WARNING: EXPORT NOTICE

Recipient agrees to not knowingly export or re-export, directly or indirectly, any product or technical data (as defined by the U.S., EU, and other Export Administration Regulations) including software, or any controlled product restricted by other applicable national regulations, received from Disclosing party under this Agreement, or any direct product of such technology, to any destination to which such export or re-export is restricted or prohibited by U.S. or other applicable laws, without obtaining prior authorization from U.S. Department of Commerce and other competent Government authorities to the extent required by those laws. This provision shall survive termination or expiration of this Agreement. According to our best knowledge of the state and end-use of this product or technology, and in compliance with the export control regulations of dual-use goods in force in the origin and exporting countries, this technology is classified as follows:

- US ECCN: 3E991
- EU ECCN: EAR99

And may require export or re-export license for shipping it in compliance with the applicable regulations of certain countries.

Application Report
SLVA829–September 2016

Preventing BQ24650 Leakage Current When Using Shaded Solar Panels

David Wiest

ABSTRACT

This application report discusses how to prevent the BQ24650 from acting as a load on the battery when the solar cells that power the system are not in direct sunlight or are partially shaded. Basic implementation of the Maximum Power Point Tracking feature is also reviewed.

Contents

List of Figures

List of Tables

1 Introduction

The BQ24650 is a highly integrated, switch-mode battery charger controller that is capable of using a solar panel as the input power source. The BQ24650 is intended for charging Li-Ion cells, with a typical application circuit seen in Figure 1. However, slight modifications to the application circuit can be made to charge other battery chemistries. Regardless of battery chemistry, small changes must be made to the application circuit to account for variations in solar cell characteristics. For more information on charging alternative battery chemistries such as Lead-Acid and LiFePO4, please refer to the application report, *Using the bq24650 to Charge a Sealed, Lead-Acid Battery* and *Using the bq24650 to Charge a LiFePO4 battery*.

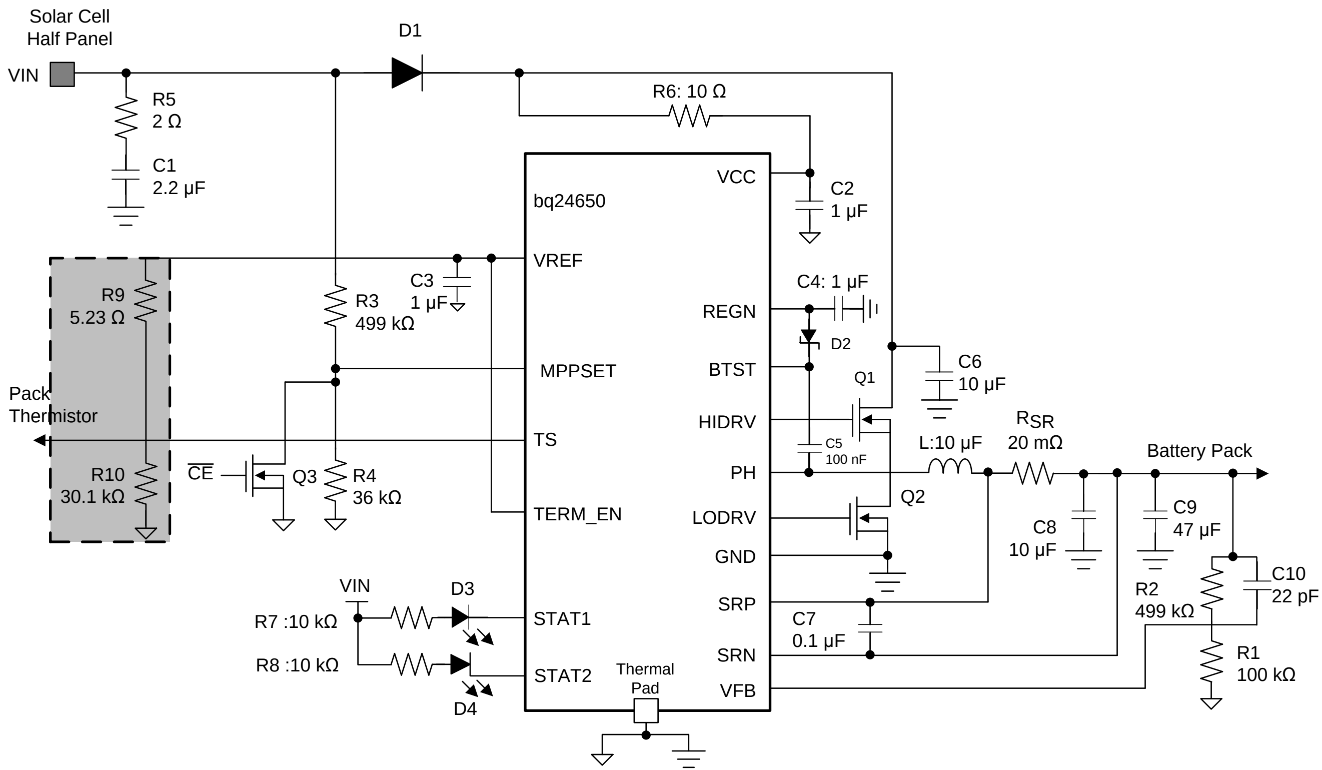

Figure 1. BQ24650 Typical Application Circuit

A solar panel typically consists of a number of smaller individual solar cells. It is these cells that generate electricity via the photovoltaic effect. Similar to a battery, increasing the number of cells in series increases the panel voltage, while increasing the number of cells in parallel increases the capability of the panel to source current.

