Constant Current Source and Temperature Sensor

FEATURES

- 1μA to 10mA Operation
- 0.02%/V Regulation
- 0.8V to 40V Operating Voltage
- Can be Used as Linear Temperature Sensor
- Draws No Reverse Current
- Supplied in Standard Transistor Packages

APPLICATIONS

- Current Mode Temperature Sensing
- Constant Current Source for Shunt References
- Cold Junction Compensation
- Constant-Gain Bias for Bipolar Differential Stage
- Micropower Bias Networks
- Buffer for Photoconductive Cell
- Current Limiter

DESCRIPTION

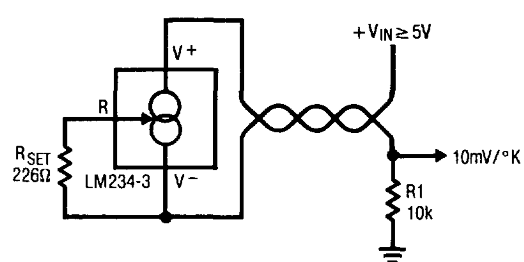
The LM134 is a three-terminal current source designed to operate at current levels from 1μA to 10mA, as set by an external resistor. The device operates as a true two-terminal current source, requiring no extra power connections or input signals. Regulation is typically 0.02%/V and terminal-to-terminal voltage can range from 800mV to 40V.

Because the operating current is *directly proportional to absolute temperature* in degrees Kelvin, the device will also find wide applications as a temperature sensor. The temperature dependence of the operating current is +0.336%/°C at room temperature. For example, a device operating at 298μA will have a temperature coefficient of +1μA/°C. The temperature dependence is extremely accurate and repeatable. Devices specified as temperature sensors in the 100μA to 1mA range are the LM134-3, LM234-3 and the LM134-6, LM234-6, with the dash numbers indicating ±3°C and ±6°C accuracies, respectively.

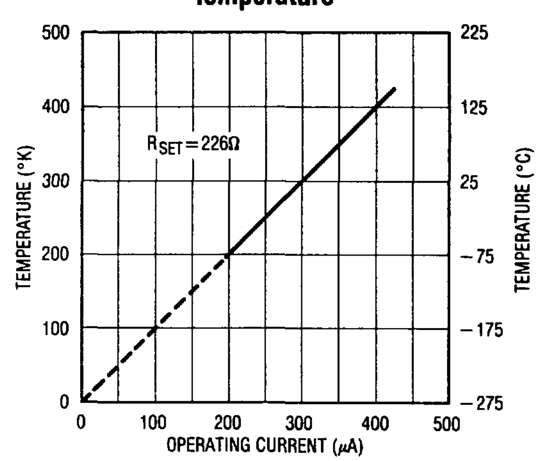
If a zero temperature coefficient current source is required, this is easily achieved by adding a diode and a resistor.

3

Remote Temperature Sensor with Voltage Output



Operating Current vs Temperature



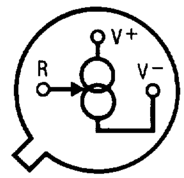
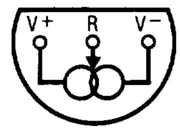
ABSOLUTE MAXIMUM RATINGS

V^+ to V^- Forward Voltage
- LM134 .... 40V
- LM134-3/LM134-6/LM234-3/LM234-6/LM334 .... 30V

V^+ to V^- Reverse Voltage 20V
R Pin to V^- Voltage 5V
Set Current 10mA
Power Dissipation 200mW
Operating Temperature Range
- LM134/LM134-3/LM134-6 .... −55°C to 125°C
- LM234-3/LM234-6 .... −25°C to 100°C
- LM334 .... 0°C to 70°C

Lead Temperature (Soldering, 10 sec.)........ 300°C

PACKAGE/ORDER INFORMATION

	ORDER PART NUMBER	
	CURRENT SOURCE	TEMP SENSOR
BOTTOM VIEW  H PACKAGE TO-46 METAL CAN	LM134H LM334H	LM134H-3 LM234H-3 LM134H-6 LM234H-6
BOTTOM VIEW  Z PACKAGE TO-92 PLASTIC	LM334Z	LM234Z-3 LM234Z-6

