maxim integrated™

MAX8869

1A, Microcap, Low-Dropout, Linear Regulator

General Description

The MAX8869 low-dropout linear regulator operates from a +2.7V to +5.5V input and delivers a guaranteed 1A load current with a low 200mV dropout. The high-accuracy (±1%) output voltage is preset at +5V, +3.3V, +2.5V, +1.8V, or +1.0V or is adjustable from +0.8V to +5V with an external resistor-divider.

The MAX8869 uses Microcap® technology and requires only a small 1µF output capacitor for guaranteed stability. An internal PMOS pass transistor allows low 500µA supply current, making this regulator useful for networking and telecom hardware as well as battery-operated equipment. Other features include soft-start, low-power shutdown, short-circuit protection, and thermal shutdown protection.

The MAX8869 is available in a 1.5W, 16-pin TSSOP package, which is 30% smaller than a SOT223 and only 1.1mm high.

Applications

Telecom Hardware

Network Equipment

Mobile Phone Base Stations

Personal Computers

Notebook Computers

Microcap is a registered trademark of American Technical Ceramics Corp.

Features

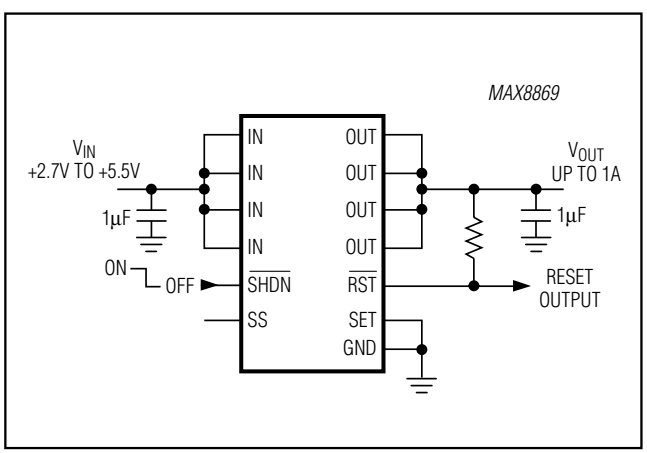
- **Guaranteed 1A Output Current**
- **Stable with C_{OUT} = 1µF**
- **Low 200mV Dropout at 1A**
- **±1% Output Voltage Accuracy**
  Preset at +5V, +3.3V, +2.5V, +1.8V, or +1.0V and Adjustable from +0.8V to +5.0V
- **54dB PSRR at 100kHz**
- **Adjustable Soft-Start**
- **3ms Reset Output**
- **Foldback Output Current Limit**
- **Thermal Overload Protection**
- **High-Power 16-Pin TSSOP Package (1.5W)**
  30% Smaller than SOT223 (Only 1.1mm High)

Ordering Information

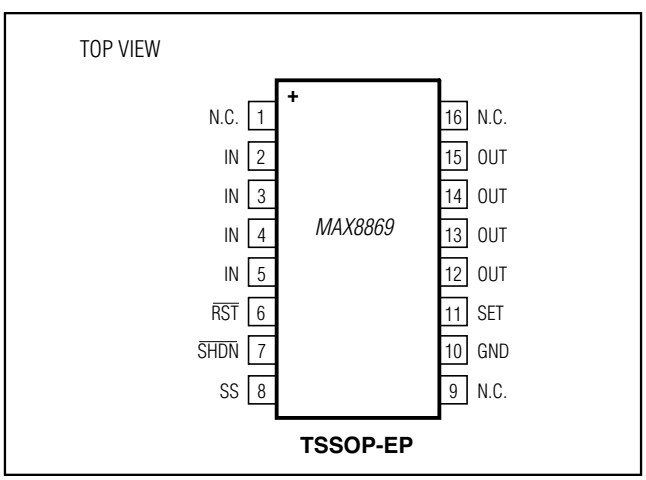
PART	PIN-PACKAGE	V_{OUT} (V)*
MAX8869EUE50+	16 TSSOP-EP**	+5.0
MAX8869EUE33+	16 TSSOP-EP**	+3.3
MAX8869EUE25+	16 TSSOP-EP**	+2.5
MAX8869EUE25/V+	16 TSSOP-EP**	+2.5
MAX8869EUE18+	16 TSSOP-EP**	+1.8
MAX8869EUE10+	16 TSSOP-EP**	+1.0

Note: *All devices are specified over the -40°C to +85°C temperature range.*
+Denotes a lead(Pb)-free/RoHS-compliant package.
**Or adjustable from +0.8V to +5.0V. Contact factory for other preset output voltages.*
***EP = Exposed pad.*
/V denotes an automotive qualified part.

Typical Operating Circuit



Pin Configuration



TSSOP-EP

For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim's website at www.maximintegrated.com.