One of the key characteristics of a solar panel is its Maximum Power Point (MPP). The MPP is the panel's most efficient operating point. If the panel cannot source the required current the solar panel voltage begins to drop, eventually reaching 0 Volts reducing the power to 0 Watts. The BQ24650 is capable of regulating charge current by tracking the panel's MPP through the voltage divider on the MPPSET pin. Using resisters R3 and R4, the user can set a minimum operating voltage for the solar cell using Equation 1.

$$V_{MPPSET} = 1.2V \times \left[1 + \frac{R3}{R4}\right] \quad (1)$$

As the input voltage drops, the BQ24650 reduces the charging current to maintain the solar panel's MPP. If the input voltage drops below V_{MPPSET}, the BQ24650 disables charging. Pulling the MPPSET pin below 75 mV also disables the charging current. For more in depth information about MPP Tracking and tracking MPP with temperature, please refer to the application report, *Maximum Power Point Tracking With the bq24650 Charger*.

2 Operation Under Normal and Shaded Conditions

Different scenarios were investigated using the BQ24650 EVM User's Guide, *bq24650EVM Synchronous, Switch-Mode, Battery Charge Controller for Solar Power* to find the source of the sinking current under shaded conditions. Normal operating conditions were tested and compared to operation under shaded conditions.

2.1 Normal Conditions

Using an HP 6654A system power supply, input current and voltage were regulated to simulate a solar panel different conditions. For the EVM, the following parameters are used:

- 21-V V_{in}
- 17.8-V V_{MPPSET}
- 12.6-V V_{BAT}
- 2-A I_{chrg}

One 820-uF capacitor with a forced voltage across the terminals was used to simulate a battery. To simulate a fully charged condition, 12.6 V was forced across the capacitor. Doing this terminated the charge, as indicated by the STAT 2 LED. In the charge completed state there was no current draw from the battery regardless of input voltage, as indicated by the voltage across the sense resistor.

To force the charger into constant current mode, 12.3 V was forced across the battery terminals with V_{in} at 21 V. Regular switching and 2 amps of charging current confirm that the charger works correctly, as seen in Figure 2.

