



# 2A, Current-Limited, High-Side P-Channel Switch with Thermal Shutdown

MAX869L

## General Description

The MAX869L P-channel load switch features an accurate user-set current limit and low on-resistance. This switch is designed to protect your power source from shorts and surges by limiting current and preventing the system supply from being pulled low. The input voltage range is 2.7V to 5.5V.

The MAX869L features a 2A, 45mΩ switch controlled by a logic signal. Current-limit accuracy is  $\pm 21\%$ , and can be set from 400mA to 2.4A using a single resistor.

The device has a low 12μA quiescent supply current, which reduces to 2μA max in shutdown. It features thermal-shutdown protection and a logic-signal output pin (FAULT) that signals when there is an overcurrent or overtemperature condition.

For other devices in this family, consult the *Selector Guide*.

## Features

- ♦ **Very Small Footprint (16-pin QSOP is the same size as an 8-pin SO)**
- ♦ **Low Resistance: 45mΩ at 3V**
- ♦  **$\pm 21\%$ -Accurate, User-Set Current Limit**
- ♦ **12μA (typ) Quiescent Current**
- ♦ **0.01μA (typ) Shutdown Current**
- ♦ **0.04μA (typ) Leakage to Output when Switch is Off**
- ♦ **2.7V to 5.5V Input Range**
- ♦ **Thermal Shutdown**
- ♦ **FAULT Output**

## Selector Guide

| PART    | R <sub>ON</sub><br>AT 3V<br>(mΩ) | NOMINAL<br>CURRENT<br>(A) | COUNT  | PACKAGE |
|---------|----------------------------------|---------------------------|--------|---------|
| MAX869L | 45                               | 2                         | Single | 16 QSOP |
| MAX890L | 90                               | 1                         | Single | 8 SO    |
| MAX891L | 150                              | 0.5                       | Single | 8 μMAX  |
| MAX892L | 300                              | 0.25                      | Single | 8 μMAX  |
| MAX894L | 150                              | 0.5                       | Dual   | 8 SO    |
| MAX895L | 300                              | 0.25                      | Dual   | 8 SO    |

## Ordering Information

| PART       | TEMP. RANGE    | PIN-PACKAGE |
|------------|----------------|-------------|
| MAX869LC/D | 0°C to +70°C   | Dice*       |
| MAX869LEEE | -40°C to +85°C | 16 QSOP     |

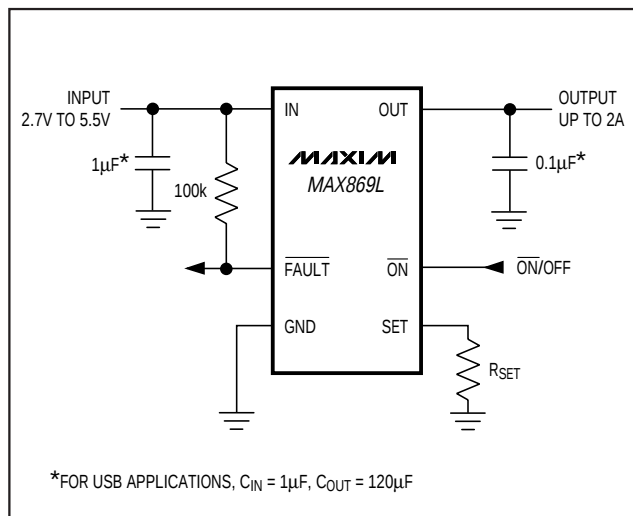
\*Dice are specified at  $T_A = +25^\circ\text{C}$ .

## Applications

Universal Serial Bus (USB)  
Notebook Computers  
Personal Communicators  
Palmtop Computers  
Hand-Held Instruments  
Portable Medical Instruments

Pin Configuration appears at end of data sheet.