19-1692; Rev 2; 10/12

ABSOLUTE MAXIMUM RATINGS

IN, $\overline{SHDN}$, $\overline{RST}$, SS to GND .....-0.3V to +6V
OUT, SET to GND .....-0.3V to (V_{IN} + 0.3V)
Output Short-Circuit Duration .....Indefinite
Continuous Power Dissipation (T_A = +70°C)
16-Pin TSSOP-EP (derate 26.1mW/°C above +70°C).....2.0W
Operating Temperature Range .....-40°C to +85°C
Junction Temperature.....+150°C
Storage Temperature Range .....-65°C to 150°C
Lead Temperature (soldering, 10s) .....+300°C
Soldering Temperature (reflow) .....+260°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} = +2.7V or $V_{OUT(NOM)}$ + 0.5V (whichever is greater), $\overline{SHDN}$ = IN, SS = open, SET = GND, C_{OUT} = 1µF, **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Input Voltage Range	V_{IN}		2.7		5.5	V
Input Undervoltage Lockout		Typical hysteresis = 50mV	2.35	2.45	2.55	V
Output Voltage Accuracy		I_{OUT} = 1mA, T_A = +85°C	-1		1	%
SET Regulation Voltage (Adjustable Mode)		I_{OUT} = 150mA, T_A = +85°C	792	800	808	mV
Line Regulation	ΔV_{LNR}	V_{IN} = V_{OUT} + 0.5V to +5.5V, I_{OUT} = 10mA		0.1		%/V
Load Regulation	ΔV_{LDR}	I_{OUT} = 1mA to 1A		0.8	1.5	%/A
Adjustable Output Voltage Range			0.8		5	V
Maximum Output Current	I_{OUT}	Continuous	1			A_{RMS}
Short-Circuit Current Limit	I_{LIM}	V_{OUT} = 0V	1.0	1.9		A
In-Regulation Current Limit	I_{LIM}	V_{SET} = 0.76V	2.0	4.0		A
SET Dual Mode Threshold			40	80	120	mV
SET Input Bias Current	I_{SET}	V_{SET} = +0.9V		50	300	nA
Ground Current	I_{GND}	I_{OUT} = 100µA		0.5	2.0	mA
		I_{OUT} = 1A		2.5		
Dropout Voltage (Note 1)		I_{OUT} = 1mA, +2.7V < V_{IN} < +5.5V		0.2		mV
		I_{OUT} = 1A, V_{OUT} = +3.3V (Note 2)		200	350	
Output Voltage Noise		f = 10Hz to 1MHz, C_{OUT} = 1µF, I_{OUT} = 150mA		150		μV_{RMS}
Power-Supply Rejection Ratio	PSRR	f = 100kHz, C_{OUT} = 1µF		54		dB
Shutdown Supply Current	I_{OFF}	$\overline{SHDN}$ = GND, V_{IN} = +5.5V, V_{OUT} = 0		0.1	10	µA
$\overline{SHDN}$ Input Threshold	V_{IH}	+2.7V < V_{IN} < +5.5V	1.6			V
	V_{IL}				0.6	
$\overline{SHDN}$ Input Bias Current		$\overline{SHDN}$ = GND or IN		0	0.1	µA
Soft-Start Charge Current	I_{SS}	V_{SS} = 0V		6		µA
$\overline{RST}$ Output Low Voltage		I_{SINK} = 1mA			0.1	V
IN Operating Voltage Range for $\overline{RST}$ Valid		I_{SINK} = 10µA	1.0		5.5	V
$\overline{RST}$ Leakage		$V_{\overline{RST}}$ = +5.5V		0.01	1	µA
$\overline{RST}$ Trip Level Referred to Nominal V_{OUT}		Falling edge, typical hysteresis = 10mV	89	92	95	% OUT
$\overline{RST}$ Release Delay		Rising edge	1	3	5.5	ms
Thermal Shutdown Threshold	T_{SHDN}	Typical thermal hysteresis = +20°C		+170		°C

Dual Mode is a trademark of Maxim Integrated Products.

ELECTRICAL CHARACTERISTICS

(V_{IN} = +2.7V or $V_{OUT(NOM)}$ + 0.5V (whichever is greater), $\overline{SHDN}$ = IN, SS = open, SET = GND, C_{OUT} = 1µF, **T_A = -40°C to +85°C**, unless otherwise noted.) (Note 3)

PARAMETER	SYMBOL	CONDITIONS	MIN	MAX	UNITS
Input Voltage Range	V_{IN}		2.7	5.5	V
Input Undervoltage Lockout		Typical hysteresis = 50mV	2.3	2.6	V
Output Voltage Accuracy		I_{OUT} = 1mA, T_A = +85°C	-1	1	%
SET Regulation Voltage (Adjustable Mode)		I_{OUT} = 150mA, T_A = +85°C	792	808	mV
Load Regulation	ΔV_{LDR}	I_{OUT} = 1mA to 1A		2.0	%/A
Adjustable Output Voltage Range			0.8	5	V
Maximum Output Current	I_{OUT}	Continuous	1		A_{RMS}
Short-Circuit Current Limit	I_{LIM}	V_{OUT} = 0V	1.0		A
In-Regulation Current Limit	I_{LIM}	V_{SET} = +0.76V	2.0		A
SET Dual Mode Threshold			40	120	mV
SET Input Bias Current	I_{SET}	V_{SET} = +0.9V		300	nA
Ground Current	I_{GND}	I_{OUT} = 100µA		2.0	mA
Dropout Voltage (Note 1)		I_{OUT} = 1A, V_{OUT} = +3.3V (Note 2)		350	mV
Shutdown Supply Current	I_{OFF}	$\overline{SHDN}$ = GND, V_{IN} = +5.5V, V_{OUT} = 0V		10	µA
$\overline{SHDN}$ Input Threshold	V_{IH}	+2.7V < V_{IN} < +5.5V	1.7		V
	V_{IL}			0.6	
$\overline{SHDN}$ Input Bias Current		$\overline{SHDN}$ = GND or IN		0.1	µA
$\overline{RST}$ Output Low Voltage		I_{SINK} = 1mA		0.1	V
IN Operating Voltage Range for $\overline{RST}$ Valid		I_{SINK} = 10µA	1.0	5.5	V
$\overline{RST}$ Leakage		$V_{\overline{RST}}$ = +5.5V		1	µA
$\overline{RST}$ Trip Level Referred to Nominal V_{OUT}		Falling edge, typical hysteresis = 10mV	88	95	% OUT
$\overline{RST}$ Release Delay		Rising edge	1	6	ms

