

## Lithium-Ion Battery Charger

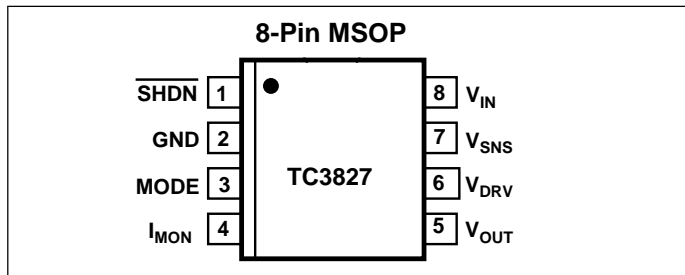
### FEATURES

- Low Power Dissipation
- Shutdown Current: 1 $\mu$ A (Typical)
- Space-Saving 8-Pin MSOP Package
- No Inductor Required
- 1% Overall System Accuracy
- Charge Current Monitor Output
- Charge Status Indicator Output
- Foldback Current Limiting
- -20°C to +85°C Ambient Operating Temperature Range

### TYPICAL APPLICATIONS

- PDAs
- Cradle Chargers
- Li-Ion Battery Chargers
- Desktop Computers
- Hand-Held Instruments
- Cellular Telephones
- Battery Operated Devices
- Self-Charging Battery Packs

### PIN CONFIGURATION



### TYPICAL APPLICATION CIRCUIT

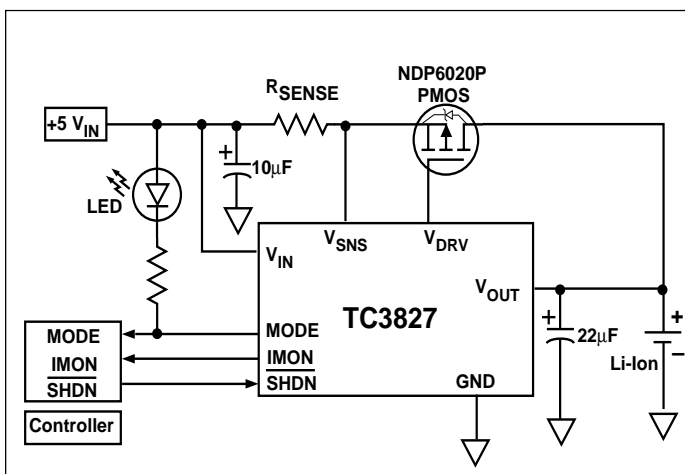


Figure 1. TC3827 Typical Application Circuit

### GENERAL DESCRIPTION

The TC3827 is a battery charger controller for a single cell Li-Ion battery. Using an external PMOS transistor, safe and fast charging of a single Li-Ion cell is accomplished.

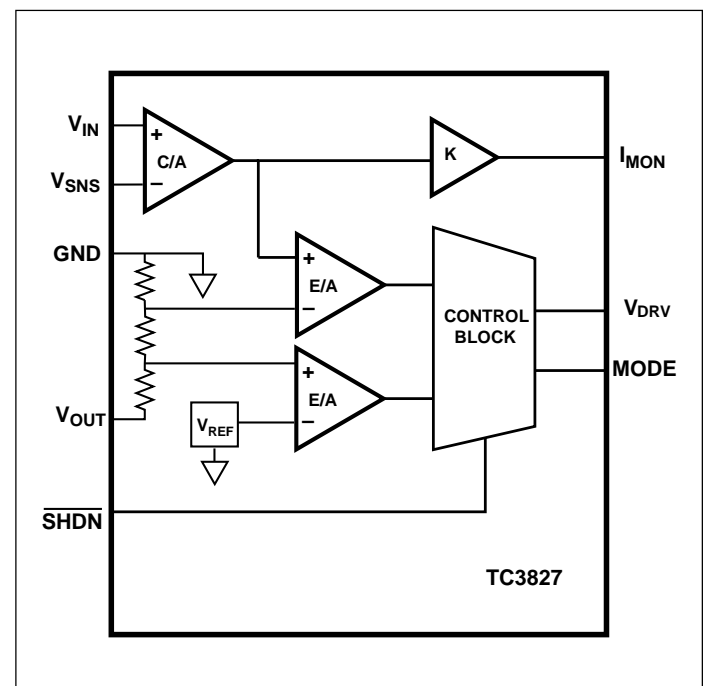
Features include over-current foldback, charge current monitor, and charge status LED indicator output. An overall system accuracy of 1% ensures that the cell capacity is fully utilized without cycle life degradation. An external resistor sets charge current.

The TC3827 operates with an input voltage range from 4.5V to 5.5V. It is specified over the ambient operating temperature range of -20°C to +85°C and is available in a space-saving 8-Pin MSOP.

### ORDERING INFORMATION

Part No.	Package	Temperature Range
TC3827-4.1VUA	8-Pin MSOP	-20°C to +85°C
TC3827-4.2VUA	8-Pin MSOP	-20°C to +85°C

### FUNCTIONAL BLOCK DIAGRAM



# Lithium-Ion Battery Charger

## TC3827

### ABSOLUTE MAXIMUM RATINGS\*

Input Voltage ( $V_{IN}$ ), $V_{OUT}$ , $V_{SNS}$ , MODE, and $I_{MON}$ .....	-0.3V to 6.0V
$\overline{SHDN}$ .....	-0.3V to ( $V_{IN} + 0.3V$ )
8-Pin MSOP (derate 4.1mW/°C above +70°C) .....	330mW
Operating Ambient Temperature Range ..	-20°C to +85°C
Storage Temperature Range .....	-65°C to +150°C
Lead Temperature (Soldering, 10 sec) .....	+300°C
Vapor Phase (60 sec) .....	+210°C
Infrared (15 sec) .....	+220°C
$I_{MON}$ (source) .....	0.375mA

$I_{MODE}$ (sink) .....	20mA
$I_{DRV}$ .....	1mA
ESD Rating .....	2kV

\*Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields. Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specifications is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability.

