LP2950/2951

100mA Low-Dropout Voltage Regulator

General Description

The LP2950 and LP2951 are micropower voltage regulators with very low dropout voltage (typically 40mV at light loads and 380mV at 100mA), and very low quiescent current (75µA typical). The quiescent current of the LP2950/LP2951 increases only slightly in dropout, thus prolonging battery life. This feature, among others, makes the LP2950 and LP2951 ideally suited for use in battery-powered systems.

Available in a 3-Pin TO-92 package, the LP2950 is pin-compatible with the older 5V regulators. Additional system functions, such as programmable output voltage and logic-controlled shutdown, are available in the 8-pin DIP and 8-pin SOIC versions of the LP2951.

Applications

- Automotive Electronics
- Voltage Reference
- Avionics

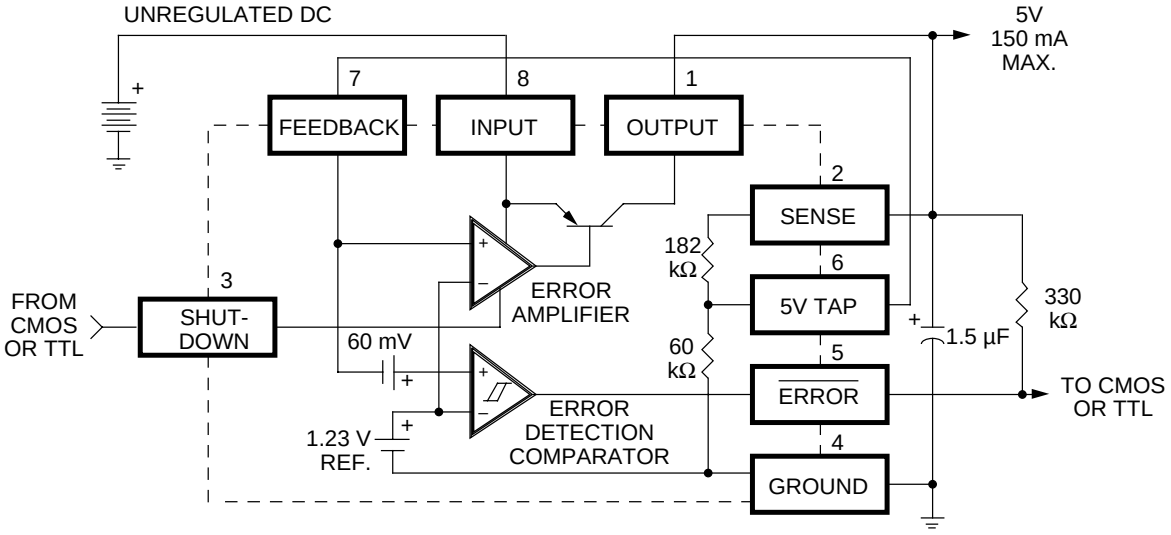
Features

- High accuracy 5V, guaranteed 100 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 1µF for stability
- Current and thermal limiting

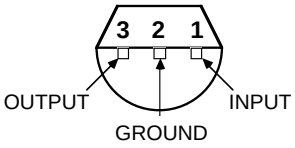
LP2951 Versions Only

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

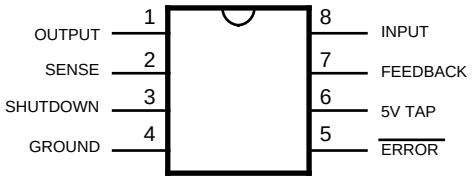
Block Diagram and Pin Configurations



LP2950 and LP2951 Block Diagram
(Pin Numbers Refer to LP2951)



TO-92 Plastic Package Bottom View
(BZ)



DIP and SO Packages
(BN and BM)

See MIC2950 for a part with 1) higher output (150 mA), 2) transient protection (60V), and 3) reverse input protection to –20V)

Additional features available with the LP2951 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 5V output, or programmed from 1.24V to 29V with the use of two external resistors.

The LP2950 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 LP2951 is available as an -02 or -03 version.

The LP2950 and LP2951 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 (0.05% typical). This greatly reduces the error in the overall circuit, and is the result of careful design techniques and process control.

Ordering Information

Part Number	Voltage	Temperature Range*	Package	Accuracy
LP2950-02BZ	5.0V	–40°C to +125°C	3-Pin TO-92 plastic	0.5%
LP2950-03BZ	5.0V	–40°C to +125°C	3-Pin TO-92 plastic	1.0%
LP2951-02BM	5.0V	–40°C to +125°C	8-Pin SOIC	0.5%
LP2951-03BM	5.0V	–40°C to +125°C	8-Pin SOIC	1.0%
LP2951-02BN	5.0V	–40°C to +125°C	8-Pin Plastic DIP	0.5%
LP2951-03BN	5.0V	–40°C to +125°C	8-Pin Plastic DIP	1.0%
LP2951-4.8BM	4.85V	–40°C to +125°C	8-Pin SOIC	1.0%

* 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 Temperature (Soldering, 5 seconds)	260°C
Storage Temperature Range	–65°C to +150°C
Operating Junction Temperature Range (Note 8)	
LP2950, LP2951	–40°C to +125°C
Input Supply Voltage	–0.3V to +30V
Feedback Input Voltage (Notes 9 and 10)	–1.5V to +30V
Shutdown Input Voltage (Note 9)	–0.3V to +30V
Error Comparator Output Voltage (Note 9)	–0.3V to +30V

ESD Rating is to be determined.

Electrical Characteristics **Note 1** T_A = 25°C except as noted.

