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How to Charge a Lead-Acid Battery With a Li-Ion Charger

Alen Chen

ABSTRACT

Lead-acid batteries are popular in many applications due to the low cost, backward compatibility, and safety consideration. One of the challenges of using a lead-acid battery is that there are limited number of charger integrated circuits (IC) which are dedicated for lead-acid batteries in the market. Conversely, with Li-ion batteries becoming more and more popular, semiconductor suppliers provide a rich charger portfolio for the Li-ion batteries on the market. This application note shows how to use a popular Li-ion charger IC (BQ24610 and BQ24650) to charge a lead-acid battery.

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1 Introduction

Lead-acid batteries are popular in many applications. Almost all applications with lead-acid batteries can be grouped as the non-frequent charging type and frequent-charging type. Non-frequent charging type batteries include backup applications, medical back up power supply, and uninterrupted power supply(UPS). Frequent charging (repeating) type batteries include high power audio box, portable power station and e-bike. For non-frequent charging applications, the constant current (CC), constant voltage (CV_{float}) charging without termination is a good option. For frequent-charging (repeating) applications, the CC, constant topping voltage($CV_{topping}$) charging with termination is a popular solution. Some of the Li-ion battery chargers can be used to implement these profiles to charge a lead-acid battery.

The BQ24610 and BQ24650 devices are highly-integrated Li-ion or Li-polymer switched-mode battery charge controllers. These devices offer a constant-frequency synchronous switching PWM controller with high-accuracy charge current and voltage regulation, charge preconditioning, termination, adapter current regulation, and charge status monitoring.

This application report discusses how to modify the BQ24610 or BQ24650 circuit for a lead-acid battery with different applications.

2 Lead-Acid Battery Charge Method and Implementation

This section discusses and compares the details of the two charging methods and the circuit implementation.

2.1 CC, $CV_{topping}$ Charging With Termination for Repeating Application

Figure 1 shows the charge profile of the CC/$CV_{topping}$ charge method. The constant-current charge applies the bulk of the charge and the topping charge continues at a lower charge current and provides saturation until the charge current drop to termination current (I_{term}) or charge safety timer expired. Once the battery voltage dropped to below recharge voltage threshold ($V_{rechrge}$), a new charge cycle is restarted.

In repeating applications, the power supply or charger does not always connect to the battery for a long time, so there is no chance to keep the battery at V_{float} even if the CC/$CV_{topping}$/CV_{float} 3-stage charge method is used. That means the CC/$CV_{topping}$ charge method can achieve a similar result compared to the CC/$CV_{topping}$/CV_{float} charge method.