Note 1: Dropout voltage is (V_{IN} - V_{OUT}) when V_{OUT} falls to 100mV below the value of V_{OUT} measured when V_{IN} = $V_{OUT(NOM)}$ +0.5V. Since the minimum input voltage is 2.7V, this specification is only meaningful when $V_{OUT} \geq 2.7V$.

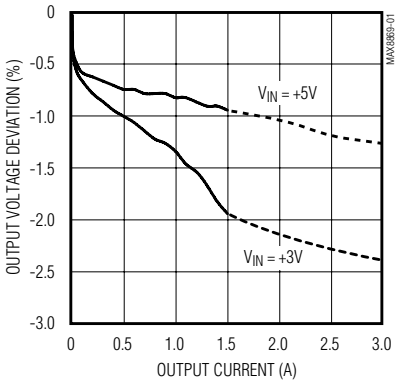
Note 2: The output voltage is externally set using a resistive voltage-divider from OUT to SET.

Note 3: Specifications to -40°C are guaranteed by design, not production tested.

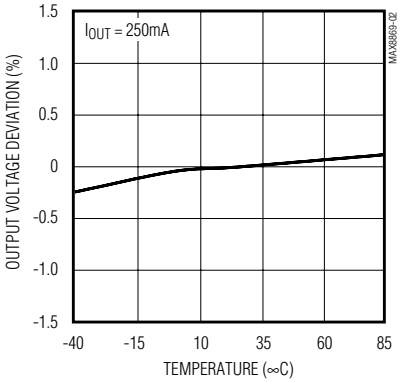
Typical Operating Characteristics

(V_{IN} = +5V, V_{OUT} = +2.5V, $\overline{SHDN}$ = IN, SS = open, C_{OUT} = 1µF, T_A = +25°C, unless otherwise noted.)

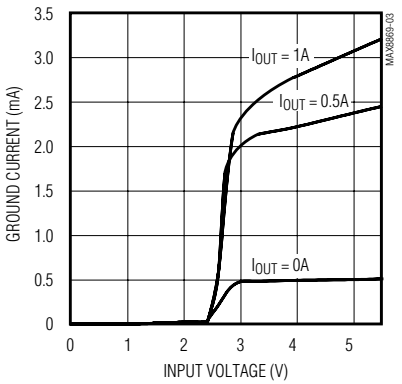
OUTPUT VOLTAGE DEVIATION vs. OUTPUT CURRENT



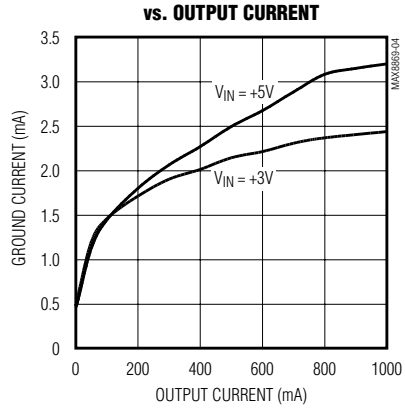
OUTPUT VOLTAGE DEVIATION vs. TEMPERATURE