Parameter	Condition	Min	Typ	Max	Units
Output Voltage T_J = 25°C	LP295x-02 (±0.5%)	4.975	5.000	5.025	V
	LP295x-03 (±1%)	4.950	5.000	5.050	V
	LP2951-4.8 (±1%)	4.802	4.850	4.899	V
Output Voltage –25°C ≤ T_J ≤ +85°C	LP295x-02 (±0.5%)	4.950		5.050	V
	LP295x-03 (±1%)	4.925		5.075	V
	LP2951-4.8 (±1%)	4.777		4.872	V
Output Voltage Over Full Temperature Range	LP295x-02 (±0.5%), –40°C to +125°C	**4.940**		**5.060**	V
	LP295x-03 (±1%), –40°C to +125°C	**4.900**		**5.100**	V
	LP2951-4.8 (±1%), –40°C to +125°C	**4.753**		**4.947**	V
Output Voltage Over Load Variation	LP295x-02 (±0.5%), 100µA ≤ I_L ≤ 100mA, T_J ≤ $T_{J(max)}$	**4.930**		**5.070**	V
	LP295x-03 (±1%), 100µA ≤ I_L ≤ 100mA, T_J ≤ $T_{J(max)}$	**4.880**		**5.120**	V
	LP2951-4.8 (±1%), 100µA ≤ I_L ≤ 100mA, T_J ≤ $T_{J(max)}$	**4.733**		**4.967**	V
Output Voltage Temperature Coefficient	LP295x-02 (±0.5%), Note 12		**20**	**100**	ppm/°C
	LP295x-03 (±1%), Note 12		**50**	**150**	ppm/°C
	LP2951-4.8 (±1%), Note 12		**50**	**150**	ppm/°C
Line Regulation	LP295x-02 (±0.5%), Notes 14, 15		0.03	0.10 **0.20**	% %
	LP295x-03 (±1%), Notes 14, 15		0.04	0.20 **0.40**	% %
	LP2951-4.8 (±1%), Notes 14, 15		0.04	0.20 **0.40**	% %
Load Regulation	LP295x-02 (±0.5%), Note 14, 100µA ≤ I_L ≤ 100mA		0.04	0.10 **0.20**	% %
	LP295x-03 (±1%), Note 14, 100µA ≤ I_L ≤ 100mA		0.10	0.20 **0.30**	% %
	LP2951-4.8 (±1%), Note 14, 100µA ≤ I_L ≤ 100mA		0.10	0.20 **0.30**	% %
Dropout Voltage	Note 5, I_L = 100µA		50	80 **150**	mV mV
	Note 5, I_L = 100mA		380	450 **600**	mV mV
Ground Current	I_L = 100µA		100	150 **200**	µA µA
	I_L = 100mA		8	12 **14**	mA mA
Dropout Current	V_{IN} = 4.5V, I_L = 100µA		180	250 **310**	µA µA

Parameter	Condition	Min	Typ	Max	Units
Current Limit	V_{OUT} = 0V		160	200 **220**	mA mA
Thermal Regulation	Note 13		0.05	0.20	%/W
Output Noise	10Hz to 100kHz, C_L = 1µF		430		μV_{RMS}
	10Hz to 100kHz, C_L = 200µF		160		μV_{RMS}
	10Hz to 100kHz, C_L = 3.3µF, 0.01µF bypass Feedback to Output		100		μV_{RMS}
Reference Voltage	LP295x-02 (±0.5%)	1.220 **1.200**	1.235	1.250 **1.260**	V V
	LP295x-03 (±1%)	1.210 **1.200**	1.235	1.260 **1.270**	V V
	LP2951-4.8 (±1%)	1.210 **1.200**	1.235	1.260 **1.270**	V V
Reference Voltage	LP295x-02 (±0.5%), Note 7	**1.190**		**1.270**	V
	LP295x-03 (±1%), Note 7	**1.185**		**1.285**	V
	LP2951-4.8 (±1%), Note 7	**1.185**		**1.285**	V
Feedback Bias Current			20	40 **60**	nA nA
Reference Voltage	LP295x-02 (±0.5%), Note 12		20		ppm/°C
	LP295x-03 (±1%), Note 12		50		ppm/°C
	LP2951-4.8 (±1%), Note 12		50		ppm/°C
Feedback Bias Current Temperature Coefficient			0.1		nA/°C
Output Leakage Current	V_{OH} = 30V		0.01	1.00 **2.00**	µA µA
Output Low Voltage (Flag)	V_{IN} = 4.5V, I_{OL} = 200µA		150	250 **400**	mV mV
Upper Threshold Voltage	Note 6	40 **25**	60		mV mV
Lower Threshold Voltage	Note 6		75	95 **140**	mV mV
Hysteresis	Note 6		15		mV
Input Logic Voltage	LP295x-02 (±0.5%) Low High	 **2.0**	1.3	 **0.7**	V V V
	LP295x-03 (±1%) Low High	 **2.0**	1.3	 **0.7**	V V V
	LP2951-4.8 (±1%) Low High	 **2.0**	1.3	 **0.7**	V V V

Parameter	Condition	Min	Typ	Max	Units
Shutdown Input Current	$V_{SHUTDOWN}$ = 2.4V		30	50 **100**	µA µA
	$V_{SHUTDOWN}$ = 30V		450	600 **750**	µA µA
Regulator Output Current in Shutdown	Note 11		3	10 **20**	µA µA

Note 1: Boldface limits apply at temperature extremes.

Note 2: Unless otherwise specified all limits guaranteed for T_J = 25°C, V_{IN} = 6V, I_L = 100µA and C_L = 1µF. Additional conditions for the 8-pin versions are Feedback tied to 5V Tap and Output tied to Output Sense (V_{OUT} = 5V) and $V_{SHUTDOWN} \le 0.8V$.

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 100mV below its nominal value measured at 1V differential. At very low values of programmed output voltage, the minimum input supply voltage of 2V (2.3V 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 95mV x 5V/1.235V = 384mV. Thresholds remain constant as a percent of V_{OUT} as V_{OUT} is varied, with the dropout warning occurring at typically 5% below nominal, 7.5% guaranteed.

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

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 resistance of the 8-pin DIP package is 105°C/W junction-to-ambient when soldered directly to a PC board. Junction-to-ambient thermal resistance for the SOIC (M) package is 160°C/W.

Note 9: May exceed input supply voltage.

Note 10: 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 11: $V_{SHUTDOWN} \ge 2V$, $V_{IN} \le 30\ V$, $V_{OUT} = 0$, with Feedback pin tied to 5V Tap.

Note 12: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

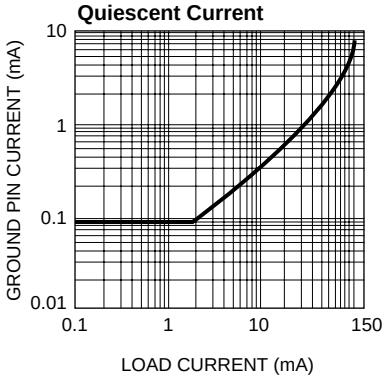
Note 13: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 50mA load pulse at V_{IN} = 30V (1.25W pulse) for t = 10ms.

Note 14: 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.

