MIC2950-02/03 and MIC2951-01/02/03

Adjustable Micropower Voltage Regulators

Preliminary Information T-58-11-23

General Description

The MIC2950 and MIC2951 are"bulletproof" micropower voltage regulators with very low dropout voltage (typically 40 mV at light loads and 380 mV at 100 mA), and very low quiescent current (75 µA typical). Like their predecessors the LP2950 and LP2951, the quiescent current of the MIC2950/MIC2951 increases only slightly in dropout, thus prolonging battery life. The MIC2950/MIC2951 are pin for pin compatible with the LP2950/LP2951.

The key additional features and improvements offered include higher output current (150mA), positive transient protection for up to 60 V (load dump), and the ability to survive an unregulated input voltage transient of up to 20V below ground (reverse battery).

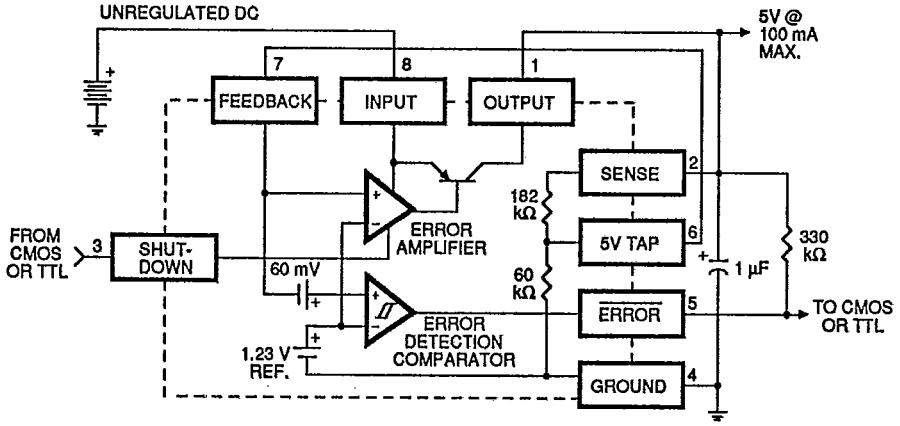
Features

- High accuracy 5V, guaranteed 150 mA output
- Extremely low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Use as regulator or reference
- Needs only 1.5 µF for stability
- Current and thermal limiting
- Unregulated DC input can withstand -20 V negative transients and +60 V positive transients

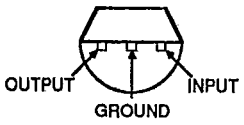
MIC2951 Versions Only

- Error flag warns of output dropout
- Logic-controlled electronic shutdown
- Output programmable from 1.24 to 29V

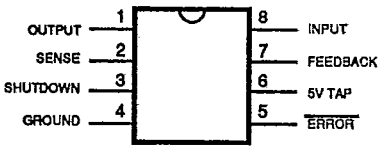
Block Diagram and Pin Configuration



MIC2951 Pinout
(MIC2951-01AJ, MIC2951-02AJ, MIC2951-03AJ, MIC2951-02BN or MIC2951-03BN)



TO-92 Plastic Package Bottom View
(MIC2950-02BZ-5.0, MIC2950-03BZ-5.0)



SO-8 Package
(MIC2951-02BM or MIC2951-03BM)

Available in a 3-pin TO-92 package, the MIC2950 is pin-compatible with the older 5V regulators. Plastic or ceramic DIP packages and additional system functions such as programmable output voltage and logic controlled shutdown are available with the 8-lead MIC2951.

These system functions also include an error flag output that warns of a low output voltage, which is often due to failing batteries on the input. This may also be used as a power-on reset. A logic-compatible shutdown input is also available which enables the regulator to be switched on and off. This part may also be pin-strapped for a 5 V output, or programmed from1.24 V to 29 V with the use of two external resistors.

The MIC2950 is available as either an -02 or -03 version. The -02 and -03 versions are guaranteed for junction temperatures from -40°C to +125°C; the -02 version has a tighter output and reference voltage specification range over temperature. The MIC2951 is available as an -01, -02 , or -03 version. The -01 version is guaranteed for junction temperatures from -55°C to +150°C, and has slightly different specifications limits over the full operating temperature range.

The MIC2950 and MIC2951 have a tight initial tolerance (0.5% typical), a very low output voltage temperature coefficient which allows use as a low-power voltage reference, and extremely good load and line regulation (.05% typical). This greatly reduces the error in the overall circuit, and is the result of careful design techniques and process control.

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Ordering Information

Part Number	Temperature Range*	Package
MIC2950-02BZ MIC2950-03BZ	-40°C to +125°C	3-pin TO-92 plastic
MIC2951-02BM MIC2951-03BM	-40°C to +125°C	8-pin SO-8
MIC2951-01AJ	-55°C to +150°C	8-pin CERDIP
MIC2951-02BJ MIC2951-03BJ	-40°C to +125°C	8-pin CERDIP
MIC2951-02BN MIC2951-03BN	-40°C to +125°C	8-pin Plastic DIP

* Junction temperatures

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, contact your local Micrel representative/distributor for availability and specifications.

Power dissipation	Internally Limited
Lead Temp. (Soldering, 5 seconds)	260°C
Storage Temperature Range	–65°C to +150°C
Operating Junction Temperature Range (Note 8)	
MIC2951-01	–55°C to +150°C
MIC2950-02/MIC2950-03, MIC2951-02/MIC2951-03	–40°C to +125°C
Input Supply Voltage (Note 9)	–20V to +60V
Feedback Input Voltage (Notes 10 and 11)	–1.5V to +30V
Shutdown Input Voltage (Note 10)	–0.3V to +30V
Error Comparator Output Voltage (Note 10)	–0.3V to +30V

ESD Rating is to be determined.

