19-3894; Rev 4; 9/08

+5V/Programmable Low-Dropout Voltage Regulator

General Description

The MAX667 low-dropout, positive, linear voltage regulator supplies up to 250mA of output current. With no load, it has a typical quiescent current of 20µA. At 200mA of output current, the input/output voltage differential is typically 150mV. Other features include a low-voltage detector to indicate power failure, as well as early-warning and low-dropout detectors to indicate an imminent loss of output voltage regulation. A shutdown control disables the output and puts the circuit into a low quiescent-current mode.

The MAX667 employs Dual Mode™ operation. One mode uses internally trimmed feedback resistors to produce +5V. In the other mode, the output may be varied from +1.3V to +16V by connecting two external resistors.

The MAX667 is a pin-compatible upgrade to the MAX666 in most applications where the input voltages are above +3.5V. Choose the MAX667 when high output currents and/or low dropout voltages are desired, as well as for improved performance at higher temperatures.

Applications

Battery-Powered Devices

Pagers and Radio Control Receivers

Portable Instruments

Solar-Powered Instruments

Features

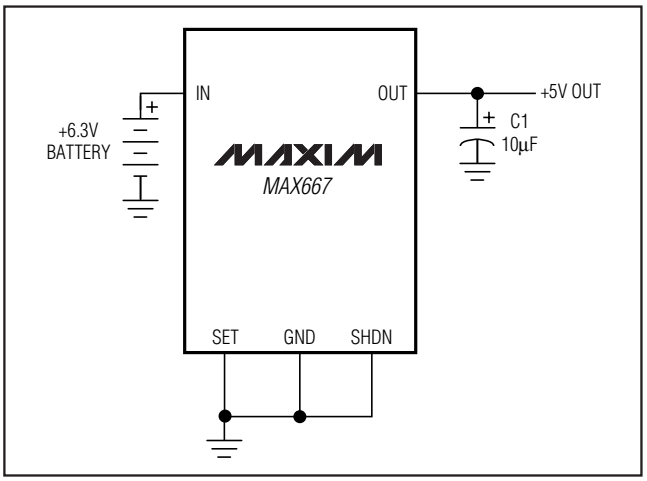
- **350mV Max Dropout at 200mA**
- **250mA Output Current**
- **Normal Mode: 20µA Typ Quiescent Current**
  Shutdown Mode: 0.2µA Typ Quiescent Current
- **Low-Battery Detector**
- **Fixed +5V (Min Component Count) or Adjustable Output**
- **+3.5V to +16.5V Input**
- **Dropout Detector Output**
- **10µF Output Capacitor**

Ordering Information

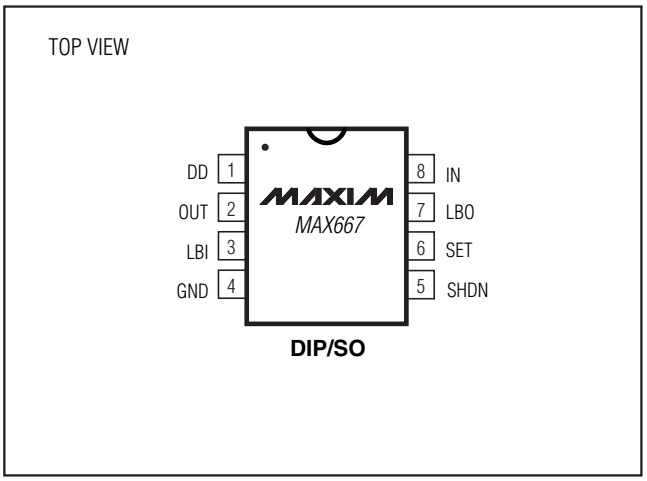
PART	TEMP RANGE	PIN-PACKAGE
MAX667CPA	0°C to +70°C	8 Plastic DIP
MAX667CSA	0°C to +70°C	8 SO
MAX667C/D	0°C to +70°C	Dice*
MAX667EPA	-40°C to +85°C	8 Plastic DIP
MAX667ESA	-40°C to +85°C	8 SO
MAX667MJA	-55°C to +125°C	8 CERDIP**
MAX667MSA/PR	-55°C to +125°C	8 SO†
MAX667MSA/PR-T	-55°C to +125°C	8 SO†

**Contact factory for dice specifications.*
***Contact factory for availability and processing to MIL-STD-883.*
†Contact factory for availability.

