MP2659 Reference Design

12V Lead-Acid Battery Charging Solution

Contents

1 Overview

1.1 Description

Lead-acid batteries are widely used in battery-powered devices due to their advantages, such as a stable voltage, low price, simple maintenance, and high reliability. However, there are few chips on the market that are designed specifically for applications that charge lead-acid batteries.

This reference design showcases a lead-acid battery charging solution. The solution uses the MP2659, a highly integrated switching charger designed for portable devices with 3-cell to 6-cell series Li-ion or Li-polymer battery packs.

1.2 Features

- Up to 36V Operating Input Voltage
- 45V Maximum Sustainable Voltage When Not Switching
- Up to 3A Charge Current
- 1-Cell, 12V Lead Acid Battery
- 0.5% Reference Voltage Accuracy
- Input Current Limit Regulation
- Minimum Input Voltage Regulation
- Charge Operation Indicator
- Dead Battery Pack Recovery
- Battery Over-Voltage Protection (OVP)
- Configurable Safety Timer
- Battery NTC Thermal Monitor

1.3 Applications

- Industrial Medical Equipment
- Power Tools
- Robot and Portable Vacuum Cleaners
- Wireless Speakers

High Voltage

Warning: Although this board is designed to satisfy safety requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

2 Reference Design

2.1 Block Diagram

Figure 1 shows a block diagram for a highly integrated switching charger for lead-acid batteries. This application has a 40W output capability and an input voltage up to 36V. To adjust the regulation voltage of the lead-acid batteries, adjust the resistance of the voltage dividers.

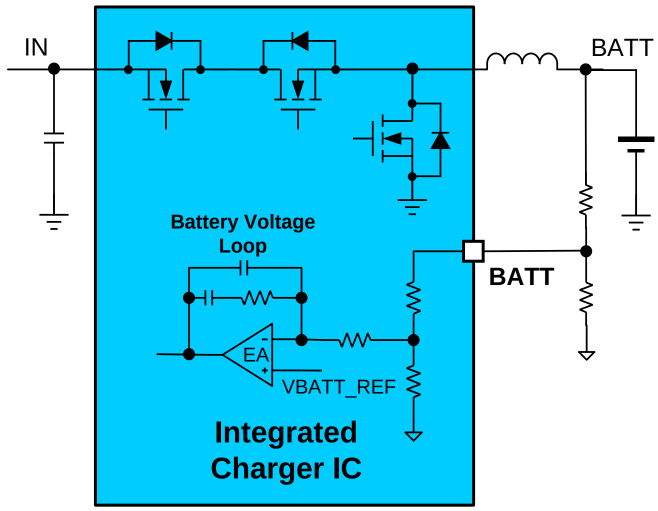


Figure 1: Block Diagram

2.2 Related Solutions

This reference design is based on the following MPS solution:

Table 1: System Specifications

MPS Integrated Circuit	Description
MP2659	36V, standalone switching charger with integrated MOSFETs, 3-cell to 6-cell series battery pack

2.3 System Specifications

Table 2: System Specifications

Parameter	Specification
Input voltage range	4.5V to 36V
Output voltage	Up to 14.4V
Maximum output current	3A
Switching frequency	680kHz or 350kHz (under nominal conditions)
Efficiency	>92%

3 Design

3.1 Design Method

Figure 2 shows an application circuit to charge lead-acid batteries with OR-selection power path management. The circuit's power stage uses one inductor (L_1) and three capacitors (C_{IN}, C_{PMID}, and C_{BATT}). With the addition of external components, the complete charging function with power path management can be implemented.

