Design Guide: TIDA-050039

Energy Harvesting From Single Cell Solar Panel for Li-Ion Battery Reference Design

TEXAS INSTRUMENTS

Description

The TIDA-050039 reference design demonstrates how to use a fully-integrated synchronous boost converter TPS61089 in combination with a single-cell solar panel to charge a Li-Ion battery for high output power applications. An additional maximum power-point (MPP) sampling network is implemented to dynamically control the input voltage to optimize the transfer of power from solar panel. By using the high-current capability, high-efficiency boost converter TPS61089, Li-Ion battery maximum charging current is up to 200mA. Total solution cost is saved. The detailed design theory, component selection, and the test results are also discussed.

Resources

TIDA-050039	Design Folder
TPS61089	Product Folder
LPV321-N	Product Folder
TLV7042	Product Folder
REF3312	Product Folder
CSD25480F3	Product Folder

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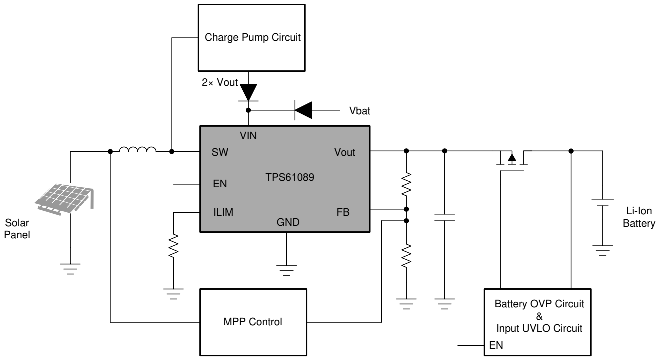
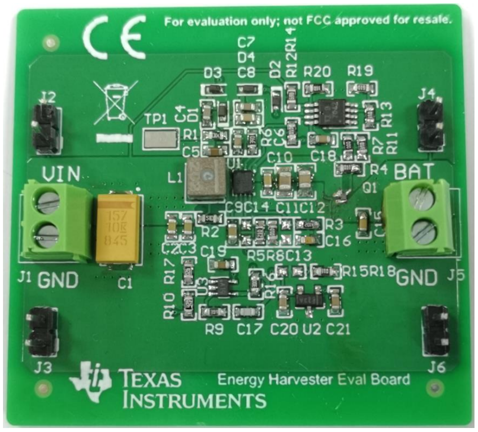
Features

- Low working input voltage range: 0.4 - 0.6V
- Fixed Maximum Power Point (MPP)
- Maximum charging current up to 200mA
- Low cost
- Simple and flexible

Applications

- Other energy harvesting



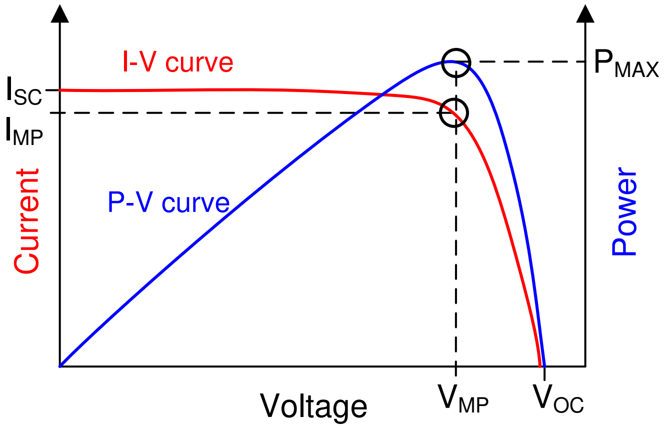


1 System Description

In general, the power that can be drawn from a single cell solar panel depends on the physical size, cell numbers in parallel and type of the cell – the smaller the solar size, the less power it can deliver. For some applications, it can be beneficial to use solar cells in series to increase the module output voltage instead of boosting from a single solar cell. However, power of the entire array solar panels in series would be significantly decreased if part of the solar array is shaded or broken. With the development of new, higher power intensity solar cell technology, there is a trend and requirement to extract more power from solar panels in parallel to charge Li-Ion battery.

The power output from a solar panel depends on a few parameters, such as the irradiation received by the panel voltage, panel temperature, and so forth. The power output also varies continuously throughout the day as the conditions affecting it change. Figure 1 shows the I-V curve and the P-V curve of a solar panel. The I-V curve represents the relationship between the panel output current and its output voltage. The panel current is at the maximum when its terminals are shorted and is at its lowest when the terminals are open and unloaded. As Figure 1 shows, when solar panel voltage times the panel output current is at the maximum, maximum power P_{max} could be obtained from the solar panel, which is known as maximum power point(MPP).