**ELECTRICAL CHARACTERISTICS:**  $V_{IN} = [V_{REG} + 1V]$ ,  $T_A = -20^\circ\text{C}$  to  $+85^\circ\text{C}$ , unless otherwise noted. Typical values at  $T_A = +25^\circ\text{C}$ ,  $R_{SENSE} = 500\text{m}\Omega$ , Test Circuit Figure 3.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Units
$I_{VIN}$	Power Supply Current	Shutdown Mode, $V_{SHDN} = 0V$ Constant Voltage Mode	— —	1 350	15 560	$\mu\text{A}$
$V_{IN}$	Power Supply Voltage In		4.5	—	5.5	V
<b>Voltage Regulation (Constant Voltage Mode)</b>						
$V_{REG}$	Battery Regulation Volts	3827- 4.2VUA 3827- 4.1VUA	— —	4.2 4.1	— —	V
$V_{OUT}$	Output Voltage Accuracy	$V_{IN} = V_{REG} + 1V$ to 5.5V,	-1	—	+1	%
$LI_{REG}$	Line Regulation	$V_{IN} = 4.5V$ to 5.5V, $I_{OUT} = 75\text{mA}$	-10	—	+10	mV
$LD_{REG}$	Load Regulation	$I_{OUT} = 10\text{mA}$ to 75mA	-1	$\pm 0.2$	+1	mV
$ID_{ISCH}$	Output Reverse Leakage	$V_{IN} = \text{Floating}$ , $V_{OUT} = V_{REG}$	—	1	5	$\mu\text{A}$
<b>MOSFET Gate Drive</b>						
$I_{DRV}$	Gate Drive Current	Sink, Constant Voltage Mode (Note 1) Source, Constant Voltage Mode (Note 1)	— 0.08	— —	1 —	mA
$V_{DRV}$	Gate Drive Min Voltage		—	1.0	—	V
<b>Current Sense Amp</b>						
$V_{GAIN}$	GAIN ( $\Delta V_{GS}/\Delta V_{OUT}$ )		—	100	—	dB
$V_{CS}$	Current Limit Threshold	$(V_{IN} - V_{SNS}) @ I_{MAX}$	40	53	75	mV
$I_{SC}$	Short Circuit Current		—	46	—	mA
K	KFactor		—	0.46	—	A/A
<b>MODE</b>						
$V_{TH}$	Mode Threshold		—	$V_{REG}$	—	V
$V_{OL}$	Mode Low Voltage	$I_{SINK} = 10\text{mA}$ , $V_{OUT} = 3.5V$	—	—	400	mV
$I_{LK}$	Mode Leakage Current	$V_{MODE} = 5.5V$ , $I_O = 0\text{mA}$ , MODE = Constant Voltage	—	—	+1	$\mu\text{A}$
<b>SHDN</b>						
$V_{IH}$	$\overline{SHDN}$ High Threshold		40	—	—	% $V_{DD}$
$V_{IL}$	$\overline{SHDN}$ Low Threshold		—	—	25	% $V_{DD}$
$I_{LK}$	$\overline{SHDN}$ Leakage Current	$V_{SHDN} = 0V$ to 5V	—	—	+1	$\mu\text{A}$
<b><math>I_{MON}</math></b>						
$\frac{\Delta V_{IMON}}{\Delta(V_{IN} - V_{SNS})}$	Current Sense Gain	$V_O = 0V$ to 3.5V, $R_L > 20\text{k}\Omega$	—	26	—	V/V

Notes: 1. Where  $V_{OUT} = 1\%$  from Nominal, continuous current.

# Lithium-Ion Battery Charger

TC3827

## PIN DESCRIPTION

Pin No. 8-Pin MSOP	Symbol	Type	Description
1	$\overline{\text{SHDN}}$	Signal Input	Shutdown Input
2	GND	Power	System Ground
3	MODE	Signal Output	Charge Mode Indicator
4	$I_{\text{MON}}$	Voltage Output	Buffered Copy of Current Sense Resistor Drop
5	$V_{\text{OUT}}$	Voltage Input	Charger DC Output Voltage Sense
6	$V_{\text{DRV}}$	Signal Output	Gate Drive to External MOSFET
7	$V_{\text{SNS}}$	Signal Input	Current Sense Voltage Input
8	$V_{\text{IN}}$	Power	Charger DC Input Voltage

## I/O DESCRIPTION

**SHDN:** When  $\overline{\text{SHDN}}$  is low,  $V_{\text{DRV}}$  is pulled high to  $V_{\text{IN}}$  and the charge is interrupted.

**GND:** Connect to the battery's negative terminal. See Layout Guidelines for information on system grounding.

**$V_{\text{OUT}}$ :** Battery positive terminal and charger regulated output voltage. This pin is connected to the external PMOS drain and directly to the load for optimal regulation.  $V_{\text{OUT}}$  pin draws typically 1 $\mu\text{A}$  from the battery when  $V_{\text{IN}}$  power is removed. Requires a Bypass capacitor.

**MODE:** Charge Status Indicator. Mode is an open-drain, N-channel MOSFET capable of sinking 20mA for an LED status indication of charger in current limited mode. LED is off in current-voltage mode.

**$V_{\text{DRV}}$ :** Gate drive output for the external PMOS pass device.

**$I_{\text{MON}}$ :** Battery Charge current profile. This output is an amplified copy of the voltage drop across the current sense resistor. It can be used as input to an A/D converter to provide the controller with information about the charge current profile.

