

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.

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

1	Introduction	2
2	Operation Under Normal and Shaded Conditions	3
2.1	Normal Conditions	4
2.2	Shaded Conditions and Battery Discharge	5
2.3	Potential Solutions	6
3	Summary	12
4	References	12

List of Figures

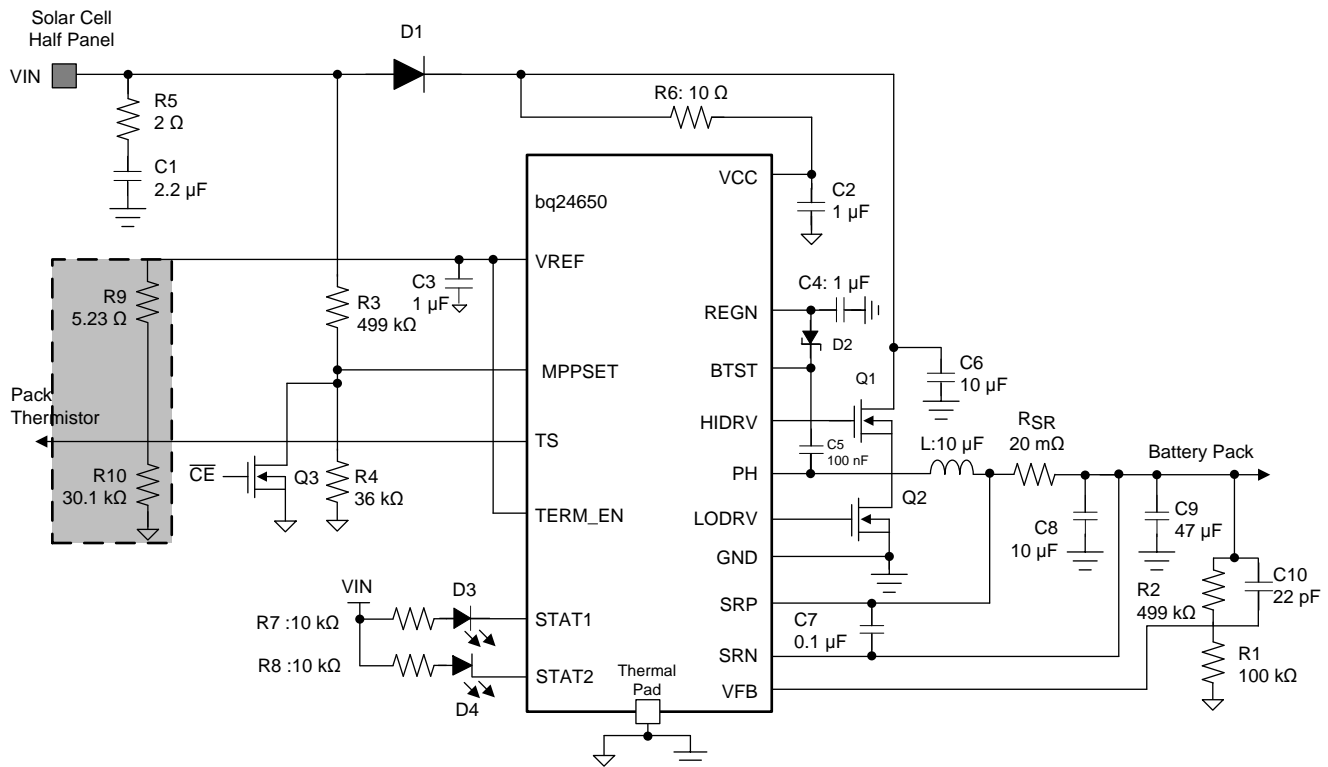
1	BQ24650 Typical Application Circuit	3
2	Battery Charging Under Normal Conditions with 21-V V_{in}	4
3	BQ24650 Sleep Mode Under Normal Conditions with 12-V V_{in}	5
4	BQ24650 Refresh Pulse and Sink Current with $V_{MPPSET} > V_{in} > V_{BAT}$	6
5	Reduced Leakage Current After Pulling MPPSET Low When $V_{MPPSET} > V_{in} > V_{BAT}$	7
6	Reduced Leakage Current Confirmed with Keithley Sourcemeter	7
7	Tracking V_{in} and V_{MPP} with a Microcontroller	8
8	Modified Schematic with Blocking Diode	9
9	STAT1 Flashing with Battery Absent with No Added Capacitor	10
10	STAT1 High When Battery Absent With Properly Sized Capacitor	11

List of Tables

1	STAT Pin Summary with Modified Schematic	11
---	--	----

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](#).



