



LP2950/LP2950AC/LP2950C 5V and LP2951/LP2951AC/LP2951C Adjustable Micropower Voltage Regulators

General Description

The LP2950 and LP2951 are micropower voltage regulators with very low quiescent current (75 μ A typ.) and very low dropout voltage (typ. 40 mV at light loads and 380 mV at 100 mA). They are ideally suited for use in battery-powered systems. Furthermore, the quiescent current of the LP2950/LP2951 increases only slightly in dropout, prolonging battery life.

The LP2950 in the popular 3-pin TO-92 package is pin-compatible with older 5V regulators. The 8-lead LP2951 is available in plastic, ceramic dual-in-line, or metal can packages and offers additional system functions.

One such feature is an error flag output which warns of a low output voltage, often due to falling batteries on the input. It may be used for a power-on reset. A second feature is the logic-compatible shutdown input which enables the regulator to be switched on and off. Also, the part may be pin-strapped for a 5V output or programmed from 1.24V to 29V with an external pair of resistors.

Careful design of the LP2950/LP2951 has minimized all contributions to the error budget. This includes a tight initial

tolerance (.5% typ.), extremely good load and line regulation (.05% typ.) and a very low output voltage temperature coefficient, making the part useful as a low-power voltage reference.

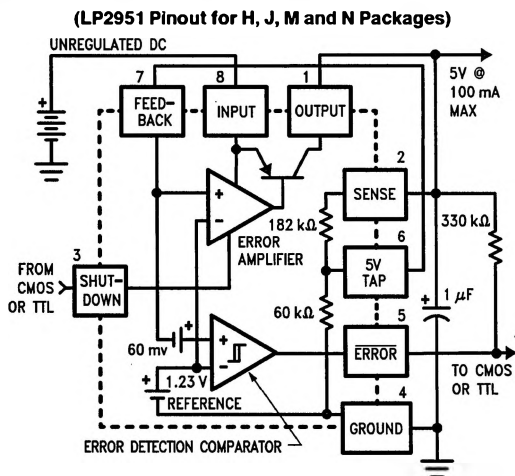
Features

- 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 1 μ F 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

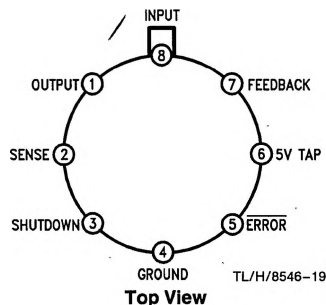
Block and Connection Diagrams



Order Number LP2951J, LP2951ACJ,
LP2951CJ, LP2951ACN or LP2951CN
See NS Package Number J08A or N08E

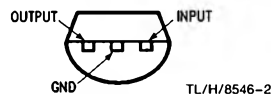
Order Number LP2951ACM or LP2951CM for SO-8
See NS Package Number M08A

Metal Can Package (H)



Order Number LP2951H
See NS Package Number H08C

TO-92 Plastic Package (Z)



Order Number LP2950ACZ-5.0
or LP2950CZ-5.0
See NS Package Number Z03A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation	Internally Limited
Lead Temp. (Soldering, 5 seconds)	260°C
Storage Temperature Range	-65° to +150°C
Operating Junction Temperature Range (Note 8)	
LP2951	-55° to +150°C
LP2950AC/LP2950C,	
LP2951AC/LP2951C	-40° to +125°C

Input Supply Voltage	-0.3 to +30V
Feedback Input Voltage (Notes 9 and 10)	-1.5 to +30V
Shutdown Input Voltage (Note 9)	-0.3 to +30V
Error Comparator Output Voltage (Note 9)	-0.3 to +30V
ESD Rating is to be determined.	

Electrical Characteristics (Note 1)

