MP2759 Reference Design

An Implementation to Adjust I_{CC} with a Digital PWM Signal

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1 Overview

1.1 Description

Much of today's electric equipment – such as industrial medical equipment, robot vacuums, drones, and high power speakers – require multiple batteries for power. Some of these devices require the ability to adjust the charging current in real time to fine-tune the device's performance under different operation modes. For example, many battery manufacturers require specific charging current levels at different temperatures to guarantee battery safety. Although the MP2759 has JEITA to adjust the charging current, a microcontroller (MCU) can enhance user configuration.

This reference design showcases a method to adjust the charging current in real time with a PWM signal from an MCU. This design is based on the MP2759, a highly integrated switching charger designed for applications with 1-cell to 6-cell series Li-ion or Li-polymer battery packs.

1.2 Features

- Up to 36V Operation Input Voltage
- Up to 3A Charge Current
- 1-Cell to 6-Cell Series with 3.6V, 4.0V, 4.1V, 4.15V, 4.2V, 4.35V, or 4.4V Battery Regulation Voltage for Each Cell
- Input Current Limit Regulation
- Input Minimum Voltage Regulation
- Supports OR Selection Power Path Management
- 0.5% Battery Regulation Voltage Accuracy
- Charge Operation Indicator
- Input Status Indicator
- Battery Over-Voltage Protection (OVP)
- Charging Safety Timer
- Battery Thermal Monitoring and Protection with JEITA Profile

1.3 Applications

- Industrial Medical Equipment
- Power Tools
- Robots 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 highly integrated switching charger used for applications with 1-cell to 6-cell series Li-ion or Li-polymer battery packs. This solution offers a 40W output capability, a maximum 36V input voltage, and a charging current that can be adjusted in real time with an external PWM signal.

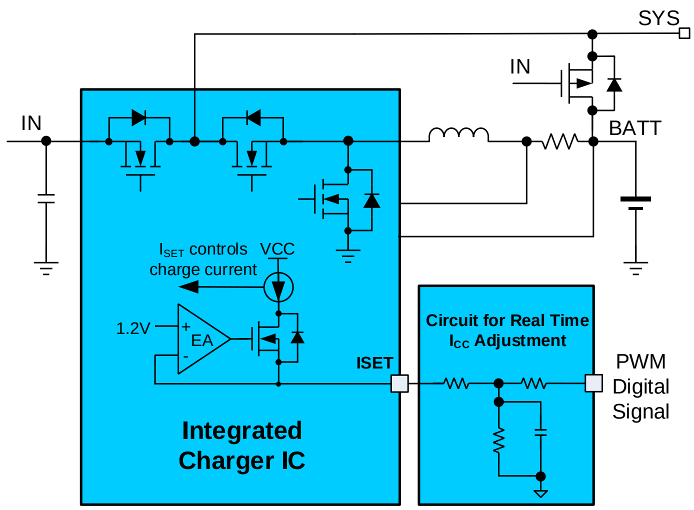


Figure 1: Block Diagram

2.2 Related Solutions

This reference design is based on the following MPS solutions:

Table 1: System Specifications

MPS Integrated Circuit	Description
MP2759	36V switching charger with power path management for 1-cell to 6-cell batteries

2.3 System Specifications

Table 2: System Specifications

Parameter	Specification
Input voltage range	4V to 36V
Output voltage	Up to 26.4V
Maximum output current	3A
Switching frequency	700kHz or 450kHz (under nominal conditions)
Efficiency	>92%

3 Design

3.1 Design Process

Figure 2 shows the application circuit that can charge multiple batteries. This circuit provides the ability to adjust the charging current in real time with power path management. This circuit's power stage uses one inductor (L_1) and 3 capacitors (C_{IN}, C_{PMID}, and C_{BATT}). With the addition of external components, the complete charging function with power path management can be realized.

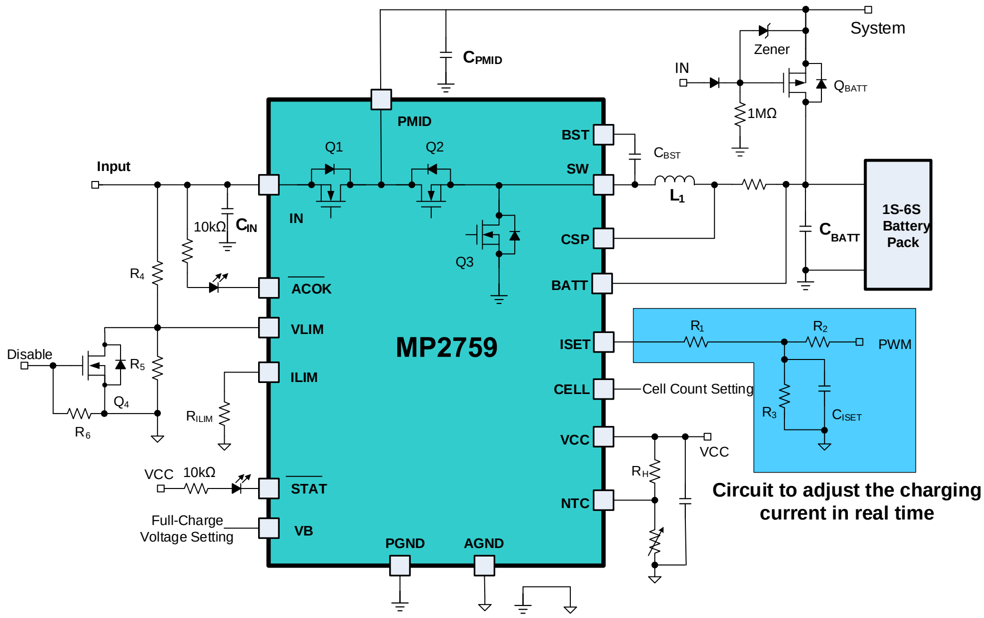


Figure 2: Application Circuit

The MP2759 provides a feature that allows the charging current to be regulated. This is accomplished by connecting a resistor (R_{ISET}) between the ISET pin and AGND. The voltage on the ISET pin is fixed at about 1.2V. The relationship between R_{ISET} and charging current can be calculated with Equation (1):

$$I_{CHG} = \frac{96(k\Omega)}{R_{ISET}(k\Omega)} \quad (1)$$

Figure 3 shows the equivalent R_{ISET} circuit. It is possible to change the equivalent R_{ISET} by modifying the duty cycle of the PWM signal from an MCU. This means that the charging current can be adjusted in real time.