Copyright © 2016, Texas Instruments Incorporated

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 resistors 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.

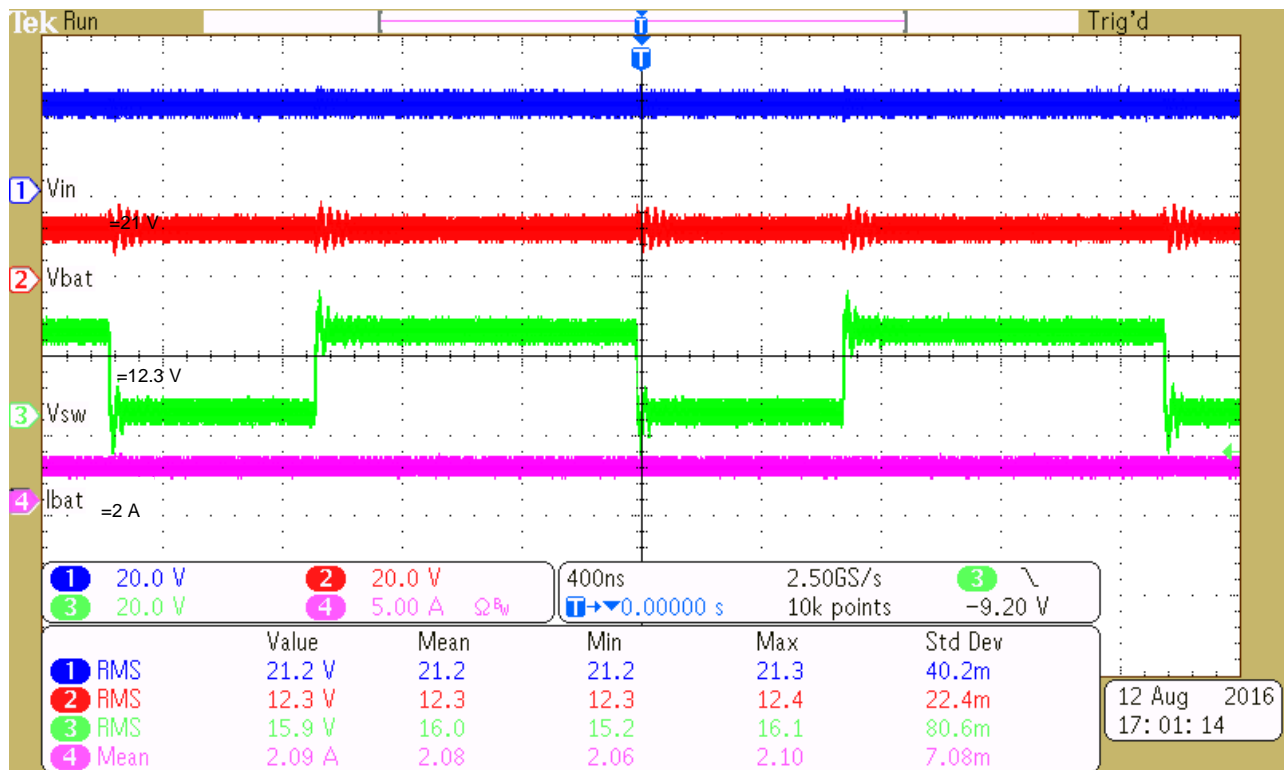


Figure 2. Battery Charging Under Normal Conditions with 21-V V_{in}

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 .

