TB3289

# MCP16311/2 and MCP73830 Single-Cell Battery Charger

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## INTRODUCTION

This document describes a Total System Solution (TSS) for a single-cell Li-Ion/Li-Polymer battery charger, consisting of a MCP16311/2 synchronous buck switching regulator, a MCP73830 1A dedicated battery charger and an external voltage drop compensation circuit.

The proposed application circuit offers an effective solution for the fast charging process of Li-Ion/Li-Polymer batteries from a wide input voltage range of 5V to 30V.

## LI-ION BATTERIES

When choosing the battery for a specific application, there are several technical aspects that should be considered:

- Rechargeable Battery vs. Primary
- Rated Capacity vs. Useful Capacity
- Internal Resistance and Pulse Capability
- Temperature Effects and Storage
- Safety and Transportation

The drawbacks of using a poor solution are:

- Reduced Runtime and Low Efficiency
- Uncertain Reliability and Leakage

Li-Ion batteries have gained popularity and are highly utilized due to their advantages compared to other chemistries, as follows:

- High-Energy Density
- Low Self-Discharge Current
- Low Maintenance Required
- High-Power Density
- High-Discharge Current Rate
- High-Charging Current Rate

On the other hand, as previously mentioned, there are also a few downsides related to:

- Aging
- Need for Protection Circuitry to Maintain Voltage and Current within Safe Limits
- Manufacturing Costs
- Transportation Conditions

As a general trend, rechargeable batteries are often used due to their cost effectiveness over their useful life span. A typical charging profile for Li-Ion batteries is depicted in Figure 1.

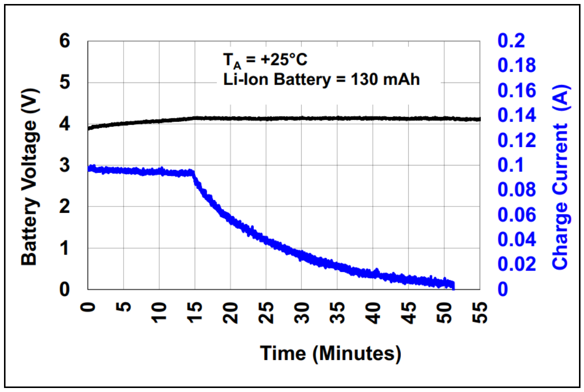


*FIGURE 1: Typical Charging Profile (Li-Ion Battery).*

## DESIGN CONSIDERATIONS

### Input Voltage Range

MCP73830 is a dedicated single cell charger for Li-Ion/Li-Polymer batteries with a 6V maximum input voltage range. In order to extend this range up to 30V, the MCP16311/2 synchronous Buck converter was connected in series with the battery charger. Figure 2 reveals the block diagram, which also includes the external compensation block; the proposed application circuit is detailed in Figure 3.

### Charge Qualification for MCP73830

When power is applied, the input supply must rise 150 mV above the battery voltage, before the MCP73830 device becomes operational. The automatic power-down circuit sets the device in Shutdown mode if the input supply falls within +50 mV of the battery voltage; the automatic circuit is always active. Whenever the input supply is within +50 mV of the voltage at the $V_{BAT}$ pin, the MCP73830 is set into Shutdown mode. For a charge cycle to begin, the automatic power-down exit conditions must be met ($V_{DD} \geq 3.6V$ and $V_{DD} \geq V_{BAT} + 150$ mV) and the charge enable input signal level must be above the input high threshold. In addition to this, the battery voltage should be less than 96.5% of $V_{REG}$. $V_{REG}$ is factory set to a typical value of 4.2V.

 

