resistor divider and precision reference set the final float voltage with 1% accuracy. The SEL pin allows users to charge either 4.1V or 4.2V cells.

When the input supply is removed, the LTC1732 automatically enters a low current sleep mode, dropping the battery drain current to 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.

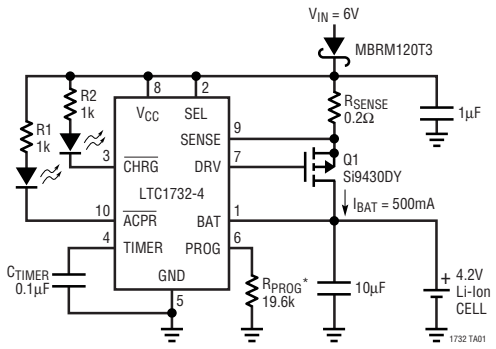
The LTC1732 begins a new charge cycle when a discharged battery is connected to the charger or when the input power is applied. In addition, if the battery remains connected to the charger and the cell voltage drops below 3.8V for the LTC1732-4 or below 4.05V for the LTC1732-4.2, a new charge cycle will begin.

The LTC1732 is available in the 10-pin MSOP package.



## TYPICAL APPLICATION

**Single Cell 4.2V Li-Ion Battery Charger**



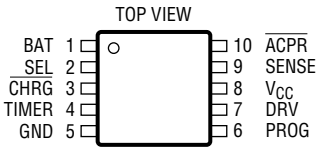

*SHUTDOWN INVOKED BY FLOATING THE PROG PIN

## ABSOLUTE MAXIMUM RATINGS

**(Note 1)**

Input Supply Voltage ($V_{CC}$) ..... 13.2V
SENSE, DRV, BAT, SEL, TIMER, PROG,
CHRG, ACPR ..... –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




MS10 PACKAGE
10-LEAD PLASTIC MSOP

$T_{JMAX}$ = 140°C, $\theta_{JA}$ = 180°C/W

| ORDER PART NUMBER |
|---|
| LTC1732EMS-4<br>LTC1732EMS-4.2 |
| MS10 PART MARKING |
| LTNJ<br>LTUA |

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°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 | 3 | mA |
| | | Sleep Mode (Battery Drain Current) | | | 7 | 20 | µA |
| $V_{BAT}$ | Regulated Output Voltage | LTC1732-4; 5V ≤ $V_{CC}$ ≤ 12V, $V_{SEL}$ = GND | ● | 4.059 | 4.1 | 4.141 | V |
| | | LTC1732-4/LTC1732-4.2; 5V ≤ $V_{CC}$ ≤ 12V, $V_{SEL}$ = $V_{CC}$ | ● | 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 | | 60 | 100 | 140 | mA |
| $I_{TRIKL}$ | Trickle Charge Current | $V_{BAT}$ = 2V, $R_{PROG}$ = 19.6k, $I_{TRIKL}$ = ($V_{CC}$ – $V_{SENSE}$)/0.2Ω | ● | 30 | 50 | 110 | 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 |
| $\Delta V_{UV}$ | $V_{CC}$ 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 |
| $V_{ASD}$ | Automatic Shutdown Threshold Voltage | ($V_{CC}$ – $V_{BAT}$) High to Low | | 30 | 54 | 90 | mV |
| | | ($V_{CC}$ – $V_{BAT}$) Low to High | | 40 | 69 | 100 | 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 Source Current, $\Delta V_{PROG}$ ≤ 5mV | ● | 300 | | | µA |
| $V_{PROG}$ | PROG Pin Voltage | $R_{PROG}$ =19.6k | | | 2.457 | | V |
| $V_{ACPR}$ | $\overline{ACPR}$ Pin Output Low Voltage | $I_{ACPR}$ = 5mA | | | 0.7 | 1.2 | V |
| $I_{CHRG}$ | $\overline{CHRG}$ Pin Weak Pull-Down Current | $V_{CHRG}$ = 1V | | 15 | 35 | 55 | µA |
| $V_{CHRG}$ | $\overline{CHRG}$ Pin Output Low Voltage | $I_{CHRG}$ = 5mA | | | 0.6 | 1.2 | V |
| $V_{SEL}$ | SEL Pin Threshold | | ● | 0.3 | | 2 | 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 |
|---|---|---|---|---|---|---|---|
| $I_{C/10}$ | 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 | | % |
| $V_{RECHRG}$ | Recharge Battery Voltage Threshold per Cell | $V_{BAT}$ from High to Low (LTC1732-4)<br>$V_{BAT}$ from High to Low (LTC1732-4.2) | | 3.72<br>3.95 | 3.80<br>4.05 | | V<br>V |

