A solar-powered buck/boost battery charger

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Introduction

Charging batteries with solar power has become very popular. A solar cell's typical voltage is 0.7 V. Panels range from having one cell to several cells in series and are therefore capable of producing a wide range of voltages. Most battery chargers on the market today step down, or buck, their input voltages. Therefore, to charge a two-cell lithium-ion (Li-Ion) battery, for example, a solar panel capable of producing at least 8.4 V is needed. However, this same charger cannot be used to step up, or boost, its input voltage to charge a multicell Li-Ion battery used in a laptop or a 12-V lead-acid battery used in a solar lantern. It is possible to modify a buck battery charger into a battery charger that both bucks and boosts. This article identifies the key concerns of changing a buck battery charger into a buck/boost SEPIC charger and provides a design example using the Texas Instruments bq24650 battery charger controller for solar power.

SEPIC power stage versus buck power stage

Figure 1 shows a simplified block diagram of a battery charger controller. The charger controller IC monitors the charging current through R_{SNS} and the battery voltage through the feedback resistors (R_{TFB} and R_{BFB}) and adjusts the output of the power stage to meet the charging parameters. If the input source voltage can be both higher and lower than the maximum battery voltage, a SEPIC power stage capable of bucking and boosting can be used.

Figure 2 compares a synchronous buck power stage and a nonsynchronous SEPIC power stage. The buck controller's high-side gate drive ($GDRV_{HI}$) is used to drive the SEPIC converter's power FET (Q_{PWR}). However, a buck controller cannot be easily configured to drive a synchronous rectifying switch for a SEPIC converter. Therefore, Q_{SYNC} is replaced by diode D_{RECT}, and the low-side gate drive is not used. A buck converter also provides continuous inductor current, filtered by the capacitors C_{O_BUCK} and C_{O_CHRGR}, to the load, regardless of which switch is on. Unlike the buck converter,

Figure 1. Block diagram of battery charger controller
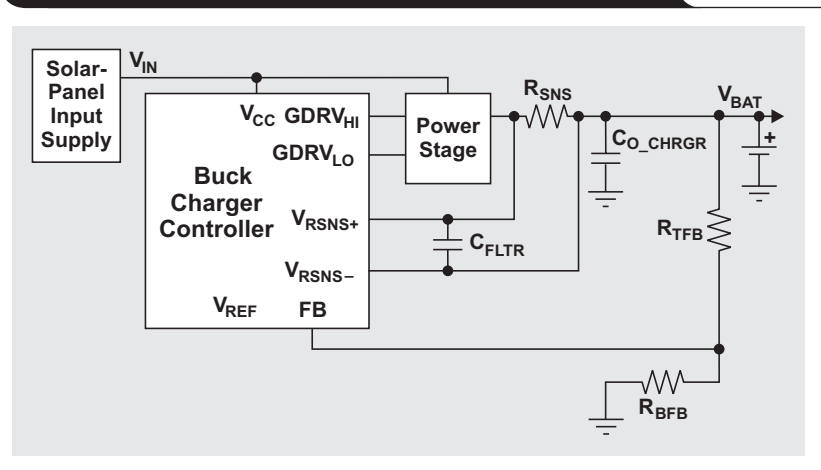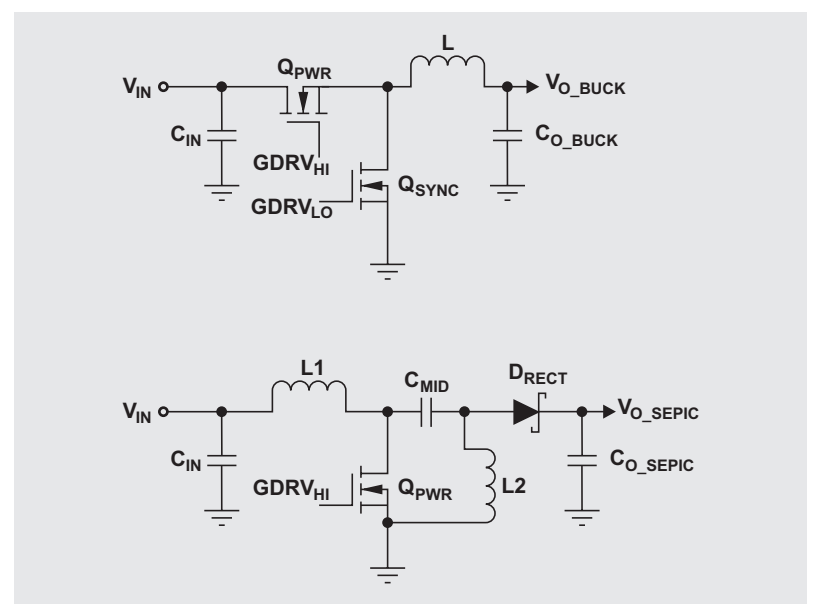

