Charge Li-Ion Batteries Directly from High Voltage Automotive and Industrial Supplies Using Standalone Charger in a 3mm × 3mm DFN

by Jay Celani

Introduction

Growth of the portable electronics market is in no small part due to the continued evolution of battery capacities. For many portable devices, rechargeable Li-Ion batteries are the power source of choice because of their high energy density, light weight, low internal resistance, and fast charge times. Charging these batteries safely and efficiently, however, requires a relatively sophisticated charging system.

One additional problem faced by battery charger designers is how to deal with relatively high voltage sources, such as those found in industrial and automotive applications. In these environments, system supply voltages exceed the input ranges of most charger ICs, so a DC/DC step-down converter is required to provide a local low voltage supply for the charger IC. The LT3650 standalone monolithic switching battery charger does not need this additional DC/DC converter. It directly accepts input voltages up to 40V and provides charge currents as high as 2A. It also includes a wealth of advanced features that assure safe battery charging and expand its applicability.

The LT3650 includes features that minimize the overall solution size, requiring only a few external components to complete a charger circuit. A fast 1MHz switching frequency allows the use of small inductors, and the IC is housed inside a tiny 3mm × 3mm DFN12-pin package. The IC has built-in reverse current protection, which blocks current flow from the battery back to the input supply if that supply is disabled or discharged to ground, so a single-cell LT3650 charger does not require an external blocking diode on the input supply.

A Charger Designed for Lithium-Ion Batteries

A Li-Ion battery requires constant-current/constant-voltage (CC/CV) charging system. A Li-Ion battery is initially charged with a constant current, generally between 0.5C and 1C, where C is the battery capacity in ampere-hours. As it is charged, the battery voltage increases until it approaches the full-charge float voltage. The charger then transitions into constant voltage operation as the charge current is slowly reduced. The LT3650-4.1 and LT3650-4.2 are designed to charge single-cell Li-Ion batteries to float voltages of 4.1V and 4.2V, respectively. The LT3650-8.2 and LT3650-8.4 are designed to charge 2-cell battery stacks to float voltages of 8.2V and 8.4V.

Once the charge current falls below one tenth of the maximum constant charge current, or 0.1C, the battery is considered charged and the charging cycle is terminated. The charger must be completely disabled after terminating charging, since indefinite trickle charging of Li-Ion cells, even at miniscule currents, can cause battery damage and compromise battery stability. A charger can top-off a battery by continuing to operate as the current falls lower than the 0.1C charge current threshold to make full use of battery capacity, but in such cases a backup timer is used to disable the charger after a controlled period of time. Most Li-Ion batteries charge fully in three hours.

The LT3650 addresses all of the charging requirements for a Li-Ion battery. The IC provides a CC/CV charging characteristic, transitioning automatically as the requirements of the battery change during a charging cycle. During constant-current operation, the maximum charge current

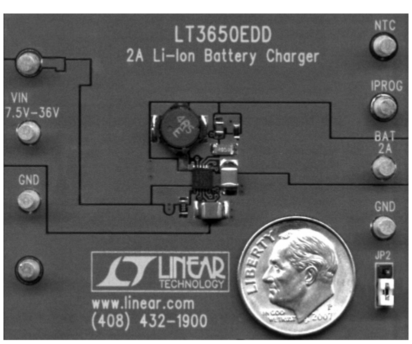

Figure 1. An LT3650 standalone battery charger is small and efficient.

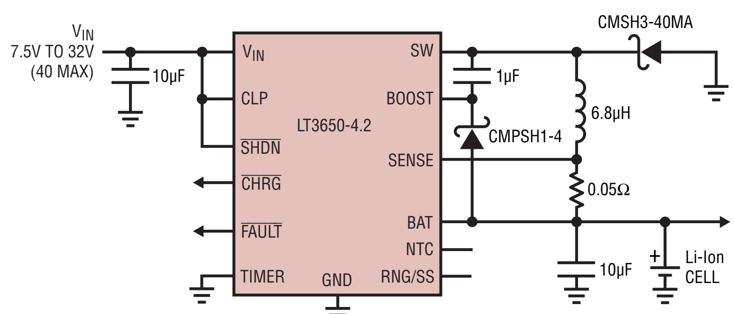

Figure 2. A single-cell 2A Li-Ion battery charger configured for C/10 charge termination