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

**Note 2:** The LTC1732E 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.

## PIN FUNCTIONS

**BAT (Pin 1):** Battery Sense Input. A bypass capacitor of 10µF or more is required to keep the loop stable when the battery is not connected. A precision internal resistor divider on this pin sets the final float potential. The resistor divider is disconnected in sleep mode to reduce the current drain on the battery.

**SEL (Pin 2):** 4.1V/4.2V Battery Selection Input Pin. Grounding this pin will set the output float voltage to 4.1V per cell, while connecting to $V_{CC}$ will set the voltage to 4.2V per cell. For the LTC1732-4.2, the SEL pin must be connected to $V_{CC}$.

**$\overline{\text{CHRG}}$ (Pin 3):** 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 more than 15ms, the N-channel MOSFET turns off and a 35µA 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 4):** 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 $t_{TIMER}$ = ($C_{TIMER}$ • 3 hours)/(0.1µF). When the TIMER pin is connected to $V_{CC}$, the timer is disabled, the constant-voltage mode is disabled and the chip will operate in constant-current mode only. Shorting the TIMER pin to GND will disable the internal timer function and the **C**/10 function.

**GND (Pin 5):** Ground.

**PROG (Pin 6):** Charge Current Program and Shutdown Input Pin. The charge current is programmed by connecting a resistor, $R_{PROG}$ to ground. The charge current is $I_{BAT}$ = ($V_{PROG}$ • 800Ω)/($R_{PROG}$ • $R_{SENSE}$). The IC 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 voltage.

