BY JINRONG QIAN, PhD • TEXAS INSTRUMENTS

Lithium-ion battery charger provides USB OTG capability

WITH USERS DEMANDING COMMUNICATION AMONG THEIR MOBILE DEVICES, SUPPORTING THE POWER NEEDS OF USB OTG (ON-THE-GO) BECOMES A REQUIREMENT. OPTIMIZE YOUR BATTERY CHARGERS FOR A CURRENT-LIMITED SOURCE, SUCH AS USB, AND FOR SUPPORTING USB OTG SPECIFICATIONS.

The USB (Universal Serial Bus) has been one of the most successful interfaces in the history of PCs. A USB not only transfers data between a portable device and a host PC, it also allows for power transmission over the USB cable. As a result, portable devices can charge lithium-ion batteries while connected to host PCs through a USB cable. You can power most of today's portable products from an ac adapter, a USB port, or a lithium-ion battery.

The USB 2.0 specification defines three modes of operation that allow peripherals to draw current from a USB. The suspend mode allows the peripheral to draw as much as 500 μA. The low-power mode defines the current consumption as high as 100 mA, and the high-power mode limits the current to 500 mA.

Traditional approaches use a low-cost linear-mode charger for USB charging. You usually disable the charger to meet the low-quiescent-current requirements of the suspend mode. The charger also has a current-selection function to set a charge current of either 100 or 500 mA. The charge current is equal to the input current from the USB output for a linear charger. So, the charge current is limited to 100 or 500 mA to meet the USB low- or high-power-mode specification. However, the charge-current regulation tolerance for most low-cost linear chargers is usually approximately ±10%. As a result, the actual typical charge current is set at approximately 90 or 450 mA to prevent it from exceeding the limit of the USB specification. This limit further curtails the charge current available to charge a battery from a USB port.

Most portable devices, such as smartphones, feature e-mail, personal organizers, touchscreens, built-in cameras, and navigation hardware and software. One common requirement is that they all demand more power for performing these advanced functions. Furthermore, the capacity of the lithium-ion batteries used in portable devices is consistently increasing, implying that USB charging time becomes longer due to the charge-current limit for a linear-mode battery charger.

A synchronous-switching converter efficiently uses the available power from the USB to charge a lithium-ion battery, shortens the charging time, and minimizes power dissipation to improve the thermal factors. This device has higher power-conversion efficiency and higher output-charge current for a given input current than does a linear-regulator charger. It steps down the voltage but provides a higher output current than input current.

Considering the power balance between the input and the output, the following **equation** yields the effective battery-charge current for a switching charger: $I_{CHG}=(V_{IN}/V_{BAT})\times I_{IN}\times\eta$, where I_{CHG}, V_{IN}, V_{BAT}, I_{IN}, and η are the battery-charge current, input voltage, battery voltage, input current, and power-conversion efficiency, respectively. This **equation** shows that a synchronous-switching converter provides a higher charge current at a lower battery voltage and a lower charging current at a higher battery voltage but always higher

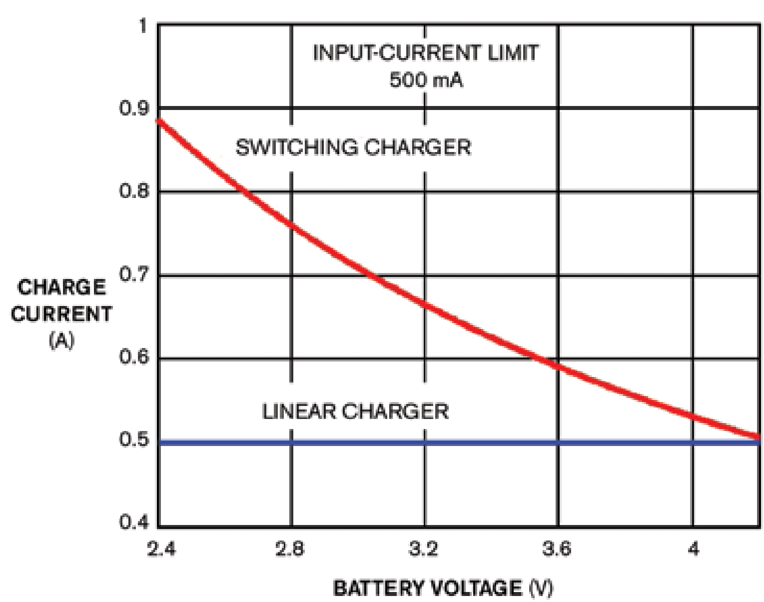

Figure 1 The switching charger can provide 40% higher average charging current than a linear-mode charger.

than the input-current limit when the input voltage is higher than the battery voltage. For USB charging applications, the input voltage is constant at 5V, and the input current is limited to either 100 or 500 mA. Thus, the charge current is inversely proportional to the battery voltage and proportional to power-conversion efficiency. A practical step-down, synchronous-switching buck converter can achieve about 90% efficiency.