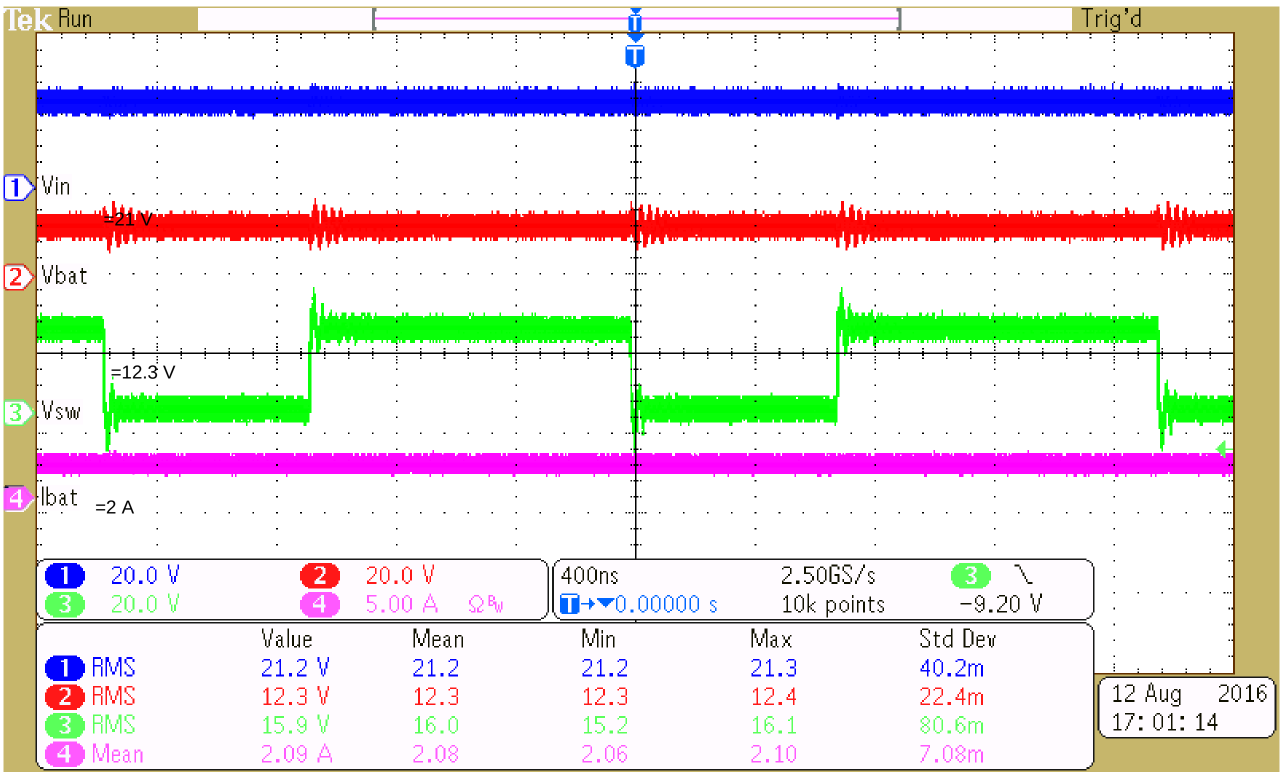

Figure 2. Battery Charging Under Normal Conditions with 21-V V_{in}

For 2 A of charging current, 40 mV is measured across the 0.02 Ω sense resistor, further confirming correct operation.

As the panel becomes “shaded” the input voltage drops until the V_{MPPSET} Loop takes over and disables charging. Under extreme shading conditions, V_{in} is roughly equal to V_{BAT}, and the BQ24650 goes into a low quiescent current sleep mode. During this mode of operation the IC is also operating correctly with no switching, as seen in Figure 3 .

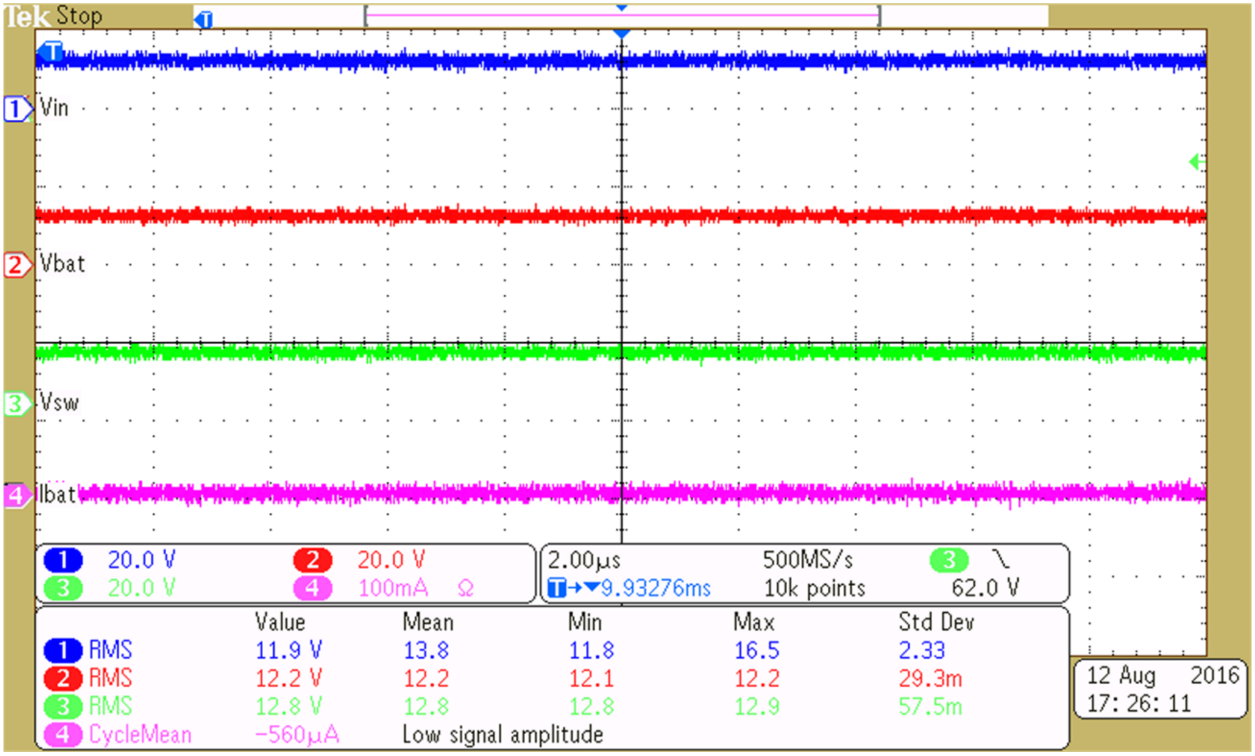

Figure 3. BQ24650 Sleep Mode Under Normal Conditions with 12-V V_{in}

In this situation there is no voltage measured across the sense resistor, confirming that the BQ24650 is not acting as a load on the battery.

2.2 Shaded Conditions and Battery Discharge

When Vin floats between V_{MPPSET} and V_{BAT} that the BQ24650 acts as a load on the battery. In this case, a Vin between 17.8 V and 12.6 V corresponds to the range of “shading” that causes the battery to discharge current. In this range, the MPPSET loop discharges current, but does not put the IC into sleep mode as evidenced in Figure 4.

