Battery-charging considerations for high-power portable devices

By Tahar Allag
System Engineer
Wenjia Liu
Applications Engineer

Introduction

Cell phones are a good example of how functionality and performance have both increased significantly in portable devices over the last few decades. They have become more complex and can do many basic tasks as well as any computer. The extra functionality that has transitioned the smartphone from a phone-call-only device to a multi-purpose portable device, which makes it more power hungry than ever before.

The internal battery pack is the main source of storing and delivering power to portable-device circuitry. Battery-charger ICs are responsible for charging the battery pack safely and efficiently. They must also control the power delivery to the system to maintain normal operation while plugged in to wall power. The battery pack is required to store a large amount of energy and be charged in a short amount of time without sacrificing weight and volume. The increased charge and discharge currents, as well as the smaller physical size, make the packs vulnerable to physical and thermal stresses. Therefore, battery chargers are no longer required to perform just as a simple stand-alone charger.

To maintain reasonable charge times and safe charging conditions, a battery-charger IC is required to be flexible because it must guarantee power to the system at all times and provide proper protection for both the battery and system. This article explores single-cell battery-charger solutions and includes a detailed discussion about the performance and constraints of chargers for compact high-power applications.

An overview of single-cell charging solutions

Rechargeable batteries are vital to portable electronic devices such as cell phones and wearable electronics. Charging circuits must be carefully designed and are highly dependent on three factors: battery chemistry, power levels, and system load. Different battery chemistries require different charging methods. An application's power requirements directly impact the charging system's cost and size. Finally, the system power requirement must be considered to determine the necessity of a power-path versus a non-power-path system.

Lithium-Ion (Li-Ion) batteries are becoming the chemistry of choice for many portable applications for several reasons. They offers a high capacity-to-size and weight ratio, and they have low self-discharge characteristics. They also have high cell-voltage characteristics, typically 3.6 V, which allows a battery pack to be designed with only one-cell. Despite all these advantages, Li-Ion batteries are fragile to stress. They require many special considerations regarding charge current, regulation voltage, trickle charge levels, temperature monitoring, and so on.

There are two basic types of charging methods: linear and switch-mode charging. Switch-mode charging minimizes power dissipation over a wide range of AC-adapter voltages, but consumes more board space and adds complexity. Additionally, switch-mode applications generally are higher cost than an equivalent linear application.

Linear chargers are smaller and great for noise-sensitive equipment. However, they are not as efficient across the entire charge cycle as their switch-mode counterparts. When selecting a charging method, the designer makes the decision by prioritizing cost, space, bill-of-material (BOM) count, and efficiency (thermal loading).

The variety of system requirements drive many different battery-charger solutions; from a simple standalone charger to an embedded charger that also provides system power. System requirements include, but are not limited to:

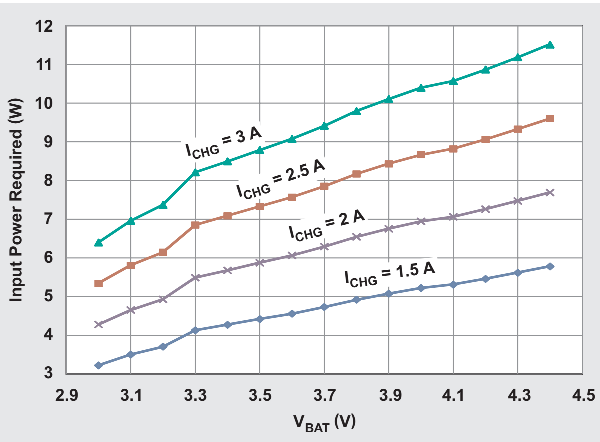
- The need for dynamic power path management (DPPM) that guarantees system instant-on with discharged or disconnected battery.
- Low FET $R_{DS(on)}$ for both the battery and system path to guarantee acceptable overall system efficiency and thermal management.
- High charge current to support high-capacity battery packs and shorten the charge time.
- Input-voltage dynamic power management (DPM) that supports the limitation of any adapter and/or USB port.

