



## 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

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**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.

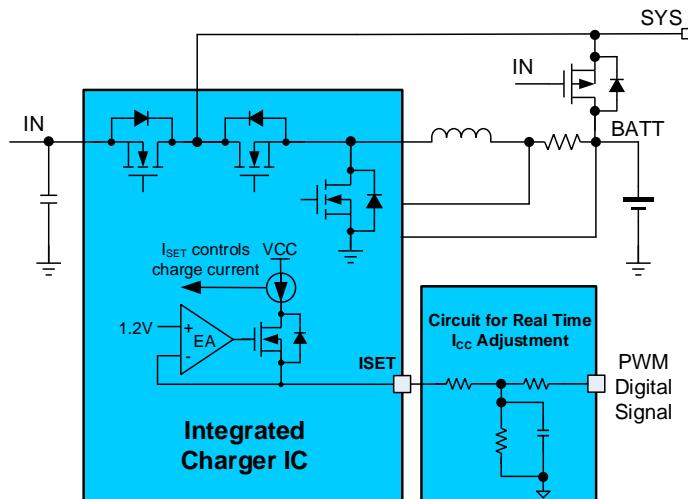


Figure 1: Block Diagram

### 2.2 Related Solutions

This reference design is based on the following MPS solutions:

Table 1: System Specifications

MPS Integrated Circuit	Description
<a href="#">MP2759</a>	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.

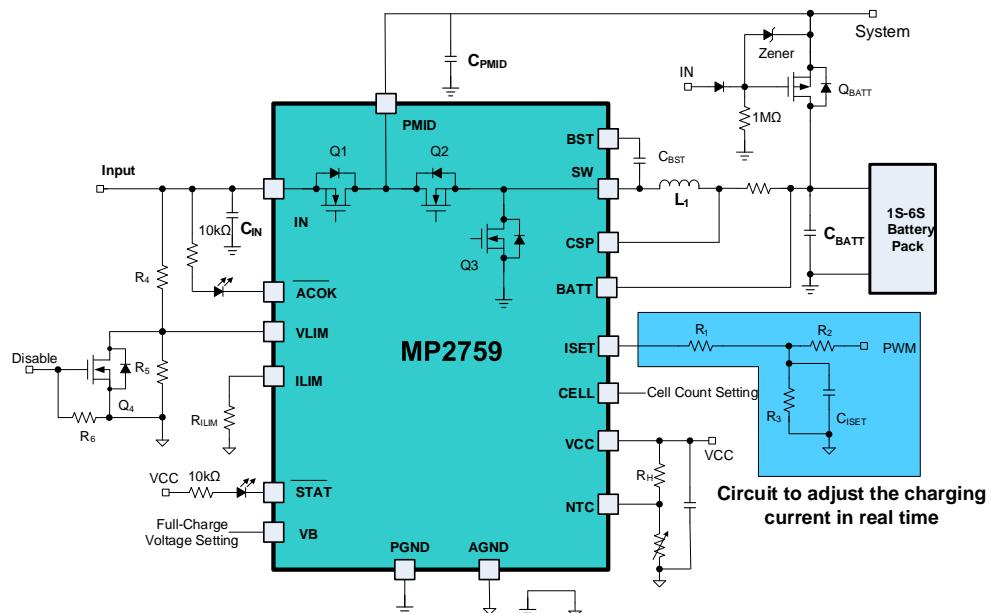


Figure 2: Application Circuit

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.

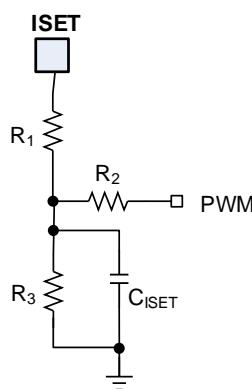


Figure 3: Equivalent  $R_{ISET}$  Circuit



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

$$R_{EQ} = \frac{1.2 \times R_1 \times G_{123}}{1.2 \times G_{123} - \left( \frac{DUTY \times V_{M\_PWM}}{R_2} + \frac{1.2}{R_1} \right)} \quad (2)$$

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  $0\Omega$ . When  $R_{EQ}$  falls below  $0\Omega$ ,  $I_{CHG} = 0A$ .

