

High-Accuracy, Low-Dropout Linear Regulators

General Description

The MAX687/MAX688/MAX689 low-dropout linear regulators operate with an input-to-output voltage differential limited only by an external PNP transistor. Outputs are fixed at 3.3V (MAX687/MAX688) or 3.0V (MAX689). The only external components required are a PNP pass transistor and output, compensation, and bypass capacitors. Base drive to the external transistor is at least 10mA, permitting output currents to exceed 1A when using high-gain transistors ($\beta >$ 100). Output current limiting is implemented by limiting the external transistor's base current. Output voltage monitoring and shutdown functions are included.

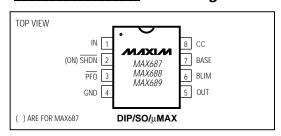
The 3.3V MAX687 automatically shuts down whenever the output voltage drops below 2.96V. An internal power-fail comparator also monitors the output and provides an early warning of low output voltage before the device shuts down. When shut down, the output is latched off until the ON input is pulsed. Turning off the power supply in this way prevents battery damage due to excessive discharge or cell-reversal. Typical applications include portable telephones and other battery-powered equipment where the power supply must be disabled when the battery voltage is low.

The MAX688 and MAX689 do not have an automatic shutdown function, and are identical except for their output voltages. Each device has an active-low shutdown-control input, used to turn its output on or off at any time. As \$\overline{SHDN}\$ falls, the device enters a standby mode before fully shutting down. When in standby, the reference and comparators are fully operational, permitting the transition from normal mode to standby mode to occur at a precise voltage level on \$\overline{SHDN}\$.

_Applications

High-Efficiency Linear Regulator Battery-Powered Devices Portable Instruments Portable Telephones Power Supply or Backup Supply for Memory

Pin Configuration



_____Features

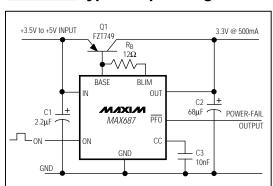
- **♦ Fixed Outputs:**
 - 3.3V (MAX687/MAX688) 3.0V (MAX689)
- ♦ Directly Drives External PNP Transistor
- ♦ 10mA Min Base-Current Drive for >1A Output
- **♦ Low Dropout Voltage:**
 - 100mV Dropout at 650mA Output (FZT749) 40mV Dropout at 200mA Output (FZT749) 0.8V Dropout at 4A Output
- ♦ Power-Fail Output Monitors the Output Voltage
- Automatic, Latched Shutdown when Output Falls Out of Regulation (MAX687)
- Precision Threshold Shutdown Control (MAX688/MAX689)
- **♦ Low Supply Current:**
 - 150µA Operating <1µA Shutdown
- ♦ 2.7V to 11.0V Supply Range
- ♦ 8-Pin DIP/SO/µMAX Packages
- ♦ <2mV Line Transient with 3.4V to 3.6V Input
 </p>
- ♦ Output Accuracy <±2%

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX687CPA	0°C to +70°C	8 Plastic DIP
MAX687CSA	0°C to +70°C	8 SO
MAX687CUA	0°C to +70°C	8 µMAX
MAX687EPA	-40°C to +85°C	8 Plastic DIP
MAX687ESA	-40°C to +85°C	8 SO

Ordering Information continued at end of data sheet.

_Typical Operating Circuit



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ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage IN to GND	12V
Terminal Voltages to GND	
PFO (MAX687)	0.3V to Vout + 0.3V
PFO (MAX688/MAX689)	0.3V to 12V
All Remaining Pins	0.3V to V _{IN} + 0.3V
PFO Sink Current	10mA
PFO Source Current (MAX687)	10mA

Continuous Power Dissipation (T _A = +70°C)
Plastic DIP (derate 9.09mW/°C above +70°C)727mW
SO (derate 5.88mW/°C above +70°C)471mW
μMAX (derate 4.1mW/°C above +70°C)330mW
Operating Temperature Ranges
MAX68_C_A0°C to +70°C
MAX68_E_A40°C to +85°C
Storage Temperature Range65°C to +165°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

