Lithium-Ion Linear Battery Charger in SOT-23

January 2001

FEATURES

- **Tiny 6-Lead SOT-23 Package**
- **1% Accurate Preset Voltages: 4.1V or 4.2V**
- Programmable Charge Current: 200mA to 700mA
- **Charge Current Monitor Output for Charge Termination**
- Automatic Shutdown with Input Supply Removal
- Manual Shutdown
- Negligible Battery Drain Current in Shutdown
- **No Blocking Diode Required**
- **No Sense Resistor Required**
- Undervoltage Lockout
- Self Protection for Overcurrent/Overtemperature

APPLICATIONS

- Cellular Telephones
- Handheld Computers
- Digital Cameras
- Charging Docks and Cradles
- Low Cost and Small Size Chargers
- Programmable Current Source

DESCRIPTION

The LTC®1734 is a low cost, single cell, constant-current/constant-voltage Li-Ion battery charger controller. When combined with a few external components, the SOT-23 package forms a very small, low cost charger for single cell lithium-ion batteries.

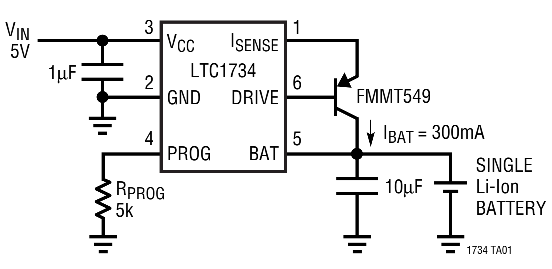
The LTC1734 is available in 4.1V and 4.2V versions with 1% accuracy. Constant current is programmed using a single external resistor between the PROG pin and ground. Manual shutdown is accomplished by floating the program resistor while removing input power automatically puts the LTC1734 into a sleep mode. Both the shutdown and sleep modes drain near zero current from the battery.

The charge current can be monitored via the voltage on the PROG pin allowing a microcontroller or ADC to read the current and determine when to terminate the charge cycle. The output driver is both current limited and thermally protected to prevent operating outside of safe limits. No external blocking diode is required.

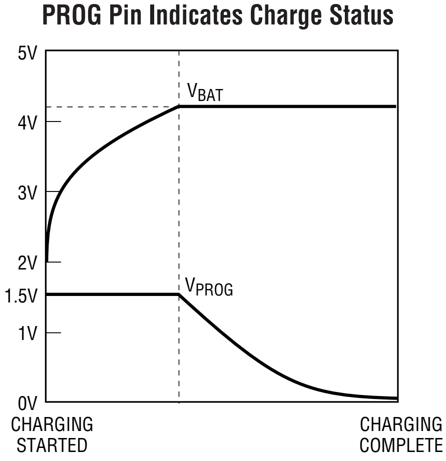
The LTC1734 can also function as a general purpose current source or as a current source for charging nickel-cadmium (NiCd) and nickel-metal-hydride (NiMH) batteries using external termination.

TYPICAL APPLICATION

300mA Li-Ion Battery Charger



PROG Pin Indicates Charge Status

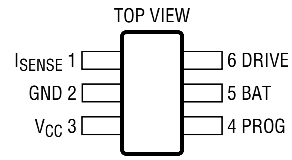


ABSOLUTE MAXIMUM RATINGS

(Note 1)

Supply Voltage (V_{CC}) ....–0.3V to 9V
Input Voltage (BAT, PROG) .... –0.3V to (V_{CC} + 0.3V)
Output Voltage (DRIVE) .... –0.3V to (V_{CC} + 0.3V)
Output Current (I_{SENSE}) .... –1A to 1A
Short-Circuit Duration (DRIVE) .... Indefinite
Junction Temperature.. 125°C
Operating Ambient Temperature Range
(Note 2) ....–40°C to 85°C
Operating Junction Temperature (Note 2) ....100°C
Storage Temperature Range .... –65°C to 150°C
Lead Temperature (Soldering, 10 sec)..................300°C