ELECTRICAL CHARACTERISTICS CURRENT SOURCE (Note 1)

SYMBOL	PARAMETER	CONDITIONS	LM134 MIN	LM134 TYP	LM134 MAX	LM334 MIN	LM334 TYP	LM334 MAX	UNITS
ΔI_{SET}	Set Current Error, $V^+ = 2.5V$ (Note 2)	$10\mu A \le I_{SET} \le 1mA$			3			6	%
		$1mA < I_{SET} \le 5mA$			5			8	%
		$2\mu A \le I_{SET} < 10\mu A$			8			12	%
	Ratio of Set Current to V^- Current	$10\mu A \le I_{SET} \le 1mA$	14	18	23	14	18	26	
		$1mA \le I_{SET} \le 5mA$		14			14		
		$2\mu A \le I_{SET} \le 10\mu A$		18	23		18	26	
V_{MIN}	Minimum Operating Voltage	$2\mu A \le I_{SET} \le 100\mu A$		0.8			0.8		V
		$100\mu A < I_{SET} \le 1mA$		0.9			0.9		V
		$1mA < I_{SET} \le 5mA$		1.0			1.0		V
$\frac{\Delta I_{SET}}{\Delta V_{IN}}$	Average Change in Set Current with Input Voltage	$1.5V \le V^+ \le 5V$ $2\mu A \le I_{SET} \le 1mA$		0.02	0.05		0.02	0.1	%/V
		$5V \le V^+ \le V_{MAX}$ (Note 4)		0.01	0.03		0.01	0.05	%/V
		$1.5V \le V \le 5V$ $1mA < I_{SET} \le 5mA$		0.03			0.03		%/V
		$5V \le V \le V_{MAX}$ (Note 4)		0.02			0.02		%/V
	Temperature Dependence of Set Current (Note 3)	$25\mu A \le I_{SET} \le 1mA$	0.96T	T	1.04T	0.96T	T	1.04T	
C_S	Effective Shunt Capacitance			15			15		pF

ELECTRICAL CHARACTERISTICS TEMPERATURE SENSOR (Note 1)

SYMBOL	PARAMETER	CONDITIONS	LM134-3, LM234-3			LM134-6, LM234-6			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	
ΔI_{SET}	Set Current Error, $V^+ = 2.5V$ (Note 2)	$100\mu A \le I_{SET} \le 1mA$ $T_j = 25°C$			±1			±2	%
	Equivalent Temperature Error				±3			±6	°C
	Ratio of Set Current to V^- Current	$100\mu A \le I_{SET} \le 1mA$	14	18	26	14	18	26	
V_{MIN}	Minimum Operating Voltage	$100\mu A \le I_{SET} \le 1mA$		0.9			0.9		V
$\frac{\Delta I_{SET}}{\Delta V_{IN}}$	Average Change in Set Current with Input Voltage	$1.5V \le V^+ \le 5V$ $100\mu A \le I_{SET} \le 1mA$		0.02	0.05		0.02	0.1	%/V
		$5V \le V^+ \le 30V$		0.01	0.03		0.01	0.05	%/V
	Temperature Dependence of Set Current (Note 3)	$100\mu A \le I_{SET} \le 1mA$	0.98T	T	1.02T	0.97T	T	1.03T	
	Equivalent Slope Error			±2			±3		%
C_S	Effective Shunt Capacitance			15			15		pF

Note 1: Unless otherwise specified, tests are performed at $T_j = 25°C$ with pulse testing so that junction temperature does not change during test.

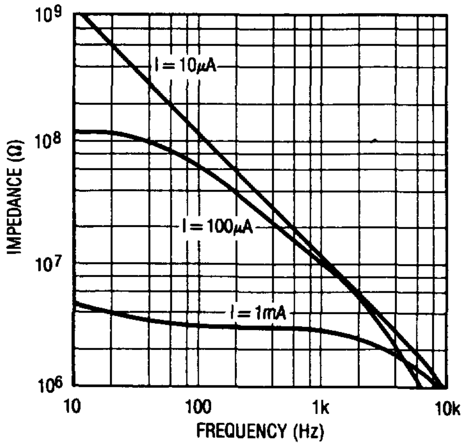
Note 2: Set current is the current flowing into the V^+ pin. It is determined by the following formula: $I_{SET} = 67.7mV/R_{SET}$ (@25°C). Set current error is expressed as a percent deviation from this amount. I_{SET} increases at 0.336%/°C@$T_j = 25°C$.

