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Smart Batteries: Not Just for Notebooks Anymore

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Introduction

With the backing of Intel and Microsoft, Smart Batteries have become the dominant battery pack solution for products that require an accurate gas gauge to predict battery life. The Smart Battery System (SBS) has simplified the design of standalone battery systems so much that it is showing up in applications outside its usual realm of notebook computers. For instance, the SBS is gaining popularity in backup power systems for mission critical high reliability applications.

The attraction of the SBS is that its modular nature makes easy to design a closed loop battery-charge system, and upgrade components as needed. All of the safety features are taken into account within the battery. This minimizes NRE costs and makes for robust systems, especially important to high reliability battery-backup applications. There is no need to become a battery expert to take advantage of the features of the SBS.

The first part of this article offers an overview of the SBS; the second part describes two of Linear Technology's Smart Battery Chargers.

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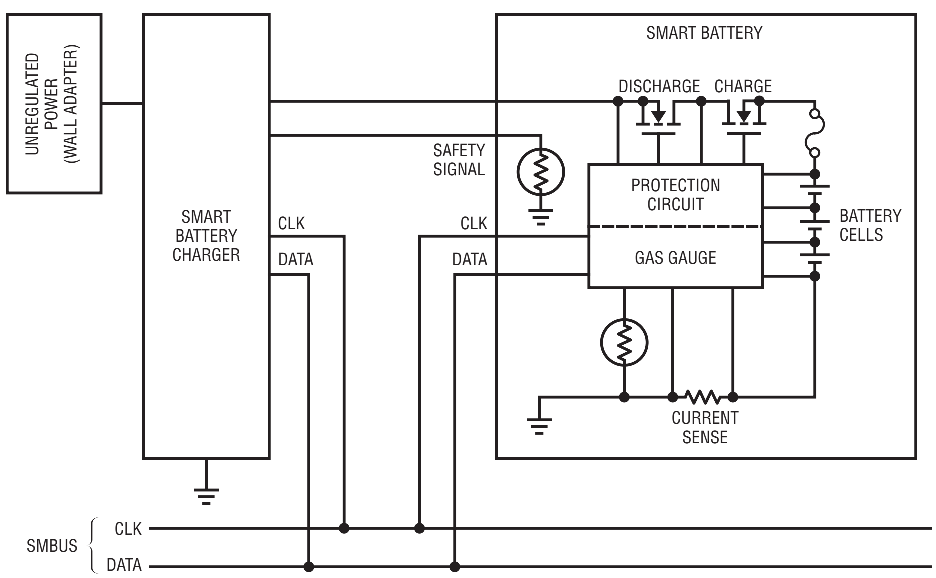

Figure 1. Simplified schematic of a Smart Battery and Smart Battery Charger. Smart Batteries have an integrated gas gauge, which communicates the condition of the battery, and requests charge (voltage and current) over the SMBus. Charge requests are satisfied by the Smart Battery Charger, which applies the requested voltage and current to the battery terminals. The beauty of the system is that the charger does not need to know the chemistry of the battery. It is up to the gas gauge to maintain the charge algorithms. The modular nature of the SBS allows for any Smart Battery Charger to charge any Smart Battery.

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About the Smart Battery System

Figure 1 shows a simplified block diagram of a Smart Battery. The biggest benefit of the Smart Battery System is the highly accurate gas gauge integrated into the battery pack. The gas gauge, as the name implies, indicates how much energy is left in the battery.

An integrated gas gauge can monitor the battery even when the battery is on the shelf, and the gas gauge is calibrated to a single battery, so accuracy is assured. A host-based gas gauge can't match this. Gas gauge measurement techniques have evolved to the point that the latest gas gauges are self-calibrating—error rates are at 1% over the lifetime of the battery. Because the gas gauge knows the battery better than any other circuit can, it is responsible for charge and discharge management.