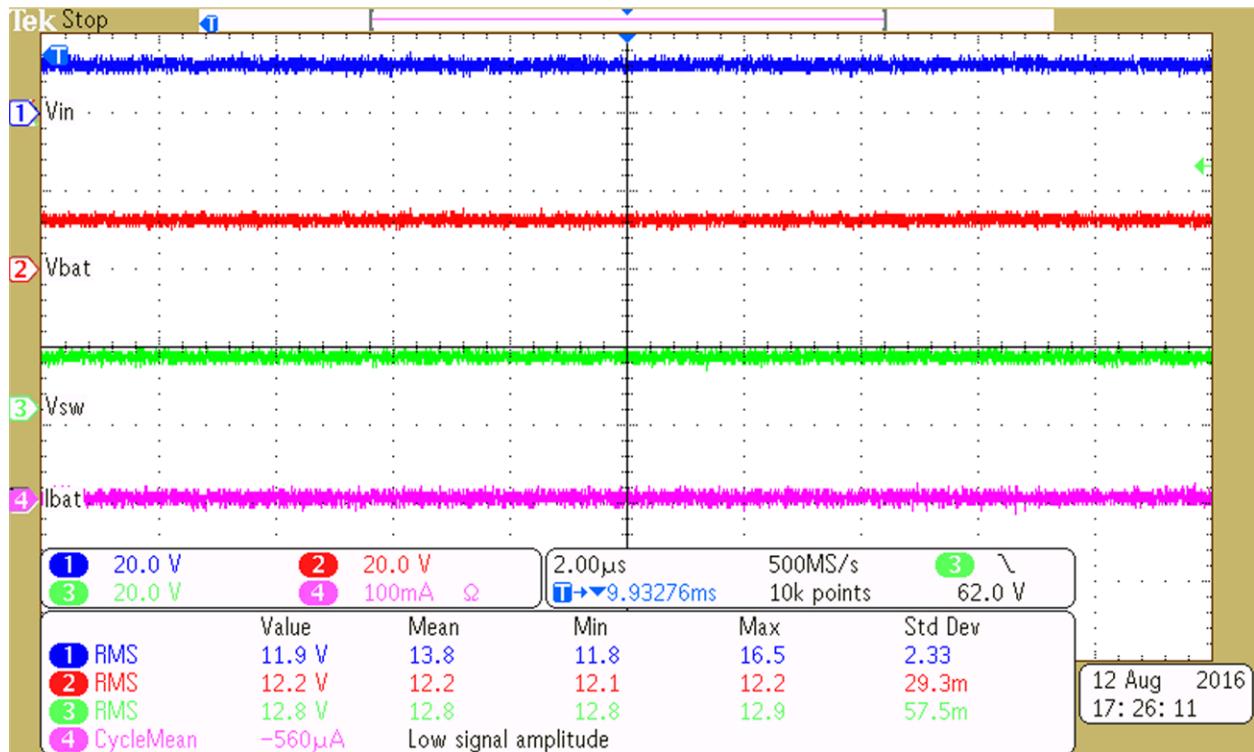


Figure 3. BQ24650 Sleep Mode Under Normal Conditions with 12-V V_{in}

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 V_{in} floats between V_{MPPSET} and V_{BAT} that the BQ24650 acts as a load on the battery. In this case, a V_{in} 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.

