19-1278; Rev 0; 8/97

MAXIM

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

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 ±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 ($\overline{FAULT}$) 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**
- ♦ **±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**
- ♦ **$\overline{FAULT}$ Output**

Selector Guide

PART	R_{ON} AT 3V (mΩ)	NOMINAL CURRENT (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°C.*

Applications

Universal Serial Bus (USB)

Notebook Computers

Personal Communicators

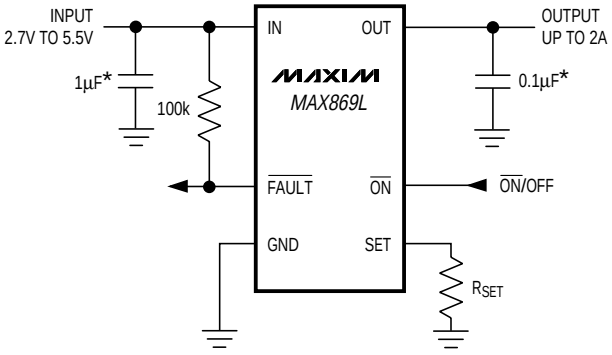
Palmtop Computers

Hand-Held Instruments

Portable Medical Instruments

Pin Configuration appears at end of data sheet.

Typical Operating Circuit



*FOR USB APPLICATIONS, C_{IN} = 1µF, C_{OUT} = 120µF

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

ABSOLUTE MAXIMUM RATINGS

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

Operating Temperature Range
MAX869LEEE.....-40°C to +85°C
Storage Temperature Range ..... -65°C to +150°C
Lead Temperature (soldering, 10sec) .....+300°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_{IN} = 3V, **T_A = 0°C to +85°C,** unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Operating Voltage		2.7		5.5	V
Quiescent Current	V_{IN} = 5V, $\overline{ON}$ = GND, I_{OUT} = 0A		12	20	µA
Off-Supply Current	$\overline{ON}$ = IN, V_{IN} = V_{OUT} = 5.5V		0.01	2	µA
Off-Switch Current	$\overline{ON}$ = IN, V_{IN} = 5.5V, V_{OUT} = 0V		0.04	30	µA
Undervoltage Lockout	Rising edge, 1% hysteresis	2.0	2.3	2.6	V
On-Resistance	V_{IN} = 4.75V		38	70	mΩ
	V_{IN} = 3.0V		45	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)	1.178	1.240	1.302	V
I_{OUT} to I_{SET} Current Ratio	I_{OUT} = 1A, V_{OUT} > 1.6V	810	955	1100	A/A
$\overline{ON}$ Input Low Voltage	V_{IN} = 2.7V to 5.5V			0.8	V
$\overline{ON}$ Input High Voltage	V_{IN} = 2.7V to 3.6V	2.0			V
	V_{IN} = 4.5V to 5.5V	2.4			
$\overline{ON}$ Input Leakage	$V_{\overline{ON}}$ = 5.5V		0.01	±1	µA
I_{SET} Bias Current	V_{SET} = 1.24V, I_{OUT} = 0A		0.05	±3	µA
$\overline{FAULT}$ Logic Output Low Voltage	I_{SINK} = 1mA, V_{SET} = 1.4V			0.4	V
$\overline{FAULT}$ Logic Output High Leakage Current	$V_{\overline{FAULT}}$ = 5.5V, V_{SET} = 1V		0.05	1	µA
Slow-Current-Loop Response Time	20% current overdrive, V_{CC} = 5V		10		µs
Fast-Current-Loop Response Time			4		µs
Turn-On Time	V_{IN} = 5V, I_{OUT} = 500mA		100	300	µs
	V_{IN} = 3V, I_{OUT} = 500mA		200		
Turn-Off Time	V_{IN} = 5V, I_{OUT} = 500mA	2	10	30	µs

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}) ≥ 0.8V.
Note 3: Specifications to -40°C are guaranteed by design, not production tested.