## Typical Operating Circuit



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## ABSOLUTE MAXIMUM RATINGS

IN to GND .....-0.3V to 6V  
 $\overline{\text{ON}}$ , FAULT to GND .....-0.3V to 6V  
 SET, OUT to GND ..... -0.3V to ( $V_{\text{IN}} + 0.3\text{V}$ )  
 Maximum Continuous Switch Current .....3A  
 Continuous Power Dissipation ( $T_A = +70^\circ\text{C}$ )  
 QSOP (derate 8.3mW/ $^\circ\text{C}$  above  $+70^\circ\text{C}$ ) .....667mW

Operating Temperature Range

MAX869LEEE.....-40 $^\circ\text{C}$  to +85 $^\circ\text{C}$

Storage Temperature Range ..... -65 $^\circ\text{C}$  to +150 $^\circ\text{C}$

Lead Temperature (soldering, 10sec) .....+300 $^\circ\text{C}$

Stresses beyond 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 beyond 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

( $V_{\text{IN}} = 3\text{V}$ ,  $T_A = 0^\circ\text{C}$  to +85 $^\circ\text{C}$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ\text{C}$ .)

| PARAMETER                                          | CONDITIONS                                                                                        | MIN   | TYP   | MAX     | UNITS         |
|----------------------------------------------------|---------------------------------------------------------------------------------------------------|-------|-------|---------|---------------|
| Operating Voltage                                  |                                                                                                   | 2.7   |       | 5.5     | V             |
| Quiescent Current                                  | $V_{\text{IN}} = 5\text{V}$ , $\overline{\text{ON}} = \text{GND}$ , $I_{\text{OUT}} = 0\text{A}$  |       | 12    | 20      | $\mu\text{A}$ |
| Off-Supply Current                                 | $\overline{\text{ON}} = \text{IN}$ , $V_{\text{IN}} = V_{\text{OUT}} = 5.5\text{V}$               |       | 0.01  | 2       | $\mu\text{A}$ |
| Off-Switch Current                                 | $\overline{\text{ON}} = \text{IN}$ , $V_{\text{IN}} = 5.5\text{V}$ , $V_{\text{OUT}} = 0\text{V}$ |       | 0.04  | 30      | $\mu\text{A}$ |
| Undervoltage Lockout                               | Rising edge, 1% hysteresis                                                                        | 2.0   | 2.3   | 2.6     | V             |
| On-Resistance                                      | $V_{\text{IN}} = 4.75\text{V}$                                                                    |       | 38    | 70      | m $\Omega$    |
|                                                    | $V_{\text{IN}} = 3.0\text{V}$                                                                     |       | 45    | 90      |               |
| Nominal Current-Limit Set Range                    | $R_{\text{SET}} = 1\%$ tolerance (Note 1)                                                         | 0.40  |       | 2.4     | A             |
| Current-Limit-Amplifier Threshold                  | $V_{\text{SET}}$ required to turn the switch off (Note 2)                                         | 1.178 | 1.240 | 1.302   | V             |
| $I_{\text{OUT}}$ to $I_{\text{SET}}$ Current Ratio | $I_{\text{OUT}} = 1\text{A}$ , $V_{\text{OUT}} > 1.6\text{V}$                                     | 810   | 955   | 1100    | A/A           |
| $\overline{\text{ON}}$ Input Low Voltage           | $V_{\text{IN}} = 2.7\text{V}$ to $5.5\text{V}$                                                    |       |       | 0.8     | V             |
| $\overline{\text{ON}}$ Input High Voltage          | $V_{\text{IN}} = 2.7\text{V}$ to $3.6\text{V}$                                                    | 2.0   |       |         | V             |
|                                                    | $V_{\text{IN}} = 4.5\text{V}$ to $5.5\text{V}$                                                    | 2.4   |       |         |               |
| $\overline{\text{ON}}$ Input Leakage               | $V_{\overline{\text{ON}}} = 5.5\text{V}$                                                          |       | 0.01  | $\pm 1$ | $\mu\text{A}$ |
| $I_{\text{SET}}$ Bias Current                      | $V_{\text{SET}} = 1.24\text{V}$ , $I_{\text{OUT}} = 0\text{A}$                                    |       | 0.05  | $\pm 3$ | $\mu\text{A}$ |
| FAULT Logic Output Low Voltage                     | $I_{\text{SINK}} = 1\text{mA}$ , $V_{\text{SET}} = 1.4\text{V}$                                   |       |       | 0.4     | V             |
| FAULT Logic Output High Leakage Current            | $V_{\text{FAULT}} = 5.5\text{V}$ , $V_{\text{SET}} = 1\text{V}$                                   |       | 0.05  | 1       | $\mu\text{A}$ |
| Slow-Current-Loop Response Time                    | 20% current overdrive, $V_{\text{CC}} = 5\text{V}$                                                |       | 10    |         | $\mu\text{s}$ |
| Fast-Current-Loop Response Time                    |                                                                                                   |       | 4     |         | $\mu\text{s}$ |
| Turn-On Time                                       | $V_{\text{IN}} = 5\text{V}$ , $I_{\text{OUT}} = 500\text{mA}$                                     |       | 100   | 300     | $\mu\text{s}$ |
|                                                    | $V_{\text{IN}} = 3\text{V}$ , $I_{\text{OUT}} = 500\text{mA}$                                     |       | 200   |         |               |
| Turn-Off Time                                      | $V_{\text{IN}} = 5\text{V}$ , $I_{\text{OUT}} = 500\text{mA}$                                     | 2     | 10    | 30      | $\mu\text{s}$ |