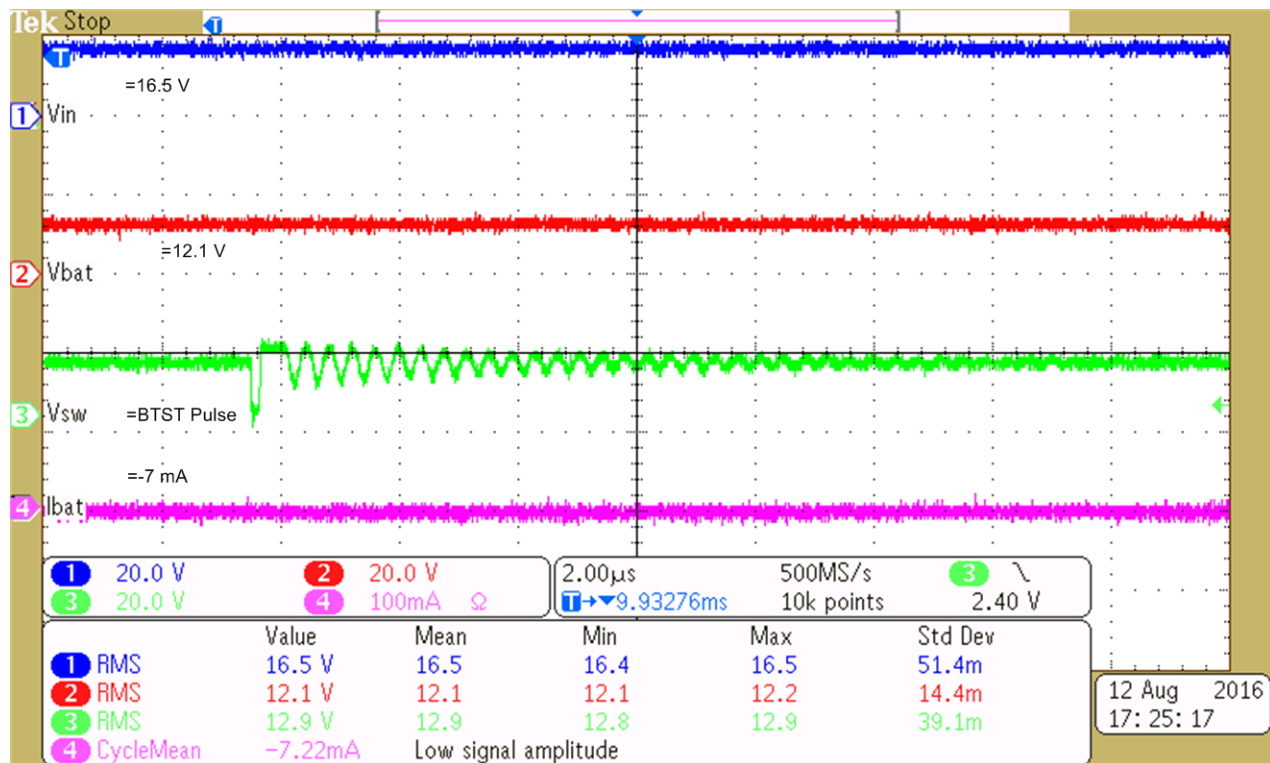


Figure 4. BQ24650 Refresh Pulse and Sink Current with $V_{MPPSET} > V_{in} > V_{BAT}$

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.