PACKAGE/ORDER INFORMATION



S6 PACKAGE
6-LEAD PLASTIC SOT-23

T_{JMAX} = 125°C, θ_{JA} = 230°C/W

ORDER PART NUMBER
LTC1734ES6-4.1 LTC1734ES6-4.2
S6 PART MARKING
LTHD LTRG

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} = 5V, GND = 0V and V_{BAT} is equal to the float voltage unless otherwise noted. All currents into device pins are positive. All currents out of device pins are negative. All voltages are referenced to GND, unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{CC} Supply							
V_{CC}	Operating Supply Range		●	4.75		8	V
I_{CC}	Quiescent V_{CC} Pin Supply Current	V_{BAT} = 5V, (Forces I_{DRIVE} = I_{BAT} = 0), I_{PROG} = 200µA,(7500Ω from PROG to GND)	●		670	1150	µA
I_{SHDN}	V_{CC} Pin Supply Current in Manual Shutdown	PROG Pin Open	●		450	900	µA
I_{BMS}	Battery Drain Current in Manual Shutdown (Note 3)	PROG Pin Open	●	–1	0	1	µA
I_{BSL}	Battery Drain Current in Sleep Mode (Note 4)	V_{CC} = 0V	●	–1	0	1	µA
V_{UVLOI}	Undervoltage Exit Threshold	V_{CC} Increasing	●	4.45	4.56	4.68	V
V_{UVLOD}	Undervoltage Entry Threshold	V_{CC} Decreasing	●	4.30	4.41	4.53	V
V_{UVHYS}	Undervoltage Hysteresis	V_{CC} Decreasing			150		mV
Charging Performance							
V_{BAT}	Output Float Voltage in Constant Voltage Mode	4.1V Version, I_{BAT} = 10mA, 4.75V ≤ V_{CC} ≤ 8V 4.2V Version, I_{BAT} = 10mA, 4.75V ≤ V_{CC} ≤ 8V	● ●	4.059 4.158	4.10 4.20	4.141 4.242	V V
I_{BAT1}	Output Full-Scale Current in Constant Current Mode	R_{PROG} = 7500Ω, 4.75 ≤ V_{CC} ≤ 8V, Pass PNP Beta > 50	●	155	200	240	mA
I_{BAT2}	Output Full-Scale Current in Constant Current Mode	R_{PROG} = 2143Ω, 4.75 ≤ V_{CC} ≤ 8V, Pass PNP Beta > 50	●	620	700	770	mA
V_{CM1}	Current Monitor Voltage on PROG Pin	I_{BAT} = 10% of I_{BAT1}, R_{PROG} = 7500Ω, 4.75V ≤ V_{CC} ≤ 8V, Pass PNP Beta > 50	●	0.05	0.15	0.28	V
V_{CM2}	Current Monitor Voltage on PROG Pin	I_{BAT} = 10% of I_{BAT2}, R_{PROG} = 2143Ω, 4.75V ≤ V_{CC} ≤ 8V, Pass PNP Beta > 50	●	0.10	0.15	0.20	V
I_{DSINK}	Drive Output Current	V_{DRIVE} = 3V	●	30			mA

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_{CC} = 5V, GND = 0V and V_{BAT} is equal to the float voltage unless otherwise noted. All currents into device pins are positive. All currents out of device pins are negative. All voltages are referenced to GND, unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Charger Manual Control							
V_{MSDT}	Manual Shutdown Threshold	V_{PROG} Increasing	●	2.05	2.15	2.25	V
V_{MSHYS}	Manual Shutdown Hysteresis	V_{PROG} Decreasing			90		mV
I_{PROGPU}	Programming Pin Pull-Up Current	V_{PROG} = 2.5V		−6	−3	−1.5	μA
Protection							
I_{DSHRT}	Drive Output Short-Circuit Current Limit	$V_{DRIVE} = V_{CC}$	●	35	65	130	mA

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

Note 2: The LTC1734E is guaranteed to meet performance specifications from 0°C to 70°C ambient temperature range and 0°C to 100°C junction temperature range. Specifications over the −40°C to 85°C operating ambient temperature range are assured by design, characterization and correlation with statistical process controls.

Note 3: Assumes that the external PNP pass transistor has negligible B-C reverse-leakage current when the collector is biased at 4.2V (V_{BAT}) and the base is biased at 5V (V_{CC}).

Note 4: Assumes that the external PNP pass transistor has negligible B-E reverse-leakage current when the emitter is biased at 0V (V_{CC}) and the base is biased at 4.2V (V_{BAT}).