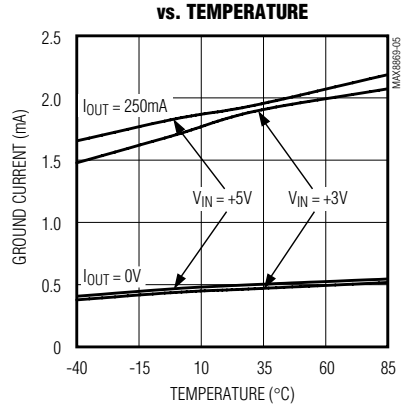
GROUND CURRENT vs. INPUT VOLTAGE



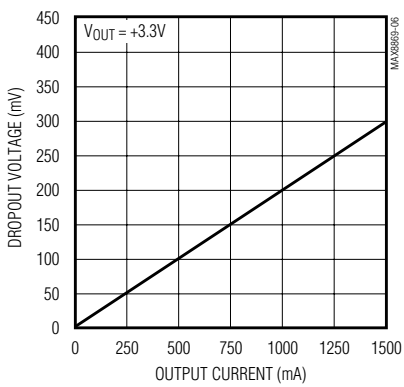
GROUND CURRENT vs. OUTPUT CURRENT



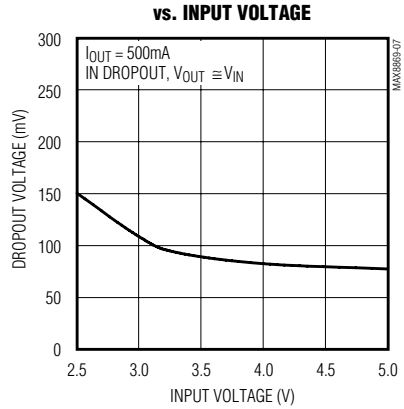
GROUND CURRENT vs. TEMPERATURE



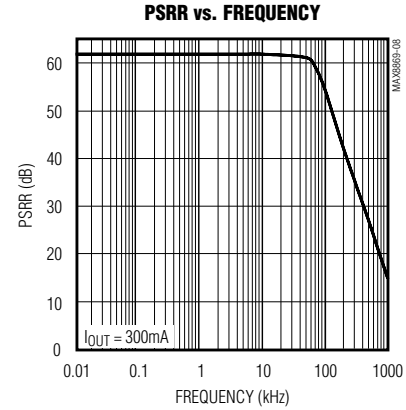
DROPOUT VOLTAGE vs. OUTPUT CURRENT



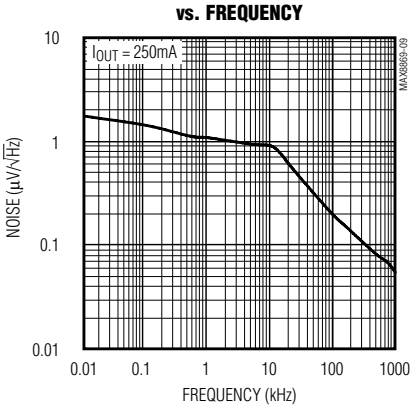
DROPOUT VOLTAGE vs. INPUT VOLTAGE



PSRR vs. FREQUENCY



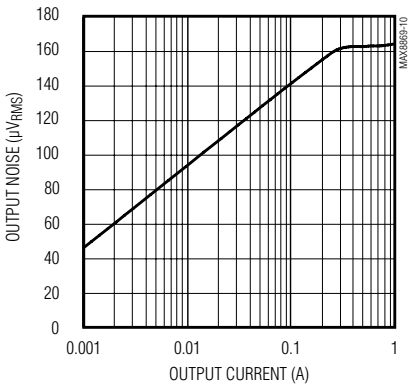
OUTPUT NOISE SPECTRAL DENSITY vs. FREQUENCY



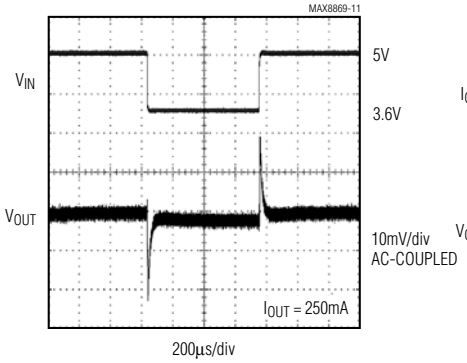
Typical Operating Characteristics (continued)

(V_{IN} = +5V, V_{OUT} = +2.5V, $\overline{SHDN}$ = IN, SS = open, C_{OUT} = 1µF, T_A = +25°C, unless otherwise noted.)