Figure 1. Solar Panel Characteristics I-V and P-V Curves



1.1 Key System Specifications

Table 1 gives the performance specification of the TIDA-050039 reference design. The maximum battery charging current is up to 200 mA.

Table 1. Key System Specifications

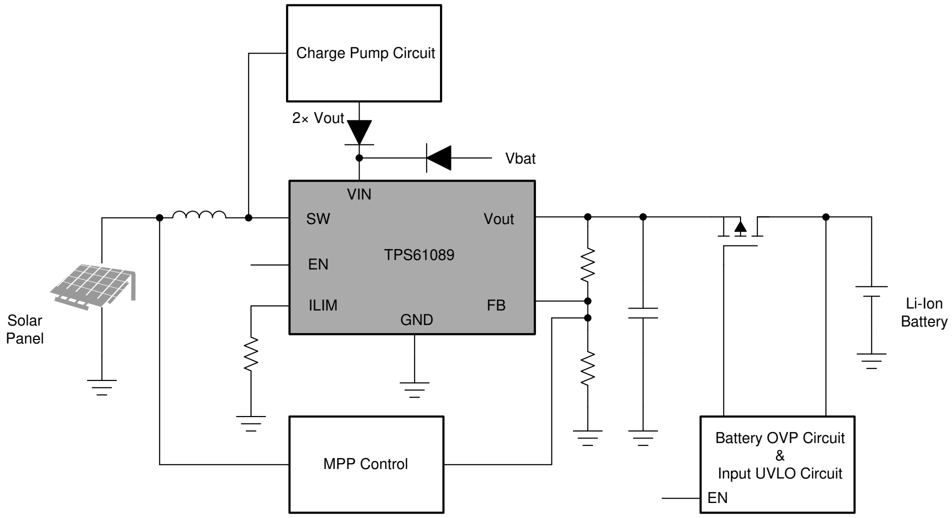
PARAMETER	DESCRIPTION
Solar panel voltage range	0.4 V - 0.55 V
Fixed MPP voltage	0.45 V
Li-Ion battery voltage range	3.0 V - 4.2 V
Li-Ion battery charging current	200 mA maximum

2 System Overview

2.1 Block Diagram

Figure 2 shows the block diagram of TIDA-050039. Since the boost converter TPS61089 input voltage undervoltage lockout (UVLO) rising threshold is 2.7 V, Li-Ion battery voltage could be used as input voltage of TPS61089 assumed Li-Ion battery minimum voltage is higher than 3.0 V. Once it starts up and keeps switching, the discrete charge pump circuit outputs a 2 × Vout voltage to supply Vin pin in order to decrease TPS61089 Rdson, therefore efficiency is increased. Energy is obtained from solar panel and stepped up to charge a Li-Ion battery with MPP control.

Figure 2. TIDA-050039 Block Diagram



2.2 Design Considerations

The reference design features the TPS61089, LPV321-N, TLV7042, REF3312, and CSD25480F3. The following subsections briefly summarize the key performance of each device. To find more information about each device, see their respective data sheets at TI.com.

2.3 Highlighted Products

2.3.1 TPS61089

The TPS61089x is a fully-integrated synchronous boost converter with a 19-mΩ main power switch and a 27-mΩ rectifier switch. The device provides a high efficiency and small size power solution for portable equipment. The TPS61089x has 7-A continuous switch current capability and provides output voltage up to 12.6 V. The TPS61089x uses adaptive constant off-time peak current control topology to regulate the output voltage. In moderate to heavy load condition, the TPS61089 works in the pulse width modulation (PWM) mode. In light load condition, the TPS61089 works in the pulse frequency modulation (PFM) mode to improve the efficiency.

- Input Voltage Range: 2.7 V to 12 V
- Adjustable Switching Frequency: 200kHz to 2.2MHz
- 4-ms Built-in Soft Start Time
- PFM Operation Mode at Light Load
- Thermal Shutdown
- 2.00-mm × 2.50 mm VQFN Hotrod Package

2.3.2 LPV321-N

LPV321-N is a lower power op amps and is the most cost effective solutions for the applications where low voltage, low power application, space saving and low price are needed. It has rail-to-rail output swing capability and the input common-mode voltage range includes ground. They all exhibit excellent speed-power ratio, achieving 152kHz of bandwidth with a supply current of only 9uA.

- Space-Saving Package
- Gain-Bandwidth Product: 152kHz
- Low Supply Current

2.3.3 TLV7042

The TLV7042 is low-voltage, nanoPower comparators. It's offer an excellent combination of speed and power, with a propagation delay of 3 µs and a quiescent supply current of 315 nA. The benefit of fast response time at nanoPower enables power-conscious systems to monitor and respond quickly to fault conditions. With an operating voltage range of 1.6 V to 6.5 V, these comparators are compatible with 3-V and 5-V systems.