Figure 2. Buck power stage (top) versus SEPIC power stage (bottom)

the SEPIC converter uses Q_{PWR} only to charge the inductor. During this time the output capacitor must supply the battery-charging current. When D_{RECT} turns on, the now charged inductor provides both the output capacitor recharging and battery-charging currents. Hence, the SEPIC converter's output-voltage ripple will always be

higher than that of a buck converter with the same inductor and output capacitance and same output power. This ripple can cause inaccurate current measurement across the current-sense resistor. As shown in Figure 1, a SEPIC charger requires a larger filtering capacitor (C_{FLTR}) and larger output capacitors (C_{O_SEPIC} and C_{O_CHRGR}) than does a buck charger.

Limiting precharge current when $V_{BAT} << V_{BAT(LOW)}$

With a deeply discharged battery, the battery voltage is below a predetermined $V_{BAT(LOW)}$ threshold. For battery safety, the charger should not provide full charge current to the battery. Therefore, a current-limiting resistor between the charger and battery is recommended to limit the charge current to a lower, precharging current value. Once the battery voltage exceeds the selected $V_{BAT(LOW)}$, this resistor can be shorted out with a FET to allow the controller to provide higher charge currents. Figure 3 shows how resistor $R_{PRECHRG}$, a FET (Q_{SHRT}), and a comparator can be used to implement this functionality.

$R_{PRECHRG}$ is sized so that the voltage drop from $I_{PRECHRG}$ flowing through $R_{PRECHRG}$, plus the deeply discharged battery voltage ($V_{BAT(LOW)}$), is higher than the charger's low-battery threshold (for example, V_{LOWV}), typically sensed by the V_{FB} pin. Q_{SHRT} is sized to accommodate the maximum battery voltage ($V_{BAT(MAX)}$) and the maximum charge current ($I_{CHRG(MAX)}$). The resistor across the comparator (R_{HYS}) provides hysteresis. Therefore, resistor dividers are needed on the sensed voltages fed to the comparator.

