A boost-topology battery charger powered from a solar panel

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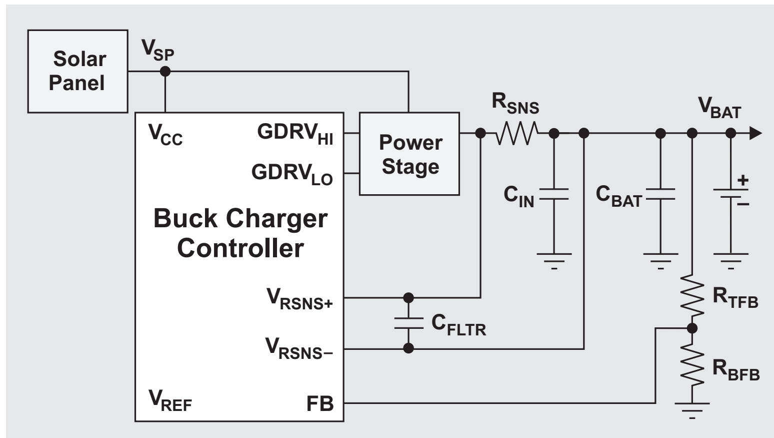
Introduction

Solar charging of batteries has recently become very popular. A solar cell's typical voltage is 0.7 V. Many panels have eight cells in series and are therefore capable of producing 5.6 V at most. This voltage is adequate for charging a single Li-ion battery, such as that used in cell phones, to 4.2 V with a buck or step-down charger. However, using the same panel to charge a multicell Li-ion battery like that used in laptop computers requires a boost or step-up charger. Most chargers currently on the market are based on a buck or step-down topology and therefore require their input voltage to be higher than the battery's fully charged voltage. However, it is possible to modify a buck battery charger into a boost or step-up battery charger. This article identifies the key concerns in implementing such a modification and provides a design example that uses the Texas Instruments (TI) bq24650 solar battery charger.

Figure 1. Block diagram of solar-powered battery charger

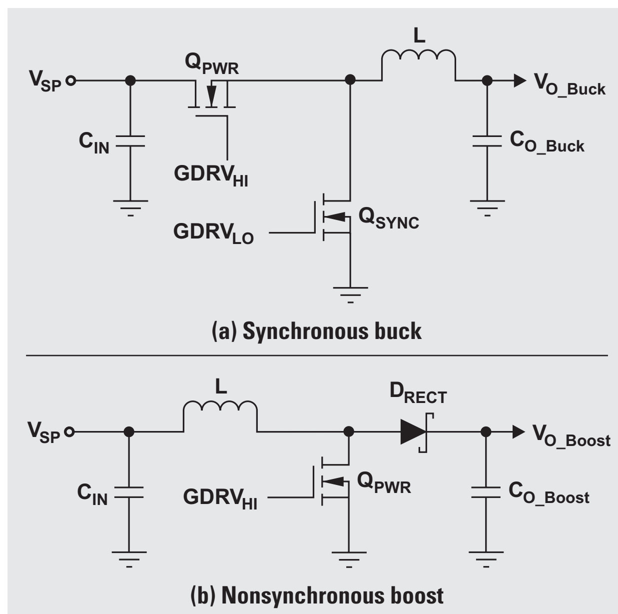


The buck power stage versus the boost power stage

Figure 1 shows a simplified block diagram of a solar-powered battery charger. The charger-controller IC monitors the charging current through a current-sense resistor (R_{SNS}) and the battery voltage (V_{BAT}) through the feedback resistors (R_{TFB} and R_{BFB}). The IC also adjusts the output of the power stage in order to meet the charging parameters. If the input source voltage (V_{SP}) will always be higher than the maximum battery voltage, a buck power stage can be used. If V_{SP} will always be lower than the maximum battery voltage, a boost power stage is required.