ELECTRICAL CHARACTERISTICS

(V_{IN} = 3V, **T_A = -40°C to +85°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	µA
Off-Supply Current	$\overline{ON}$ = IN, V_{IN} = V_{OUT} = 5.5V			2.5	µA
Off-Switch Current	$\overline{ON}$ = IN, V_{IN} = 5.5V, V_{OUT} = 0V			30	µA
Undervoltage Lockout	Rising edge, 1% hysteresis	2.0		2.85	V
On-Resistance	V_{IN} = 4.75V			70	mΩ
	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	µs
Turn-Off Time	V_{IN} = 5V, I_{OUT} = 500mA	2		30	µs

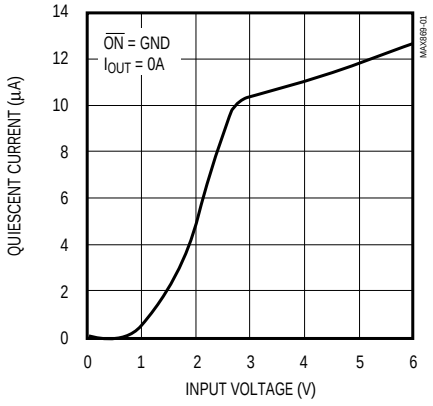
Note 1: Guaranteed by design. Derived from the I_{SET} current ratio; current-limit amplifier and external set resistor accuracies.
Note 2: Tested with I_{OUT} = 200mA and V_{SET} raised until (V_{IN} - V_{OUT}) ≥ 0.8V.
Note 3: Specifications to -40°C are guaranteed by design, not production tested.

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

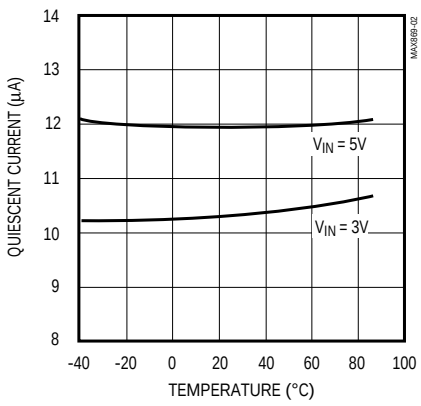
Typical Operating Characteristics

(T_A = +25°C, unless otherwise noted.)