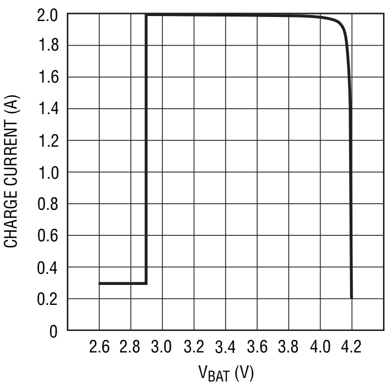

Figure 3. Battery charge current vs BAT pin voltage for the charger shown in Figure 2

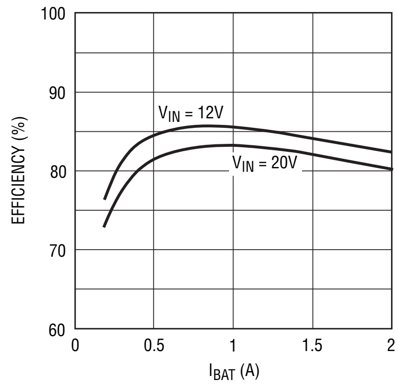

Figure 4. Power conversion efficiency vs charger output current (I_{BAT}) for the battery charger shown in Figure 2

provided to the battery is programmable via a sense resistor, up to a maximum of 2A. Maximum charge current can also be adjusted using the RNG/SS pin. The charger transitions to constant-voltage mode operation as the battery approaches the full-charge float voltage. Power is transferred through an internal NPN switch element, driven by a boosted drive to maximize efficiency. A precision $\overline{\text{SHDN}}$ pin threshold allows incorporation of accurate UVLO functions using a simple resistor divider.

Charge Cycle Termination and Automatic Restart

A LT3650 charger can be configured to terminate a battery charge cycle using one of two methods: it can use low charge current (C/10) detection, enabled by connecting the TIMER pin to ground, or terminate based on the onboard safety timer, enabled by connecting a capacitor to the TIMER pin. After termination, a new charge cycle automatically restarts should the battery voltage fall to 97.5% of the float voltage.

When C/10 termination mode is selected, the LT3650 terminates a charging cycle when the output current has dropped to 1/10 of the programmed maximum. In a 2A charger, for example, the charge cycle terminates when the battery charge current falls to 200mA.

Timer termination, or top-off charging, is enabled when a capacitor is connected to the TIMER pin. The value of the capacitor sets the safety timer duration—0.68µF corresponds to a 3-hour cycle time. When timer termination is implemented, the charger continues to operate in constant-voltage mode when charge currents fall below C/10, allowing additional low current charging to occur until the timer cycle has elapsed, thus maximizing use of the battery capacity. During top-off charging, the $\overline{\text{CHRG}}$ and $\overline{\text{FAULT}}$ status pins communicate "charge complete." At the end of the timer cycle, the LT3650 terminates the charging cycle.

After charge cycle termination, the LT3650 enters standby mode where the IC draws 85µA from the input supply and less than 1µA from the battery. Both the $\overline{\text{CHRG}}$ and $\overline{\text{FAULT}}$ pins are high impedance during standby mode. Should the battery voltage drop to 97.5% of the float voltage, the LT3650 automatically restarts and initializes a new charging cycle.

A Basic Charger

Figure 2 shows a basic 2A single-cell Li-Ion battery charger that operates from a 7.5V to 32V input. Charging is suspended if the input supply voltage exceeds 32V, but the IC can withstand input voltages as high as 40V without damage. The 2A maximum charge current corresponds to 100mV across the 0.05Ω external sense resistor. This basic design does not take advantage of the status pins, battery temperature monitoring, or a safety timer features. The battery charging cycle terminates when the battery voltage approaches 4.2V and the charge current falls to 200mA. A new charge cycle is automatically initiated when the battery voltage falls to 4.1V.