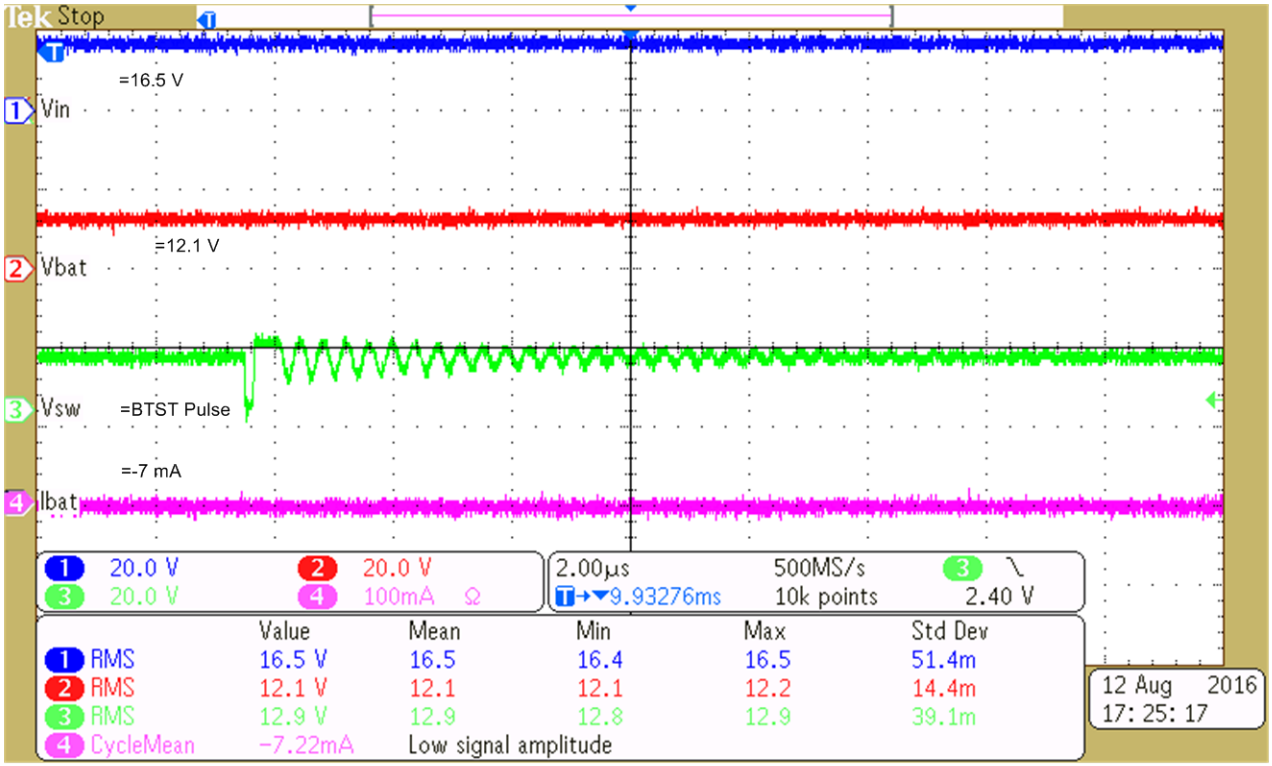

Figure 4. BQ24650 Refresh Pulse and Sink Current with $V_{MPPSET} > V_{in} > V_{BAT}$

Figure 4 shows that the chip is still active through the bootstrap capacitor refresh pulse, even though charging current is disabled. There is also several mA being drawn from the battery, as well as a small negative voltage across the sense resistor. Roughly half of the battery current develops a voltage across the sense resistor, indicating that the leakage current is being split through SRP and SRN.

2.3 Potential Solutions

2.3.1 Disabling the BQ24650 by Pulling MPPSET Low

There are multiple methods that can be used to address this issue. Pulling the MPPSET pin low through external logic is one method, while using a reverse blocking diode between the SRN and the external capacitor/battery node is another. Figure 5 shows the converter not switching and leakage current being reduced after pulling MPPSET low when V_{in} is between V_{MPPSET} and V_{BAT}. After pulling MPPSET low, leakage current is reduced to levels comparable to current drawn in sleep mode.

