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Speed Up Li-ion Battery Charging and Reduce Heat with a Switching PowerPath Manager

by Steven Martin

Introduction

Designers of handheld products race to pack as many “cool” features as possible into ever smaller devices. Big, bright color displays, Wi-Fi, WiMax, Bluetooth, GPS, cameras, phones, touch screens, movie players, music players and radios are just a few of the features common in today’s battery powered portable devices. One big problem with packing so many features into such a small space is that the “cool” product must actually stay cool while in use. Minimizing dissipated heat is a priority in handhelds, and a significant source of heat is the battery charger.

One component of handhelds has changed little over the years—the Li-ion battery. While the capacities of today’s batteries have increased from a few hundred milliampere hours to several ampere-hours to accommodate the ever expanding feature set of modern portable products, the basic Li-Ion battery technology has remained unchanged. Why has Li-ion survived so long? Unmatched energy density (both by mass and volume), high voltage, low self-discharge, wide usable temperature range, no memory effect, no cell reversal, no cell balancing, and low environmental impact all make the Li-Ion battery the preferred

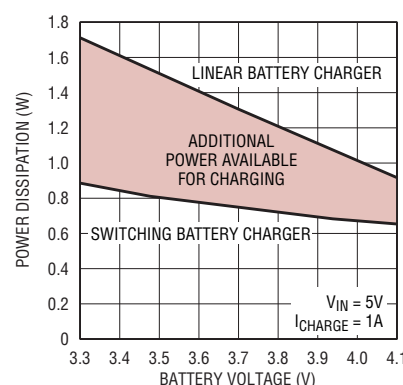


Figure 1. Reduce battery charge time and keep handheld devices cool by using a switching PowerPath manager/battery charger.

choice for high performance portable products.

Charging today’s big batteries, however, is no small deal. In order to charge them in a reasonable amount of time, they should be charged at a rate commensurate with their capacity and with a specific algorithm. For example, to fully charge a 1Ah battery in approximately one hour requires one amp of charge current. If USB powered charging is desired, then only 500mA of current is available, doubling the charge time to two hours.

Another problem with higher charge currents is the additional heat lost in

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LTC4088/LTC4098, continued from page 1

the charging process. Since charge power for these devices usually comes from a 5V source, such as a USB port or 5V wall adapter, power loss can be significant. Assuming a healthy Li-Ion battery spends significant time at its “happy voltage” of 3.7V during charging, then charging efficiency via a linear charging element can at best be 3.7V/5V or 74%. When the battery voltage is less than 3.7V, losses are even worse. Even at the maximum float voltage of 4.2V, where the battery spends about 1/3 of the charge time, charging efficiency can’t be better than 84%.

With a 1Ah battery charged at a “1C” rate, we can expect about 1.3W of power to be lost while delivering 3.7W to the battery over the longest part of the charge cycle. Note, however, that the energy delivered to the battery doesn’t result in any significant temperature rise as the battery is storing the energy for future use. This means that the predominant source of heat during charging is generated by the charger itself. With this in mind, at a given power level it makes sense to move to a switching battery charger for improved charging efficiency, less charger generated heat and reduced charge time.

Both the LTC4088 and LTC4098 are examples of single-cell Li-ion bat-

tery chargers from Linear Technology that not only offer the high efficiency of a switching battery charger but also include PowerPath technology. PowerPath control is a technique that uses a third, or intermediate, node to allow instant-on operation, which provides power to the system when the battery voltage is below the system cutoff. Only products like the LTC4088 and LTC4098 combine a step down DC/DC switching regulator with a linear battery charger in a unique way that ensures high efficiency power delivery to both the system load and the battery. Before we delve into these parts, let’s take a look at how it was done before.

Old School: Linear PowerPath

The intermediate node topology isn’t new. Figure 2 shows an example of a linear PowerPath topology. In this architecture, a current limited switch delivers power from an input connector to both the external load and linear battery charger. The linear battery charger then delivers power from the intermediate node to the battery.

If the load current is far enough below the input current limit to allow some current to be directed to battery charging, the voltage at V_{OUT} is nearly equal to the input supply voltage, let’s say 5V. In this case, the path from V_{IN} to

V_{OUT} is extremely efficient since there is no significant voltage drop across the pass element. Note, however, that the voltage drop between V_{OUT} (~5V) and V_{BAT} (say 3.5V) means the linear charger is running inefficiently. Thus, power delivered to the load arrives efficiently while power delivered to the battery arrives inefficiently.