INPUT-CURRENT-LIMIT-REGULATION ACCURACY PLAYS AN IMPORTANT ROLE IN MAXIMIZING THE POWER AVAILABLE FROM THE USB PORT.

Figure 1 shows the battery-charge current for a switch-mode, step-down charger and a linear-mode charger with a 5V USB input and 500-mA input-current limit. The switching charger can provide 40% higher average charging current than a linear-mode charger. **Figure 2** shows one example of a 3-MHz synchronous-switching, step-down charger, which integrates N-channel MOSFETs Q_2 and Q_3 that switch on and off at a 3-MHz switching frequency. Operating at this speed means that the circuit can use significantly smaller passive components—the output inductor and the capacitor. Thus, you can use the chip in size-constrained portable devices. N-channel MOSFET Q_1 blocks any leakage current from the battery to the input when the adapter is unconnected. You use a charge-pump circuit comprising bootstrap capacitor C_4 with an integrated diode to drive N-channel MOSFETs Q_1 and Q_2 and to charge capacitor C_4 when MOSFET Q_3 conducts. The integrated Type III loop compensator for battery-charge voltage and current loop further minimizes the need for external components and improves reliability.

You use the typical constant-current/constant-voltage-charging profile to charge a lithium-ion battery. A constant current of less than 1C charge rate—the current to completely discharge the battery in one hour—charges the battery when the battery voltage is below 4.2V for a battery with a lithium-cobalt-dioxide cathode and graphite-anode materials. It operates in constant-voltage mode to improve safety when the battery voltage reaches 4.2V while tapping down the charge current. The charge current and voltage are programmable through the I^2C (inter-integrated-circuit) communication protocol.

USB applications have limited input current. When the input current reaches the maximum current limit programmed by the I^2C, the input-current-regulation loop becomes active and reduces the PWM (pulse-width-modulated) controller's duty-cycle output by sensing current through MOSFET Q_1 so that it will comply with USB specifications. Input-current-limit-regulation accuracy also plays an important role in maximizing the power available from the USB port. With this method, you can achieve less than a 5% tolerance of MOSFET current sensing. **Figure 3** shows the experimental results for charging a lithium-ion battery through a linear charger and a switch-mode charger through a USB port. The switch-mode charger can shorten the battery-charging time by more than 10%.

SAFETY CONCERNS

Safety is a critical factor for consumer products. Input-overvoltage protection is necessary for most popular USB- or mini-USB-cable connections between adapters and portable devices. This feature improves safety by disabling the charger when the input voltage is above a safe voltage threshold. Once you remove the overvoltage, battery charging can resume. This

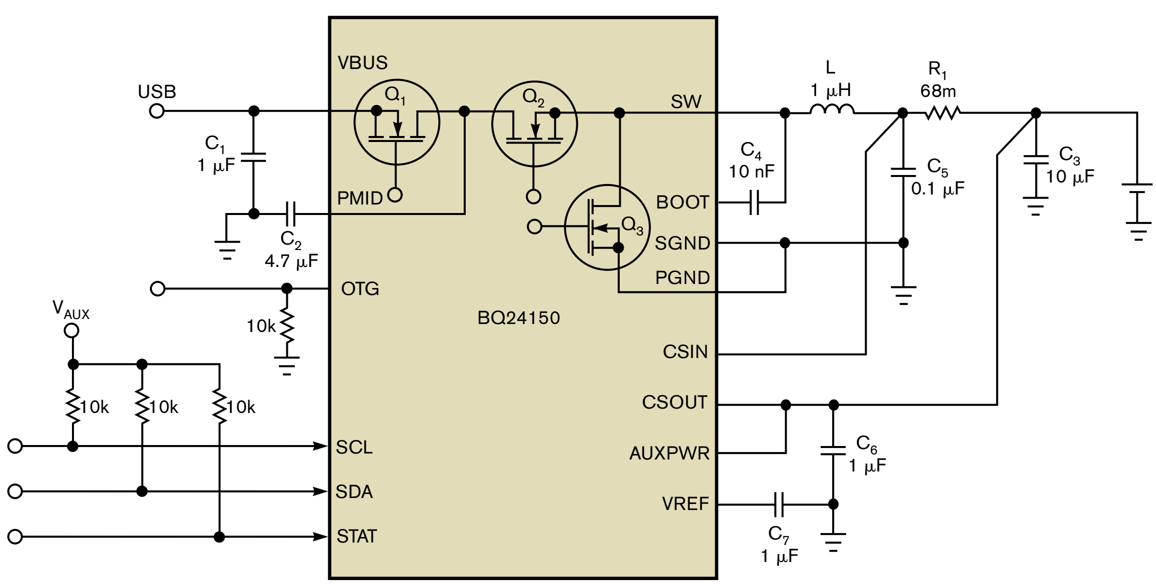

Figure 2 This 3-MHz synchronous-switching, step-down charger integrates power MOSFETs.

protection allows you to use adapters without damaging the charging system. A dynamic host-controlled safety timer starts a 32-minute timer that the host can stop with any write-action through the I^2C interface at the beginning of charging. Once the host stops the 32-minute timer, it automatically resets a 32-second timer by writing a one to the reset bit of the timer reset in the control register. This action causes the host to continuously start the 32-second timer to keep normal charging until charging terminates. If the 32-second timer expires because there is no writing action to the reset bit of the timer reset, the charging terminates, and the charge parameters reset to the default values. The 32-minute timer then restarts, and charging resumes.