Safety Features: Preconditioning, Bad Battery Detection, and Temperature Monitor

Li-Ion batteries can sustain irreversible damage when deeply discharged, so care must be taken when charging such a battery. A gentle preconditioning charge current is recommended to activate any safety circuitry in a battery pack and to re-energize deeply discharged cells, followed by a full charge cycle. If a battery has sustained damage from excessive discharge, however, the battery should not be recharged. Deeply discharged cells can form copper shunts that create resistive shorts, and charging such a damaged battery could cause an unsafe condition due to excessive heat generation. Should a deeply discharged battery be encountered, a battery charger must be intelligent enough to determine whether or not the battery has sustained deep-discharge damage, and avoid initiating a full charge cycle on such a damaged battery.

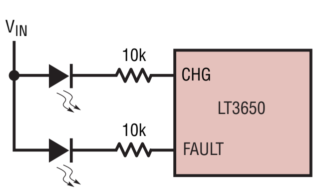

Figure 5. Visual charger status is easily implemented using LEDs

Table 1. Status pin state and corresponding operating states

$\overline{\text{CHRG}}$	$\overline{\text{FAULT}}$	Charger Status
High Impedance	High Impedance	Standby/Shutdown/Top-off
Low	High Impedance	CV/CC Charging (>C/10)
High Impedance	Low	Bad Battery Detected
Low	Low	Temperature Fault

The LT3650 employs an automatic precondition mode, which gracefully initiates a charging cycle into a deeply discharged battery. If the battery voltage is below the precondition threshold of 70% of the float voltage, the maximum charge current is reduced to 15% of the programmed maximum (0.15C) until the battery voltage rises past the precondition threshold.

If the battery does not respond to the precondition current and the battery voltage does not rise past the precondition threshold, a full-current charge cycle does not initiate.

If the safety timer is used for termination, the LT3650 also enables deep-discharge damage detection and incorporates a "bad battery" detection fault. Should the battery voltage remain below the precondition threshold for 1/8 of the charge cycle time (typically 22.5 minutes), the charger suspends the charging cycle and signals a "bad battery" fault on the status pins. The LT3650 maintains this fault state indefinitely, but automatically resets itself and starts a new charging cycle if the damaged battery is removed and another battery is connected.

Li-Ion batteries have a relatively narrow temperature range where they can be safely charged. The LT3650 has a provision for monitoring battery

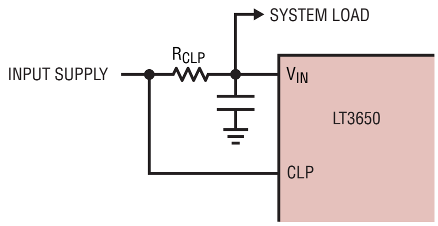

Figure 6. R_{CLP} sets the input supply current limit

temperature, and suspends charging should the temperature fall outside of the safe charging range.

Under/overtemperature protection is enabled by connecting a 10k (B = 3380) NTC thermistor from the IC's NTC pin to ground. This thermistor must be in close proximity to the battery, and is generally housed in the battery case. This function suspends a charging cycle if the temperature of the thermistor is greater than 40°C or less than 0°C. Hysteresis corresponding to 5°C on both thresholds prevents mode glitching. Both the $\overline{CHRG}$ and $\overline{FAULT}$ status output pins are pulled low during a temperature fault, signaling that the charging cycle is suspended. If the safety timer is used for termination, the timer is paused for the duration of a temperature fault, so a battery receives a full-duration charging cycle, even if that cycle is interrupted by the battery being out of the allowed temperature range.