Now take the alternate case where the load current exceeds the input current limit setting. Here the input current limit control engages and the voltage at the intermediate node, V_{OUT} , drops to just under the battery voltage, thus bringing in the battery as a source of additional current. Although this is desired behavior, ensuring load current is prioritized over charge current, notice that there is now inefficiency at the pass element because a large voltage difference does exist between the input pin, again at 5V, and the output pin, which now may be about 3.5V.

From these examples we can see that while a linear PowerPath topology performs the necessary PowerPath control functions under all conditions, it has some inherent inefficiencies. Specifically, with the linear PowerPath topology there is likely to be power wasted in one or the other of the two linear pass elements under various conditions. In the next section we’ll see how a switching PowerPath avoids the pitfalls of the linear PowerPath.

New School: High Efficiency with Switching PowerPath

Figure 3 shows an alternative to the linear PowerPath, a *switching* PowerPath. Here a step-down DC/DC converter delivers power from the input connector to the intermediate node V_{OUT} . A linear battery charger is connected from the intermediate node to the battery as in the case of the linear PowerPath. The big difference from linear PowerPath is that the path from V_{IN} to V_{OUT} maintains relatively high efficiency regardless of the voltage difference since it is a switching, rather than a linear, path.

Then what about the linear battery charging path, the other big part of

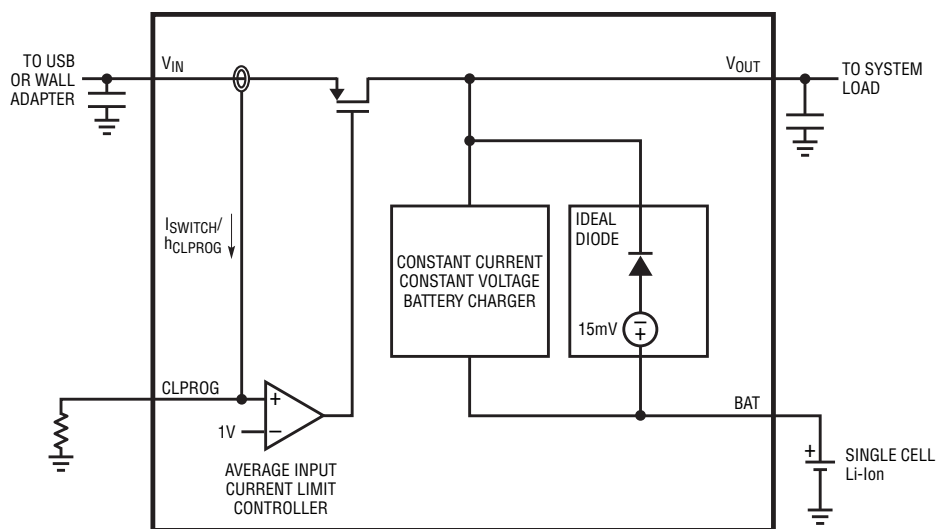
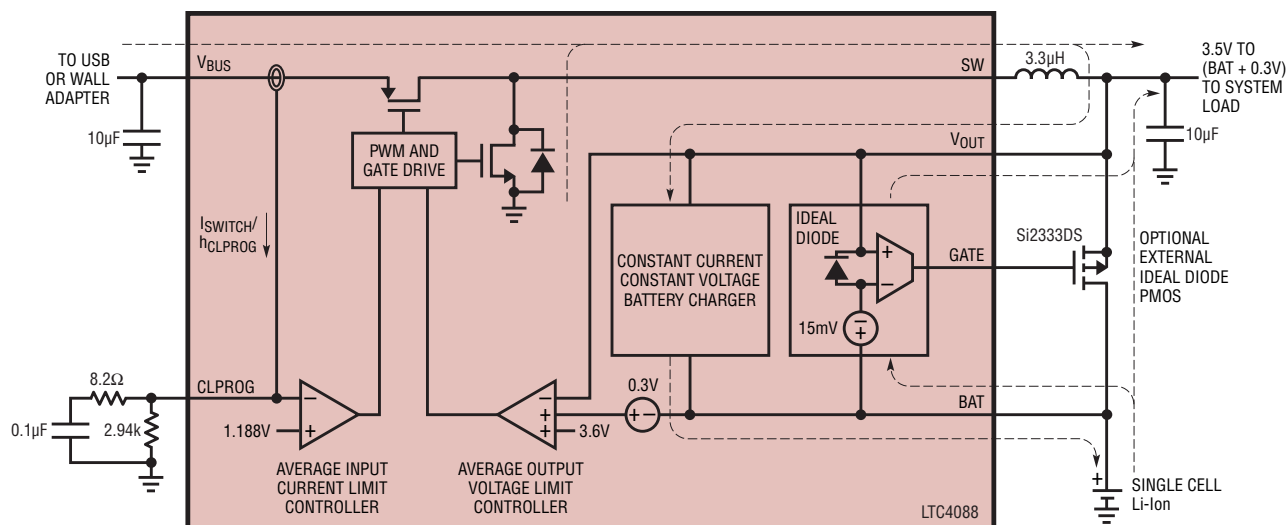