**Note 1:** Guaranteed by design. Derived from the  $I_{\text{SET}}$  current ratio; current-limit amplifier and external set resistor accuracies.

**Note 2:** Tested with  $I_{\text{OUT}} = 200\text{mA}$  and  $V_{\text{SET}}$  raised until  $(V_{\text{IN}} - V_{\text{OUT}}) \geq 0.8\text{V}$ .

**Note 3:** Specifications to -40 $^\circ\text{C}$  are guaranteed by design, not production tested.

# 2A, Current-Limited, High-Side P-Channel Switch with Thermal Shutdown

MAX869L

## ELECTRICAL CHARACTERISTICS

( $V_{IN} = 3V$ ,  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted.) (Note 3)

| PARAMETER                                   | CONDITIONS                                              | MIN  | TYP | MAX  | UNITS     |
|---------------------------------------------|---------------------------------------------------------|------|-----|------|-----------|
| Operating Voltage                           |                                                         | 2.9  |     | 5.5  | V         |
| Quiescent Current                           | $V_{IN} = 5V$ , $\overline{ON} = GND$ , $I_{OUT} = 0A$  |      |     | 25   | $\mu A$   |
| Off-Supply Current                          | $\overline{ON} = IN$ , $V_{IN} = V_{OUT} = 5.5V$        |      |     | 2.5  | $\mu A$   |
| Off-Switch Current                          | $\overline{ON} = IN$ , $V_{IN} = 5.5V$ , $V_{OUT} = 0V$ |      |     | 30   | $\mu A$   |
| Undervoltage Lockout                        | Rising edge, 1% hysteresis                              | 2.0  |     | 2.85 | V         |
| On-Resistance                               | $V_{IN} = 4.75V$                                        |      |     | 70   | $m\Omega$ |
|                                             | $V_{IN} = 3.0V$                                         |      |     | 90   |           |
| Nominal Current-Limit Set Range             | $R_{SET} = 1\%$ tolerance (Note 1)                      | 0.40 |     | 2.4  | A         |
| Current-Limit-Amplifier Threshold           | $V_{SET}$ required to turn the switch off (Note 2)      | 1.14 |     | 1.34 | V         |
| $I_{OUT}$ to $I_{SET}$ Current Ratio        | $I_{OUT} = 1A$ , $V_{OUT} > 1.6V$                       | 765  |     | 1145 | A/A       |
| $\overline{FAULT}$ Logic Output Low Voltage | $I_{SINK} = 1mA$ , $V_{SET} = 1V$                       |      |     | 0.4  | V         |
| Turn-On Time                                | $V_{IN} = 5V$ , $I_{OUT} = 500mA$                       |      |     | 400  | $\mu s$   |
| Turn-Off Time                               | $V_{IN} = 5V$ , $I_{OUT} = 500mA$                       | 2    |     | 30   | $\mu s$   |

**Note 1:** Guaranteed by design. Derived from the  $I_{SET}$  current ratio; current-limit amplifier and external set resistor accuracies.