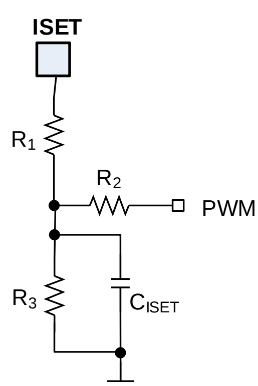


Figure 3: Equivalent R_{ISET} Circuit

Based on Figure 3, the equivalent resistance (R_{EQ}) between the ISET pin and AGND can be calculated with Equation (2)

$$R_{EQ} = \frac{1.2xR_1xG_{123}}{1.2xG_{123} - (\frac{DUTYxV_{M\_PWM}}{R_2} + \frac{1.2}{R_1})} \quad (2)$$

Where DUTY is the PWM duty cycle, V_{M_PWM} is the PWM amplitude (the same as the MCU supply voltage, which is about 3.3V), and G_{123} can be estimated with Equation (3):

$$G_{123} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad (3)$$

For Equation (1), Equation (2), and Equation (3), R_{EQ} must exceed 0Ω. When R_{EQ} falls below 0Ω, I_{CHG} = 0A.

Based on the analysis above, the parameters (R_1, R_2, R_3, and C_{ISET}) can be designed with the following guidelines:

1. The equivalent resistor corresponding to the maximum charging current is R_{MAX_ICHG}, which can be calculated with Equation (4):

$$R_{MAX\_ICHG} = R_1 + R_2//R_3 \quad (4)$$

2. Choose an appropriate R_1, estimated with Equation (5):

$$R_1 = 0.5xR_{MAX\_ICHG} \quad (5)$$

3. Calculate R_2 and R_3 with Equation (6):

$$\begin{cases} R_2//R_3 = 0.5xR_1 \\ \frac{MAX\_DUTYxV_{M\_PWM} - 1.2}{R_2} = \frac{1.2}{R_3} \end{cases} \quad (6)$$

   Where MAX_DUTY is the maximum PWM duty when the charging current falls to 0A. It is recommended to make MAX_DUTY about 80%.

4. Choose an appropriate C_{ISET} to filter the PWM signal to DC signal, estimated with Equation (7):

$$f_{FILTER} = \frac{1}{2\pi x(R_2//R_3)xC_{ISET}} << f_{PWM} \quad (7)$$

   Where f_{FILTER} is the cut-off frequency of the RC filter (recommended to be about 10Hz), and f_{PWM} is the PWM frequency (recommended to exceed 1kHz).