**$V_{\text{IN}}$ :** Charger power supply input (+6V absolute max.). Bypass to GND with a capacitor.

**$V_{\text{SNS}}$ :** Battery charge current sense voltage feedback. This voltage is developed across a small value precision resistor that is in series with the battery.

## FUNCTIONAL DESCRIPTION

The TC3827 controller only requires a P-channel power MOSFET and two small capacitors to perform as an inexpensive Li-Ion battery charger. The TC3827 controller drives an external PMOS to provide a regulated output current to charge the battery. Initially, current limited charging occurs until a pre-specified battery voltage is measured at the  $V_{\text{OUT}}$  pin. It then switches to constant-voltage mode. During constant-voltage mode the TC3827 works like a linear regulator, holding the output voltage within the specified accuracy. The charger output is sensed at the  $V_{\text{OUT}}$  pin. The charging current follows the foldback characteristic as shown in Figure 2. The sense resistor sets the maximum charging current,  $I_{\text{MAX}}$ . The voltage drop across the current sense resistor is sensed at the  $V_{\text{SNS}}$  input. An amplified copy of this sense voltage is provided as output on the current monitor pin ( $I_{\text{MON}}$ ). When the battery is deeply discharged to a minimum voltage level, or if the battery is shorted, the current sense circuit folds back the charge current to limit the power dissipation of the PMOS. Both the  $V_{\text{IN}}$  and  $V_{\text{OUT}}$  pins

of the IC need a suitable bypass capacitor. The TC3827 also has a logic-level shutdown input,  $\overline{\text{SHDN}}$ , which may be connected to the input voltage to enable the IC. Pulling it "low" or to ground will disable the PMOS drive ( $V_{\text{DRV}}$  pulled up to  $V_{\text{IN}}$  voltage). Also, a charger mode pin (MODE) is provided to drive an optional LED for a visual indication of current limited mode operation. LED will be turned off in constant voltage mode operation.

## TC3827

### APPLICATIONS INFORMATION

A typical Li-Ion cell should be charged at a controlled current until it reaches 4.1V or 4.2V (depending on the type of cell), then charged at this voltage. The TC3827 is designed to offer the maximum integration and function with a small application circuit. The only necessary external components are a PMOS, two small capacitors, and an  $R_{SENSE}$ .

The charge current profile can be monitored using the voltage signal at  $I_{MON}$ . The use of an LED as a status indicator is optional. The application circuit is shown in Figure 1.

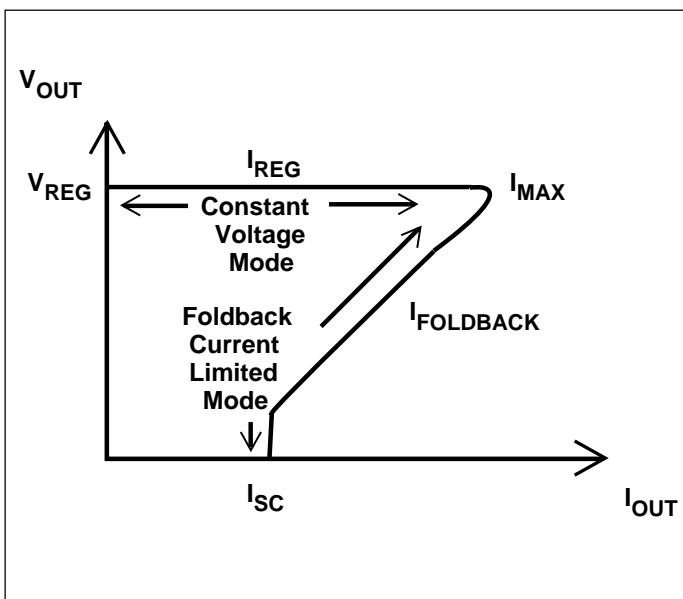


Figure 2. TC3827 Charging Characteristic

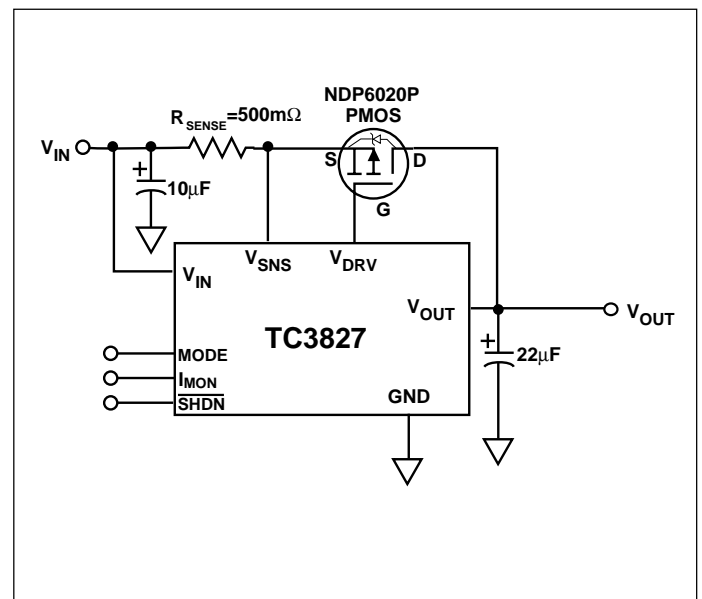


Figure 3. TC3827 Test Circuit

### SELECTING EXTERNAL COMPONENTS

#### Power Supply Input

In most applications, this will be a small “wall cube” switching converter with an output voltage limit range of 5V to 6V.

#### P-Channel Pass Device

The PMOS is used to regulate current from the source into the Li-Ion cell. Specifications to consider when choosing an appropriate PMOS are the minimum drain-source breakdown voltage, the minimum turn-on threshold voltage ( $V_{GSTH}$ ), drain current and power-dissipation capabilities.