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):

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

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

$$\begin{cases} R_2 // R_3 = 0.5 \times R_1 \\ \frac{MAX\_DUTY \times V_{M\_PWM} - 1.2}{R_2} = \frac{1.2}{R_3} \end{cases} \quad (6)$$

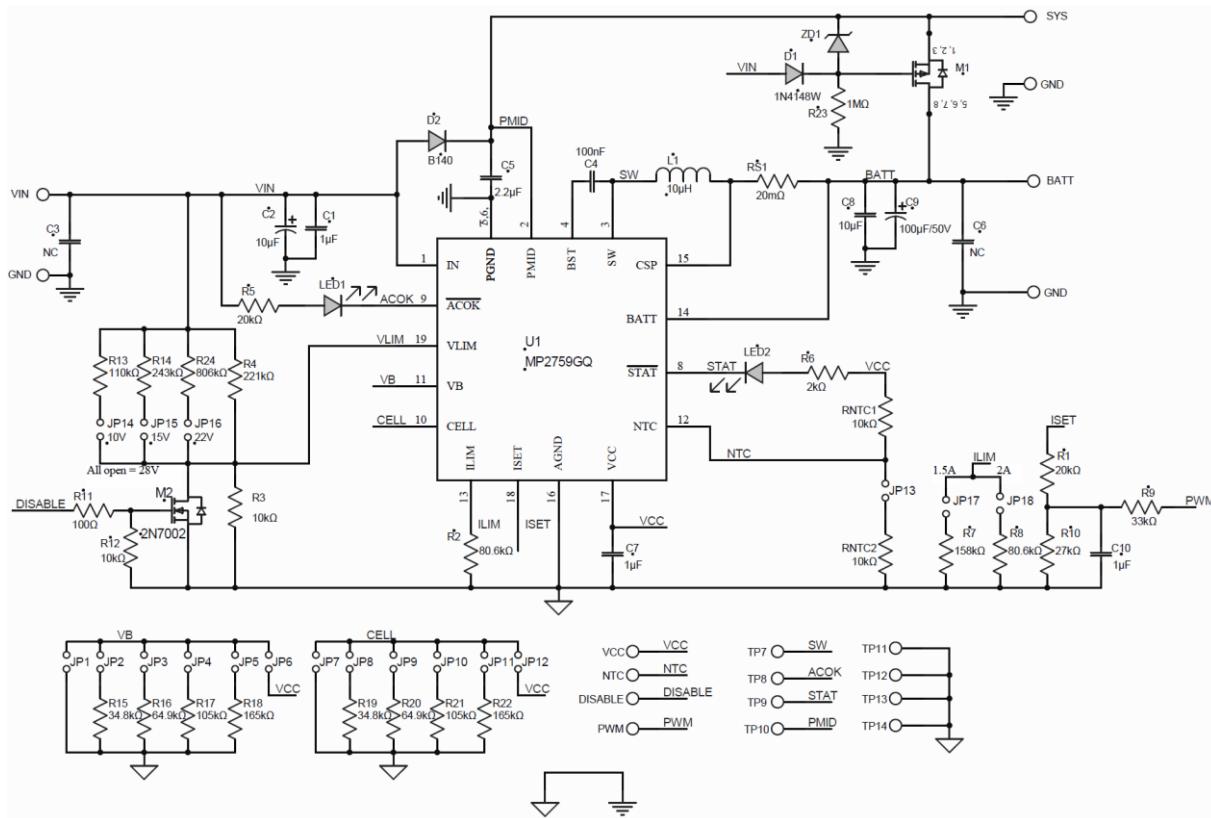
Where  $MAX\_DUTY$  is the maximum PWM duty when the charging current falls to 0A. It is recommended to make  $MAX\_DUTY$  about 80%.

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

$$f_{FILTER} = \frac{1}{2\pi(R_2 // R_3) \times C_{ISET}} \ll f_{PWM} \quad (7)$$

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  $\geq 47\mu F$  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
<b>IN</b>	$\leq 20V$ input	Add a $1\mu F/50V$ ceramic capacitor to the IN pin for adaptor applications. Add a $\geq 47\mu F$ capacitor for solar applications.
	$>20V$ input	Add a $47\mu F/50V$ 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.
<b>BATT</b>	1-cell, 2-cell, 3-cell or 4-cell	Add a $10\mu F/50V$ ceramic capacitor to the BATT pin.
	5-cell or 6-cell	Add a TVS diode or $\geq 47\mu F$ electrolytic capacitor to the BATT pin.
<b>PMID</b>	-	Add a $2.2\mu F/50V$ 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