3.2 Schematic

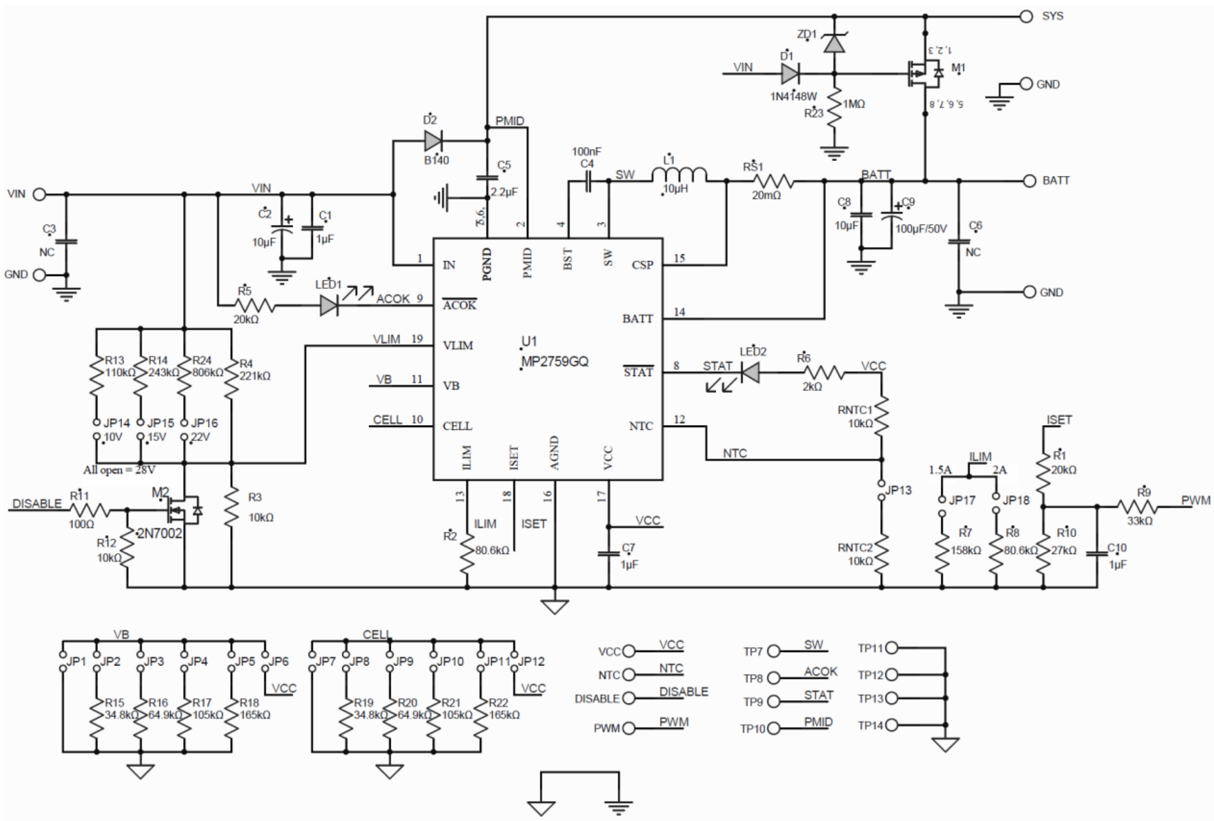


Figure 4: MP2759 Solution Schematic

Figure 4 shows the MP2759 solution schematic. To create this schematic, follow the guidelines below:

1. The standard evaluation board can operate safely when 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} = 700kHz or I_{CC} < 2.5A. For applications where f_{SW} = 450kHz and I_{CC} > 2.5A, select an inductor with a higher inductance or higher saturation current.
5. For more component selection information, refer to the MP2759 datasheet.

Table 4 lists the recommended components for applications that exceed 20V.

Table 4: Recommended 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	1-cell, 2-cell, 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	1µF	Ceramic capacitor, 50V, X7R	1206	Wurth	885012208093
1	C2	10µF	Electrolytic capacitor, 50V	DIP	Jianghai	CD287-50V10
1	C4	100nF	Ceramic capacitor, 50V, X7R	0603	muRata	GRM188R71H104KA93D
1	C5	2.2µF	Ceramic capacitor, 50V, X7R, 1206;	1206	muRata	GRM31CR71H225KA88L
2	C7, C10	1µF	Ceramic capacitor, 25V, X7R	0603	TDK	C1608X7R1E105K
1	C8	10µF	Ceramic capacitor, 50V, X5R	1206	muRata	GRM31CR61H106KA12L
1	C9	100µF	Electrolytic capacitor, 50V, 100µF	DIP	Rubycon	50YXF100MEFC
1	L1	10µH	Inductor, 10µH, 35m, 4A	SMD	Wurth	744066100
1	RS1	20mΩ	Film resistor, 1%	0805	Yageo	RL0805FR-070R02L
1	R1	20kΩ	Film resistor 1%	0603	Yageo	RC0603FR-0720KL
2	R2, R8	80.6kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0780K6L
3	R3, RNTC1 RNTC2	10kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0710KL
1	R4	221kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07221KL
1	R5	20kΩ	Film resistor, 5%	0603	Yageo	CR03T03705NJ20K
1	R6	2kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-072KL
1	R7	158kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07158KL
1	R9	33kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0733KL
1	R10	27kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0727KL
1	R11	100Ω	Film resistor, 1%	0603	Yageo	RC0603FR-07100RL
1	R12	10kΩ	Film resistor, 5%	0603	Yageo	RC0603JR-0710K
1	R13	110kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07110KL
1	R14	243kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07243KL
2	R15, R19	34.8kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0734K8L
2	R16, R20	64.9kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-0764K9L
2	R17, R21	105kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07105KL
2	R18, R22	165kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07165KL
1	R23	1MΩ	Film resistor, 5%	0603	Yageo	RC0603JR-071ML
1	R24	806kΩ	Film resistor, 1%	0603	Yageo	RC0603FR-07806KL
1	LED1	Red	Red LED	0805	Bright LED	F3D02R-4A
1	LED2	Green	Green LED	0805	Bright LED	F3D02HG-1A
1	U1	MP2759	1-cell to 6-cell battery charger	QFN-19 (3mmx 3mm)	MPS	MP2759GQ-0000

1	M1	60V, 23mΩ	P-channel MOSFET, 60V, 23mΩ	SO-8	Analog Power	AM4417P
1	M2	60V	N-channel MOSFET, 60V	SOT-23	On Semiconductors	2N7002LT1G
1	D1	Diode	Diode;75V;0.15A	SOD-123	Diodes	1N4148W
1	D2	Schottky Diode	Schottky diode;40V;1A	SMA	Diodes	B140
1	ZD1	Zener Diode	Zener diode, 11V, 5mA/50mW	SOD-123	Diodes	BZT52C11
6	VIN, GND, BATT, GND, SYS, GND	2.0mm	2.0mm male needle	DIP	Any	Any
4	TP7, TP8, TP9, TP10	Test point	Test point	DIP	Any	Any
4	TP11, TP12, TP13, TP14	GND test point	GND test point	SMD	Any	Any
21	VCC, NTC, DISABLE, JP1 to JP18	2.54mm	2.54mm connector	DIP	Any	Any
5	JP4, JP9, JP13, JP14, JP18	Jumper	Jumper	DIP	Any	Any

3.4 PCB Layout

The PCB layout in Figure 5, Figure 6, Figure 7, and Figure 8 refers to the standard MP2759 evaluation board.