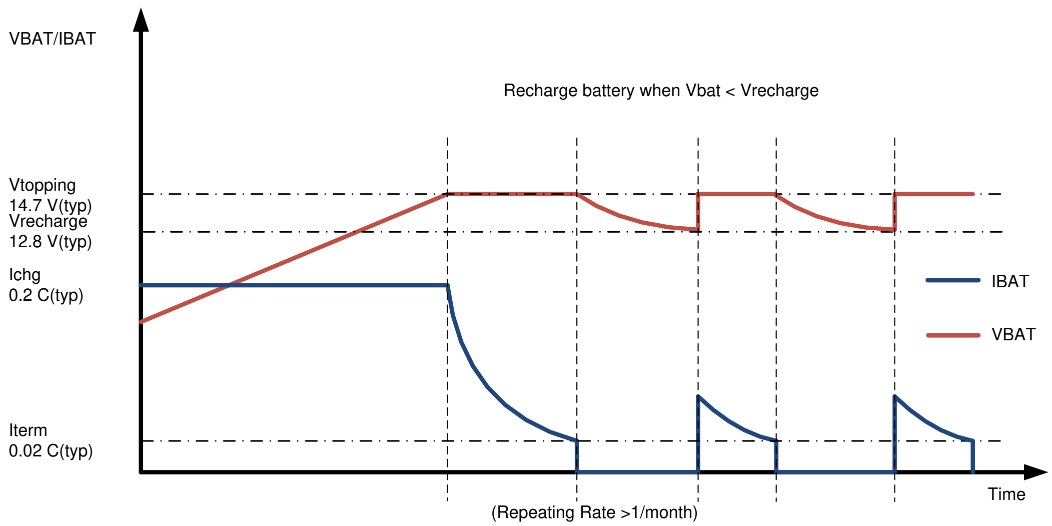


Figure 1. Charging Profile for Repeating Applications

Compared to the Li-ion battery, a lead-acid battery has to be charged with a much wider recharge threshold. Normally the charge voltage and recharge voltage threshold are very close in the Li-ion charger BQ246xx (2.05 V vs 2.1 V on FB pin), which would cause the lead-acid battery be recharged too frequently and keep it at a high voltage for a long time and leads to water loss and capacity loss. So an external component is required to increase the gap between the charge voltage and recharge voltage.

Figure 2 shows the schematic used to implement the algorithm. Two resistors and one signal FET are needed in addition to the typical circuit.

The circuit uses the STAT2 pin, which is pulled high while the battery is charging, to turn on Q4 and increase the constant voltage (CV) regulation point of the charger to $V_{topping}$ until the charger senses that the charge current has tapered off. Once the charging current drops to I_{term}, STAT2 goes to low. This causes Q4 to turn off, thus lowering the recharge threshold voltage of BQ246xx to $V_{recharge}$ which is about 85% to 95% status of charge (SOC). Once V_{BAT} drops to $V_{recharge}$ (due to self-discharge or load), the charger will restart a new charge cycle to maintain the SOC of the battery.

Equation 1 gives the $V_{topping}$ regulation voltage (Q4 on during charging):

$$V_{topping} = V_{FB} \times \left(\frac{RBP \,||\, RB + RT}{RBP \,||\, RB} \right)$$

where

- V_{FB} is the 2.1-V feedback reference voltage in the data sheet (1)

Equation 2 gives the $V_{recharge}$ threshold voltage (Q4 off after termination):

$$V_{recharge} = (V_{FB} - V_{RECHG}) \times \left(\frac{RB + RT}{RB} \right)$$

where

- V_{RECHG} is the 50-mV recharge hysteresis voltage in the data sheet (2)