Parameter	Conditions (Note 2)	LP2951		LP2950AC LP2951AC			LP2950C LP2951C			Units
		Typ	Tested Limit (Note 3)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	
Output Voltage	$T_J = 25^\circ\text{C}$	5.0	5.025 4.975	5.0	5.025 4.975		5.0	5.05 4.95		V max V min
	$-25^\circ\text{C} \leq T_J \leq 85^\circ\text{C}$					5.05 4.95			5.075 4.925	V max V min
	Full Operating Temperature Range		5.06 4.94			5.06 4.94			5.1 4.9	V max V min
Output Voltage	$100\text{ }\mu\text{A} \leq I_L \leq 100\text{ mA}$ $T_J \leq T_{J\text{MAX}}$		5.075 4.925			5.07 4.93			5.12 4.88	V max V min
Output Voltage Temperature Coefficient	(Note 12)	20	120	20		100	50		150	ppm/°C
Line Regulation (Note 14)	$6\text{V} \leq V_{in} \leq 30\text{V}$ (Note 15)	0.03	0.1 0.5	0.03	0.1	0.2	0.04	0.2	0.4	% max % max
Load Regulation (Note 14)	$100\text{ }\mu\text{A} \leq I_L \leq 100\text{ mA}$	0.04	0.1 0.3	0.04	0.1	0.2	0.1	0.2	0.3	% max % max
Dropout Voltage (Note 5)	$I_L = 100\text{ }\mu\text{A}$	50	80 150	50	80	150	50	80	150	mV max mV max
	$I_L = 100\text{ mA}$	380	450 600	380	450	600	380	450	600	mV max mV max
Ground Current	$I_L = 100\text{ }\mu\text{A}$	75	120 140	75	120	140	75	120	140	μA max μA max
	$I_L = 100\text{ mA}$	8	12 14	8	12	14	8	12	14	mA max mA max
Dropout Ground Current	$V_{in} = 4.5\text{V}$ $I_L = 100\text{ }\mu\text{A}$	110	170 200	110	170	200	110	170	200	μA max μA max
Current Limit	$V_{out} = 0$	160	200 220	160	200	220	160	200	220	mA max mA max
Thermal Regulation	(Note 13)	0.05	0.2	0.05	0.2		0.05	0.2		%/W max
Output Noise, 10 Hz to 100 KHz	$C_L = 1\text{ }\mu\text{F}$	430		430			430			μV rms
	$C_L = 200\text{ }\mu\text{F}$	160		160			160			μV rms
	$C_L = 3.3\text{ }\mu\text{F}$ (Bypass = 0.01 μF Pins 7 to 1 (LP2951))	100		100			100			μV rms
8-Pin Versions only		LP2951		LP2951AC			LP2951C			
Reference Voltage		1.235	1.25 1.26 1.22 1.2	1.235	1.25 1.22	1.26 1.2	1.235	1.26 1.21	1.27 1.2	V max V max V min V min
Reference Voltage	(Note 7)		1.27 1.19			1.27 1.19			1.285 1.185	V max V min

Electrical Characteristics (Note 1) (Continued)

Parameter	Conditions (Note 2)	LP2951		LP2951AC			LP2951C			Units
		Typ	Tested Limit (Note 3)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	
8-Pin Versions only (Continued)										
Feedback Pin Bias Current		20	40 60	20	40	60	20	40	60	nA max nA max
Reference Voltage Temperature Coefficient	(Note 12)	20		20			50			ppm/°C
Feedback Pin Bias Current Temperature Coefficient		0.1		0.1			0.1			nA/°C
Error Comparator										
Output Leakage Current	V _{OH} = 30V	0.01	1 2	0.01	1	2	0.01	1	2	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
Shutdown Input										
Input Logic Voltage	Low (Regulator ON) High (Regulator OFF)	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 11)	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 $T_J = 25^\circ C$, $V_{in} = 6V$, $I_L = 100 \mu A$ and $C_L = 1 \mu F$. Additional conditions for the 8-pin versions are Feedback tied to 5V Tap and Output tied to Output Sense ($V_{out} = 5V$) and $V_{shutdown} \leq 0.8V$.

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 100 mV 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 $95 mV \times 5V/1.235V = 384 mV$. 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: $V_{ref} \leq V_{out} \leq (V_{in} - 1V)$, $2.3V \leq V_{in} \leq 30V$, $100 \mu A \leq I_L \leq 100 mA$, $T_J \leq T_{JMAX}$.

Note 8: The junction-to-ambient thermal resistance of the TO-92 package is $180^\circ C/W$ with 0.4" leads and $160^\circ C/W$ with 0.25" leads to a PC board. The thermal resistance of the 8-pin DIP packages is $105^\circ C/W$ for the molded plastic (N) and $130^\circ C/W$ for the cerdip (J) junction to ambient when soldered directly to a PC board. Thermal resistance for the metal can (H) is $160^\circ C/W$ junction to ambient and $20^\circ C/W$ junction to case. Junction to ambient thermal resistance for the S.O. (M) package is $160^\circ C/W$.

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: $V_{shutdown} \geq 2V$, $V_{in} \leq 30V$, $V_{out} = 0$, Feedback pin tied to 5V Tap.