Note 3: I_{SET} is directly proportional to absolute temperature (°K). I_{SET} at any temperature can be calculated from: $I_{SET} = I_0 (T/T_0)$ where I_0 is I_{SET} measured at T_0 (°K).

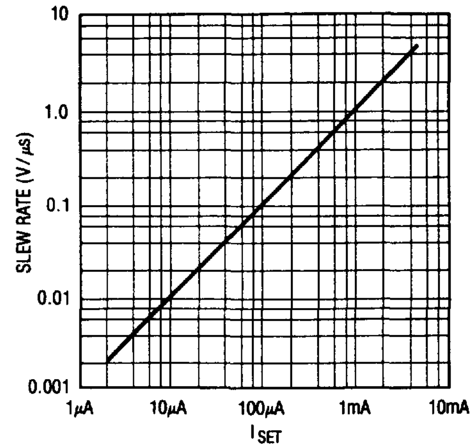
Note 4: $V_{MAX} = 40V$ for LM134 and 30V for other grades.

TYPICAL PERFORMANCE CHARACTERISTICS

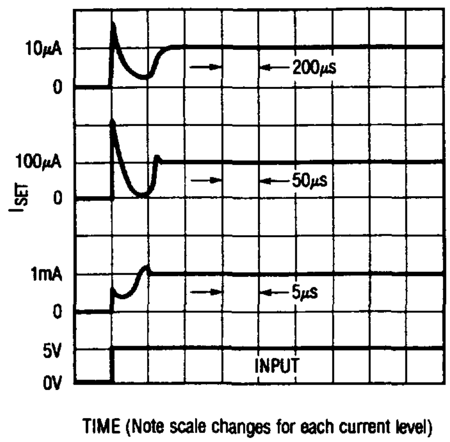
Output Impedance



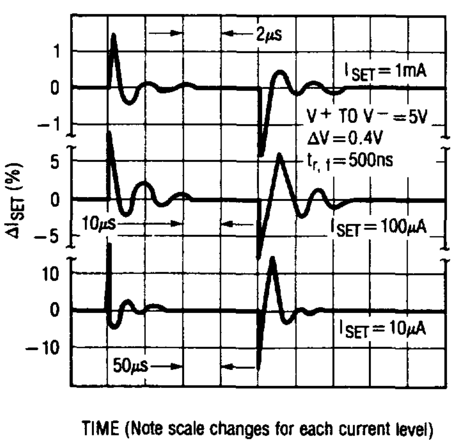
Maximum Slew Rate for Linear Operation



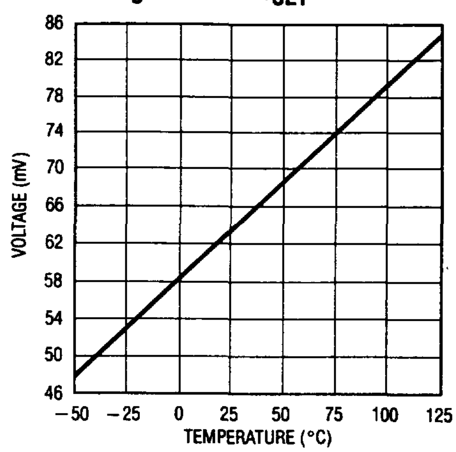
Start-Up



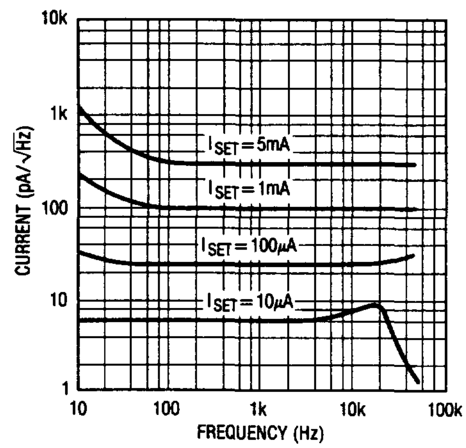
Transient Response



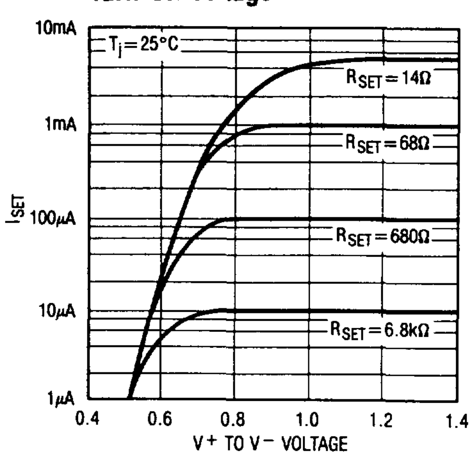
Voltage Across R_{SET}



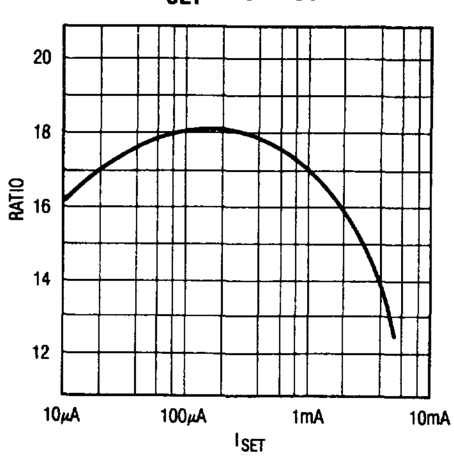
Current Noise



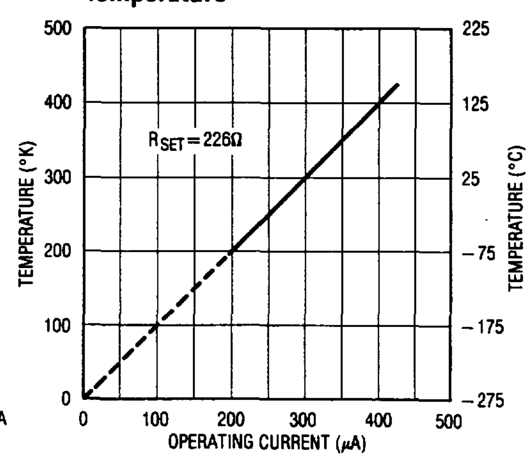
Turn-On Voltage



Ratio of I_{SET} to V^- Current



Operating Current vs Temperature



APPLICATIONS INFORMATION

Basic Theory of Operation