Figure 2 shows a synchronous buck power stage and a nonsynchronous boost power stage. Both use the high-side gate drive ($GDRV_{HI}$) to drive the power FET (Q_{PWR}). However, a buck controller cannot be easily configured to drive a synchronous rectifying switch for a boost converter; so Q_{SYNC} is replaced by diode D_{RECT}, and the low-side gate drive ($GDRV_{LO}$) is not used. A buck converter also provides continuous inductor current that is filtered by capacitors C_{IN} and C_{BAT} (see Figure 1) regardless of which switch is on. Unlike the buck converter, the boost converter uses Q_{PWR} only to charge the inductor. During this time the output capacitor must supply the battery-charge current. When D_{RECT} turns on, the now charged inductor provides both the output-capacitor and the battery-charging currents. Therefore, the boost converter's output-voltage ripple

Figure 2. Power-stage topologies



will always be higher than that of a buck converter that uses the same inductor and output capacitance and the same output power. This ripple can cause inaccurate current measurement across the current-sense resistor. Compared to the buck power stage shown in Figure 1, the boost power stage will require a larger sense-voltage filter capacitor (C_{FLTR}) and a larger output capacitance (C_{BAT}).

Limiting precharge current when $V_{BAT} << V_{SP}$

The boost power stage's rectifying diode provides a DC current path from V_{SP} to the battery when the controller is not switching. With a deeply discharged battery, the battery voltage could be below the solar panel's output voltage, causing the charger controller to stop switching and no longer regulate the battery-charging current. Therefore, a current-limiting resistor ($R_{Precharge}$) in series with the diode (see Figure 3) is required to limit the charge current to a lower, precharging current value. Once the battery voltage reaches V_{SP}, the controller begins switching, and $R_{Precharge}$ can be shorted out with a FET (Q_{Short}) to allow the controller to provide higher charge currents. Figure 3 shows how $R_{Precharge}$ can be used with Q_{Short} and a comparator to implement this functionality.

$R_{Precharge}$ is sized to give the maximum recommended precharge current for the battery at the solar panel's maximum power-point voltage (V_{SP_MPP}). Q_{Short} is sized to accommodate the maximum battery voltage ($V_{BAT(max)}$) and the maximum charge current ($I_{CHRG(max)}$). The comparator feedback resistor (R_{HYS}) provides hysteresis. Therefore, resistor dividers are needed on the sensed-voltage inputs to the comparator.

Ensuring operation when $V_{BAT} > V_{SP}$ or when $V_{BAT} < V_{BATSHT}$

A buck charger expects the battery voltage to always be less than the charger's input voltage. In fact, many chargers have a feature that puts the charger into sleep mode if V_{BAT} is greater than V_{SP}. Alternatively, if V_{BAT} falls below a certain threshold (V_{BATSHT}), the IC may assume the battery is shorted and enter protection mode. If the voltages at the current-sense pins (V_{RSNS+} and $V_{RSNS–}$) are used to determine the battery's state, the sensed voltages will need to be level shifted to avoid a false detection of a shorted output. Figure 4 shows how to use an instrumentation amplifier, configured as a current-shunt monitor, to level shift the current information sensed across R_{SNS}. This circuit lowers the DC set point of the sensed voltages enough that the IC will not enter sleep mode but keeps the voltages high enough that the IC does not enter short-circuit-protection mode. If the charger does not have its own reference voltage (V_{REF}), an external reference IC can be used.