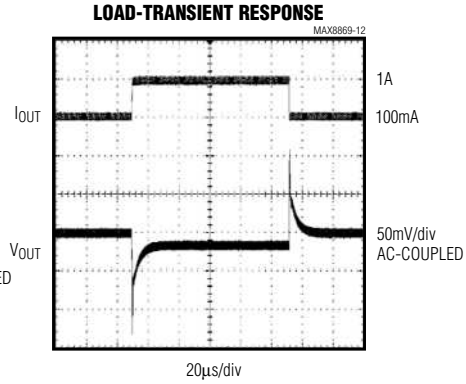
OUTPUT NOISE vs. OUTPUT CURRENT



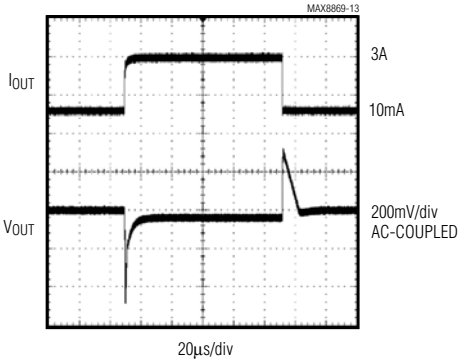
LINE-TRANSIENT RESPONSE



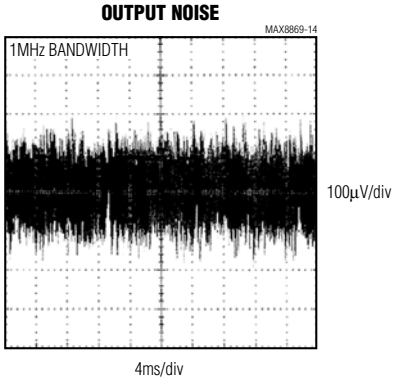
LOAD-TRANSIENT RESPONSE



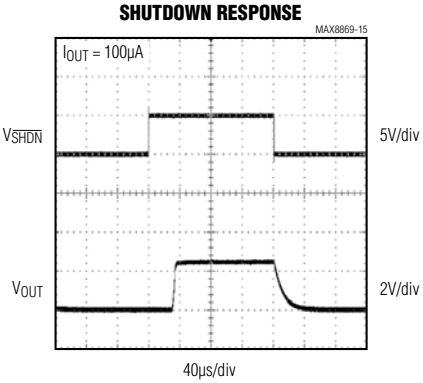
LOAD-TRANSIENT RESPONSE



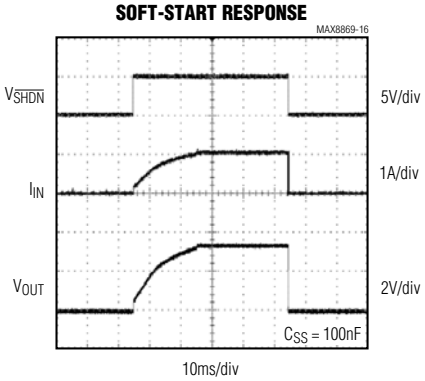
OUTPUT NOISE



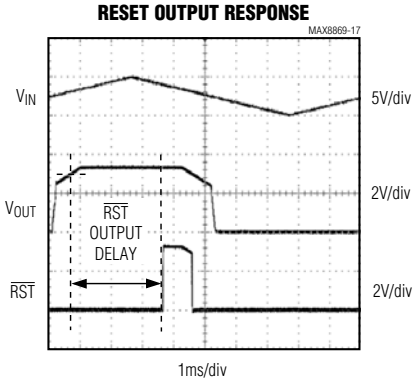
SHUTDOWN RESPONSE



SOFT-START RESPONSE



RESET OUTPUT RESPONSE



Pin Description

PIN	NAME	FUNCTION
1, 9, 16	N.C.	No Connection. Not internally connected.
2, 3, 4, 5	IN	Regulator Input. Connect to power source (+2.7V to +5.5V). Bypass with 1µF or greater capacitor to GND (see *Capacitor Selection and Regulator Stability*). Connect all IN inputs together for proper operation.
6	$\overline{RST}$	Reset Output. Open-drain output is low when V_{OUT} is 8% below its nominal value. $\overline{RST}$ remains low while the output voltage (V_{OUT}) is below the reset threshold and for at least 3ms after V_{OUT} rises to within regulation. Connect a 100kΩ pullup resistor to OUT to obtain an output voltage.
7	$\overline{SHDN}$	Active-Low Shutdown Input. A logic low reduces the supply current to 0.1µA. Connect $\overline{SHDN}$ to IN for normal operation. In shutdown, $\overline{RST}$ is low and the soft-start capacitor discharges.
8	SS	Soft-Start Control. Connect a soft-start capacitor from SS to GND (see *Soft-Start Capacitor Selection*). Leave SS open to disable soft-start.
10	GND	Ground. Solder both GND and EP to a large pad or to the circuit-board ground plane to maximize power dissipation.
11	SET	Voltage-Setting Input. Connect SET to GND for factory-preset output voltage. Connect SET to an external resistor-divider for adjustable output operation.
12, 13, 14, 15	OUT	Regulator Output. Bypass with a 1µF or greater low-ESR capacitor to GND (see *Capacitor Selection and Regulator Stability*). Connect all OUT outputs together for proper operation.
—	EP	Exposed Pad. Connect to a large ground plane to maximize thermal performance. Not intended as an electrical connection point.

Detailed Description

The MAX8869 features Dual Mode operation, allowing a fixed output of +5V, +3.3V, +2.5V, +1.8V, or +1.0V, or adjustable output from +0.8V to +5.0V. The regulators are guaranteed to supply 1A of continuous output current with only 1µF of output capacitance.

As shown in the functional diagram (Figure 1), the device has a 0.8V reference, error amplifier, MOSFET driver, P-channel pass transistor, internal feedback voltage-divider, soft-start function, reset timer, and Dual Mode and low V_{OUT} comparators.

The 0.8V reference is connected to the error amplifier's inverting input. The error amplifier compares this reference with the selected feedback voltage and amplifies the difference. The MOSFET driver reads the error signal and applies the appropriate drive to the P-channel transistor. If the feedback voltage is high, the pass transistor's gate is pulled up, allowing less current to pass to the output. The low V_{OUT} comparator senses when the feedback voltage has dropped 8% below its expected level, causing $\overline{RST}$ to go low.

The output voltage is fed back through either an internal resistor-divider connected to OUT or an external resistor network connected to SET. The Dual Mode comparator examines V_{SET} and selects the feedback path. If V_{SET} is below 80mV, the internal feedback path is used and the output voltage is regulated to the factory-preset voltage. Otherwise, the output voltage is set with the external resistor-divider.

Internal P-Channel Pass Transistor

The MAX8869 features a 1A P-channel MOSFET pass transistor. Unlike similar designs using PNP pass transistors, P-channel MOSFETs require no base drive, which reduces quiescent current. PNP-based regulators also waste considerable current in dropout when the pass transistor saturates and use high base-drive currents under large loads. The MAX8869 does not suffer from these problems and consumes only 500µA of quiescent current even in dropout.