Typical Operating Circuit



Pin Configuration



TM *Dual Mode is a trademark of Maxim Integrated Products.*

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

+5V/Programmable Low-Dropout Voltage Regulator

ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage .....+18V
Output Short Circuited to Ground.....1sec
LBO Output Sink Current 50mA
LBO Output Voltage .....GND to V_{OUT}
SHDN Input Voltage .....-0.3V to (V_{IN} + 0.3V)
Input Voltages LBI, SET.....-0.3V to (V_{IN} - 1.0V)
Continuous Power Dissipation
Plastic DIP (derate 9.09mW/°C above +70°C) 727mW
SO (derate 5.88mW/°C above +70°C).....471mW
CERDIP (derate 8.00mW/°C above +70°C).....640mW
Operating Temperature Ranges
MAX667C_A.....0°C to +70°C
MAX667E_A.....-40°C to +85°C
MAX667MJA .....-55°C to +125°C
Storage Temperature Range .....-65°C to +160°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

(GND = 0V, V_{IN} = +9V, V_{OUT} = +5V, C1 = 10µF, unless otherwise noted.)

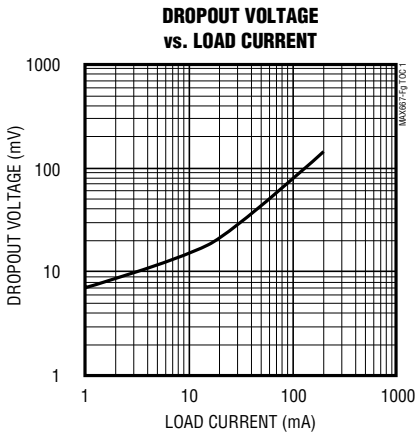
PARAMETER	SYMBOL	CONDITIONS		T_A = +25°C MIN	TYP	MAX	T_A = T_{MIN} to T_{MAX} MIN	TYP	MAX	UNITS
Input Voltage	V_{IN}						3.5		16.5	V
Output Voltage	V_{OUT}	V_{SET} = 0V, V_{IN} = 6V, I_{OUT} = 10mA, T_A = -40°C to +85°C			5		4.8		5.2	V
		V_{SET} = 0V, V_{IN} = 6V, I_{OUT} = 10mA, T_A = -55°C to +125°C			5		4.75		5.25	
Maximum Output Current	I_{OUT}	V_{IN} = 6V, 4.5V < V_{OUT} < 5.5V		250			250			mA
Quiescent Current	I_Q	V_{SHDN} = 2V			0.2	1			2	µA
		V_{SHDN} = 0V, V_{SET} = 0V	I_{OUT} = 0µA		20	25			35	
			I_{OUT} = 100µA		20	30			50	
			I_{OUT} = 200mA		5	15			20	mA
Dropout Voltage (Note1)		I_{OUT} = 100µA			5	60			75	mV
		I_{OUT} = 200mA			150	250			350	
Load Regulation		I_{OUT} = 10mA to 200mA			50	100			250	mV
Line Regulation		V_{IN} = 6V to 10V, I_{OUT} = 10mA			5	10			15	mV
SET Reference Voltage	V_{SET}				1.225		1.20		1.25	V
SET Input Leakage Current	I_{SET}	V_{SET} = 1.5V			0.01	±10			±1000	nA
Output Leakage Current	I_{OUT}	V_{SHDN} = 2V			0.1				1	µA
Short-Circuit Current	I_{OUT}	(Note 2)				400			450	mA
Low-Battery Detector Reference Voltage	V_{LBI}				1.225		1.195		1.255	V
Low-Battery Detector Input Leakage Current	I_{LBI}	V_{LBI} = 1.5V			0.01	±10			±1000	nA
Low-Battery Detector Output Voltage	V_{LBO}	V_{IN} = 9V, V_{LBI} = 2V, I_{LBO} = 10mA				0.25			0.4	V
SHDN Threshold	V_{SHDN}	V_{IH}		1.5			1.5			V
		V_{IL}				0.3			0.3	
SHDN Leakage Current	I_{SHDN}	V_{SHDN} = 0V to V_{IN}			0.01	±10			±1000	nA
Dropout Detector Output Voltage	V_{DD}	V_{SET} = 0V, V_{SHDN} = 0V, R_{DD} = 100kΩ, I_{OUT} = 10mA	V_{IN} = 7V						0.25	V
			V_{IN} = 4.5V				3.5			

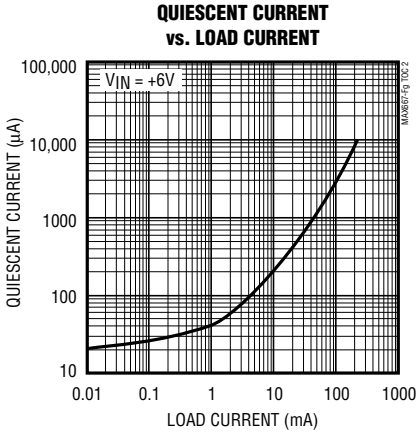
Note 1: Dropout Voltage is V_{IN}-V_{OUT} when V_{OUT} falls to 0.1V below its value at V_{IN} = V_{OUT} + 2V.
Note 2: Short-Circuit Current is pulse tested to maintain junction temperature. Short-circuit duration is limited by package dissipation.