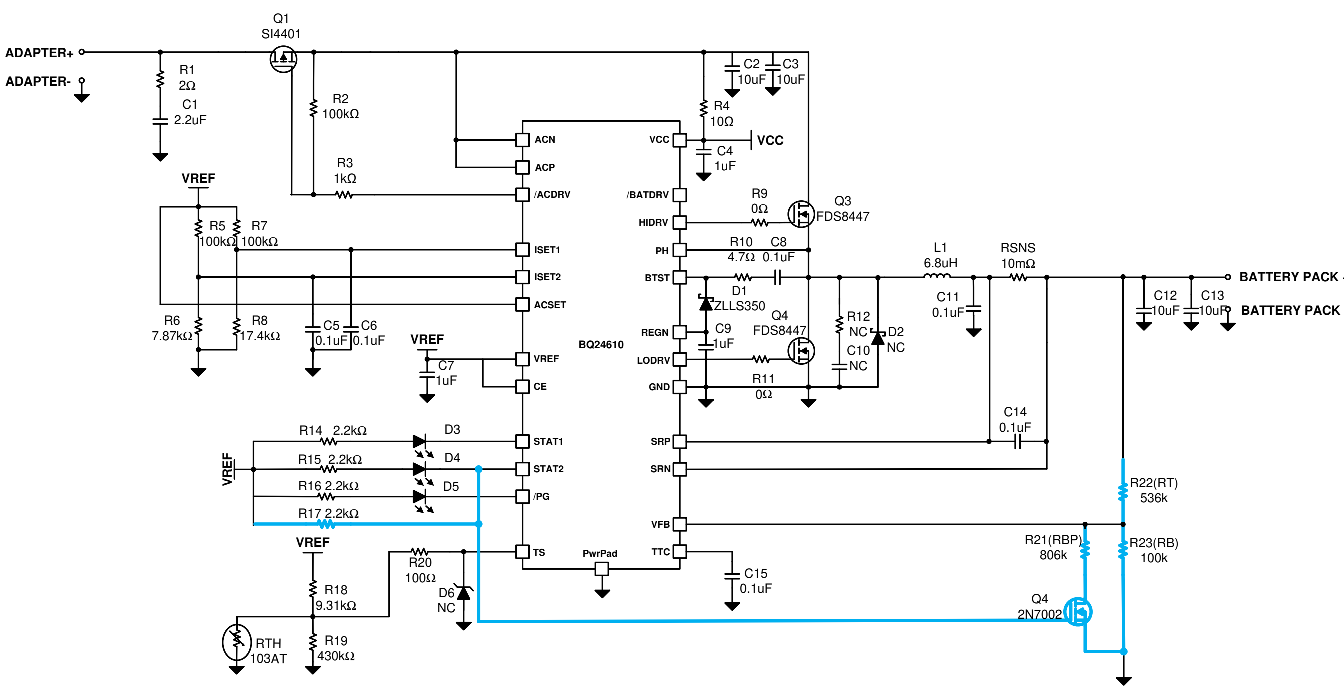
Conversely, this modification also impacts the pre-charge to fast-charge transition threshold (V_{pre_fast}). Equation 3 gives the new V_{pre_fast} threshold voltage. If the battery voltage is lower than V_{pre_fast} - hysteresis, the charge current will be precharge current ($I_{pre\text{-}charge}$), which is set on the Iset2 pin. If the battery voltage is higher than V_{pre_fast}, the charge current will increase to normal charge current (I_{charge}) which is set on the Iset1 pin.

$$V_{pre\_fast} = V_{LOWV} \times \left(\frac{RBP \,||\, RB + RT}{RBP \,||\, RB} \right)$$

where

- V_{LOWV} is the 1.55-V pre-charge to fast-charge transition threshold based on FB in the data sheet (3)

In general, the pre-charge phase is not required for the lead-acid battery, but it provides an additional protection for a deeply discharged battery. Typically, voltage of an ‘empty’ lead-acid battery is higher in this threshold, so pre-charge is not seen during normal use.



V_{IN} = 18 V to 28 V, $V_{topping}$ = 14.7 V, I_{charge} = 2.4 A, $I_{pre\text{-}charge}$ = I_{term} = 0.24 A, 10-hour safety timer

Figure 2. Schematic for Repeating Applications

2.2 CC/CV_{float} Charging Without Termination for Backup Application

Figure 3 shows the charge profile of CC/constant float voltage(CV_{float}) charge. The constant-current charging applies the bulk of the charge, the float charge continues at a lower charge current and compensates for the loss caused by self-discharge. This charge method does not have topping charge phase, so it needs a longer time to get the battery to full charge, compared to the $CC/CV_{topping}$ charge method. In a backup application, the battery is almost always in standby mode and is rarely discharged and charged, so using this charge method to keep battery voltage at V_{float} is suitable.