#### Bypass Capacitors

Bypass  $V_{IN}$  with a capacitor value of at least 10µF. Bypass  $V_{OUT}$  with a capacitor value of at least 1µF.

### CHARGER MODES DESCRIPTION

#### Initiating a Charge Cycle

The TC3827 initiates a charge upon toggling the shut-down pin high, insertion of the battery or application of an external power source. The TC3827 provides a foldback current limited charge where an external current sense resistor sets  $I_{MAX}$ . The voltage drop across the current sense resistor is applied to the  $V_{IN}$ - $V_{SNS}$  pins and presented to the current limited control-loop. The current loop will protect a deeply discharged (or shorted) battery by folding back the current limited charge, and reduces the power dissipation in PMOS.

#### Current Limited, Constant-voltage Charge Cycle

The TC3827 begins to charge the Li-Ion cell by turning on the external PMOS. The charge continues until the battery voltage rises to the lithium-ion cell voltage of 4.2V or 4.1V (depending on type of cell). As the battery voltage reaches the regulated output voltage, the internal feedback

control loop changes from current limiting to voltage regulation. If an external micro-controller determines battery conditions are unsafe for charge it can toggle the shutdown pin low and interrupt the charge cycle. Otherwise, once the pre-determined cell voltage is reached the TC3827 shifts into a constant-voltage mode (linear regulation) and a variable charge current is applied as required to maintain the battery cell voltage to within 1% accuracy of the cell voltage set-point.

### I<sub>MON</sub> – Charge Current Status

The I<sub>MON</sub> pin provides an output voltage that is proportional to the battery charging current. It is an amplified version of the sense resistor voltage drop that the current loop uses to control the PMOS device. This voltage signal can be applied to the input of an A/D Converter and used by a controller to display information about the state of the battery or charge current profile.

### MODE – Charge Mode Status LED

The MODE pin indicates the battery charging mode. An LED can be connected to the MODE for a visible indicator. Alternatively, a pull-up resistor (typically 100kΩ) from the interfacing logic supply to MODE provides a logic-level output. The MODE pin will toggle LOW and the LED will illuminate when the charger is in the current limited mode. The MODE pin toggles to a high impedance state and the LED will be off during constant-voltage mode charging or if the battery is not connected. The MODE pin toggles at a V<sub>OUT</sub> of V<sub>REG</sub>, typically.

## APPLICATION CIRCUIT DESIGN

Due to the low efficiency of Linear Regulator Charging, the most important factors are thermal design and cost, which is a direct function of the input voltage, output current and thermal impedance between the PMOS and the ambient cooling air. The worst-case situation is when the battery is shorted since the PMOS has to dissipate the maximum power. A tradeoff must be made between the charge current, cost and thermal requirements of the charger. Higher current requires a larger PMOS with more effective heat dissipation leading to a more expensive design. Lowering the charge current reduces cost by lowering the size of the PMOS, possibly allowing a smaller package such as 6-Pin SOT. The following designs consider both options.

### Higher Current Option

The current sense resistor for the circuit shown in Figure 1 is calculated by:  $R_{SENSE} = V_{CS} / I_{MAX}$ .

Where V<sub>CS</sub> is the current limit threshold voltage of 40mV to 75mV, 50mV typical. If I<sub>MAX</sub> = 1A is desired, R<sub>SENSE</sub> = 50mΩ.

### Pre-regulated Input Voltage (5V ± 0%)

For this application, the required θ<sub>JA</sub> thermal impedance is calculated as follows:

if: the PMOS data sheet allows a max junction temperature of T<sub>JMAX</sub> = 150°C,  
then: at 50°C ambient with convection cooling, the maximum allowed junction temperature rise is:

$$T_{JMAX} - T_{AMAX} = 150^{\circ}\text{C} - 50^{\circ}\text{C} = 100^{\circ}\text{C}.$$

$$\theta_{JA} = \Delta T / (I_{Ox} k \times V_{IN}) = 100 / (1 \times 0.46 \times 5.5) = 39.5^{\circ}\text{C/W}$$

This k factor is:  $k = I_{SC} / I_{MAX} \approx 0.46$ .

This thermal impedance can be realized using the transistor shown in Figure 1 when mouted to a heat sink. The θ<sub>SA</sub> or thermal impedance of a suitable heatsink is calculated below:

$$\theta_{SA} \leq (\theta_{JA} - \theta_{JC} - \theta_{CS}) = 39.5 - 2.5 - 0.3 = 36.7^{\circ}\text{C/W}$$

Where the θ<sub>JC</sub>, or junction-to-case thermal impedance is for the PMOS from the PMOS data sheet. A low cost heatsink is Thermalloy type PF430, with a θ<sub>SA</sub> = +25.3°C/W.

## TC3827

### Lower Current Option

#### Preregulated Input Voltage (5V +/- 10%)

If lower charging current is allowed, the  $\Theta_{JA}$  value can be increased, and the system cost decreased. This is accomplished by using a FDC638P PMOS, for example, in a 6-Pin SOT package mounted on a small 1in x 1in area of 2oz Cu on FR-4 board. This provides a convection cooled thermal impedance of  $\Theta_{JA} = +78^{\circ}\text{C}/\text{W}$ . Allowing a maximum FET junction temperature of  $+150^{\circ}\text{C}$ , at  $+50^{\circ}\text{C}$  ambient, with convection cooling the maximum allowed heat rise is:

$$150^{\circ}\text{C} - 50^{\circ}\text{C} = 100^{\circ}\text{C}.$$

The maximum short circuit current,  $I_{SC}$ , is found as:

$$I_{SC} = \Delta T / (\Theta_{JA} \times V_{IN}) = 100 / (78 \times 5.5) = 0.23\text{A}$$