 $(V_{IN}=3.8V,\overline{SHDN}=V_{IN}~(MAX688/MAX689),~R_{B}=0\\ \Omega,~C1=2.2\\ \mu\text{F},~C2=10\\ \mu\text{F},~C3=10\\ \text{note},~T_{A}=T_{MIN}~\text{to}~T_{MAX},~\text{unless otherwise noted}.$

PARAMETER	SYMBOL	CON	IDITIONS	MIN	TYP	MAX	UNITS
LINEAR REGULATOR				•			
Supply Voltage	VIN	(Note 1)		2.7		11.0	V
		MAX687/MAX688	VIN = 3.8V, IBASE = 1mA	3.2	3.3	3.4	
	Vout		$3.8V \le V_{IN} \le 11.0V$, $1\mu A \le I_{BASE} \le 10mA$	3.13	3.3	3.47	
Output Voltage	VOUI		VIN = 3.5V, IBASE = 1mA	2.9	3.0	3.1] v
		MAX689	$3.5V \le V_{IN} \le 11.0V$, $1\mu A \le I_{BASE} \le 10mA$	2.85	3.0	3.15	
Dropout Voltage (Note 2)	V _{IN} - V _{OUT}	PNP = FZT749, I _{LOAE}) = 200mA, C2 = 20μF		40		mV
Line Regulation		MAX687/MAX688	3.8V ≤ V _{IN} ≤ 11.0V, I _{BASE} = 1mA		0.4	1.4	- mV/V
		MAX689	$3.5V \le V_{IN} \le 11.0V$, $I_{BASE} = 1mA$		0.4	1.4	
Load Regulation		1μA ≤ I _{BASE} ≤ 10mA			45	60	mV
Supply Current		V _{IN} = 3.8V, PNP = FZT749, no load	On		150	250	μΑ
	IGND		Standby, MAX688/MAX689		11	25	
			Shutdown		< 0.02	1	
BASE Sink Current	IBASE	VBASE = VIN - 1V		10	20	40	mA
Base-Current Limit		R _B is connected from BASE to BLIM (Ω), R _B = 0 Ω to 100 Ω		70 R _B + 5Ω	100 R _B + 5Ω	130 R _B + 5Ω	mA
Start-Up Time		(Note 3)			300		μs
Start-Up Overshoot		(1000 0)			2		%
Load Capacitance	C2	PNP = FZT749, I _{LOAD} = 100mA (Note 4)		10			μF

ELECTRICAL CHARACTERISTICS (continued)

 $(V_{IN}=3.8V, \overline{SHDN}=V_{IN} \text{ (MAX688/MAX689)}, R_B=0\Omega, C1=2.2\mu\text{F}, C2=10\mu\text{F}, C3=10n\text{F}, T_A=T_{MIN} \text{ to } T_{MAX}, \text{ unless otherwise noted.}$ Typical values are at $T_A=+25^{\circ}\text{C.}$)

