

Battery Removal Detection Using Single Cell Linear Chargers



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Introduction

In applications with removable rechargeable batteries, the system needs to know whether a battery is connected. Detecting this is not as simple as reading the voltage on the BAT pin. An open battery protector IC can make a connected battery appear disconnected, while residual charge stored in the BAT pin capacitor can make a disconnected battery appear connected. This application brief describes how to implement battery removal detection in software using the registers available on the BQ2519x and BQ2518x linear battery charger ICs.

Behavior with No Battery Connected

This implementation takes advantage of the repeated charge cycles that occur when VIN is connected, charging is enabled, and no battery is connected. Figure 1 shows the resulting VBAT behavior:

1. The BAT pin capacitor charges up to the battery regulation voltage, VBATREG.
2. Charging terminates and the BATFET (Q4) is turned off.
3. The BAT pin capacitor begins to discharge due to leakage and loading on the BAT pin.
4. VBAT falls below the recharge threshold, triggering a recharge cycle and enabling charging.
5. The cycle repeats.

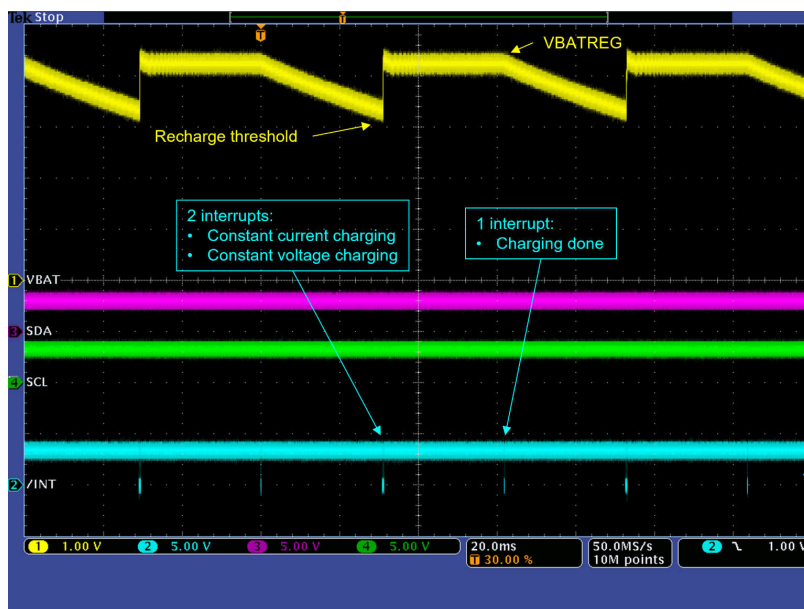


Figure 1. BAT Pin Voltage and Charge Status Interrupts With No Battery Connected and Charging Enabled

This cycle causes the charging status bits (CHG_STAT) to alternate between "Charging" and "Charging done." An interrupt is issued on the /INT pin each time the charging status changes, resulting in repeated charge status interrupts.

Battery Removal Detection Sequence

The host can use the repeated charge status interrupts that occur when an input source is connected, charging is enabled, and the battery is disconnected to initiate a sequence to check whether a battery is connected. After disabling charging, the host checks whether the BAT pin voltage falls below the battery undervoltage lockout (BUVLO) threshold by reading the BUVLO_STAT bit after a BUVLO interrupt occurs. With no battery connected, the BAT pin capacitor discharges below the BUVLO threshold. However, a low battery voltage can also trigger BUVLO. A low battery voltage can often be distinguished from a disconnected battery by lowering the BUVLO threshold to the minimum setting and checking whether the BUVLO_STAT bit remains clear. The following sequence checks for these conditions and can be used to detect whether a battery is connected:

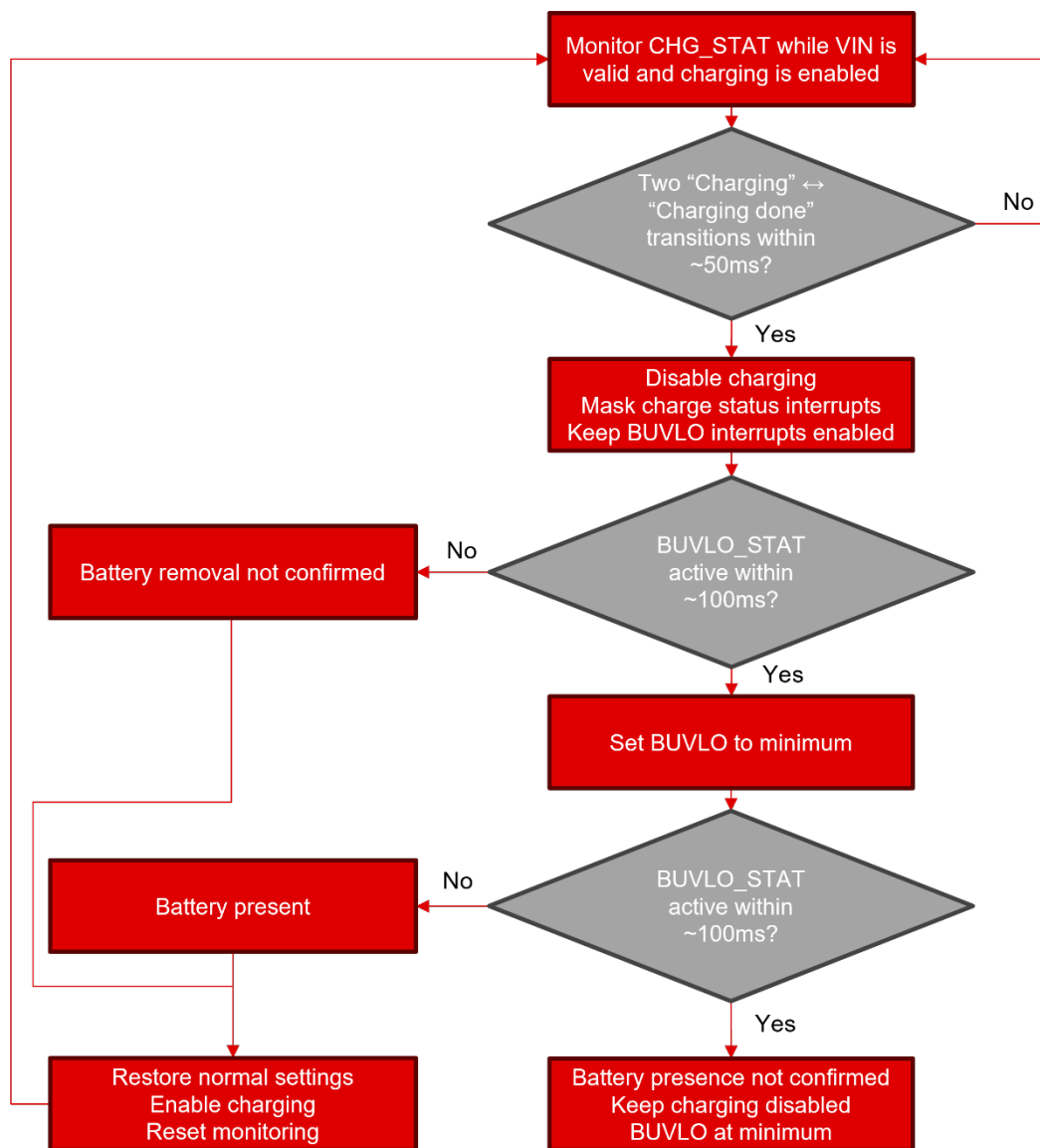


Figure 2. Battery Removal Detection Sequence

1. Monitor for repeated charge status interrupts while VIN is valid (VIN_PGOOD_STAT=1) and charging is enabled. On each interrupt, read the status and flag bits. If CHG_STAT changes between "Charging" and "Charging done," then changes back within around 50ms, continue to step 2. Treat both constant current and constant voltage charging as "Charging."
2. Disable charging using the charge disable bit. Mask charge status interrupts while leaving BUVLO interrupts enabled.