Smart Battery Chargers

In an SBS Li-ion battery pack, there are built-in MOSFETS that can block charge or discharge current (see Figure 1). The SBS gas gauge can easily prevent over-discharge by turning off the discharge MOSFET when the battery voltage reaches a certain point; but when it comes to charging the battery, the gas gauge must work with an external charger. Smart Batteries are designed to work with Smart Battery Chargers. A Smart Battery Charger has advantages over a fixed standalone charger, such as:

- ❑ True Plug and Play operation, independent of battery chemistry and cell-configuration. Any Smart Battery Pack will work with any Smart Battery Charger. Batteries with different chemistries, cell-configurations, and even different charge algorithms can be swapped with no modification to the charger circuit.
- ❑ Built in safety features. The battery, because of its gas gauge, takes care of itself.
- ❑ A reliable battery detection system.
- ❑ Automatic charge management without the need of a host processor.
- ❑ Any Smart Battery and Smart Charger form a closed loop charge system that requires no host processor intervention. A host is welcome to gather gas gauge information if required.

To understand how all this is possible, let's see how the Smart Battery system actually works.

More Information about Smart Batteries…

- ❑ SBS gas gauge www.sbs-forum.org/specs/sbdat110.pdf
- ❑ Smart Batter Charger www.sbs-forum.org/specs/sbc110.pdf
- ❑ Smart Battery System Manager (SBSM) www.sbs-forum.org/specs/sbsm100b.pdf
- ❑ SMBus ....www.smbus.org/specs

How SMBus is used for a Closed Loop Charge Process

The Smart Battery System utilizes the System Management Bus or SMBus standard, which is a based on, and a subset of, the very popular and now recently made public domain two wire I^2C serial bus standard. In practice SMBus devices easily coexist with I^2C devices on the same bus.

The Smart Battery Standard defines fixed addresses for the battery and charger, and it defines some commands that allow the gas gauge to communicate to the Smart Battery Charger over the SMBus. This forms a closed loop system where the gas gauge determines the charge state of the battery, and evaluates other conditions (such as battery temperature) to see

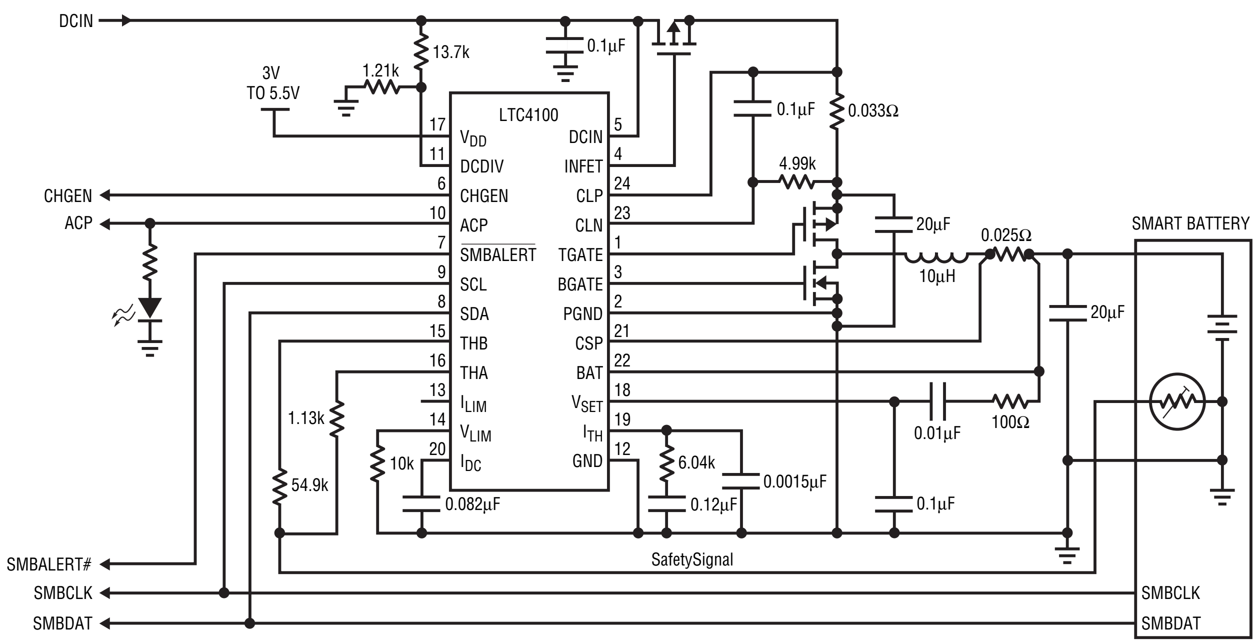

Figure 2. The LTC4100 in a feature-rich, simple and compact 4A Smart Battery charger

if a safe charge can be performed. The gas gauge requests a charge current and voltage from the Smart Charger via the SMBus. Because the gas gauge is in charge, the charger is not burdened with algorithms involving the battery cell configuration or chemistry.