Compact single-cell charger applications

Power requirements (adapter limitation)

Currently, most smartphone adapters are specified for 5- to 10-W maximum output power. Figure 1 shows the input power needed from the USB port or adapter for different charging current levels. For a 1.5-A charge current, the required power increases linearly from 3 W to 5 W as the battery voltage increases from 3 V to full charge. For a 3-A charge rate, up to 12 W is needed from the input during the charge cycle. In this scenario, depending on the battery's state of charge, a 5-W or 10-W adapter can crash and the system collapses. To prevent this from happening, the charger is required to have some kind of protection to reduce the power drawn from the input.

Figure 1. Input power needed for different charge currents



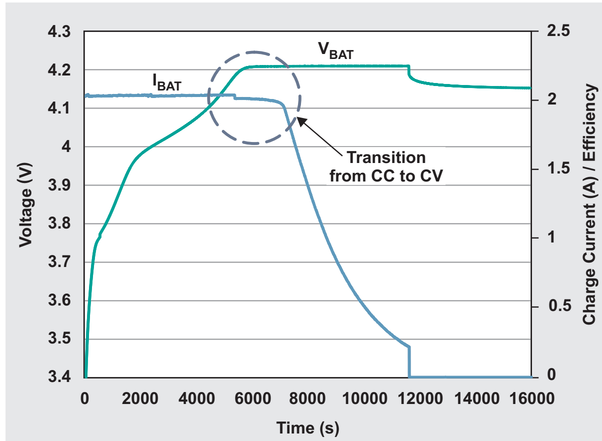
A battery charger such as the bq24250 from Texas Instrument has dynamic power management (DPM) that monitors input voltage (V_{IN_DPM}). During the normal charging process, if the input power source is not able to support the programmed or default charging current, the input voltage decreases. If the input voltage drops to the V_{IN_DPM} threshold set by the designer, the charge current is reduced. This limits the power drawn from the input supply and prevents further drop of the input voltage. This feature ensures IC compatibility with adapters that have different current capabilities without any hardware change.

Charge time

As described earlier, charge time depends on the battery capacity and charge rate. The easiest way to decrease charge time is to charge at a faster rate. However, charging a battery with higher than 80% (0.8C) of the battery's full capacity causes stress on the battery. This decreases its lifetime or possibly damages the pack with catastrophic results. Texas Instruments has developed charge-time optimization of charge cycles to reduce charge time for a given charge rate compared to other solutions.

The charge cycle of Li-Ion batteries is mainly composed of three phases: pre-charger (trickle), fast charge (constant current), and taper (constant voltage). The transition between one phase to another is not ideal for many switch-mode chargers. Figure 2 highlights the phase transition from constant current to constant voltage in a legacy charger circuit. Both voltage and current do not have a sharp transition. This behavior causes both time and power loses during the charge cycle.

Figure 2: Charge cycle of a legacy charger without time-optimizer technology



A Li-Ion battery charger from Texas Instruments improves this transition using the time-optimizer technology. Figure 3 shows a charge cycle of the same battery and under the same charging conditions as in Figure 2. The charge time is reduced by more than 15%. The transition is much sharper on the new charger, which spends more time in the fast-charge (CC) phase before transitioning into the taper (CV) phase. This puts more Coulombs into the pack at a faster rate, thereby reducing the charge time without increasing the charge rate.

Figure 3: Time-optimized charge cycle for a switch-mode Li-Ion battery charger

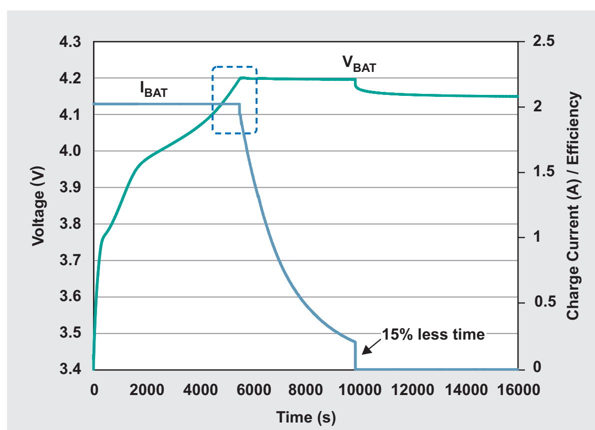
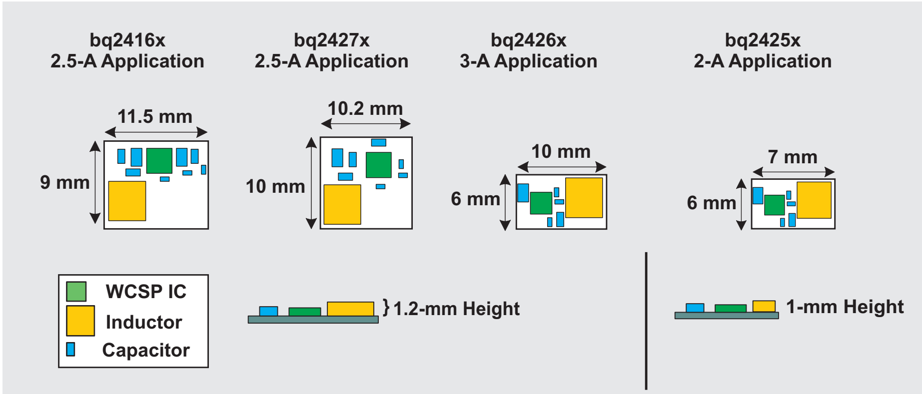