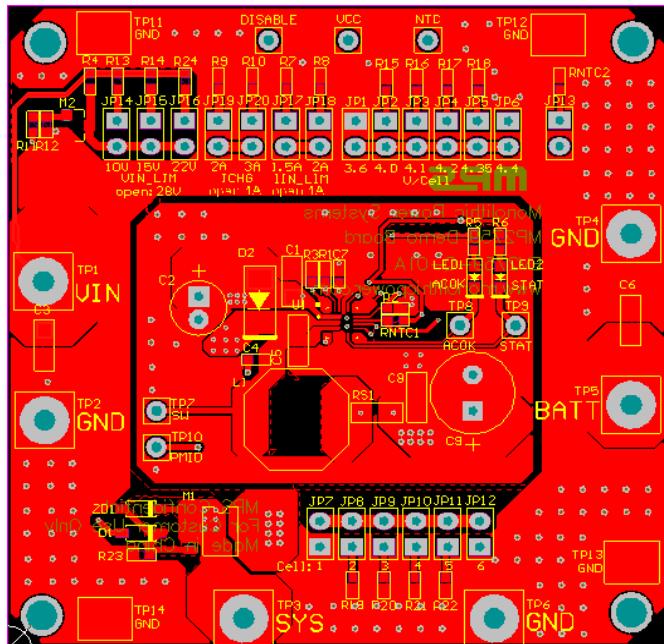
Qty	Ref	Value	Description	Package	Manufacturer	Manufacturer P/N
1	C1	1 $\mu$ F	Ceramic capacitor, 50V, X7R	1206	Wurth	885012208093
1	C2	10 $\mu$ F	Electrolytic capacitor, 50V	DIP	Jianghai	CD287-50V10
1	C4	100nF	Ceramic capacitor, 50V, X7R	0603	muRata	GRM188R71H104KA9 3D
1	C5	2.2 $\mu$ F	Ceramic capacitor, 50V, X7R, 1206;	1206	muRata	GRM31CR71H225KA 88L
2	C7, C10	1 $\mu$ F	Ceramic capacitor, 25V, X7R	0603	TDK	C1608X7R1E105K
1	C8	10 $\mu$ F	Ceramic capacitor, 50V, X5R	1206	muRata	GRM31CR61H106KA 12L
1	C9	100 $\mu$ F	Electrolytic capacitor, 50V, 100 $\mu$ F	DIP	Rubycon	50YXF100MEFC
1	L1	10 $\mu$ H	Inductor, 10 $\mu$ H, 35m, 4A	SMD	Wurth	744066100
1	RS1	20m $\Omega$	Film resistor, 1%	0805	Yageo	RL0805FR-070R02L
1	R1	20k $\Omega$	Film resistor 1%	0603	Yageo	RC0603FR-0720KL
2	R2, R8	80.6k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-0780K6L
3	R3, RNTC1 RNTC2	10k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-0710KL
1	R4	221k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-07221KL
1	R5	20k $\Omega$	Film resistor, 5%	0603	Yageo	CR03T03705NJ20K
1	R6	2k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-072KL
1	R7	158k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-07158KL
1	R9	33k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-0733KL
1	R10	27k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-0727KL
1	R11	100 $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-07100RL
1	R12	10k $\Omega$	Film resistor, 5%	0603	Yageo	RC0603JR-0710K
1	R13	110k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-07110KL
1	R14	243k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-07243KL
2	R15, R19	34.8k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-0734K8L
2	R16, R20	64.9k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-0764K9L
2	R17, R21	105k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-07105KL
2	R18, R22	165k $\Omega$	Film resistor, 1%	0603	Yageo	RC0603FR-07165KL
1	R23	1M $\Omega$	Film resistor, 5%	0603	Yageo	RC0603JR-071ML
1	R24	806k $\Omega$	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	MP2759QQ-0000



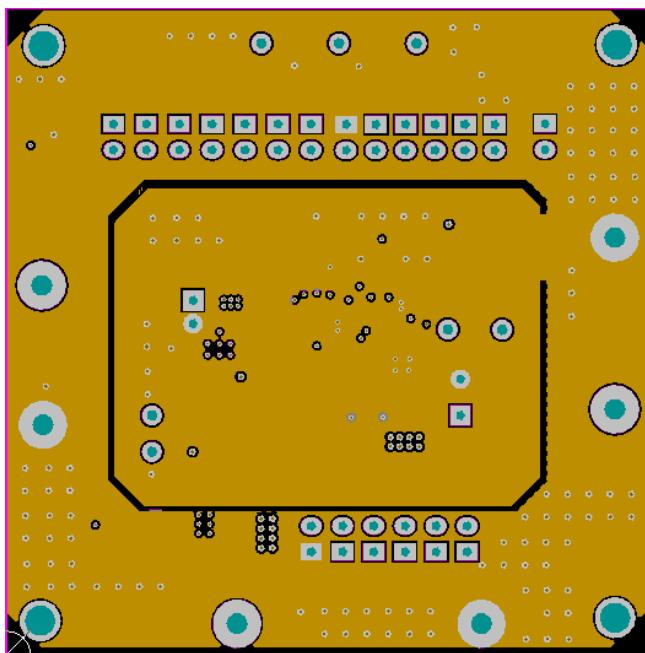
1	M1	60V, 23mΩ	P-channel MOSFET, 60V, 23mΩ	SO-8	Analog Power	AM4417P
1	M2	60V	N-channel MOSFET, 60V	SOT-23	On Semiconductors	2N7002LT1G
1	D1	Diode	Diode;75V;0.15A	SOD-123	Diodes	1N4148W
1	D2	Schottky Diode	Schottky diode;40V;1A	SMA	Diodes	B140
1	ZD1	Zener Diode	Zener diode, 11V, 5mA/50mW	SOD-123	Diodes	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, DISAB LE, 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**