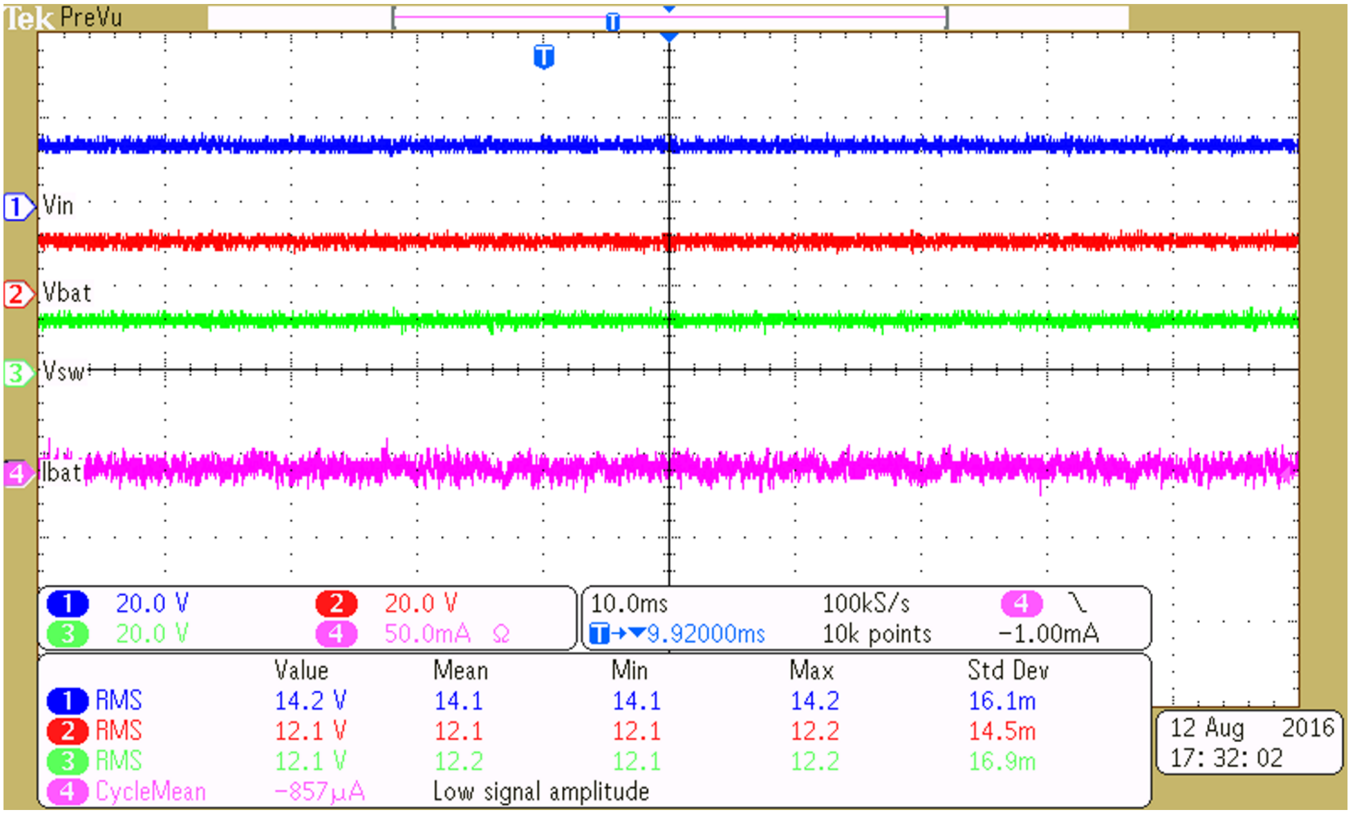

Figure 5. Reduced Leakage Current After Pulling MPPSET Low When $V_{MPPSET} > V_{in} > V_{BAT}$

Figure 6. Reduced Leakage Current Confirmed with Keithley Sourcemeter

Due to current probe limitations, a Keithley Sourcemeter with higher resolution was used to simulate a battery under the same conditions, and confirmed that no current was being drawn from the battery. This is seen in Figure 6.

One possible solution is to use a microcontroller, if one is already present in the project. Vin can be sampled using the internal ADC, making sure that the maximum input voltage is divided down to match the maximum input voltage of the ADC. The user can then write code to compare the sampled value to the MPP value given on the solar panel datasheet, and use the I/O pins of the microcontroller to turn on an NMOS acting as a pull down network on MPPSET, as seen in Figure 7.