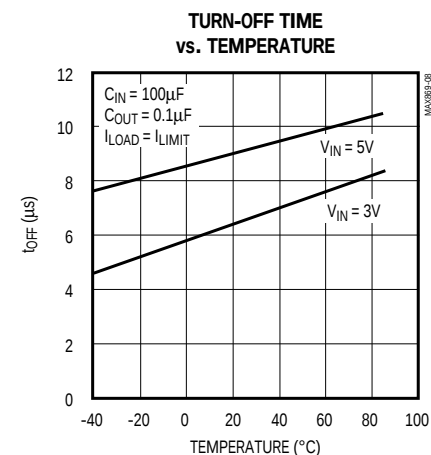
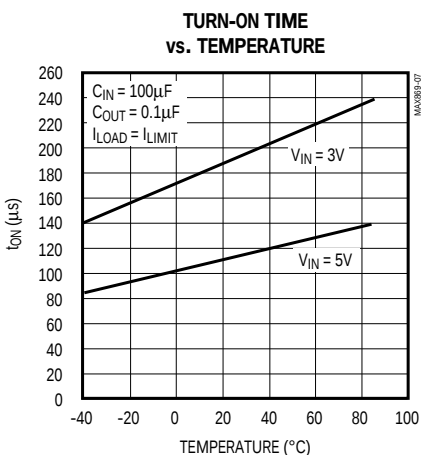
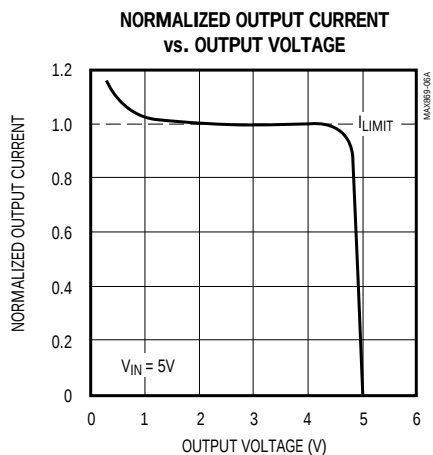
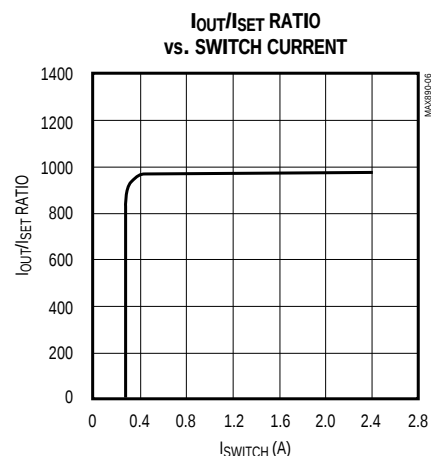
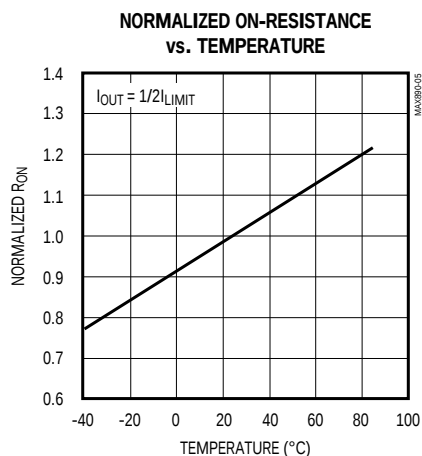
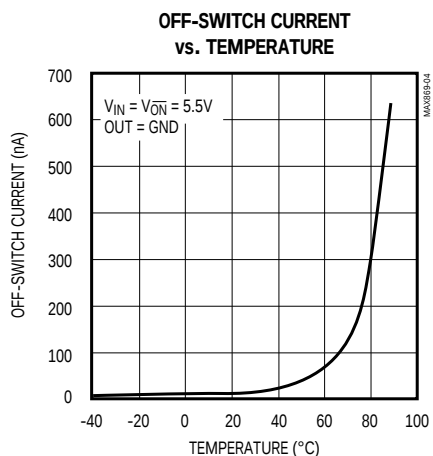
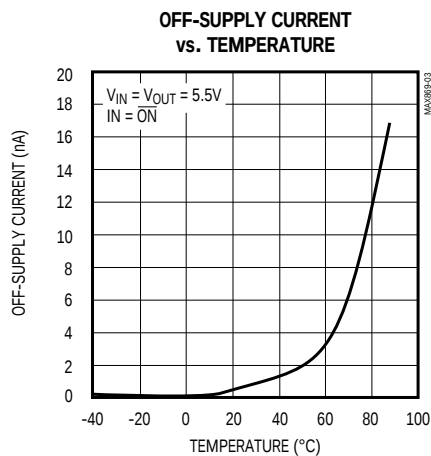
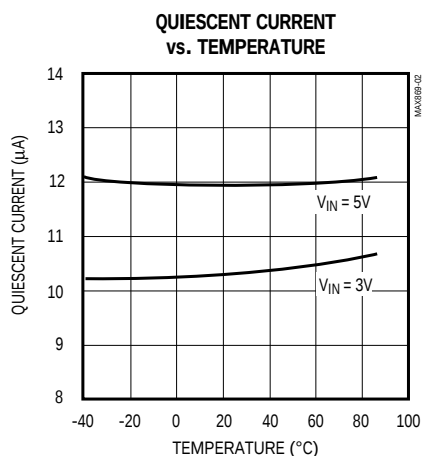
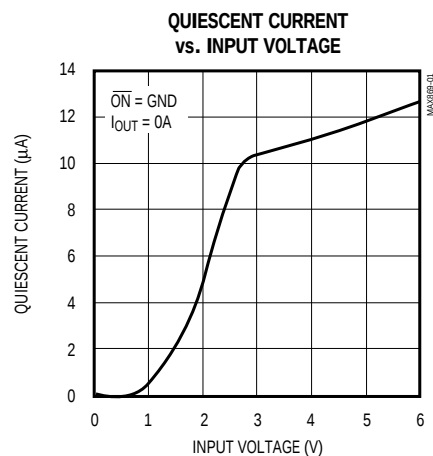
**Note 2:** Tested with  $I_{OUT} = 200mA$  and  $V_{SET}$  raised until  $(V_{IN} - V_{OUT}) \geq 0.8V$ .