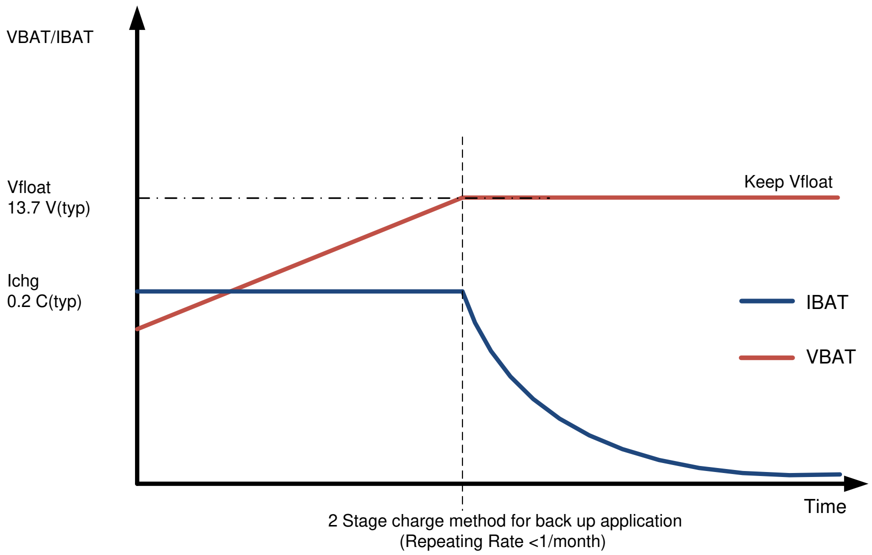
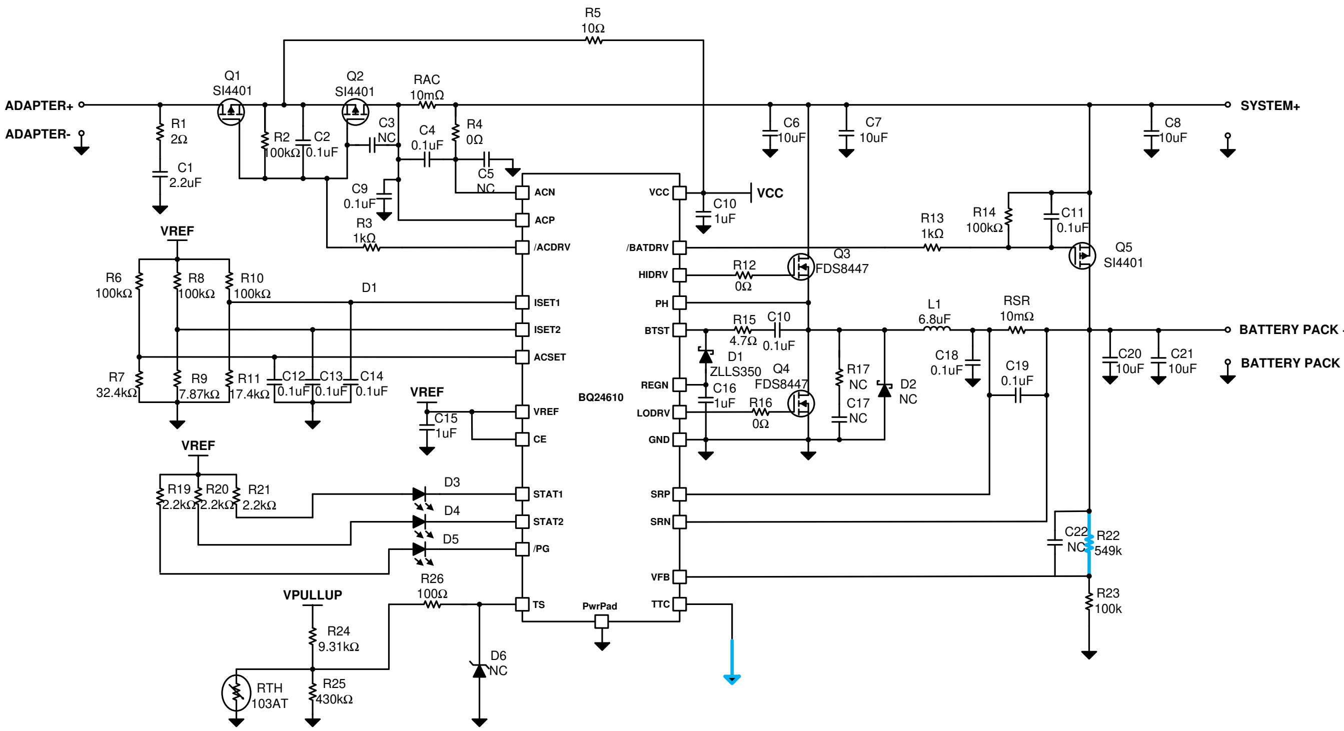