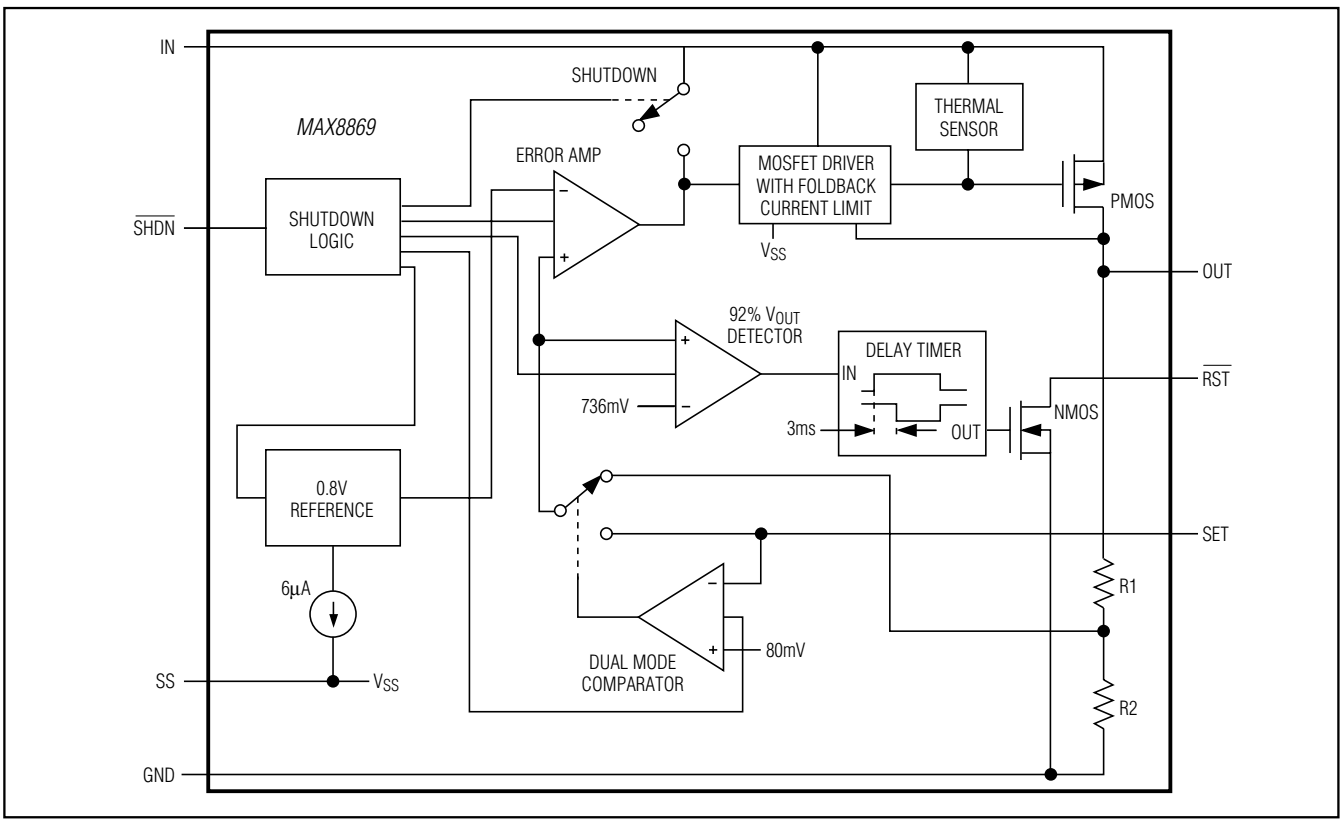


Figure 1. Functional Diagram

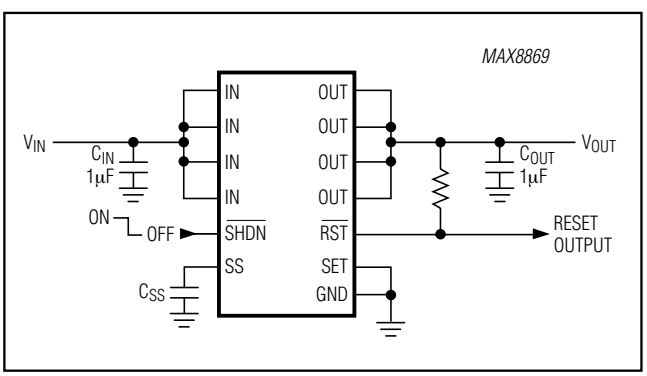


Figure 2. Typical Operating Circuit with Preset Output Voltage

Output Voltage Selection

The MAX8869 features Dual Mode operation. Connect SET to GND (Figure 2) for preset voltage mode (see *Ordering Information*). In adjustable mode, set the output between +0.8V to +5.0V through two external resistors connected as a voltage-divider to SET (Figure 3). The output voltage is set by the following equation:

$$V_{OUT} = V_{SET} (1 + R1 / R2)$$

where V_{SET} = +0.8V. To simplify resistor selection:

$$R1 = R2 (V_{OUT} / V_{SET} - 1)$$

Since the input bias current at SET is nominally 50nA, large resistance values can be used for R1 and R2 to minimize power consumption without losing efficiency. Up to 80kΩ is acceptable for R2.

In preset voltage mode, the impedance between SET and ground should be less than 10kΩ. Otherwise, spurious conditions could cause the voltage at SET to exceed the 80mV Dual Mode threshold.

Shutdown

A logic low on $\overline{SHDN}$ disables the MAX8869. In shutdown, the pass transistor, control circuitry, reference, and all biases are turned off, reducing supply current to typically 0.1µA. Connect $\overline{SHDN}$ to IN for normal operation. In shutdown, $\overline{RST}$ is low and the soft-start capacitor is discharged.