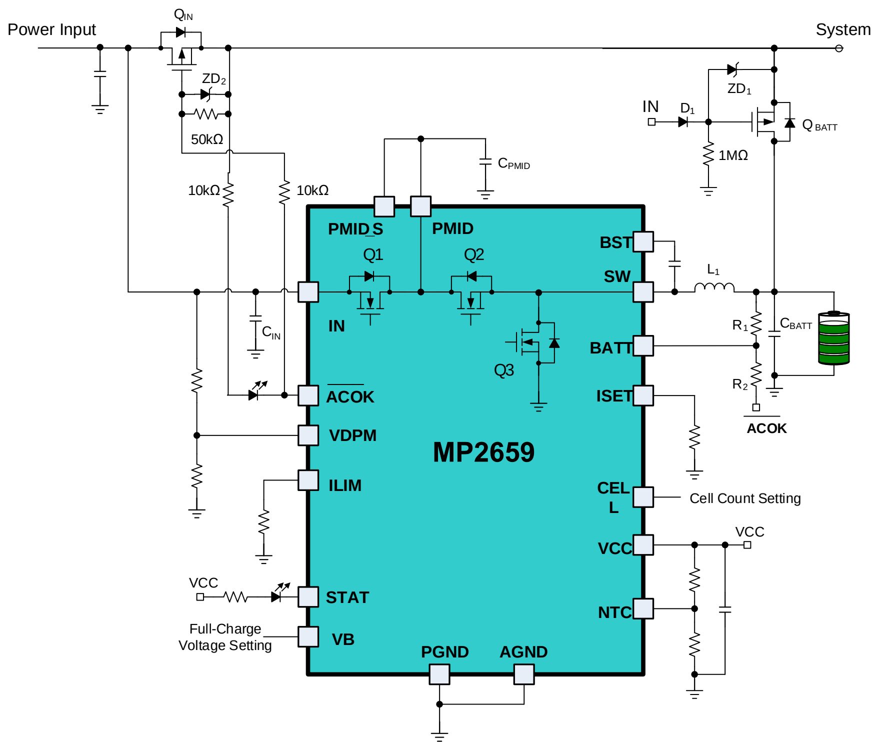


Figure 2: Application Circuit

OR-selection power path management can be realized with two P-channel MOSFETs and other components (e.g. ZD1, ZD2, D1, and resistors). When there is no input source, Q_{BATT} turns on and transfers energy from the battery to the system. When an input source is present, Q_{BATT} turns off, and the system's power is supplied by the input source from Q_{IN}.

The MP2659 is designed for 3-cell to 6-cell series Li-ion and Li-polymer batteries. Each cells has a regulated battery voltage (3.6V, 4.15V, 4.2V, or 4.35V). To charge a lead-acid battery, there is a specific regulated battery voltage that can be set using resistor dividers (R_1 and R_2). R_1 and R_2 can be calculated with Equation (1):

$$\frac{R_2}{R_1 + R_2} = \frac{V_{BATT\_REG}}{V_{BATT\_TERM}} \qquad (1)$$

Where V_{BATT_REG} = the number of cells multiplied by V_{BATT_CELL} (set by the CELL and VB pins), and V_{BATT_TERM} is the lead-acid battery's termination voltage. R_1 should range between 2kΩ and 5kΩ.

3.2 Schematic

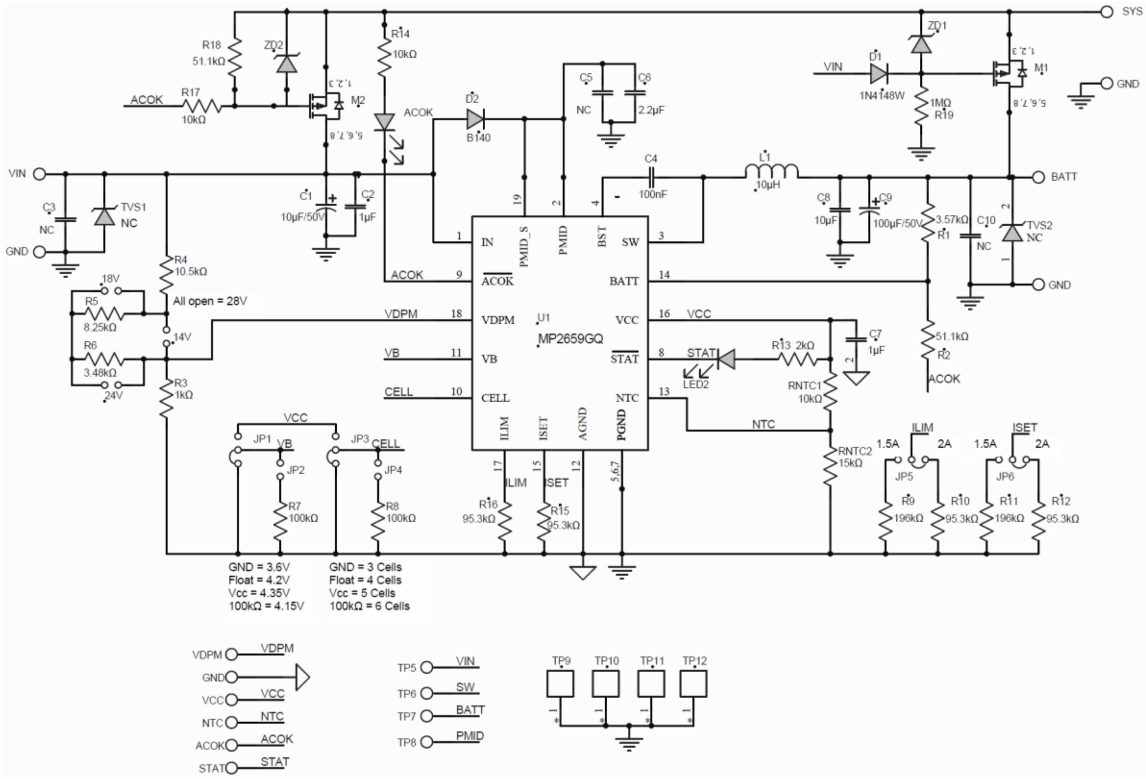


Figure 3: MP2659 Solution Schematic

Figure 3 shows MP2659 solution schematic. To create this schematic, follow the guidelines below:

1. This circuit can work safely under applications where V_{IN} < 20V.
2. For applications where V_{IN} exceeds 20V, place a ≥47µF electrolytic capacitor between VIN and GND. Add a Schottky diode with a higher current capacity (e.g. B240A) between VIN and PMID. Use a TVS diode to clamp the VIN voltage if its voltage spike reaches 45V.
3. Consider the voltage spike on PMID during battery insertion. Add an extra TVS diode to clamp the PMID voltage if its voltage spike reaches 45V.
4. The inductor on this evaluation board can only be used in applications where f_{SW} = 680kHz or I_{CC} < 2.2A. For applications where f_{SW} = 350kHz and I_{CC} > 2.2A, select an inductor with a higher inductance or higher saturation current.
5. For more component selection information, refer to the MP2659 datasheet.

Table 4 lists recommended components for applications where V_{IN} exceeds 20V.

Table 4: Component Selections

Pin	Condition	Recommendations
IN	≤20V input	Add a 1µF/50V ceramic capacitor to the IN pin for adaptor applications. Add a ≥47µF capacitor for solar applications.
	>20V input	Add a 47µF/50V electrolytic capacitor to the IN pin. A TVS diode is required if the IN voltage exceeds the pin's maximum voltage rating during the VIN hot-insertion test.
BATT	3-cell or 4-cell	Add a 10µF/50V ceramic capacitor to the BATT pin.
	5-cell or 6-cell	Add a TVS diode or ≥47µF electrolytic capacitor to the BATT pin.
PMID	-	Add a 2.2µF/50V ceramic capacitor (1206 size preferred) to the PMID pin. Add a 2A/40V Schottky diode from IN to PMID. A TVS diode is required if the PMID voltage exceeds the pin's maximum voltage rating during the VBATT hot-insertion test.

3.3 BOM

Table 3: Bill of Materials

Qty	Ref	Value	Description	Package	Manufacturer	Manufacturer P/N
1	C1	10µF	Electrolytic capacitor, 50V	DIP	Jianghai	CD287-50V10
1	C2	1µF	Ceramic capacitor , 50V, X7R, 1206	1206	Wurth	885012208093
1	C4	100nF	Ceramic capacitor, 50V, X7R, 0603	0603	Murata	GRM188R71H104 KA93D
1	C6	2.2µF	Ceramic capacitor, 50V, X7R, 1206	1206	Murata	GRM31CR71H225 KA88L
1	C7	1µF	Ceramic capacitor, 25V, X7R, 0805	0805	Wurth	885012207078
1	C8	10µF	Ceramic capacitor. 50V. X5R	1206	Murata	GRM31CR61H106 KA12L
1	C9	100µF	Electrolytic capacitor, 50V, 100µF	DIP	Rubycon	50YXF100MEFC
1	L1	10µH	Inductor, 10µH, 35m, 4A	SMD	Wurth	744066100
1	ACOK	Red	Red LED	0805	Bright LED	F3D02R-4A
1	CHG	Green	Green LED	0805	Bright LED	F3D02HG-1A
1	R1	3.57kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-073K57L
2	R2, R18	51.1kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0751K1L
4	R15, R16, R10, R12	95.3kΩ	Film resistor ,1%	0603	Yageo	RC0603FR-0795K3L
1	R3	1kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-071KL
1	R4	10.5kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0710K5L
1	R5	8.25kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-078K25L
1	R6	3.48kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-073K48L
2	R7, R8	100kΩ	Film resistor, 5%	0603	Yageo	RC0603JR-07100KL
2	R9, R11	196kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07196KL
1	R13	2kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-072KL
1	R14	10kΩ	Film resistor, 5%	0603	Yageo	RC0603JR-0710K
2	RNTC1, R17	10kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0710KL
1	RNTC2	15kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0715KL
1	R19	1MΩ	Film resistor, 5%	0603	Yageo	RC0603JR-071ML
1	U1	MP2659	3-cell to 6-cell battery charger	QFN-19 (3mmx 3mm)	MPS	MP2659GQ-0000
1	D1	Diode	Diode, 75V, 0.15A	SOD-123	Diodes	1N4148W

1	D2	30V	Schottky diode. 40V. 1A	SMA	Diodes	B140
2	ZD1, ZD2	12V	Zener diode, 12V	SOD-123	Diodes	BZT52C12
2	QIN, QBATT	60V, 23mΩ	P-channel MOSFET, 60V, 23mΩ	SO-8	Analog Power	AM4417P
4	VIN, GND, GND, BATT	2mm	2.0mm male needle	DIP	Any	
4	TP5, TP6, TP7, TP8	Test point	Test point	DIP	Any	
4	TP9, TP10, TP11, TP12	GND test point	GND test point	SMD	Any	
15	VDPM, GND, VCC, NTC, ACOK, STAT JP1, JP2, JP3, JP4, JP5, JP6, JP7, JP8, JP9	2.54mm	2.54mm connector	DIP	Any	
5	JP1, JP3, JP5, JP6, JP8	Sub-block	Sub-block	DIP	Any	

3.4 PCB Layout

The PCB layout in Figure 4, Figure 5, Figure 6, and Figure 7 refers to the standard MP2659 evaluation board.