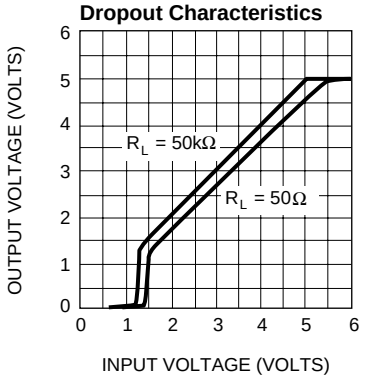
Note 15: Line regulation for the LP2951 is tested at 150°C for I_L = 1mA. For I_L = 100µA and T_J = 125°C, line regulation is guaranteed by design to 0.2%. See Typical Performance Characteristics for line regulation versus temperature and load current.

Typical Performance Characteristics

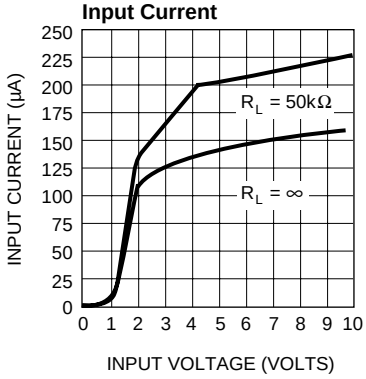
Quiescent Current



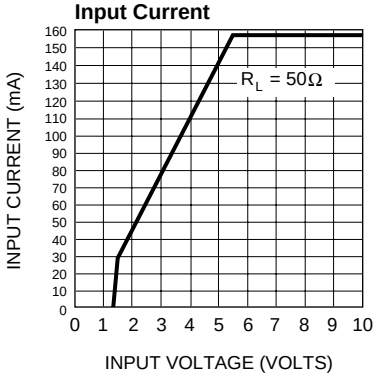
Dropout Characteristics



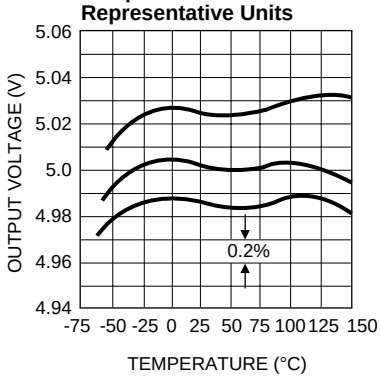
Input Current



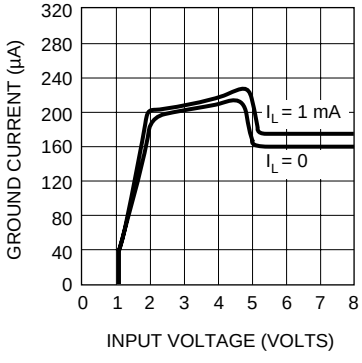
Input Current



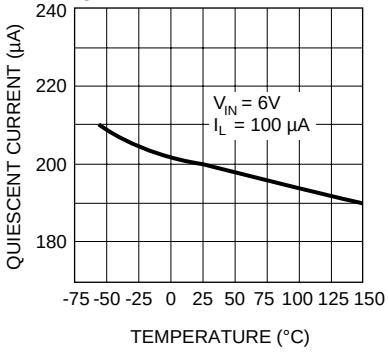
Output Voltage vs. Temperature of 3 Representative Units