Ensuring operation when $V_{BAT} > V_{IN}$ or when $V_{BAT} < V_{TH(BATSHORT)}$

A buck charger expects the battery voltage to always be less than its input voltage. In fact, many chargers have a feature that puts the charger into sleep mode if V_{BAT} is greater than V_{IN}. Alternatively, if V_{BAT} falls below a certain threshold, the IC may assume the battery is shorted and enter protection mode. If the current-sense pins (V_{RSNS+} and V_{RSNS-}) are used to determine the battery's state, the sensed voltages need to be level shifted. 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 keeps the DC set point of the sensed voltages low enough that the IC does not enter sleep mode; it also keeps the voltages high enough so that the IC does not enter short-circuit protection. If the charger does not have its own reference voltage (V_{REF}), an external reference IC can be used.
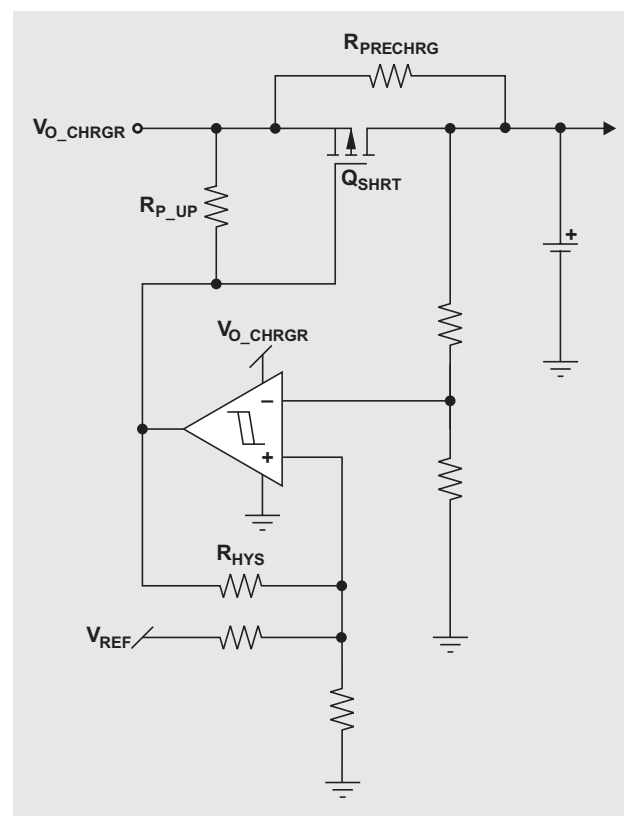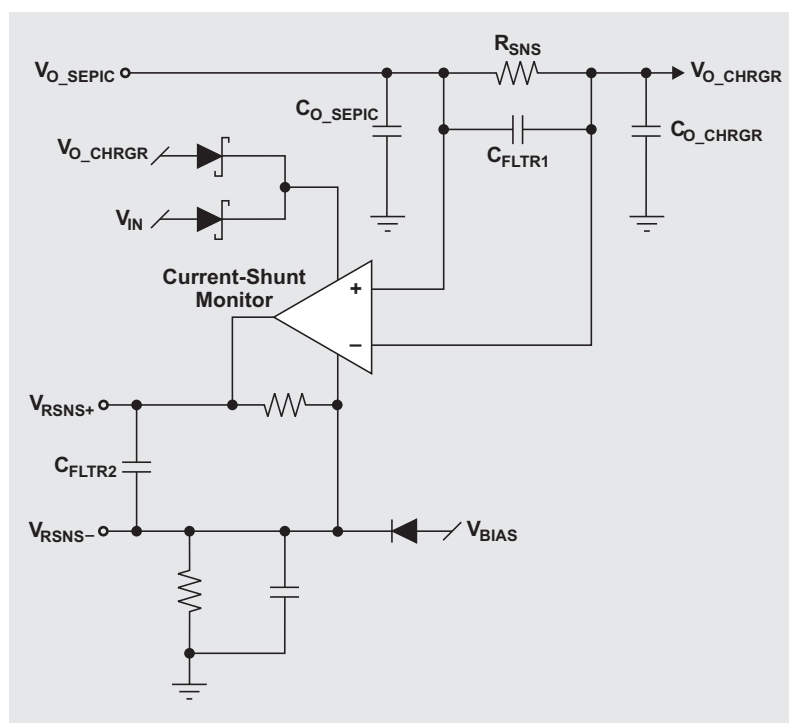

Figure 3. Precharge circuitry

Figure 4. Current-sense level-shift circuit

Computing the maximum charge current

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

$$I_{CHRG(MAX)} = \frac{V_{IN(MPP)} \times I_{IN(MPP)} \times \eta_{EST}}{V_{BAT}},$$

where $V_{IN(MPP)}$ is the solar panel's maximum power-point voltage, and $I_{IN(MPP)}$ is the solar panel's maximum power-point current.

R_{SNS} should be sized to provide $I_{CHRG(MAX)}$. Because capacitor C_{MID} between the inductors stays charged to the input voltage, Q_{PWR} must have a voltage rating slightly higher than $V_{IN(MAX)} + V_{BAT(MAX)}$. In a SEPIC converter, L1's peak current is the maximum input current ($I_{IN(MPP)}$) plus half the ripple current ($\Delta I_L/2$), and the peak current of L2 and diode D_{RECT} is the maximum output current ($I_{CHRG(MAX)}$) plus $\Delta I_L/2$. Q_{PWR} sees the sum of these peak currents when it is on, so it must have a current rating higher than $I_{IN(MPP)} + I_{CHRG(MAX)} + \Delta I_L$. The bq24650 charger controller can adjust the charge current to keep the solar-panel output at its maximum power point.