When the gas gauge requests charge, the Smart Charger evaluates the requested charge parameters and does the best job it can to comply with them while at the same time independently evaluating various safety conditions. In order for charge process to happen, *both* the battery and the charger must agree it is safe to proceed. This keeps the loop simple and safe.

Flexible Communications

Although the SMBus standard only allows a single battery and a single charger to exist on a bus, multiple *bus masters* can coexist on the same bus. This allows the "Smarts" of the Smart Battery System to be distributed or augmented.

If you read Smart Battery Specifications, you might come across the terms called levels such as level 2 and level 3. This has nothing to do with sophistication or revision levels. It simply is a way of defining who is primarily responsible for the communication of charge request between the battery and the charger. A level 2 system means the Smart Battery is an SMBus bus master and transmits its charge commands to the charger directly. This is the simplest loop. A level 3 system means any device other than the Smart Battery itself, such as a host, is responsible for sending the commands to the charger. The latter configuration allows for other devices to take more control of the process to implement other unique features beyond those available by default with a level 2 system. Linear technology takes advantage of that capability in the LTC1760 smart charger by building the bus master into the charger. This allows for parallel charge and discharge of dual batteries, which has numerous advantages, explained in the "LTC1760 Dual Smart Battery Charger" section, below.

Safety and Reliability in the SMBus

The SMBus standard incorporates fail-safe mechanisms for SMBus crashes or hangs that allow bus recovery. The charger has watchdog timers that monitor the frequency of charge request commands, and can detect a loss of communication or closed loop operation so that it can pause the charge process and prevent accidental overcharge. For Li-ion batteries this is critically important.

Battery Detection via the Safety Signal

Reliable battery detection and additional safety is achieved by use of the Safety Signal, formerly known as the thermistor signal. The Safety Signal is produced by applying a voltage to a resistor, or thermistor in the Smart Battery via the dedicated SS pin (see Figure 1). A Smart Charger can measure the value of the resistance of the SS pin to ground, and from the resulting value, know if the battery is physically present, and if an NTC thermistor is present, determine if the temperature range is acceptable to allow charge.

The thermistor on the Safety Signal is *not* the same thermistor the gas gauge uses to evaluate temperature. It is a redundant system check that allows the charger to make its own determination, independent of the gas gauge.

Alarms Warn of Impending Problems

An active safety feature called alarms is available to the Smart Battery. Alarms cover temperature, overcharge and over-discharge fault conditions, and are sent when the battery is close to taking direct action to stop the condition of concern. The gas gauge can send alarms to both the host and the Smart Battery Charger via the SMBus.

Over-Discharge Recovery

Over-discharge presents a special challenge that is fully addressed by the Smart Battery System. What happens if the battery does not have enough charge to support SMBus communications? One cannot attempt to detect the battery via its terminals, since the gas gauge will have already turned off the discharge MOSFET to protect the battery cells. A Smart Battery Charger, though, can use the safety signal to check for the battery pack, regardless of its state of charge.

A Smart Battery Charger, upon detection of a new battery, applies a constant current charge up to 100mA to the battery terminals. This low current quickly charges the cells enough