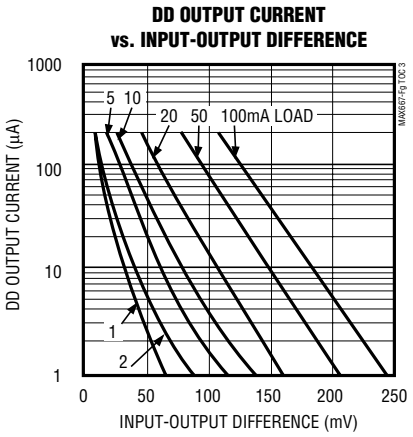
+5V/Programmable Low-Dropout Voltage Regulator

Typical Operating Characteristics

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







Pin Description

PIN	NAME	FUNCTION
1	DD	Dropout Detector Output—the collector of a PNP pass transistor. Normally an open circuit, it sources current as dropout is reached.
2	OUT	Regulated Output Voltage. OUT falls to 0V when SHDN is above 1.5V. SET determines output voltage when SET is above 50mV; otherwise, it is 5V. OUT must be connected to an output filter capacitor.
3	LBI	Low-Battery Detector. A CMOS input to an internal 1.255V comparator whose output is the LBO pin.
4	GND	Ground
5	SHDN	Shutdown Input. Connect to GND for normal operation (output active). Pull above 1.5V to disable OUT, LBO, and DD and to reduce quiescent current to less than 1µA.
6	SET	(Output) Voltage Set, CMOS Input. Connect to GND for 5V output. For other voltages, connect external resistive divider from OUT.
7	LBO	Low-Battery Output. An open-drain N-channel transistor that sinks current to GND when LBI is less than 1.22V.
8	IN	Positive Input Voltage (unregulated)

Detailed Description

Figure 1 shows a micropower bandgap reference, an error amplifier, a PNP pass transistor, and two comparators as the main elements of the MAX667. One comparator, C1, selects the fixed 5V or adjustable operation with an external voltage divider. The other comparator, C2, is a low-battery detector.

The bandgap reference, which is trimmed to 1.22V, connects internally to one input of the error amplifier, A1. The feedback signal from the regulator output supplies the other input of A1 from either an on-chip voltage divider or two external resistors. When SET is grounded, the internal divider provides the error amplifier feedback signal for a fixed 5V output. When SET is more than 50mV above ground, the error amplifier's input switches directly to SET while an external resistor divider from OUT determines the output voltage.

A second comparator, C2, compares the LBI input to the internal reference voltage. LBO is an open-drain FET connected to GND. The low-battery threshold can also be set with a voltage divider at LBI. In addition, the MAX667 has a shutdown input (SHDN) that disables the load and the device while reducing quiescent current when it is pulled high.

+5V Output

Figure 2 shows the connection for a fixed 5V output. The SET input is grounded, and no external resistors are required. Figure 3 shows adjustable output operation. R1 and R2 set the output voltage. SHDN should be grounded if not used.