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Electrical Characteristics (Note 1)

Parameter	Conditions (Note 2)	MIC2951-01 Typ.	MIC2951-01 Tested Limit (Note 3)	MIC2950-02 MIC2951-02 Typ.	MIC2950-02 MIC2951-02 Tested Limit (Note 3)	MIC2950-02 MIC2951-02 Design Limit (Note 4)	MIC2950-03 MIC2951-03 Typ.	MIC2950-03 MIC2951-03 Tested Limit (Note 3)	MIC2950-03 MIC2951-03 Design Limit (Note 4)	Units
Output Voltage	$T_J = 25°C$	5.000	5.025 4.975	5.000	5.025 4.975		5.000	5.050 4.950		V max V min
	$-25°C \le T_J \le 85°C$					5.050 4.950			5.075 4.925	V max V min
	Full Operating Temperature Range		**5.060** **4.940**			**5.060** **4.940**			**5.100** **4.900**	V max V min
Output Voltage	$100\ \mu A \le I_L \le 150$ mA $TJ \le TJ_{MAX}$		**5.075** **4.925**			**5.070** **4.930**			**5.120** **4.880**	V max V min
Output Voltage Temperature Coefficient	(Note 13)	**20**	**120**	**20**		**100**	**50**		**150**	ppm/°C
Line Regulation (Note 14)	$6V \le V_{IN} \le 30V$ (Note 15)	0.03	0.10 **0.50**	0.03	0.10	**0.20**	0.04	0.20	**0.40**	% max % max
Load Regulation (Note 14)	$100\ \mu A \le I_L \le 150$ mA	0.04	0.10 **0.30**	0.04	0.10	**0.20**	0.10	0.20	**0.30**	% max % max
Dropout Voltage (Note 5)	$I_L = 100\ \mu A$	50	80 **150**	50	80	**150**	50	80	**150**	mV max mV max
	$I_L = 150$ mA	380	450 **600**	380	450	**600**	380	450	**600**	mV max mV max
Ground Current	$I_L = 100\ \mu A$	75	120 **140**	75	120	**140**	75	120	**140**	µA max µA max
	$I_L = 150$ mA	11	16 **20**	11	16	**20**	11	16	**20**	mA max mA max
Dropout Ground Current	$V_{IN} = 4.5V$ $I_L = 100\ \mu A$	110	170 **200**	110	170	**200**	110	170	**200**	µA max µA max
Current Limit	$V_{OUT} = 0$	240	300 **350**	240	300	**350**	240	300	**350**	mA max mA max
Thermal Regulation	(Note 14)	0.05	0.20	0.05	0.2		0.05	0.20		%/W max
Output Noise, 10 Hz to 100 KHz	$C_L = 1.5\ \mu F$	430		430			430			µV rms
	$C_L = 200\ \mu F$	160		160			160			µV rms
	$C_L = 3.3\ \mu F$ (Bypass = 0.01 µF Pins 7–1 (MIC2951))	100		100			100			µV rms

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Electrical Characteristics (Note 1) (Continued)

Parameter	Conditions (Note 2)	MIC2951-01 Typ.	MIC2951-01 Tested Limit (Note 3)	MIC2951-02 Typ.	MIC2951-02 Tested Limit (Note 3)	MIC2951-02 Design Limit (Note 4)	MIC2951-03 Typ.	MIC2951-03 Tested Limit (Note 3)	MIC2951-03 Design Limit (Note 4)	Units
Reference Voltage		1.235	1.250 **1.260** 1.220 **1.200**	1.235	1.250 1.220	 **1.260** **1.200**	1.235	1.260 1.210	 **1.270** **1.200**	V max V max V min V min
Reference Voltage	(Note 7)		**1.270** **1.190**			**1.270** **1.190**			**1.285** **1.185**	V max V min
Feedback Pin Bias Current		20	40 **60**	20	40	 **60**	20	40	 **60**	nA max nA max
Reference Voltage Temperature Coefficient	(Note 13)	20		20			50			ppm/°C
Feedback Pin Bias Current Temperature Coefficient		0.1		0.1			0.1			nA/°C
Output Leakage Current	V_{OH} = 30V	0.01	1.00 **2.00**	0.01	1.00	 **2.00**	0.01	1.00	 **2.00**	µA max µA max
Output Low Voltage	V_{IN} = 4.5V I_{OL} = 400 µA	150	250 **400**	150	250	 **400**	150	250	 **400**	mV max mV max
Upper Threshold Voltage	(Note 6)	60	40 **25**	60	40	 **25**	60	40	 **25**	mV min mV min
Lower Threshold Voltage	(Note 6)	75	95 **140**	75	95	 **140**	75	95	 **140**	mV max mV max
Hysteresis	(Note 6)	15		15			15			mV
Input Logic Voltage	 Low High	1.3	 **0.6** **2.0**	1.3		 **0.7** **2.0**	1.3		 **0.7** **2.0**	V V max V min
Shutdown Pin Input Current	$V_{SHUTDOWN}$ = 2.4V	30	50 **100**	30	50	 **100**	30	50	 **100**	µA max µA max
	$V_{SHUTDOWN}$ = 30V	450	600 **750**	450	600	 **750**	450	600	 **750**	µA max µA max
Regulator Output Current in Shutdown	(Note 12)	3	10 **20**	3	10	 **20**	3	10	 **20**	µA max µA max

Note 1: Boldface limits apply at temperature extremes.