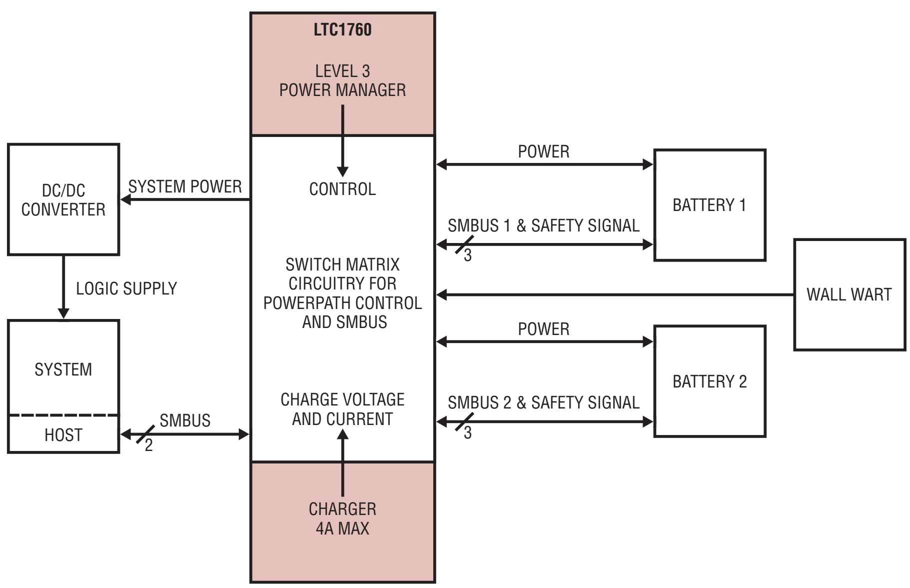

Figure 5. Simplified schematic of a dual battery system using the LTC1760. The LTC1760 acts as a Level 3 bus master, and handles both charge and discharge of the batteries. Even batteries of different chemistries or cell configurations can be used.

to where the gas gauge can come on line and take over the recovery charge process. As soon as the gas gauge sends its first valid charge request commands, the Smart Battery Charger stops applying the wake up charge and immediately implements the requested charge values. A wake up charge is not applied again until a new battery physically takes its place.

As foolproof as this recovery process sounds, there is one more safety issue to address. Consider the case where a new fully-charged Li-ion battery is attached to a Smart Charger, but permanent SMBus communication problems prevent the battery from communicating over the SMBus. The charger would apply the wake up charge indefinitely in the absence of any requests from the gas gauge. This would lead to a potentially dangerous overcharge situation.

To cover this situation, the Safety Signal comes to the rescue again. The resistance of the safety signal can fall into several ranges. Each range defines the acceptable duration of the wake up charge. Batteries thus fall into two categories: those that have the chemistry to receive an indefinite wake up charge and those that can only accept a short 3-minute wake up charge. NiMH batteries fall into the first category where as Li-ion batteries fall into the latter category. In the case of a damaged Li-ion battery, the battery will only receive a short wake up charge, thus preventing the possibility of accidental overcharge. The downside of this important safety feature is that overly discharged batteries *must* be designed to allow SMBus communication to be established within those three minutes regardless of the state of the cells.

Space Saving, Advanced Smart Battery Chargers

As shown above, the Smart Battery System offers advanced capabilities with little required design effort. Linear Technology's Smart Battery Chargers take advantage of Smart Battery System features and add a few of their own, while maintaining compliance to the standard.

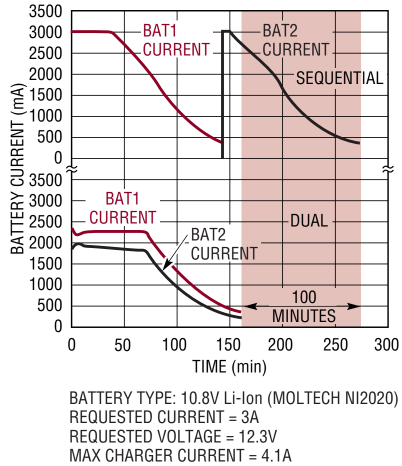

Figure 3. Charging batteries in parallel is almost twice as fast as charging them sequentially.

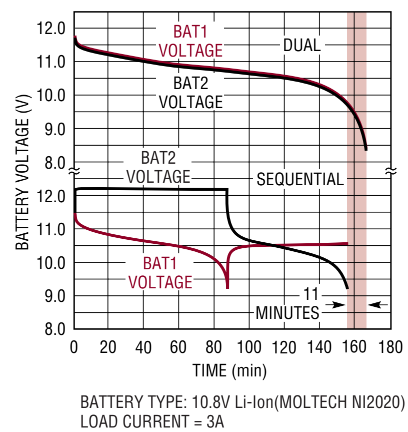

Figure 4. Batteries can run longer when discharged in parallel than they would when discharged sequentially.