Design example of a solar-charged battery

Table 1 maps the functional pin names from Figure 1 to the corresponding bq24650 pin names in Figure 5. Figure 5 shows the charge controller configured to charge a two-cell Li-Ion battery with a maximum charge voltage of 8.4 V. The maximum charge current was limited to 1.3 A. The power NFET (Q2) and rectifying diode (D1) were sized using standard design guidelines for a SEPIC converter. The inductor and the output capacitors (C3 and C4) were sized to reduce inductor-current ripple and the resulting output-voltage ripple as well as to improve the small-signal control-loop phase margin. A coupled inductor, in the same footprint but only slightly taller than its single-inductor counterpart, was used instead of two separate inductors. The coupling effect allows the use of half the inductance that would have been necessary for the same current ripple

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 SEPIC charger
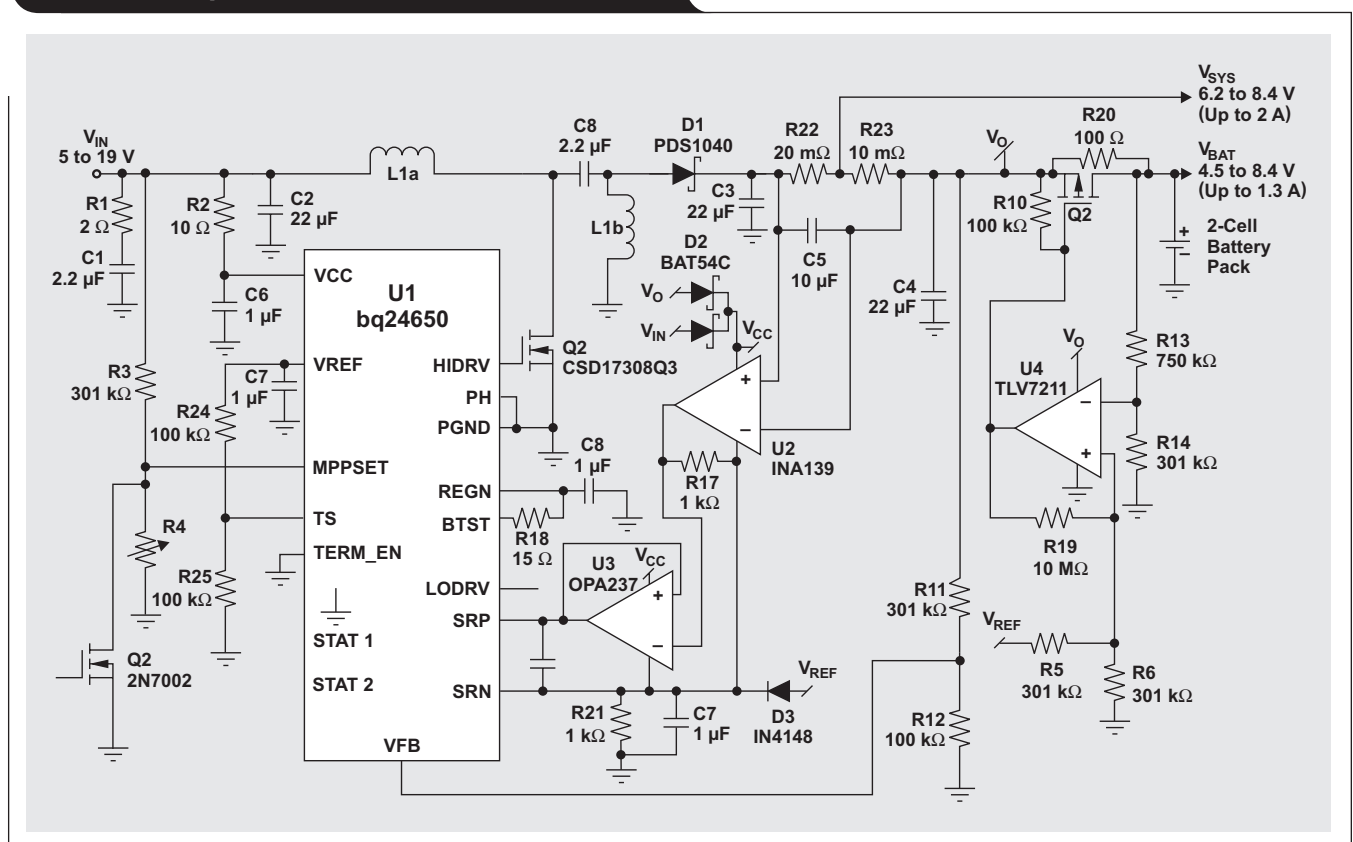
if two separate inductors had been used. R18 was used to slow down the fast turn-on of Q1. Also, the controller's PH pin was grounded to help provide the boosted output voltage. A 10-µF filter capacitor (C5) was necessary to reduce switching noise coupled into the current-shunt monitor (U2). To prevent the output of the current-shunt monitor (U2) from loading the SRP pin, a unity-gain buffer (U3), with ground shifted to match that of the current monitor, was necessary. With a discharged battery voltage of 4.5 V and the bq24650's V_{LOWV} = 1.55 V/2.1 V × 8.4 V = 6.2 V, a minimum precharge resistance ($R_{PRECHRG(MIN)}$) greater than

$$\frac{6.2\ V - 4.5\ V}{0.133\ A} = 13\ \Omega$$

was needed. A value of 100 Ω was selected for R20.