+5V/Programmable Low-Dropout Voltage Regulator

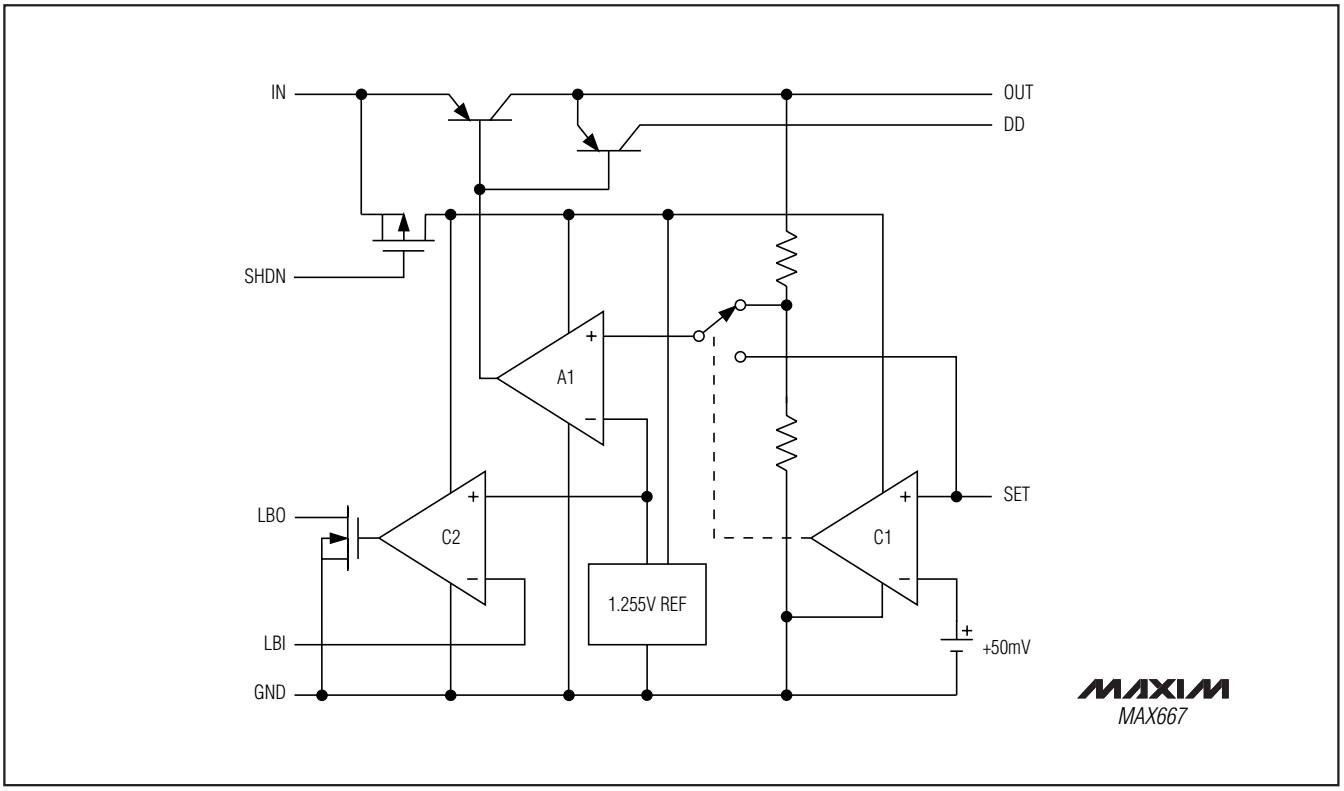


Figure 1. MAX667 Block Diagram

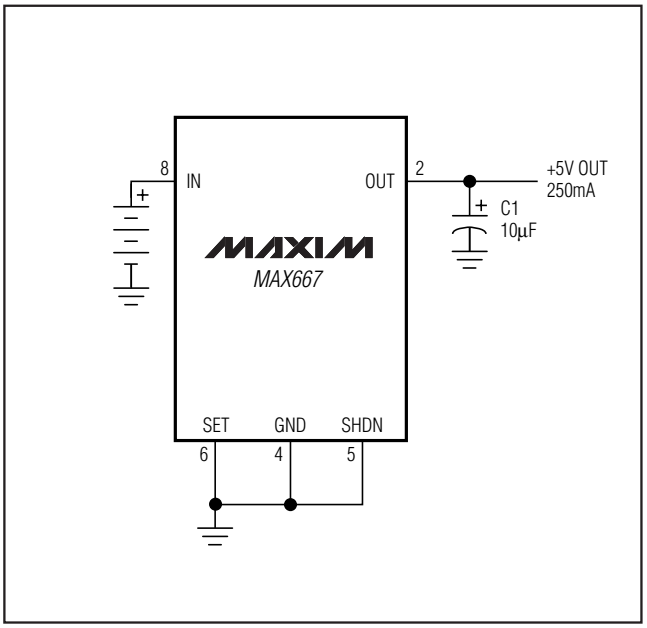


Figure 2. Fixed +5V Regulator

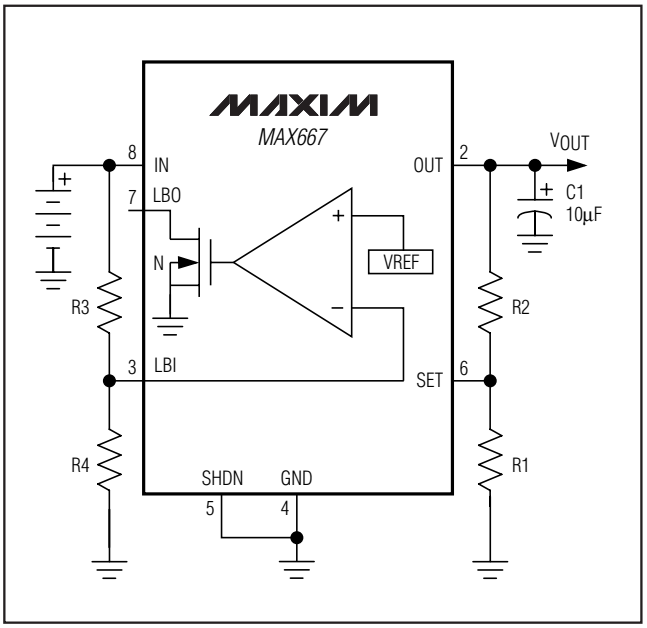


Figure 3. Adjustable Output and Low-Battery Detector

Output-Voltage Selection

If SET is connected to a resistive voltage divider (Figure 3), the output voltage is set by the equation:

$$V_{OUT} = V_{SET} \times (R1 + R2) / R1,$$

where V_{SET} = 1.22V

To simplify resistor selection:

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

Since the input bias current at SET has a maximum value of 10nA, relatively large values can be used for R1 and R2 with no loss of accuracy. 1MΩ is a typical value for R1. The V_{SET} tolerance is less than ±25mV. This allows the output to be preset without trim pots, using only fixed resistors in most cases. However, when resistor values greater than 1MΩ are used, pay special attention to printed circuit board leakage that can introduce error at the SET input.