Note 2: Unless otherwise specified all limits guaranteed for $T_J = 25°C$, $V_{IN} = 6$ V, $I_L = 100$ µA and $C_L = 1$ µF. Additional conditions for the 8-pin versions are Feedback tied to 5V Tap and Output tied to Output Sense ($V_{OUT} = 5$ V) and $V_{SHUTDOWN} \leq 0.6$ V.

Note 3: Guaranteed and 100% production tested.

Note 4: Guaranteed but not 100% production tested. These limits are not used to calculate outgoing AQL levels.

Note 5: Dropout Voltage is defined as the input to output differential at which the output voltage drops 100 mV below its nominal value measured at 1V differential. At very low values of programmed output voltage, the minimum input supply voltage of 2 V (2.3 V over temperature) must be taken into account.

Note 6: Comparator thresholds are expressed in terms of a voltage differential at the Feedback terminal below the nominal reference voltage measured at 6V input. To express these thresholds in terms of output voltage change, multiply by the error amplifier gain = V_{OUT} / V_{REF} = (R1 + R2)/R2. For example, at a programmed output voltage of 5V, the Error output is guaranteed to go low when the output drops by 95 mV x 5V/1.235 V = 384 mV. Thresholds remain constant as a percent of VOUT as VOUT is varied, with the dropout warning occurring at typically 5% below nominal, 7.5% guaranteed.

Note 7: $V_{REF} \leq V_{OUT} \leq (V_{IN} - 1\ V)$, $2.3V \leq V_{IN} \leq 30V$, $100\ \mu A < I_L \leq 150$ mA, $T_J \leq T_{J\,MAX.}$

Note 8: The junction-to-ambient thermal resistance of the TO-92 package is 180°C/W with 0.4" leads and 160°C/W with 0.25" leads to a PC board. The thermal resistances of the 8-pin DIP packages are105°C/W for the molded plastic (N) and 130°C/W for the CERDIP (J) junction to ambient when soldered directly to a PC board. Junction to ambient thermal resistance for the S.O. (M) package is 160°C/W.

Note 9: Maximum positive supply voltage of 60 V must be of limited duration (< 100 mS) and duty cycle (1%). The maximum continuous supply voltage is 30 V.

Note 10: May exceed input supply voltage.

Note 11: When used in dual-supply systems where the output terminal sees loads returned to a negative supply, the output voltage should be diode-clamped to ground.

Note 12: $V_{SHUTDOWN} \geq 2$ V, $V_{IN} \leq 30$ V, $V_{OUT} = 0$, with Feedback pin tied to 5V Tap.

Note 13: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 14: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 50 mA load pulse at $V_{IN} = 30$ V (1.25 W pulse) for T = 10 mS.

Note 15: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered in the specification for thermal regulation.

Note 16: Line regulation for the MIC2951 is tested at 150°C for $I_L = 1$ mA. For $I_L = 100$ µA and $T_J = 125°C$, line regulation is guaranteed by design to 0.2%. See Typical Performance Characteristics for line regulation versus temperature and load current.

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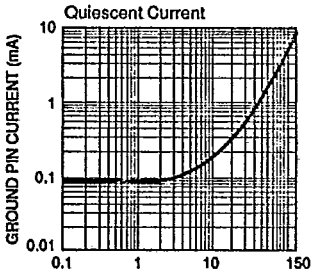
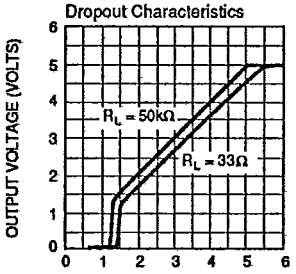
Typical Performance Characteristics

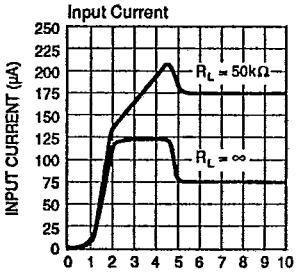
Quiescent Current



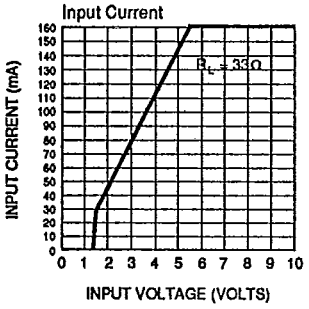
Dropout Characteristics



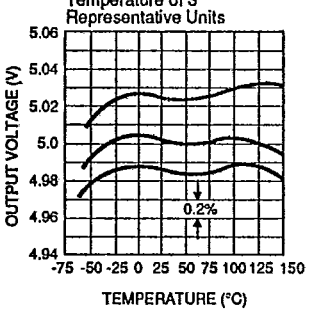
Input Current



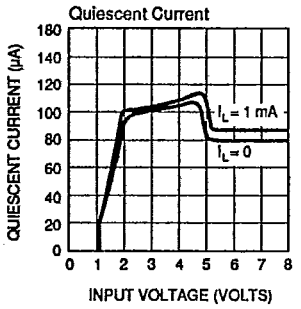
Input Current



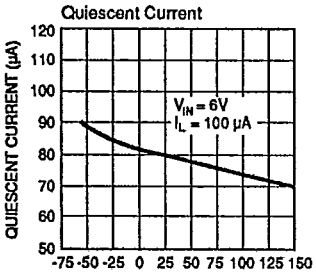
Output Voltage vs. Temperature of 3 Representative Units