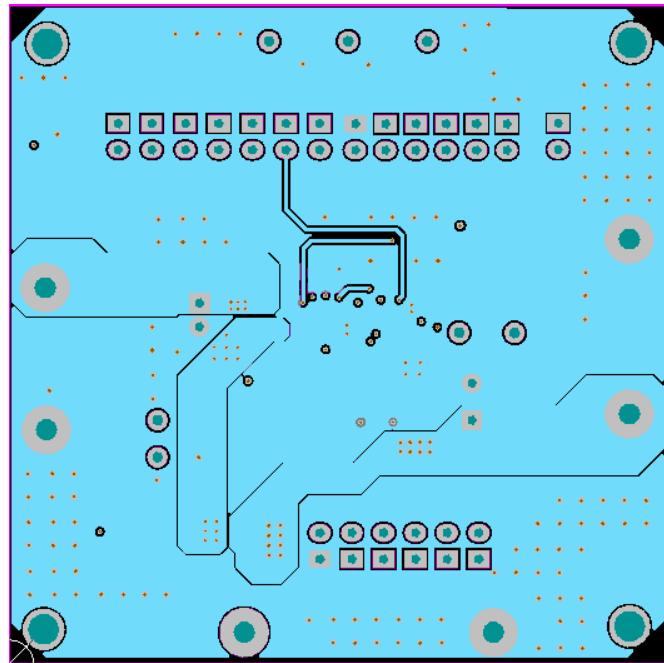


Figure 7: Middle Layer 2

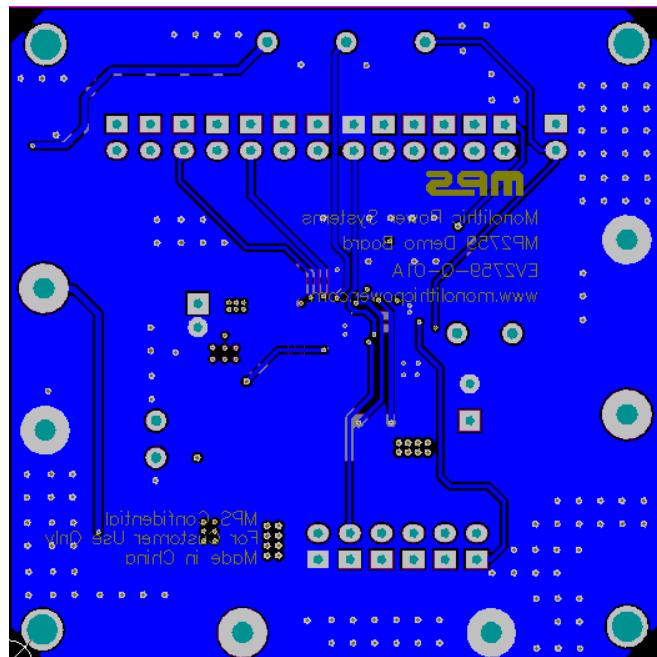
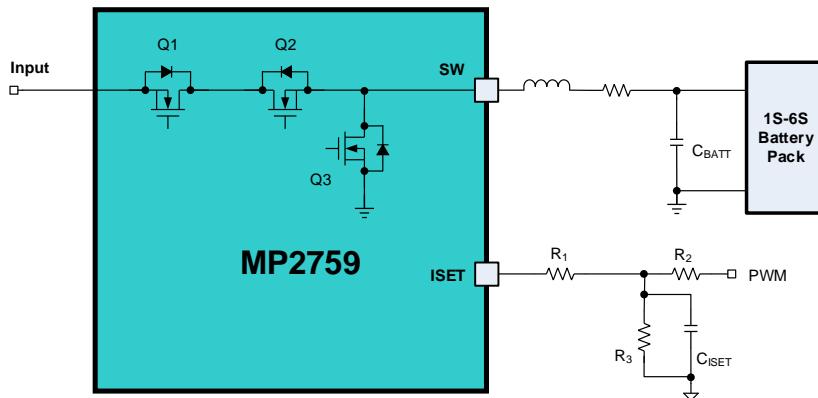


Figure 8: Bottom Layer

## 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:

- $R_1 = 20\text{k}\Omega$
- $R_2 = 33\text{k}\Omega$
- $R_3 = 27\text{k}\Omega$
- $C_{ISET} = 1\mu\text{F}$
- $V_{M\_PWM} = 3.3\text{V}$
- $f_{PWM} = 2\text{kHz}$