Figure 4: DPPM charger application area for different applications



Board size and BOM cost

For higher charge rates, linear chargers become less attractive. Their reduced efficiency over the charge cycle increases thermal loading on the system. This is especially true in size-constrained boards and high-power applications. These conditions drive the requirement for a fully-integrated switch-mode charger.

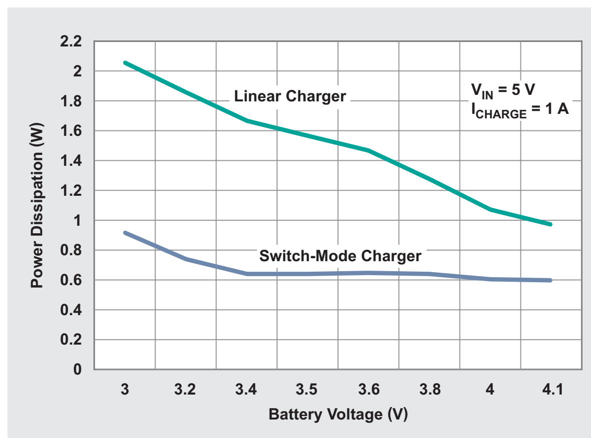
Vendors such as Texas Instrument are pushing the envelope of innovation to meet market demand by reducing the BOM cost and board space without sacrificing device performance. For example, the bq24250 is a highly-integrated single-cell Li-Ion battery charger and system power-path management IC targeted for space-limited, portable applications with high-capacity batteries. Figure 4 shows a range of devices with actual application area size. For instance, the bq2425x family of chargers can provide a charge current of up to 2 A, an economical BOM, and a 42-mm^2 application area.

Thermal performance and efficiency

Reducing the size of the charger area affects the thermal performance of the whole board. Less available area results in less space to dissipate the heat caused by the power dissipated during charging. For a given board area, the only way to reduce thermal loading is to improve charger efficiency during power conversion. Higher efficiency results in lower power dissipation. Thus, less heat is generated from the IC and the board.

When comparing power dissipation between linear and switch-mode chargers in higher power applications, linear chargers becomes less desirable as the power dissipated can be very high—especially for lower battery voltages. This is because the linear chargers use a linear regulator to do the power conversion. On the other hand, switch-mode charging is much more efficient over the entire battery voltage range and results in less power dissipation. Figure 5 shows a comparison in power dissipation between linear and switch-mode chargers.

Figure 5: Comparison of power dissipation between a linear versus switch-mode charger



Choosing a switch-mode charger over a linear charger is a logical choice to improve charger thermal dissipation on the board. Lowering the $R_{DS(on)}$ of the integrated FET inside the switch charger helps improve charger efficiency at high currents. This is because most power dissipation at higher currents for a switch charger is caused by the FET's $R_{DS(on)}$. The bq24250 Li-Ion battery charger has integrated power FETs with low $R_{DS(on)}$. Internal high-side and low-side MOSFETs are rated to only 100 mΩ each.

This helps reduce power dissipation from the input to system output. The $R_{DS(on)}$ of the FET switch to the battery is only 20 mΩ. This also helps reduce losses during battery charging and discharging. Figure 6 provides system efficiency data for the bq24250, which can be as much as 95%.