- Wide supply voltage range of 1.6 V to 6.5 V
- Quiescent supply current of 315 nA
- Low propagation delay of 3 us
- Internal hysteresis

2.3.4 REF3312

The REF33xx is a low-power, precision, low-dropout voltage reference family available in tiny SC70-3 and SOT-23-3 packages, and in a 1.5-mm × 1.5-mm UQFN-8 package. Small size and low power consumption (5-µA max) make the REF33xx ideal for a wide variety of portable and battery-powered applications.

The REF33xx can be operated at a supply voltage 180 mV above the specified output voltage under normal load conditions, with the exception of the REF3312, which has a minimum supply voltage of 1.7 V. All models are specified for the wide temperature range of –40°C to +125°C.

- Low supply current
- Low temperature shift: 30 ppm/°C (max)
- High initial accuracy: ±0.15% (max)
- 0.1-Hz to 10-Hz Noise: 35 uVpp

2.3.5 CSD25480F3

This –20-V, 110-mΩ, P-Channel FemtoFET™ MOSFET is designed and optimized to minimize the footprint in many handheld and mobile applications. This technology is capable of replacing standard small signal MOSFETs while providing a substantial reduction in footprint size.

- Low on-resistance
- Ultra-low Q_g and Q_{gd}
- Ultra-small footprint
- Low profile
- Integrated ESD protection diode

2.4 System Design Theory

The entire schematic of TIDA-050039 can be found in the TIDA-050039 design folder. The following subsections explain the behavior of each sub circuit.

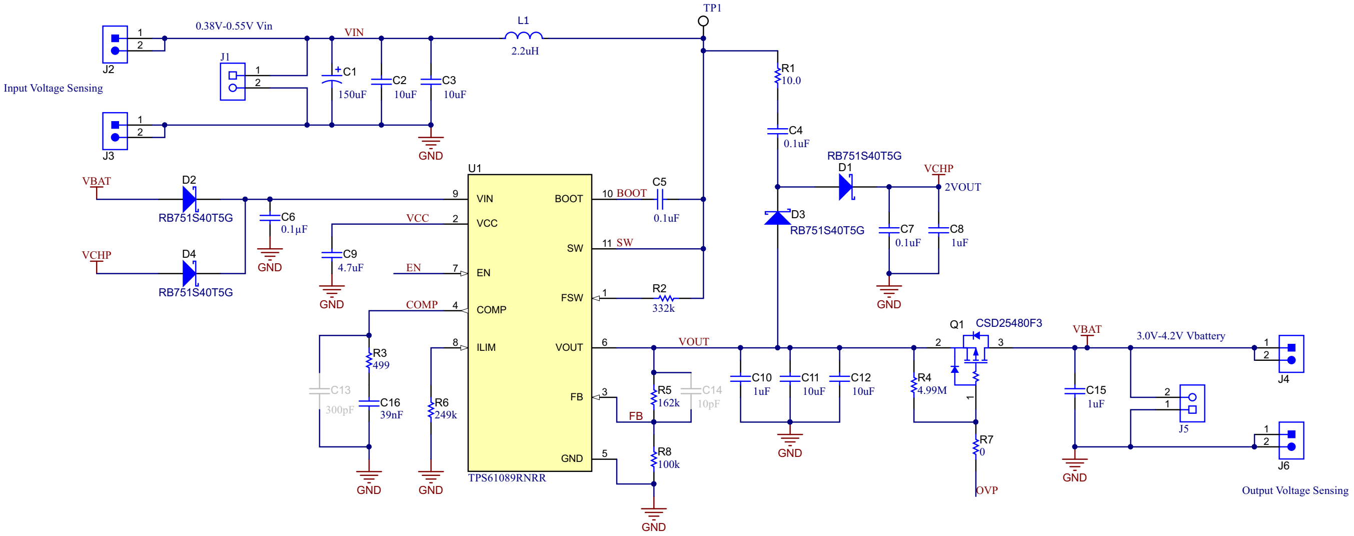
2.4.1 Boost Converter Solution

Figure 3 shows the TPS61089 boost converter, which is main circuit of TIDA-050039. Most of the external components are selected based on the suggestion in the data sheet. TPS61089 operates at a quasi-constant frequency pulse width modulation (PWM) in moderate to heavy load condition. Based on the Vin to Vout ratio, a circuit predicts the required off-time of the switching cycle. In light load condition, the TPS61089 implements PFM mode to improve the efficiency.