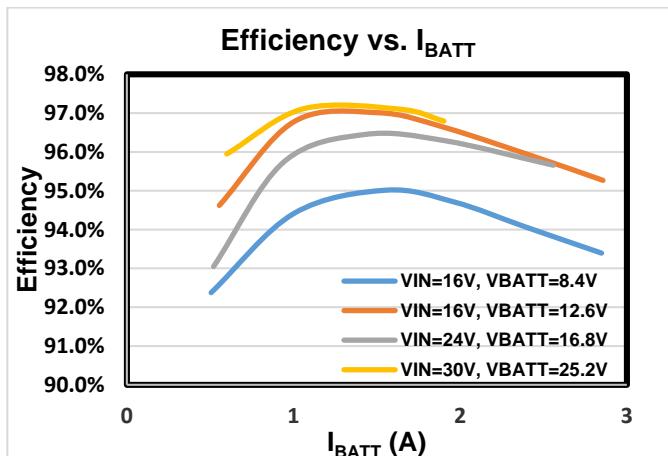
After setting the parameters, it is possible to adjust the charging current between 0A and 2.7A in real time, as long as the PWM duty cycle is between 0% and 82%.

### 4.1 Efficiency

$L = 10\mu\text{H}/35\text{m}\Omega$ ,  $f_{SW} = 700\text{kHz}$ ,  $R_{SNS} = 20\text{m}\Omega$ , and  $T_A = 25^\circ\text{C}$ .

**Figure 10: Efficiency vs. Charge Current**

Constant voltage mode





## 4.2 Time Domain Waveforms

$L = 10\mu H/35m\Omega$ ,  $f_{SW} = 700kHz$ ,  $R_{SNS} = 20m\Omega$ , and  $T_A = 25^\circ C$ .

Figure 11: Battery Charge Curve

$V_{IN} = 24V$ , 3-cell,  $V_{BATT\_REG} = 4.2V$ ,  $I_{CC} = 3A$ ,  
 $I_{IN\_LIM} = 2A$

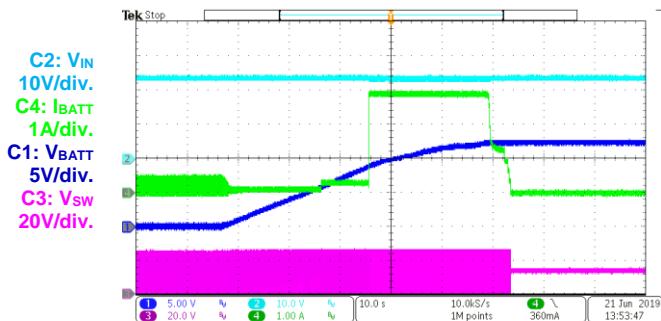


Figure 13: Steady State

$V_{IN} = 24V$ , 4-cell,  $V_{BATT} = 10V$ ,  $I_{CC} = 3A$ ,  
 $I_{IN\_LIM} = 2A$ , pre-charge mode

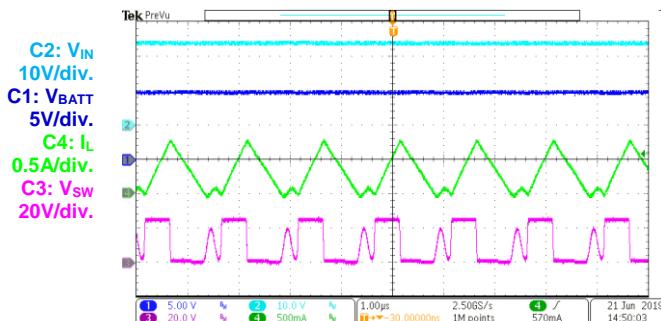


Figure 15: Steady State

$V_{IN} = 24V$ , 4-cell,  $V_{BATT} = 16.8V$ ,  $I_{CC} = 3A$ ,  
 $I_{IN\_LIM} = 2A$ , constant voltage charge mode

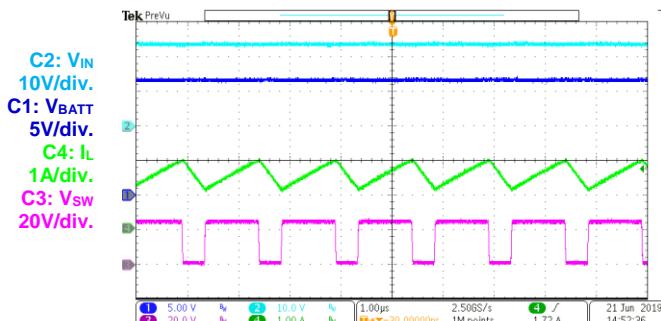


Figure 12: Steady State

$V_{IN} = 24V$ , 4-cell,  $V_{BATT} = 7V$ ,  $I_{CC} = 3A$ ,  
 $I_{IN\_LIM} = 2A$ , trickle charge mode