Figure 6 shows the efficiency of this charger. Although the bq24650 is internally compensated for a buck charger, when it is configured as a SEPIC charger its small-signal control loop is stable over a wide operating range, as shown in Figure 7. When using the bq24650 with a different power-stage inductor and different capacitors and batteries, the designer is responsible for confirming loop stability.

Conclusion

The demand for a buck/boost battery charger is growing, especially as demand for charging from solar panels grows. By following the guidelines presented in this article and using the proposed additional circuitry, the designer can convert a buck charger controller like the bq24650 into a SEPIC charger. When converting a different buck charger into a buck/boost SEPIC charger, the designer is responsible for understanding how that charger operates in order to determine which additional circuitry is necessary and to confirm stable operation.

Related Web sites

power.ti.com
www.ti.com/product/*partnumber*
Replace *partnumber* with bq24650, CSD17308Q3, INA139, OPA237, or TLV7211

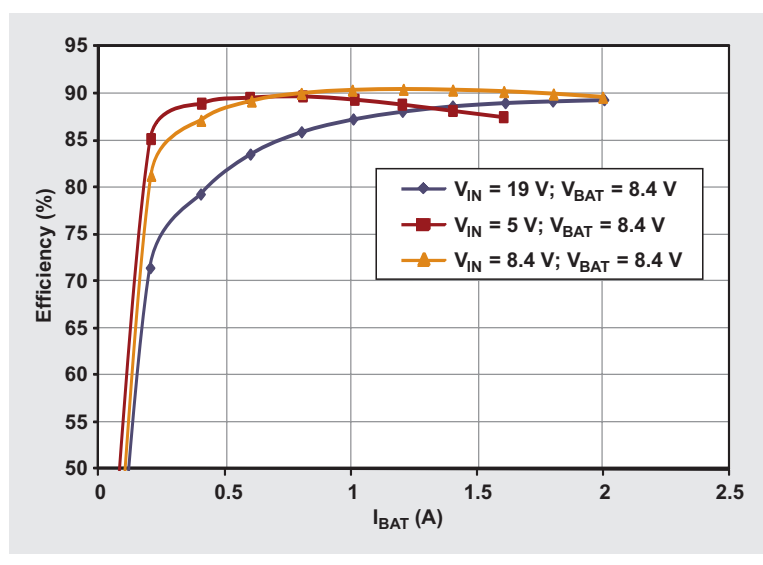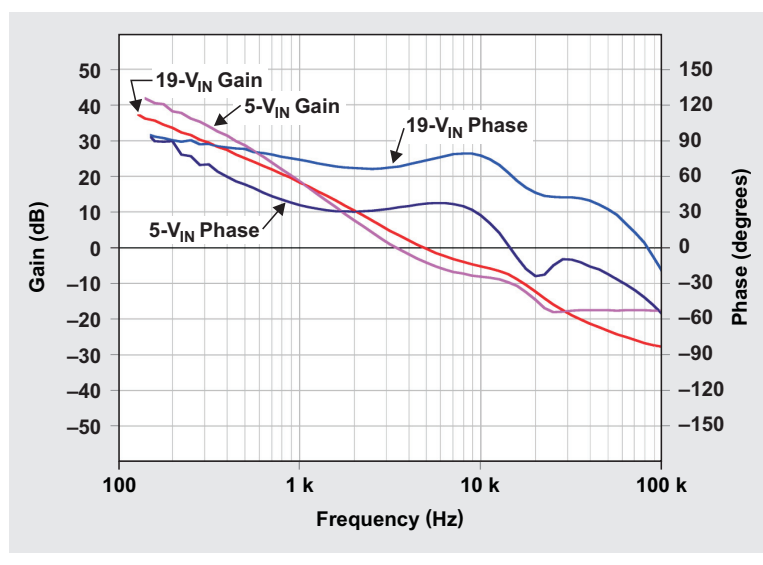Figure 6. Efficiency of charger in Figure 5

Figure 7. Bode plot of gain and phase with an open feedback loop at full charge current

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