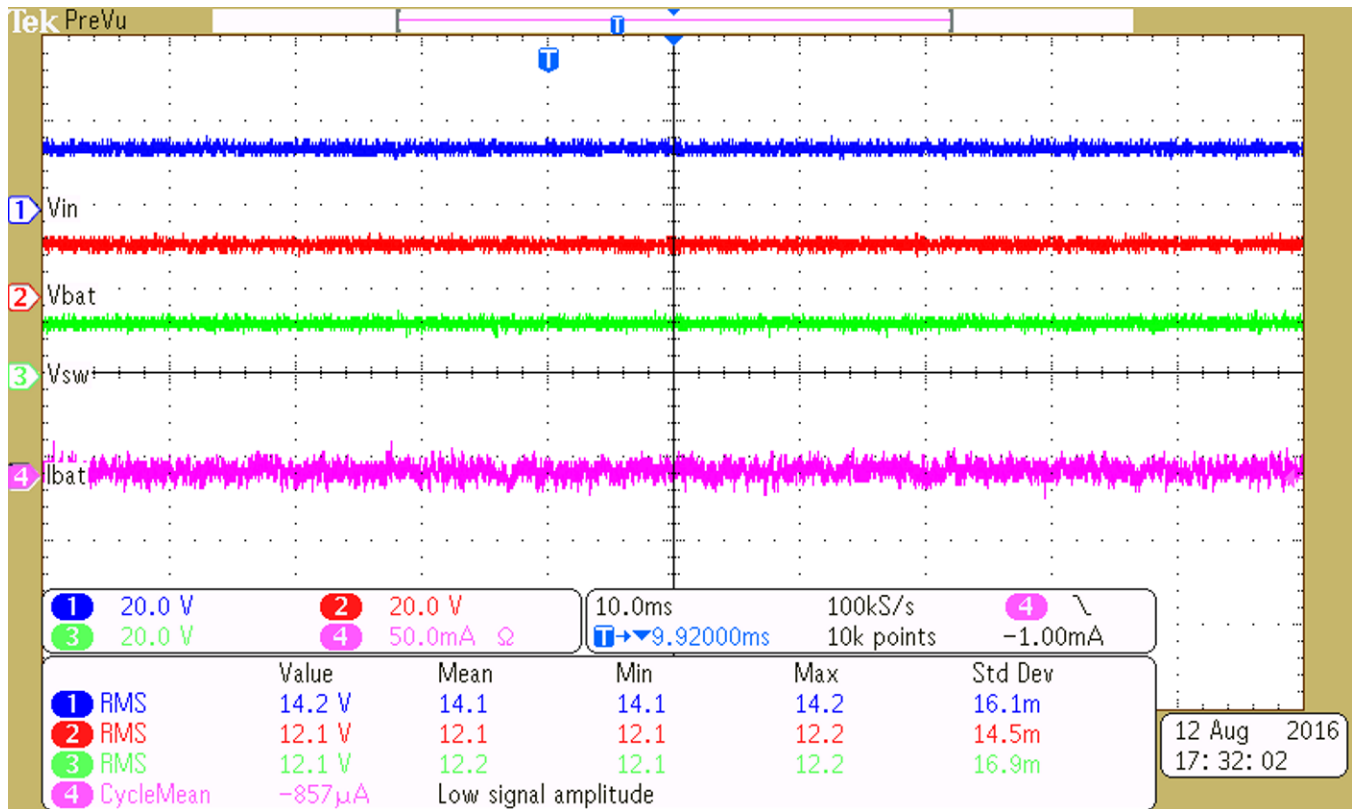


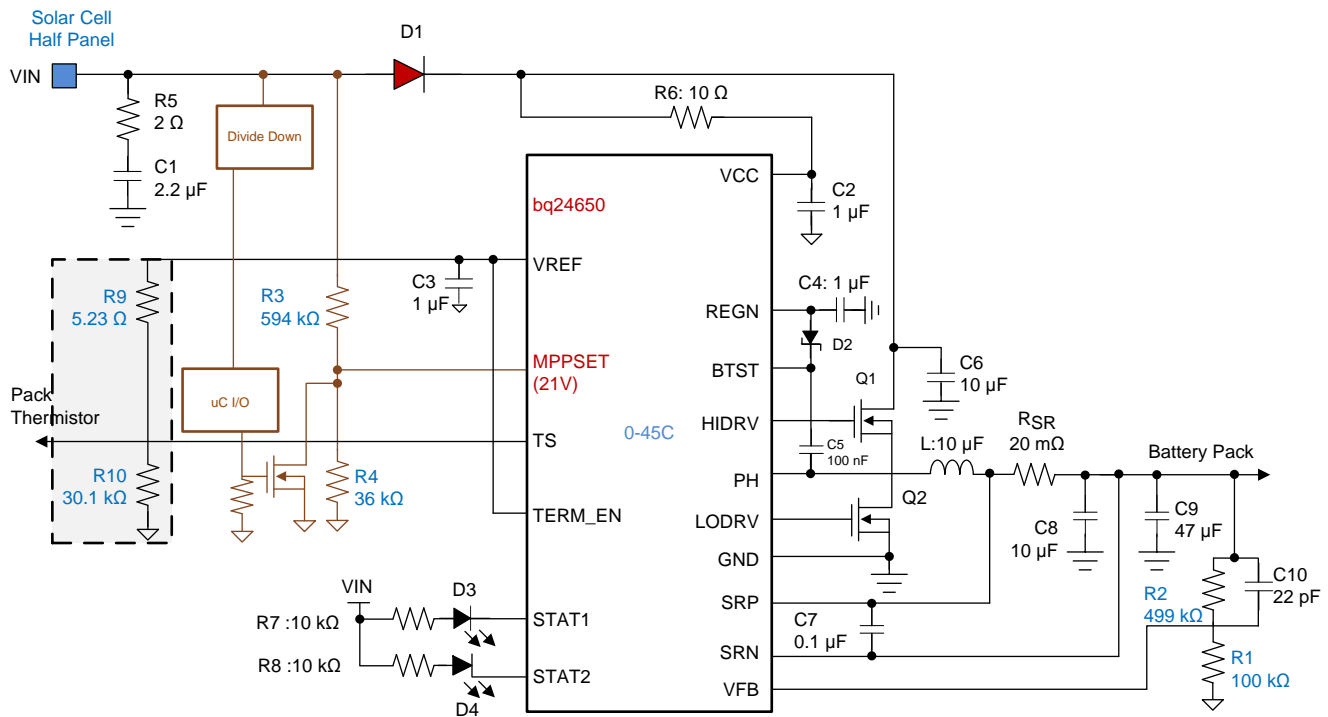
Figure 5. Reduced Leakage Current After Pulling MPPSET Low When $V_{MPPSET} > V_{in} > V_{BAT}$