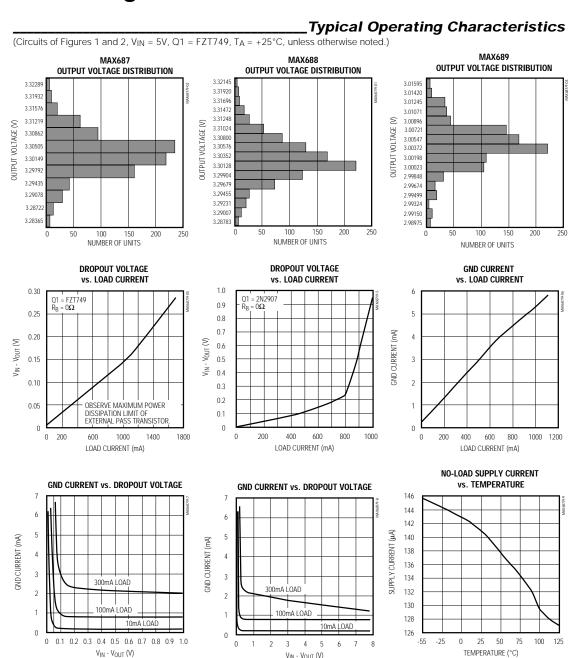
PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS	
MAX687: ON, PFO, SHDN							_	
PFO Threshold Voltage Below V _{NOM} (Note 5)	V _{NOM} - VPFT	Falling Vout, comparators monitor Vout		110	170		mV	
PFO Hysteresis					7		mV	
Shutdown Threshold Voltage Below V _{PFT}	VPFT - VSD	Falling V _{OUT} , comparate	Falling V _{OUT} , comparators monitor V _{OUT}		70		mV	
Shutdown Threshold Voltage	V _{SD}	Falling Vout, comparate	ors monitor V _{OUT}	2.96			V	
PFO Output Voltage High	V _{OH}	I _{SOURCE} = 50µA, part o	n, V _{IN} = 2.7V	V _{OUT} - 0	.3		V	
PFO Output Voltage Low	Vol	ISINK = 1.2mA, VIN = 2.	7V		0.06	0.3	V	
ON Throshold Voltage	VIH	Output turns on		1.0			V	
ON Threshold Voltage	VIL	Output remains off				0.2	7 V	
ON Input Leakage Current					0.2	100	nA	
MAX688/MAX689: SHDN, PFO	•							
PFO Threshold Voltage	VPFT	Falling Vout, com-	MAX688	3.07	3.13	3.19	V	
Pro Tillesiloid Voltage	VPFI	parators monitor Vout	MAX689	2.77	2.85	2.89	7 v	
PFO Hysteresis					7		mV	
	Vson	On, SHDN falling		1.25				
SHDN Threshold Voltages	Vssy	Standby		1.0		1.2	V	
	V _{SSD}	Shutdown				0.2	1	
SHDN Hysteresis		Rising SHDN, standby→on			70		mV	
SHDN Input Current		V <u>SHDN</u> = 1.23V		-25		25	nA	
PFO, SHDN Transient Rejection		Glitch immunity			100		μs	
PFO Output Voltage Low	Vol	ISINK = 1.2mA, VIN = 2.7V			0.06	0.3	V	
PFO Off Leakage Current		V PFO = 11V, V SHDN > 1.25V				1	μΑ	
Output Noise Voltage		10Hz ≤ f ≤ 10kHz, I _{LOAD} = 200mA			66		μVRMS	
Output Noise Voltage	en	10Hz ≤ f ≤ 1MHz, I _{LOAD} = 200mA			105			

- Note 1: Minimum V_{IN} for regulated V_{OUT} depends on the characteristics of the external PNP transistor, and on the load. The reference and comparators are functional down to the minimum voltage specified, but the output may not be in regulation.
- Note 2: Dropout voltage is defined as V_{IN} V_{OUT} when V_{OUT} is 50mV below its value at V_{IN} = V_{NOM} + 1V.
- Note 3: The start-up time specification is the time taken from ON or SHDN rising to BASE sinking current. V_{OUT} rise time is longer and is a function of load capacitance, C2, and load resistance, R_L.
- Note 4: Minimum load capacitance is a function of R_L . Minimum $C2 = 10\mu F$ for loads up to 100mA and $1\mu F/10mA$ for higher loads. ESR of C2 should be no larger than 1/100 of R_L . Guaranteed by design.
- Note 5: The nominal output voltage, V_{NOM}, is defined under the default conditions of testing: V_{IN} = 3.8V, I_{BASE} = 1mA, T_A = T_{MIN} to T_{MAX}.