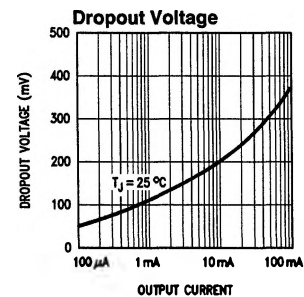
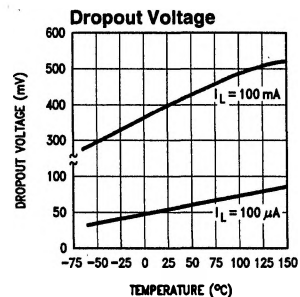
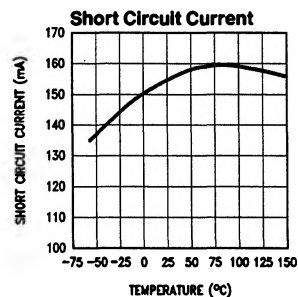
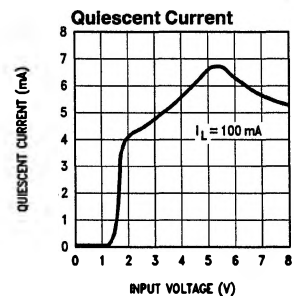
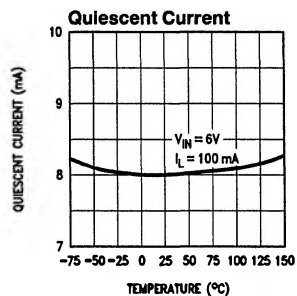
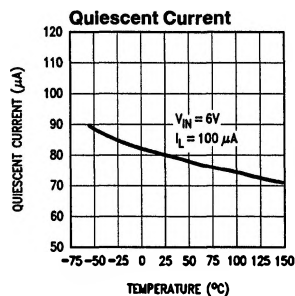
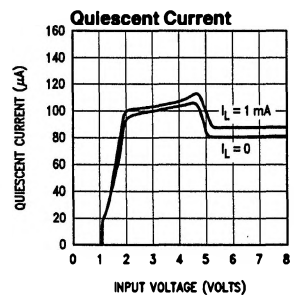
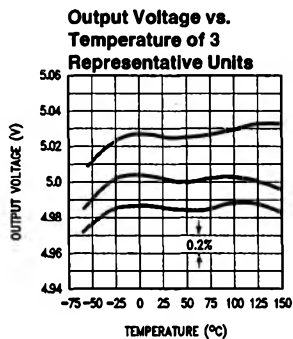
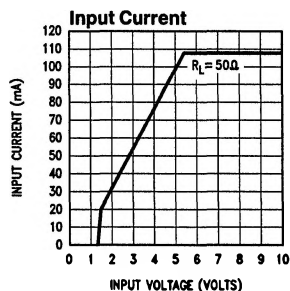
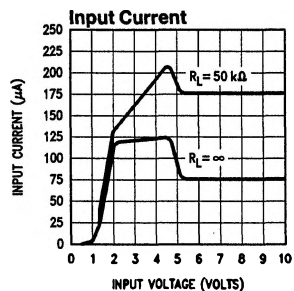
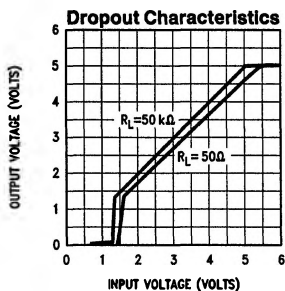
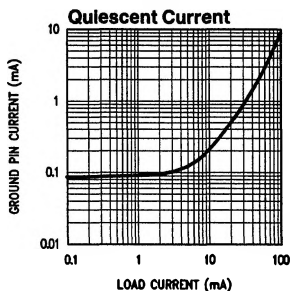
Note 12: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

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 50 mA load pulse at $V_{IN} = 30V$ (1.25V pulse) for $T = 10 ms$.