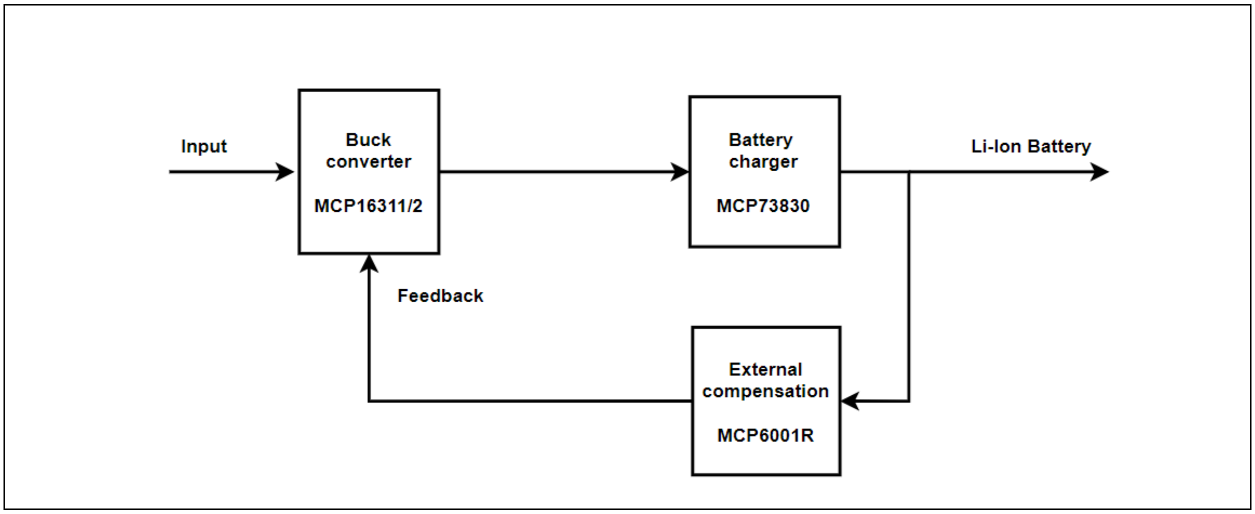


**FIGURE 2:** *MCP16311/2 and MCP73830 Single-Cell Battery Charger Block Diagram.*

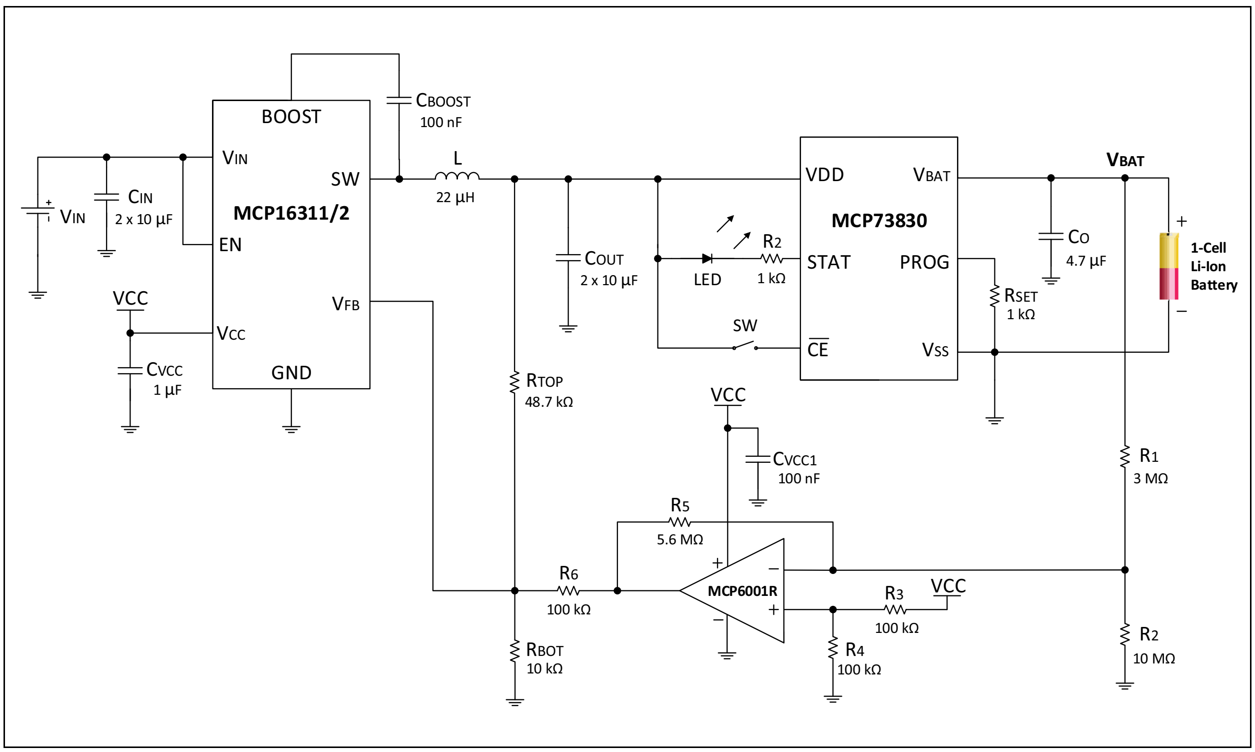


**FIGURE 3:** *MCP16311/2 and MCP73830 Single-Cell Battery Charger Proposed Application Schematic.*

### Preconditioning Mode for MCP73830

If the voltage at the $V_{BAT}$ pin is less than the preconditioning threshold, the MCP73830 device enters Preconditioning mode. The preconditioning threshold is factory set to a 72% x $V_{REG}$ typical value. In this mode of operation, the MCP73830 device supplies 10% of the fast charge current (established with the value of the $R_{SET}$ resistor connected to the PROG pin, as shown in Equation 1) to the battery.