VBAT supplies TPS61089 Vin pin through diode D2 at startup because TPS61089 input pin UVLO threshold is 2.7 V. After TPS61089 starts switching, VOUT regulates equaling to Li-Ion battery voltage. The discrete charge pump circuit (composed of C4, D1, D3, C7, C8) output voltage VCHP is twice of Vout. Once VCHP is stable, diode D4 conducts so that VCHP supplies TPS61089 VIN pin. By doing so, TPS61089 high & low side MOSFET on-resistance would be decreased so that boost converter efficiency increases. With the external power supply for TPS61089 VIN pin, the boost converter is able to keep working at power Vin down to 0.4 V.

The P-channel MOSFET Q1 is turned off when OVP signal is high to protect Li-Ion battery from over charging. Possible maximum output current depends on the input-to-output voltage ratio. This circuit provides output current up to 200 mA.

Figure 3. TPS61089 Boost Converter



2.4.2 Fixed MPP Circuit

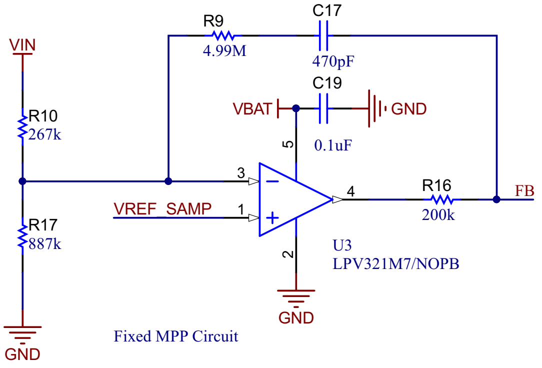
Due to the high conversion ratio which is necessary to boost from 0.4 V to 0.55 V to a suitable supply voltage for Li-ion battery up to 4.2 V, the input current is increasing as high as possible. Without additional control, the output voltage of the solar panel collapses. The DC-DC converter basically shorts the solar panel because it tries to draw enough current to maintain its output voltage. This current may be more than the solar panel can provide.

To dynamically control the input current, the additional MPP circuit is added shown in Figure 4. The low-power-consuming operational amplifier is powered by the Li-Ion battery. The operational amplifier output is connected to the feedback pin of TPS61089 to control the output voltage of converter depending on the input voltage of solar panel. The reference voltage V_{REF_SAMP} is generated by REF3312 in Figure 5.

During steady-state conditions, the input current is proportional to the output current by the conversion ratio set by the output voltage divider. With lower input current, the MPP circuit reduces the set output voltage to a much lower value by injecting current into the feedback node. As the converter output voltage is reduced, input current is also reduced. The decreases the current pulled from the solar panel and solar panel voltage will then increase according to its I-V curve.

To keep the circuit easy, TIDA-050039 implements a fixed MPP voltage 0.45 V, approximately 0.8 times solar panel voltage at no load. The fixed MPP point could be adjusted based on solar panel type.

Figure 4. Fixed MPP Circuit



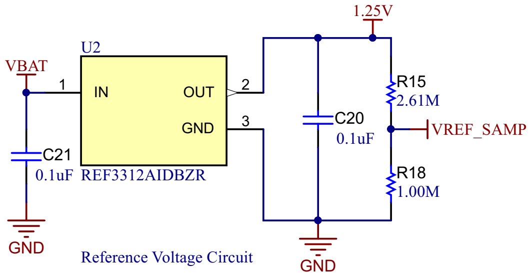
2.4.3 Reference Voltage Circuit

Figure 5 shows the TIDA-050039 reference voltage circuit. REF3312 is a low-power, precision, low-dropout voltage reference. It outputs 1.25 V at output. By configuring resistor dividers R15 and R18, the reference voltage V_{REF_SAMP} can be calculated using Equation 1.

$$V_{REF\_SAMP} = 1.25V \times \frac{R_{18}}{R_{20} + R_{18}} \tag{1}$$

Here select R15 as 2.61 MΩ and R18 as 1.00 MΩ to establish a 0.346 V DC voltage as MPP circuit and input UVLO circuit reference voltage.