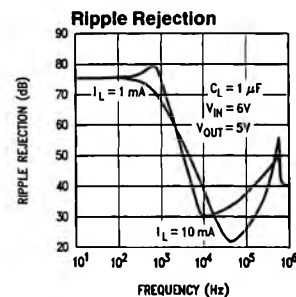
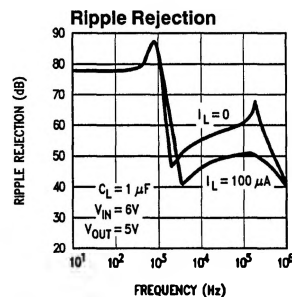
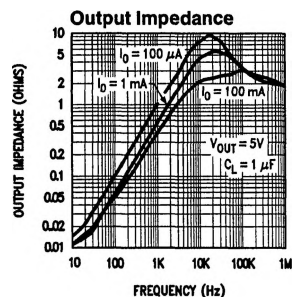
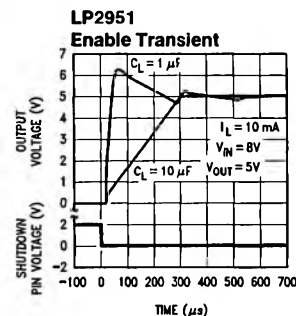
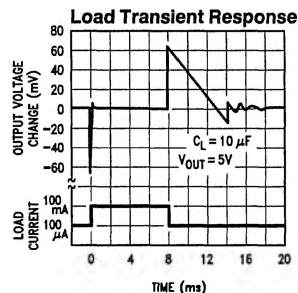
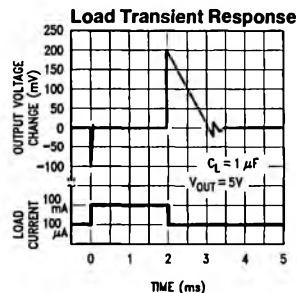
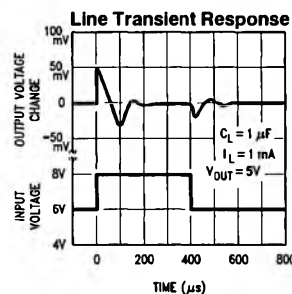
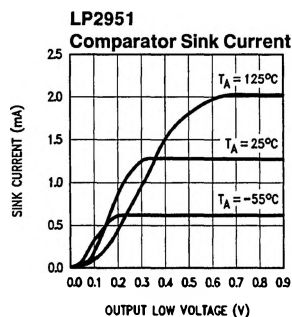
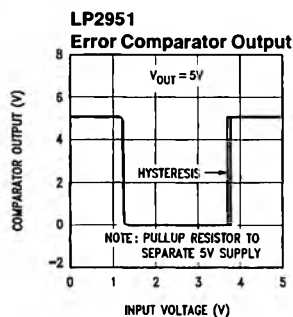
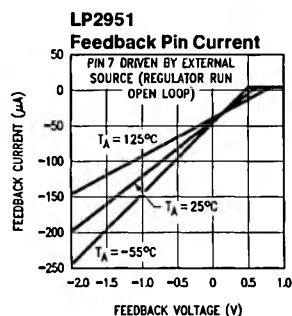
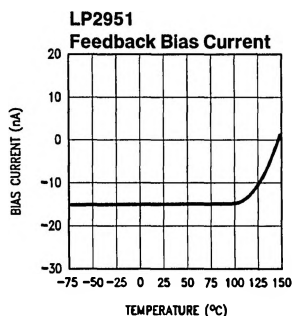
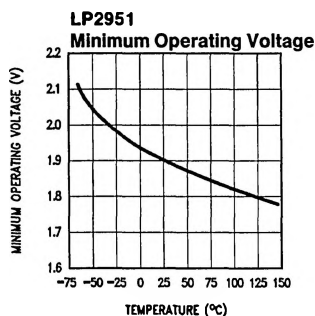
Note 14: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

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

Typical Performance Characteristics

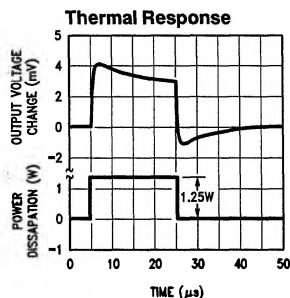
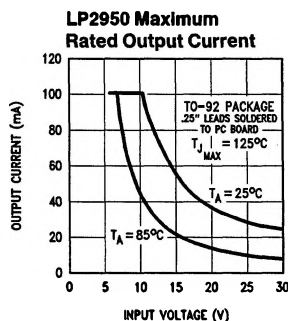
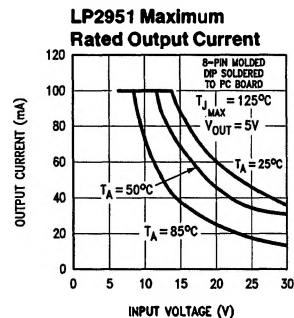
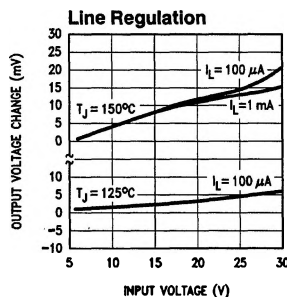
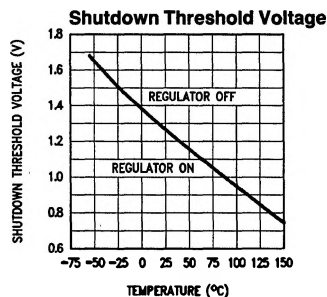
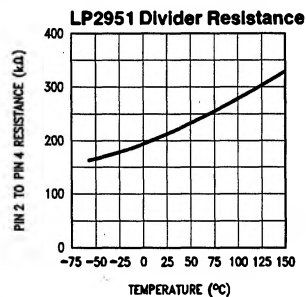
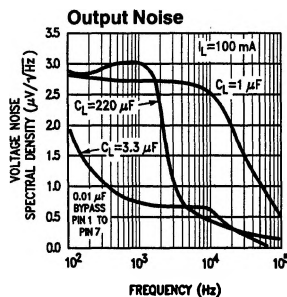
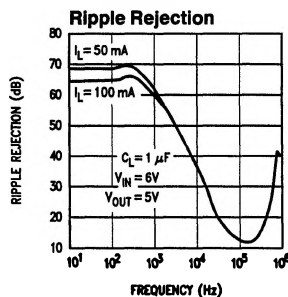