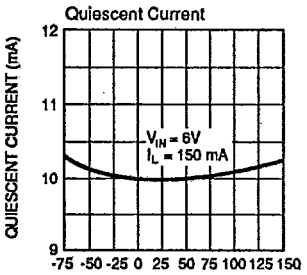
Quiescent Current



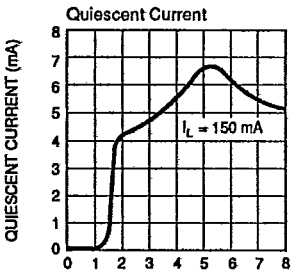
Quiescent Current



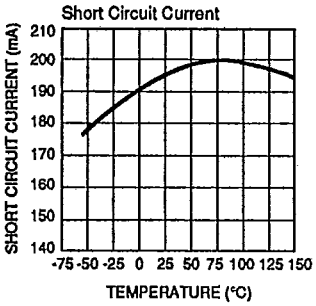
Quiescent Current



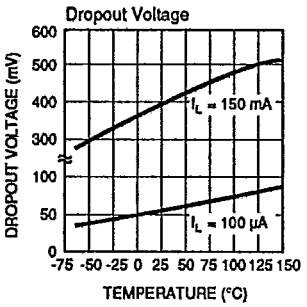
Quiescent Current



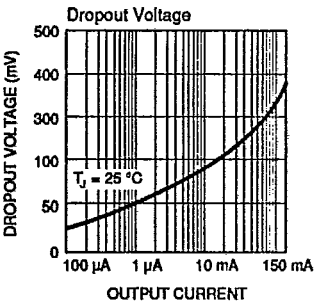
Short Circuit Current



Dropout Voltage



Dropout Voltage



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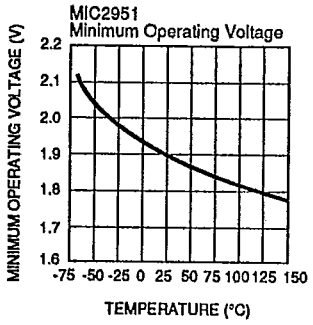
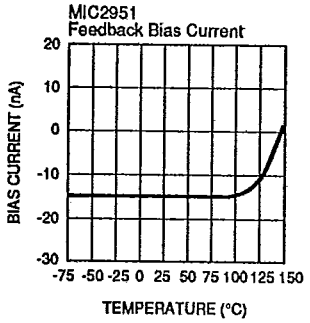
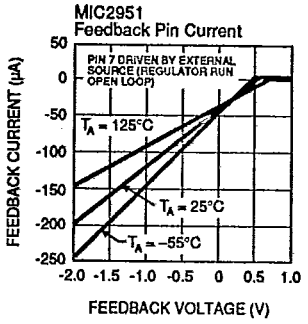
MIC2951
Minimum Operating Voltage