Thus the maximum charging current,  $I_{MAX}$ , is:

$$I_{MAX} = I_{SC} / k = 0.51\text{A}$$

The current sense resistor for this application is then:

$$R_{SENSE} = V_{CS} / I_{MAX} = 0.05 / 0.51 = 98\text{m}\Omega \approx 100\text{m}\Omega$$

### FET Selection

The type and size of the pass transistor is determined by the threshold voltage, input-output voltage differential and load current. The selected PMOS must satisfy the physical and thermal design requirements. To ensure that the maximum  $V_{GS}$  provided by the controller will turn on the FET at worst case conditions, (i.e., temperature and manufacturing tolerances) the maximum available  $V_{GS}$  must be determined. Maximum  $V_{GS}$  is calculated as follows:

$$V_{GSMAX} = V_{IN} - (I_{MAX} \times R_{SENSE}) - V_{DRVMAX}$$

For example:

$$V_{IN} = 5\text{V}, \text{ and } I_{MAX} = 1\text{A},$$

$$V_{GSMAX} = 5\text{V} - (1\text{A} \times 50\text{m}\Omega) - 1\text{V} = 3.95\text{V}$$

The difference between  $V_{IN}$  and  $V_O$  ( $V_{DS}$ ) must exceed the voltage drop due to the sense resistor plus the ON-resistance of the PMOS at the maximum charge current.

$$V_{DS} \leq V_{IN} - V_O - V_{CS} = 5\text{V} - 4.2\text{V} - 0.075\text{V} = 0.725\text{V}$$

The maximum  $R_{DS(ON)}$  required at the available gate drive ( $V_{DR}$ ) and Drain-to-Source voltage ( $V_{DS}$ ) is:

$$R_{DS(ON)} = V_{DS} / I_{MAX} \leq 0.725\text{V} / 1\text{A} = 725\text{m}\Omega$$

The selected PMOS must satisfy these criteria.

### External Capacitors

The TC3827 is stable with or without a battery load, and virtually any good quality output filter capacitors can be used, independent of the capacitor's minimum ESR (Effective Series Resistance) value. The actual value of the capacitor and its associated ESR depends on the  $g_m$  and capacitance of the external PMOS device. A  $22\mu\text{F}$  tantalum or aluminum electrolytic capacitor at the output is sufficient to ensure stability for up to a 10A output current.

### Shutdown Mode

Applying a logic high signal to the  $\overline{\text{SHDN}}$  pin or tying it to the input pin will enable the output. Pulling this pin low or tying it to ground will disable the output. In shutdown mode, the controller's quiescent current is reduced to typically  $1\mu\text{A}$ .

### Short Circuit Protection

The PMOS is protected during short circuit conditions with a foldback type of current limiting that reduces the power dissipation.

### Current Sense Resistor

The current limit sense resistor,  $R_{SENSE}$ , is calculated previously. Proper de-rating is advised to select the power dissipation rating of the resistor. The simplest and cheapest sense resistor for high current applications, is a PCB trace. However, the temperature dependence of the copper trace and the thickness tolerances of the trace must be considered in the design.

Copper's Tempco, in conjunction with the proportional-to-absolute temperature ( $\pm 0.3\%$ ) current limit voltage, can provide an accurate current limit. Alternately, an appropriate sense resistor, such as surface mount sense resistors, available from KRL, can be used.

### PCB Layout Issues

For optimum voltage regulation, place the load as close as possible to the device's  $V_{OUT}$  and GND pins. It is recommended to use dedicated PCB traces to connect the PMOS drain to the positive terminal and  $V_{SS}$  to the negative terminal of the load to avoid voltage drops along the high current carrying PCB traces.

If the PCB layout is used as a heatsink, adding many vias around the power FET helps conduct more heat from the FET to the back-plane of the PCB, thus reducing the maximum FET junction temperature.