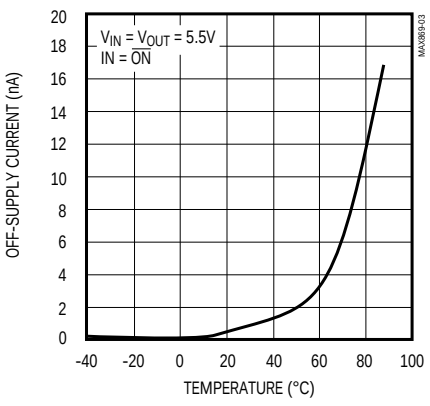
QUIESCENT CURRENT vs. INPUT VOLTAGE



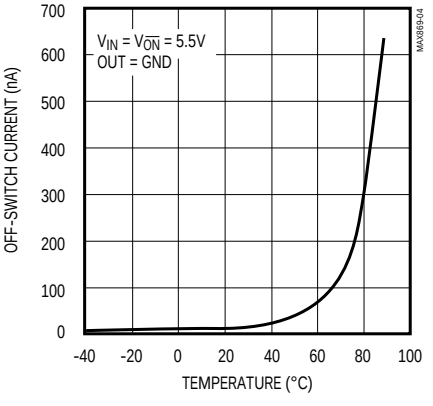
QUIESCENT CURRENT vs. TEMPERATURE



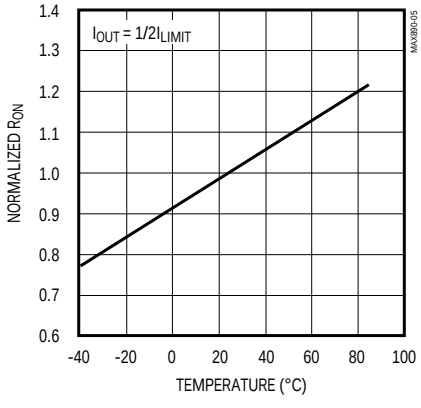
OFF-SUPPLY CURRENT vs. TEMPERATURE



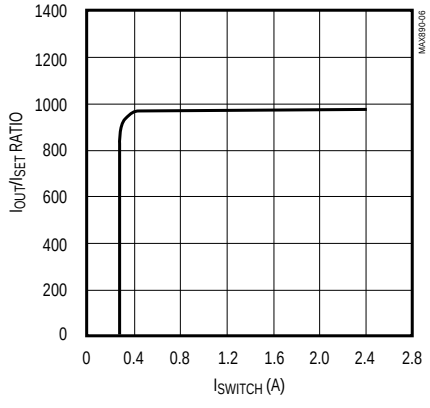
OFF-SWITCH CURRENT vs. TEMPERATURE



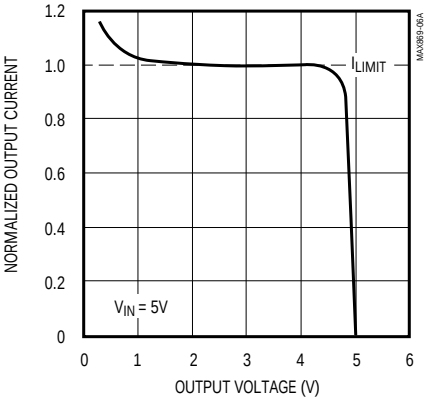
NORMALIZED ON-RESISTANCE vs. TEMPERATURE



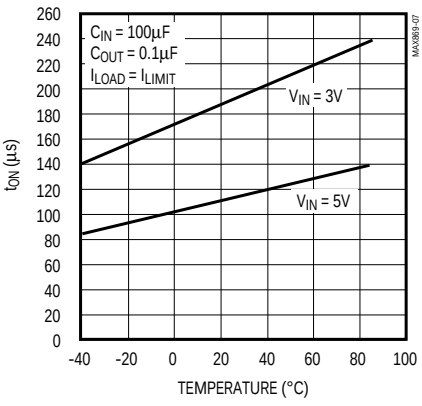
IOUT/ISET RATIO vs. SWITCH CURRENT



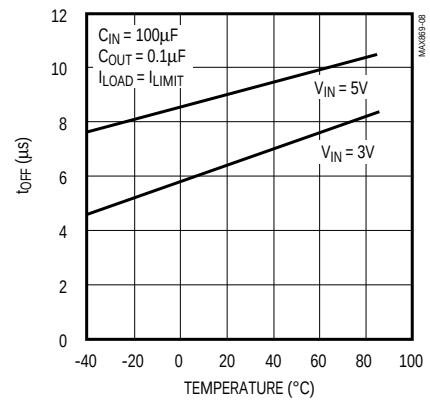
NORMALIZED OUTPUT CURRENT vs. OUTPUT VOLTAGE



TURN-ON TIME vs. TEMPERATURE



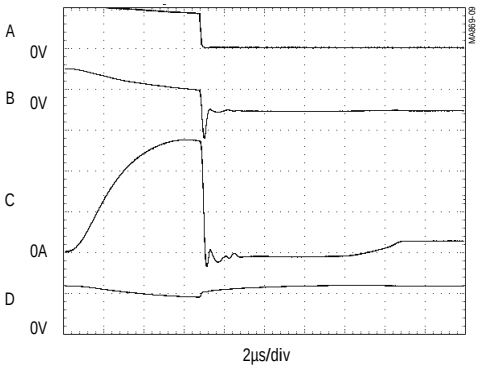
TURN-OFF TIME vs. TEMPERATURE



Typical Operating Characteristics (continued)