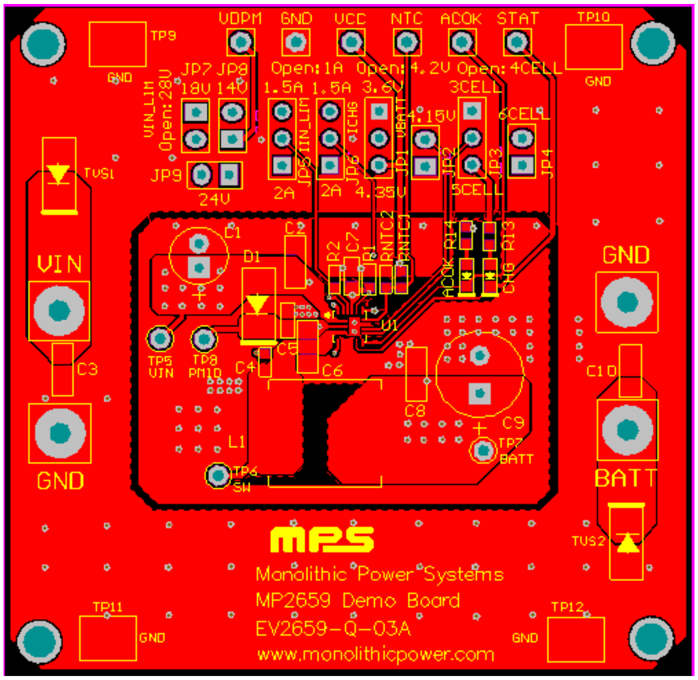


Figure 4: Top Layer

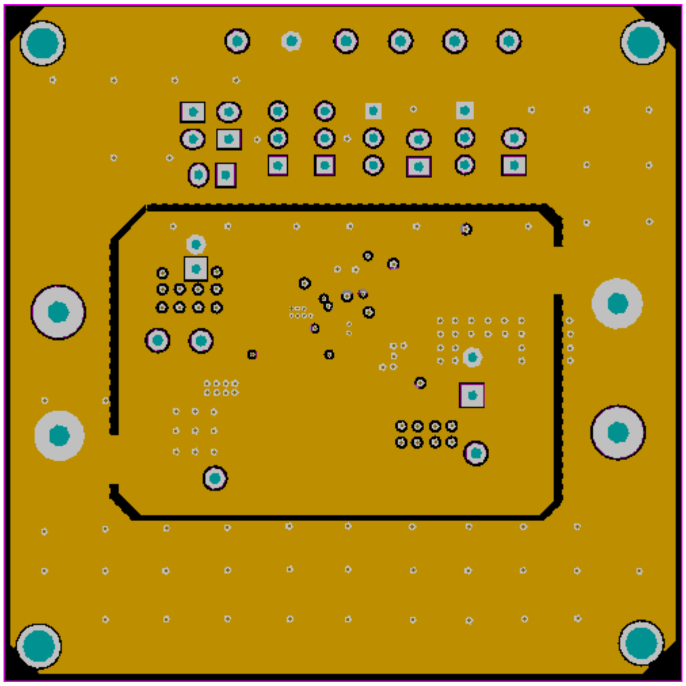


Figure 5: Middle Layer 1

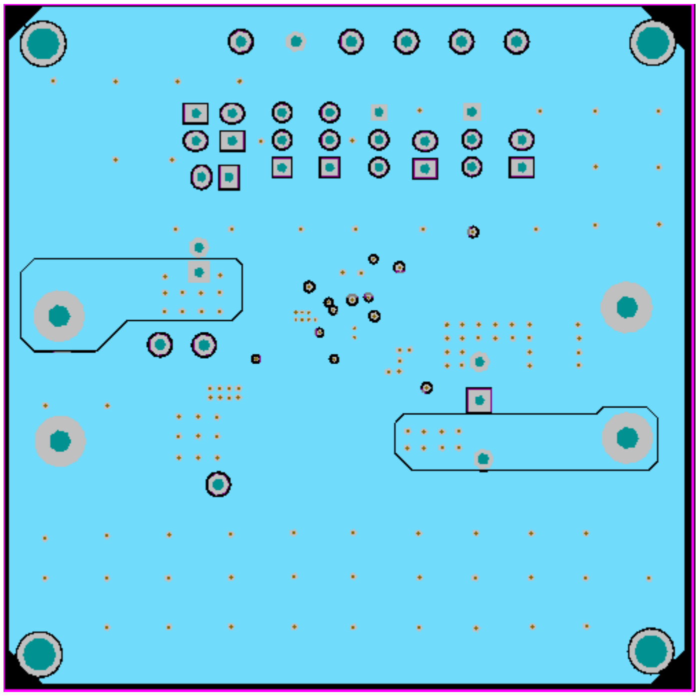


Figure 6: Middle Layer 2

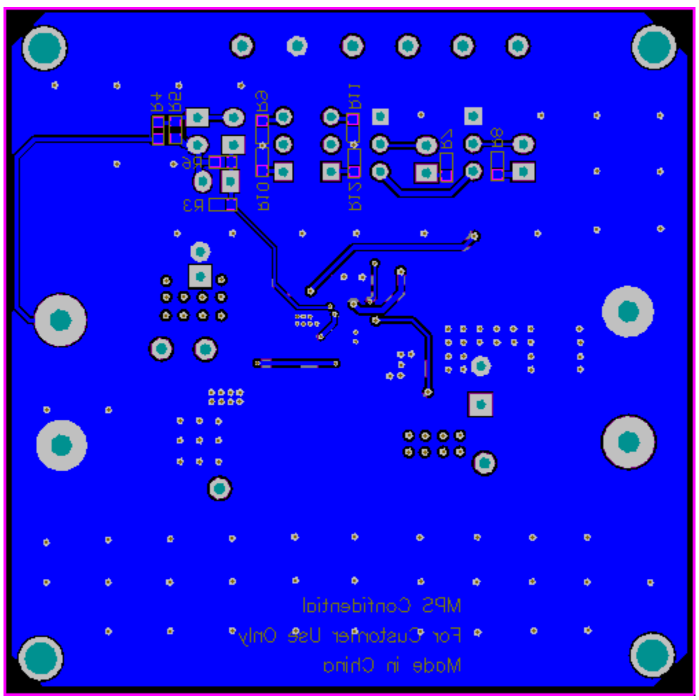


Figure 7: Bottom Layer

4 Test Results

The EV2659-Q-03A was used to test the12V lead-acid battery charging process.

To fine-tune the battery regulation voltage to charge lead-acid batteries, add an auxiliary circuit (see Figure 8).