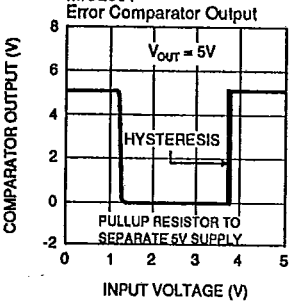
MIC2951
Feedback Bias Current



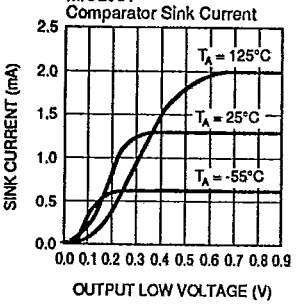
MIC2951
Feedback Pin Current



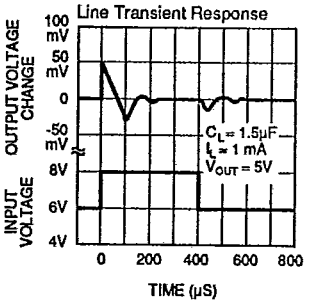
MIC2951
Error Comparator Output



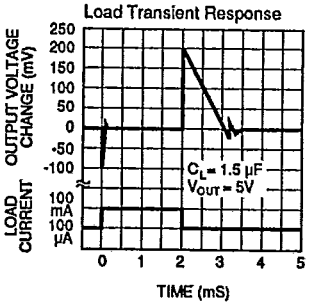
MIC2951
Comparator Sink Current



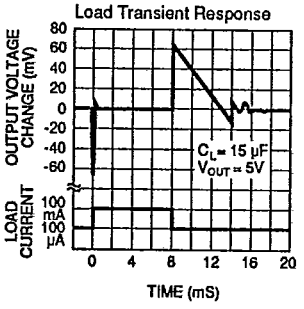
Line Transient Response



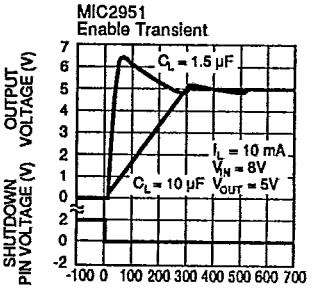
Load Transient Response



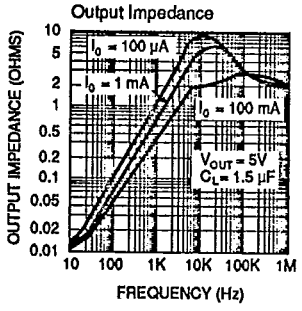
Load Transient Response



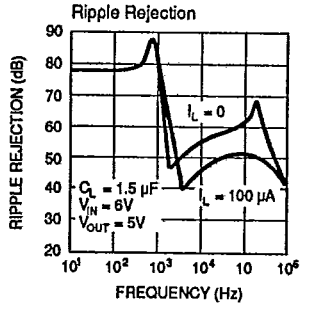
MIC2951
Enable Transient



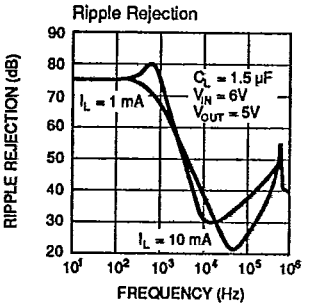
Output Impedance



Ripple Rejection



Ripple Rejection



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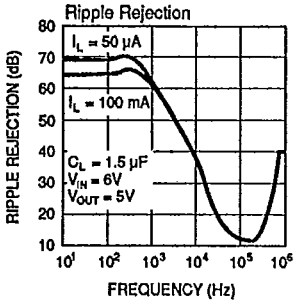
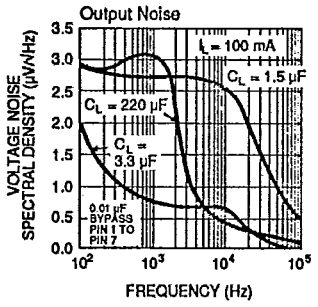
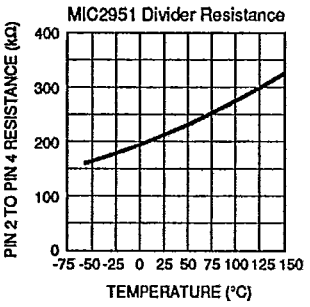
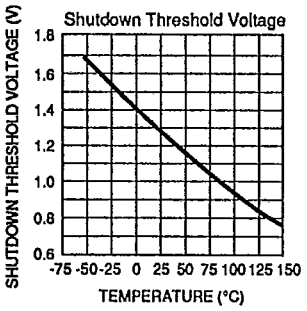
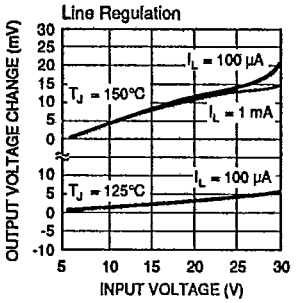
Typical Performance Characteristics (Continued)

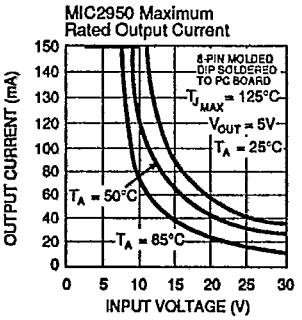


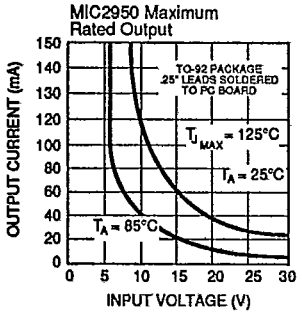


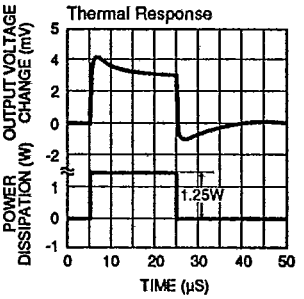












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Applications Information

Automotive Applications

The MIC2950/2951 are ideally suited for automotive applications for a variety of reasons. They will operate over a wide range of input voltages, have very low dropout voltages (40 mV at light loads), and very low quiescent currents (75 µA typical). These features are necessary for use in battery powered systems, such as automobiles. They are also "bulletproof"devices; with the ability to survive both reverse battery(negative transients up to 20 V below ground), and load dump(positive transients up to 60 V) conditions. A wide operating temperature range with low temperature coefficients is yet another reason to use these versatile regulators in automotive designs.

External Capacitors

A 1.5 µF (or greater) capacitor is required between the MIC2950/MIC2951 output and ground to prevent oscillations due to instability. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an ESR of about 5 Ω or less and a resonant frequency above 500 kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.5 µF for current below 10 mA or 0.15 µF for currents below 1 mA. Using the 8-pin versions at voltages below 5 V runs the error amplifier at lower gains so that more output capacitance is needed. For the worst-case situation of a 150 mA load at 1.23V output (Output shorted to Feedback) a 5 µF (or greater) capacitor should be used.

The MIC2950 will remain stable and in regulation with no load in addition to the internal voltage divider, unlike many other voltage regulators. This is especially important in CMOS RAM keep-alive applications. When setting the output voltage of the MIC2951 version with external resistors, a minimum load of 1 µA is recommended.

A 0.1 µF capacitor should be placed from the MIC2950/ MIC2951 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

Stray capacitance to the MIC2951 Feedback terminal (pin 7) can cause instability. This may especially be a problem when using high value external resistors to set the output voltage. Adding a 100 pF capacitor between Output and Feedback and increasing the output capacitor to at least 3.3 µF will remedy this.

Error Detection Comparator Output

A logic low output will be produced by the comparator whenever the MIC2951 output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 60 mV divided by the 1.235 reference voltage. (Refer to the block diagram on Page 1). This trip level remains "5% below normal" regardless of the programmed output voltage of the MIC2951. For example, the error flag trip level is typically 4.75V for a 5V output or 11.4V for a 12V output. The out of regulation condition may be due either to low input voltage, current limiting, or thermal limiting.

Figure 1 is a timing diagram depicting the $\overline{\text{ERROR}}$ signal and the regulated output voltage as the MIC2951 input is ramped up and down. The $\overline{\text{ERROR}}$ signal becomes valid (low) at about 1.3V input. It goes high at about 5V input (the input voltage at which $V_{OUT} = 4.75$). Since the MIC2951's dropout voltage is load-dependent (see curve in Typical Performance Characteristics), the input voltage trip point (about 5V) will vary with the load current. The output voltage trip point (approx. 4.75V) does not vary with load.