Shutdown (Standby) Mode

SHDN puts the device into standby mode to conserve power. When this pin is held low, the IC operates normally. If it is driven above 1.5V, the chip shuts down. Quiescent current of the MAX667 is then reduced to less than 1µA, and OUT turns off.

Note that the voltage for SHDN must never be more than 0.3V higher than V_{IN}.

Low-Battery Function

The MAX667 contains circuitry for low-battery detection. If the voltage at LBI falls below the regulator's internal reference (1.22V), LBO, an open-drain output, sinks current to GND. The threshold can be set to any level above the reference voltage by connecting a resistive divider to LBI based on the equation:

$$R3 = R4 \times (V_{BATT} / V_{LBI} - 1)$$

where V_{BATT} is the desired threshold of the low-battery detector, and R3 and R4 are the LBI input divider resistors.

Since LBI input current is no more than 10nA, high values for R3 and R4 minimize loading. If V_{OUT} is 5V, a 5.5V low-battery threshold can be set using 8.2MΩ for R3 and 2.4MΩ for R4. When resistor values greater than 1MΩ are used, pay special attention to PC board leakage that can introduce error at the LBI input.

When the voltage at LBI is below the internal threshold, LBO sinks current to GND. A pull-up resistor of 10kΩ or more connected to OUT can be used with this pin when driving CMOS circuits. Any pull-up resistor connected to LBO should **not** be returned to a voltage source greater than V_{OUT}. When LBI is above the threshold or the MAX667 is in SHDN mode, the LBO output is off.

Dropout Detector

The minimum input-output differential, or dropout voltage, determines the regulator's lowest usable input voltage. In battery-operated systems, this determines the useful end-of-life battery voltage. The MAX667 features very low dropout voltage (see *Electrical Characteristics*). In addition, the MAX667 has a dropout detector output, DD, that changes as the dropout voltage approaches its limit. DD is an open collector of a PNP transistor. The dropout voltage and the dropout detector both depend on the output current and temperature. When the input voltage is more than 300mV above the output voltage, the dropout detector will not conduct. As the differential decreases below 300mV, the DD source current increases abruptly. This current signals a warning that regulation is about to be lost.

Connecting a resistor (typically 100kΩ) from DD to ground develops a voltage that can be monitored by analog circuits or changed to digital levels by a comparator. LBI may be used for this purpose.

Applications Information

Output Capacitor

As with all PNP output regulators, an output capacitor (C1, Figure 2) is required to maintain stability. 10µF is recommended. To ensure stability, the output-capacitor ESR must be sufficiently high. Figure 4 shows the minimum required output-capacitor ESR for a given temperature. Alternatively, a resistor may be added in series with the output capacitor (Figure 5); the sum of the out-