PIN FUNCTIONS

I_{SENSE} (Pin 1): Sense Node for Charge Current. Current from V_{CC} passes through the internal current sense resistor and reappears at I_{SENSE} to supply current to the external PNP's emitter. The PNP's collector provides charge current to the battery.

GND (Pin 2): Ground. Provides a reference for the internal voltage regulator and return for all internal circuits. When in the constant voltage mode, the LTC1734 will precisely regulate the voltage between the BAT and GND pins. The battery ground should tie close enough to the GND pin to avoid voltage drop errors.

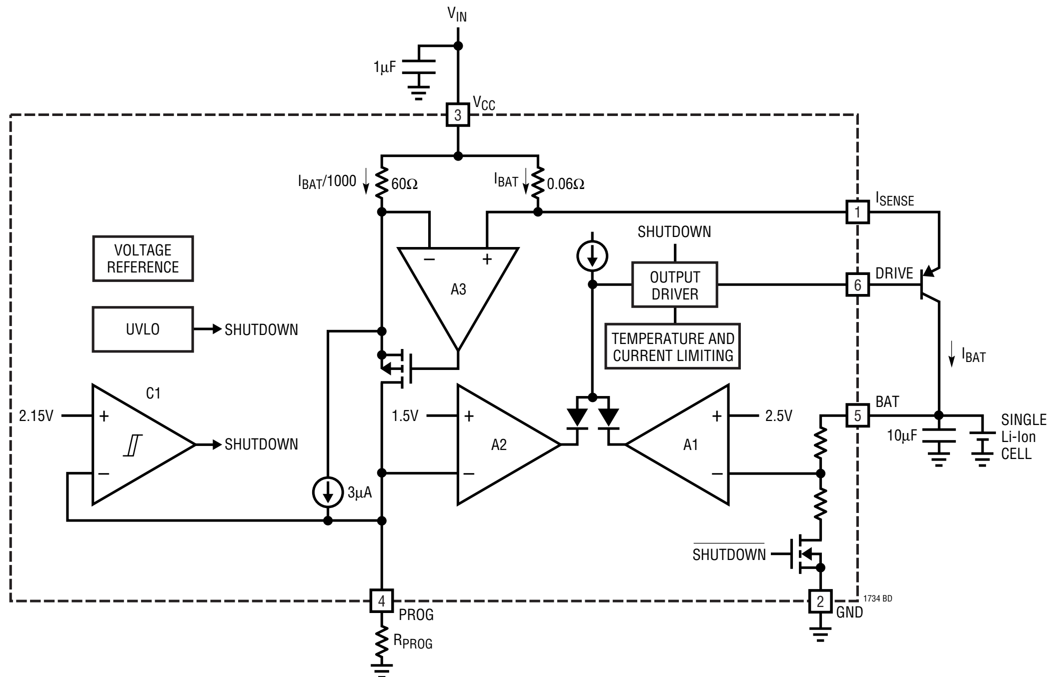
V_{CC} (Pin 3): Positive Input Supply Voltage. This pin supplies power to the internal control circuitry and external PNP transistor through the internal current sense resistor. This pin should be bypassed to ground with a capacitor in the range of from 1μF to 10μF.

PROG (Pin 4): Charge Current Programming, Charge Current Monitor and Manual Shutdown Pin. Provides a virtual reference voltage of 1.5V for an external resistor (R_{PROG}) tied between this pin and ground that programs the battery charge current while the charger is in the constant current mode. The typical charge current will be 1000 times the current through this resistor ($I_{BAT} = 1500/R_{PROG}$). This pin also allows for the charge current to be monitored. The voltage on this pin is proportional to the battery charging current so that at **C**/10 the voltage will be 1.5V/10. Floating the pin allows an internal current source to pull the pin voltage above the shutdown threshold voltage. Because this pin is in a signal path, excessive capacitive loading can cause AC instability. See the Applications Information section for more details.

BAT (Pin 5): Battery Voltage Sense Input. A precision internal resistor divider sets the final float voltage on this pin. This divider is disconnected in the manual shutdown or sleep mode. When charging, approximately 34μA flows into the BAT pin. To minimize float voltage errors, avoid excessive resistance between the battery and the BAT pin. For dynamically stable operation, this pin requires a minimum bypass capacitance to ground of 5μF to frequency compensate for the high frequency inductive effects of the battery and wiring.