When the voltage at the $V_{BAT}$ pin rises above the preconditioning threshold, the MCP73830 device enters Constant-Current (Fast Charge) mode.

**EQUATION 1: $R_{SET}$ CALCULATION**

$$R_{SET} = \frac{1000}{I_{REG}}$$

Where:

$I_{REG}$ = Fast charge current regulation

For this application:

$I_{REG}$ = 1A

$R_{SET}$ = 1 kΩ

The preconditioning voltage for which the charging current is 10% of $I_{REG}$ can be approximated to a typical value given by Equation 2.

**EQUATION 2: PRECONDITIONING VOLTAGE**

$$V_{PTH} = 72\% \times V_{REG} \cong 3V$$

### Output Voltage Settings

The recommended $V_{DD}$ supply for the MCP73830 device ranges from $V_{REG}$ (typical) + 0.3V to 6V, while the start-up value is 3.75V. Therefore, the output voltage of MCP16311/2 is set by the external resistive divider, according to Equation 3.

**EQUATION 3: RESISTOR DIVIDER CALCULATION**

$$R_{TOP} = R_{BOT} \times \left(\frac{V_{OUT}}{V_{FB}} - 1\right)$$

Where:

$R_{BOT}$ = Bottom resistor

$R_{TOP}$ = Top resistor connected between $V_{DD}$ and $R_{BOT}$

$V_{FB}$ = Feedback voltage

For this application:

$V_{OUT}$ = 4.7V

$V_{FB}$ = 0.8V

$R_{TOP}$ = 48.7 kΩ

$R_{BOT}$ = 10 kΩ

### External Compensation Circuit

The battery charging control output is the drain terminal of an internal P-channel MOSFET. The MCP73830 device provides constant current and voltage regulation to the battery pack by controlling the MOSFET in its linear region. When the battery voltage reaches $V_{PTH}$ and the device exits the preconditioning stage, the charging current goes up to 1A. If the input voltage of the battery charger is constant, then the voltage drop on the internal P-channel MOSFET can be high when $V_{BAT}$ is low. For example, in the application circuit depicted by Figure 3, $V_{OUT}$ is set to 4.7V. Besides this, to calculate the power dissipation, Equation 4 can be used.

**EQUATION 4: DISSIPATED POWER ON THE P-CHANNEL MOSFET**

$$P_{dissipated} = (V_{DDMAX} - V_{BAT}) \times I_{REG}$$

Where:

$V_{DDMAX}$ = Maximum input voltage

$V_{BAT}$ = Battery voltage

$I_{REG}$ = Selected fast charging current

For this particular application, if the battery voltage is around 3.7V, a dissipated power of 1W will result, which cannot be acceptable for certain designs, thus requiring the reduction of the fast charging current.

Therefore, an external compensation circuit has been implemented for this design, in order to maintain a constant voltage drop on the internal P-channel MOSFET and to reduce the dissipated power. An operational amplifier (which is supplied from $V_{CC}$) will inject an error voltage into the FB pin to adjust the output voltage of the MCP16311/2, taking into consideration the battery voltage.

On the negative input of the operational amplifier, the battery voltage is applied through a resistive divider (see Equation 5), while on the positive input, a reference level resulted from $V_{CC}$ is set (see Equation 6).

**EQUATION 5: VOLTAGE LEVEL ON THE NEGATIVE INPUT OF THE OPERATIONAL AMPLIFIER**

$$V_{-} = \frac{R_2}{R_1 + R_2} \times V_{BAT}$$

**EQUATION 6: VOLTAGE LEVEL ON THE POSITIVE INPUT OF THE OPERATIONAL AMPLIFIER**

$$V_{+} = \frac{R_4}{R_3 + R_4} \times V_{CC}$$

The Differential Mode Gain ($G_{DM}$) is given by Equation 7.

**EQUATION 7: DIFFERENTIAL MODE GAIN**

$$G_{DM} = \frac{R_5}{R_1 /\!/ R_2}$$

The Operational Amplifier Common Mode Input Voltage (VCM) is depicted in Equation 8.

**EQUATION 8: COMMON MODE INPUT VOLTAGE**

$$V_{CM} = \frac{V_+ + \frac{V_{CC}}{2}}{2}$$

The Operational Amplifier Total Input Offset Voltage ($V_{OST}$) is detailed in Equation 9.

**EQUATION 9: INPUT OFFSET VOLTAGE**

$$V_{OST} = V_- - V_+$$

The output voltage of the Op Amp is shown in Equation 10.

**EQUATION 10: OP AMP OUTPUT VOLTAGE**

$$V_{OPAMP} = \frac{V_{CC}}{2} + (V_+ - V_-) + V_{OST} \times (1 + G_{DM})$$

The resulted output voltage error is then injected into the FB pin through the R6 resistor and it will maintain approximately 500 mV constant drop on the internal P-channel MOSFET of the battery charger during fast charging.