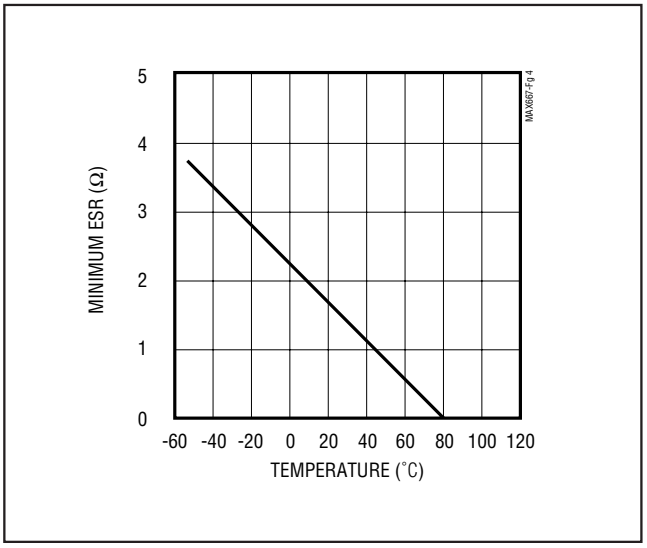


Figure 4. Minimum Required Output-Capacitor ESR vs. Temperature

+5V/Programmable Low-Dropout Voltage Regulator

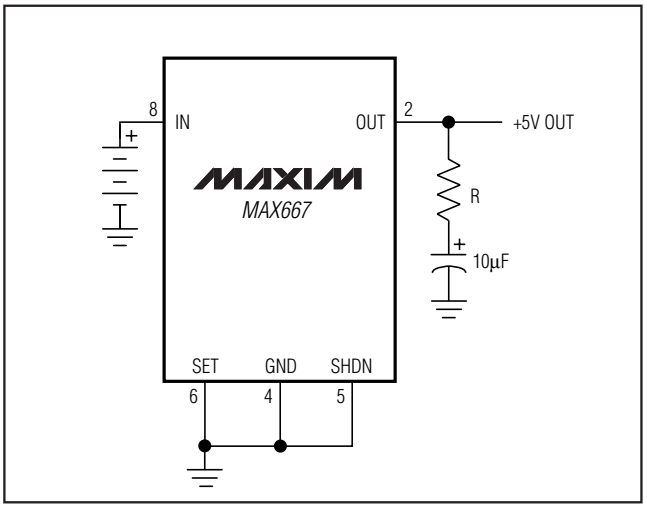


Figure 5. Alternative Stability Scheme Using Resistor R

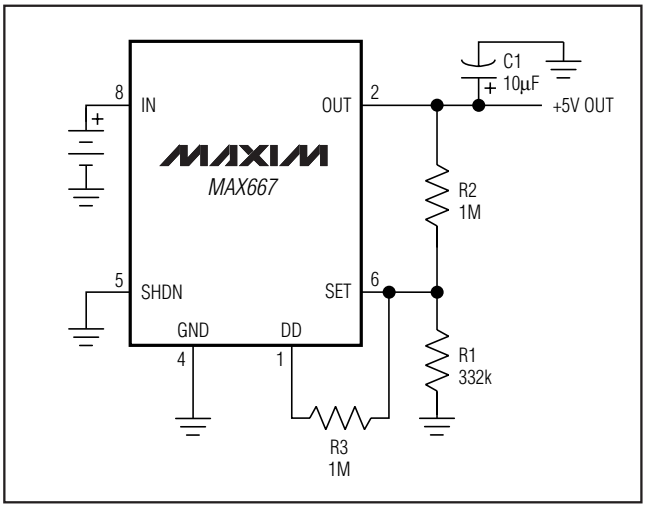


Figure 7. Connection for Minimum Quiescent Current Near Dropout

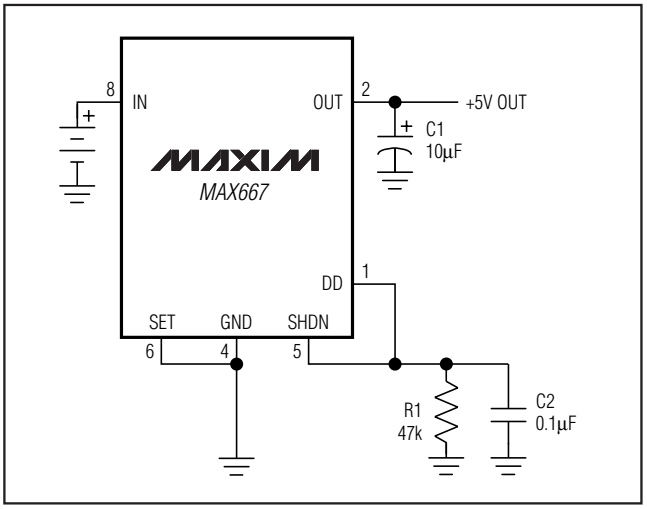


Figure 6. Quiescent-Current Reduction Below Dropout

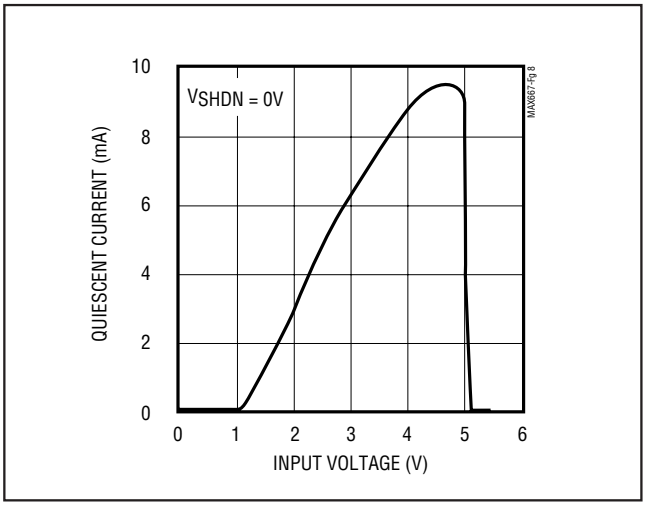


Figure 8. Quiescent Current Below Dropout for Circuit of Figure 2

put-capacitor ESR and this series resistance should, at minimum, meet the requirements shown in Figure 4.

An upper limit to the output-capacitor ESR is important only if step changes to the load are anticipated. Higher ESR results in higher-amplitude output-voltage transients when the output current is varied. A Sanyo OS-CON capacitor, whose ESR is nearly flat over temperature (and is low to begin with), in series with the appropriate resistor ensures the best load-transient performance. A less expensive alternative is to use a tantalum capacitor in series with the resistor.

In most cases, inexpensive aluminum-electrolytic capacitors work well with the MAX667 over their entire temperature range, having sufficient ESR to ensure stability without the need for a series resistor. The ESR of aluminum electrolytics rises, often dramatically, as temperature decreases. For surface-mount applications, certain tantalum capacitors have sufficient ESR; an example is the TAJB106K016 chip capacitor made by AVX (phone: (803) 448-9411, fax: (803) 448-1943).