**DRV (Pin 7):** 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.

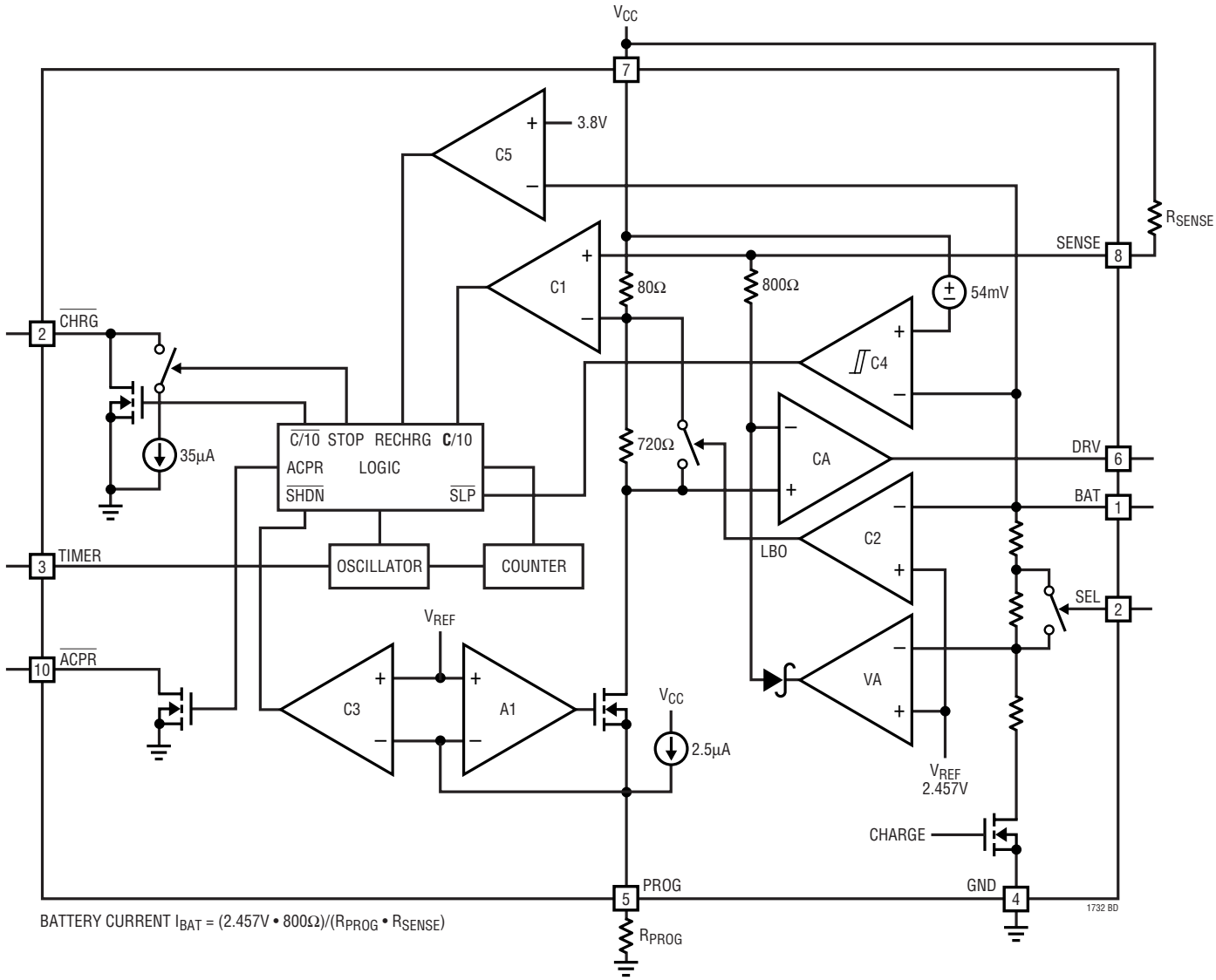
**$V_{CC}$ (Pin 8):** Positive Input Supply Voltage. When $V_{BAT}$ is within 54mV of $V_{CC}$, the LTC1732 is forced into sleep mode, dropping $I_{CC}$ to 7µA. $V_{CC}$ ranges from 4.5V to 12V. Bypass this pin with a 1µF capacitor.

**SENSE (Pin 9):** 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:

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

**$\overline{\text{ACPR}}$ (Pin 10):** Wall Adapter Present Output. When the input voltage (wall adaptor) is applied to the LTC1732, this pin is pulled to ground by an internal N-channel MOSFET that is capable of sinking 5mA to drive an external LED.

## BLOCK DIAGRAM




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

## OPERATION

The LTC1732 is a linear battery charger controller. 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 terminate.

## OPERATION

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 charge cycle is 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.

Replacing the battery while in the charge mode will cause the timer to be reset if the cell voltage of the new battery is below 3.8V. If the voltage is above 3.8V, the timer will continue for the remaining charge time. In the case when a time out has occurred, a new battery with the cell voltage of less than 3.8V can be inserted and charged automatically with the full programmed charge time.

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 LTC1732 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, **C**/10 comparator and the trickle charge function are all disabled.

The charger can be shut down by floating the PROG pin. An internal current source will pull this pin high and clamp it 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

### Stop Charging

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 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 $\overline{CHRG}$ pin output is forced to a high impedance state.

### Shutdown

The LTC1732 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 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.

## APPLICATIONS INFORMATION

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 charging. 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 an 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 35µA 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.