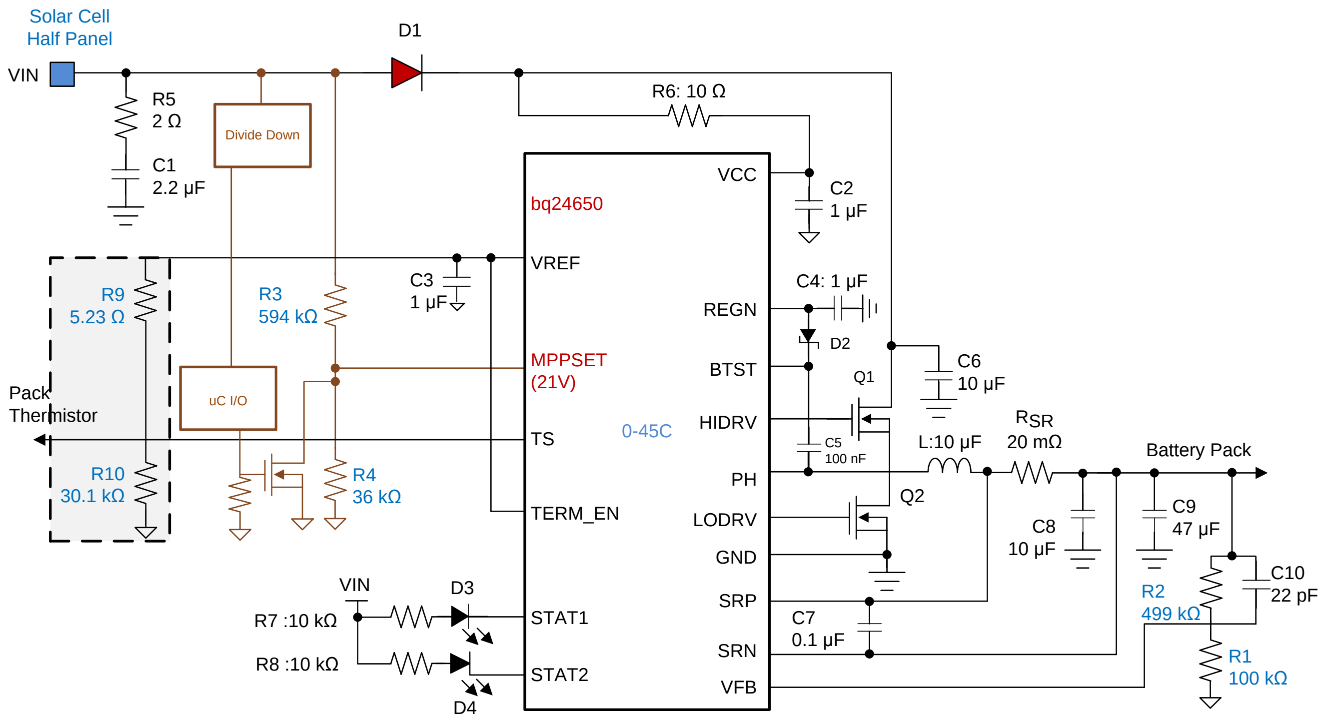

Figure 7. Tracking Vin and V_{MPP} with a Microcontroller

If a microcontroller is readily available in the project, this solution only costs three extra resistors and the firmware to sample the input voltage with the microcontroller's internal ADC. This application report only discusses this method of pulling down MPPSET. Many other solutions exist that utilize Light Dependent Resistors (LDR's), photodiodes, phototransistors, and other logic schemes, but they may come at a larger solution size and higher cost.

2.3.2 Placing a Schottky Diode between Vbat and SRN

Another recommended solution is to remove the diode D_1 and place a Schottky diode between SRN and the resistor feedback network to block reverse current. The main benefit of this approach is that it is a simple, low cost approach that requires only two additional components. A low component count reduces solution cost and does not require significant area in a PCB layout. This solution also does not require any additional logic at the MPPSET pin. Figure 8 shows the modified schematic.

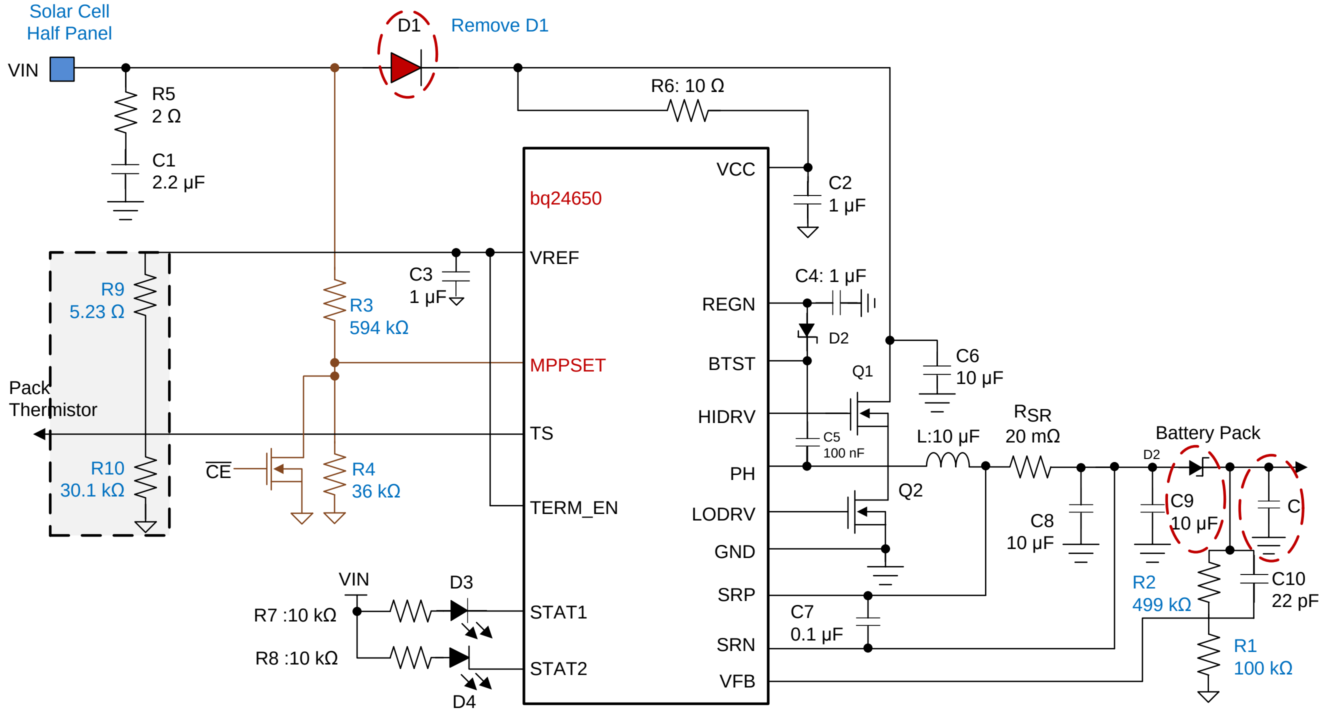

Figure 8. Modified Schematic with Blocking Diode

There are two things to consider with this approach:

- There is a small decrease in efficiency due to the drop across the Schottky diode
- The battery detection scheme does not function unless an extra capacitor is placed after the diode

The efficiency drop is small, due to the low Vf of the diode. However, when the battery is absent the STAT1 pin flashes instead of remaining off. Figure 9 shows the oscillation of the STAT1 pin with VD+ being the voltage at the battery terminal, and VD– as the voltage at SRN.