Figure 5. Reference Voltage Circuit



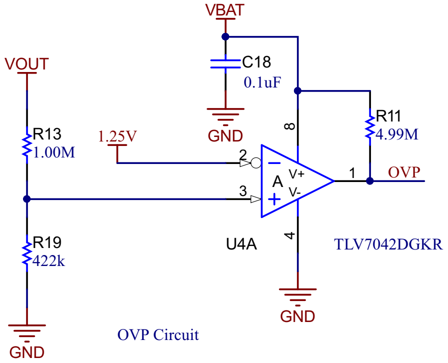
2.4.4 Battery OVP Circuit

Figure 6 shows the TIDA-050039 battery OVP circuit. TLV7042 is a dual-channel nanoPower comparator. By configuring resistors R13 and R19, the OVP threshold can be calculate using Equation 2.

$$V_{OVP} = 1.25V \times \frac{R_{13} + R_{19}}{R_{19}} \tag{2}$$

By selecting R13 as 1 MΩ and R19 as 422 kΩ, the OVP threshold is set to 4.212 V. Once TPS61089 output voltage is higher than 4.212 V, OVP signal will be high to turn off P-channel MOSFET Q1 to protect Li-Ion battery from over charging.

Figure 6. Battery OVP Circuit



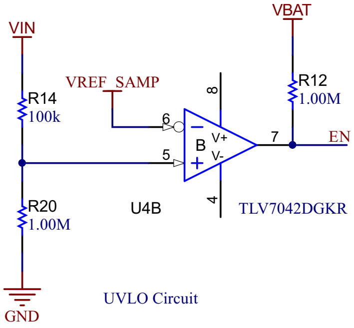
2.4.5 Input Voltage UVLO Comparator Circuit

Figure 7 shows the TIDA-050039 input UVLO comparator circuit. When detecting input voltage of solar panel is less than a certain voltage or disconnected, TPS61089 boost converter will be disabled in order to save energy. The input voltage UVLO threshold can be calculated using Equation 3

$$V_{IN\_UVLO} = 0.346V \times \frac{R_{14} + R_{20}}{R_{20}} \tag{3}$$

The input voltage UVLO threshold here is 0.381V by selecting 100 kΩ for R14 and 1.00 MΩ for R20.

Figure 7. Input Voltage UVLO Comparator Circuit



3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

This reference design uses the following hardware to do the measurement:

- Two-Source Meter
- Two DMM
- One digital oscilloscope

3.2 *Testing and Results*

3.2.1 Test Setup

This section describes how to properly connect the setup of the TIDA-050039.

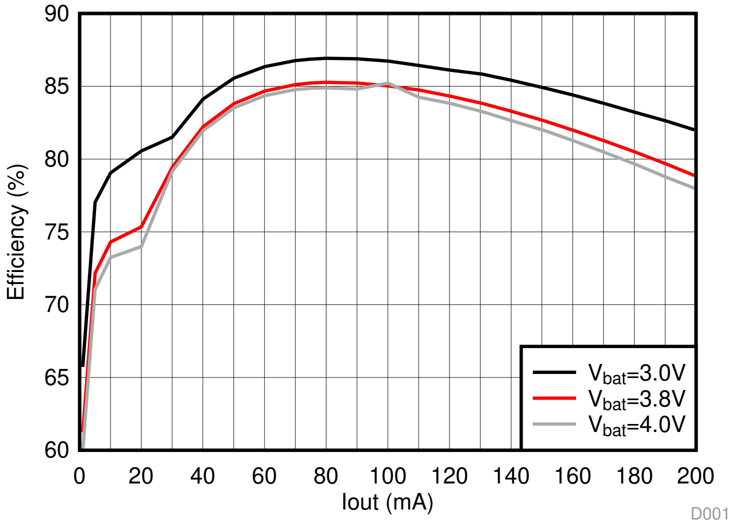
- Vin is connected to source meter SM1 configured as a current source with voltage compliance (clamp) set to the open circuit voltage 0.6V. The source meter SM1 simulates the solar panel behavior
- Vout is connected to source meter SM2 configured as a voltage source set to the battery voltage. The current sunk by the source meter was the output current of the charger. SM2 simulates the Li-Ion battery.
- Turn on the source meter SM2 to start up the boost converter.
- Turn on the source meter SM1.

3.2.2 Test Results

3.2.2.1 Efficiency Curve

The efficiency curve is shown in Figure 8 at different battery voltages.