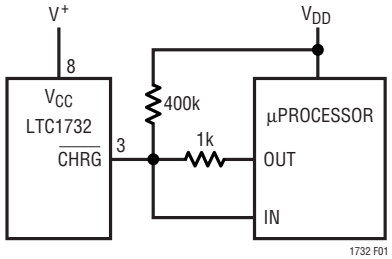



**Figure 1. Microprocessor Interface**

When the LTC1732 is in charge mode, the $\overline{CHRG}$ pin is pulled low 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 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 35µA current source is connected to the $\overline{CHRG}$ pin. The IN pin will then be pulled high by the 1k pull-up. By forcing the OUT pin into a high impedance state, the current source will pull the pin low through the 400k resistor. When the internal timer has expired, the $\overline{CHRG}$ pin will change to high impedance state and the 400k resistor will then pull the pin high to indicate the charging has stopped.

### $\overline{ACPR}$ Output Pin

The LTC1732 has an $\overline{ACPR}$ output pin to indicate that the input supply (wall adapter) is higher than 4.1V and 55mV above the voltage at the BAT pin. When both conditions are met, the $\overline{ACPR}$ pin is pulled down to ground by an N-channel MOSFET that is capable of driving an LED. Otherwise, this pin is in a high impedance state.

### End of Charge (C/10)

The LTC1732 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 35µA current source to ground. After an internal time delay of 15ms, 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.

### Output Voltage Selection

The float voltage at the BAT pin can be selected by the SEL pin. Shorting the SEL pin to ground will set the float voltage to 4.1V, while connecting it to $V_{CC}$ sets it to 4.2V. This feature allows the charger to be used with different types of Li-Ion cells. Because the recharge threshold voltage level of the LTC1732-4.2 is preset for 4.05V, this version is *not* recommended for 4.1V cells. When

## APPLICATIONS INFORMATION

charging 4.1V cells, use the LTC1732-4 with the SEL pin grounded. The LT1732-4 can also be used for charging 4.2V cells by connecting the SEL pin to $V_{CC}$ (the recharge threshold level is preset to 3.8V, thus allowing either 4.1V or 4.2V cells to be charged).

### Gate Drive

Typically the LTC1732 controls an external P-channel MOSFET to supply current to the battery. 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 LTC1732 can be used as a programmable current source by connecting 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.

### Battery Detection

The LTC1732 can detect the insertion of a new battery. When a battery with cell voltage of less than 3.8V is inserted, the LTC1732 resets the timer and starts the charging cycle immediately. If the cell voltage of the new battery is above 3.8V, the charging will not start. If a new battery (with cell voltage above 3.8V) is inserted while in the charging process, the timer will not be reset. It will continue until the timer runs out.

After a time out has occurred and the battery remains connected, a new charge cycle will begin if the battery voltage drops below 3.8V (LTC1732-4) or 4.05V (LTC1732-4.2) due to self-discharge or external loading.

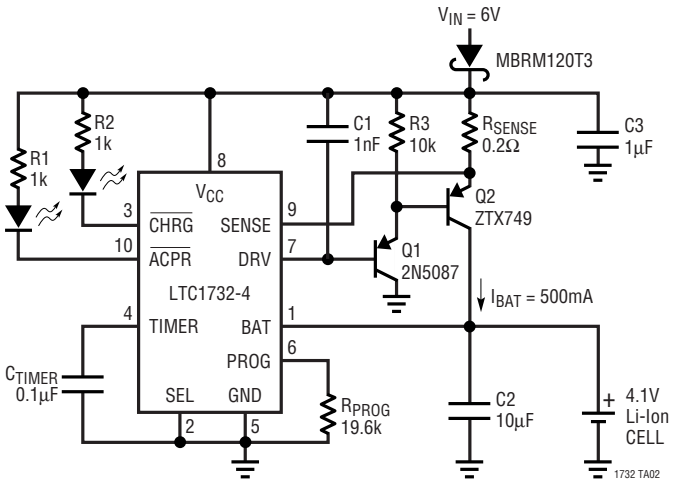
### Stability

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.