By using this compensation circuit, the power dissipation is now shown in Equation 11.

**EQUATION 11: DISSIPATED POWER ON THE P-CHANNEL MOSFET AFTER COMPENSATION**

$$P_{dissipated\_comp} = (V_{Drop}) \times I_{REG}$$

Where:

$V_{DROP}$ = Voltage drop on the internal P-channel MOSFET of the battery charger

In this case, the dissipated power is reduced to 500 mW, which represents half of the initial value, but considering that the preconditioning voltage threshold is around 3V, the necessity for putting into practice an external compensation circuit becomes mandatory, especially when the value of the fast charging current is high.

A possible implementation of the proposed application circuit from Figure 3 is revealed in Figure 4.

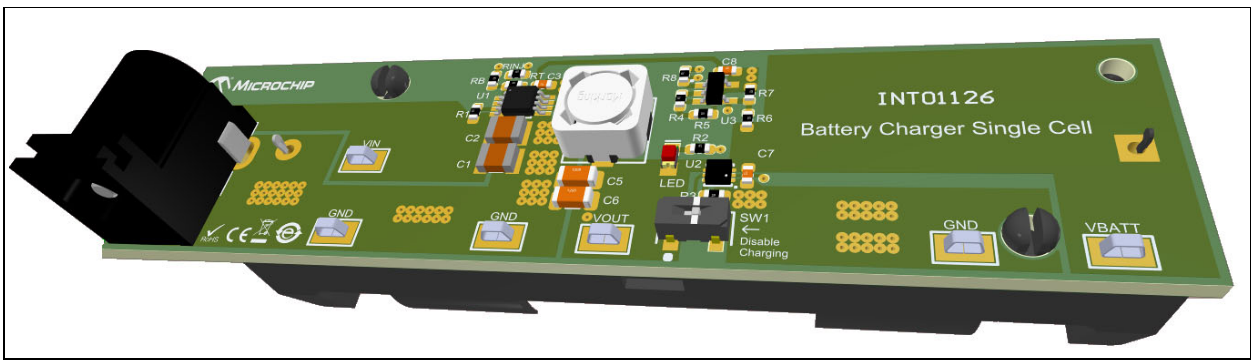


*FIGURE 4: MCP16311/2 Battery Charger Single Cell PCB Implementation.*

## APPLICATION EXAMPLE

- Input Voltage Range: 5V – 30V
- 1A Fast Charging Current
- 100 mA in Preconditioning Mode
- External Voltage Compensation for maintaining constant voltage drop on the internal P-channel MOSFET of the MCP73830 Battery Charger

The voltage drop on the P-channel MOSFET of the battery charger vs. the battery voltage for the application circuit presented in Figure 3 is shown in Figure 5.

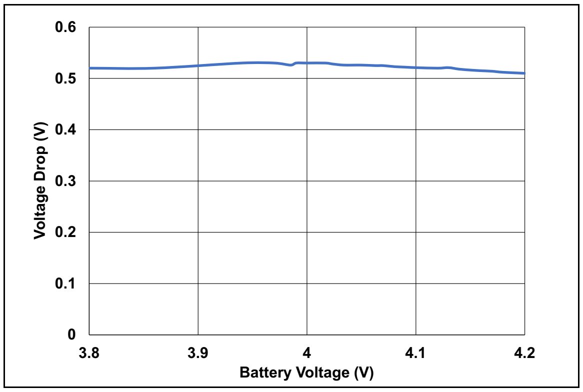


***FIGURE 5:*** *Voltage Drop On The P-channel MOSFET vs. Battery Voltage.*

## CONCLUSION

This technical brief proposes a complete system solution for charging a single-cell Li-Ion/Li-Polymer battery. The usage of a MCP16311/2 connected in series with the battery charger offers the advantage of extended input voltage range, up to 30V. The MCP73830 can deliver a maximum of 1A fast charging current and the addition of the external compensation circuit represents a feature which significantly reduces the dissipated power on the internal P-channel MOSFET of the battery charger.

As a drawback, the components for the external compensation circuit add some complexity and extra cost for this solution, but the benefits are quite significant.

## REFERENCES

- MCP16311/2 Data Sheet – *"30V Input, 1A Output, High-Efficiency, Integrated Synchronous Switch Step-Down Regulator"* (DS20005255)
- MCP73830 Data Sheet – *"Single-Cell Li-Ion/Li-Polymer Battery Charge Management Controllers in 2x2 TDFN"* (DS20005049)
- MCP6001/1R/1U/2/4 Data Sheet – *"1 MHz, Low-Power Op Amp"* (DS20001733)

 

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