In an SBS, the charger resides in the system, sharing precious PCB real estate with other devices. Linear Technology has two products that directly address those needs: The LTC4100 single Smart Battery Charger and the LTC1760 dual Smart Battery Charger are switching buck regulators that include features defined in the Smart Battery standard and other important performance enhancements.

One of the most important recent advances in DC/DC converter design is the use of high capacitance and voltage (high C/V) ceramic capacitors. In switching regulator applications, their low ESR allows them to handle large ripple current per µF of capacitance compared to most other types of capacitors, even while remaining inexpensive to buy.

Ceramics have a problem, though. They have piezo-electric properties that can generate audible noise with the PCB acting as a sounding board. There are conditions where audio-frequency signals are generated by typical switching battery chargers. The LTC4100 and LTC1760 are designed to operate outside of the audio range to avoid this problem.

Another challenge is to use smaller inductors, which usually means a reduction in inductance value while still support high currents. Smaller inductance for a given switching frequency means more ripple current and the corresponding increase in capacitor count to handle the higher ripple current. To keep the ripple current down, the switcher must switch at higher frequencies than before. The LTC4100 and LTC1760 operate at 300kHz, which allows the use of small inductors.

The LTC4100 Single Smart Battery Charger

Single battery applications tend to be systems that are smaller or have lower power requirements. The LTC4100 is a Level 2 (slave) Smart Battery Charger specifically designed to reduce PCB space. It is compliant with both the V1.1 of the Smart Battery Charger and SMBus V1.1 standards. Figure 2 shows a typical application circuit.

The LTC4100 includes a host of features to improve charge times in a variety of applications:

- ❑ It can charge batteries up to 4A and switch continuously down to zero load current, so as to not make audible noise under any conditions and take full advantage of ceramic capacitors capabilities.
- ❑ The high 300kHz switching frequency allows the use of small, common, low cost 10µH inductors and ceramic capacitors for bulk C filtering.
- ❑ Input voltage range is 6V to 32V while output charge voltage range is from 6.4V to 26V.
- ❑ Precision charge capabilities are assured by the 10-bit current DAC and an 11-bit voltage DAC

with accuracies of 5% and accuracies of 0.8%, respectively.

- ❑ A topside P-channel MOSFET allows 98% maximum duty cycles, dramatically reducing total part count and IC pin count while providing efficiency greater than 95%.
- ❑ SMBus accelerators keep the data moving along in high capacitance traces while preventing bus noise from corrupting data. (More information about SMBus accelerators is available in the LTC1694 datasheet).
- ❑ A user adjustable AC present signal with precision 3% accurate user adjustable trip points.

The LTC4100 also includes important protection features:

- ❑ A safety signal circuit that rejects false thermistor tripping due to ground bounce caused by the sudden presence of high charge currents
- ❑ A DC input FET DIODE circuit that prevents battery current from flowing backwards into the wall adapter or DC power source
- ❑ An ultra fast overvoltage comparator circuit prevents voltage overshoot when the battery is suddenly removed or disconnects itself during charge
- ❑ An input current limit sensing circuit that is used to reduce charge current to prevent wall adapter overload as the system power increases.
- ❑ Many unique features, such as a special current limit and voltage limit system, which prevents SMBus data corruption errors from generating false charge values that would potentially harm the battery.

The LTC1760 Dual Smart Battery Charger

The LTC1760 complies to the Smart Battery System Manager (SBSM) specification V1.0.