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. V_{in} 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.



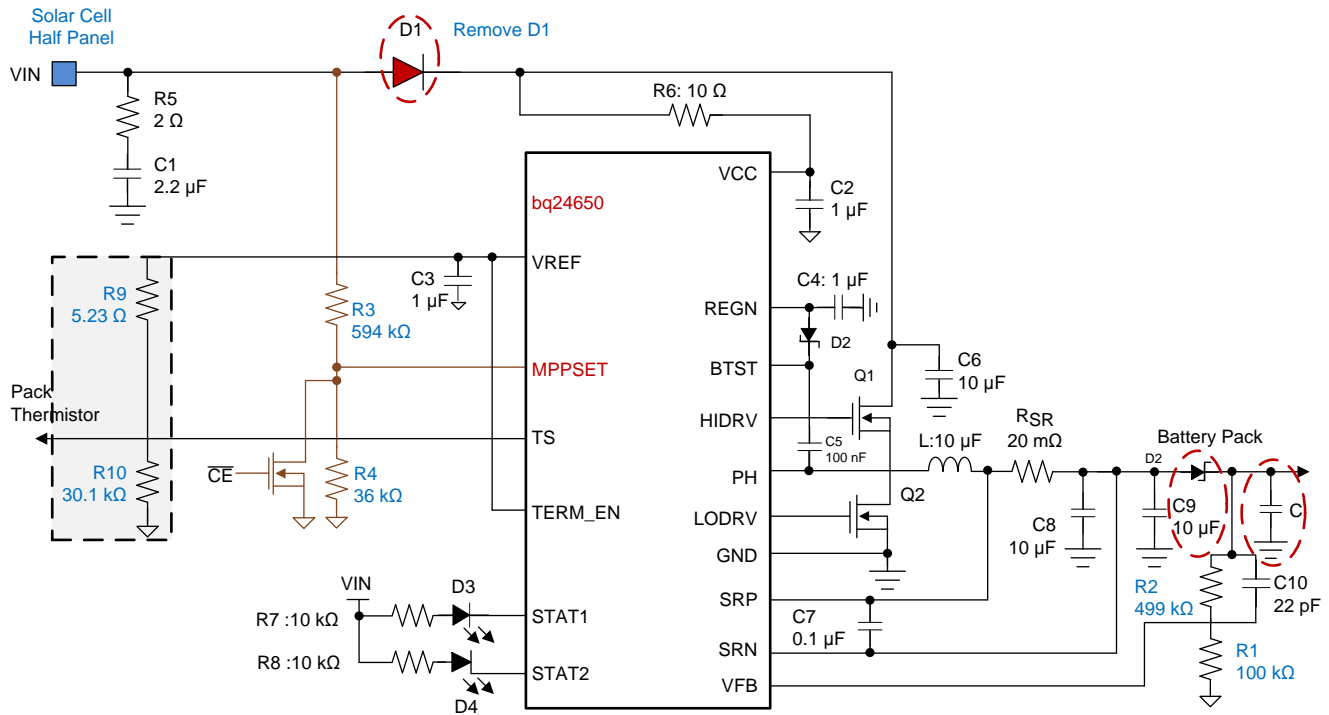
Copyright © 2016, Texas Instruments Incorporated

Figure 7. Tracking V_{in} 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.