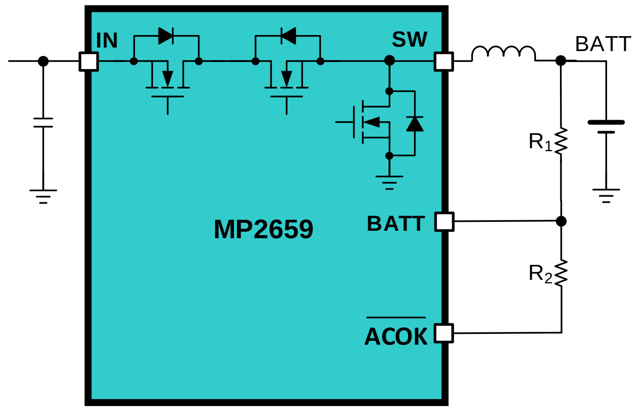


Figure 8: Auxiliary Circuit to Fine-Tune Battery Voltage Regulation

For OR-selection power path management, add an auxiliary circuit (see Figure 9).

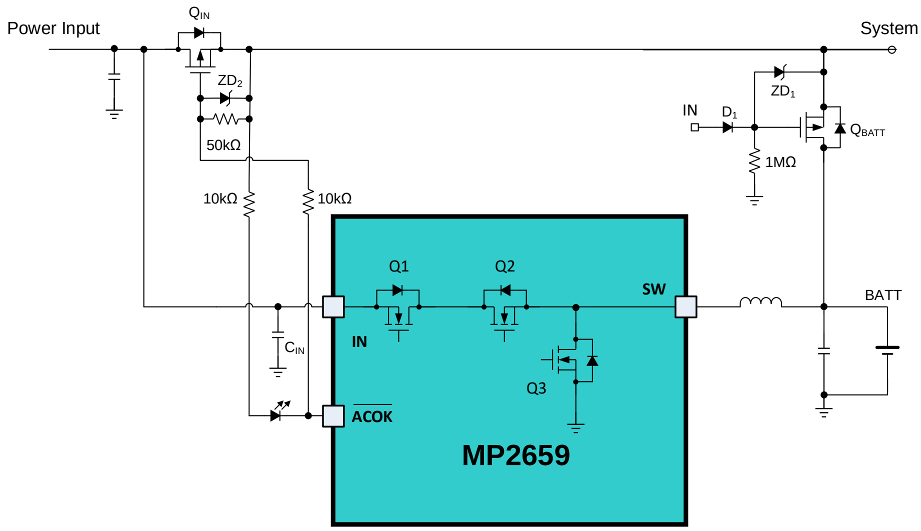


Figure 9: Auxiliary Circuit for OR-Selection Power Path Management

For OR-selection power path management (and to ensure that V_{BATT_TERM} = 13.96V) with the auxiliary circuit, set the following parameters on the evaluation board:

- Cell numbers = 3
- VB = 4.35V/cell

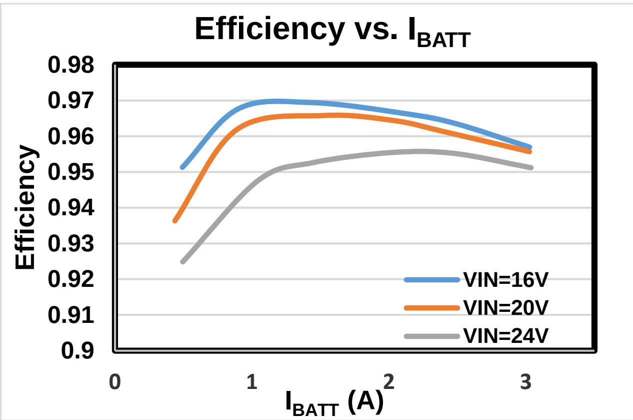
Set the following parameters for the auxiliary circuit:

- R_1 = 3.57kΩ
- R_2 = 51.1kΩ
- Q_{IN} = Q_{BATT} = AM4417P
- ZD_1 = ZD_2 = BZT52C12
- D_1 = 1N4148W

4.1 Efficiency

L = 10µH/35mΩ, f_{SW} = 680kHz, and T_A = 25°C.

Figure 10: Efficiency vs. Charge Current
Constant voltage mode



4.2 Time Domain Waveforms

L = 10µH/35mΩ, f_{SW} = 680kHz, and T_A = 25°C.

Figure 11: Battery Charge Curve
V_{IN} = 20V, V_{BATT_TERM} = 14V, I_{CC} = 2A, I_{IN_LIM} = 2A

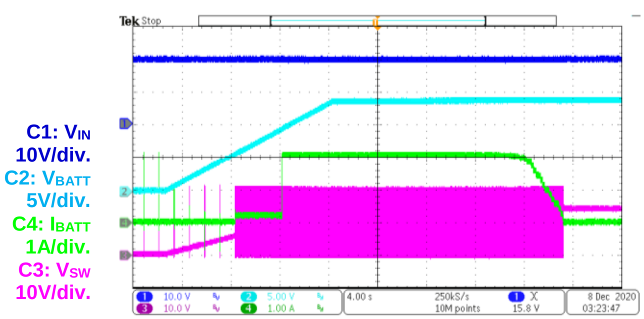


Figure 12: Auto-Recharge
V_{IN} = 20V, V_{BATT_TERM} = 14V, I_{CC} = 2A, I_{IN_LIM} = 2A

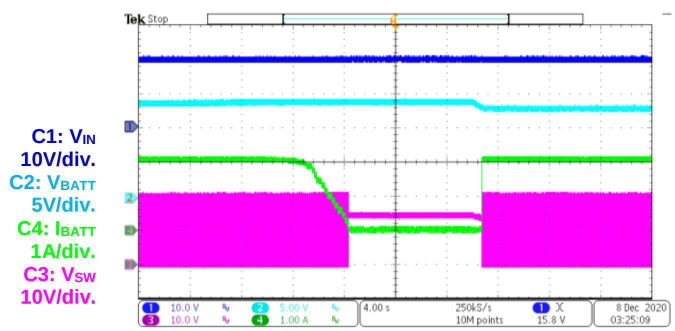


Figure 13: Steady State
V_{IN} = 20V, V_{BATT} = 4V, I_{CC} = 2A, I_{IN_LIM} = 2A, trickle charge mode

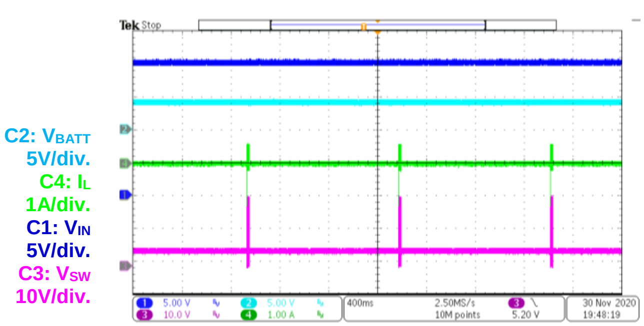


Figure 14: Steady State
V_{IN} = 20V, V_{BATT} = 8V, I_{CC} = 2A, I_{IN_LIM} = 2A, pre-charge mode

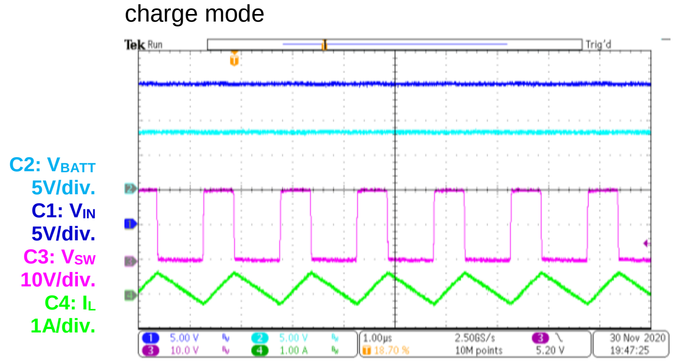


Figure 15: Steady State
V_{IN} = 20V, V_{BATT} = 12V, I_{CC} = 2A, I_{IN_LIM} = 2A, constant current charge mode

C2: V_{BATT} 5V/div.
C1: V_{IN} 5V/div.
C4: I_L 1A/div.
C3: V_{SW} 10V/div.