Figure 3. Precharge circuitry

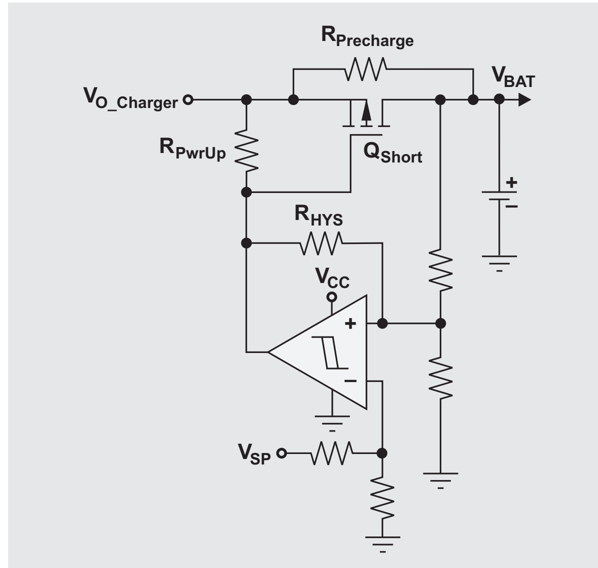
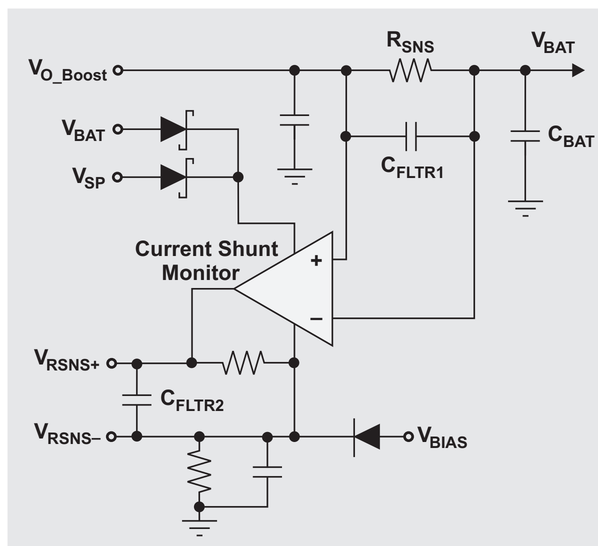


Figure 4. Current-sensing circuit with level shifting



Computing the maximum charge current

A boost charger's maximum charge current is a function of its available input power. A simple way to estimate the maximum charge current is to first estimate the input-to-output efficiency, $P_{OUT}/P_{IN} = \eta_{est}$, where η_{est} is an estimate of the boost charger's efficiency in similar operating conditions. The following equation can then be used to estimate the maximum charge current at a specific battery voltage:

$$I_{CHRG(max)} = \frac{V_{SP\_MPP} \times I_{SP\_MPP} \times \eta_{est}}{V_{BAT}},$$

where V_{SP_MPP} is the solar panel's maximum power-point voltage, and I_{SP_MPP} is the solar panel's maximum power-point current.

R_{SNS} should be sized to provide $I_{CHRG(max)}$. Q_{PWR} has a voltage rating slightly higher than $V_{SP(max)}$, and Q_{PWR} and L1 have current ratings equal to at least I_{SP_MPP}. The charger's control circuitry that manages input voltage and current will adjust the charge current to keep the charger operating at the solar panel's maximum power point. Charge controllers such as the bq24650 perform the same function with maximum-power-point tracking (MPPT).

Design example using the bq24650

Table 1 maps the functional pin names from Figure 1 to the corresponding bq24650 pin names in Figure 5. Figure 5 shows TI's bq24650 charger controller configured to charge a 12.6-V, 3-cell Li-ion battery from a 5-V solar panel. The maximum charge current is limited to 1.2 A. The power n-channel FET (Q1) and rectifying diode (D1) are sized by using standard design guidelines for boost converters. The inductor (L1) and output capacitors (C3 and C4) are sized to reduce inductor-current ripple and the resulting output-voltage ripple. R18 is used to slow down the fast turn-on of Q1. Also, the controller's PH pin is grounded to help provide the boosted output voltage. To prevent the output of the current-shunt monitor (U2) from loading the SRP pin, a unity-gain buffer (U3) is necessary.