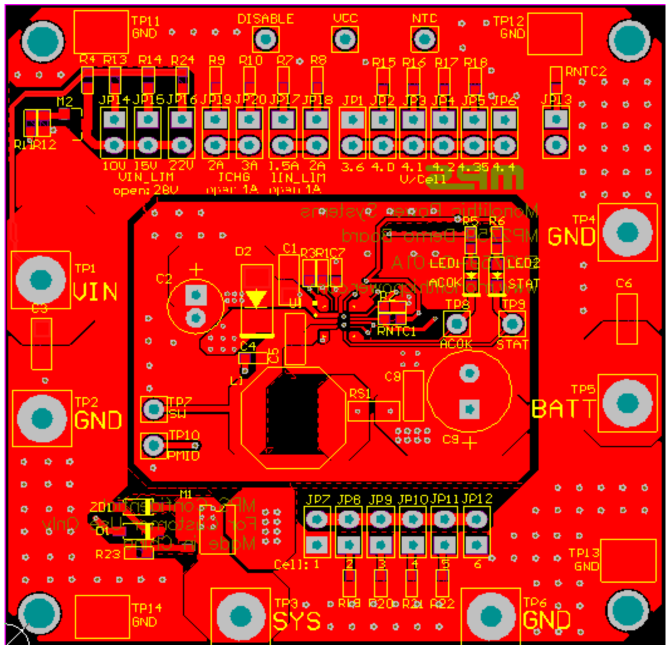


Figure 5: Top Layer

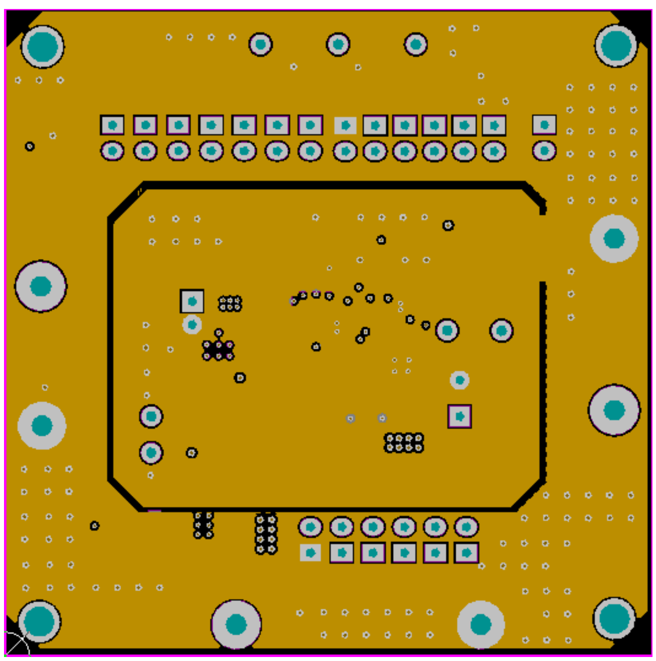


Figure 6: Middle Layer 1

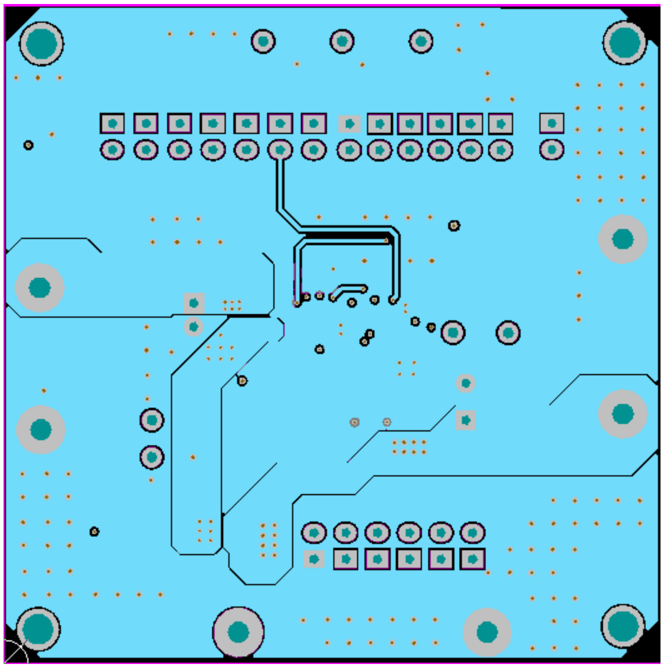


Figure 7: Middle Layer 2

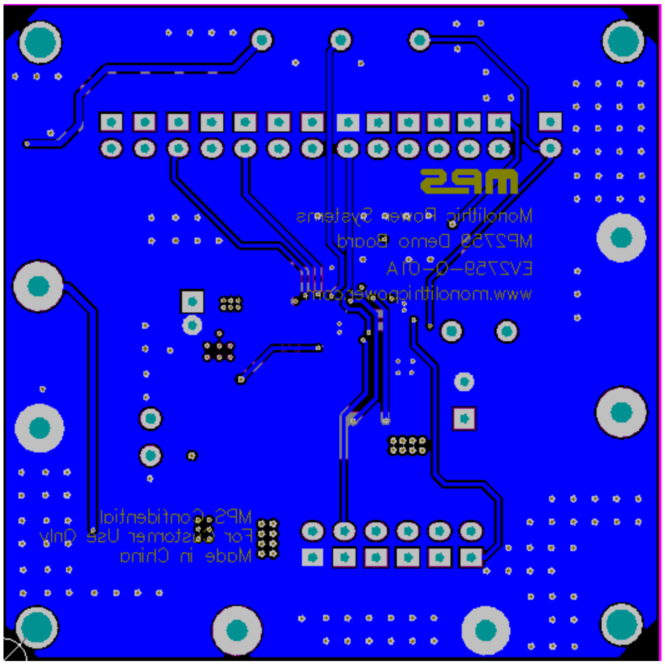


Figure 8: Bottom Layer

4 Test Results

The EV2759-Q-01A was used to test whether the charging current was being adjusted in real time.