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MAX687/MAX688/MAX689

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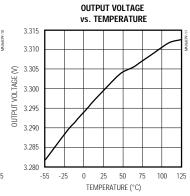
V_{IN} - V_{OUT} (V)

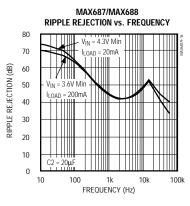
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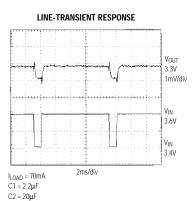


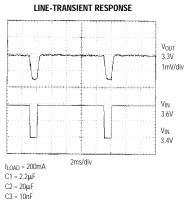
(Circuits of Figures 1 and 2, V_{IN} = 5V, Q1 = FZT749, T_A = +25°C, unless otherwise noted.)

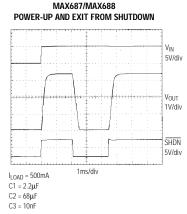


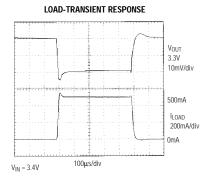


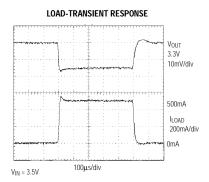












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C3 = 10nF

Pin Description

PIN	NAME	FUNCTION
1	IN	Positive input voltage, 2.7V to 11.0V
2	ON (MAX687)	ON activates the regulator when pulsed high. In order for the regulator to remain on, ON must remain high until V _{OUT} exceeds the internal shutdown threshold voltage. The MAX687 is shut down when V _{OUT} < 2.96V, and remains latched off until ON is pulsed high. When powered up, the MAX687 does not start up until ON is pulsed high. Connect to V _{IN} if not used.
2	SHDN (MAX688/ MAX689)	$\overline{SHDN} \text{ is a three-level input that controls the mode of operation.} \text{The device is on when V} \overline{SHDN} > 1.25 \text{V}.$ The output is disabled and the supply current is reduced (I _{IN} < 25 \mu A, standby mode) when V \overline{SHDN} < 1.2V, and is fully off (I _{IN} < 1 \mu A, shutdown mode) when V \overline{SHDN} < 0.2V. Connect \overline{SHDN} to IN if the shutdown function is not used. \overline{PFO} is low when \overline{SHDN} is low (below 0.2V).
3	PFO	Power-Fail Output. PFO trips when V _{OUT} is 170mV below nominal V _{OUT} at I _{BASE} = 1mA. PFO sources and sinks current in the MAX687, but is an open drain in the MAX688/MAX689. When shut down, PFO is always low and sinks current. Leave PFO open if not used.
4	GND	Ground
5	OUT	Regulator Output. MAX687/MAX688, 3.3V; MAX689, 3.0V.
6	BLIM	Base current limit. A resistor (R _B) connected between BASE and BLIM sets the maximum base drive to the PNP transistor: $I_{BASE} \le 0.1V / (R_B + 5\Omega)$. This limits quiescent current rise during dropout and also provides current limiting without using a current-sense resistor in the collector of the external PNP, thus not impacting dropout. Output current limiting accuracy depends on how well the external PNP beta (hFE) is controlled. Connect to BASE if not used.
7	BASE	Base drive for the external PNP transistor. Current limiting is controlled using a resistor (R _B) connected between BASE and BLIM. For maximum output current, connect BASE to BLIM.
8	CC	Compensation Capacitor. Connect a non-polarized capacitor (10nF to 100nF) from CC to GND.

_Detailed Description

The MAX687/MAX688/MAX689 are precision low-dropout linear regulators employing external PNP transistors to achieve a wide range of output currents at voltages of 3.0V or 3.3V. The maximum base current for the PNP can be limited using a resistor. Limiting the base drive keeps high currents from being wasted when the device is in dropout (e.g., at low input voltages), and limits the regulator's output current. The dropout voltage is limited only by the PNP transistor's VCE(SAT). The Power-Fail Output (PFO) goes low when the output voltage drops 170mV below the nominal level.

The three devices differ in their output voltages, in their shutdown-control functions, and in $\overline{\text{PFO}}$'s output drive (see Table 1).