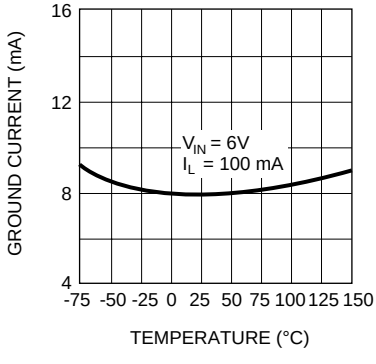
Ground Current



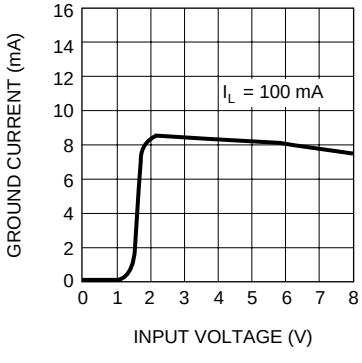
Quiescent Current



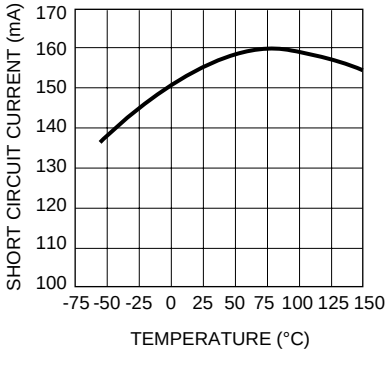
Ground Current



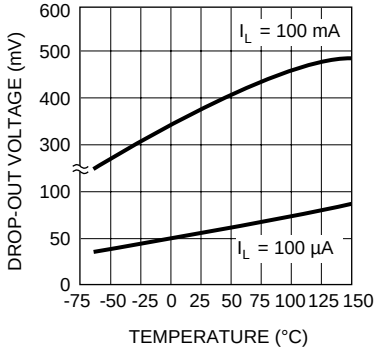
Ground Current



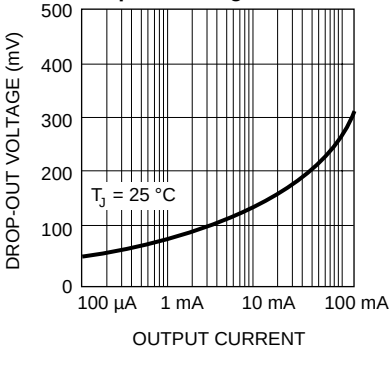
Short Circuit Current



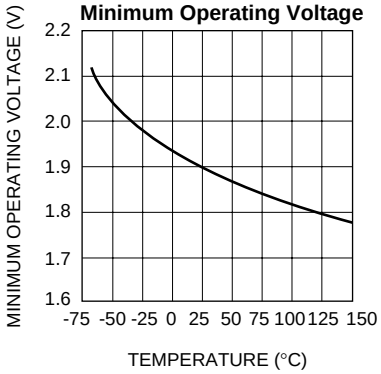
Drop-out Voltage



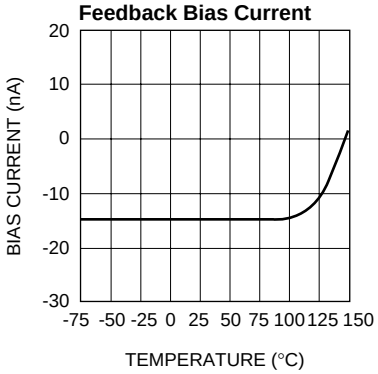
Drop-out Voltage



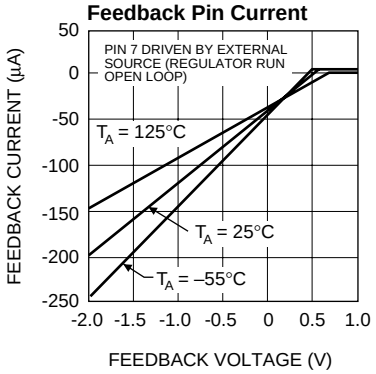
LP2951
Minimum Operating Voltage



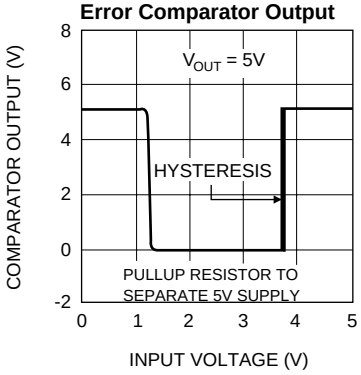
LP2951
Feedback Bias Current



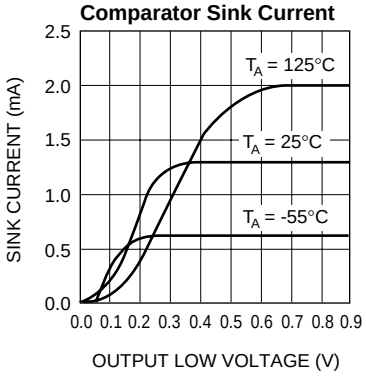
LP2951
Feedback Pin Current



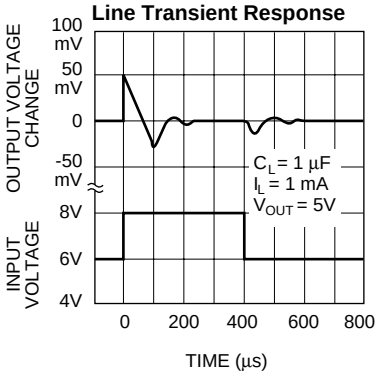
LP2951
Error Comparator Output



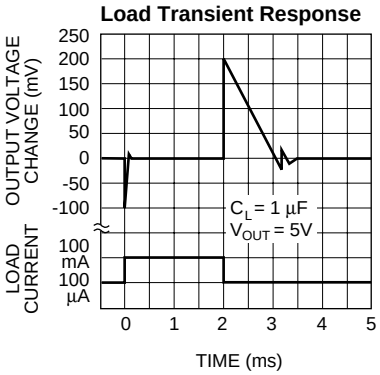
LP2951
Comparator Sink Current



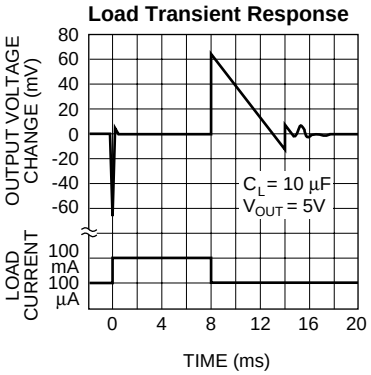
Line Transient Response



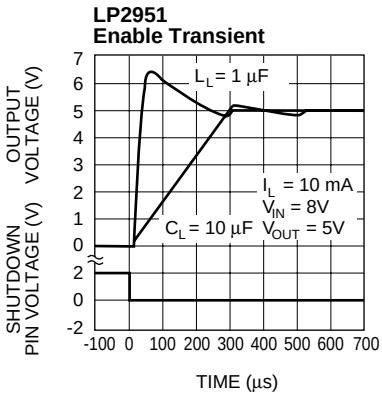
Load Transient Response



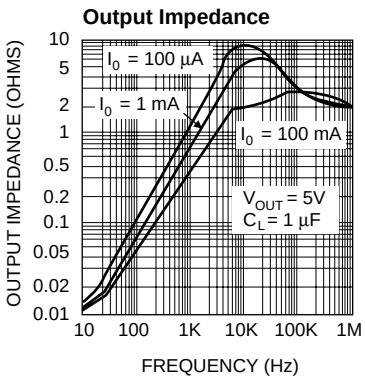
Load Transient Response



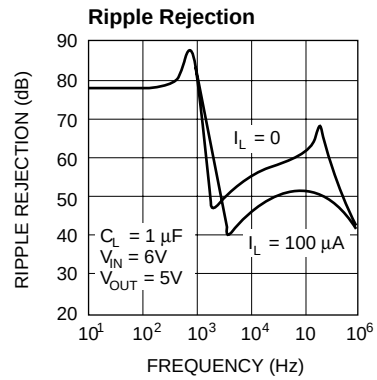
LP2951
Enable Transient



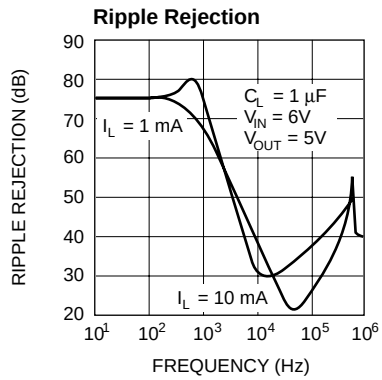
Output Impedance



Ripple Rejection

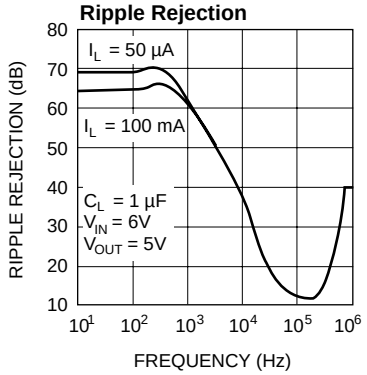


Ripple Rejection

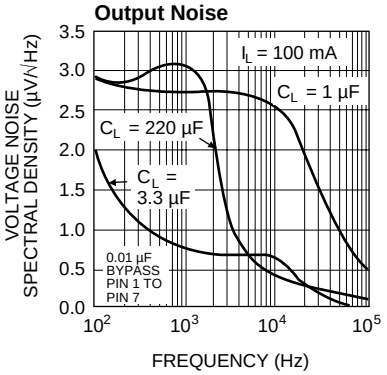


Typical Performance Characteristics (Continued)