**Note 3:** Specifications to  $-40^{\circ}C$  are guaranteed by design, not production tested.

# 2A, Current-Limited, High-Side P-Channel Switch with Thermal Shutdown

## Typical Operating Characteristics

( $T_A = +25^\circ\text{C}$ , unless otherwise noted.)

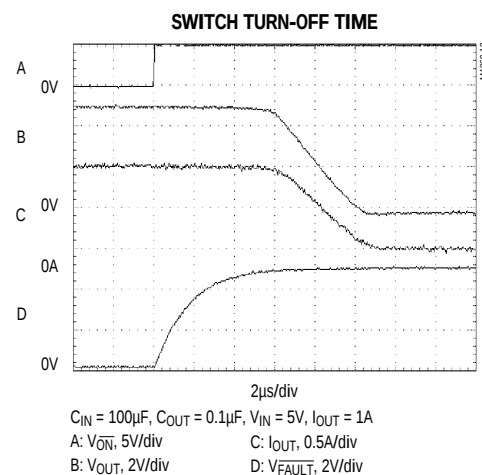
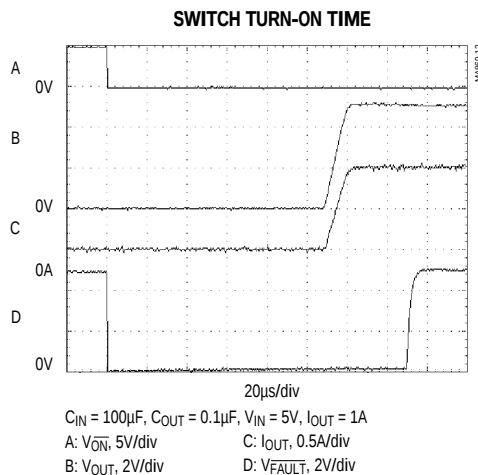
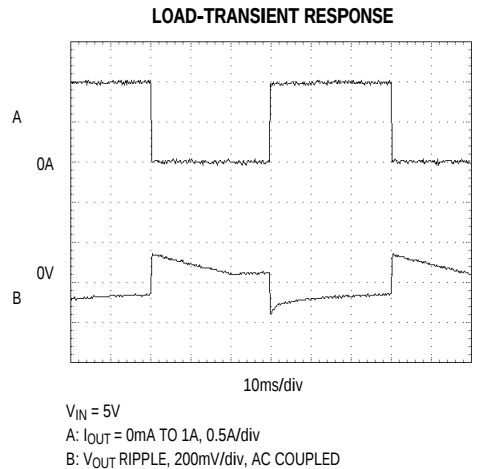
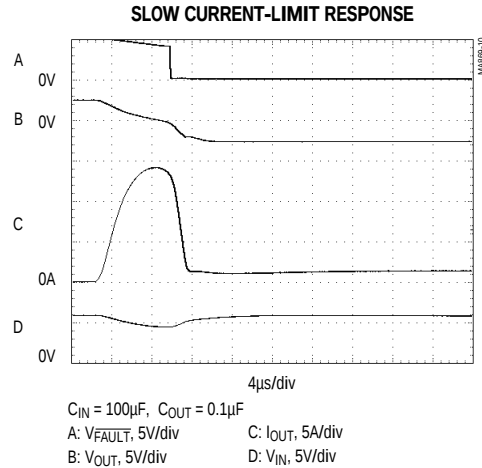
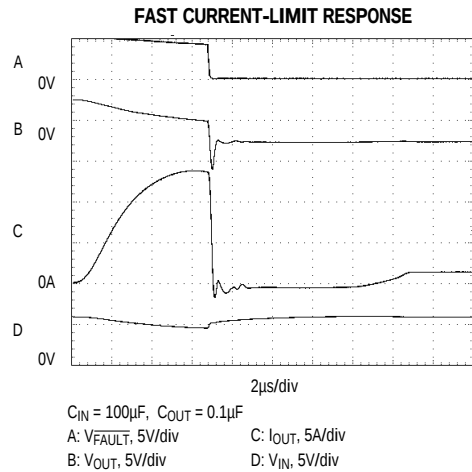