If a PNP transistor is used for 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.

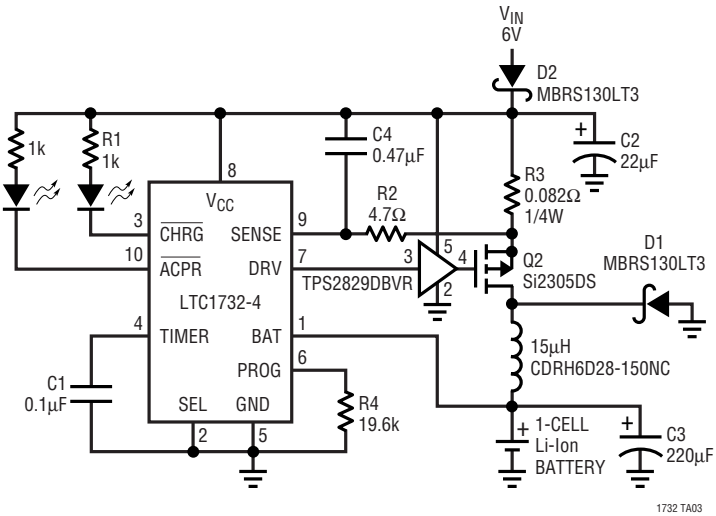
## TYPICAL APPLICATIONS

**Linear Charger Using a PNP Transistor**



## TYPICAL APPLICATIONS

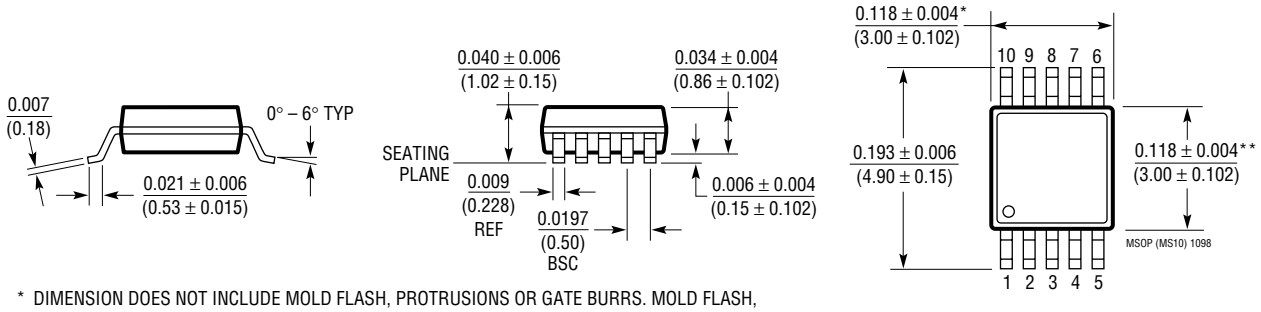
**Single Cell 4.1V, 1.5A Li-Ion Battery Charger**




## PACKAGE DESCRIPTION

**Dimensions in inches (millimeters) unless otherwise noted.**

**MS10 Package**
**10-Lead Plastic MSOP**
(LTC DWG # 05-08-1661)




* 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

## 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 |
| LTC1541 | Op Amp, Comparator and Reference with 5µA $I_{CC}$ | Low Cost Linear Charger—See Design Note 188 |
| LT1620 | Rail-to-Rail Current Sense Amplifier | Precise Output Current Programming, Up to 32V $V_{OUT}$, Up to 10A $I_{OUT}$ |
| LTC1729 | Termination Controller for Li-Ion | Time or Charge Current Termination, Automatic Charger/Battery Detection, Status Output, Preconditioning, 8-Lead MSOP |
| LTC1731 | Li-Ion Linear Battery Charger Controller | CC/CV Charges Li-Ion Cells, 8-Lead MSOP, Programmable Timer |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