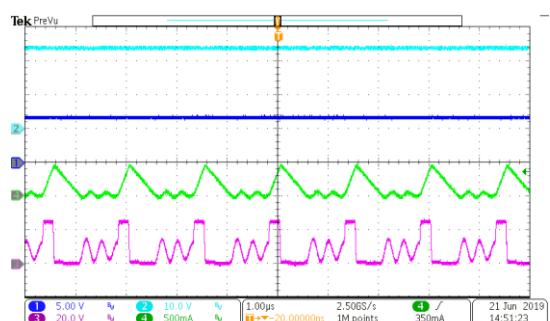


Figure 14: Steady State

$V_{IN} = 24V$ , 4-cell,  $V_{BATT} = 10V$ ,  $I_{CC} = 3A$ ,  
 $I_{IN\_LIM} = 2A$ , constant current charge mode

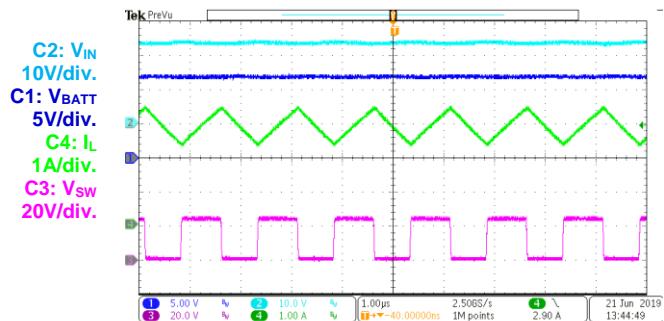
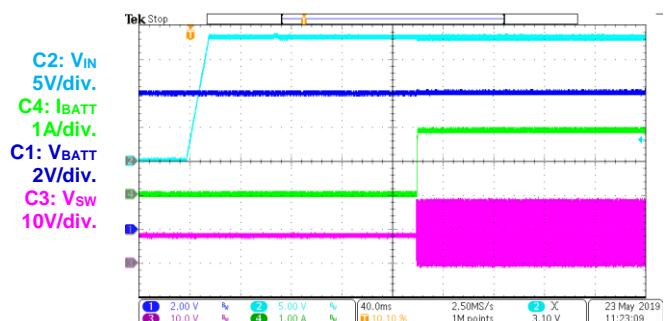


Figure 16: Start-Up

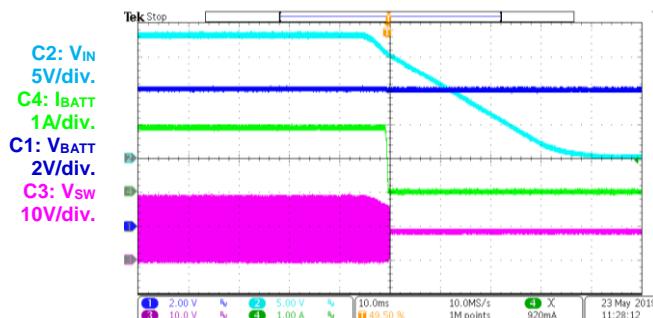
$V_{IN} = 18V$ , 2-cell,  $V_{BATT} = 8V$ ,  $I_{CC} = 2A$ ,  
 $I_{IN\_LIM} = 2A$ , constant current charge mode