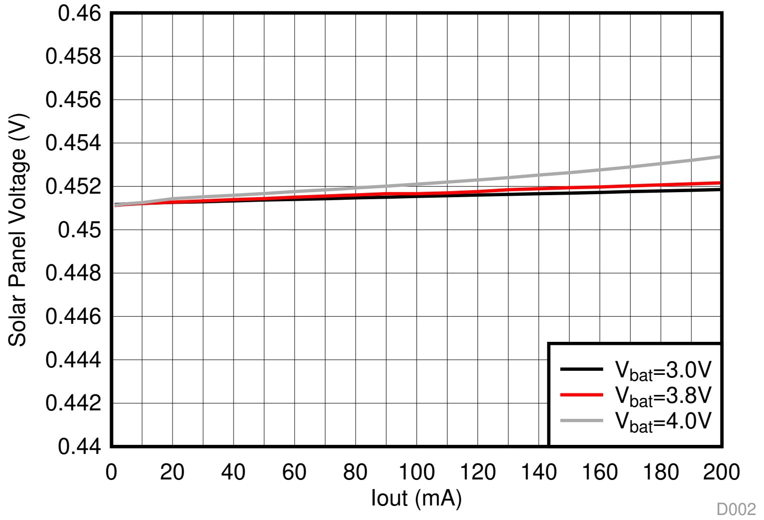
Figure 8. Efficiency Curve



3.2.2.2 Input Voltage VS Charging Current Curve

The solar panel input voltage VS charging current curve is shown in Figure 9. Solar panel is regulated at a fixed 0.45V MPP point at different charging current conditions.

Figure 9. Input Voltage VS Charging Current Curve



3.2.2.3 Steady State Waveform

Figure 10 and Figure 11 show the steady state waveform in 1 A and 2 A input current conditions separately. Solar panel voltage regulates at 0.45V with 1 A and 2 A input current.

Figure 10. Steady State at V_{bat} = 3.6 V, I_{in} = 1 A

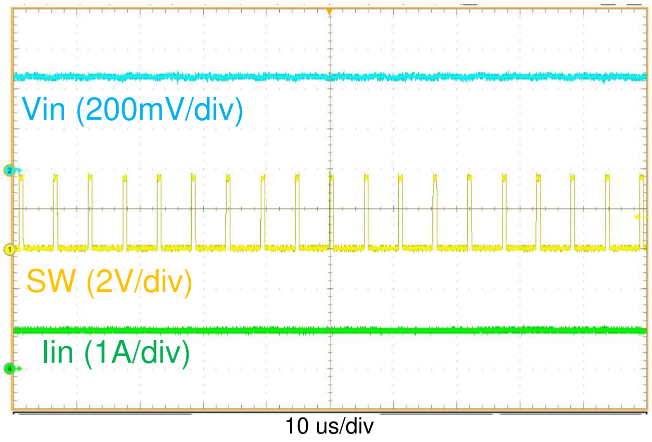
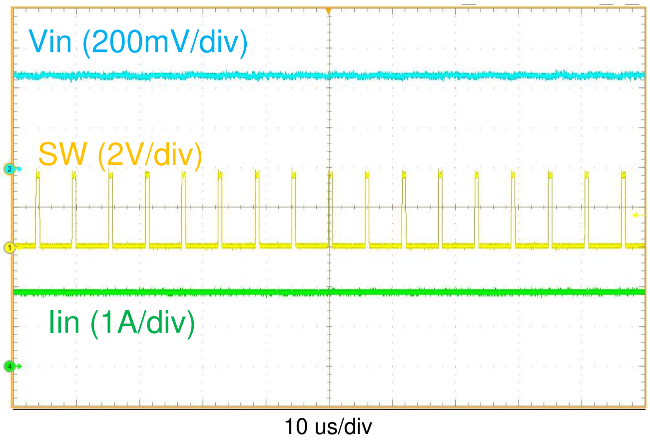


Figure 11. Steady State Waveform at V_{bat} = 3.6 V, I_{in} = 2 A



3.2.2.4 Startup and Shutdown Waveform

Figure 12 shows the startup waveform when battery voltage is 3.6 V and input current is 2 A. Figure 13 shows the shutdown waveform when battery voltage is 3.6 V and input current is 2 A.

Figure 12. Startup Waveform at V_{bat} = 3.6 V, I_{in} = 2A

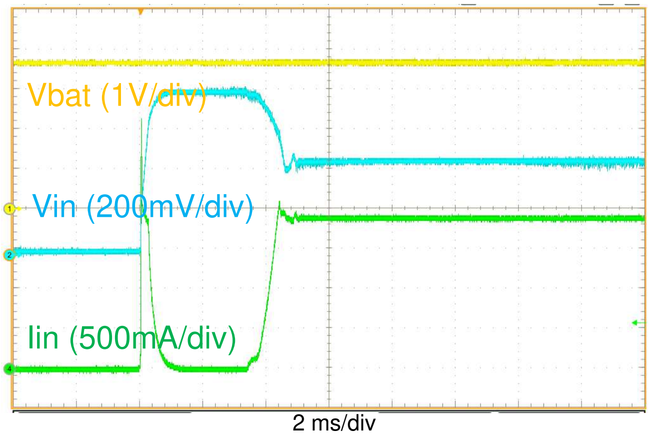
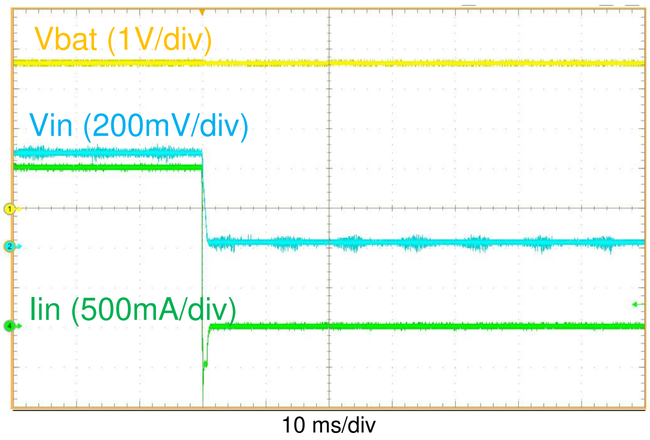