# 2A, Current-Limited, High-Side P-Channel Switch with Thermal Shutdown

MAX869L

## Typical Operating Characteristics (continued)

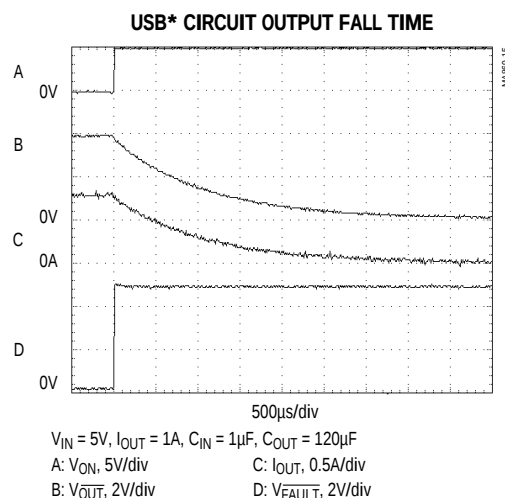
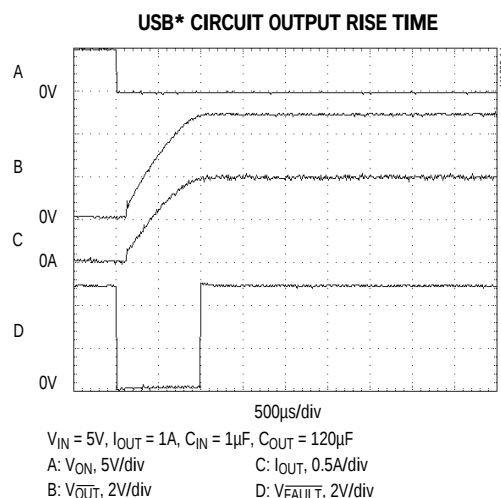
( $T_A = +25^\circ\text{C}$ , unless otherwise noted.)



# 2A, Current-Limited, High-Side P-Channel Switch with Thermal Shutdown

## Typical Operating Characteristics (continued)

( $T_A = +25^\circ\text{C}$ , unless otherwise noted.)



\*REFER TO TYPICAL OPERATING CIRCUIT

## Pin Description

| PIN                    | NAME                      | FUNCTION                                                                                                                                                                                                                           |
|------------------------|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1, 4, 5,<br>12, 13, 16 | IN                        | Input, P-channel MOSFET source. Bypass IN with a $1\mu\text{F}$ capacitor to ground.                                                                                                                                               |
| 2, 3, 6,<br>11, 14, 15 | OUT                       | Switch output. P-channel MOSFET drain. Bypass OUT with a $0.1\mu\text{F}$ capacitor to GND.                                                                                                                                        |
| 7                      | $\overline{\text{ON}}$    | Active-Low Switch-On Input. A logic low turns the switch on.                                                                                                                                                                       |
| 8                      | GND                       | Ground                                                                                                                                                                                                                             |
| 9                      | SET                       | Set Current-Limit Input. A resistor from SET to ground sets the current limit for the switch. $R_{SET} = 1,184 / I_{LIMIT}$ , where $I_{LIMIT}$ is the desired current limit in amperes.                                           |
| 10                     | $\overline{\text{FAULT}}$ | Fault-Indicator Output. This open-drain output goes low when in current limit or when the die temperature exceeds $+135^\circ\text{C}$ . $\overline{\text{FAULT}}$ remains low for Turn-On Time + $50\mu\text{s}$ during start-up. |

