

800 mA standalone linear Li-Ion battery charger with thermal regulation

Introduction

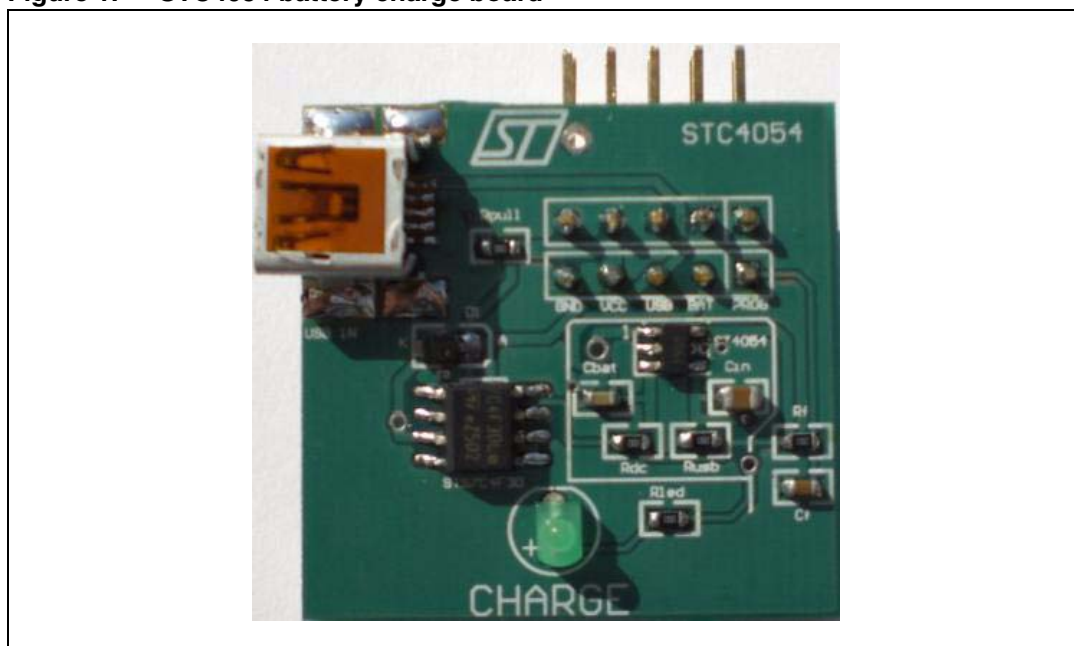
One way to minimize the size and complexity of a battery charger is to use a linear-type charger. The linear charger drops the AC adapter voltage down to the battery voltage. The number of external components is low: linear chargers require input and output bypass capacitors, and sometimes need an external pass transistor, and resistors for setting voltage and current limits.

The main pitfall of a linear charger is power dissipation. The charger simply drops the AC adapter voltage down to the battery voltage.

In the case of a 0.8 A charger, a $5\text{ V} \pm 10\%$ regulated AC adapter voltage, and battery voltage that varies between 4.2 V and 2.5 V, the power dissipation can range from 0.64 W to 2.0 W.

This type of charger is simpler than the switch-mode type, mainly because the passive LC filter is not required. It dissipates the most power when the battery voltage is at its minimum, since the difference between the fixed input voltage and the battery voltage is greatest during this condition.

Figure 1. STC4054 battery charge board



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1 STC4054 description

The STC4054 is a constant current/constant voltage charger for single cell Li-Ion battery. No external sense resistor or blocking diode is required and its ThinSOT package make it ideally suited for portable applications.

Its power dissipation can range from 0.2 W to 1.68 W because of Trickle charge mode. In fact, if $V_{BAT} < 2.9$ V, I_{BAT} is only $0.8 A/10 = 80$ mA.

The maximum power dissipation occurs when V_{BAT} is 2.9 V with maximum charge current.

The STC4054 is designed to work within USB power specifications. An internal block regulates the current when the junction temperature increases in order to protect the device when it operates in high power or high ambient temperature environments.