## TYPICAL CURVES

**V<sub>OUT</sub> vs I<sub>LOAD</sub> (V<sub>IN</sub>=5.1V)**

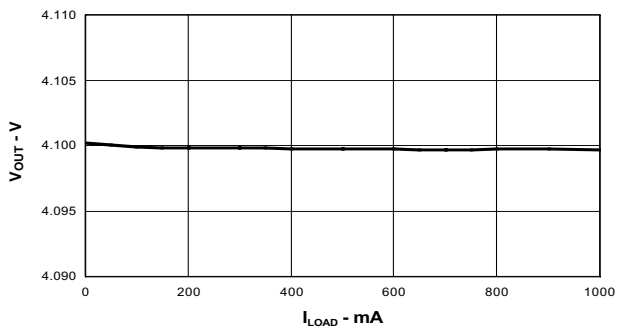


Figure. 4

**V<sub>OUT</sub> vs V<sub>IN</sub> (I<sub>LOAD</sub>=1A)**

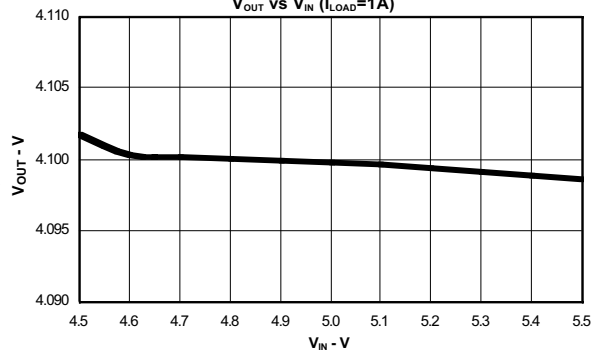


Figure. 5

**V<sub>OUT</sub> vs V<sub>IN</sub> (I<sub>LOAD</sub>=10mA)**

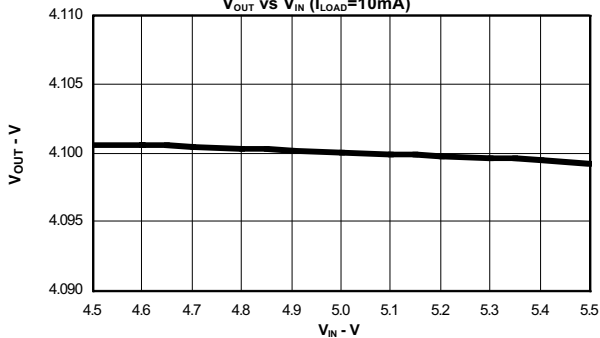


Figure. 6

**I<sub>GND</sub> vs V<sub>IN</sub> (I<sub>LOAD</sub>=10mA)**

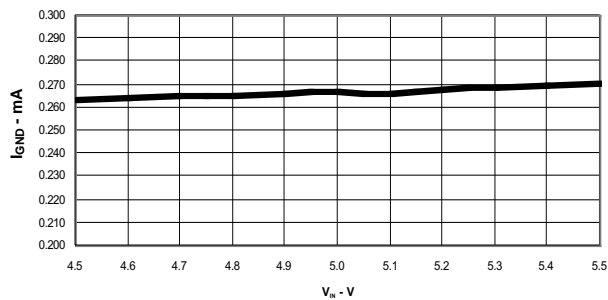


Figure. 7

**I<sub>GND</sub> vs V<sub>IN</sub> (I<sub>LOAD</sub>=1A)**

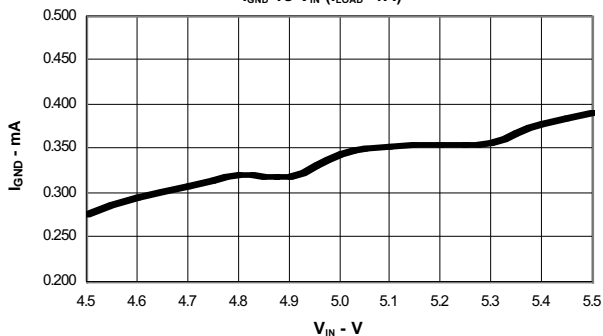