Figure 13. Shutdown Waveform at V_{bat} = 3.6 V, I_{in} = 2 A



3.2.2.5 *Input Current Transient Waveform*

Figure 14 and Figure 15 show the input current transient waveform from 0.2 A to 1.2 A and from 1.2 A to 0.2 A separately. Figure 16 and Figure 17 show the input current transient waveform from 1.2 A to 2.2 A and from 2.2 A to 1.2 A separately. The solar panel voltage will regulate at fixed 0.45 V when input current transient happens.

Figure 14. Input Current Transient Waveform from 0.2 A to 1.2 A

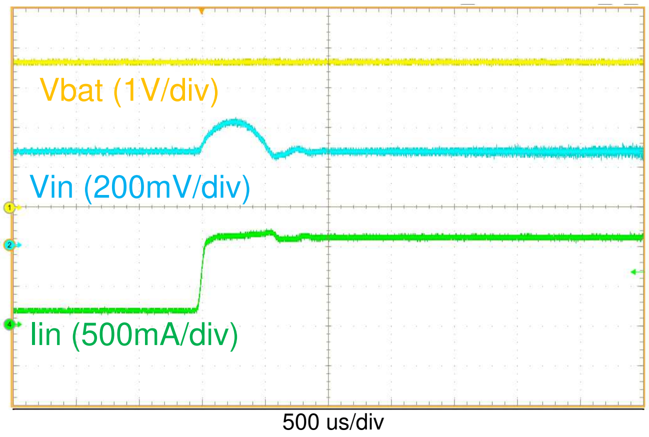


Figure 15. Input Current Transient Waveform from 1.2 A to 0.2 A

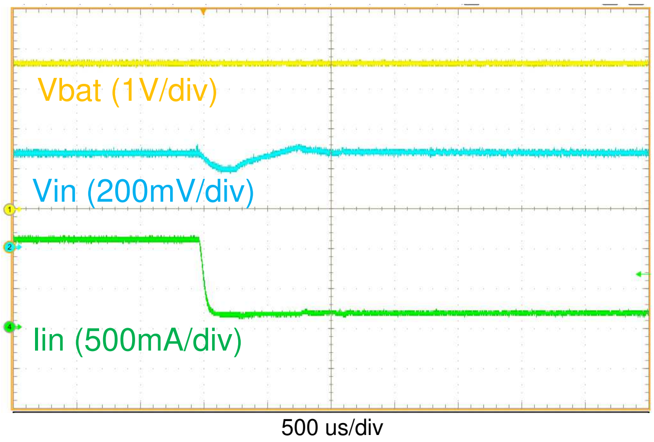


Figure 16. Input Current Transient from 1.2 A to 2.2 A

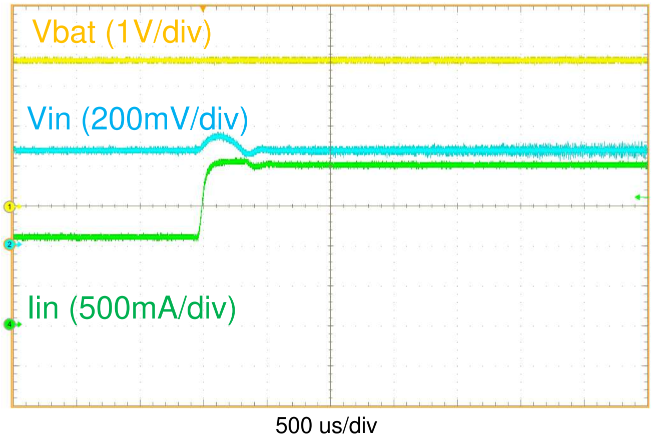
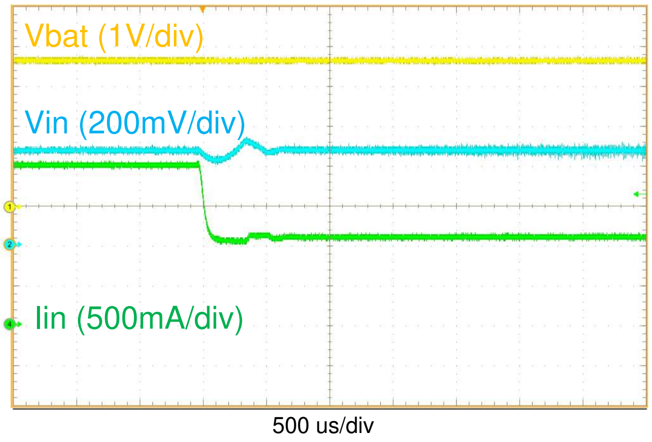