The charge voltage is fixed at 4.2 V, and the charge current limitation can be programmed using a single resistor connected between the PROG pin and GND. The charge cycle finishes when the current flowing to the battery is 1/10 of the programmed value. If the external adaptor is removed, the STC4054 turns off and just 2 μ A can flow from the battery to the device. The device can be put into Shutdown mode, reducing the supply current to 25 μ A. The device is delivered in a TSOT23-5L ThinSOT package.

Figure 2. Block diagram

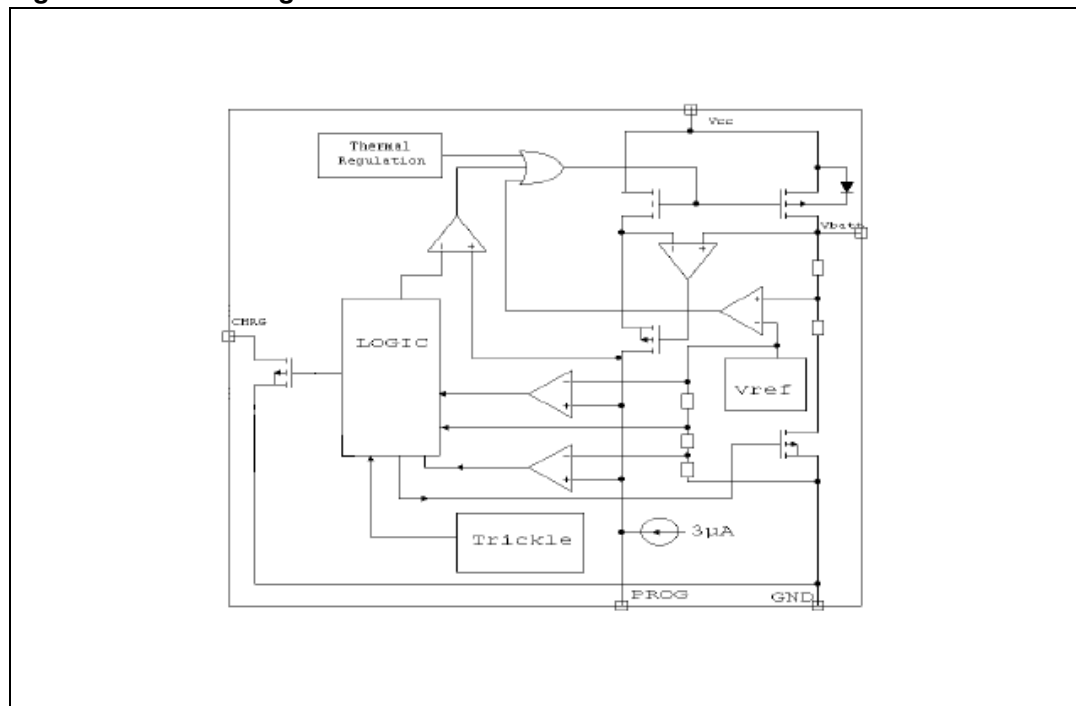


Figure 3. Top component demo board

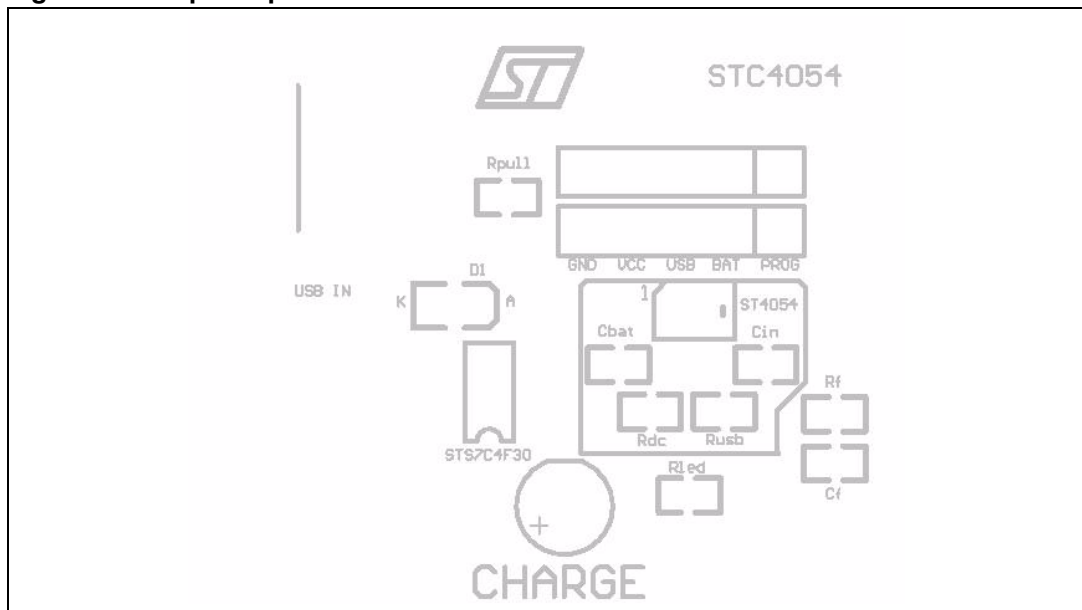


Figure 4. Top layer layout

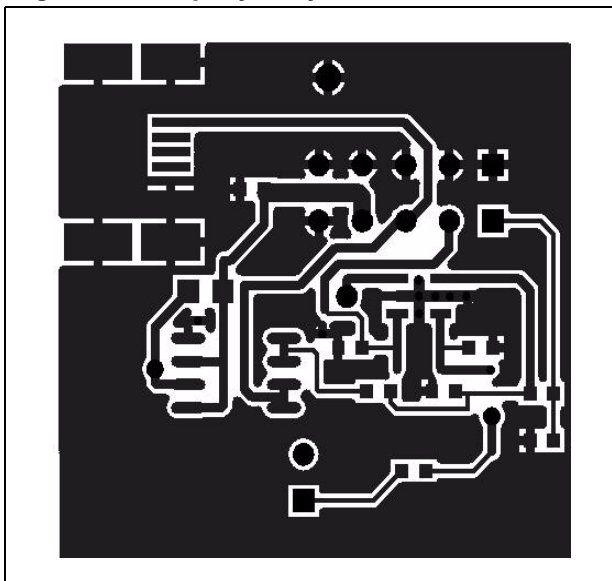


Figure 5. Bottom layer layout

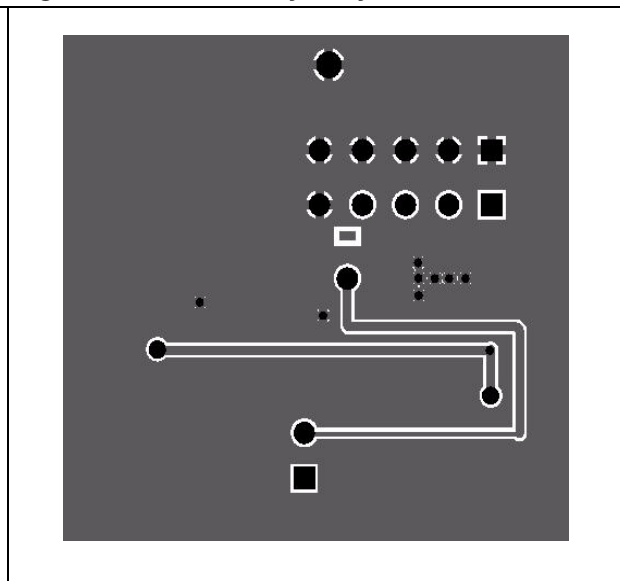


Figure 6. Complete charge cycle (750 mA/h battery)