Copyright © 2016, Texas Instruments Incorporated

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 V_f 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.

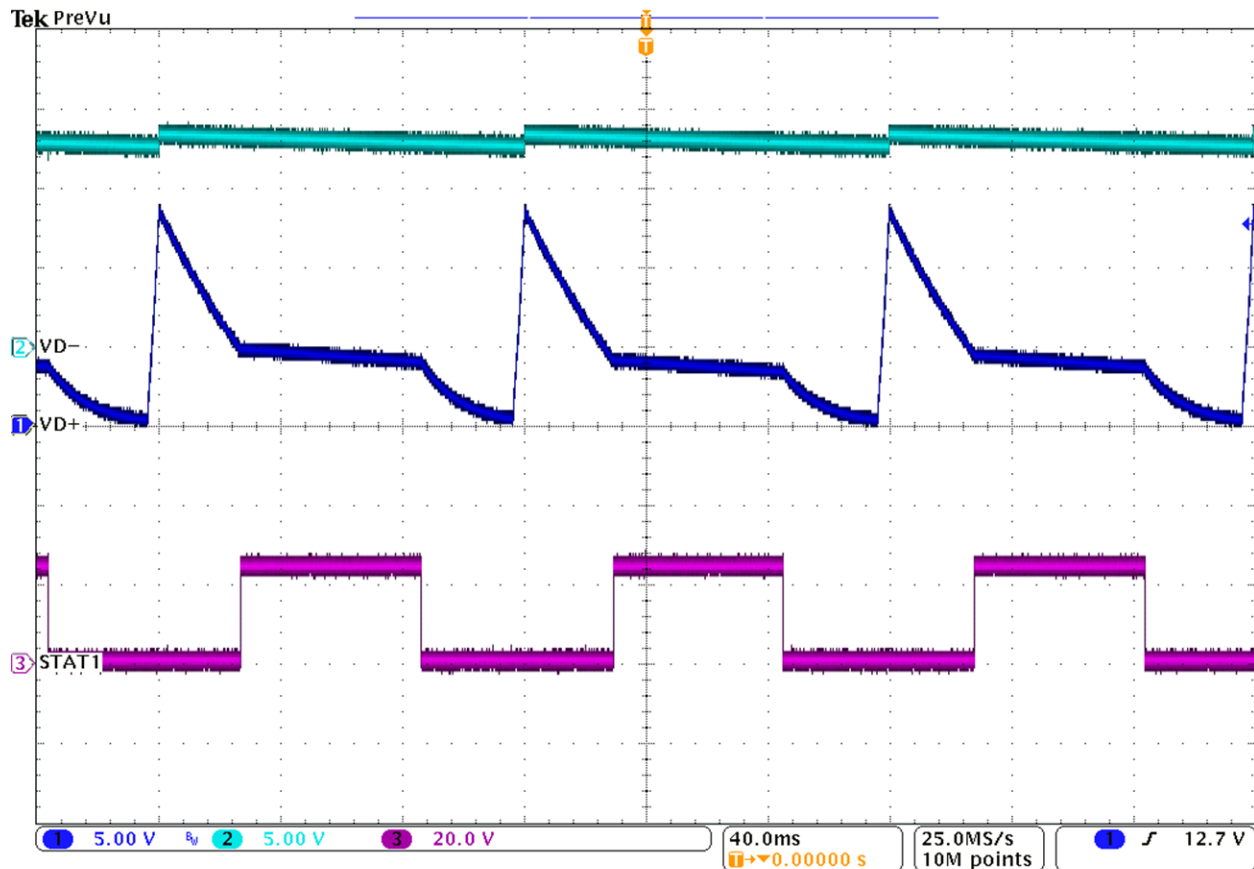


Figure 9. STAT1 Flashing with Battery Absent with No Added Capacitor

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.