The error comparator has an open-collector output which requires an external pullup resistor. Depending on system requirements, this resistor may be returned to the 5V output or some other supply voltage. In determining a value for this resistor, note that while the output is rated to sink 400 µA, this sink current adds to battery drain in a low battery condition. Suggested values range from 100k to 1MΩ. The resistor is not required if this output is unused.

In shutdown mode, $\overline{\text{ERROR}}$ will go high if it has been pulled up to an external 5 V supply. To avoid this invalid response, $\overline{\text{ERROR}}$ should be pulled up to V_{OUT} (See figure 2).

Programming the Output Voltage (MIC2951)

The MIC2951 may be pin-strapped for 5V using its internal voltage divider by tying Pin 1 (output) to Pin 2 (sense) and Pin 7 (feedback) to Pin 6 (5V Tap). Alternatively, it may be programmed for any output voltage between its 1.235 reference and its 30V maximum rating. An external pair of resistors is required, as shown in Figure 2.

The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \times \{ 1 + R_1/R_2 \} + I_{FB} R_1$$

where V_{REF} is the nominal 1.235 reference voltage and I_{FB} is the feedback pin bias current, nominally -20 nA. The minimum recommended load current of 1 µA forces an upper limit of 1.2 MΩ on the value of R_2, if the regulator must work with no load (a condition often found in CMOS in standby), I_{FB} will produce a 2% typical error in V_{OUT} which may be eliminated at room temperature by trimming R_1. For better accuracy, choosing R_2 = 100k reduces this error to 0.17% while increasing the resistor program current to 12 µA. Since the MIC2951 typically draws 60 µA at no load with Pin 2 open-circuited, this is a small price to pay.

Reducing Output Noise

In reference applications it may be advantageous to reduce the AC noise present at the output. One method is to reduce the regulator bandwidth by increasing the size of the output

capacitor. This is the only method by which noise can be reduced on the 3 lead MIC2950 and is relatively inefficient, as increasing the capacitor from 1 µF to 220 µF only decreases the noise from 430µV to 160 µV rms for a 100kHz bandwidth at 5V output.

Noise can be reduced fourfold by a bypass capacitor across R_1, since it reduces the high frequency gain from 4 to unity. Pick

$$C_{BYPASS} \cong \frac{1}{2\pi R_1 \cdot 200\ Hz}$$

or about 0.01 µF. When doing this, the output capacitor must be increased to 3.3 µF to maintain stability. These changes reduce the output noise from 430 µV to 100 µV rms for a 100 kHz bandwidth at 5V output. With the bypass capacitor added, noise no longer scales with output voltage so that improvements are more dramatic at higher output voltages.

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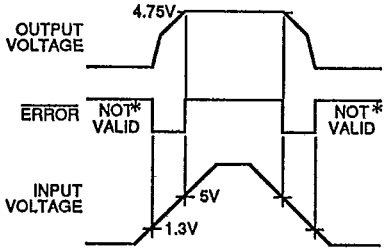
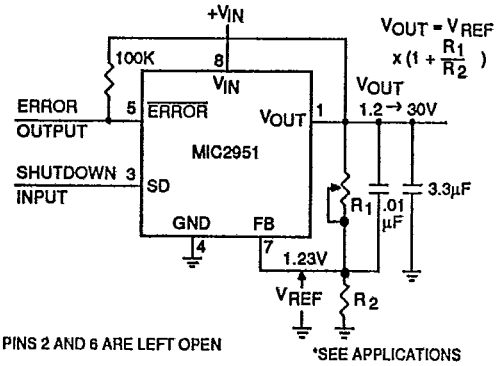


* SEE APPLICATIONS INFORMATION

Figure 1. ERROR Output Timing

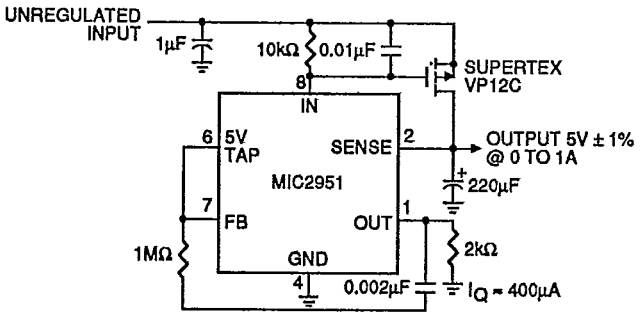


NOTE: PINS 2 AND 6 ARE LEFT OPEN

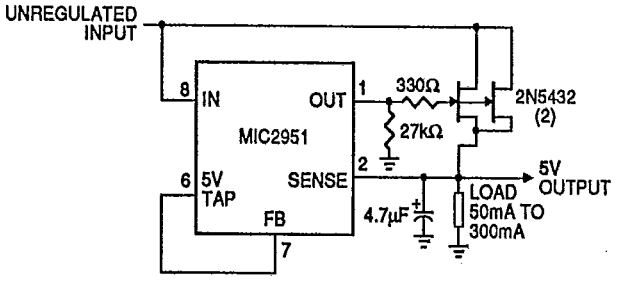
*SEE APPLICATIONS INFORMATION

Figure 2. Adjustable Regulator

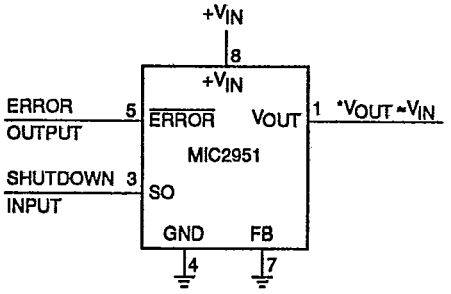
Typical Applications



1A Regulator with 1.2 V Dropout



300 mA Regulator with 0.75 V Dropout



Wide Input Voltage Range Current Limiter

*MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40 mV TO 400 mV, DEPENDING ON LOAD CURRENT. CURRENT LIMIT IS TYPICALLY 240 mA.