Typical Performance Characteristics (Continued)



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Typical Performance Characteristics (Continued)



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Application Hints

EXTERNAL CAPACITORS

A 1.0 μF (or greater) capacitor is required between the LP2950/LP2951 output and ground for stability. Without this capacitor the part will oscillate. Most types of tantalum or aluminum electrolytics work fine here; even film types work but are not recommended for reasons of cost. 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 $5\ \Omega$ 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 stability. The capacitor can be reduced to 0.33 μF for currents below 10 mA or 0.1 μF for currents below 1 mA. 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 100 mA load at 1.23V output (Output shorted to Feedback) a 3.3 μF (or greater) capacitor should be used.

Unlike many other regulators, the LP2950 will remain stable and in regulation with no load in addition to the internal voltage divider. 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 1 μA is recommended.

A 0.1 μF 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

Application Hints (Continued)

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 μ F will fix this problem.

ERROR DETECTION COMPARATOR OUTPUT

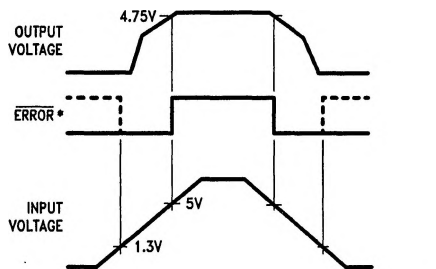
The comparator produces a logic low output whenever the LP2951 output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 60 mV divided by the 1.235 reference voltage. (Refer to the block diagram in the front of the datasheet.) This trip level remains "5% below normal" regardless of the programmed output voltage of the 2951. 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 below gives a timing diagram depicting the **ERROR** signal and the regulated output voltage as the LP2951 input is ramped up and down. The **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 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 (approx. 4.75V) does not vary with load.

The error comparator has an open-collector output which requires an external pullup resistor. This resistor may be returned to the 5V output or some other supply voltage depending on system requirements. In determining a value for this resistor, note that while the output is rated to sink 400 μ A, this sink current adds to battery drain in a low battery condition. Suggested values range from 100k to 1 M Ω . 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. As seen in Figure 2, an external pair of resistors is required.



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*In shutdown mode, **ERROR** will go high if it has been pulled up to an external 5V supply. To avoid this invalid response, **ERROR** should be pulled up to V_{OUT} (see Figure 2).

FIGURE 1. ERROR Output Timing

The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \cdot \left(1 + \frac{R_1}{R_2}\right) + I_{FB}R_1$$

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 μ A forces an upper limit of 1.2 M Ω 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 μ A. Since the LP2951 typically draws 60 μ A at no load with Pin 2 open-circuited, this is a small price to pay.

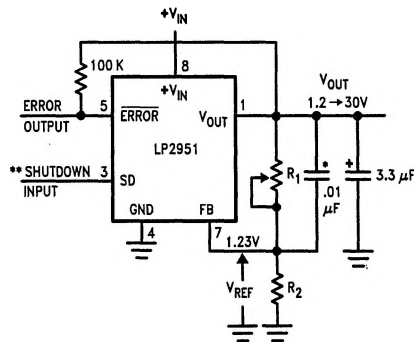
REDUCING OUTPUT NOISE

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 way noise can be reduced on the 3 lead LP2950 but is relatively inefficient, as increasing the capacitor from 1 μ F to 220 μ F only decreases the noise from 430 μ V to 160 μ V rms for a 100 kHz 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

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

or about 0.01 μ F. When doing this, the output capacitor must be increased to 3.3 μ F to maintain stability. These changes reduce the output noise from 430 μ V to 100 μ V 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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FIGURE 2. Adjustable Regulator

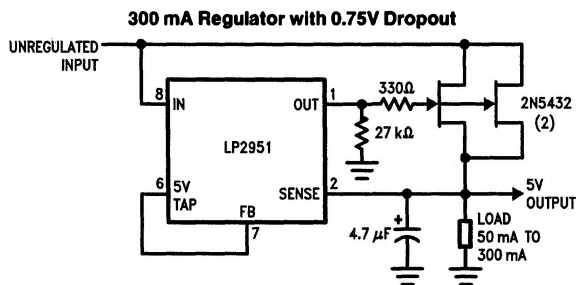
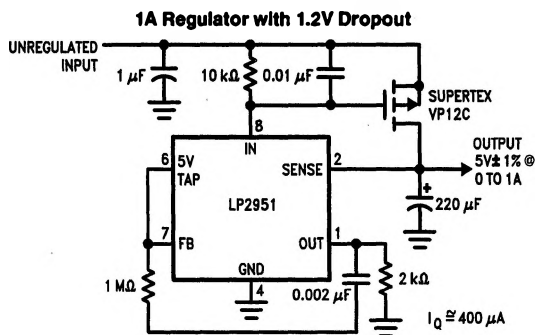
*See Application Hints