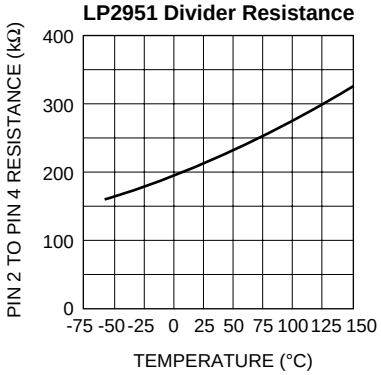
Ripple Rejection



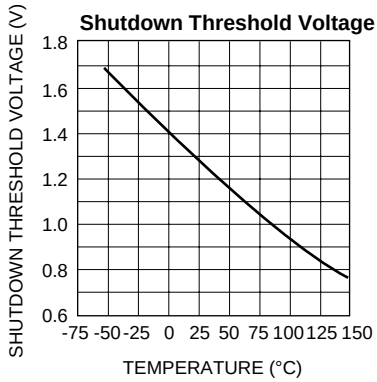
Output Noise



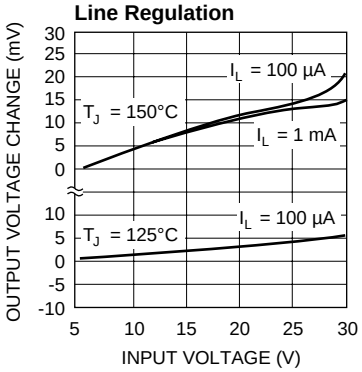
LP2951 Divider Resistance



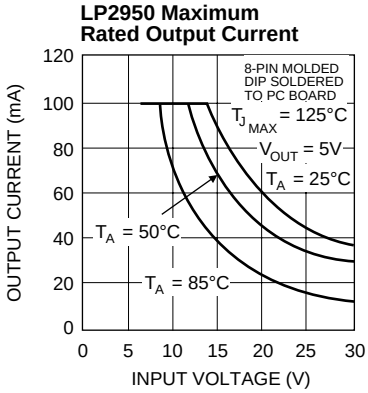
Shutdown Threshold Voltage



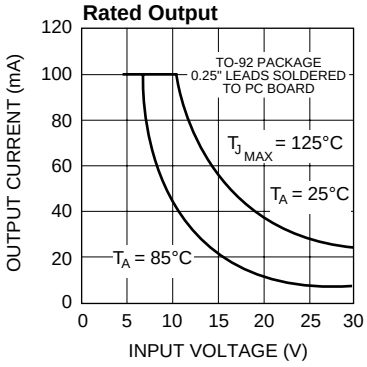
Line Regulation



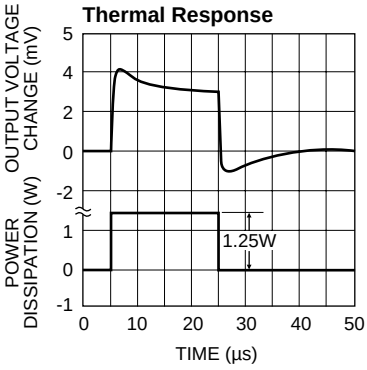
LP2950 Maximum Rated Output Current



LP2950 Maximum Rated Output



Thermal Response



Applications Information

External Capacitors

A 1.0µF (or greater) capacitor is required between the LP2950/ LP2951 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 tantalum capacitors are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. 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 0.33µF for current below 10mA or 0.1µF for currents below 1mA. Using the 8-Pin versions at voltages below 5V runs the error amplifier at lower gains so that more output capacitance is needed. For the worst-case situation of a 100mA load at 1.23V output (Output shorted to Feedback) a 3.3µF (or greater) capacitor should be used.

The LP2950 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 LP2951 version with external resistors, a minimum load of 1µA is recommended.

A 0.1µF capacitor should be placed from the LP2950/LP2951 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 LP2951 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 100pF capacitor between Output and Feedback and increasing the output capacitor to at least 3.3µF will remedy this.

Error Detection Comparator Output

A logic low output will be produced by the comparator whenever the LP2951 output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 60mV divided by the 1.235V 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 LP2951. 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 LP2951 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} = 4.75V). Since the LP2951'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 (approximately 4.75V) does not vary with load.

The error comparator has an open-collector output which requires an external pull-up 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 400µA, 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.

Programming the Output Voltage (LP2951)

The LP2951 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 1.235V 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

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

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 = 100kΩ reduces this error to 0.17% while increasing the resistor program current to 12µA. Since the LP2951 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 LP2950 and is relatively inefficient, as increasing the capacitor from 1µF to 220µF only decreases the noise from 430µV to 160µV 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

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

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 430µV to 100µV rms for a 100kHz 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.