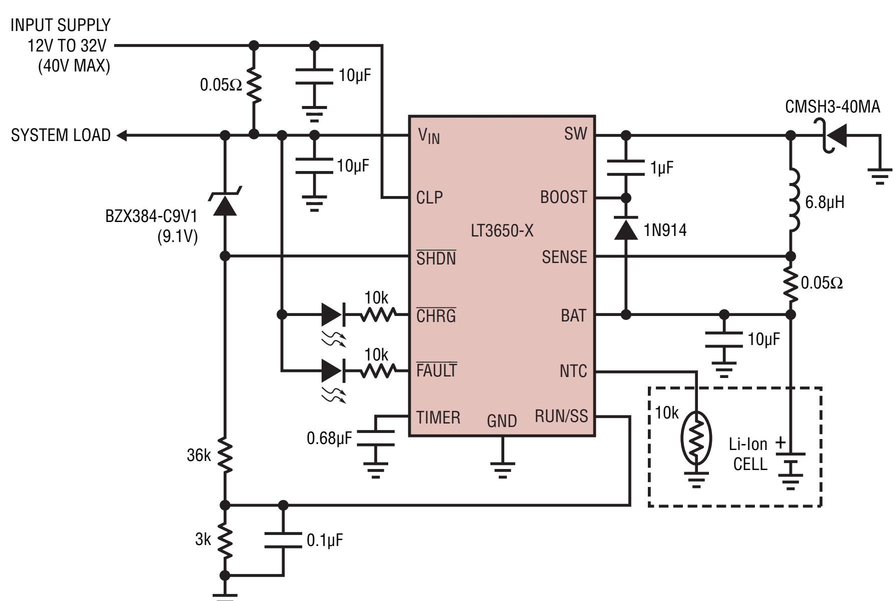

Figure 7. A single cell Li-Ion 2A battery charger with 3 hour safety timer termination, LED status indicators, temperature sensing, low input voltage charge current foldback, and input supply current limit

Status Indicator Pins

The status of a LT3650 charger is communicated via the state of two pins: $\overline{CHRG}$ and $\overline{FAULT}$. These status pins are open-collector pull-down, reporting the operational and fault status of the battery charger. CC/CV charging is indicated while charge currents are greater than 1/10 the programmed maximum charge current. The status pins also communicate bad battery and battery temperature fault states. Table 1 shows a fault-state matrix for these two pins.

The status outputs can be used as digital status signals in processor-controlled systems, and/or connected to pull current through an LED for visual status display. The status pins can sink currents up to 10mA and can handle voltages as high as 40V, so a visual display can be implemented by simply connecting an LED and series resistor to V_{IN}.

Maximum Charging Current Programming and Adjustment

Maximum charge current is set using an external sense resistor placed between the BAT and SENSE pins of the LT3650. Maximum charge current corresponds to 100mV across this resistor. The LT3650 supports maximum charge currents up to 2A, corresponding to a 0.05Ω sense resistor.

The LT3650 includes two control pins that allow reduction of the programmed maximum charge current. The RNG/SS pin voltage directly affects the maximum charge current such that the maximum voltage allowed across the sense resistor is 1/10 the voltage on RNG/SS for RNG/SS < 1V. This pin sources a constant 50µA, so the voltage on the pin can be programmed by simply connecting a resistor from the pin to ground. A capacitor tied to this pin generates a voltage ramp at start-up, creating a soft-start function. The pin voltage can be forced externally for direct control over charge current.

The IC includes a PowerPath™ control feature, activated via the CLP pin, which acts to reduce battery charge current should the load on a

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The LT5581's RMS measurement capability provides accurate RF power readings to within ±0.2dB regardless of waveforms that have high crest-factor modulated content, multicarrier or multitone. Moreover, the LT5581 offers exceptional accuracy of ±1dB over its operating temperature range of –40°C to 85°C.

Operating over a wide supply voltage range of 2.7V to 5.25V, the LT5581's low power consumption makes it ideal for battery-powered communication and multimedia devices. Yet, it has the accuracy performance to meet the performance required by basestations, picocells and femtocells, cable infrastructure and optical communication systems. Additionally, the LT5581's wide frequency range extends to applications including WiMAX and wireless systems in the 5GHz ISM bands. The LT5581's single-ended RF input does not require an external RF transformer, thus simplifying the application design while reducing costs. The LT5581 has a fast response time of 1μs rise time to a full power swing, suitable for time-division duplexing systems.