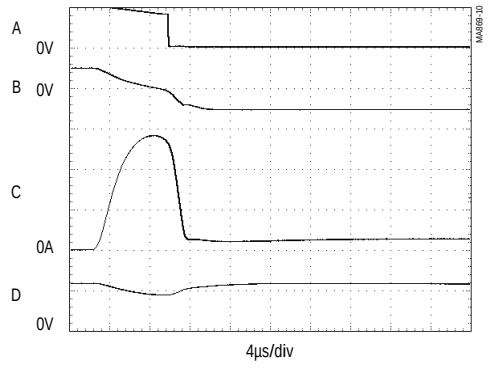
(T_A = +25°C, unless otherwise noted.)

FAST CURRENT-LIMIT RESPONSE



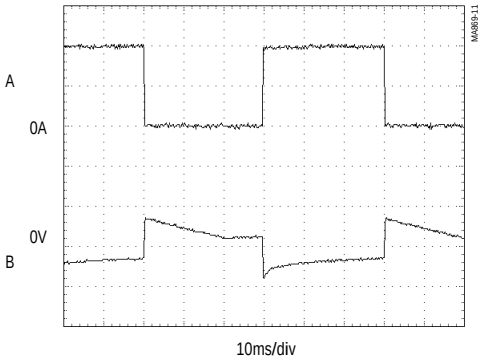
C_{IN} = 100µF, C_{OUT} = 0.1µF
A: $V_{\overline{FAULT}}$, 5V/div
B: V_{OUT}, 5V/div
C: I_{OUT}, 5A/div
D: V_{IN}, 5V/div

SLOW CURRENT-LIMIT RESPONSE



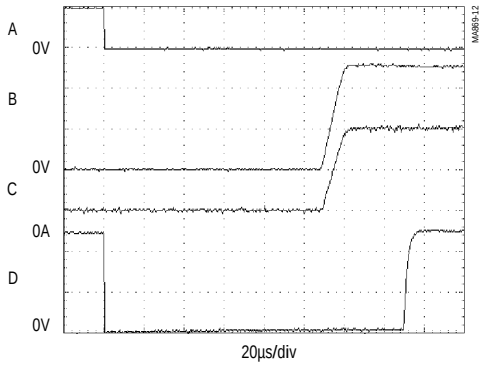
C_{IN} = 100µF, C_{OUT} = 0.1µF
A: $V_{\overline{FAULT}}$, 5V/div
B: V_{OUT}, 5V/div
C: I_{OUT}, 5A/div
D: V_{IN}, 5V/div

LOAD-TRANSIENT RESPONSE



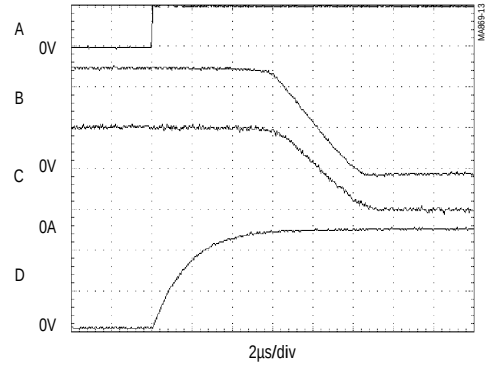
V_{IN} = 5V
A: I_{OUT} = 0mA TO 1A, 0.5A/div
B: V_{OUT} RIPPLE, 200mV/div, AC COUPLED

SWITCH TURN-ON TIME



C_{IN} = 100µF, C_{OUT} = 0.1µF, V_{IN} = 5V, I_{OUT} = 1A
A: $V_{\overline{ON}}$, 5V/div
B: V_{OUT}, 2V/div
C: I_{OUT}, 0.5A/div
D: $V_{\overline{FAULT}}$, 2V/div