Battery Drain

The MAX667 uses a PNP output transistor. When the input voltage falls below the desired output voltage, the

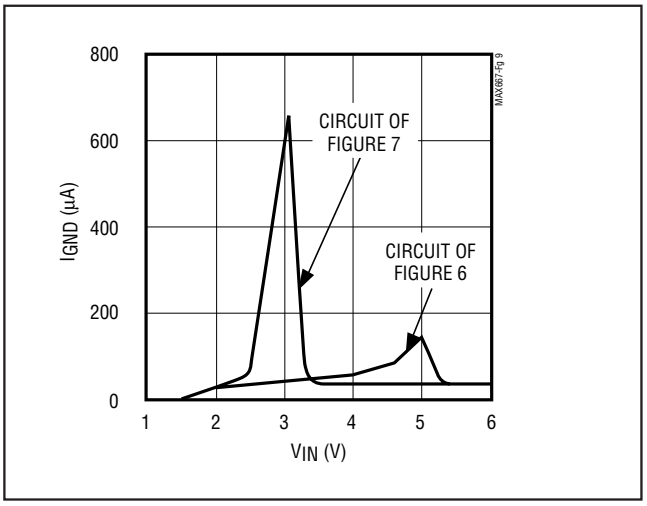


Figure 9. Quiescent Current Below Dropout with Connections of Figures 6 and 7

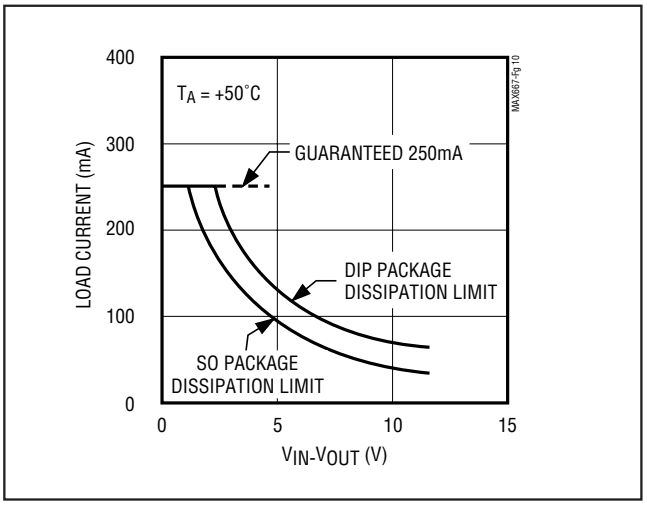


Figure 10. MAX667 Load Current vs. Input-Output Differential Voltage

PNP transistor is turned on fully as regulation is lost. Even with a load current of a few microamperes, the base current will be driven above 5mA. Figure 8 shows how this base current may be significant. Consequently, a mostly discharged battery can be further discharged at end-of-life.

Figure 6 shows how this condition can be modified by connecting DD to SHDN with a 47kΩ resistor, R1, paralleled with a 0.1µF capacitor to GND. This modification reduces the no-load quiescent current to approximately 160µA when dropout is reached (Figure 9), but increases the dropout voltage by about 0.1V. The output voltage drops to approximately 3V once DD begins to activate SHDN, but it does not fall to zero because SHDN is only partially activated.

A second alternate connection (Figure 7) further reduces quiescent current near the dropout voltage, compared to the circuit in Figure 6. The output must be set with external resistors (R1, R2), so DD lowers the output voltage as the input voltage falls by sourcing current into SET via R3. Quiescent current remains low for inputs down to 3.5V, and peaks before falling to 0 at low input voltages. Although the current peak is higher than with the connection in Figure 6, this may be more useful because the quiescent current peaks at an input voltage well below the useful range of most batteries (Figure 9). Also, as IN falls below 5V, OUT tracks IN minus the dropout voltage. This connection still allows separate use of the SHDN input.

Power Dissipation

The MAX667 can regulate currents as high as 250mA and withstand input-output differential voltages as high

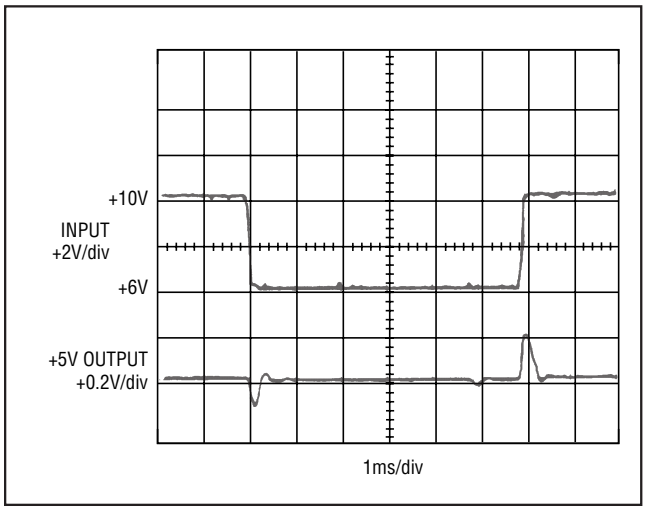


Figure 11. Output Response to +4V/100µs Input Step

as 15.2V, but not simultaneously. The maximum power dissipation is dependent on the package and the temperature (see *Absolute Maximum Ratings*). Figure 10 shows the maximum output current at various input-output differential voltages for the plastic DIP and SO packages. The MAX667 can withstand short-circuit loads up to 1 second.