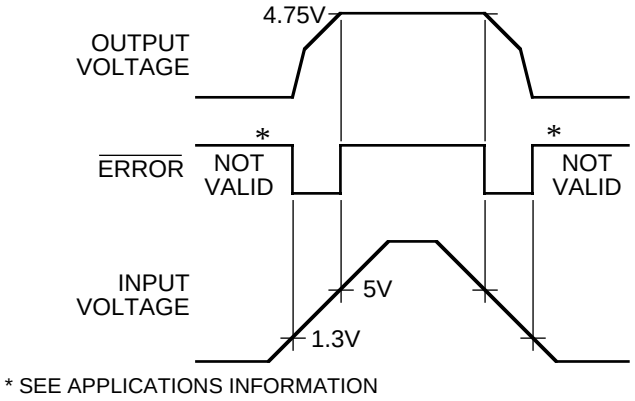


Figure 1. ERROR Output Timing

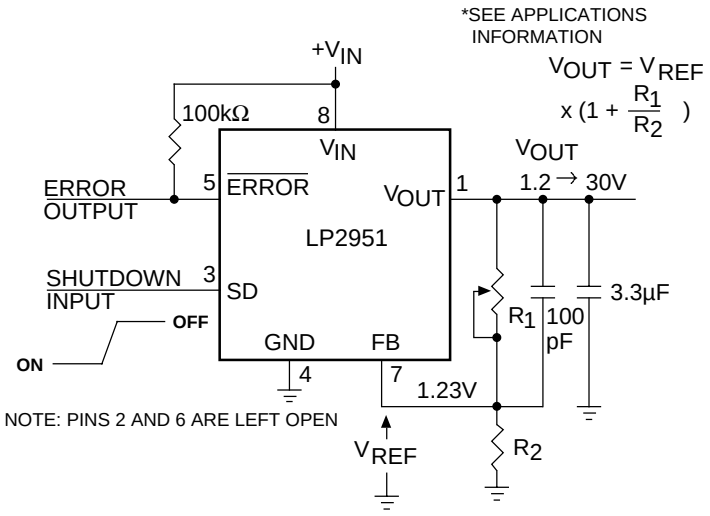
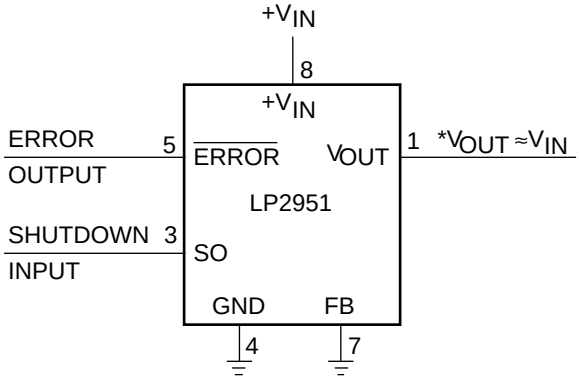


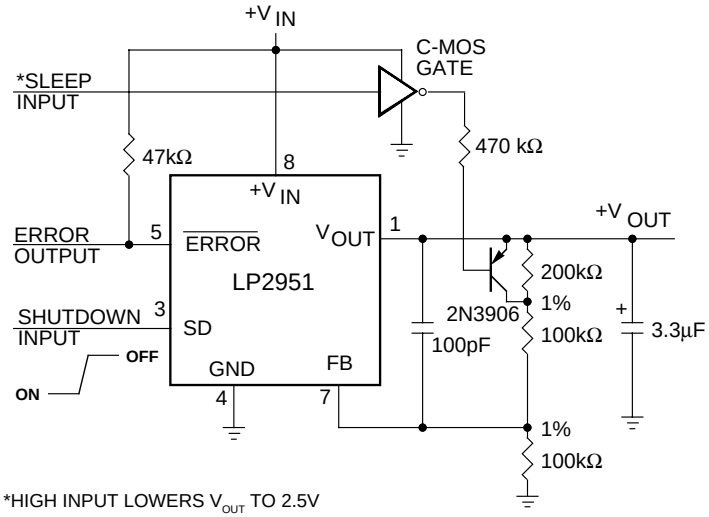
Figure 2. Adjustable Regulator

Typical Applications



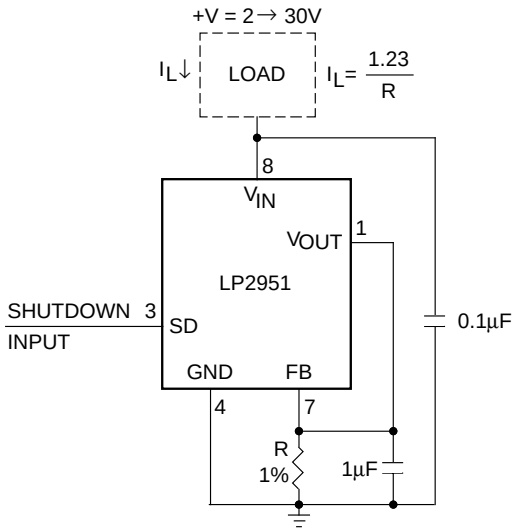
*MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT. CURRENT LIMIT IS TYPICALLY 160mA.

Wide Input Voltage Range Current Limiter

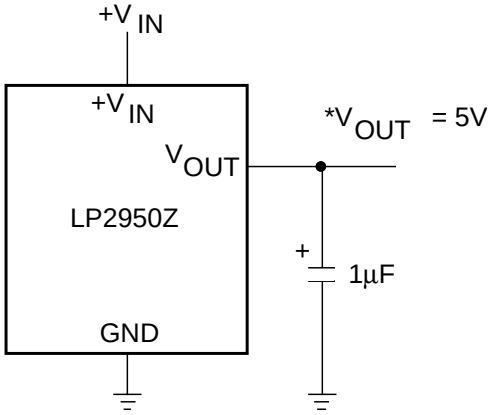


*HIGH INPUT LOWERS V_{OUT} TO 2.5V

5 V Regulator with 2.5 V Sleep Function

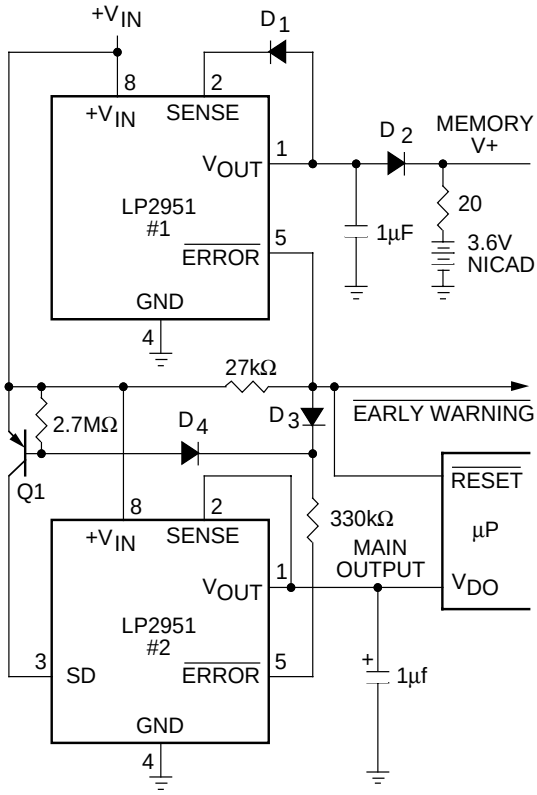


Low Drift Current Source



5 Volt Current Limiter

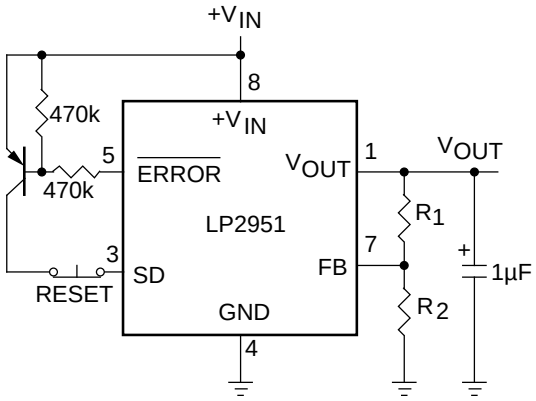
* MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT.