To adjust the charging current with an MCU, an auxiliary circuit must be added to the evaluation board (see Figure 9).

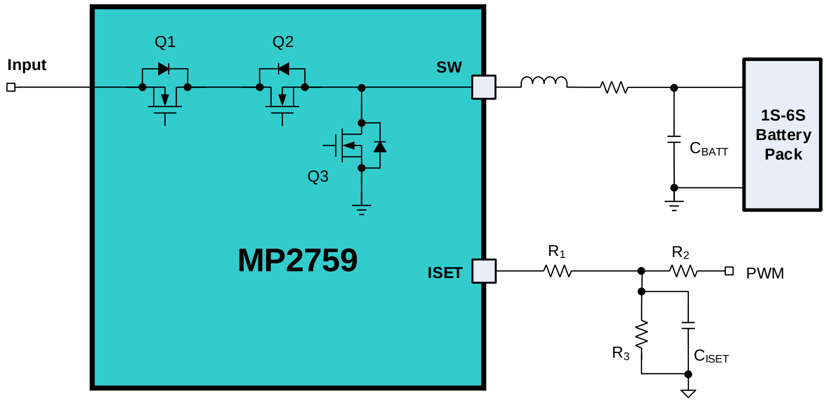


Figure 9: Auxiliary Circuit to Adjust the Charging Current in Real Time

Set the following parameters:

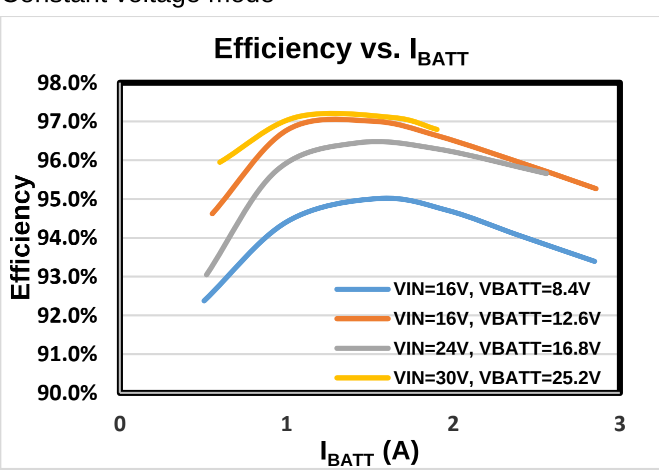
- R_1 = 20kΩ
- R_2 = 33kΩ
- R_3 = 27kΩ
- C_{ISET} = 1µF
- V_{M_PWM} = 3.3V
- f_{PWM} = 2kHz

After setting the parameters, it is possible to adjust the charging current between 0A and 2.7A in real time, as long as the PWM duty cycle is between 0% and 82%.

4.1 Efficiency

L = 10µH/35mΩ, f_{SW} = 700kHz, R_{SNS} = 20mΩ, and T_A = 25°C.

Figure 10: Efficiency vs. Charge Current
Constant voltage mode



4.2 Time Domain Waveforms

L = 10μH/35mΩ, f_{SW} = 700kHz, R_{SNS} = 20mΩ, and T_A = 25°C.

Figure 11: Battery Charge Curve
V_{IN} = 24V, 3-cell, V_{BATT_REG} =4.2V, I_{CC} = 3A, I_{IN_LIM} = 2A

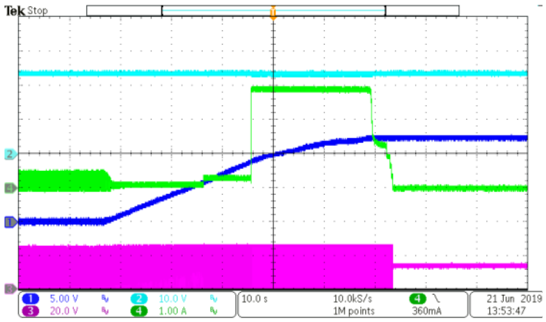


Figure 12: Steady State
V_{IN} = 24V, 4-cell, V_{BATT} = 7V, I_{CC} = 3A, I_{IN_LIM} = 2A, trickle charge mode

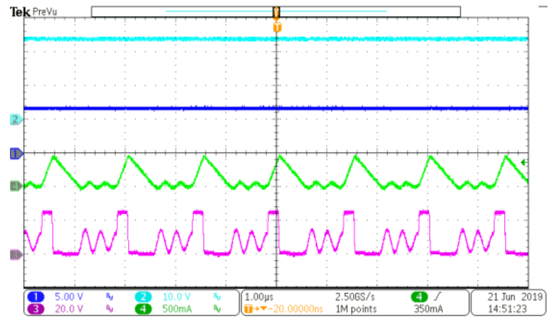


Figure 13: Steady State
V_{IN} = 24V, 4-cell, V_{BATT} = 10V, I_{CC} = 3A, I_{IN_LIM} = 2A, pre-charge mode

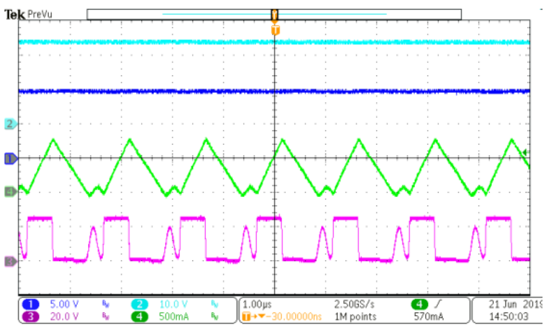


Figure 14: Steady State
V_{IN} = 24V, 4-cell, V_{BATT} = 10V, I_{CC} = 3A, I_{IN_LIM} = 2A, constant current charge mode

