USB Power Controller/Charger Reduces Both Design Time and Battery Charge Time

by Roger Zemke

Introduction

Rechargeable batteries are commonly used to power portable Universal Serial Bus (USB) devices, such as PDAs or MP3 players. The USB itself can be used to directly power the device or charge a battery. The LTC4055 uses PowerPath™ control to seamlessly and efficiently steer the load to the preferred source of power; all while remaining within the specified USB current limit; and charge the battery with any available leftover current. When the USB is present, the LTC4055 connects the USB power directly to the load. When both the USB and a wall adapter are present, the LTC4055 can be configured to have the wall adapter supercede the USB as the source of power. These direct connections to the load translate to higher load voltages and greater efficiency.

USB hosts, or powered hubs, provide as much as 500mA from their nominal 5V supply. The greater efficiency of running the load at the USB supply voltage (instead of the battery voltage) means there is more current left in the 500mA USB budget for charging the battery. Because the battery is not in the power path while the application is tied to the USB or wall adapter, the application can be powered even if the battery is low or dead. The same reasoning applies for fully charged batteries. A fully charged battery, which is not in the power path until the USB or external power is removed, stays fully charged. Figure 1 shows just how simple the PowerPath control and battery charging in a USB application can be implemented using the LTC4055.

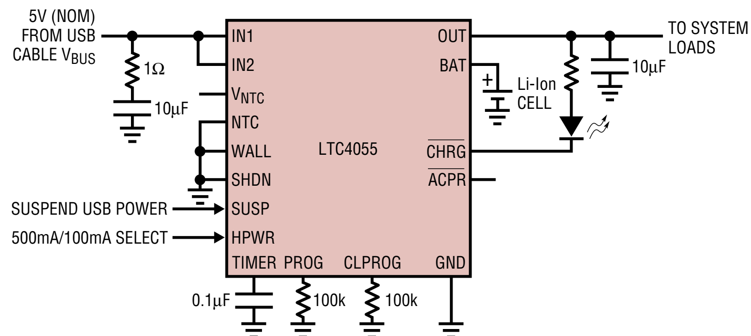
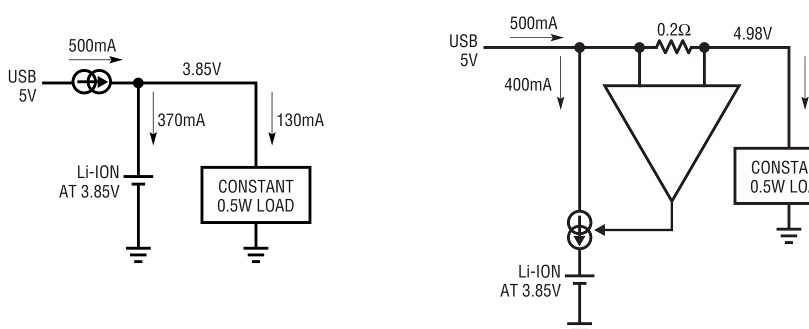


Figure 1. Standalone USB Li-Ion battery charger with PowerPath control from input to output and battery to output—configured for 500mA USB current limit and 500mA maximum charge current.

PowerPath

Let's examine how PowerPath control reduces charge time. Assume the application load is a DC/DC converter. Such converters are effectively constant power devices. The higher the input voltage to the DC/DC converter the lower the current draw. In a USB application where the current is limited, it makes sense to run the converter at as high an input voltage as possible. This minimizes the current draw from the bus—leaving more current for battery charging.

Figure 2 compares a topology that includes the battery in the power path to one that switches the battery out of the power path when it is not needed. Figure 2a shows a constant 0.5W load tied directly to the Li-Ion battery. The USB current is limited to 500mA and the nominal battery voltage is 3.85V. Thus, the current required to power the load is 0.5W/3.85V = 130mA. That



a) Without PowerPath control

b) With PowerPath control

Figure 2. PowerPath control increases available charging current (and reduces charge times) over traditional methods. In this example, the increase is 30mA (8%).