Table 1. Device Functions

FUNCTION	MAX687	MAX688	MAX689
Vout	3.3V	3.3V	3.0V
Shutdown Control	Automatic at low VOUT. Latched. Use ON to start.	External SHDN	External SHDN
PFO	Sources & Sinks	Open Drain	Open Drain

The MAX687's output voltage is internally monitored; a falling VouT is signaled by PFO going low. As the output falls further, the MAX687 automatically enters a low-power shutdown mode, where the base drive to the external PNP is cut off. PFO trips at a minimum of 110mV below the nominal VouT, and shutdown occurs by 2.96V. PFO is guaranteed to trip before the device

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shuts down. Once the MAX687 is shut down, it can only be turned on again when (a) the ON pin is pulsed high, and (b) the conditions that triggered shutdown have changed (e.g., the load has been reduced or the input voltage has increased). In order for the MAX687 to latch into its on state, the ON pulse must remain high until the output voltage has risen above the shutdown threshold. The internal shutdown can be used to prevent deep discharge of a battery, for example, to provide "self backup" of CMOS RAM or to protect the battery itself.

The RC circuit attached to the ON input in Figure 1 achieves automatic start-up at power-on by delivering a brief pulse whenever the input voltage is suddenly applied. This circuit is not suitable for applications where the input voltage rises slowly. The RC values should be chosen to keep ON high until the output rises above about 3.13V. The values shown in Figure 1 for C4 and R1 (0.1µF and $10k\Omega$) are suitable for most applications. To ensure start-up when the input voltage is very close to the circuit's dropout voltage, when the circuit is used to drive a very large capacitive load, or for high-power circuits ($I_{LOAD} > 3A$), increase the value of R1 to increase the ON pulse width.

The 3.3V MAX688 and the 3.0V MAX689 incorporate the same \overline{PFO} warning whenever V_{OUT} droops. However, the MAX688/MAX689 do not automatically shut down when the output voltage drops even further. Instead, the \overline{SHDN} input controls external shutdown. As \overline{SHDN} is pulled low, the chip first enters a low-current standby state (<25µA). The threshold at which standby mode is entered is precisely controlled (±2%) so the output can be turned off at a well-defined point.

70mV of hysteresis between the standby and on states prevents chatter between the two modes. The voltage applied to the \overline{SHDN} pin can be derived from a resistive divider from V_{IN} . When $V_{\overline{SHDN}}$ is less than 1.2V, the output is off. The device is fully shut down (<1µA) when \overline{SHDN} is pulled below 200mV. \overline{SHDN} is not latched, and as \overline{SHDN} is raised, the MAX688/MAX689 exit shutdown and enter the standby mode. At the higher \overline{SHDN} threshold, the output is turned on.

Figure 1 shows a typical circuit for the MAX687, and Figure 2 shows the same circuit configured for the MAX688/MAX689.

The accuracy of the output current limit depends on accurate knowledge of the PNP pass transistor's current gain (h_{FE}). With R_B = 12 Ω , BLIM limits base current to 6mA (I_{BASE} = 0.1V / (R_B + 5 Ω)). See Base-Current Limiting section.

The PFO comparators on all three devices, and the internal shutdown comparator on the MAX687, reject high-speed spikes (<100µs). This reduces the PFO output's noise sensitivity, and stops the MAX687 from being shut down inadvertently when there is noise on the input supply.

_Transistor Selection

Specifications

The PNP pass transistor must meet specifications for

- current gain,
- power dissipation, and
- collector current.