3. With no battery connected, a BUVLO interrupt occurs after the BAT pin voltage falls below the BUVLO threshold. This delay is around 40ms in the EVM waveform shown in Figure 4 but depends on the BAT pin capacitance and loading and can be measured on the PCB.
4. Read BUVLO_STAT to confirm that the device entered BUVLO. If BUVLO is not detected within around 100ms, restore the normal settings, enable charging, and restart monitoring. Otherwise, continue to step 5.
5. Set the BUVLO threshold to the lowest value, then read BUVLO_STAT again.
6. If BUVLO_STAT clears and remains clear for around 100ms after lowering BUVLO, this indicates that a battery is connected. For example, lowering the BUVLO threshold from 3.0V to 2.0V allows a 2.5V battery to clear BUVLO. Restore the normal BUVLO threshold and interrupt settings, enable charging, and restart monitoring.
7. If BUVLO_STAT remains active or becomes active again within around 100ms of lowering BUVLO, battery presence has not been confirmed. The battery can be absent, disconnected by a protector IC, or below the minimum BUVLO threshold. Leave charging disabled and the BUVLO threshold at the minimum setting.

The battery removal detection pseudocode is shown below:

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Monitor battery:
  Read CHG_STAT on each charger interrupt while VIN is valid and charging is enabled.
  Treat constant-current and constant-voltage as CHARGING.

If two CHARGING ↔ CHARGE_DONE transitions occur
within around 50ms:
  Disable charging immediately.
  Mask charge-status interrupts; keep BUVLO interrupts enabled.
  wait for BUVLO_STAT, up to around 100ms.

If BUVLO is not detected:
  Report removal not confirmed.
  Restore normal settings and enable charging.
  Reset monitoring.
Otherwise:
  Set BUVLO to its minimum threshold.

  If BUVLO_STAT is clear and remains clear
  for around 100ms:
    Report battery present.
    Restore normal settings and enable charging.
    Reset monitoring.
  Otherwise:
    Report battery presence not confirmed.
    Leave charging disabled and BUVLO at its minimum setting.

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Table 1. Example Timings

Interval	Time
Maximum time between two "Charging" ↔ "Charging done" transitions	50ms
Time waiting for BUVLO after disabling charging	100ms
Time checking whether BUVLO stays clear after lowering BUVLO to the minimum setting	100ms

These example timings must be adjusted for the BAT pin capacitance and loading in the application.