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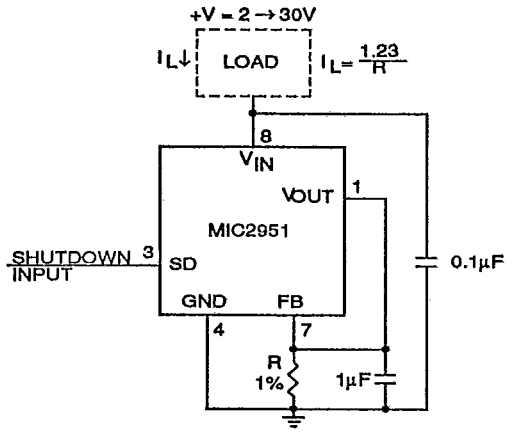
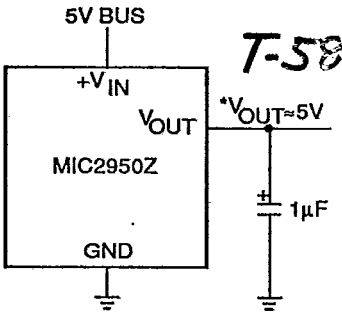
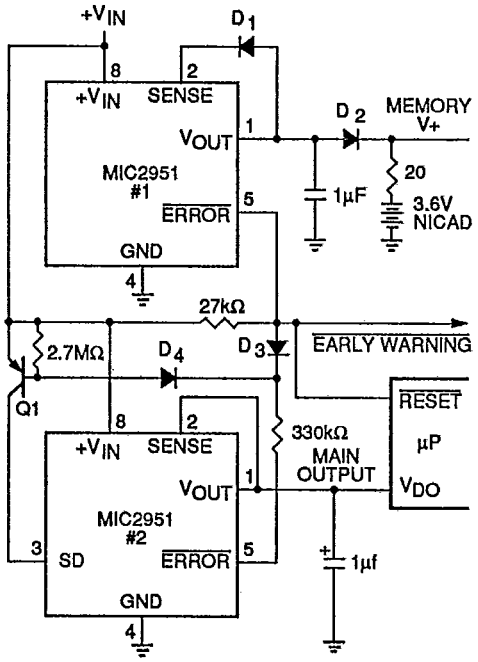


Low Drift Current Source



5 Volt Current Limiter

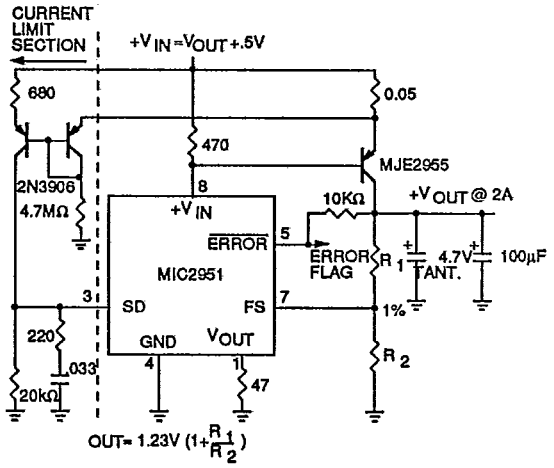
* MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40 MV TO 400 MV, DEPENDING ON LOAD CURRENT. CURRENT LIMIT IS TYPICALLY 240 MA.



Regulator with Early Warning and Auxillary Output

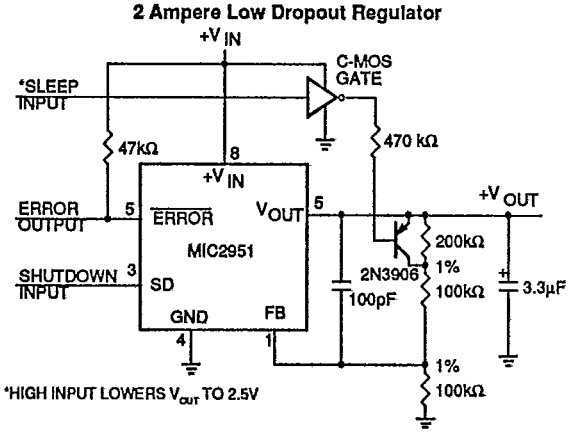
- EARLY WARNING FLAG ON LOW INPUT VOLTAGE
- MAIN OUTPUT LATCHES OFF AT LOWER INPUT VOLTAGES
- BATTERY BACKUP ON AUXILLARY OUTPUT

OPERATION: REG. #1'S V_{OUT} IS PROGRAMMED ONE DIODE DROP ABOVE 5 V. ITS ERROR FLAG BECOMES ACTIVE WHEN $V_{IN} \leq 5.7$ V. WHEN V_{IN} DROPS BELOW 5.3 V, THE ERROR FLAG OF REG. #2 BECOMES ACTIVE AND VIA Q1 LATCHES THE MAIN OUTPUT OFF. WHEN V_{IN} AGAIN EXCEEDS 5.7 V REG. #1 IS BACK IN REGULATION AND THE EARLY WARNING SIGNAL RISES, UNLATCHING REG. #2 VIA D3.



FOR 5 V_{OUT}, USE INTERNAL RESISTORS. WIRE PIN 6 TO 7, AND WIRE PIN 20 TO $+V_{OUT}$ BUS.