The hfE influences the maximum output current the circuit can deliver. The largest guaranteed output current

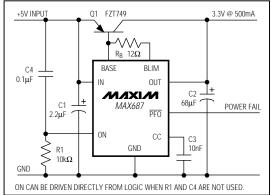


Figure 1. MAX687 Operating Circuit

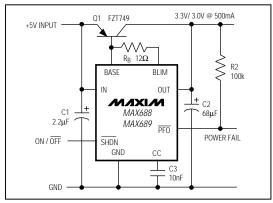


Figure 2. MAX688/MAX689 Operating Circuit

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is given by $I_{LOAD(MAX)} = 10 \text{mA} \times h_{FE(MIN)}$. The transistor's rated power dissipation must exceed the actual power dissipated in the transistor. The power dissipated (PD) equals the maximum load current ($I_{LOAD(MAX)}$) times the maximum input to output voltage differential: PD = $I_{LOAD(MAX)} \times (V_{IN(MAX)} - V_{OUT})$. The rated transistor collector current must exceed the maximum load current. Suitable transistors include the Zetex FZT749, and the 2N2907A (see Table 2).

Base-Current Limiting

A comparator monitors the voltage across the external base-current-limiting resistor (between BASE and BLIM). This sets the maximum base current. If BASE and BLIM are shorted, base current is limited nominally to 20mA due to an internal 5Ω resistor in series with the external resistance. Choose the base-current-limiting resistor, R_B , so the drop across it at rated load is approximately 50mV.

$$R_B \; = \; \frac{\left(50 m V\right) x \; h_{FE(MIN)}}{I_{LOAD(MAX)}} \; - \; 5 \Omega$$

The base drive is controlled so the voltage on BLIM is limited to 100mV below the voltage on BASE; with a 50mV nominal drop across $R_B+5\Omega$, base-current drive is limited to twice the nominal. This limits base current when the external PNP is heavily saturated, such as when the regulator is in dropout due to low input voltage. In addition, if the external PNP's h_{FE} is defined within reasonable limits, base-current control effectively limits output current without a dropout voltage penalty.

Capacitor Selection

Bypass Capacitor (C1)

Connect a bypass capacitor from IN to GND. $4.7\mu\text{F}$ makes the circuit insensitive to layout, and is sufficient for any load. Smaller values may be used—down to $0.33\mu\text{F}$ —with low-ESR capacitors, good board layout, and a low-impedance incoming supply.

Connect the bypass capacitor directly between pins 1 and 4 of the IC, using short leads. Connect the emitter of the PNP transistor directly to the bypass capacitor using a very short trace.

Output Capacitor (C2)

The output filter capacitor must be at least $10\mu F$. For currents above 100mA, use $1\mu F$ of capacitance for every 10mA of load current (e.g., $20\mu F$ for 200mA load, $50\mu F$ for 500mA). Low-ESR capacitors give best stability and transient response. Ensure that the capacitor's ESR is less than 1% of the load resistance. See Table 2 for a list of manufacturers. Sanyo OS-CON capacitors are recommended for applications operating at temperatures below $0^{\circ}C$.

Compensation Capacitor (C3)

Connect a compensation capacitor from CC to GND. 10nF is recommended, although higher values (up to 100nF) may also be used. Higher C3 values eliminate power-on overshoot, but extend power-up times. Current flowing into or out of CC causes the regulator's reference voltage to change, resulting in shifted output voltage and trip thresholds. Use non-polarized capacitors (e.g., ceramic, polyester, etc.) to keep leakage currents below 25nA. Aluminum and tantalum electrolytic capacitors are unsultable because of their high leakage currents.

_Power-Fail Output

The PFO output trips when VOUT is 170mV below nominal VOUT at IBASE = 1mA. PFO sources and sinks current in the MAX687, but is an open drain in the MAX688/MAX689 and only sinks current. When shut down, PFO is always low regardless of the voltage at OUT. Leave PFO open if it is not used.

8 ______

_Applications Information

High-Power Output Circuit

Figure 3 shows a pseudo-Darlington transistor configuration to increase load-current capability and maintain a low dropout voltage with a 4A load. A heatsink must be added when high power is dissipated in the pass transistor.

Figure 4 shows the (V_{IN} - V_{OUT}) voltage required to maintain regulation for different load currents. Figure 5 shows an oscilloscope plot of the transient response of a 200mA to 4A load step.