Table 1. Cross-reference for controller pin names

FIGURE 1 CONTROLLER PIN NAME	bq24650 PIN NAME
$GDRV_{HI}$	HIDRV
$GDRV_{LO}$	LODRV
V_{RSNS+}	SRP
V_{RSNS-}	SRN
FB	VFB

Figure 5. The bq24650 configured as a boost charger

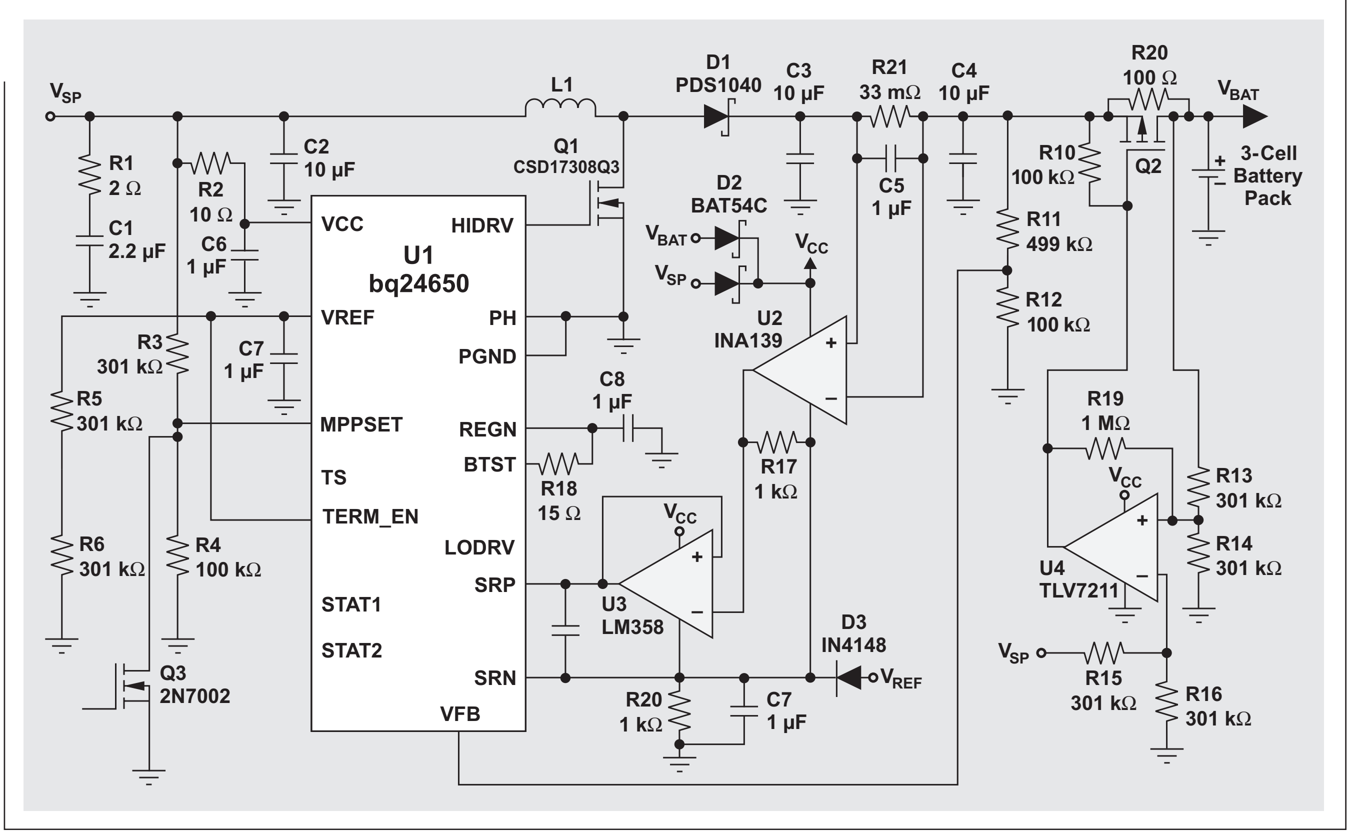
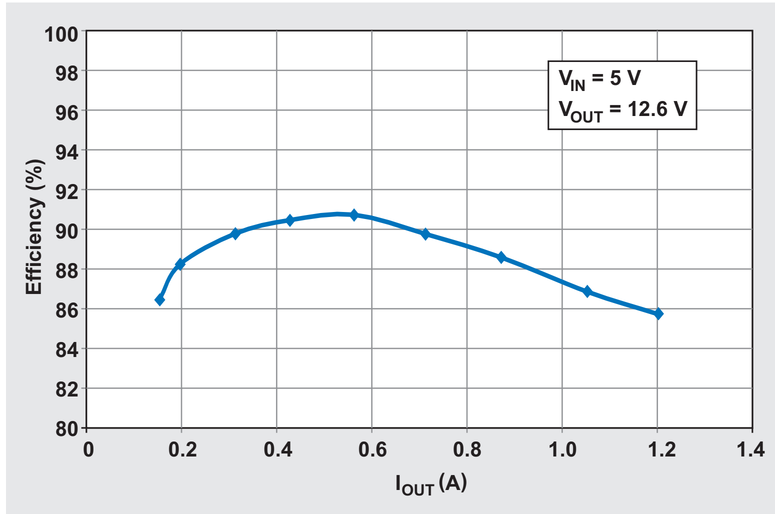