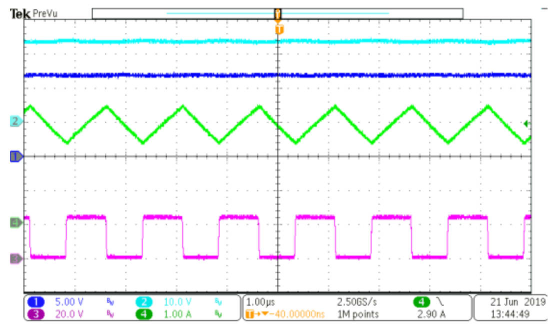


Figure 15: Steady State
V_{IN} = 24V, 4-cell, V_{BATT} = 16.8V, I_{CC} = 3A, I_{IN_LIM} = 2A, constant voltage charge mode

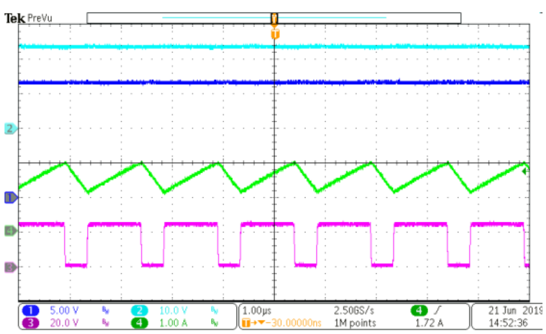


Figure 16: Start-Up
V_{IN} = 18V, 2-cell, V_{BATT} = 8V, I_{CC} = 2A, I_{IN_LIM} = 2A, constant current charge mode

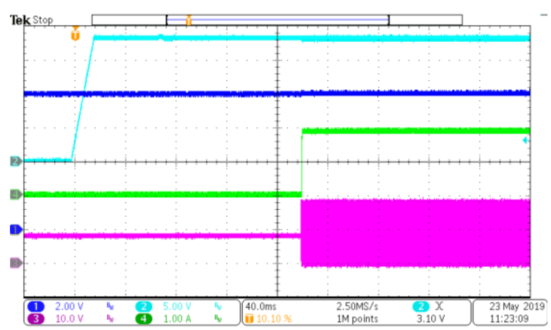


Figure 17: Shutdown

V_{IN} = 18V, 2-cell, V_{BATT} = 8V, I_{CC} = 2A,
I_{IN_LIM} = 2A, constant current charge mode

C2: V_{IN} 5V/div.
C4: I_{BATT} 1A/div.
C1: V_{BATT} 2V/div.
C3: V_{SW} 10V/div.

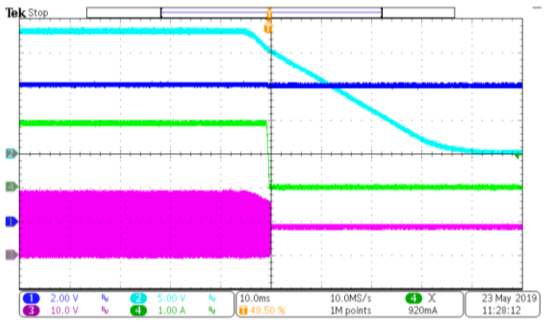


Figure 18: Start-Up

V_{IN} = 18V, 2-cell, V_{BATT} = 8V, I_{CC} = 2A,
I_{IN_LIM} = 1A, I_{SYS} = 0.9A, power path operation

C2: V_{IN} 10V/div.
C1: V_{SYS} 10V/div.
C4: I_{BATT} 0.5A/div.
C3: V_{SW} 20V/div.

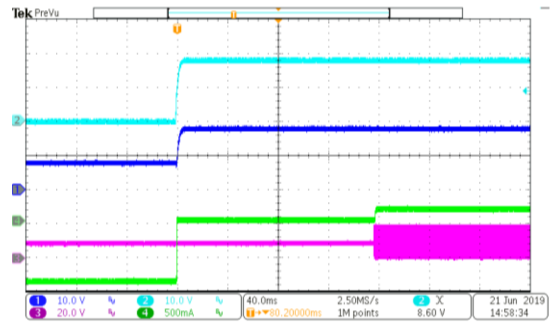


Figure 19: Shutdown

V_{IN} = 18V, 2-cell, V_{BATT} = 8V, I_{CC} = 2A,
I_{IN_LIM} = 1A, I_{SYS} = 0.9A, power path operation

C2: V_{IN} 10V/div.
C1: V_{SYS} 10V/div.
C4: I_{BATT} 0.5A/div.
C3: V_{SW} 20V/div.

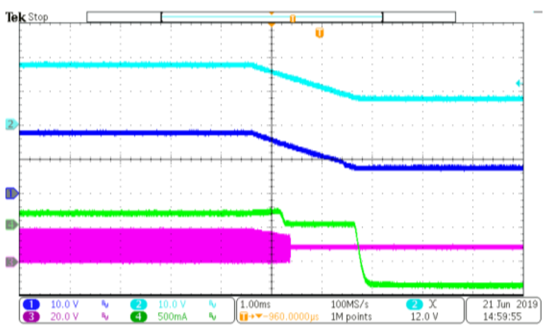


Figure 20: Start-Up, Adjusting Charging Current in Real Time

V_{IN} = 16V, V_{BATT} = 12V, I_{IN_LIM} = 3A,
V_{M_PWM} = 3.3V, f_{PWM} = 2kHz, duty = 50%

C1: V_{IN} 10V/div.
C2: Disable 2V/div.
C3: V_{PWM} 2V/div.
C4: I_{BATT} 1A/div.