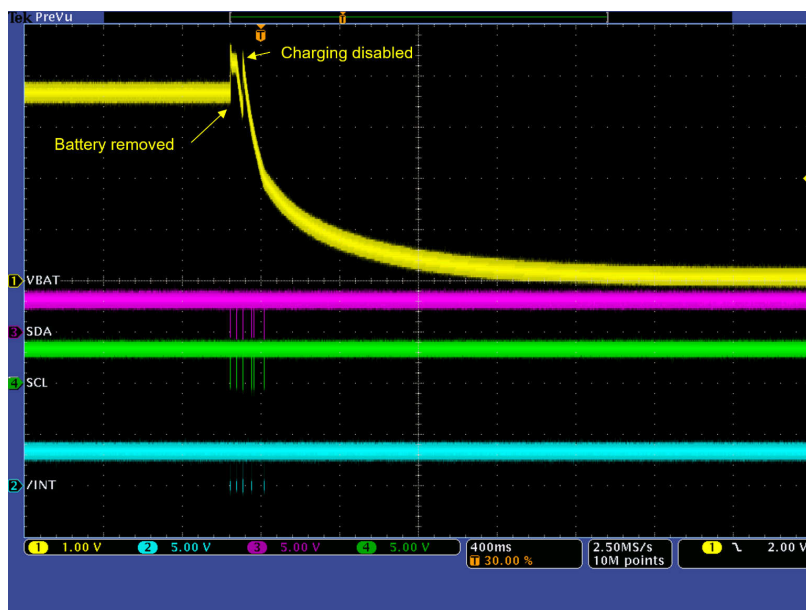


Figure 3. Battery Removal Detection Waveform

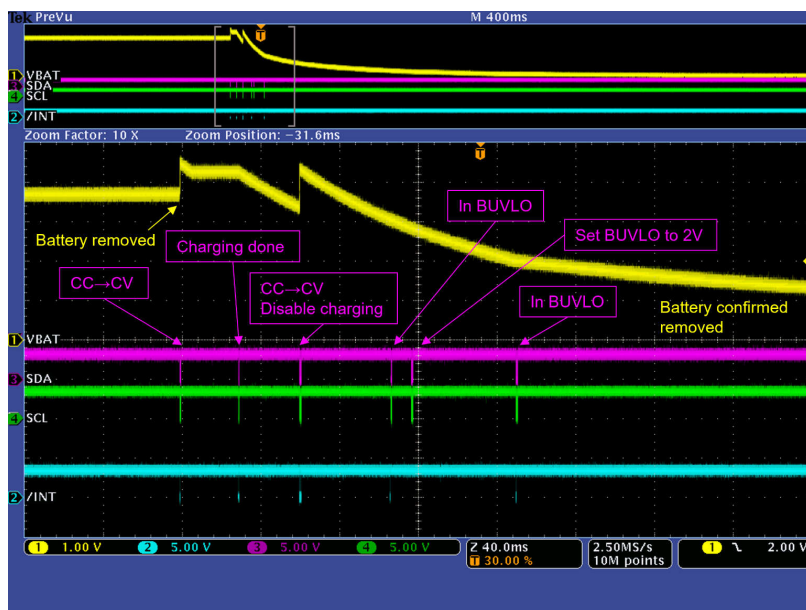


Figure 4. Battery Removal Detection Waveform (Zoomed In)

The I2C transaction that disables charging can be seen on the SDA line in Figure 4. Approximately 40ms later, a BUVLO interrupt pulse indicates that the BUVLO status has changed. This delay can vary with the effective capacitance on the BAT pin, so confirm the timing on the PCB.

Battery Reconnection

This method applies when the reconnected battery voltage is above the minimum BUVLO threshold and any battery protector allows the battery voltage to reach the BAT pin. After battery presence is not confirmed, the host can periodically read BUVLO_STAT while keeping charging disabled and the BUVLO threshold at its minimum setting. When a battery is reconnected and raises the BAT pin voltage above the BUVLO rising threshold, BUVLO_STAT clears. The host can then restore the normal BUVLO threshold and interrupt settings, enable charging, and restart monitoring. Polling is needed because exiting BUVLO does not generate a BUVLO

interrupt. Figure 5 shows battery removal and reconnection, with charging enabled after the host reads that BUVLO_STAT has cleared.