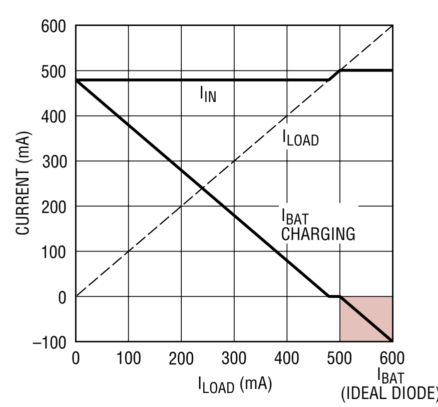


Figure 3. Input and battery currents as a function of load current in high power mode with the current limit set to 500mA (R_{CLPROG} = 100kΩ) and the charge current set to ≥ 500mA (R_{PROG} ≤ 100kΩ). Note that as load current exceeds the USB current limit, the charge current to the battery becomes negative.

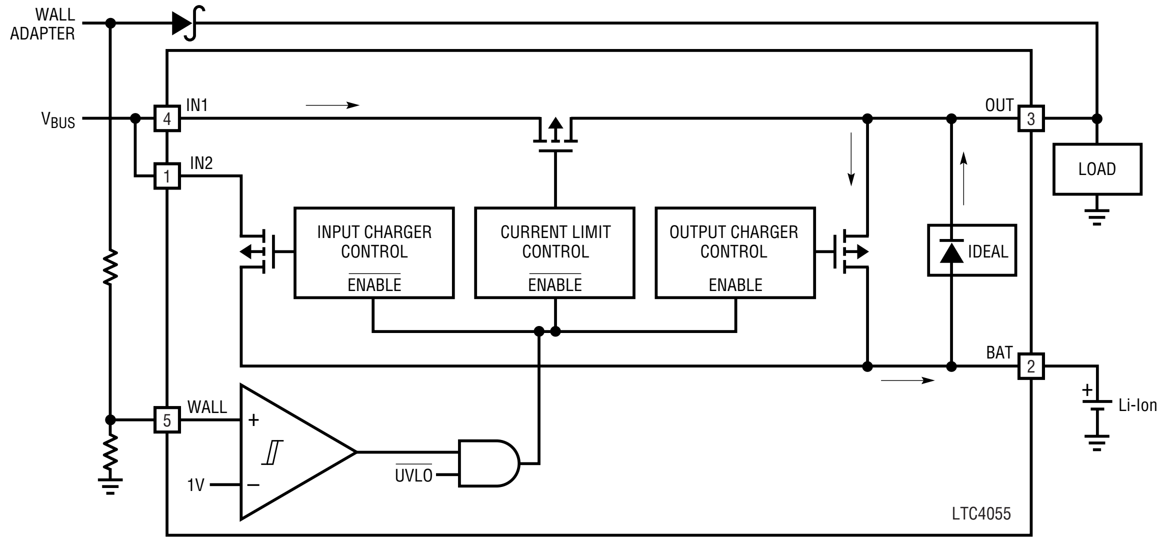


Figure 4. Simplified block diagram of the PowerPath control

leaves 370mA (500mA – 130mA) to charge the battery. Figure 2b shows a 0.5W constant power load tied directly to the USB through a sense resistor. The voltage at the load is 4.98V and the current required by the load is 100mA (0.5W/5V). The current left for battery charging is 400mA (500mA – 100mA), an 8% improvement over the 370mA available when the battery is in the power path.

The LTC4055 has an internal 200mΩ power switch that connects the USB power to the load when the USB is present. The result is the load is running off of USB voltage instead of the lower voltage of the battery. The LTC4055 has a unique current control scheme that keeps the USB current limited while charging a battery under varying load conditions. This current control scheme means that as the load current is decreased more current is available for battery charging. Figure 3 shows a plot of the LTC4055's input and battery charge currents as a function of the load current for the application shown in Figure 1.

A simplified block diagram of the PowerPath for the LTC4055 is shown in Figure 4. It consists of the internal current limited 200mΩ power switch from the inputs to the output of the LTC4055. There are two battery charger paths within the LTC4055. The first is the input charger from the input to the battery and is meant for USB charging. The other battery charger path is the output charger from the output to the battery and is meant for charging the battery when an external adapter is detected.

An internal ideal diode function prevents reverse conduction from the load to the battery when the load voltage is greater than the battery voltage. This same ideal diode function provides a low forward drop (55mV typ. at 100mA) from the battery to the load if the load current should exceed the USB limit or if the battery is the only source of power. The forward characteristics of the ideal diode compared to those of a Schottky diode are shown in Figure 5.