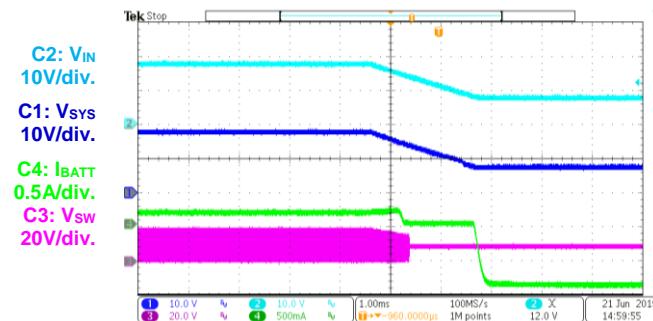
**Figure 17: Shutdown**

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



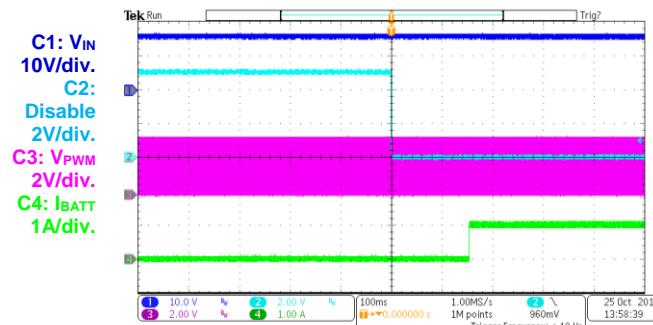
**Figure 19: Shutdown**

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



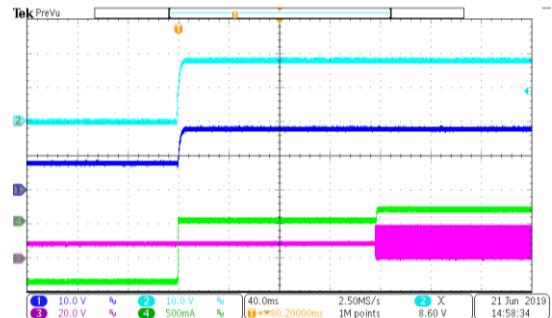
**Figure 21: Charge Enable, Adjusting Charging Current in Real Time**

$V_{IN} = 16V$ ,  $V_{BATT} = 12V$ ,  $I_{IN\_LIM} = 3A$ ,  
 $V_{M\_PWM} = 3.3V$ ,  $f_{PWM} = 2kHz$ , duty = 50%



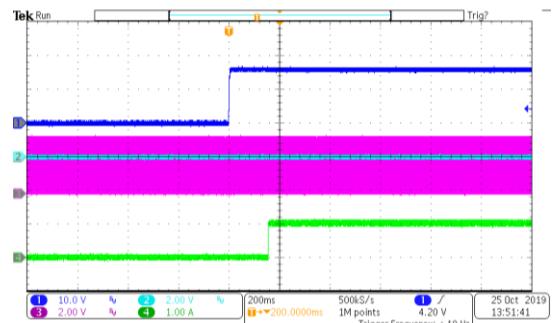
**Figure 18: Start-Up**

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



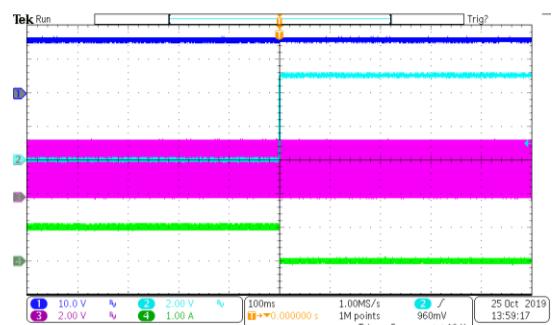
**Figure 20: Start-Up, Adjusting Charging Current in Real Time**

$V_{IN} = 16V$ ,  $V_{BATT} = 12V$ ,  $I_{IN\_LIM} = 3A$ ,  
 $V_{M\_PWM} = 3.3V$ ,  $f_{PWM} = 2kHz$ , duty = 50%



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

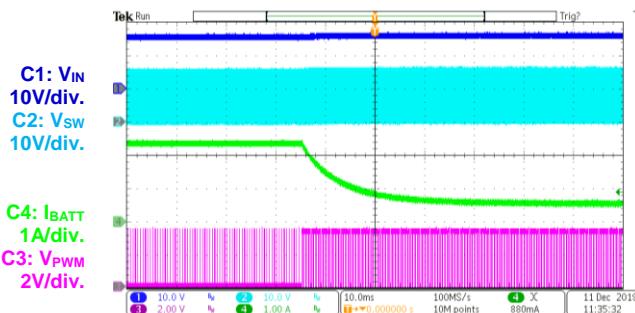
$V_{IN} = 16V$ ,  $V_{BATT} = 12V$ ,  $I_{IN\_LIM} = 3A$ ,  
 $V_{M\_PWM} = 3.3V$ ,  $f_{PWM} = 2kHz$ , duty = 50%





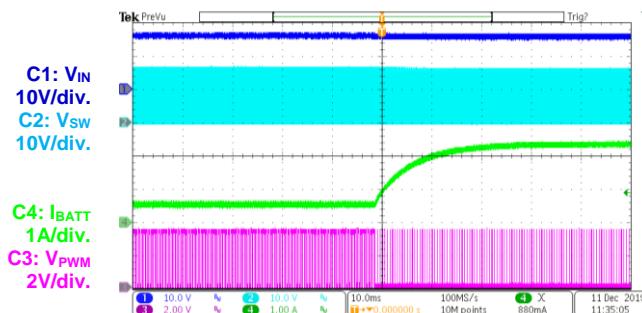
**Figure 23: Charging Current Transition (2.4A to 0.5A)**