Figure 3. Charging Profile for Backup Applications

Figure 4 shows the schematic used to implement the algorithm. The TTC pin (or TERM_EN on BQ24650) needs to be tied to GND to disable termination, and the charge voltage is set to V_{float} with the feedback resistor divider.



V_{IN} = 18 V to 28 V, V_{float} = 13.7 V, I_{charge} = 2.4 A, $I_{pre\text{-}charge}$ = 0.24 A, with power path selector

Figure 4. Schematic for Backup Applications

3 Design Examples

The Panasonic® LC-RA1212 is used in this design example. The LC-RA1212 is a 12-V, 12-Ah, valve-regulated, lead-acid battery. Its topping charge voltage is 14.7 ±0.2 V, float charge voltage is 13.7 V ±0.1 V. A charge rate of 0.2C is used in this design example. Contact your battery vendor to get the battery specifications and charging parameters, these charging parameters might not be suitable for your battery.

3.1 *Example 1, CC/CV$_{topping}$ Charging With Termination for Repeating Application*

Table 1. Design Specification

Parameter	Value
Input voltage(V_{IN})	18 V to 28 V
Topping charge voltage ($V_{topping}$)	14.7 V
Recharge voltage($V_{recharge}$)	13 V (about 85% to approximately 95% SOC)
Charge current	2.4 A
Battery capacity	12 Ah
Termination and pre-charge current	0.24 A
Safety timer	10 hours

This section describes how to choose and design RT, RB, RBP and Q4 in Figure 2 only; see the related data sheet for the selection and design of other components.

Step 1: Determine the recharge voltage threshold. Typically, the lead-acid battery is recharged at SOC 85% to approximately 95% (12.5 V to approximately 13 V $V_{recharge}$) to maintain the remaining capacity and avoid water loss. If this threshold is too high, the battery will be recharged to frequency and keep the terminal voltage in a high level which would cause water loss and capacity loss. If this threshold is too low, the remaining capacity will be low and cause shorter system run time and sulfating. For this design example, $V_{recharge}$ is set to 13 V. A general signal MOSFET such as the 2n7002 is good for Q4.

Step 2: Calculate the RT. Consider power consumption and leakage current into the VFB pin, start this calculation with RB 100 kΩ:

$$V_{recharge} = (V_{FB} - V_{RECHG}) \times \left(\frac{RB + RT}{RB}\right) = (2.1\ V - 0.05\ V) \times \left(\frac{100\ k + RT}{100\ k}\right) = 13\ V \quad (4)$$

Thus,

$$RT = 534.15\ k\Omega \rightarrow 536\ k\Omega \text{ standard value} \quad (5)$$

Step 3: Calculate the RBP:

$$V_{topping} = V_{FB} \times \left(\frac{RBP\ ||\ RB + RT}{RBP\ ||\ RB}\right) = 2.1\ V \times \left(\frac{RBP\ ||\ 100\ k + 534.15\ k}{RBP\ ||\ 100\ k}\right) = 14.7\ V \quad (6)$$

Thus,

$$RBP = 811.11\ k\Omega \rightarrow 806\ k\Omega \text{ standard value} \quad (7)$$

Step 4: Verify pre-charge to fast-charge transition threshold:

$$V_{pre\_fast} = V_{LOWV} \times \left(\frac{RBP\ ||\ RB + RT}{RBP\ ||\ RB}\right) = 1.55\ V \times \left(\frac{806\ k\ ||\ 100\ k + 536\ k}{806\ k\ ||\ 100\ k}\right) = 10.89\ V \quad (8)$$

Step 5: Connect a suitable cap to the TTC pin (BQ2461x) to enable termination and set the safety timer to longer than the typical charging time. It is recommended to set the safety timer to 2 × (1 / (Charge Rate)). For example, the charge rate is 0.2C and 2 × 1 / 0.2 = 10 hr is the recommended safety timer setting. Pull TERM_EN pin (BQ24650) to VREF to enable termination.