The LTC1760 has all the same basic electrical specifications as the

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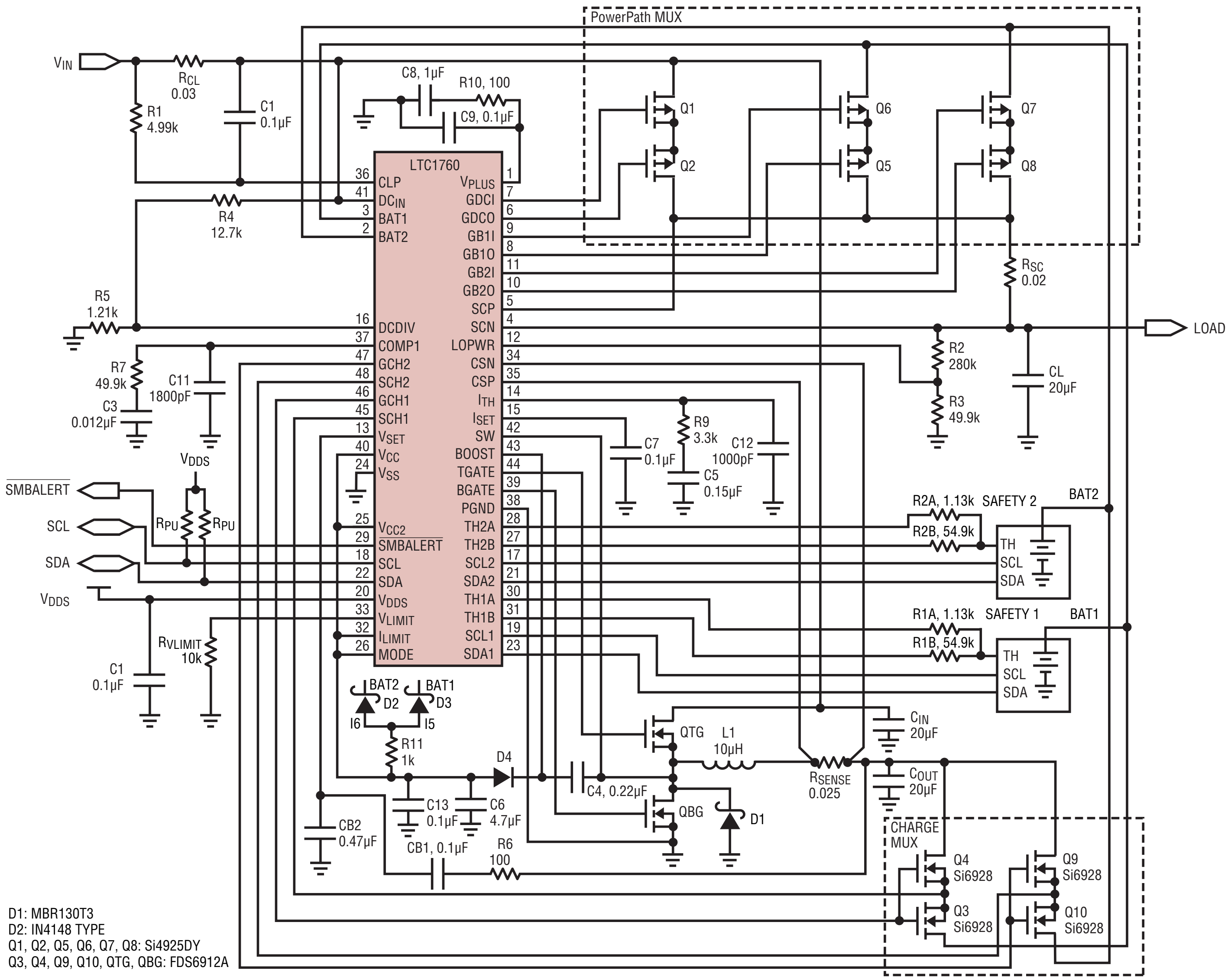

Figure 6. Dual battery charger/controller safely charges and discharges two Smart Batteries in parallel, even two batteries with different chemistries. Parallel charge and discharge is far more efficient and faster than serial charging, and some high power applications require parallel discharge of batteries to supply higher currents than a single battery can offer.

input), the catch MOSFET turns OFF. The 10.5mV current sense threshold of CS+ input is temperature dependent so it can follow the temperature variation of the MOSFET's $R_{DS(ON)}$, as long as it is mounted close to the MOSFET on the PC board. To calculate the amount of reverse current that turns the catch MOSFET off, use $R_{DS(ON)}$ at room temperature with a 10.5mV current sense threshold. Just as with the Timer function, the catch MOSFET should not be turned off under normal conditions. Therefore, a catch MOSFET with sufficiently low $R_{DS(ON)}$ should be used or voltage divider on the CS+ pin can be added.

Conclusion

The LTC3900 MOSFET is a comprehensive solution for implementing robust, high efficiency, high performance synchronous converters.

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LTC4100 including the SMBus accelerators except it is designed to work with two batteries (see Figure 5). Traditionally, dual battery systems are sequential-discharge systems designed to simply increase total battery run time. Dual-battery systems are increasingly used in parallel-discharge systems to satisfy current requirements beyond the capability of a sequential, battery 1 then battery 2 discharge priority system. The LTC1760 addresses the issue by allowing the safe parallel discharge of two batteries.