DRIVE (Pin 6): Base Drive Output for the External PNP Pass Transistor. Provides a controlled sink current that drives the base of the PNP. This pin has current limiting protection.

BLOCK DIAGRAM



OPERATION

The LTC1734 is a linear battery charger controller. Operation can best be understood by referring to the Block Diagram. Charging begins when V_{CC} rises above the UVLO (Undervoltage Lockout) threshold V_{UVLOI} and an external current programming resistor is connected between the PROG pin and ground. When charging, the collector of the external PNP provides the charge current. The PNP's emitter current flows through the I_{SENSE} pin and through the internal 0.06Ω current sense resistor. This current is close in magnitude, but slightly more than the collector current since it includes the base current. Amplifier A3, along with the P-channel FET, will force the same voltage that appears across the 0.06Ω resistor to appear across the internal 60Ω resistor. The scale factor of 1000:1 in resistor values will cause the FET's drain current to be 1/1000 of the charge current and it is this current that flows through the PROG pin. In the constant current mode, amplifier A2 is used to limit the charge current to the maximum that is programmed by R_{PROG}.

The PROG pin current, which is 1/1000 of the charge current, develops a voltage across the program resistor. When this voltage reaches 1.5V, amplifier A1 begins diverting current away from the output driver, thus limiting the charge current. This is the constant current mode. The constant charge current is 1000 • (1.5V/R_{PROG}).

As the battery accepts charge, its voltage rises. When it reaches the preset float voltage of 4.2V (LTC1734-4.2 version), a precisely divided down version of this voltage (2.5V) is compared to the 2.5V internal reference voltage by amplifier A1. If the battery voltage attempts to exceed 4.2V (2.5V at amplifier A1's input) the amplifier will divert current away from the output driver thus limiting charge current to that which will maintain 4.2V on the battery. This is the constant voltage mode.

When in the constant voltage mode, the 1000:1 current ratio still holds and the voltage on the PROG pin will indicate the charge current as a proportion of the maximum current set by the current programming resistor. The battery charge current is 1000 • (V_{PROG}/R_{PROG}) amps. This feature allows a microcontroller with an ADC to easily monitor charging current and if desired, manually shut down the charger at the appropriate time.

OPERATION

When V_{CC} is applied, the charger can be manually shut down by floating the otherwise grounded end of R_{PROG}. An internal 3μA current source pulls the PROG pin above the 2.15V threshold of voltage comparator C1 initiating shutdown.

For charging NiMH or NiCd batteries, the LTC1734 can be turned into a constant current source by grounding the BAT pin. This will prevent amplifier A1 from trying to limit charging current and only A2 will control the current.

Fault conditions such as overheating of the die or excessive PNP base current drive are monitored and limited.

When input power is removed or manual shutdown is entered, the charger will drain only tiny leakage currents from the battery, thus maximizing battery standby time. With V_{CC} removed the external PNP's base is connected to the battery by the charger. In manual shutdown the base is connected to V_{CC} by the charger.

APPLICATIONS INFORMATION

Charging Operation

Charging begins when an input voltage is present that exceeds the undervoltage lockout threshold (V_{UVLOI}), a Li-Ion battery is connected to the charger output and a program resistor is connected from the PROG pin to ground. During the first portion of the charge cycle, when the battery voltage is below the preset float voltage, the charger is in the constant current mode. As the battery voltage rises and approaches the preset float voltage, the charge current begins to decrease and the constant voltage portion of the charge cycle begins. The charge current will continue to decrease exponentially as the battery approaches a fully charged condition.

Should the battery be removed during charging, a built-in protection circuit will prevent BAT from rising above 5V.

Manual Shutdown

Floating the program resistor shuts down the charger. In this mode, a small current is drawn from the supply (I_{SMS}) while only a negligible leakage current is delivered to the battery load (I_{BMS}).

Sleep Mode

When the input supply is disconnected, the IC enters the sleep mode. In this mode, the battery drain current (I_{BSL}) is a negligible leakage current, allowing the battery to remain connected to the charger for an extended period of time without discharging the battery. The leakage current is due to the reverse-biased B-E junction of the external PNP transistor.