Battery protection and battery-life extension

A major issue with the high-power portable electronics is battery life cycle. The reduction of battery capacity over time greatly impacts the user's experience by reducing runtime. The main contributor to improve the battery pack life cycle is to reduce stress during charge and discharge. Li-Ion batteries are very sensitive to stresses caused by overcurrent or overvoltage on the pack.

Battery-charger ICs such as the bq24250 can regulate the battery voltage with ±0.5% accuracy in room temperature. For charge current, this IC provides ±0.75% accuracy for up to 2-A charge current over the 0 to 125°C temperature range. This accuracy allows designers to precisely program the voltage and current level according to the application needs. With these accurate charging parameters, batteries can be charged more aggressively without reducing the life cycle. Thus, charge time is reduced while maintaining a safe charging solution.

Figure 7 shows the accuracy of three charge currents over temperatures ranging from 0°C to 125°C . For up to 1.5-A charge currents, accuracy is within 2% of the typical value shown in the datasheet.

System-off mode (SYSOFF)

During presale shipping and storage, the battery needs to be disconnected from the rest of the system to prevent depleting the battery. The bq24250 battery charger has a SYSOFF mode that can be set to turn off the battery FET and disconnect the battery from the system. When the SYSOFF mode is used, the leakage current from the battery into the IC is reduced to less than 1 µA (Figure 8). The designer programs the system to automatically exit SYSOFF mode when the end customer plugs a power supply into the charger.

Application flexibility

In today's highly competitive market, most players are constantly pursuing lower costs, which potentially can bring higher margins and greater competency. Being able to repurpose the same chip for various products or multiple generations has a direct cost savings for different system designs. It also shortens the application learning curve and avoids unnecessary risk by using a known working solution.

The market is pushing for a family of battery chargers that integrates several features to provide flexibility for different applications. One example is a charger with a wide input-voltage range so it is applicable for a broad range of adapters, which could potentially reduce inventory costs. The flexibility in charge currents can support the higher current for applications like power banks and smartphones as well as low-level charging to applications like *Bluetooth*® headsets.

Figure 6: System efficiency of the bq24250 Li-Ion battery charger—4.2-V regulation

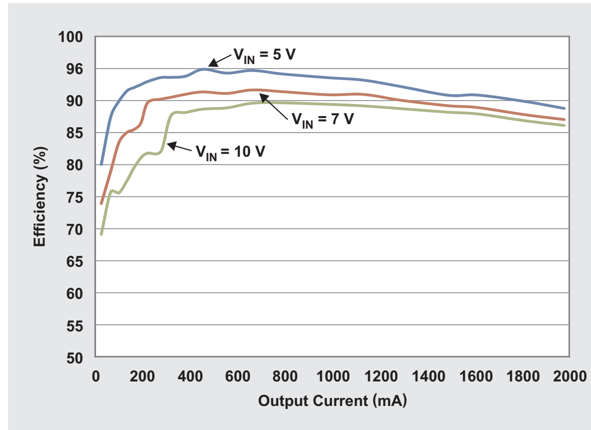


Figure 7: Charge current accuracy versus temperature

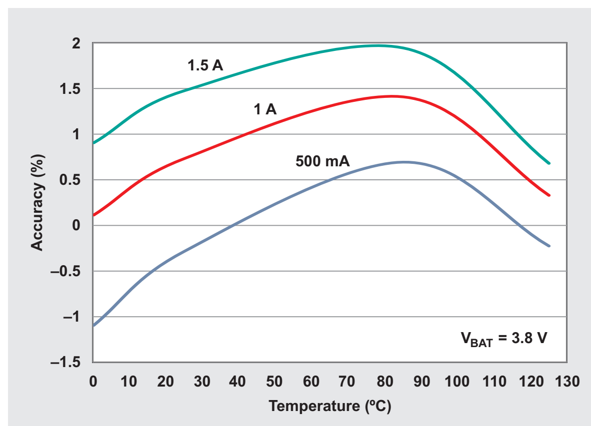
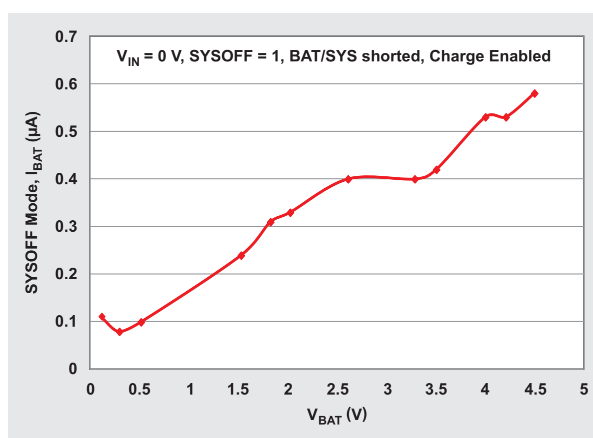