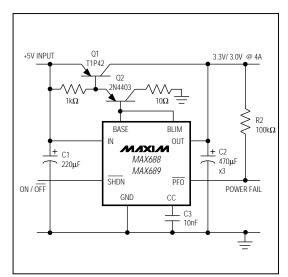


Figure 3. 4A Low-Dropout Circuit

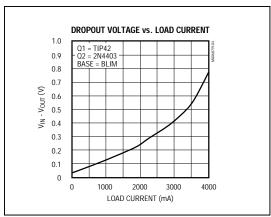


Figure 4. Dropout Voltage vs. Load Current of Figure 3

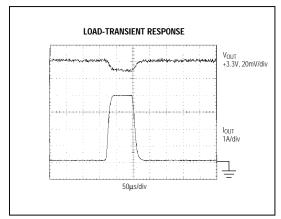


Figure 5. Transient Response for a 200mA to 4A Load Step Using Circuit of Figure 3

MAX687/MAX688/MAX689

High-Accuracy, Low-Dropout Linear Regulators

Table 2a. Component Suppliers

DEVICE	MANUFACTURER	PRODUCTION METHOD		
CAPACITORS				
267 series	Matsuo	Surface Mount		
F95 Tantalum series	Nichicon			
595 Tantalum series	Sprague			
OS-CON series low-ESR organic semiconductor	Sanyo	Through-Hole		
LXF series	United Chemi-Con			
BIPOLAR TRANSISTORS				
ZTX749	X749 Zetex			
T1P42	Motorola	Through-Hole		
2N4403	Motorola	Tillough-noie		
2N2907A	Motorola			
CMPT2907A	Central Semiconductor			
PZT2907AT1	Motorola	Surface Mount		
FZT749	Zetex			

Table 2b. Manufacturers' Phone and Fax Numbers

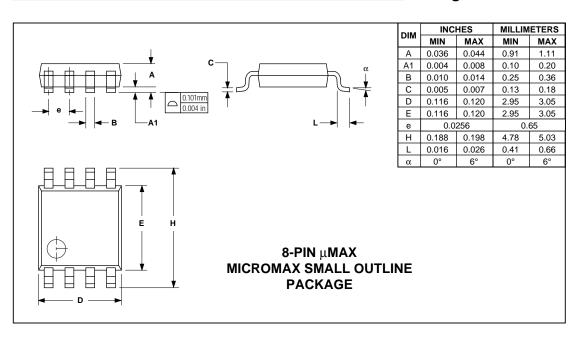
MANU- FACTURER	COUNTRY	TELEPHONE	FAX
Central Semiconductor	USA	(516) 435-1110	(516) 435-1824
Matsuo	USA	(714) 969-2491	(714) 960-6492
Motorola	USA	(602) 244-3370	(602) 244-4015
Nichicon	USA	(708) 843-7500	(708) 843-2798
MICHICOH	Japan	+81-7-5231- 8461	+81-7-5256- 4158
Canyo	USA	(619) 661-6835	(619) 661-1055
Sanyo	Japan	+81-7-2070- 6306	+81-7-2070- 1174
Sprague	USA	(603) 224-1961	(603) 224-1430
United Chemi-Con	USA	(714) 255-9500	(714) 255-9400
7etex	USA	(516) 543-7100	(516) 864-7630
Zelex	UK	+44-61-627- 5105	+44-61-627- 5467

_Ordering Information (continued)

PART	TEMP. RANGE	PIN-PACKAGE
MAX688CPA	0°C to +70°C	8 Plastic DIP
MAX688CSA	0°C to +70°C	8 SO
MAX688CUA	0°C to +70°C	8 µMAX
MAX688EPA	-40°C to +85°C	8 Plastic DIP
MAX688ESA	-40°C to +85°C	8 SO
MAX689CPA	0°C to +70°C	8 Plastic DIP
MAX689CSA	0°C to +70°C	8 SO
MAX689CUA	0°C to +70°C	8 µMAX
MAX689EPA	-40°C to +85°C	8 Plastic DIP
MAX689ESA	-40°C to +85°C	8 SO

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Package Information



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