During normal charging, a single-cell, synchronous-switch-mode charger, such as Texas Instruments' BQ24150, is in 32-second mode with host control and 32-minute mode without host control (**Reference 1**). The process repeats until the battery fully charges. If the 32-minute timer expires without a write command, it turns off the charger and announces a fault on the status register. This function prevents the battery from overcharging. Such dynamic host-controlled battery charging ensures that the battery is charging safely.

Thermal safety is another important consideration for integrated-power-MOSFET converters. One effective approach is to monitor and regulate the silicon-junction temperature in real time by introducing a thermal-regulation loop. You accomplish this task by reducing the charging current to control power dissipation and improve the thermal design so that the charger can operate safely.

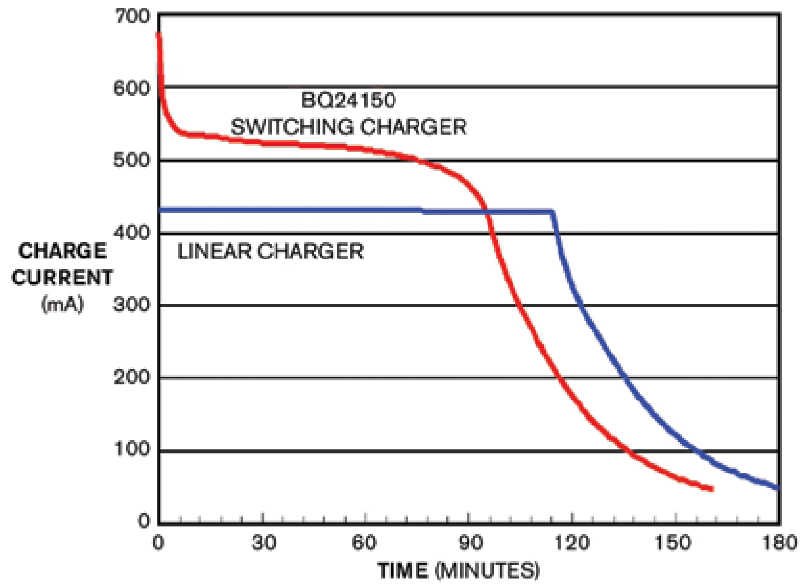

Figure 3 An experimental test-battery charge profile shows that the switch-mode charger can shorten the battery-charging time by more than 10%.

Go to www.edn.com/ms4306 and click on Feedback Loop to post a comment on this article.

For more technical articles, go to www.edn.com/features.

USB OTG SUPPORT

When you connect a portable device to a laptop computer through a USB port, you are automatically configuring the laptop as a host to provide 5V USB voltage for data communication. However, this configuration does not define the host for the communication between two portable slave devices—for example, sending the photos from a digital still camera to a cellular phone through a USB cable. USB OTG determines which system will be a host to provide 5V USB voltage from a lithium-ion battery. You cannot use a linear charger as a boost converter for this task.

You can use a synchronous-switching step-down converter as a bidirectional power converter, a synchronous boost converter, and a method of boosting the battery voltage to the 5V USB voltage to power another portable device in the USB port. For typical USB OTG applications, maximum output current of 200 mA is good enough for normal operation. High light-load efficiency is critical for extending battery runtime, which requires that the boost converter in USB OTG mode operates in PFM (pulse-frequency-modulation) mode to minimize switching losses. The typical application circuit in **Figure 2** operates in boost mode when you enable the USB OTG function. This feature enables support for the USB OTG specifications and facilitates communication between two slave portable devices.

The fully integrated, 3-MHz, synchronous-switching, step-down battery charger makes more efficient use of USB-port power, provides speedier charging for lithium-ion batteries, and provides 10% shorter USB charging time than does a linear-mode charger. The integrated loop compensator and 3-MHz switching frequency allow use of a chip inductor for minimizing the need for a number of external components. It also provides USB OTG support to allow communication between two slave mobile devices. EDN

REFERENCE

1 "BQ24150/51 Fully Integrated Switch-Mode One-Cell Li-Ion Charger with Full USB Compliance and USB-OTG Support," Texas Instruments, focus.ti.com/lit/ds/symlink/bq24150.pdf.

AUTHOR'S BIOGRAPHY

Jinrong Qian, PhD, is an applications-engineering manager and distinguished member of the technical staff for the battery-management group at Texas Instruments. He has published myriad peer-reviewed power-electronics transactions and power-management papers and holds 20 US patents. Qian earned a bachelor's degree in electrical engineering from Zhejiang University (Hangzhou, China) and a doctorate from Virginia Polytechnic Institute and State University (Blacksburg, VA). You can reach him at ti_jinrongqian@list.ti.com.