Figure 8: Battery leakage current in SYSOFF mode



Many chargers provide two chip-control schemes: I^2C communication and standalone. This allows the tailoring each application as needed. In I^2C mode, designers can program various parameters such as V_{IN_DPM} threshold, charge current, input current limit, regulation voltage, and termination level. When operating in standalone mode, where the host control is not desired, designers can use external settings to program the above parameters and utilize external pins to select different levels of input-current limit and to enable/disable the chip.

The BC1.2-compliant, D+/D– USB detection feature offers greater flexibility for more robust USB charging. In the past, USB charging was very straight forward where the device took power directly from the USB port to the battery with little control. In today's high-power applications, devices are requesting far more power from the USB port, which leads to more complicated standards and protocols being implemented. Furthermore, with the various USB standards normalized in the same USB port connector, the ability to recognize which type of device is connected is a very useful and competitive feature.

Conclusion

There are many options available for charging high-power portable devices. Currently available charging ICs that support power-path management and high charging current with improved efficiency can reduce charge time, thermal stress and solution size. A low-cost BOM and a small size solution bring the device cost down without sacrificing size and capability.

References

1. Texas Instruments. "Reference Design for 2A Single Input I2C/Standalone Switch-Mode Li-Ion Battery Charger," Reference Design. Available: www.ti.com/2q14-tida00048
2. Tahar Allag and James Smith, "Using bq2425x's DPM Feature for Solar Panel Applications," Application Report, July 2013. Available: www.ti.com/2q14-slua687
3. Tahar Allag and James Smith, "Selecting the Best bq2425x Single Cell I2C, Standalone Switch-Mode Battery Charger for your Application," Application Report, June 2013. Available: www.ti.com/2q14-slua685

Related Web sites

www.ti.com/2q14-bq24250

www.ti.com/2q14-bq24251

www.ti.com/2q14-bq24253

www.ti.com/2q14-bq24257

Subscribe to the AAJ:
www.ti.com/subscribe-aaj

TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page
support.ti.com

TI E2E™ Community Home Page
e2e.ti.com

Product Information Centers

Americas	Phone	+1(512) 434-1560
Brazil	Phone	0800-891-2616
Mexico	Phone	0800-670-7544
	Fax	+1(972) 927-6377
	Internet/Email	support.ti.com/sc/pic/americas.htm

Europe, Middle East, and Africa

Phone

European Free Call	00800-ASK-TEXAS (00800 275 83927)
International	+49 (0) 8161 80 2121
Russian Support	+7 (4) 95 98 10 701

Note: The European Free Call (Toll Free) number is not active in all countries. If you have technical difficulty calling the free call number, please use the international number above.

Fax	+(49) (0) 8161 80 2045
Internet	www.ti.com/asktexas
Direct Email	asktexas@ti.com

Japan

Fax	International	+81-3-3344-5317
	Domestic	0120-81-0036
Internet/Email	International	support.ti.com/sc/pic/japan.htm
	Domestic	www.tij.co.jp/pic

Asia

Phone — Toll-Free Number

Note: Toll-free numbers may not support mobile and IP phones.

Australia	1-800-999-084
China	800-820-8682
Hong Kong	800-96-5941
India	000-800-100-8888
Indonesia	001-803-8861-1006
Korea	080-551-2804
Malaysia	1-800-80-3973
New Zealand	0800-446-934
Philippines	1-800-765-7404
Singapore	800-886-1028
Taiwan	0800-006800
Thailand	001-800-886-0010

International	+86-21-23073444
Fax	+86-21-23073686
Email	tiasia@ti.com or ti-china@ti.com
Internet	support.ti.com/sc/pic/asia.htm

IMPORTANT NOTICE

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265