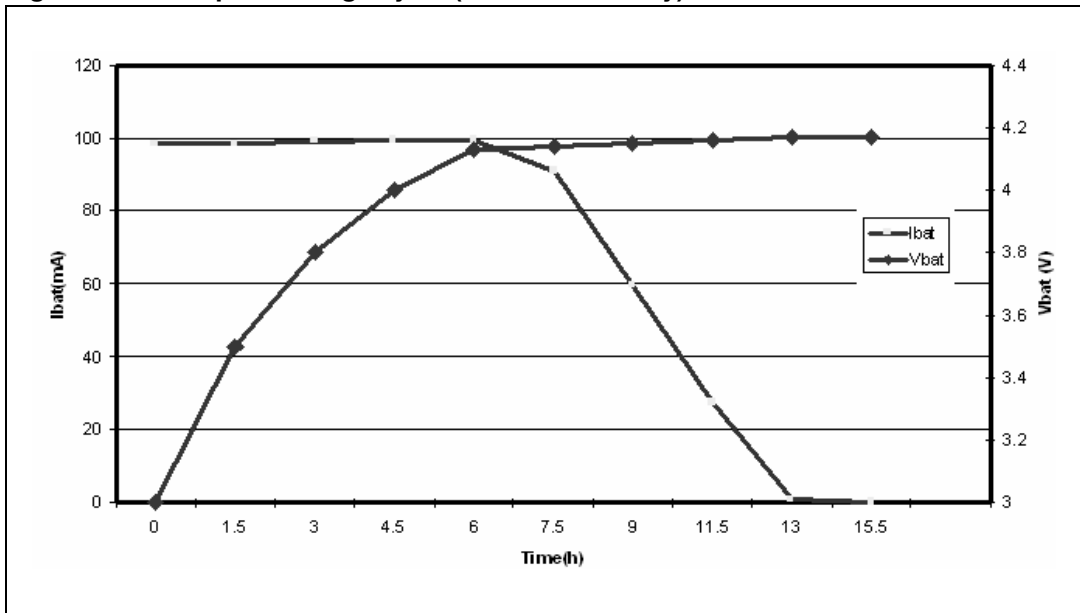
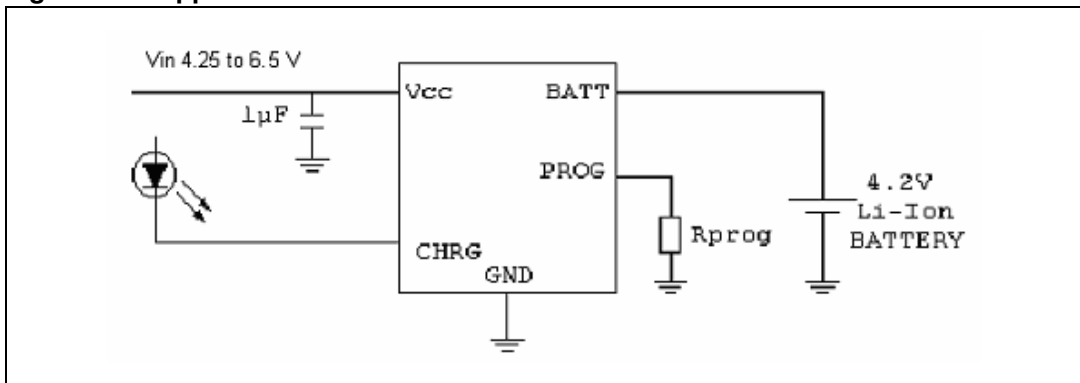


Figure 7. Application circuit



2 Stability considerations

The STC4054 contains two control loops: constant voltage and constant current. The constant-voltage loop is stable without any compensation when a battery is connected with low impedance leads. Excessive lead length, however, may add enough series inductance to require a bypass capacitor of at least 1 μF from BAT to GND. Furthermore, a 4.7 μF capacitor with a 0.2 Ω to 1 Ω series resistor from BAT to GND is required to keep ripple voltage low when the battery is disconnected.