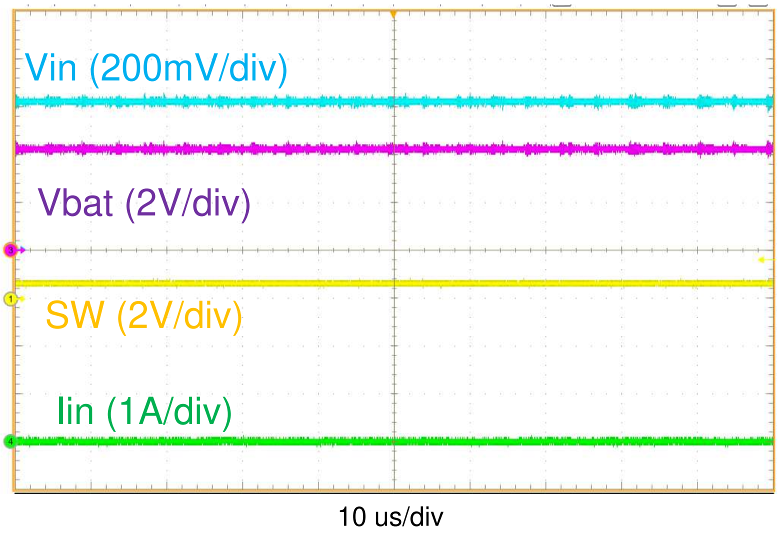
Figure 17. Input Current Transient from 2.2 A to 1.2 A



3.2.2.6 Battery OVP Waveform

Figure 18 shows the battery voltage OVP waveform when battery voltage is 4.25V. When battery over voltage protection triggers, P-channel MOSFET is turned off and Boost converter stops switching.

Figure 18. OVP Waveform at V_{bat} = 4.25 V



3.2.2.7 Thermal Picture

Figure 19 shows the thermal condition when Li-Ion battery voltage is 3.0 V and input current is 2 A. Figure 20 shows the thermal condition when Li-Ion battery voltage is 3.8 V and input current is 2 A. The picture were captured with no airflow.

Figure 19. Thermal Picture at V_{bat} = 3.0 V, I_{in} =2 A

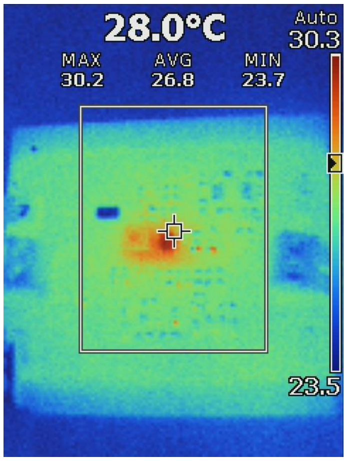
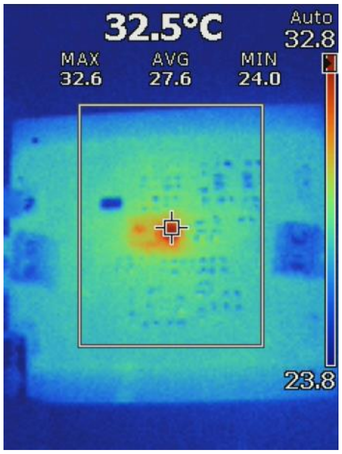


Figure 20. Thermal Picture at V_{bat} = 3.8 V, I_{in} = 2 A



4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-050039.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-050039.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-050039.

4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-050039.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-050039.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-050039.

5 Software Files

To download the software files, see the design files at TIDA-050039.

6 Related Documentation

1. *TPS61089x 12.6-V, 7-A Fully-Integrated Synchronous Boost Converters in 2.0-mm x 2.5-mm VQFN Package*

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