Figure. 8

**I<sub>GND</sub> vs I<sub>LOAD</sub> (V<sub>IN</sub> = 5.1V)**

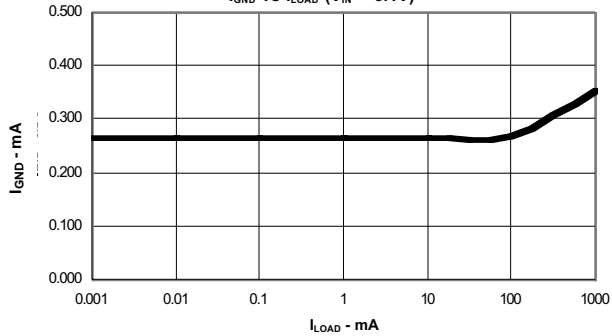


Figure. 9

# Lithium-Ion Battery Charger

## TYPICAL CURVES (CONT.)

TC3827

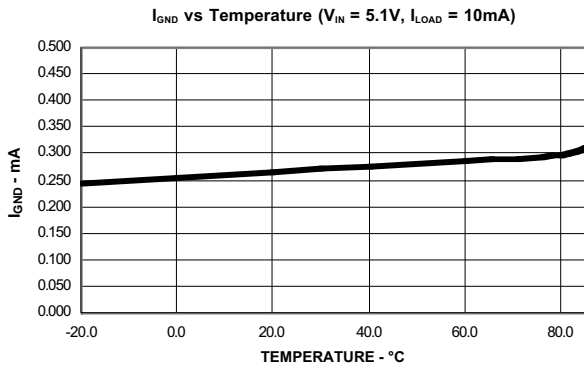


Figure. 10

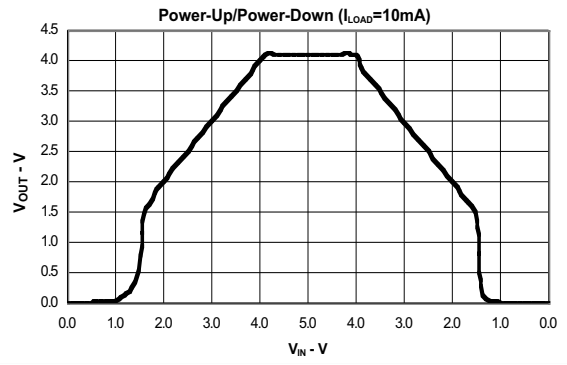


Figure. 11

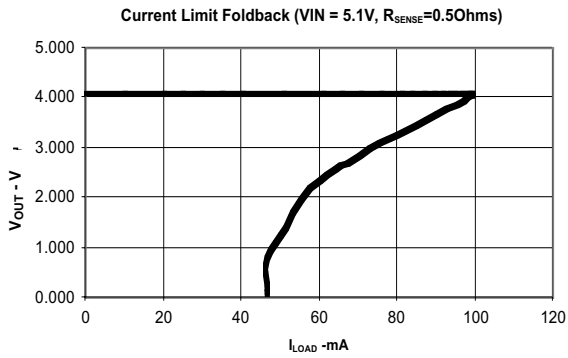


Figure. 12

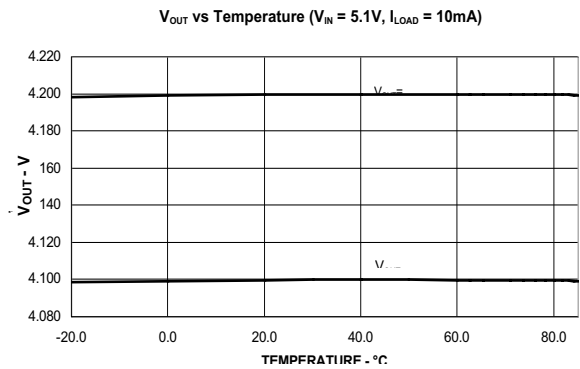


Figure. 13

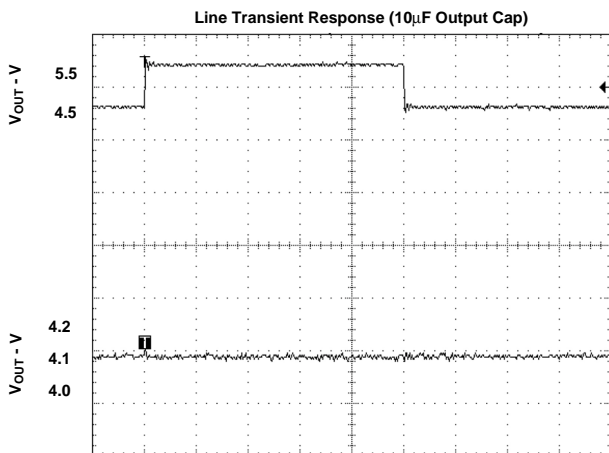
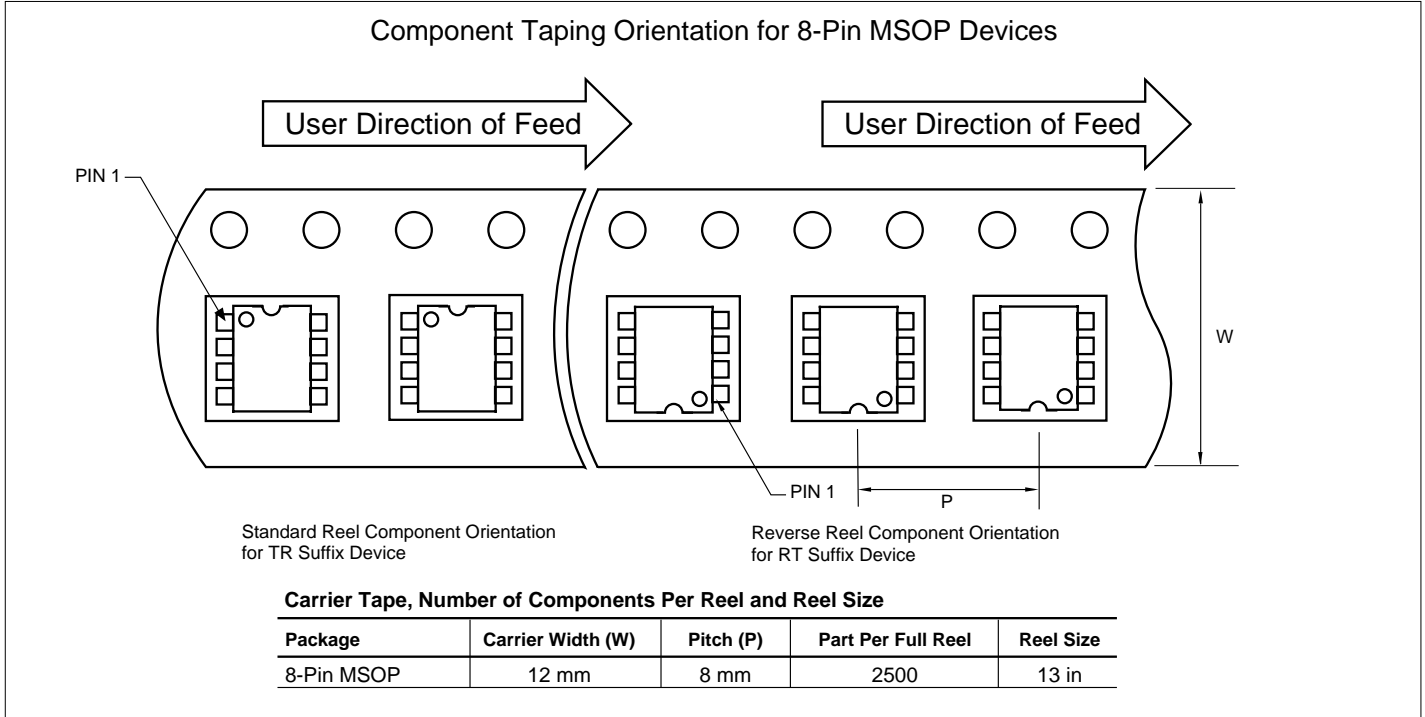