## Detailed Description

The MAX869L P-channel MOSFET power switch limits output current to a programmed level. When the output current passes through the main switch, a smaller current also passes through the replica switch ( $I_{OUT} / 955$ ) and through  $R_{SET}$  (Figure 1). When the voltage on  $R_{SET}$  exceeds the trip voltage of 1.24V, the current-limit error amplifier regulates the output current to the programmed current limit,  $I_{LIMIT}$  (400mA to 2.4A).

This switch is not bidirectional; therefore, the input voltage must be higher than the output voltage.

### Setting the Current Limit

The MAX869L features internal current-limiting circuitry with a maximum programmable value ( $I_{MAX}$ ) of 2.4A. For best performance, set the current limit ( $I_{LIMIT}$ ) between  $0.2 I_{MAX} \leq I_{LIMIT} \leq I_{MAX}$ . This current limit remains in effect throughout the input supply-voltage range.

Program the current limit with a resistor ( $R_{SET}$ ) from SET to ground (Figure 2) as follows:

$$I_{SET} = I_{LIMIT} / 955$$

$$R_{SET} = 1.24\text{V} / I_{SET} = 1,184 / I_{LIMIT}$$

where  $I_{LIMIT}$  is the desired current limit.

# 2A, Current-Limited, High-Side P-Channel Switch with Thermal Shutdown

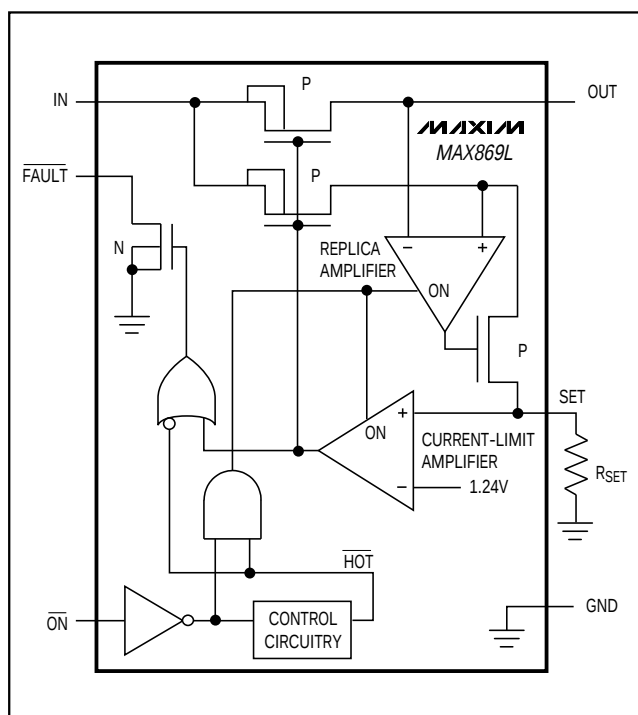


Figure 1. Functional Diagram

## Short-Circuit Protection

The MAX869L is a short-circuit-protected switch. In the event of an output short circuit ( $V_{OUT} \leq 1.6V$  typical), the current through the switch is limited by the internal current-limiting error amplifier to  $1.4 \times I_{LIMIT}$ . When the short-circuit condition is removed, the current-limit amplifier sets the current limit back to  $I_{LIMIT}$ .

For a high  $\Delta V_{DS}/\Delta t$  during an output short-circuit condition, the switch turns off and disconnects the input supply from the output. The current-limiting amplifier then slowly turns the switch on with the output current limited to  $1.4 \times I_{LIMIT}$ . When the short-circuit condition is removed, the current limit is set back to  $I_{LIMIT}$ . Refer to the Fast Current-Limit Response and Slow Current-Limit Response graphs in the *Typical Operating Characteristics*.

## Thermal Shutdown

The MAX869L features thermal shutdown. The switch turns off when the junction temperature exceeds  $135^{\circ}C$ . Once the device cools by  $10^{\circ}C$ , the switch turns back on. If the fault condition is not removed, the switch cycles on and off, resulting in a pulsed output.