$\overline{RST}$ Comparator

The MAX8869 features a low V_{OUT} indicator that asserts when the output voltage falls out of regulation. The open-drain $\overline{RST}$ goes low when OUT falls 8%

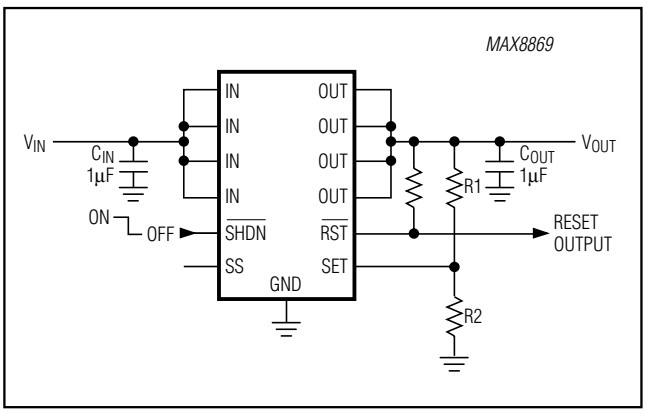


Figure 3. Typical Operating Circuit with Adjustable Output Voltage

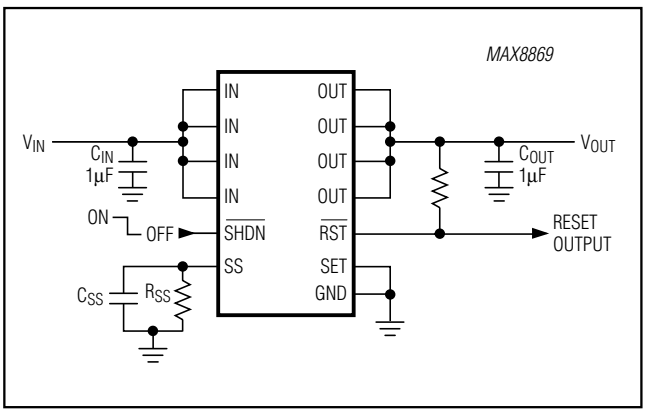


Figure 4. Typical Operating Circuit with Soft-Start and Current-Limit Reduction

below its nominal output voltage. $\overline{RST}$ remains low for 3ms after OUT has returned to its nominal value. A 100kΩ pullup resistor from $\overline{RST}$ to a suitable logic supply voltage (typically OUT) provides a logic control signal. $\overline{RST}$ can be used as a power-on-reset signal to a microcontroller (µC) or can drive an external LED for indicating a power failure. $\overline{RST}$ is low during shutdown. $\overline{RST}$ remains valid for an input voltage as low as 1V.

Soft-Start

As shown in Figure 4, a capacitor on SS allows a gradual buildup of the MAX8869 output, reducing the initial in-rush current peaks at startup. When $\overline{SHDN}$ is driven low, the soft-start capacitor is discharged. When $\overline{SHDN}$ is driven high or power is applied to the device, a constant 6µA current charges the soft-start capacitor. The resulting linear ramp voltage on SS increases the current-limit comparator threshold, limiting the P-channel gate drive (see *Soft-Start Capacitor Selection*). Leave SS unconnected to disable the soft-start feature.

Current Limiting

The MAX8869 features a 4A current limit when the output voltage is in regulation. When the output voltage drops by 8% below its nominal, the current limit folds back to 1.7A. The output can be shorted to ground for an indefinite period of time without damaging the device. Avoid continuous output current of more than 1A to prevent damage.

Both the in-regulation and short-circuit current limits can be reduced from their nominal values by reducing the voltage at the soft-start input (SS) below 1.25V. The current limits scale proportionately with the voltage by $I_{LIM} = I_{LIM_NOM} \times (V_{SS} / 1.25)$. Since the SS input sources a nominal 6µA current, the current limit can be set by tying a resistor (R_{SS}) between SS and GND, so that $I_{LIM} = I_{LIM_NOM} \times (I_{SS} \times R_{SS} / 1.25)$ where I_{SS} = 6µA . With R_{SS} in place, soft-start can still be achieved by placing a capacitor (C_{SS}) in parallel with R_{SS}. The output current now ramps up asymptotically to the reduced current limit rather than the nominal one, increasing the soft-start time. The time required for the current limit to reach 90% of its steady-state value is given by $t_{SS} = 2.3 R_{SS}C_{SS}$.

Thermal Overload Protection

Thermal overload protection limits total power dissipation in the MAX8869. When the junction temperature exceeds T_J = +170°C, the thermal sensor turns off the pass transistor, allowing the IC to cool. The thermal sensor turns the pass transistor on once the IC's junction temperature drops approximately 20°C. Continuous short-circuit conditions will consequently result in a pulsed output.

Thermal overload protection is designed to safeguard the MAX8869 in the event of fault conditions. For continuous operation, do not exceed the absolute maximum junction temperature rating of T_J = +150°C.