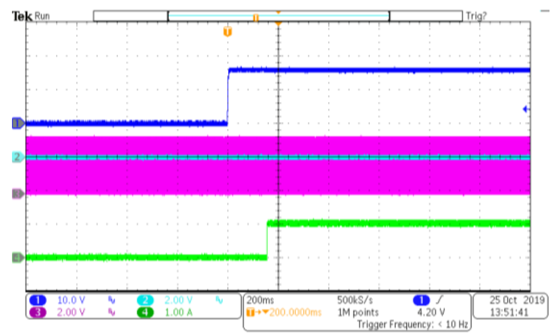


Figure 21: Charge Enable, Adjusting Charging Current in Real Time

V_{IN} = 16V, V_{BATT} = 12V, I_{IN_LIM} = 3A,
V_{M_PWM} = 3.3V, f_{PWM} = 2kHz, duty = 50%

C1: V_{IN} 10V/div.
C2: Disable 2V/div.
C3: V_{PWM} 2V/div.
C4: I_{BATT} 1A/div.

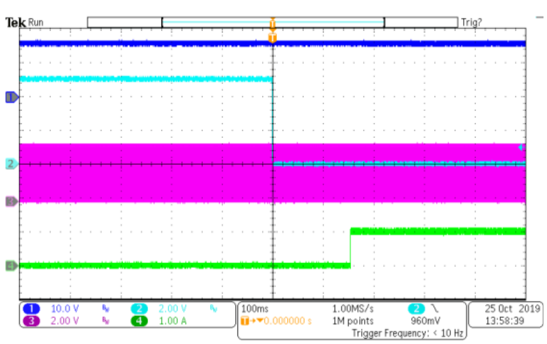


Figure 22: Charge Disable, Charge Current Real-time Adjustment

V_{IN} = 16V, V_{BATT} = 12V, I_{IN_LIM} = 3A,
V_{M_PWM} = 3.3V, f_{PWM} = 2kHz, duty = 50%

C1: V_{IN} 10V/div.
C2: Disable 2V/div.
C3: V_{PWM} 2V/div.
C4: I_{BATT} 1A/div.

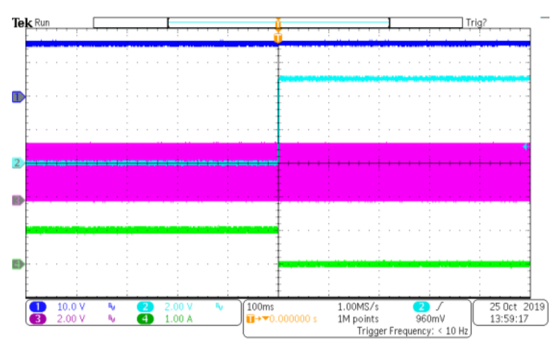


Figure 23: Charging Current Transition (2.4A to 0.5A)
V_{IN} = 16V, V_{BATT} = 12V, I_{IN_LIM} = 3A,
V_{M_PWM} = 3.3V, f_{PWM} = 2kHz, duty = 10% to 65%

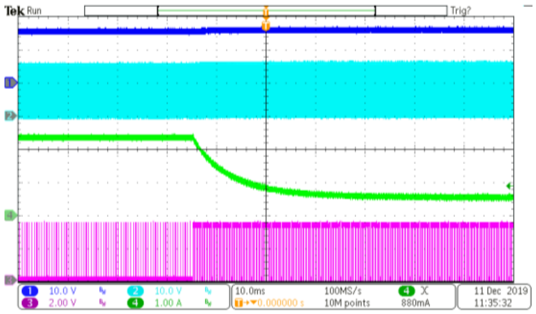


Figure 24: Charging Current Transition (0.5A to 2.4A)
V_{IN} = 16V, V_{BATT} = 12V, I_{IN_LIM} = 3A,
V_{M_PWM} = 3.3V, f_{PWM} = 2kHz, duty = 65% to 10%

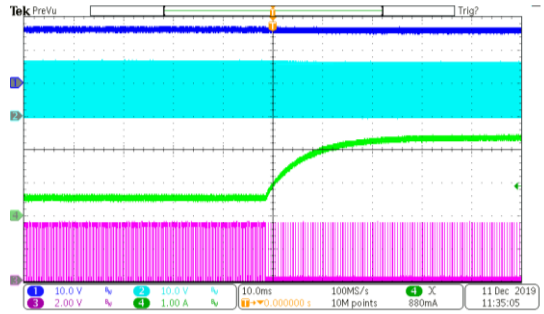


Figure 25: V_{IN_LIM} Loop Control
V_{IN} = 24V/1A, 3-cell, V_{BATT} = 10V, I_{CC} = 3A,
I_{IN_LIM} = 2A, V_{IN_LIM} = 15V

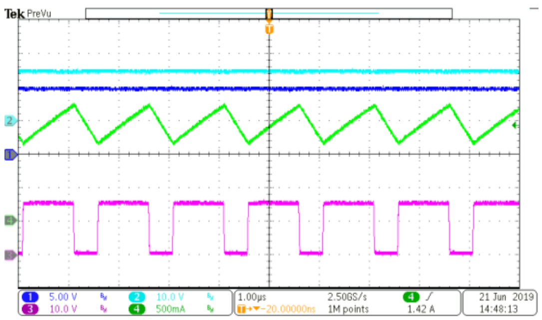
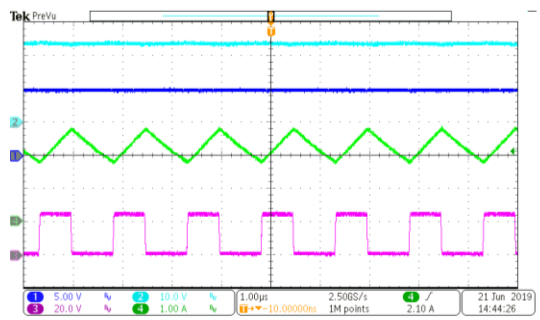


Figure 26: I_{IN_LIM} Loop Control
V_{IN} = 24V, 3-cell, V_{BATT} = 10V, I_{CC} = 3A,
I_{IN_LIM} = 1A



4.3 Thermal Measurements

L = 10μH/35mΩ, R_{SNS} = 20mΩ, f_{SW} = 700kHz, T_A = 25°C, and burns in 20 minutes. Board information: 63.5mmx63.5mm, 4-layer, 1oz/layer.