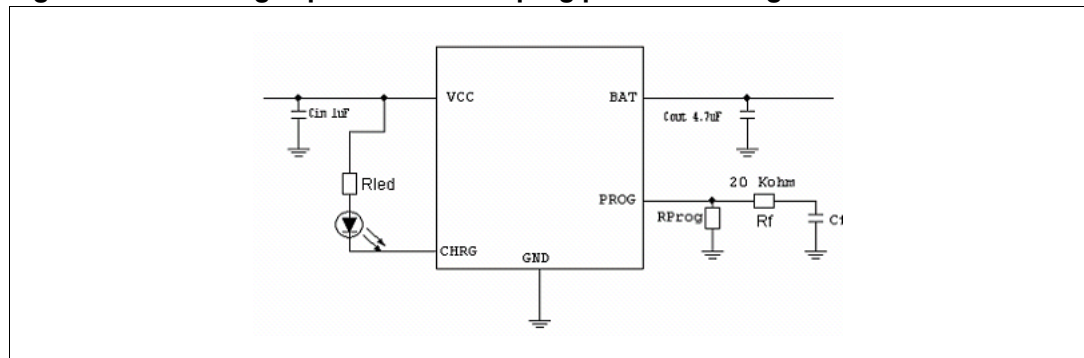
In constant-current mode, the PROG pin is in the feedback loop, instead of the battery. Because of the additional pole created by PROG pin capacitance, capacitance on this pin must be kept to a minimum. With no additional capacitance on the PROG pin, the charger is stable with program resistor values as high as 12 kΩ. However, additional capacitance on this node reduces the maximum allowed program resistor. Therefore, if the PROG pin is loaded with a capacitance, C_{PROG}, the following equation should be used to calculate the maximum resistance value for R_{PROG}:

Equation 1

$$R_{\text{PROG}} \leq \frac{1}{2 \pi \cdot 5 \cdot 10^5 \cdot C_{\text{PROG}}}$$

Average, rather than instantaneous, battery current may be of interest to the user. For example, if a switching power supply operating in low current mode is connected in parallel with the battery, the average current being pulled out of the BAT pin is typically of more interest than the instantaneous current pulses. In such a case, a simple RC filter can be used on the PROG pin to measure the average battery current as shown in [Figure 6](#). A 20 kΩ resistor has been added between the PROG pin and the filter capacitor to ensure stability (C1 = 100 nF).

Figure 8. Isolating capacitive load on prog pin and filtering



3 Board layout considerations

Because of the small size of the ThinSOT package, it is very important to use a good thermal PC board layout to maximize the available charge current. The thermal path for the heat generated by the IC is from the die to the copper lead frame, through the package leads, (especially the ground lead) to the PC board copper. The PC board copper is the heat sink. The footprint copper pads should be as wide as possible and expand out to larger copper areas to spread and dissipate the heat to the surrounding ambient. Feed through vias to inner or backside copper layers are also useful in improving the overall thermal performance of the charger. Other heat sources on the board, not related to the charger, must also be considered when designing a PC board layout because they will affect overall temperature rise and the maximum charge current.

Table 1 lists thermal resistance for several different board sizes and copper areas.

Figure 3 shows the complete assembly board.

Table 1. Measured thermal resistance (2-layer board)

Copper area		Board area	Junction-to-ambient Thermal resistance
Topside	Downside		
2500 mm ²	2500 mm ²	2500 mm ²	125 °C/W
1000 mm ²	2500 mm ²	2500 mm ²	125 °C/W
225 mm ²	2500 mm ²	2500 mm ²	130 °C/W
100 mm ²	2500 mm ²	2500 mm ²	135 °C/W
50 mm ²	2500 mm ²	2500 mm ²	150 °C/W

4 External components

This application requires few external components: two ceramic capacitors ($C_{IN} = 1 \mu\text{F}$, $C_{OUT} = 4.7 \mu\text{F}$), and one resistor (R_{PROG}).

For input and output capacitors, the use of ceramic capacitors with low ESR is recommended. For good stability of devices supplied with a low input voltage of 4.25 V at maximum output ratings, the use of 1 μF /6.3 V input capacitor (minimum value) and 4.7 μF /6.3 V output capacitor (minimum value) is recommended.