2 Ampere Low Dropout Regulator



*HIGH INPUT LOWERS V_{OUT} TO 2.5V

5 V Regulator with 2.5 V Sleep Function

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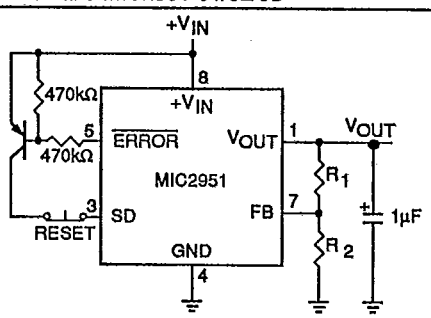
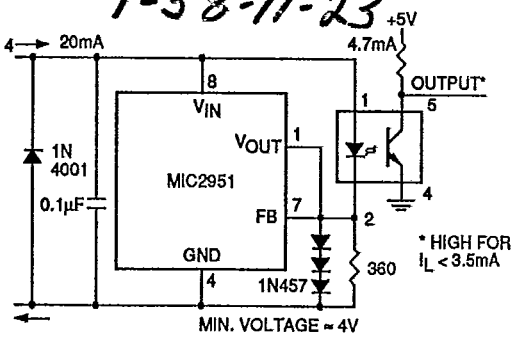
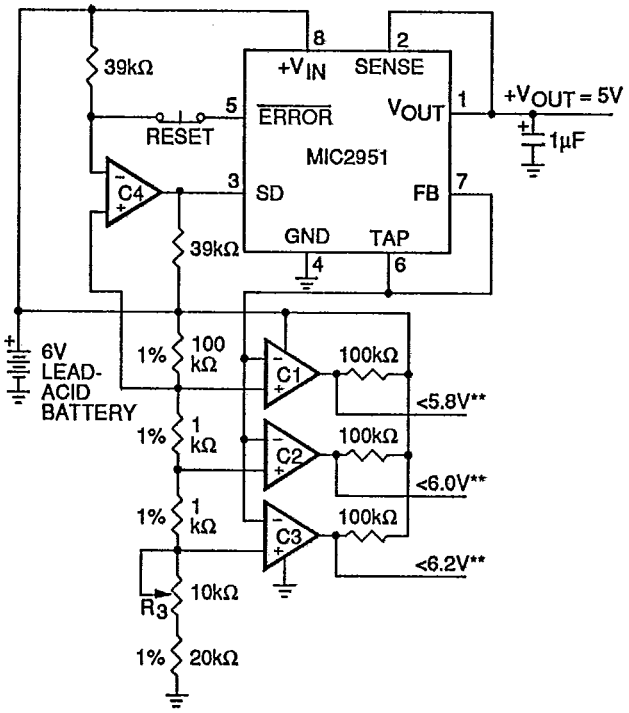


Latch Off When Error Flag Occurs



Open Circuit Detector for 4→20 Current Loop



*OPTIONAL LATCH OFF WHEN DROP OUT OCCURS. ADJUST R3 FOR C2 SWITCHING WHEN V_{IN} IS 6.0V
**OUTPUTS GO LOW WHEN V_{IN} DROPS BELOW DESIGNATED THRESHOLDS.

Regulator with State-of-Charge Indicator

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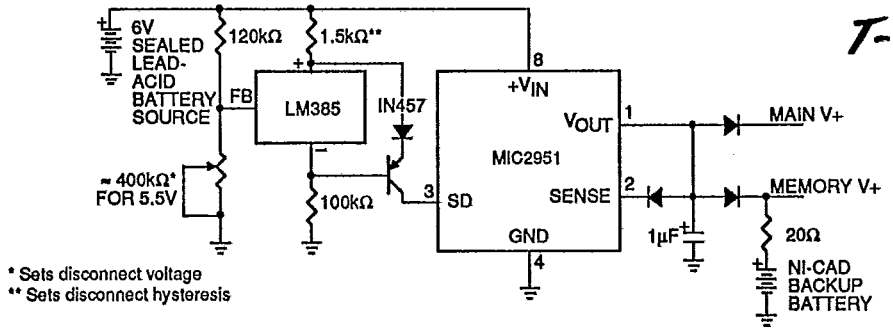
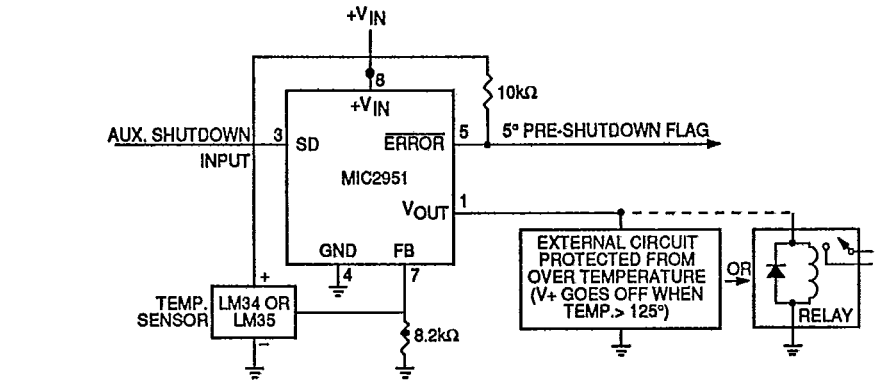


Low Battery Disconnect

For values shown, Regulator shuts down when V_{IN} < 5.5 V and turns on again at 6.0 V. Current drain in disconnected mode is 150µA.



System Overtemperature Protection Circuit

Schematic Diagram

T-59-11-23