Figure 27: Thermal Image
V_{IN} = 36V, V_{BATT} = 24V, I_{CC} = 2A,
T_{RISE} = 67.3°C to 25°C = 42.3°C

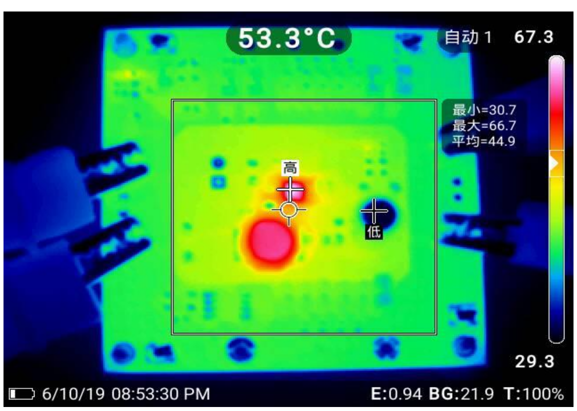
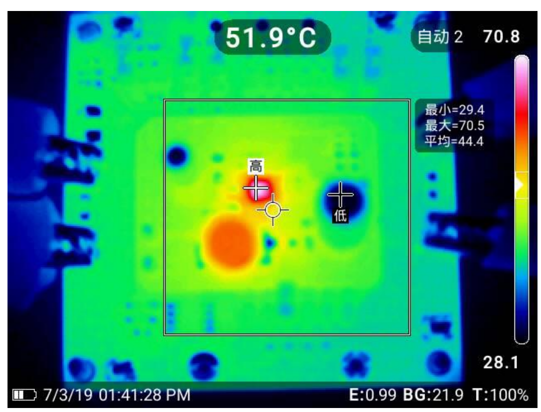


Figure 28: Thermal Image
V_{IN} = 16V, V_{BATT} = 12V, I_{CC} = 3A,
T_{RISE} = 70.8°C to 25°C = 45.8°C



5 Start-Up

5.1 Connectors and Jumpers

The EV2759-Q-01A is designed for the MP2759, a highly integrated switching charger for 1-cell to 6-cell Li-ion and Li-Polymer batteries that are connected in series. This board's layout accommodates most commonly used capacitors. The addition of auxiliary circuits allows the charging current to be adjusted in real time via a PWM signal from an MCU (see Figure 9 on page 12).

Table 5 lists the connectors.

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.
TP5/BATT	Connect to the battery pack's positive terminal.
TP4/GND	Connect to the battery pack's negative terminal.
TP3/SYS	Connect to the system load's positive terminal.
TP6/GND	Connect to the system load's negative terminal.
TP7/SW	Test point for the switching node.
TP10/PMID	Test point for PMID.
DISABLE, VCC, NTC, TP8/ACOK, TP9/STAT	Test connection for related signals.
TP11, TP12, TP13, TP14 / GND	Test point for ground.

1. Connect the system load to the SYS and GND connectors. Ensure that the load's positive and negative terminals are connected correctly. Ensure that the maximum system load current does not exceed the input source capacity. If the system load can exceed the input source's output current limit, use a Schottky diode with appropriate current capacity to bypass the Q1 body diode.
2. Connect the battery pack to the BATT and GND connectors. Ensure that the battery's positive and negative terminals are connected correctly.

   If using a battery emulator, preset the battery emulator to the correct voltage. Turn the emulator off, connect the emulator to BATT and GND, then turn the emulator's output on.
3. Preset the input power source to its correct voltage, then turn the power source off. Connect the power source to VIN and GND, then turn the power source on. The EVB should start charging.
4. Ensure that the NTC jumper has been connected to avoid triggering an NTC fault.
5. To modify the charging parameters, configure the EVB using the jumpers.

Table 6 lists the adjustable parameters.

Table 6: Adjustable Parameters

Adjustable Parameter	Value	Units
Charge current	0 to 3, adjustable with an MCU	A
Input current limit	1, 1.5, or 2	A
Cell numbers	1, 2, 3, 4, 5, or 6	N/A
Battery regulation voltage (each cell)	3.6, 4.0, 4.15, 4.2, 4.35, or 4.4	V
Minimum input voltage limit	10, 15, 22, or 28	V

Table 7 lists the jumper connections.

Table 7: Jumpers

Jumpers	Description	Configurations	Default
JP1, JP2, JP3, JP4, JP5, JP6	Selects the battery regulation voltage for each cell	3.6V, 4.0V, 4.15V, 4.2V, 4.35V, or 4.4V	4.2V
JP7, JP8, JP9, JP10, JP11, JP12	Selects the battery cell number	1 cell, 2 cells, 3 cells, 4 cells, 5 cells, or 6 cells	3 cells
JP13	NTC divider	Connect to NTC pin (pull up to VCC) or voltage divider	NTC divider
JP14, JP15, JP16	Selects the minimum input voltage limit	10V, 15V, 22V, or 28V	10V
JP17, JP18	Selects the input current limit	1A, 1.5A, or 2A	2A

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REVISION HISTORY

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