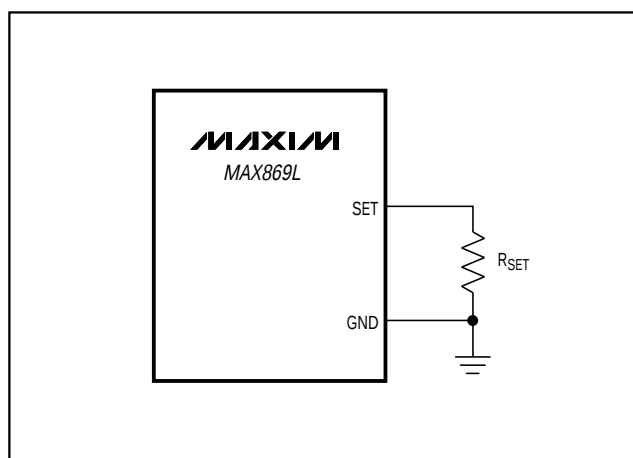


Figure 2. Setting the Current Limit

## Fault Indicator

The MAX869L provides a fault output (FAULT). This open-drain output goes low when in current limit or when the die temperature exceeds  $135^{\circ}C$ . A  $100k\Omega$  pull-up resistor from FAULT to IN provides a logic-control signal.

## Applications Information

### Input Capacitor

To limit the input voltage drop during momentary output short-circuit conditions, connect a capacitor from IN to GND. A  $1\mu F$  ceramic capacitor is adequate for most applications; however, higher capacitor values further reduce the voltage drop at the input.

### Output Capacitor

Connect a  $0.1\mu F$  capacitor from OUT to GND to prevent inductive parasitics from pulling OUT below GND during turn-off. USB applications require  $C_{OUT}$  to be at least  $120\mu F$ . This larger output capacitance slows the output rise and fall times, as shown in the *Typical Operating Characteristics*, but does not adversely affect the MAX869L's turn-off response time.

### Layout and Thermal-Dissipation Considerations

To take full advantage of the switch-response time to output short-circuit conditions, it is very important to keep all traces as short as possible to reduce the effect of undesirable parasitic inductance. Place input and output capacitors as close as possible to the device (less than 5mm).

# 2A, Current-Limited, High-Side P-Channel Switch with Thermal Shutdown

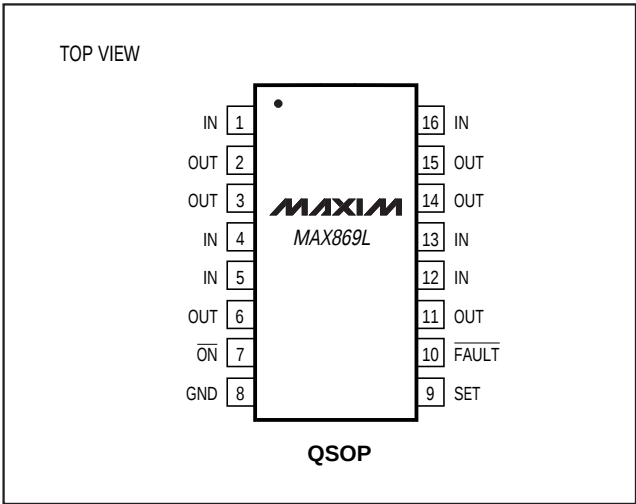
Under normal operating conditions, the package can dissipate and channel heat away. Calculate the maximum power as follows:

$$P = I^2_{LIMIT} \times R_{ON}$$

where  $R_{ON}$  is the on-resistance of the switch.

When the output is short circuited, the voltage drop across the switch equals the input supply. Hence, the power dissipated across the switch increases, as does the die temperature. If the fault condition is not removed, the thermal-overload-protection circuitry turns the switch off until the die temperature falls by 10°C. A ground plane in contact with the device helps dissipate additional heat.

## Pin Configuration



## Chip Information

TRANSISTOR COUNT: 433

SUBSTRATE CONNECTED TO GND

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### Офис по работе с юридическими лицами:

105318, г.Москва, ул.Щербаковская д.3, офис 1107, 1118, ДЦ «Щербаковский»

Телефон: +7 495 668-12-70 (многоканальный)

Факс: +7 495 668-12-70 (доб.304)

E-mail: [info@moschip.ru](mailto:info@moschip.ru)

Skype отдела продаж:

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