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

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:

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

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

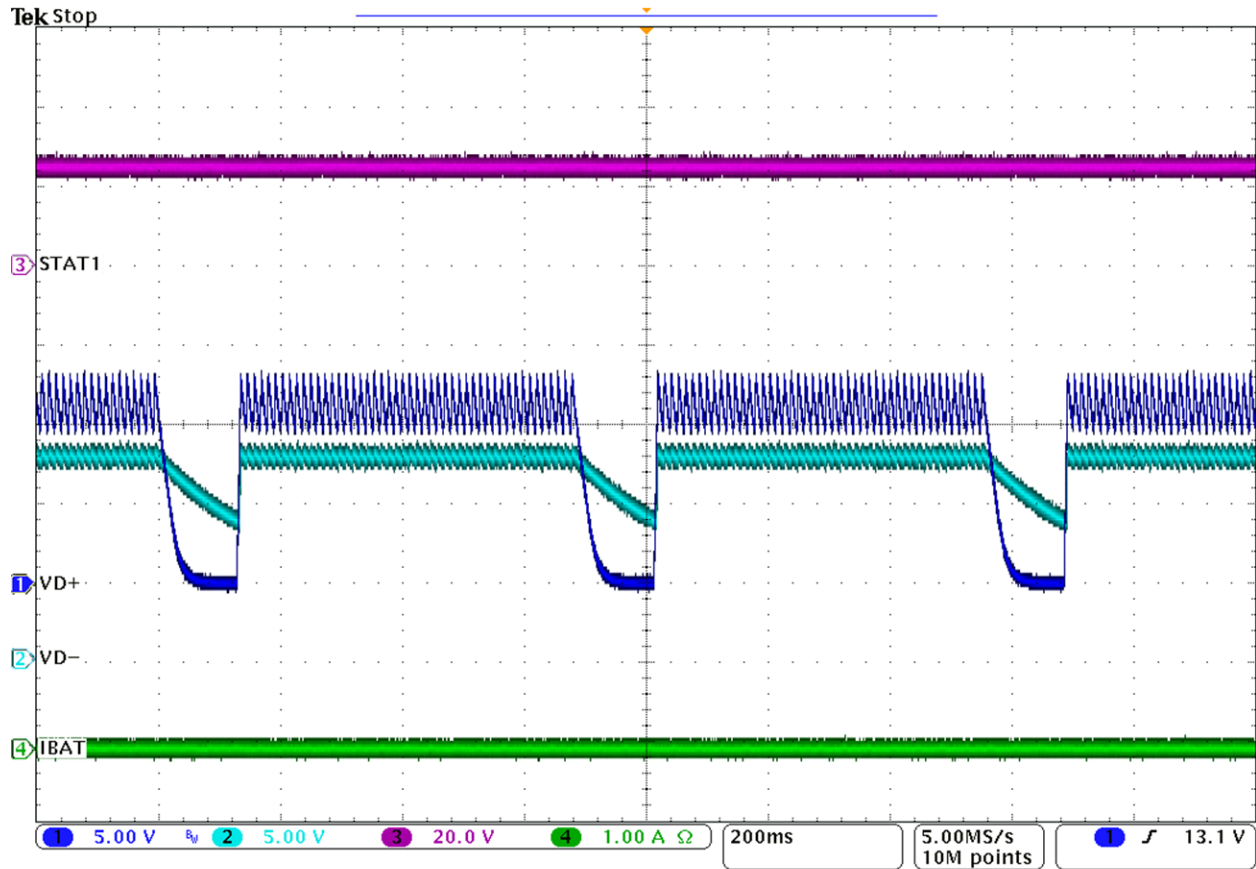


Figure 10. STAT1 High When Battery Absent With Properly Sized Capacitor

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 its 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.](#)

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com