A wall adapter comparator is provided internal to the LTC4055 to detect the presence of an alternate external power source. When the wall adapter is detected, the comparator enables the output battery charger and disables both the power path from input to output and the input battery charger. When the wall adapter is present this comparator is important to prevent reverse conduction from the output of the LTC4055 to the input or USB. Figure 4 shows the connection of the wall adapter to the output using a power Schottky. The output of the wall adapter comparator also drives an open drain status pin ($\overline{ACPR}$). This status pin can be used to enable an external power PMOS FET to make a low impedance connection from the wall adapter to the output of the LTC4055, as shown in Figure 6.

Programmability

Input current limiting and battery charge current are both independently programmable. This allows the current limit and the charge current to be tailored to the application. An external programming resistor (R_{CLPROG}) sets the current limit for the 200mΩ switch. The battery chargers have their constant current mode current set by an external programming resistor (R_{PROG}) as well. The current limit programming resistor also sets the maximum battery charge current allowed for the input charger and does not impact the output charger current. This allows the output charger to be programmed for something greater than the cur-

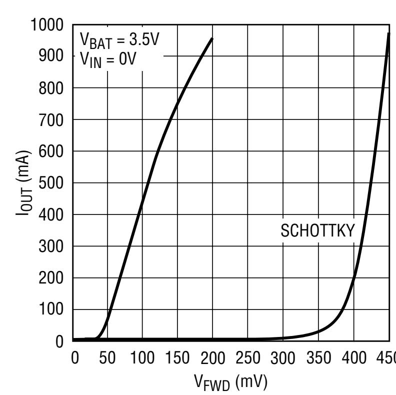


Figure 5. Ideal diode and Schottky diode forward voltage versus current

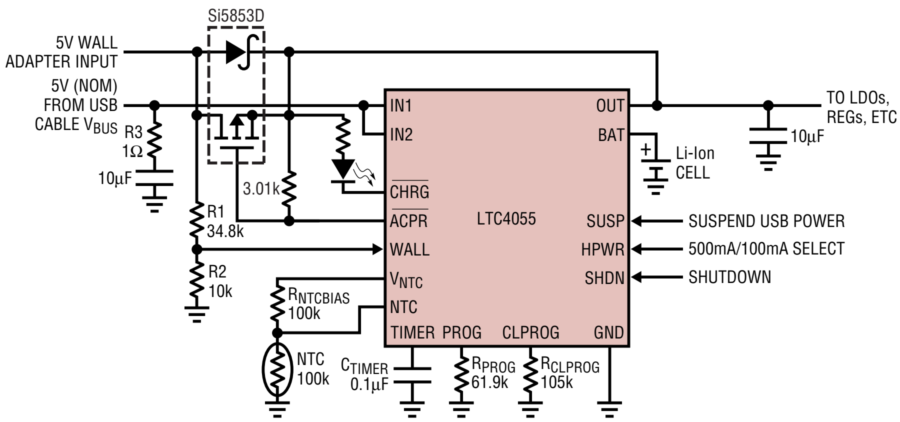


Figure 6. USB power control and battery charger application with a wall adapter input configured to charge the battery at 800mA when the adapter is present.

rent limit when an external adapter is available.

The input current limit and maximum input battery charge current (I_{CL}) is programmed as follows:

$$I_{CL} = \frac{50,000}{R_{CLPROG}}$$

The maximum battery charge current (I_{CHG}) is programmed as follows:

$$I_{CHG} = \frac{50,000}{R_{PROG}}$$

Figure 3 shows input and battery currents as a function of load current. The input current limit is set to 500mA by setting the current limit programming resistor to 100k and the charge current programming resistor to 100k or less. Figure 7 shows the input and battery charge currents for a case where the battery is programmed for something less than 500mA. In this case the battery charge current is programmed to 250mA by setting the charge current programming resistor to 200k.