Table 2. Bill of materials

Symbol	Parameter	Type	Qty	Supplier	Value	Unit
C_{IN}	Input cap.	Ceramic low ESR GRM155F50J105ZE01	1	Murata	1	μF
C_{BAT}	Output cap.	Ceramic low ESR GRM188r60J475ke19	1	Murata	4.7	μF
Rusb	Usb current set	Thick film type 1% CRG0603J2K0	1	THCO	2	$\text{K}\Omega$
Rdc	DC current set	Thick film type 1% CRG0603J10K0	1	THCO	10	$\text{K}\Omega$
N-Pmos	Nmos-Pmos IC	STS7C4F30	1	ST		
D1	SCHOTTKY	STPS1L40M	1	ST		
R_{LED}	Limit LED current	Thick film type 1% CRG0603J1K0	1	THCO	1	$\text{K}\Omega$
R_{pull}	Pull down resistor	Thick film type 1% CRG0603J1K0	1	THCO	1	$\text{K}\Omega$
R_f	Resistance filter	Thick film type 1% CRG0603J20K0	1	THCO	20	$\text{K}\Omega$
C_f	Capacitor filter	Ceramic Low ESR GRM188r71e104ka01	1	Murata	100	nF
LED charge	LED	1.8 mm-GREEN LED L-2060GD	1	KINGBRIGHT		
USB In	Connector USB	Mini B 54819-0572	1	Molex		

5 Power dissipation

The conditions that cause the STC4054 to reduce charge current through thermal feedback can be approximated by considering the power dissipated in the IC. For high charge currents, the STC4054 power dissipation is approximately:

Equation 2

$$P_D = (V_{CC} - V_{BAT}) \cdot I_{BAT}$$

where P_D is the power dissipated, V_{CC} is the input supply voltage, V_{BAT} is the battery voltage and I_{BAT} is the current charge current. It is not necessary to perform any worst-case power dissipation scenarios because the STC4054 will automatically reduce the charge current to maintain the die temperature at approximately 120°C.

However, the approximate ambient temperature at which the thermal feedback begins to protect the IC is:

Equation 3

$$T_A = 120^\circ\text{C} - P_D \theta_{JA}$$

Equation 4

$$T_A = 120^\circ\text{C} - (V_{CC} - V_{BAT}) \cdot I_{BAT} \theta_{JA}$$

Example: Consider an STC4054 operating from a 5 V wall adapter providing 400 mA to a 3.7 V Li-Ion battery. The ambient temperature above which the STC4054 will begin to reduce the 400 mA charge current is approximately:

Equation 5

$$T_A = 120^\circ\text{C} - (5\text{ V} - 3.7\text{ V}) \cdot (400\text{ mA}) \cdot 150^\circ\frac{\text{C}}{\text{W}} = 42^\circ\text{C}$$

The STC4054 can be used above 42°C, but the charge current will be reduced from 400 mA. The approximate current at a given ambient temperature can be calculated:

Equation 6

$$I_{BAT} = \frac{120^\circ\text{C} - T_A}{(V_{CC} - V_{BAT}) \cdot \theta_A}$$

Using the previous example with an ambient temperature of 65°C, the charge current will be reduced to approximately:

Equation 7

$$I_{BAT} = \frac{120^\circ\text{C} - 65^\circ\text{C}}{(5\text{ V} - 3.7\text{ V}) \cdot 150^\circ\frac{\text{C}}{\text{W}}} = 282\text{ mA}$$