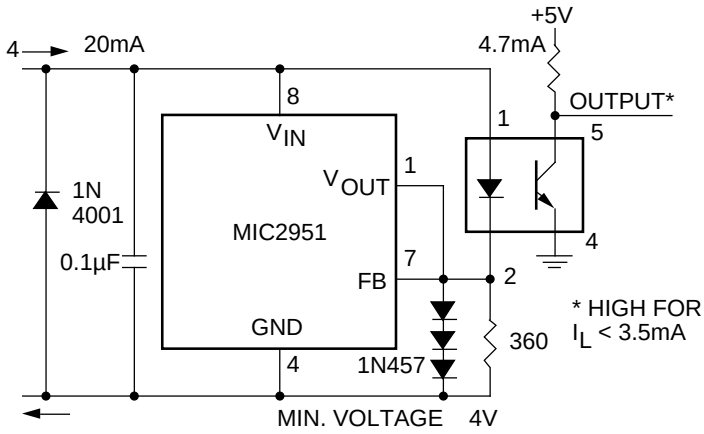
Regulator with Early Warning and Auxiliary Output

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

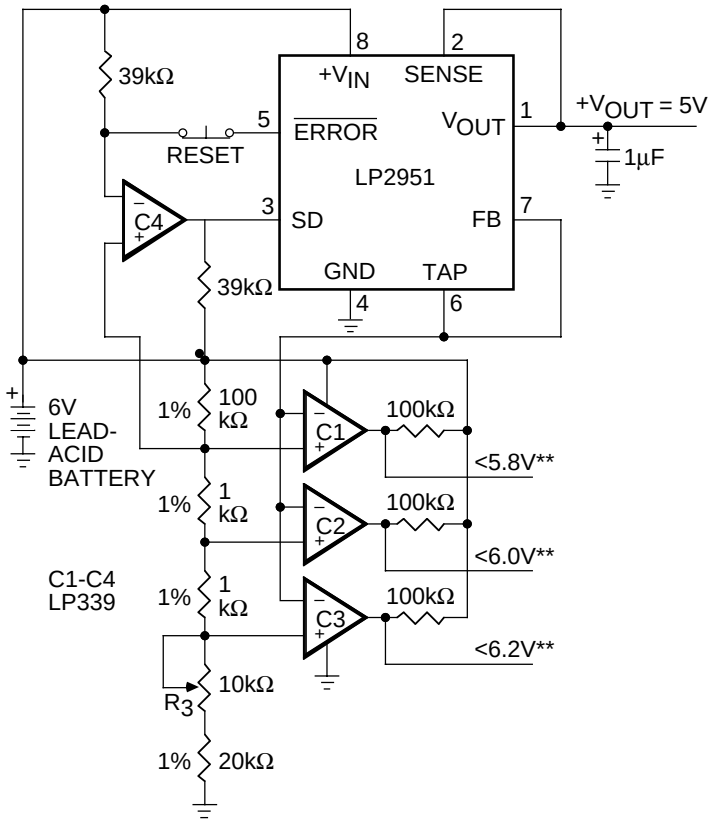
OPERATION: REG. #1'S V_{OUT} IS PROGRAMMED ONE DIODE DROP ABOVE 5 V. ITS ERROR FLAG BECOMES ACTIVE WHEN $V_{IN} \leq 5.7$ V. WHEN V_{IN} DROPS BELOW 5.3 V, THE ERROR FLAG OF REG. #2 BECOMES ACTIVE AND VIA Q1 LATCHES THE MAIN OUTPUT OFF. WHEN V_{IN} AGAIN EXCEEDS 5.7 V REG. #1 IS BACK IN REGULATION AND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



Latch Off When Error Flag Occurs



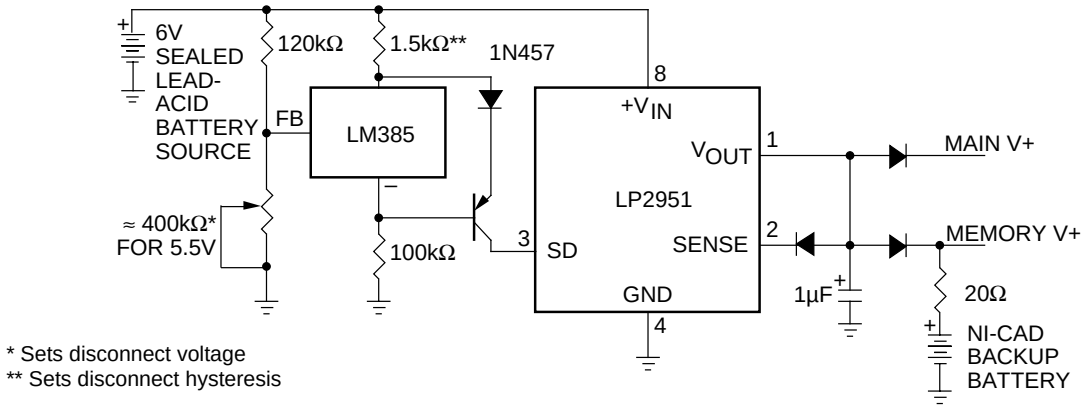
Open Circuit Detector for 4mA to 20mA Current Loop