The LT5581 also incorporates a shutdown feature. When the LT5581's Enable input pin is pulled low, the chip draws a typical shutdown current of 0.2μA, and a maximum of 6μA. The device is offered in a tiny 8-lead, 3mm × 2mm DFN surface mount package.

LT3650, continued from page 7

monitored input supply become excessive. The CLP pin can be configured to implement an input current limit function for systems having multiple loads that share the LT3650 V_{IN} supply. The LT3650 reduces maximum battery charge current if the voltage on the CLP pin exceeds the voltage on V_{IN} by 50mV. Total load current on the input power supply can be monitored by connecting a sense resistor from the CLP pin to V_{IN}, and connecting any external loads to the V_{IN} pin. The LT3650 servos the charger maximum output current such that 50mV is maintained across the CLP sense resistor.

A Full Complement of Battery Charger Features

Figure 7 shows a battery charger that incorporates many of the LT3650's unique features. This charger incorporates top off charging with a 3-hour backup safety timer, and directly accepts input voltages from 12V to 40V (32V operating maximum). This charger uses a 9.1V Zener diode to level-shift the input supply, incorporating an undervoltage lockout function for V_{IN} < 10V.

Battery pack temperature-sensing is enabled by connecting an NTC thermistor to the NTC pin. Charging is suspended if the battery temperature does not remain within a 0°C to 40°C range. The charger uses a resistor divider to modulate the voltage on RNG/SS, which reduces the maximum battery charge current if V_{IN} is below 20V, useful for current-limited input sources such as wall adapters. A capacitor on the RNG/SS pin enables a soft-start function. A secondary system load is supported, with the input supply protected by an input current limit feature, incorporated by connecting the input supply to the CLP pin via a 0.05Ω sense resistor. The maximum charge current is automatically reduced to keep the total input supply current from exceeding the 1A limit set by the sense resistor.

Conclusion

The LT3650 provides a versatile and easy-to-use platform for a wide variety of efficient Li-Ion battery charger solutions. Low power dissipation makes continuous charging up to 2A practical, deriving power directly from input supplies up to 32V without the need for an intermediate DC/DC converter. The compact size of the IC coupled with modest external component requirements allows construction of space saving, cost-effective, and feature-rich Li-Ion battery chargers.

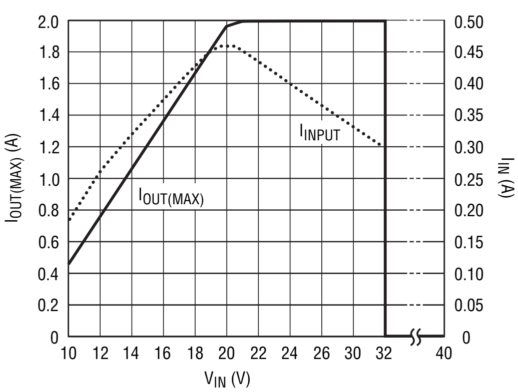

Figure 8. Charger maximum input current (I_{IN}) and maximum output current ($I_{OUT(MAX)}$) vs V_{IN} for the battery charger shown in Figure 7. Charge current reduction for V_{IN} < 20V keeps the charger input supply current below 0.5A

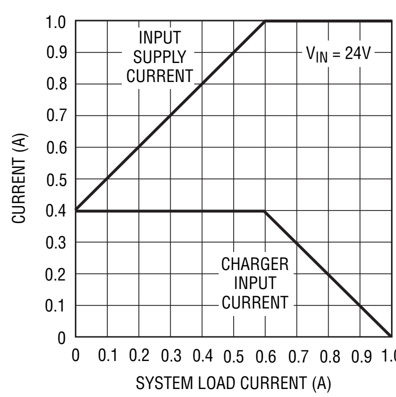

Figure 9. Charger maximum input current, system load current, and total input supply current for the battery charger shown in Figure 7 for V_{IN} = 24V. Battery charger output current is reduced to maintain a maximum input supply current of 1A, which corresponds to 50mV across the 0.05Ω resistor that is connected between the CLP and V_{IN} pins of the LT3650.