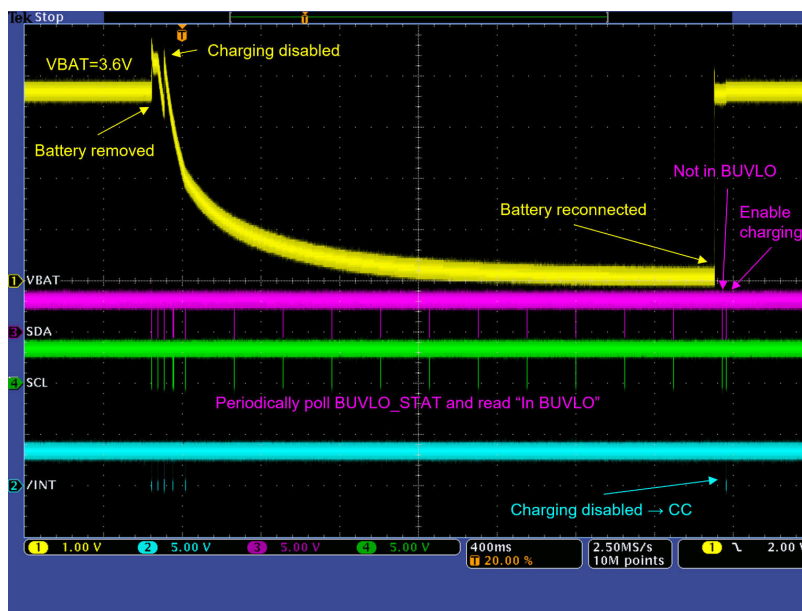


Figure 5. Battery Removal and Reconnection Waveform

Battery Protector Recovery

This method also detects battery reconnection through a battery protector. If the battery voltage is below the undervoltage protection (UVP) threshold of the protector, the protector turns off its discharge FET to prevent the battery from discharging further. With the discharge FET off, the battery voltage cannot reach the BAT pin because the discharge FET body diode blocks current from the battery to the BAT pin. Therefore, the host needs to enable charging for enough time to allow the battery to charge above the UVP recovery threshold and allow the protector to turn on the discharge FET. The recovery conditions of the protector are specified in its datasheet.

In the example implementation, after battery presence is not confirmed, the host keeps charging disabled and continues checking for battery reconnection. If the battery is not detected after some time and VIN is still valid, the host restores the normal BUVLO threshold and charge status interrupt settings, then enables charging for some amount of time to allow the battery protector an opportunity to recover from UVP. After this recovery time, the host resumes battery removal monitoring with charging enabled. If the repeated "Charging" to "Charging done" transitions do not occur, this indicates that the battery is connected and holding the BAT pin voltage. In this example, the battery protector is the BQ29700, which has a UVP threshold of 2.8V and a 100mV recovery hysteresis, resulting in a 2.9V UVP recovery threshold. Figure 6 shows an example of battery protector UVP recovery after the host enables charging.

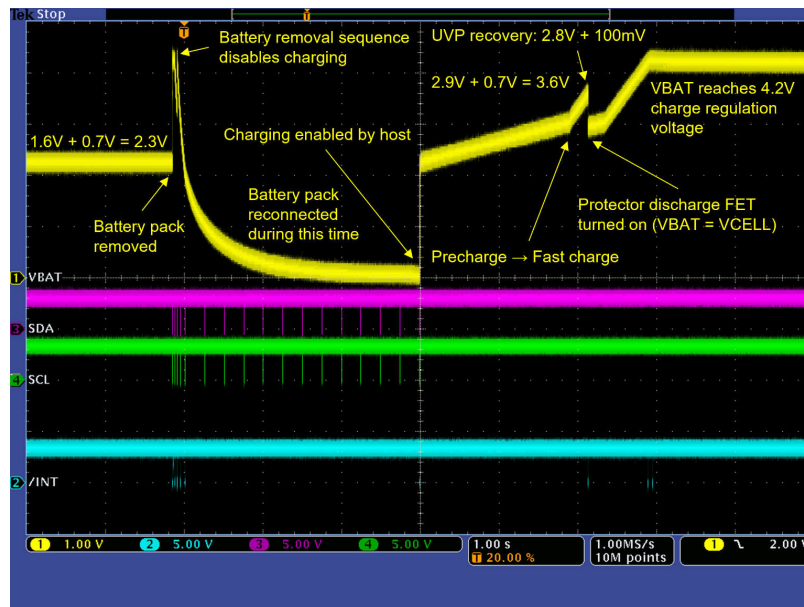


Figure 6. Battery Protector UVP Recovery Waveform

Summary

This application brief describes how to implement battery removal detection in software on the BQ2519x and BQ2518x linear battery charger ICs. The method also supports battery reconnection and battery protector recovery.

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