Operating Region and Power Dissipation

Maximum power dissipation of the MAX8869 depends on the thermal resistance of the case and circuit board, the temperature difference between the die junction and ambient air, and the rate of air flow. The power dissipation across the device is $P = I_{OUT} (V_{IN} - V_{OUT})$. The resulting maximum power dissipation is:

$$P_{MAX} = [(T_{J(MAX)} - T_A) / (\theta_{JC} + \theta_{CA})]$$

where $(T_{J(MAX)} - T_A)$ is the temperature difference between the maximum allowed die junction (150°C) and the surrounding air; θ_{JC} (junction to case) is the

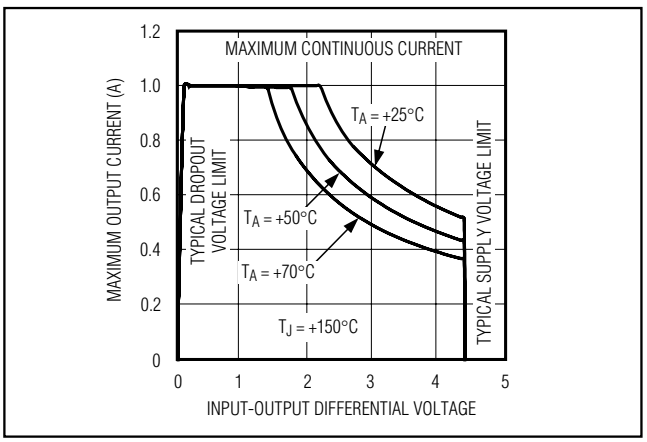


Figure 5. Power Operating Region: Maximum Output Current vs. Input-Output Differential Voltage

thermal resistance of the package chosen, and θ_{CA} is the thermal resistance from the case through the PC board, copper traces, and other materials to the surrounding air. Figure 5 shows the allowable power dissipation for typical PC boards at +25°C, +50°C, and +70°C ambient temperatures.

The MAX8869 TSSOP-EP package features an exposed thermal pad on its underside. This pad lowers the package's thermal resistance by providing a direct thermal heat path from the die to the PC board. Additionally, GND also channels heat. Connect the exposed thermal pad and GND to circuit ground by using a large pad (1in^2 minimum recommended) or multiple vias to the ground plane.

Applications Information

Capacitor Selection and Regulator Stability

Capacitors are required at the MAX8869 input and output. Connect 1µF or greater capacitors between IN and GND (C_{IN}) and OUT and GND (C_{OUT}). Due to the MAX8869's relatively high bandwidth, use only surface-mount ceramic capacitors that have low equivalent series resistance (ESR) and high self-resonant frequency (SRF). Make the input and output traces at least 2.5mm wide (the width of the four parallel inputs and outputs), and connect C_{IN} and C_{OUT} within 6mm of the IC to minimize the impact of PC board trace inductance. The width of the ground trace should be maximized underneath the IC to ensure a good connection between GND and the ground side of the capacitors.

The output capacitor's ESR and SRF can affect stability and output noise. Use capacitors with greater than 5MHz SRF and ESR of 60mΩ or less to ensure stability and optimum transient response. This is particularly true in applications with very low output voltage (<2V) and high output current (>0.5A).

Since some capacitor dielectrics may vary over bias voltage and temperature, consult the capacitor manufacturer specifications to ensure that the capacitors meet these requirements over all voltage and temperature conditions used.

Soft-Start Capacitor Selection

A capacitor (C_{SS}) connected from SS to GND causes the MAX8869 output current to slowly rise during start-up, reducing stress on the input supply. The rise time to full current limit (t_{SS}) is determined by:

$$t_{SS} = 2.08 \times 10^{-4} \times C_{SS}$$

where C_{SS} is in nF. Typical capacitor values between 10nF to 100nF, with a 5V rating, are sufficient.

Because this ramp is applied to the current-limit comparator, the actual time for the output voltage to ramp up depends on the load current and output capacitor. Leave SS open to disable soft-start.

Input-Output (Dropout) Voltage

A regulator's minimum input-to-output voltage differential (dropout voltage) determines the lowest usable supply voltage. In battery-powered systems, this determines the useful end-of-life battery voltage. Since a 0.2Ω P-channel MOSFET is used as the pass device, dropout voltage is the product of $R_{DS(ON)}$ and load current (see *Electrical Characteristics* and Dropout Voltage vs. Output Current in *Typical Operating Characteristics*). The MAX8869 operating current remains low in dropout.

Noise, PSRR, and Transient Response

The MAX8869 is designed to achieve low dropout voltage and low quiescent current in battery-powered systems while still maintaining good noise, transient response, and AC rejection (see PSRR vs. Frequency in the *Typical Operating Characteristics)*. When operating from very noisy sources, supply noise rejection and transient response can be improved by increasing the values of the input and output capacitors and employing passive postfiltering. MAX8869 output noise is typically 150µV$_{RMS}$. (see the Output Noise plot in the *Typical Operating Characteristics)*.

Chip Information

PROCESS: BiCMOS

Package Information

For the latest package outline information and land patterns (footprints), go to **www.maximintegrated.com/packages**. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
16 TSSOP	U16E+3	21-0108	90-0120

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	8/00	Initial release	—
1	6/10	Added lead-free versions to *Ordering Information*, updated Continuous Power Dissipation and added Soldering Temperature to *Absolute Maximum Ratings*, and added EP row to *Pin Description*	1, 2, 6
2	10/12	Added automotive qualified part to *Ordering Information*	1

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