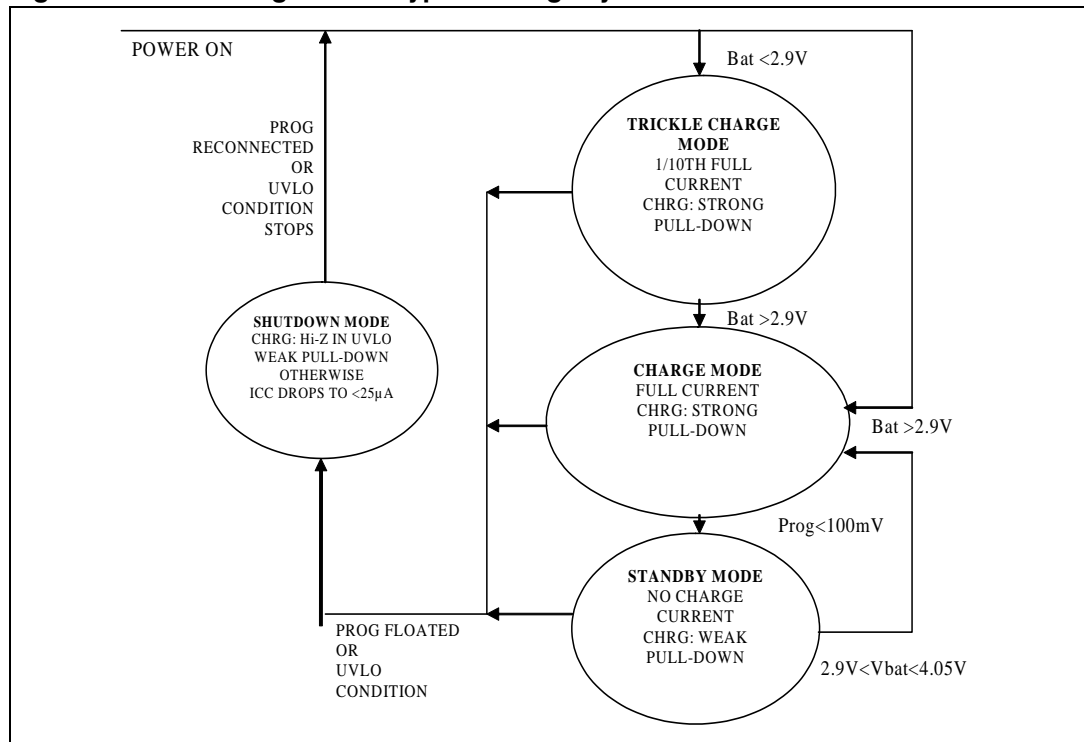
Furthermore, the voltage at the PROG pin will change proportionally with the charge current as discussed in the Programming Charge Current section. It is important to remember that STC4054 applications do not need to be designed for worst-case thermal conditions since the IC will automatically reduce power dissipation when the junction temperature reaches approximately 120 °C.

6 Automatic recharge

Once the charge cycle is terminated, the STC4054 continuously monitors the voltage on the BAT pin using a comparator with a 2 ms filter time ($t_{RECHARGE}$). A charge cycle restarts when the battery voltage falls below 4.05 V (which corresponds to approximately 80% to 90% battery capacity).

This ensures that the battery is kept at or near a fully charged condition and eliminates the need for periodic charge cycle initiations. CHRG output enters a strong pulldown state during recharge cycles.

Figure 9. State diagram of a typical charge cycle

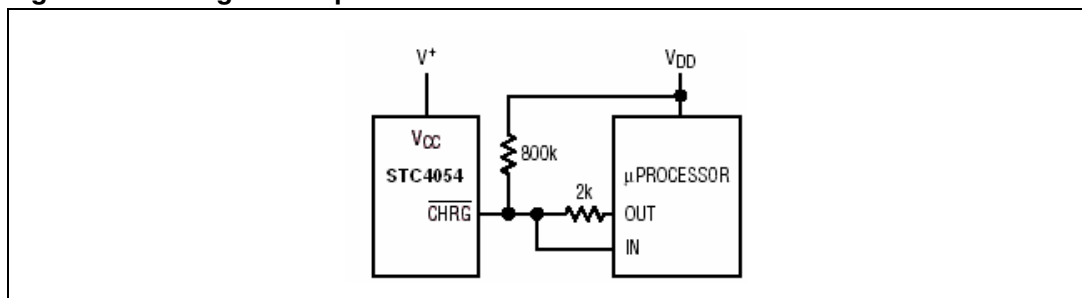


7 CHRG status output pin

The CHRG pin can provide an indication that the input voltage is greater than the undervoltage lockout threshold level. A weak pull-down current of approximately 20 μA indicates that sufficient voltage is applied to V_{CC} to begin charging. When a discharged battery is connected to the charger, the constant current portion of the charge cycle begins and the CHRG pin pulls to ground. The CHRG pin can sink up to 10mA to drive an LED that indicates that a charge cycle is in progress. When the battery is nearing full charge, the charger enters the constant-voltage portion of the charge cycle and the charge current begins to drop. When the charge current drops below 1/10 of the programmed current, the charge cycle ends and the strong pull-down is replaced by the 20 μA pull-down, indicating that the charge cycle has ended. If the input voltage is removed or drops below the undervoltage lockout threshold, the CHRG pin becomes high impedance.