USB Compatibility

The USB specification provides for two power modes, high power (500mA) and low power (100mA). The HPWR pin on the LTC4055 selects the power mode. The current limiting for the LTC4055 should be configured for the high power mode and the power mode control pin (HPWR) on the LTC4055 controls whether the current limiting is set for high or low power. When operating in low power mode (see Figure 8) the current limit is set for 20% of its programmed high power current limit and the maximum charge current is set to 16% of the programmed current limit. Note that the current limit only applies to currents from the input of the LTC4055. The output charger charges at the programmed charge current.

The USB power specification states that high power applications must operate at voltages as low as 4.5V and low power applications must operate as low as 4.35V. These voltages include resistive drops in the cables and connectors of the interface. This assumes the cables and connectors are fully USB compliant. In cases where resistive drops exceed those anticipated by the USB specification, the LTC4055 has a unique feature that allows it to work properly under these conditions. The undervoltage charge current limiting feature reduces the charge current when the voltage at the input drops below approximately 4.4V. This prevents the input from dropping too far and shutting off the charger. An abrupt shutoff of current can cause the voltage to rise again re-enabling the charger. The voltage then drops and the cycle repeats. The under-voltage charge current limiting feature prevents this drop out oscillation by adjusting the charge current in an effort to maintain a constant minimum input voltage of approximately 4.35V.

The USB specification for low power bus current is 500µA from a device while in the Suspend state. The LTC4055 is designed to allow an application to abide by this specification. A suspend mode pin has been integrated into the LTC4055 that cuts the bus current to approximately 100µA. This is accomplished by turning off input charging and the input power path to the load. If an external source is not available in this mode, the application remains active by drawing power from the battery via the LTC4055's ideal diode function.

Thermal Regulation

Thermal charge current regulation within the LTC4055 protects the part and surrounding circuitry from excessive temperature, and allows the user to push the limits of the power handling capability of a given circuit board without risk of damaging the LTC4055. The internal thermal regulation reduces the programmed charge

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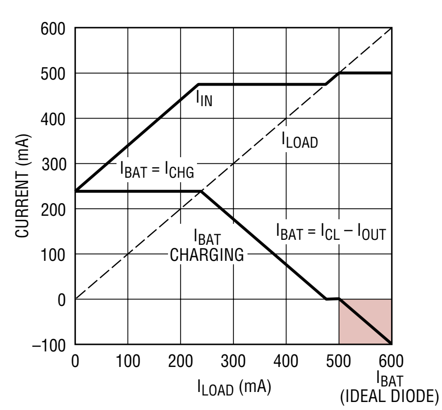

Figure 7. Input and battery currents as a function of load current in high power mode with the current limit set to 500mA and the charge current set to 250mA (R_{CLPROG} = 100k, R_{PROG} = 200k).

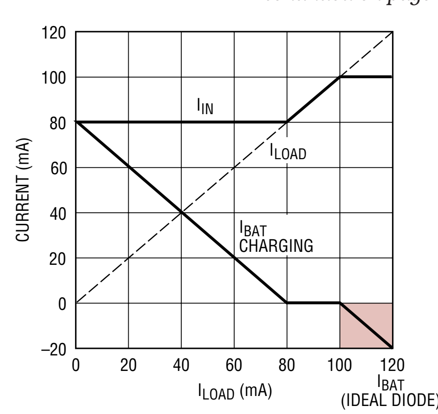

Figure 8. Input and battery currents as a function of load current in low power mode with R_{CLPROG} = 100k and R_{PROG} = 100k, the current limit is 100mA and the charge current is 80mA.

V_{SENSE} = 50mV for the LTC4150, therefore:

$$f = G_{VF} \bullet | I_{BATTERY} \bullet R_{SENSE} | \qquad (3)$$

Since I • t = Q, the coulombs of battery charge per $\overline{INT}$ pulse (interrupt interval) can be derived from Equation 4:

$$\text{One } \overline{INT} = \frac{1}{G_{VF} \bullet R_{SENSE}} \text{Coulombs} \qquad (4)$$

Battery capacity is most often expressed in ampere-hours:

$$1\text{Ah} = 3600 \text{ Coulombs} \qquad (5)$$

Combining Equations 4 and 5:

$$\text{One } \overline{INT} = \frac{1}{3600 \bullet G_{VF} \bullet R_{SENSE}} \text{Ah} \qquad (6)$$

or

$$1\text{Ah} = 3600 \bullet G_{VF} \bullet R_{SENSE} \text{ Interrupts} \qquad (7)$$

The charge measurement can then be scaled with a microcontroller.