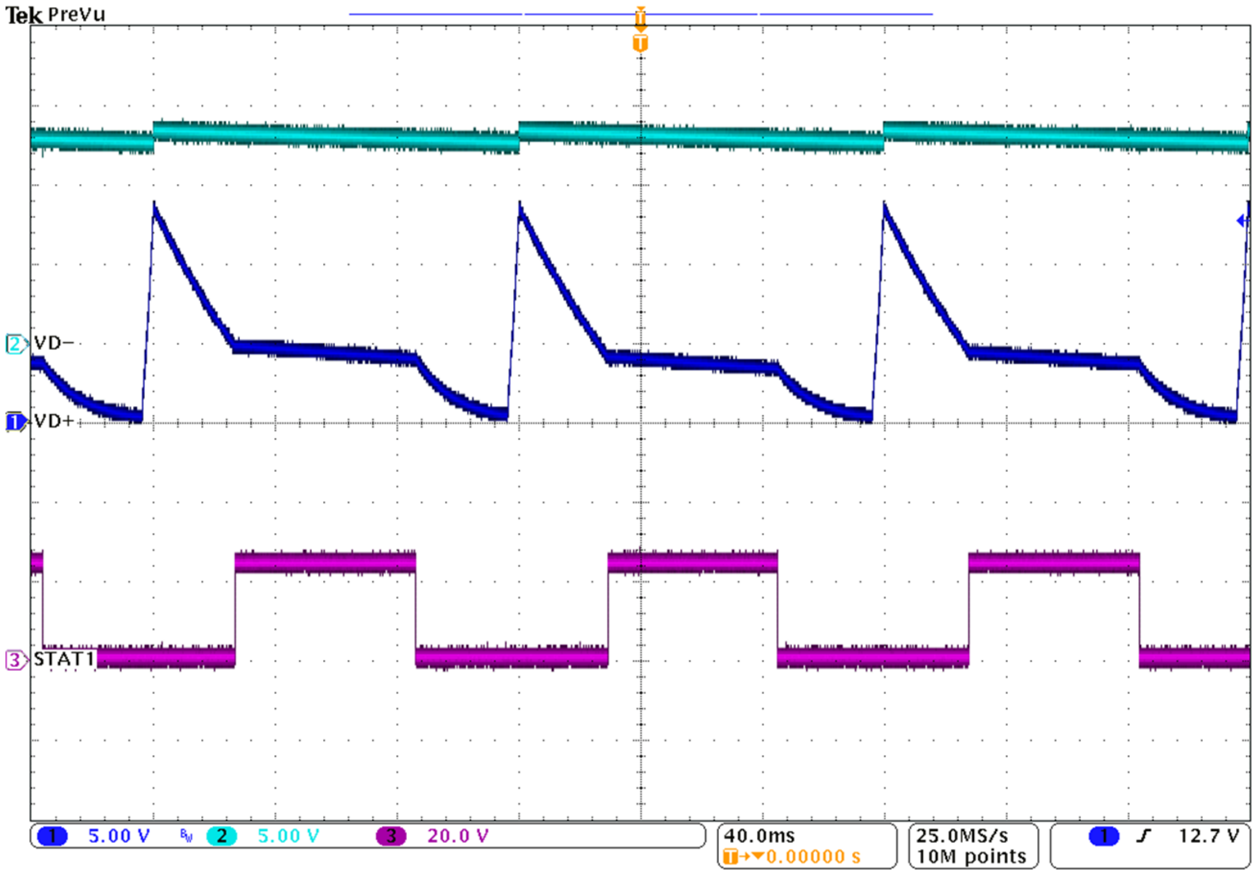

Figure 9. STAT1 Flashing with Battery Absent with No Added Capacitor

Placing an appropriately sized capacitor at VD+ allows this voltage to reach V_{LOWV} at the appropriate time in the battery detection scheme. Calculations for choosing the correct capacitance can be seen below, starting with Equation 2.

$$V_{LOWW} = V_{REG} \times \left[1 - e^{(-t_{DSCH}/\tau)}\right] \tag{2}$$

In Equation 2 , τ is the RC time constant set by the added capacitance C and the sum of the feedback resistors R2 and R1. The rest of the values can be taken from the datasheet as:

- $\tau = (R_1+R_2)C$
- V_{LOWV} = 1.55 V
- V_{REG} = 2.1 V
- t_{DSCH} = 1 second

Solving for C gives a maximum capacitance of 1.24 uF. Choosing a 1 uF gives the VD+ waveform seen in Figure 10. The STAT1 pin is high, correctly indicating that a battery is absent.