$$V_{out} = V_{Ref} \left(1 + \frac{R_1}{R_2}\right)$$

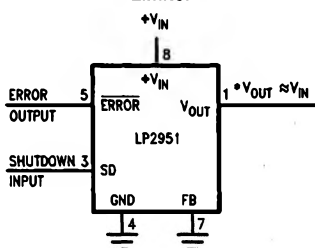
**Drive with TTL-high to shut down. Ground or leave open if shutdown feature is not to be used.

Note: Pins 2 and 6 are left open.

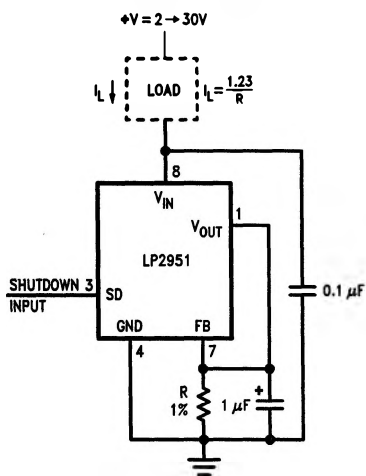
Typical Applications



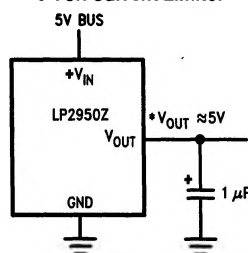
Wide Input Voltage Range Current Limiter



Low Drift Current Source



5 Volt Current Limiter



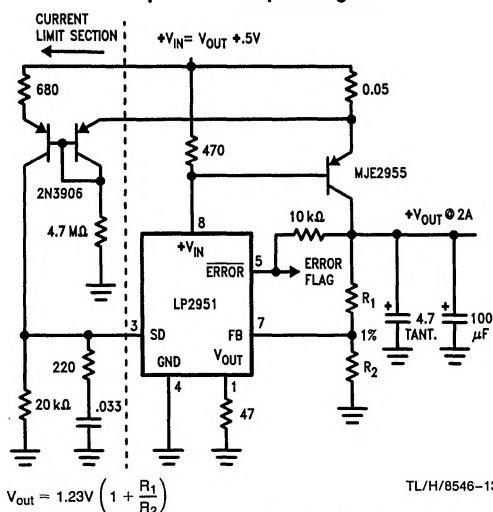
*Minimum input-output voltage ranges from 40 mV to 400 mV, depending on load current. Current limit is typically 160 mA.

The circuit diagram illustrates a two-stage battery monitoring system. The first stage, labeled 'EARLY WARNING', uses an LP2951 comparator (#1). Its non-inverting input (+VIN) is connected to the positive supply rail, and its inverting input (SENSE) is connected to the battery voltage (V+) through a 2.7 MΩ resistor. The comparator's output (VOUT) is connected to the base of a PNP transistor (Q1) and also to the positive supply rail through a 27 kΩ resistor. The transistor's emitter is connected to the positive supply rail, and its collector is connected to the battery voltage (V+) through a 330 kΩ resistor. The second stage, labeled 'MAIN OUTPUT', uses another LP2951 comparator (#2). Its non-inverting input (+VIN) is connected to the positive supply rail, and its inverting input (SENSE) is connected to the battery voltage (V+) through a 330 kΩ resistor. The comparator's output (VOUT) is connected to the base of a PNP transistor (Q2) and also to the positive supply rail through a 330 kΩ resistor. The transistor's emitter is connected to the positive supply rail, and its collector is connected to the battery voltage (V+) through a 330 kΩ resistor. Both comparators have their error inputs connected to the positive supply rail and their ground pins connected to ground. The battery voltage (V+) is connected to the positive supply rail through a 3.6V NICAD battery and a 1 μF capacitor. The output of the second stage is connected to the positive supply rail through a 330 kΩ resistor and to the battery voltage (V+) through a 330 kΩ resistor. The output is also connected to the positive supply rail through a 330 kΩ resistor and to the battery voltage (V+) through a 330 kΩ resistor. The output is also connected to the positive supply rail through a 330 kΩ resistor and to the battery voltage (V+) through a 330 kΩ resistor.

- 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 5V. Its error flag becomes active when $V_{in} \leq 5.7V$. When V_{in} drops below 5.3V, the error flag of Reg. #2 becomes active and via Q1 latches the main output off. When V_{in} again exceeds 5.7V Reg. #1 is back in regulation and the early warning signal rises, unlatching Reg. #2 via D3.