Figure 6 shows the efficiency of the charger in Figure 5. Although the bq24650 is internally compensated as a buck charger, its small-signal control loop is stable over a wide operating range when the IC is operating as a boost charger (see Figure 7). When using the bq24650 with different power-stage inductors and capacitors, the designer is responsible for confirming loop stability.

Figure 6. Efficiency of boost charger in Figure 5



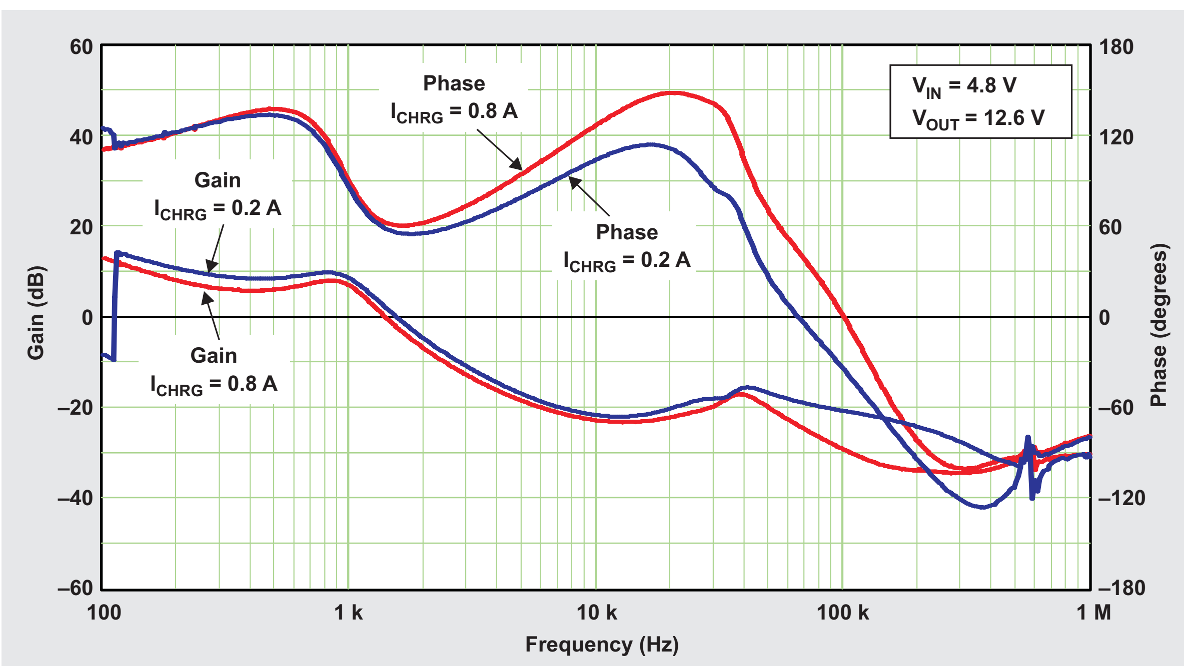
Conclusion

The demand for step-up battery chargers is growing, especially as the demand for charging from solar panels grows. Following the guidelines presented in this article, a designer can convert the bq24650 buck charger into a boost charger. When converting a different buck charger into a boost charger, the designer is responsible for understanding how that charger operates in order to determine which additional circuitry is necessary as well as to confirm stable operation.

Related Web sites

power.ti.com
www.ti.com/sc/device/*partnumber*
Replace *partnumber* with bq24650, CSD17308Q3, INA139, LM358, or TLV7211

Figure 7. Bode plot of gain and phase with an open feedback loop



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