*OPTIONAL LATCH OFF WHEN DROP OUT OCCURS. ADJUST R3 FOR C2 SWITCHING WHEN V_{IN} IS 6.0V

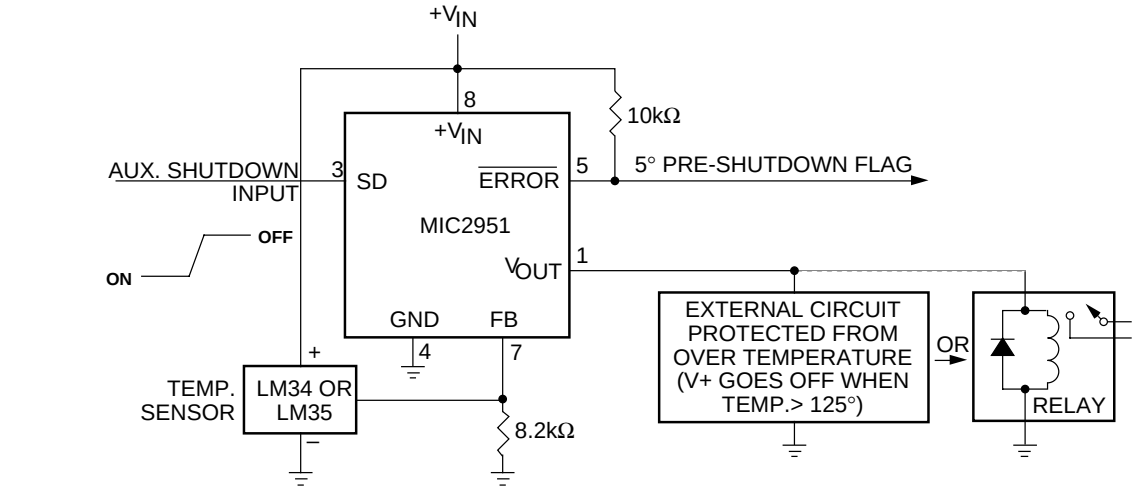
**OUTPUTS GO LOW WHEN V_{IN} DROPS BELOW DESIGNATED THRESHOLDS.

Regulator with State-of-Charge Indicator

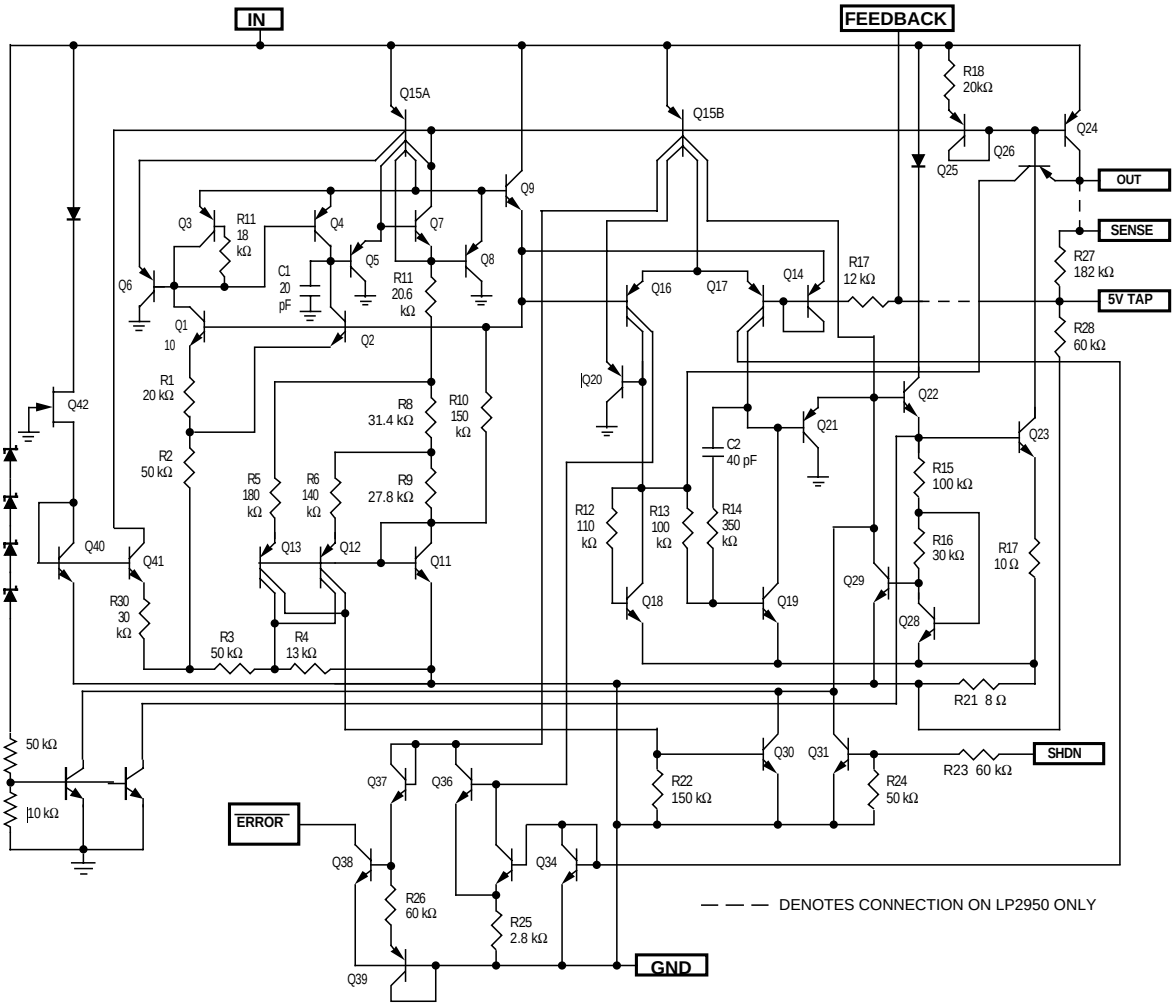


Low Battery Disconnect

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 Over Temperature Protection Circuit


IN
FEEDBACK
Q15A
Q15B
R18
20kΩ
Q24
Q26
Q25
OUT
SENSE
R27
182 kΩ
5V TAP
R28
60 kΩ
Q9
Q3
R11
18
kΩ
Q4
Q7
Q5
Q8
Q6
C1
20
pF
R11
20.6
kΩ
Q1
10
Q2
Q16
Q17
Q14
R17
12 kΩ
Q20
Q22
Q21
C2
40 pF
Q23
R15
100 kΩ
R1
20 kΩ
R8
31.4 kΩ
R10
150
kΩ
R2
50 kΩ
R5
180
kΩ
R6
140
kΩ
R9
27.8 kΩ
R12
110
kΩ
R13
100
kΩ
R14
350
kΩ
R16
30 kΩ
R17
10 Ω
Q42
Q40
Q41
Q13
Q12
Q11
Q18
Q19
Q29
Q28
R30
30
kΩ
R3
50 kΩ
R4
13 kΩ
R21 8 Ω
50 kΩ
10 kΩ
Q37
Q36
Q30
Q31
SHDN
R23 60 kΩ
R22
150 kΩ
R24
50 kΩ
ERROR
Q38
Q34
R26
60 kΩ
R25
2.8 kΩ
Q39
GND
— — — DENOTES CONNECTION ON LP2950 ONLY