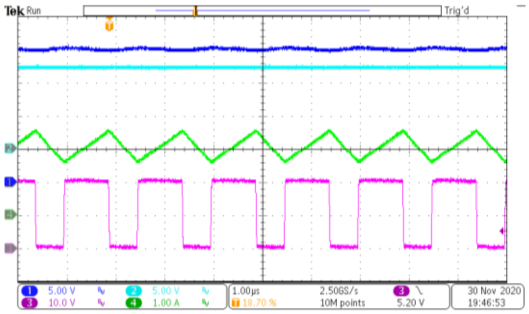


Figure 16: Steady State
V_{IN} = 20V, V_{BATT} = 14V, I_{CC} = 2A, I_{IN_LIM} = 2A, constant voltage charge mode

C4: I_L 1A/div.
C2: V_{BATT} 5V/div.
C1: V_{IN} 5V/div.
C3: V_{SW} 10V/div.

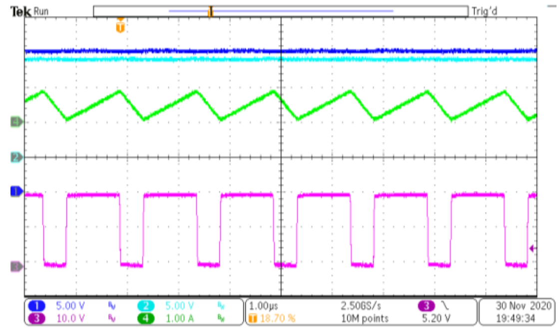


Figure 17: Start-Up
V_{IN} = 20V, V_{BATT} = 13V, I_{CC} = 2A, I_{IN_LIM} = 2A, I_{SYS} = 1A, power path operation

C1: V_{IN} 10V/div.
C2: V_{BATT} 5V/div.
C4: I_{BATT} 1A/div.
C3: V_{SYS} 5V/div.

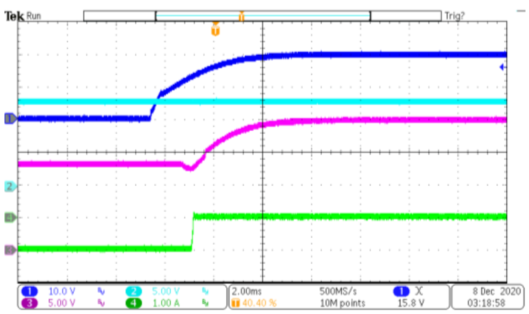


Figure 18: Shutdown
V_{IN} = 20V, V_{BATT} = 13V, I_{CC} = 2A, I_{IN_LIM} = 2A, I_{SYS} = 1A, power path operation

C1: V_{IN} 10V/div.
C2: V_{BATT} 5V/div.
C4: I_{BATT} 1A/div.
C3: V_{SYS} 5V/div.

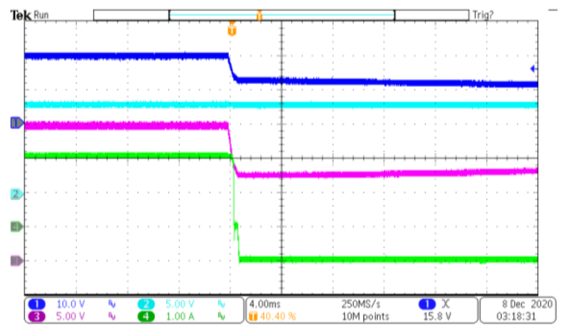


Figure 19: V_{IN_LIM} Loop Control
V_{IN} = 20V/1A, V_{BATT} = 12V, I_{CC} = 3A, I_{IN_LIM} = 2A, V_{IN_LIM} = 15V

C2: V_{BATT} 5V/div.
C1: V_{IN} 5V/div.
C4: I_L 0.5A/div.
C3: V_{SW} 10V/div.

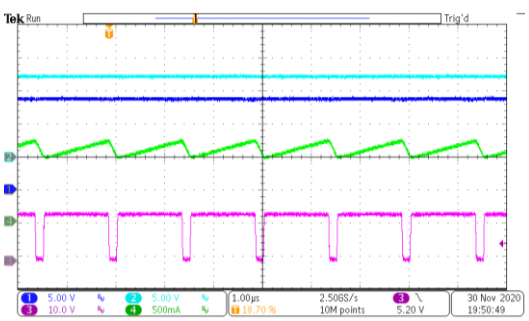
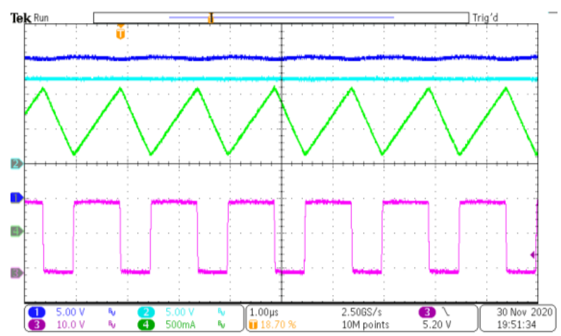