2 Ampere Low Dropout Regulator

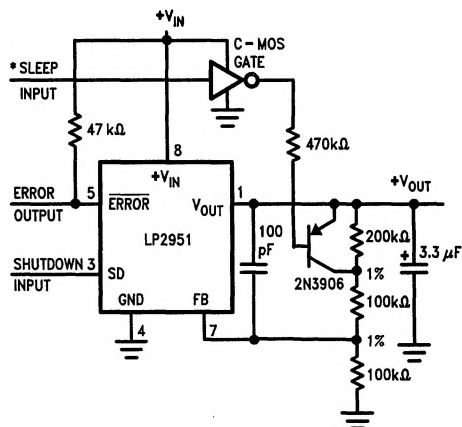


TL/H/8546-13

$$V_{out} = 1.23V \left(1 + \frac{R_1}{R_2} \right)$$

For 5V_{out}, use internal resistors. Wire pin 6 to 7, & wire pin 2 to +V_{out} Buss.

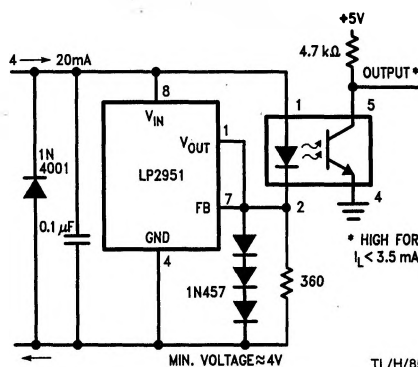
5V Regulator with 2.5V Sleep Function



• High input lowers V_{out} to 2.5V

TL/H/8546-14

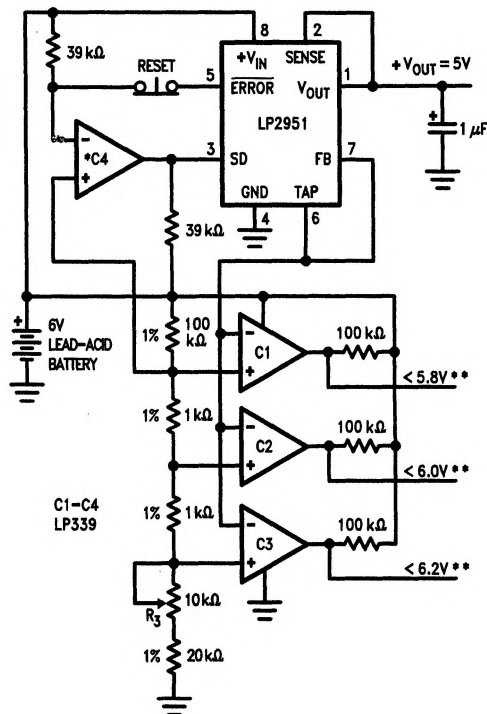
Open Circuit Detector for 4 → 20 mA Current Loop



TL/H/8546-15

Typical Applications (Continued)

Regulator with State-of-Charge Indicator



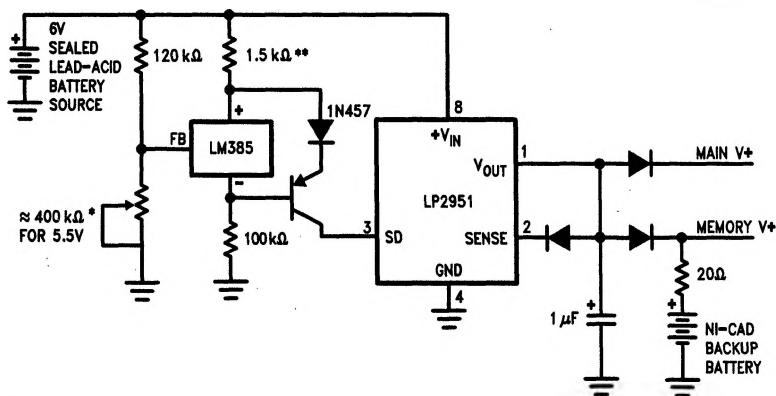
TL/H/8546-16

*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.