Step 6: Select other components such as the inductor, sense resistor, or input/output capacitor with the guidance in the data sheet.

3.2 Example 2, CC/CV$_{float}$ Charging Without Termination for Backup Application

It is easy to implement this charge method with the BQ24610 or BQ24650 devices, the termination must be disabled and the charge voltage must be set to V_{float}. To disable termination, tie TTC (BQ24610) to GND or the TERM_EN (BA24650) pin to GND. Other configurations are the same with the typical application circuit, see Figure 4.

4 Test Result

Figure 5 shows the measured charging profile for repeating applications. As the image illustrates, the repeating charging with termination charging profile can be implemented with the revised circuit of the BQ24610 and BQ24650 devices for Li-Ion battery charger. In this test, a 120-mA discharge current was applied around 580 minutes to get the full charging profile in a reasonable time frame.

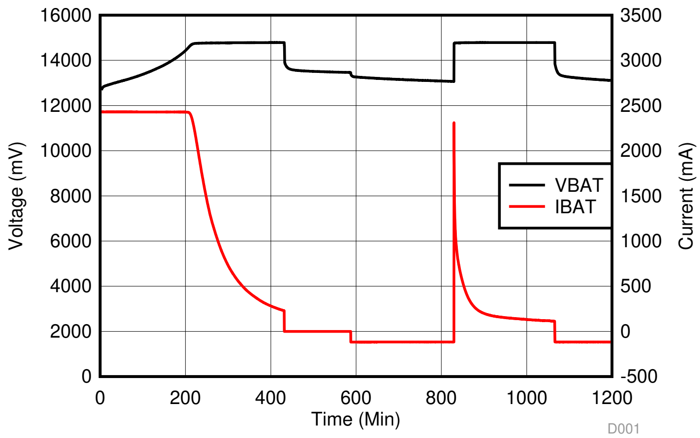


Figure 5. Measured Charging Profile for Repeating Applications

Figure 6 shows the measured charging profile for backup applications. As the image illustrates, the charging profile without termination can be implemented with the revised circuit of the BQ24610 and BQ24650 devices for Li-Ion battery charger.

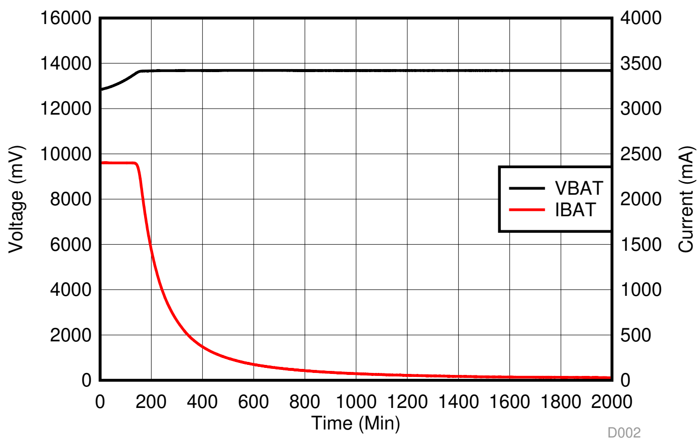


Figure 6. Measured Charging Profile for Backup Applications

5 Summary

With the simple circuit modification, The Li-Ion battery charger devices BQ24610 and BQ24650 can be configured as lead-acid battery chargers for different types of applications. Widely used Li-Ion chargers can be enabled as lead-acid battery chargers.