Figure 20: I_{IN_LIM} Loop Control
V_{IN} = 20V, V_{BATT} = 12V, I_{CC} = 3A, I_{IN_LIM} = 1A

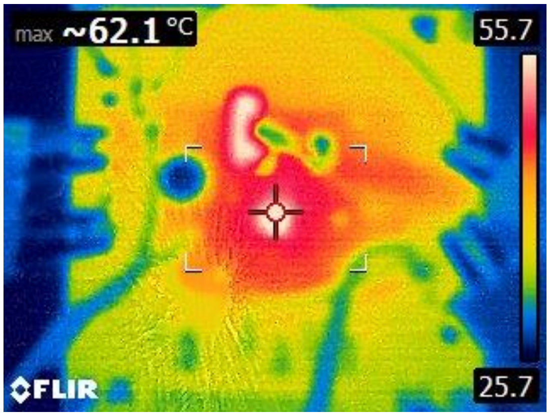
C2: V_{BATT} 5V/div.
C1: V_{IN} 5V/div.
C4: I_L 0.5A/div.
C3: V_{SW} 10V/div.



4.3 Thermal Measurements

L = 10μH/35mΩ, f_{SW} = 680kHz, T_A = 25°C, and burns in 30 minutes. Board information: 63.5mmx63.5mm, 4-layer, 1oz/layer.

Figure 21: Thermal Image
V_{IN} = 20V, V_{BATT} = 12V, I_{CC} = 3A,
T_{RISE} = 62.1°C to 25°C = 37.1°C



5 Start-Up

5.1 Connectors and Jumpers

Table 5: Connectors

Connectors	Description
TP1/VIN	Connect to the input source's positive terminal.
TP2/GND	Connect to the input source's negative terminal.
TP3/BATT	Connect to the battery pack's positive terminal.
TP4/GND	Connect to the battery pack's negative terminal.
TP5/VIN	Test point of VIN.
TP6/SW	Test point of the switching node.
TP7/BATT	Test point of BATT.
TP8/PMID	Test point of PMID.
TP9, TP10, TP11, TP12	Test point of ground.
VDPM, VCC, NTC, ACOK, STAT	Test connection for related signals.

Table 6: Jumpers and Shunts

Jumpers	Description	Default	All Open
JP1, JP2	Selects the battery regulation voltage for each cell.	4.35V	4.2V
JP3, JP4	Selects the battery cell numbers.	3 cells	4 cells
JP5	Selects the input current limit.	2A	1A
JP6	Selects the constant current charge current.	2A	1A
JP7,JP8,JP9	Selects the input voltage minimum limit.	14V	28V

5.2 Quick Start Guide

The EV2659-Q-03A is designed for the MP2659, a highly integrated switching charger that charges batteries across a wide full-battery voltage range. It layout accommodates most commonly used capacitors. A solution for a 1-cell, 12V lead-acid battery charging application with OR-selection power path management can be implemented with the addition of auxiliary circuits.

1. Connect the battery pack to the BATT and GND connectors. Ensure that the battery's positive and negative terminals are correctly connected.
2. If using a battery emulator, preset the battery emulator to a proper voltage, then turn the emulator off. Connect the battery emulator to BATT and GND, then turn the emulator's output on.
3. Preset the input power source to its proper voltage then turn the power source off. Connect the power source to VIN and GND, then turn the power source on. The board should start charging the battery.
4. To modify the charging parameters, configure the evaluation board using the jumpers (see Table 6). Table 7 lists the adjustable parameters.

Table 7: Adjustable Parameters

Parameter	Value	Units
Charge current	1, 1.5, or 2	A
Input current limit	1, 1.5, or 2	A
Cells	3 or 4	N/A
Battery regulation voltage (each cell)	3.6, 4.2, 4.35, or 4.15	V
Minimum input voltage limit	14, 18, 24, or 28	V
Battery termination voltage	According to R_1, R_2 value	kΩ

5. Note that the MP2659 utilizes dead battery pack recovery if the battery voltage drops below 1.5V/cell. During recovery the devices charges for a 20ms pulse, with a 1.4s suspension time.

6 Disclaimer

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Inclusion of MPS products in critical applications is understood to be fully at the risk of the customer.

Questions concerning potential risk applications should be directed to MPS.

MPS semiconductors are typically used in power supplies in which high voltages are present during operation. High-voltage safety precautions should be observed in design and operation to minimize the chance of injury.

REVISION HISTORY

Revision #	Revision Date	Description	Pages Updated
1.0	4/14/2021	Initial Release	-