SWITCH TURN-OFF TIME



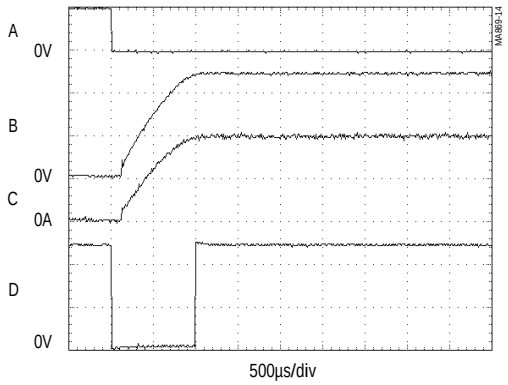
C_{IN} = 100µF, C_{OUT} = 0.1µF, V_{IN} = 5V, I_{OUT} = 1A
A: $V_{\overline{ON}}$, 5V/div
B: V_{OUT}, 2V/div
C: I_{OUT}, 0.5A/div
D: $V_{\overline{FAULT}}$, 2V/div

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

Typical Operating Characteristics (continued)

(T_A = +25°C, unless otherwise noted.)

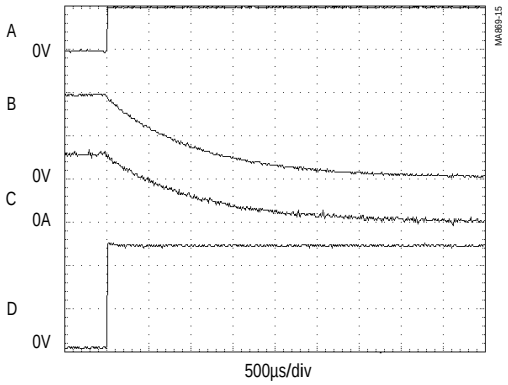
USB* CIRCUIT OUTPUT RISE TIME



500µs/div

V_{IN} = 5V, I_{OUT} = 1A, C_{IN} = 1µF, C_{OUT} = 120µF
A: V_{ON}, 5V/div
B: $V_{\overline{OUT}}$, 2V/div
C: I_{OUT}, 0.5A/div
D: $V_{\overline{FAULT}}$, 2V/div

USB* CIRCUIT OUTPUT FALL TIME



500µs/div

V_{IN} = 5V, I_{OUT} = 1A, C_{IN} = 1µF, C_{OUT} = 120µF
A: V_{ON}, 5V/div
B: $V_{\overline{OUT}}$, 2V/div
C: I_{OUT}, 0.5A/div
D: $V_{\overline{FAULT}}$, 2V/div

*REFER TO *TYPICAL OPERATING CIRCUIT*

Pin Description

PIN	NAME	FUNCTION
1, 4, 5, 12, 13, 16	IN	Input, P-channel MOSFET source. Bypass IN with a 1µF capacitor to ground.
2, 3, 6, 11, 14, 15	OUT	Switch output. P-channel MOSFET drain. Bypass OUT with a 0.1µF capacitor to GND.
7	$\overline{ON}$	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	$\overline{FAULT}$	Fault-Indicator Output. This open-drain output goes low when in current limit or when the die temperature exceeds +135°C. $\overline{FAULT}$ remains low for Turn-On Time + 50µs 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 $I_{MAX} \le I_{LIMIT} \le I_{MAX}$. 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:

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

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

where I_{LIMIT} is the desired current limit.