High Side Sensing up to 8.5V

Figure 2 shows a typical application design for a 2-cell lithium-ion battery system with 500mA of maximum load current. Using Equation 2 to calculate R_{SENSE} = 50mV/0.5A = 0.1Ω. With R_{SENSE} = 0.1Ω, Equation 6 shows that each interrupt corresponds to 0.085mAh of charge with G_{VF} = 32.55 Hz/V. A battery with 850mAh of capacity takes a total of 10,000 $\overline{INT}$ assertions to fully charge or discharge.

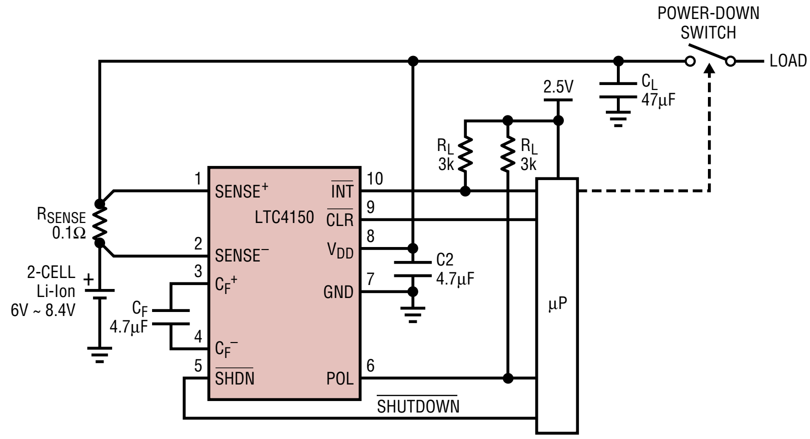

Figure 2. A 2-cell lithium-ion battery gas gauge

The LTC4150 can be shut down, when not needed, to a low current mode (1.5µA max) reducing the drain on the battery.

Accurate Prediction of Battery Capacity

The factors that affect the accuracy of the capacity prediction are the input offset voltage, the integral nonlinearity error (INL), the tolerance of the sense resistor, and the self-discharge of the battery. The self-discharge rate of a Li-Ion type of battery is around 2%–4% per month at room temperature. The LTC4150 has 0.3% of INL error across the input and common mode range, see Figure 3, and 150µV of input offset voltage.

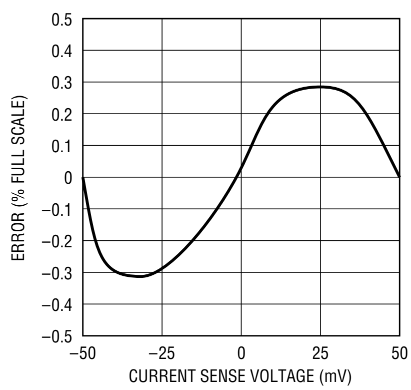

Figure 3. Integral nonlinearity of the LTC4150 is within 0.3% over the entire sense voltage range.

Conclusion

The LTC4150 offers a simple and compact solution for high side coulomb counting/battery gas gauging for battery voltages up to 8.5V(2-cell Li-Ion or 6-cell NiCd or NiMH batteries). The only required external components are the sense resistor and a filter capacitor to average out transient events and ripple current.

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current if the die temperature attempts to rise above a preset value of approximately 105°C. Another benefit of the LTC4055 thermal regulation is that charge current can be set according to typical, not worst-case, ambient temperatures for a given application with the assurance that the charger will automatically reduce the current in worst-case conditions. Thermal regulation simplifies design, maximizes charge current and prevents overheating.

Conclusion

The LTC4055 is a complete PowerPath controller and Li-Ion battery charger for portable USB applications. The LTC4055 is designed to provide device power and Li-Ion battery charging from the USB while maintaining the current limits imposed by the USB specification. This is accomplished by reducing battery charge current as output/load current is increased. The available bus current is maximized to minimize battery charge times.

The LTC4055's versatility, simplicity, high level of integration and small size makes it an ideal choice for many portable USB applications. The LTC4055 is available in a small 16-lead low profile 4mm × 4mm QFN package.