Low Battery Disconnect

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



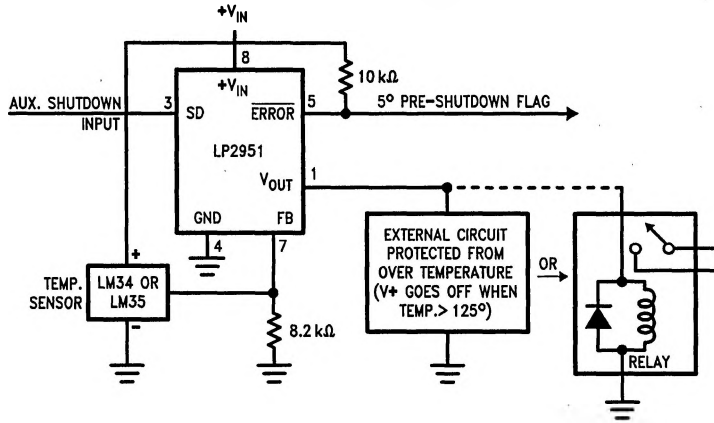
*Sets disconnect Voltage

**Sets disconnect Hysteresis

TL/H/8546-17

Typical Applications (Continued)

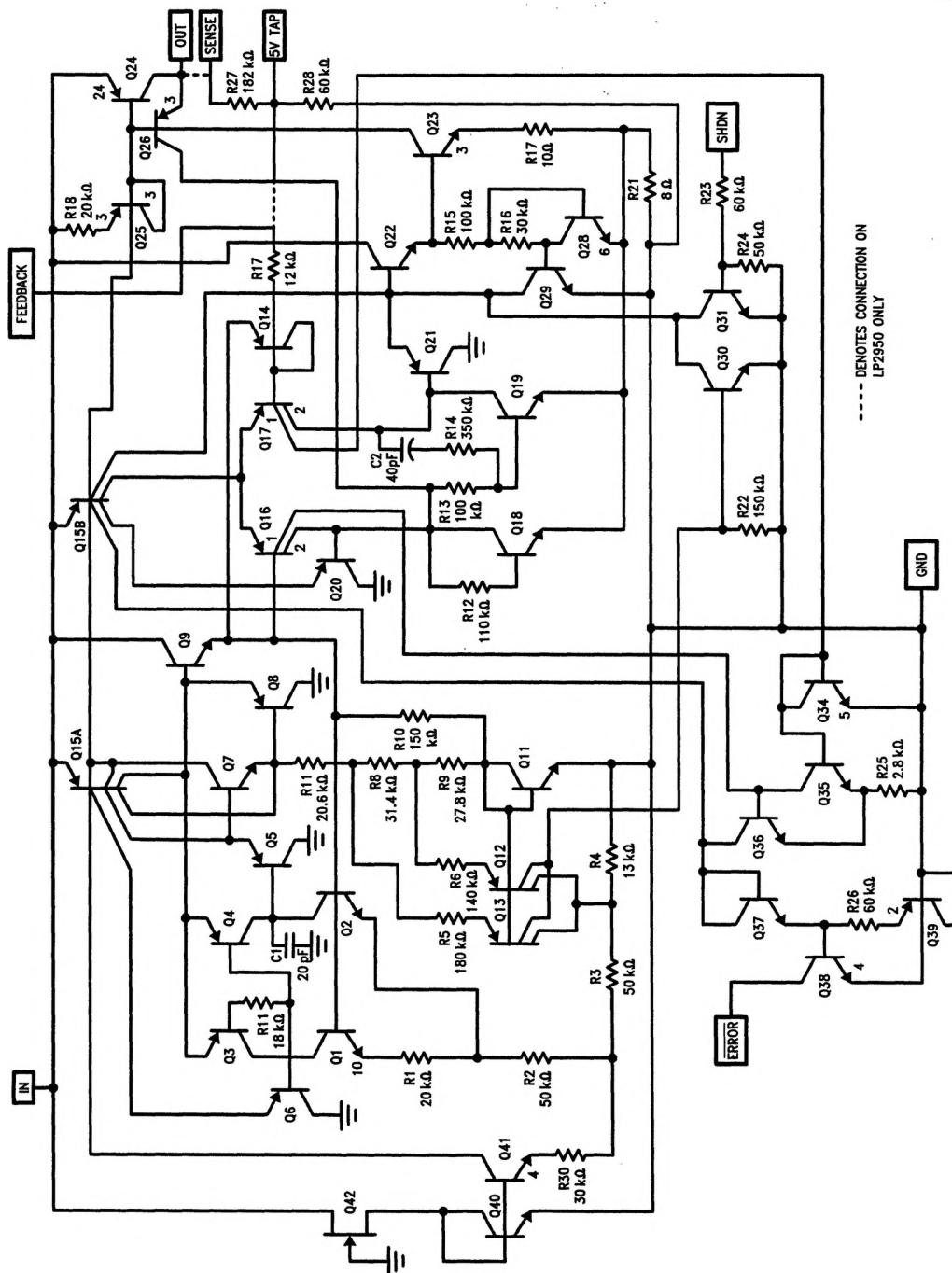
System Overtemperature Protection Circuit



TL/H/8546-18

LM34 for 125°F Shutdown
LM35 for 125°C Shutdown

Schematic Diagram



----- DENOTES CONNECTION ON
LP2950 ONLY