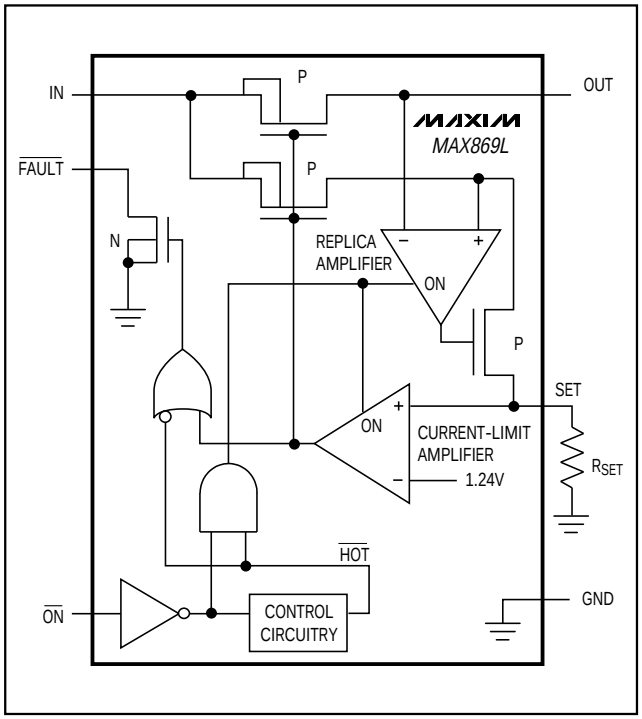


Figure 1. Functional Diagram

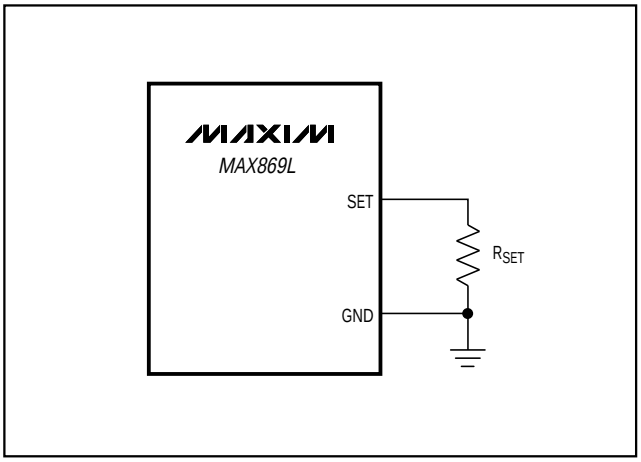


Figure 2. Setting the Current Limit

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 x 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 x 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°C. Once the device cools by 10°C, the switch turns back on. If the fault condition is not removed, the switch cycles on and off, resulting in a pulsed output.

Fault Indicator

The MAX869L provides a fault output ($\overline{FAULT}$). This open-drain output goes low when in current limit or when the die temperature exceeds 135°C. A 100kΩ pull-up resistor from $\overline{FAULT}$ 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 1µF ceramic capacitor is adequate for most applications; however, higher capacitor values further reduce the voltage drop at the input.

Output Capacitor

Connect a 0.1µF 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 120µF. 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

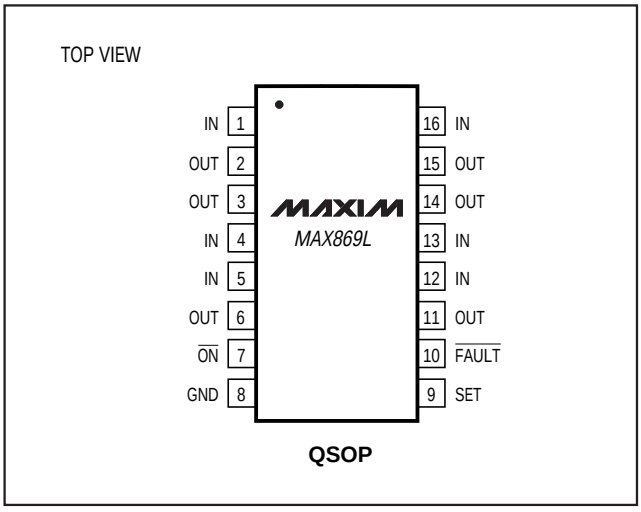
Under normal operating conditions, the package can dissipate and channel heat away. Calculate the maximum power as follows:

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

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