Figure 10 shows that by using two different value pull-up resistors, a microprocessor can detect all three states from this pin. To detect when the STC4054 is in charge mode, force the digital output pin (OUT) high and measure the voltage at the CHRG pin. The N-channel MOSFET will pull the pin voltage low even with the 2 k pull-up resistor. Once the charge cycle terminates, the N-channel MOSFET is turned off and a 20 μA current source is connected to the CHRG pin. The IN pin will then be pulled high by the 2 k pull-up resistor. To determine if there is a weak pull-down current, the OUT pin should be forced to a high impedance state. The weak current source will pull the IN pin low through the 800 k resistor; if CHRG is high impedance, the IN pin will be pulled high, indicating that the part is in a UVLO state.

Figure 10. Using a microprocessor to determine CHRG state



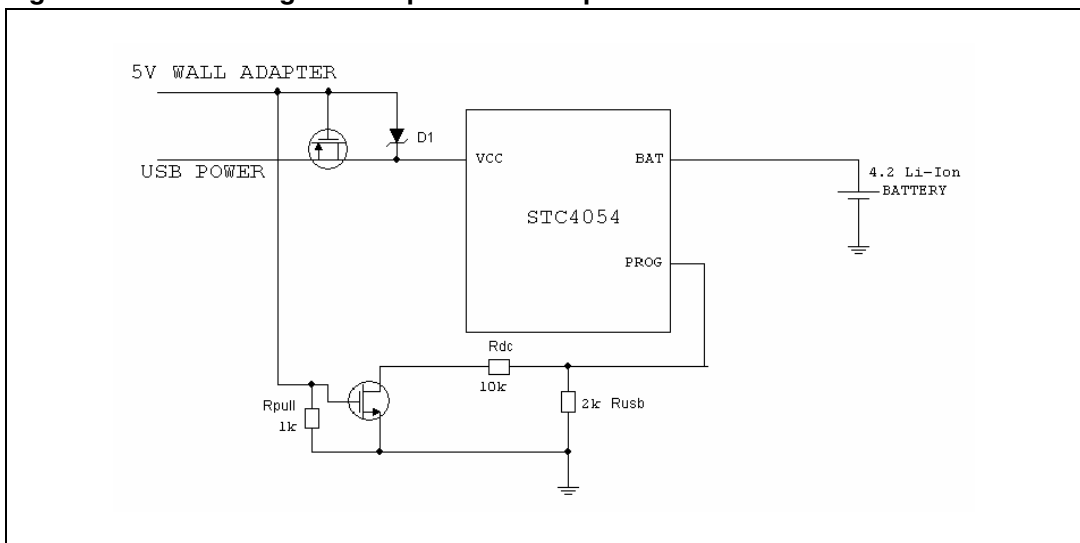
8 USB and wall adapter power

Although the STC4054 allows charging from a USB port, a wall adapter can also be used to charge Li-Ion batteries.

Figure 11 shows an example of how to combine wall adapter and USB power inputs. A P-channel MOSFET is used to prevent back conducting into the USB port when a wall adapter is present and a Schottky diode is used to prevent USB power loss through the 1 k pull-down resistor.

Typically a wall adapter can supply significantly more current than the 500 mA limited USB port. Therefore, an N-channel MOSFET and an extra program resistor are used to increase the charge current to 850 mA when the wall adapter is present.

Figure 11. Combining wall adapter and USB power



9 Programming charge current

The charge current is programmed using a single resistor from the PROG pin to ground. The battery charge current is 1000 times the current out of the PROG pin. The program resistor value is calculated using the following equation:

Equation 8

$$R_{\text{PROG}} = 1000 \cdot \frac{1.00 \text{ V}}{I_{\text{BAT}}}$$

The charge current out of the BAT pin can be determined at any time by monitoring the PROG pin voltage using the following equation:

Equation 9

$$I_{\text{BAT}} = \frac{V_{\text{PROG}}}{R_{\text{PROG}}} \cdot 1000$$

10 Revision history

Table 3. Document revision history

Date	Revision	Changes
3-Aug-2006	1	Initial release
07-Sep-2006	2	Minor text changes
19-Sep-2006	3	Table 2 changed
05-Oct-2007	4	Changed Figure 1 , Figure 3 , Figure 4 and Figure 5

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