Operation from AC Sources

The MAX667 is a micropower CMOS regulator intended principally for battery operation. When operating from AC sources, consider power-supply ripple rejection. The MAX667's error amplifier produces very low gain bandwidth, and the input power-supply rejection ratio

+5V/Programmable Low-Dropout Voltage Regulator

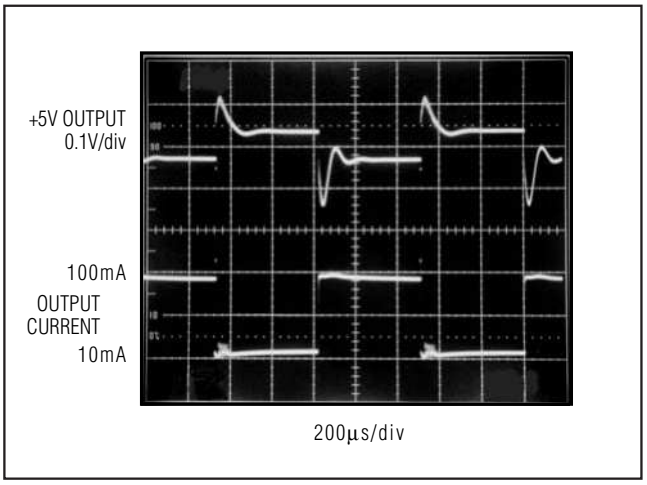


Figure 12. Output Response to 10mA/100mA Load Step with 10µF Output Capacitor (1.5Ω ESR)

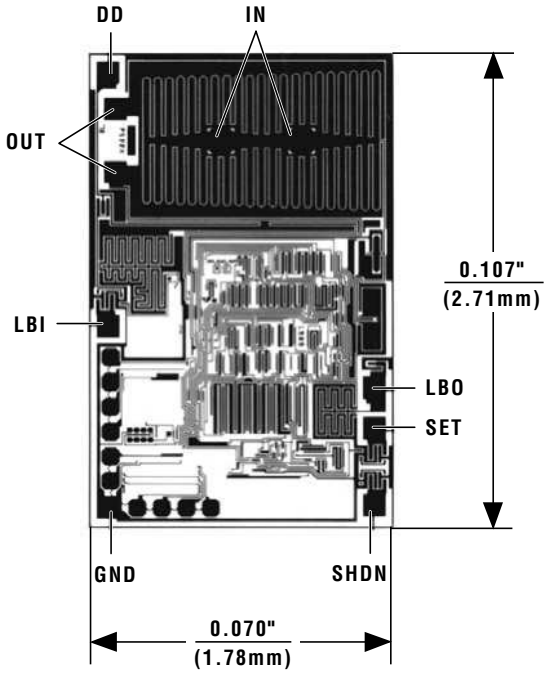
(PSRR) is therefore not specified. Since the output must be connected to a 10µF or larger filter capacitor, the capacitor characteristics dominate the PSRR. Large values of input and output capacitors reduce the ripple.

In addition, both DD and LBI/LBO can trigger on the lowest DC component of the ripple, particularly at high load currents. In the case of the low-battery detector, the ripple can be effectively filtered out by placing a capacitor to ground in parallel with the LBI input pin. The high resistance values that can be used for the voltage divider allow relatively small capacitance values to form an effective lowpass filter at 120Hz. When power is first applied, however, this filter tends to hold LBO low longer than normal.

Transient Considerations

The low operating current and gain-bandwidth product of the internal reference and amplifier result in limited rejection of fast-step input changes. Negative-going steps, which occur in under 100µs, may turn off the output for several milliseconds. An input filter (nominally 10µF) is recommended if input changes greater than 1V and faster than 100µs (other than turn-on or turn-off) are anticipated. Figure 12 shows the output response to a 10mA/100mA instantaneous load step. The relationship between output-capacitor ESR and load-transient response is explained in the *Output Capacitor* section.

Chip Topography



TRANSISTOR COUNT: 65
SUBSTRATE MUST BE LEFT UNCONNECTED

Package Information

For the latest package outline information and land patterns, go to **www.maxim-ic.com/packages**.

PACKAGE TYPE	PACKAGE CODE	DOCUMENT NO.
8 PDIP	P8-T	21-0043
8 SO	S8-4	21-0041
8 CERDIP	J8-2	21-0045

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
4	9/08	Added information for rugged plastic product	1, 8

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