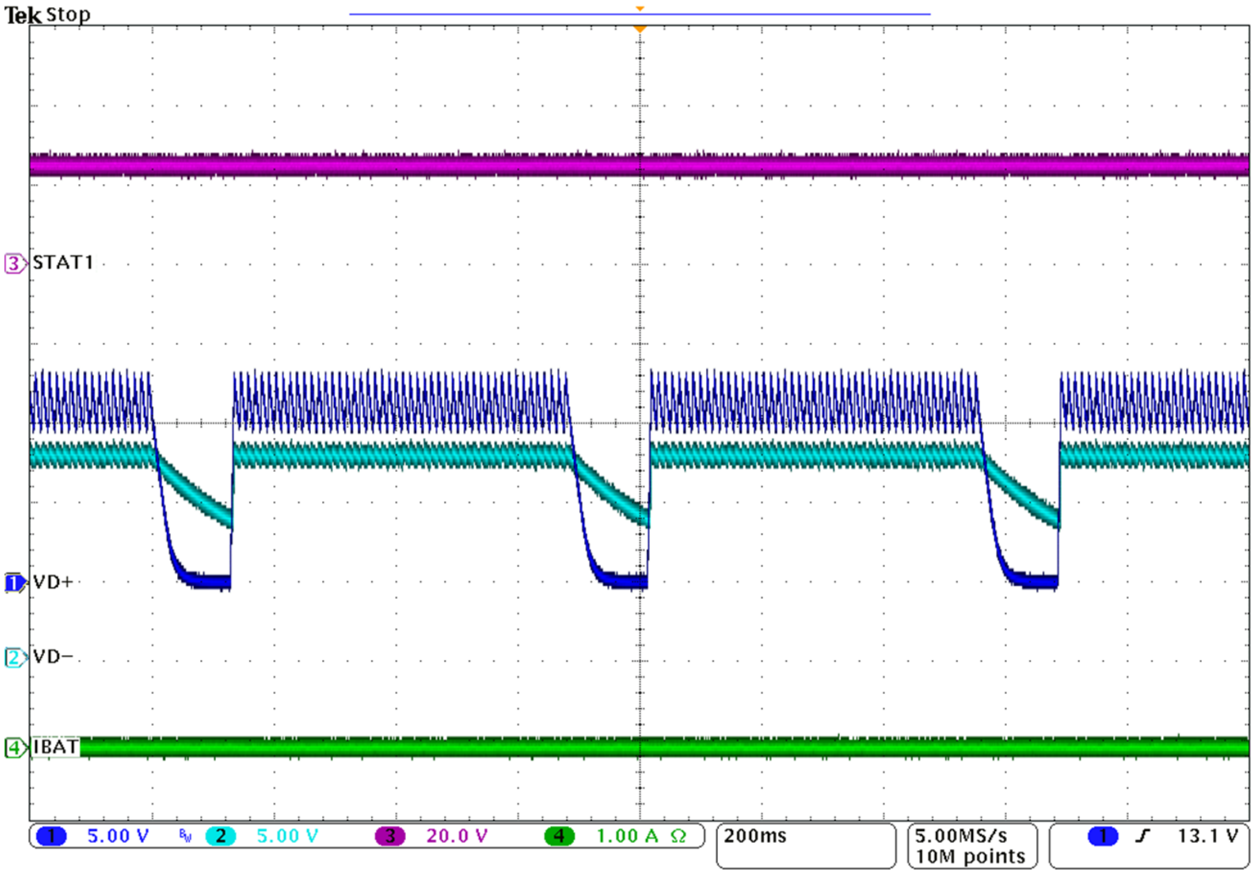

Figure 10. STAT1 High When Battery Absent With Properly Sized Capacitor

Table 1 below summarizes the STAT pin levels using this modified schematic.

Table 1. STAT Pin Summary with Modified Schematic

	Stat1	Stat2
0.1 µF Cap (Too Small)		
Battery Absent	On	Off
Charging	On	Off
Charge Complete	Off	On
1 µF Cap (Correct)		
Battery Absent	Off	Off
Charging	On	Off
Charge Complete	Off	On
10 µF Cap (Too Large)		
Battery Absent	Flash	Off
Charging	On	Off
Charge Complete	Off	On

This approach allows the leakage current to be stopped with minimal effort, while retaining proper functionality of the BQ24650.

3 Summary

When using the BQ24650 with solar panels, the panels may experience shading that causes the panel voltage to drop below the Maximum Power Point voltage being tracked by the device. Under this condition, the charger IC no longer attempts to charge the battery, but it is still “on” and running the battery detection routine, as well as maintaining the voltage on the bootstrap capacitor. During this time, the charger IC actually acts as a load on the battery by sinking current to maintain it’s current state. This can be prevented by pulling the MPPSET pin below 75 mV to make the device enter a Hi-Z mode, or by placing a Schottky Diode between the battery and the SRN node to block any reverse current.

4 References

- *Synchronous Switch-Mode Battery Charge Controller for Solar Power*
- *bq24650EVM Synchronous, Switch-Mode, Battery Charge Controller for Solar Power*
- *Using the bq24650 to Charge a Sealed, Lead-Acid Battery*
- *Using the bq24650 to Charge a LiFePO4 battery*
- *Maximum Power Point Tracking With the bq24650 Charger.*

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265