It also charges the batteries in parallel. A parallel-charge, parallel-discharge dual-battery system can reduce charge times and increase run times over an equivalent sequential system[1]—see Figures 3 and 4.

The key to allowing the LTC1760 to safely control two batteries in parallel is the utilization of the ideal diode[2] concept where the power MOSFETs are driven to act like diodes as opposed to simple on-off switches.

It is no simple feat to safely juggle the charge and discharge state of multiple batteries and a DC input power source. Supply continuity is paramount—changing from one power path to another should not interrupt power to the system. This daunting task has historically fallen to the host running custom application software. The LTC1760 avoids the need for complicated software development by operating in a *stand-alone* Level 3 Bus Master mode, thus precluding the need for host intervention. The LTC1760 polls each battery at an accelerated rate so that it can continuously optimize battery charging and PowerPath switching modes between two batteries and a wall adapter. It also has built in crises power management hardware to keep the power flowing even if the SMBus is jammed with traffic.

If there is a feature that will shorten charge times, lengthen run times or make the system more robust, it has been included in the LTC1760:

- ❑ Proprietary charge algorithms allow parallel charging even for two batteries of different chemistries or cell configuration.
- ❑ Level 3 capabilities allow the LTC1760 to implement a servo charge current and charge voltage system that eliminates hardware related losses that would extend charge time (see Figure 7).
- ❑ A turbo-charge mode maximizes the charge current for the fastest battery charging possible.
- ❑ Support for full dual battery conditioning, another name for gas gauge calibration for less sophisticated gas gauges.

As sophisticated the LTC1760 is, it remains easy to use. There are only four key parameter choices to make. You can literally drop it into your system, throw some smart batteries and an AC adapter at it, and it will start working right away. A full schematic is shown in Figure 6 (Figure 5 shows a simplified schematic).

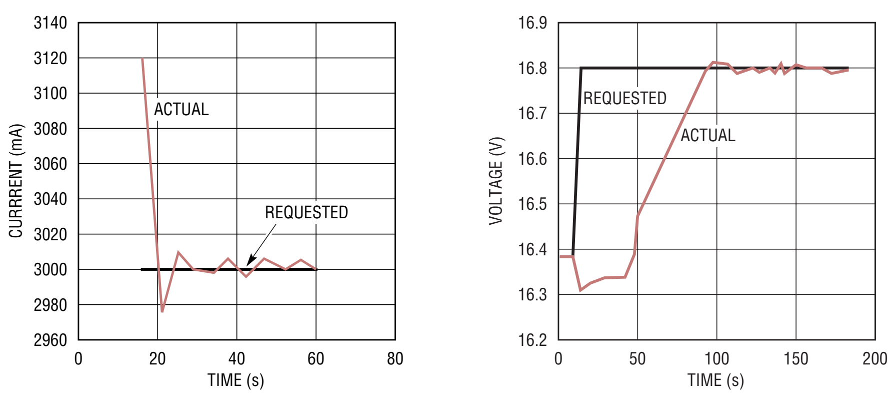

Figure 7. The LTC1760's servo charge current and voltage system eliminates hardware related inefficiencies, therefore decreasing charge times. This is only one of the many unique performance-enhancing features in the LT1760.

Conclusion

The LTC4100 offers a simple and reliable Smart Battery System implementation that uses a single battery. The LTC1760 represents perhaps the most comprehensive single chip dual battery system, providing more control, safety, and automatic crisis management compared to any other solution available today. Both parts offer minimal NRE effort needed to get up and running as a complete battery standalone charger system—no battery expertise required. They are also reduce solution cost, PCB space and part count.

Notes

[1] For a more in depth description of parallel charge, parallel discharge systems, see *Linear Technology* Magazine, December 2001, page 12, "Monolithic Dual Battery Power Manager Increases Run Time and Decreases Charge Time").

[2] For more about ideal diodes, see *Linear Technology* magazine, December 2002, page 1, "Ideal Diode Controller Eliminates Energy Wasting Diodes in Power OR-ing Applications", or any materials describing the LTC4412.