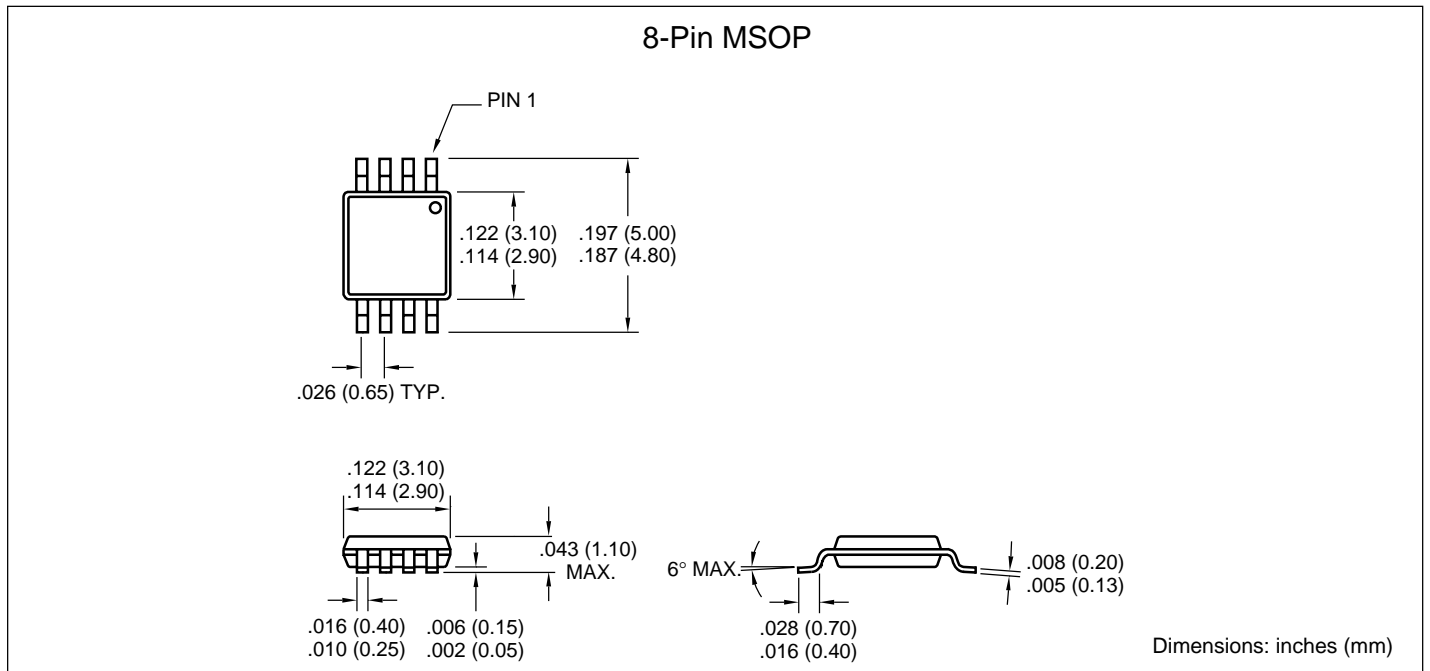
Figure. 14



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#### San Jose

Microchip Technology Inc.  
2107 North First Street, Suite 590  
San Jose, CA 95131  
Tel: 408-436-7950 Fax: 408-436-7955

#### Toronto

6285 Northam Drive, Suite 108  
Mississauga, Ontario L4V 1X5, Canada  
Tel: 905-673-0699 Fax: 905-673-6509

### ASIA/PACIFIC

#### China - Beijing

Microchip Technology Beijing Office  
Unit 915  
New China Hong Kong Manhattan Bldg.  
No. 6 Chaoyangmen Beidajie  
Beijing, 100027, No. China  
Tel: 86-10-85282100 Fax: 86-10-85282104

#### China - Shanghai

Microchip Technology Shanghai Office  
Room 701, Bldg. B  
Far East International Plaza  
No. 317 Xian Xia Road  
Shanghai, 200051  
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

#### Hong Kong

Microchip Asia Pacific  
RM 2101, Tower 2, Metroplaza  
223 Hing Fong Road  
Kwai Fong, N.T., Hong Kong  
Tel: 852-2401-1200 Fax: 852-2401-3431

#### India

Microchip Technology Inc.  
India Liaison Office  
Divyasree Chambers  
1 Floor, Wing A (A3/A4)  
No. 11, O'Shaughnessy Road  
Bangalore, 560 025, India  
Tel: 91-80-2290061 Fax: 91-80-2290062

#### Japan

Microchip Technology Intl. Inc.  
Benex S-1 6F  
3-18-20, Shinyokohama  
Kohoku-Ku, Yokohama-shi  
Kanagawa, 222-0033, Japan  
Tel: 81-45-471-6166 Fax: 81-45-471-6122

#### Korea

Microchip Technology Korea  
168-1, Youngbo Bldg. 3 Floor  
Samsung-Dong, Kangnam-Ku  
Seoul, Korea  
Tel: 82-2-554-7200 Fax: 82-2-558-5934

### ASIA/PACIFIC (continued)

#### Singapore

Microchip Technology Singapore Pte Ltd.  
200 Middle Road  
#07-02 Prime Centre  
Singapore, 188980  
Tel: 65-334-8870 Fax: 65-334-8850

#### Taiwan

Microchip Technology Taiwan  
11F-3, No. 207  
Tung Hua North Road  
Taipei, 105, Taiwan  
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

### EUROPE

#### Australia

Microchip Technology Australia Pty Ltd  
Suite 22, 41 Rawson Street  
Epping 2121, NSW  
Australia  
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

#### Denmark

Microchip Technology Denmark ApS  
Regus Business Centre  
Lautrup hofj 1-3  
Ballerup DK-2750 Denmark  
Tel: 45 4420 9895 Fax: 45 4420 9910

#### France

Arizona Microchip Technology SARL  
Parc d'Activite du Moulin de Massy  
43 Rue du Saule Trapu  
Batiment A - 1er Etage  
91300 Massy, France  
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

#### Germany

Arizona Microchip Technology GmbH  
Gustav-Heinemann Ring 125  
D-81739 Munich, Germany  
Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

#### Germany

Analog Product Sales  
Lochhamer Strasse 13  
D-82152 Martinsried, Germany  
Tel: 49-89-895650-0 Fax: 49-89-895650-22

#### Italy

Arizona Microchip Technology SRL  
Centro Direzionale Colleoni  
Palazzo Taurus 1 V. Le Colleoni 1  
20041 Agrate Brianza  
Milan, Italy  
Tel: 39-039-65791-1 Fax: 39-039-6899883

#### United Kingdom

Arizona Microchip Technology Ltd.  
505 Eskdale Road  
Winnersh Triangle  
Wokingham  
Berkshire, England RG41 5TU  
Tel: 44 118 921 5869 Fax: 44-118 921-5820

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