Undervoltage Lockout

Undervoltage lockout (UVLO) keeps the charger off until the input voltage exceeds a predetermined threshold level (V_{UVLOI}) of 4.56V. Approximately 150mV of hysteresis is built in to prevent oscillation around the threshold level. In undervoltage lockout, battery drain current is very low (<1μA).

Programming Constant Current

When in the constant current mode, the full-scale current is programmed using a single external resistor between the PROG pin and ground. The charge current will be 1000 times greater than the current through the program resistor. The program resistor value is selected by dividing the voltage forced across the resistor (1.5V) by the desired resistor current. Different charge currents can be programmed using a DAC, or using a PWM output from a microcontroller or by switching in different program resistors.

The LTC1734 is designed for a maximum current of approximately 700mA. This translates to a maximum PROG pin current of 700μA and a minimum program resistor of approximately 2.1k. Because the PROG pin is in a closed-loop signal path, the pole frequency must be kept high enough to maintain adequate AC stability. See the Stability section for more details.

Monitoring Charge Current

The voltage on the PROG pin indicates the charge current as a proportion of the maximum current set by the

APPLICATIONS INFORMATION

program resistor. The charge current is equal to 1000 • (V_{PROG}/R_{PROG}) amps. This feature allows a microcontroller with an ADC to easily monitor charging current and if desired, manually shut down the charger at the appropriate time. See Figure 1 for an example. The minimum PROG pin current is about 3μA (I_{PROGPU})

Errors in the charge current monitor voltage on the PROG pin are inversely proportional to battery current and can be statistically approximated as follows:

$$\text{One Sigma Error(\%)} \cong 1 + 0.3/I_{BAT}(A)$$

Dynamic loads on the battery will cause transients to appear on the PROG pin. Should they cause excessive errors in charge current monitoring, a simple RC filter as shown in Figure 2 can be used to filter the transients. The filter will also quiet the PROG pin to help prevent inadvertent momentary entry into the manual shutdown mode.

Because the PROG pin is in a closed-loop signal path the pole frequency must be kept high enough to maintain adequate AC stability. This means that the maximum resistance and capacitance presented to the PROG pin must be limited. See the Stability section for more details.

Constant Current Source

The LTC1734 can be used as a constant current source by disabling the voltage control loop as shown in Figure 3.

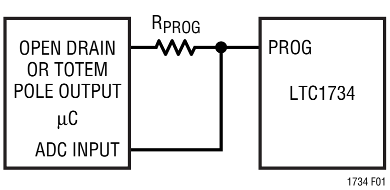


Figure 1. Interfacing with a Microcontroller

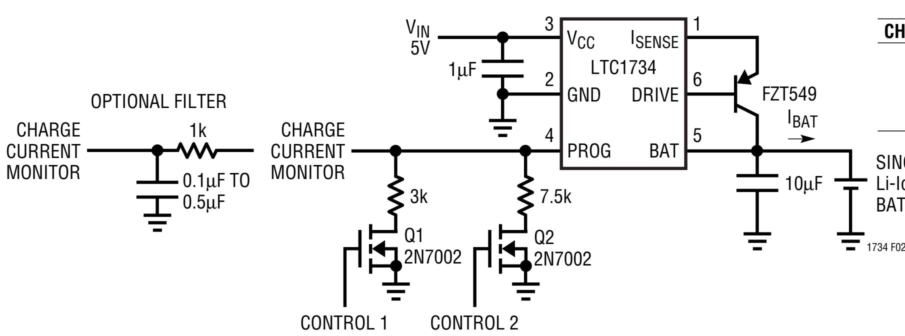
This is done by pulling the BAT pin below the preset float voltages of 4.1V or 4.2V by grounding the BAT pin. The program resistor will determine the output current. The output current range is between approximately 200mA and 700mA, depending on the maximum power rating of the external PNP pass transistor.

External PNP Transistor

The external PNP pass transistor must have adequate beta, low saturation voltage and sufficient power dissipation capability (including any heat sinking, if required).