Figure 2. Block diagram of a traditional linear PowerPath, which has significant inherent efficiency limitations.



the total efficiency picture? Voltage drops between V_{OUT} and the battery would pretty much erase the efficiency gains made by the switching regulator. Total efficiency remains high with the the LTC4088 and LTC4098 because of a feature called Bat-Track™. With Bat-Track, the output voltage of the switching regulator is programmed to track the battery voltage plus a few hundred millivolt difference. Since the output voltage is never significantly above the battery voltage, little power is ever lost to the linear battery charger. The battery charger pass element leaves most of the voltage control duties to the switching regulator and exists merely to control charge current, float voltage and battery safety monitoring—tasks at which it excels.

USB-Based Constant-Power Charging

These days, an important feature in many portable products is the convenience of charging from a USB port. The LTC4088 and LTC4098 have a unique control system that allows them to limit their input current consumption for USB compliant applications while maximizing power available to the load and battery charging. These two devices not only have low and high power USB settings of 100mA and 500mA, but they also

support a higher power 1A setting for wall adapter applications.

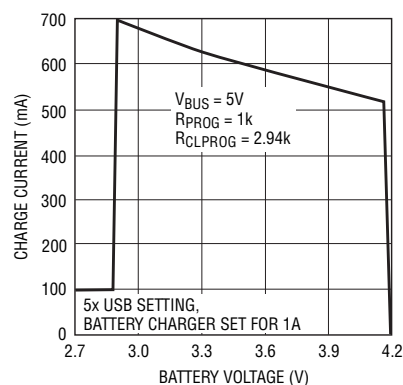
For products with large batteries, USB current control can be the limiting factor in determining how much power is delivered to the battery for charging. With a linear PowerPath topology, input and output are current limited—the sum of the load current and the battery charging current cannot exceed the input current. In this case, a switching PowerPath has a significant advantage over a linear PowerPath. In a switching PowerPath topology the input is still current limited, but this only limits available *power* to the load and charger. This is an important distinction. Figure 4 shows an example of how the LTC4088 can provide up to a 40% increase in

charge current over a linear PowerPath design.

Notice that while the USB current is limited to 500mA, it's possible for the charge current to be above 500mA due to the high efficiency of the switching PowerPath system. So not only does the higher efficiency produce little heat, but it also reduces charge time.

The input current limited topology of the LTC4088 and LTC4098 offers a big advantage over devices that use an output current controlled topology to maintain USB compliance. This is because as the battery voltage rises throughout the charge cycle, the effective power consumed by the battery also rises, assuming a constant current. In order to retain USB compliance in an output current controlled system (assuming perfect efficiency) one would have to limit the battery charge current to its power-limited value at the highest battery voltage.

For example, to remain below 2.5W ($5V_{IN} \cdot 500mA$) of power delivery at a 4.2V battery voltage, the charge current must not exceed 595mA. This current limit is overly conservative when the battery voltage is low, say 3.4V, where it would be possible to deliver 735mA without violating the USB specification. Input current limited devices designed specifically for USB compliance, such as the LTC4088



and LTC4098, allow the charger to use this additional available current. In contrast, an output current regulated switching charger designed for USB compliance must be programmed to limit battery charging current to the high voltage case (595mA), thus hamstringing it at low battery voltages. Said another way, an input current limited switching charger *always* extracts as much power from the input source as is allowed, whereas an output current controlled one does not.