$V_{IN} = 16V$ ,  $V_{BATT} = 12V$ ,  $I_{IN\_LIM} = 3A$ ,  
 $V_{M\_PWM} = 3.3V$ ,  $f_{PWM} = 2kHz$ , duty = 10% to 65%



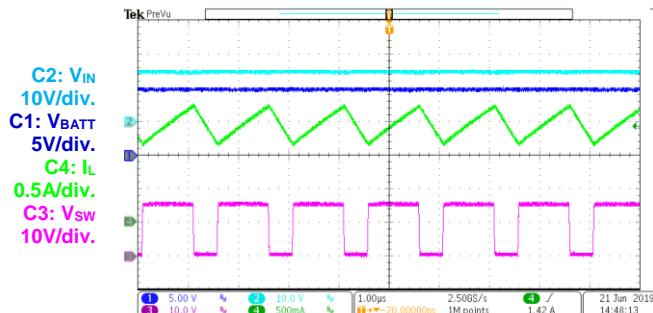
**Figure 24: Charging Current Transition (0.5A to 2.4A)**

$V_{IN} = 16V$ ,  $V_{BATT} = 12V$ ,  $I_{IN\_LIM} = 3A$ ,  
 $V_{M\_PWM} = 3.3V$ ,  $f_{PWM} = 2kHz$ , duty = 65% to 10%



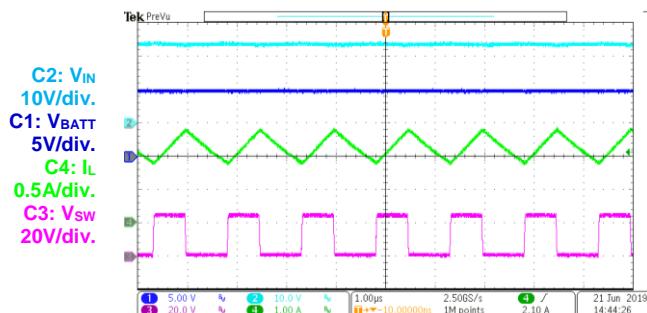
**Figure 25:  $V_{IN\_LIM}$  Loop Control**

$V_{IN} = 24V/1A$ , 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,  $V_{BATT} = 10V$ ,  $I_{CC} = 3A$ ,  
 $I_{IN\_LIM} = 1A$

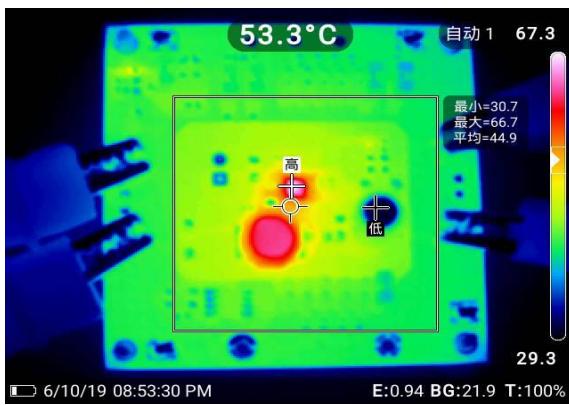


#### 4.3 Thermal Measurements

$L = 10\mu H/35m\Omega$ ,  $R_{SNS} = 20m\Omega$ ,  $f_{SW} = 700kHz$ ,  $T_A = 25^\circ C$ , and burns in 20 minutes. Board information: 63.5mmx63.5mm, 4-layer, 1oz/layer.

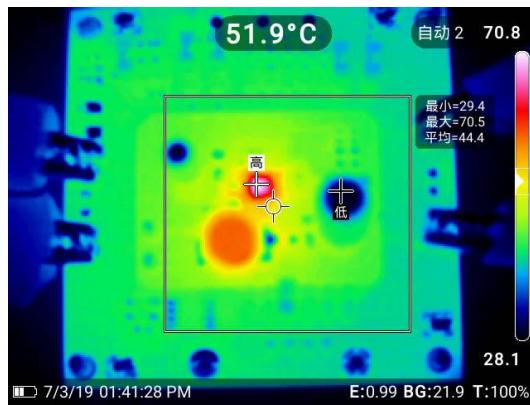
**Figure 27: Thermal Image**

$V_{IN} = 36V$ ,  $V_{BATT} = 24V$ ,  $I_{CC} = 2A$ ,  
 $T_{RISE} = 67.3^\circ C$  to  $25^\circ C = 42.3^\circ C$



**Figure 28: Thermal Image**

$V_{IN} = 16V$ ,  $V_{BATT} = 12V$ ,  $I_{CC} = 3A$ ,  
 $T_{RISE} = 70.8^\circ C$  to  $25^\circ C = 45.8^\circ C$





## 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**

<b>Jumpers</b>	<b>Description</b>	<b>Configurations</b>	<b>Default</b>
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	-