To provide 700mA of charge current with the minimum available base drive of approximately 30mA requires a PNP beta greater than 23. If lower beta PNP transistors are used, more base current is required from the LTC1734. This can result in the output drive current limit being reached, or thermal shutdown due to excessive power dissipation. Excessive beta can affect stability (see Stability section)

With low input voltages, the PNP saturation voltage (V_{CESAT}) becomes important. The V_{CESAT} must be less than the minimum input voltage minus the voltage drop across the internal sense resistor minus the battery float voltage. If the PNP transistor can not achieve the low saturation voltage required, base current will dramatically increase. This is to be avoided for a number of reasons: output drive may reach current limit resulting in the charger's characteristics to go out of specifications, excessive power dissipation may force the IC into thermal shutdown, or the battery could become discharged because some of the current from the DRIVE pin could be pulled from the battery through the forward biased collector base junction.



CHARGE CURRENT	CONTROL 1	CONTROL 2
0	LOW	LOW
200mA	LOW	HIGH
500mA	HIGH	LOW
700mA	HIGH	HIGH

Figure 2. Logic Control Programming of Output Current to 0mA, 200mA, 500mA or 700mA

APPLICATIONS INFORMATION

For example, to program a charge current of 500mA with a minimum supply voltage of 4.75V, the minimum operating V_{CE} is:

$$V_{CE(MIN)}(V) = 4.75 – (0.5)(0.1) – 4.2 = 0.5V$$

The actual battery charge current (I_{BAT}) is slightly smaller than the expected charge current because the charger senses the emitter current and the battery charge current will be reduced by the base current. In terms of β (I_C/I_B), I_{BAT} can be calculated as follows:

$$I_{BAT}(A) = 1000 \cdot I_{PROG}[\beta/(\beta + 1)]$$

If β = 50, then I_{BAT} is 2% low. If desired, the 2% loss can be compensated for by increasing I_{PROG} by 2%.

Another important factor to consider when choosing the PNP pass transistor is the power handling capability. The PNP's data sheet will usually give the maximum rated power dissipation at a given ambient temperature with a power derating for elevated temperature operation. The maximum power dissipation of the PNP when charging is:

$$P_{D(MAX)}(W) = I_{BAT} (V_{DD(MAX)} – V_{BAT(MIN)})$$

$V_{DD(MAX)}$ is the maximum supply voltage and $V_{BAT(MIN)}$ is the minimum battery voltage when discharged.

Table 1. Recommended Low V_{CESAT} PNP Transistors

Maximum Current (A)	Maximum P_D at T_A = 25°C	Package Style	Zetex Part Number
1	0.5	SOT-23	FMMT549 or FMMT717
1	1	SOT-89	FCX589 or FCX717
2	2	SOT-223	FZT549 or BCP69

Stability

The LTC1734 contains two control loops; constant voltage and constant current. To maintain adequate AC stability in the constant voltage mode, a capacitance (5μF to 100μF) is required from the BAT pin to ground. A battery and the interconnecting wires can appear inductive at high frequencies, and since the battery is in the feedback loop, this capacitance is necessary to compensate for the inductance. The capacitor ESR can range from near zero ohms to several ohms.

In general, compensation is optimal with 4.7μF to 22μF and ESR of 0.5Ω to 1.5Ω. Using high beta PNP transistors (>300) and very low ESR output capacitors (especially ceramic) reduces the phase margin, possibly resulting in oscillation. Adding series resistance to the capacitor will restore the phase margin. The last transistor listed in each row of Table 1 is high beta.

In the constant current mode it is the PROG pin that is in the feedback loop and not the battery. Because the PROG pin is in a closed-loop signal path, the pole frequency should be kept above 400kHz to maintain adequate AC stability. In addition, high loop gains should be avoided by limiting R_{PROG} to 15k or less. The pole frequency is determined by R_{PROG} and the external capacitive loading on the PROG pin. Once R_{PROG} is determined, the maximum value of C which will give adequate stability can be calculated as follows:

$$C_{MAX} (F) = 1/(6.28 \cdot R_{PROG} \cdot 400k)$$

A capacitance of 25pF or less is acceptable for any R_{PROG} value.

To minimize capacitive loading of the PROG pin, a 10k resistor can be added between the PROG pin and the monitoring circuit to allow the charger to be unaffected by the capacitance.