Instant-On (Low Battery System Start)

Figure 5 shows the instant-on feature of the switching PowerPath topology. When the battery voltage is very low and the system load does not exceed the available programmed power, the output voltage is maintained at approximately 3.6V. This prevents the system from having to wait for the battery voltage to come up before turning on the device—a frustrating scenario to the end user.

This is the primary reason for having a decoupled output node and battery node (i.e. the 3-terminal topology). This feature can be used to power the system in a low power mode. For example, it may be just enough power to start up and indicate to the user that the system is charging.

Automatic Load Prioritization

The current delivered to the system at V_{OUT} , as well as the battery charge current, form a combined load on the switching regulator. If this combined load does not exceed the power level programmed by the input current limit circuit then the switching PowerPath topology happily delivers charge and load current without concern. If, however, the total load exceeds the available power, the battery charger automatically gives up some or all of its share of the power to support the extra load. That is, the system load is always prioritized and battery charging is only performed opportunistically. This algorithm provides uninterrupted power to the system load. Even if the system load alone exceeds the power available from the input limiting cir-

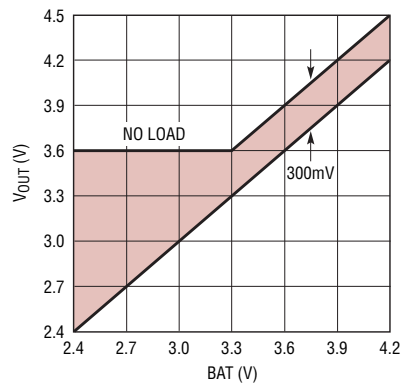


Figure 5. V_{OUT} vs BAT

cuit, the input current does not exceed its programmed limit. Rather the battery charger shuts off completely and the extra power is drawn from the battery via the ideal diode.

When the ideal diode is engaged, the conduction path from the battery to the output pin is approximately 180mΩ. If this is sufficient for the application, then no external components are needed. If greater conductance is necessary, however, an external MOSFET can be used to supplement the internal ideal diode. The LTC4088 and LTC4098 both have a control pin for driving the gate of the optional external transistor. Transistors with resistance of 30mΩ or lower can be used to supplement the internal ideal diode.

Full Featured Battery Charger

The LTC4088 and LTC4098 both include a full featured battery charger. The battery chargers feature programmable charge current, cell preconditioning with bad-cell detection and termination, CC-CV charging, C/10 end of charge detection, safety timer termination, automatic recharge and a thermistor signal conditioner for temperature qualified charging.

LTC4098 Enhancements

The LTC4098 has a few features that the LTC4088 does not. First, it supports the ability to control an external high voltage switching regulator to receive power from a second input supply such as an automobile battery. It also includes an independent overvoltage protection module that can, in con-

junction with an external MOSFET, provide significant input protection to the low voltage (USB/WALL) input.

High Voltage Input Controller

The LTC4098's external input control circuit recognizes when a second input supply is present and prioritizes that input in the event that both it and the USB/WALL input are powered simultaneously. Furthermore, the LTC4098 interfaces with a number of Linear Technology high voltage step-down switching regulators to allow for higher voltage inputs, such as an automotive battery. Using the same Bat-Track technique described above, the auxiliary input controller commands the high voltage regulator to develop a voltage at V_{OUT} that tracks just above the battery. Again, this technique results in high charging efficiency even when charging from a fairly high voltage.

Overvoltage Protection

The LTC4098 includes an overvoltage protection controller that can be used to protect the low voltage USB/Wall input from the inadvertent application of high voltage or from a failed wall adapter. This circuit controls the gate of an external high voltage N-type MOSFET. By using an external transistor for high voltage standoff, the protection level is not limited to the process parameters of the LTC4098. Rather the specifications of the external transistor determine the level of protection provided.

Conclusion

The LTC4088 and LTC4098 represent a new paradigm in power management and battery charging. Both optimize power delivery by combining constant input power limiting with a high efficiency switching regulator and Bat-Track battery charging. Other benefits include instant-on system starting, automatic load prioritization and unmatched charging efficiency. The LTC4098 goes a step beyond with an auxiliary input controller for higher input voltages (such as a car battery) and an overvoltage protection controller. 