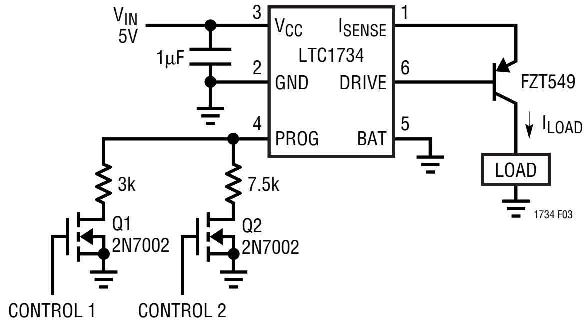
V_{CC} Bypass Capacitor

Many types of capacitors with values ranging from 1μF to 10μF located close to the LTC1734 will provide adequate 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 hot power source. To prevent these transients from exceeding the absolute maximum voltage rating, several ohms can be added in series with the input ceramic capacitor.

Internal Protection

Internal protection is provided to prevent excessive DRIVE currents (I_{DSHRT}) and excessive internal self-heating in case of a fault condition, such as a shorted DRIVE pin or the external PNP pass transistor operating in deep saturation.

APPLICATIONS INFORMATION



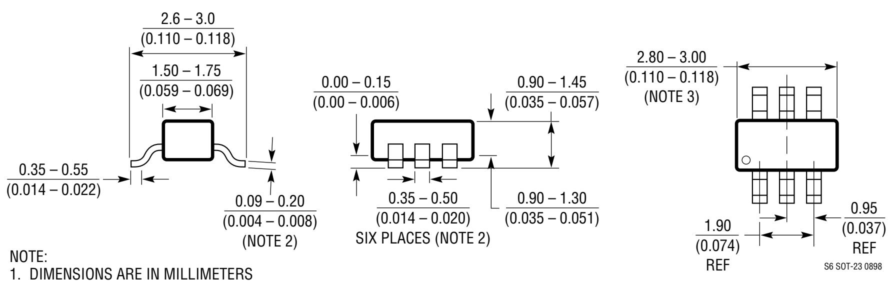
CHARGE CURRENT	CONTROL 1	CONTROL 2
0	LOW	LOW
200mA	LOW	HIGH
500mA	HIGH	LOW
700mA	HIGH	HIGH

Figure 3. Programmable Current Source with Output Current of 0mA, 200mA, 500mA or 700mA

PACKAGE DESCRIPTION

Dimensions in inches (millimeters) unless otherwise noted.

S6 Package
6-Lead Plastic SOT-23
(LTC DWG # 05-08-1634)



NOTE:
1. DIMENSIONS ARE IN MILLIMETERS
2. DIMENSIONS ARE INCLUSIVE OF PLATING
3. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
4. MOLD FLASH SHALL NOT EXCEED 0.254mm
5. PACKAGE EIAJ REFERENCE IS SC-74A (EIAJ)

RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT®1510	200kHz Constant-Current/Constant-Voltage Battery Charger	Up to 1.5A Charge Current for Li-Ion, NiCd, NiMH or Lead-Acid Batteries
LT1510-5	500kHz Constant-Current/Constant-Voltage Battery Charger	Up to 1A Charge Current for Li-Ion, NiCd, NiMH or Lead-Acid Batteries
LT1571-1/LT1571-2 LT1571-5	200kHz/500kHz Constant-Current/Constant-Voltage Battery Charger Family	Up to 1.5A Charge Current for 1-, 2- or Multiple Cell Li-Ion Batteries, Preset and Adjustable Battery Voltages, **C**/10 Charge Detection
LTC1729	Li-Ion Battery Charger Termination Controller	Can be Used with LTC Battery Chargers to Provide Charge Termination, Preset Voltages, **C**/10 Charge Detection and Timer Functions
LTC1731	Linear Constant-Current/Constant-Voltage Charger Controller	Simple Charger Uses External FET. Features Preset Voltages, **C**/10 Charge Detection and Programmable Timer
LTC1732	Linear Constant-Current/Constant-Voltage Charger Controller	Simple Charger Uses External FET. Input Power Good Indication Features Preset Voltages, **C**/10 Charge Detection and Programmable Timer
LT1769	200kHz Constant-Current/Constant-Voltage Battery Charger	Up to 2A Charge Current for Li-Ion, NiCd, NiMH or Lead-Acid Batteries with Input Current Limit

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