The equivalent circuit of the LM134 is shown in Figure 1. A reference voltage of 64mV is applied to the minus input of A1 with respect to the V^- pin. A1 serves the drive to Q2 to keep the R pin at 64mV, independent of the value of R_{SET}. Transistor Q1 is matched to Q2 at a 17:1 ratio so that the current flowing out of the V^- pin is always 1/18 of the total current into the V^+ pin. This total current is called I_{SET} and is equal to

$$\left(\frac{64mV}{R_{SET}}\right)\left(\frac{18}{17}\right)=\frac{67.7mV}{R_{SET}}.$$

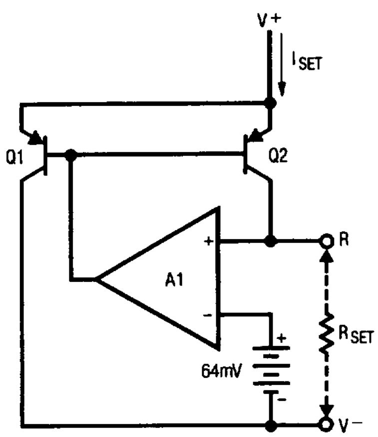


Figure 1

The 67.7mV equivalent reference voltage is directly proportional to absolute temperature in degrees Kelvin (see curve, "Operating Current vs Temperature"). This means that the reference voltage can be plotted as a straight line going from 0mV at absolute zero temperature to 67.7mV at 298°K (25°C). The slope of this line is $67.7mV/298=227\mu V/°C$.

The accuracy of the device is specified as a percent error at room temperature, or in the case of the -3 and -6 devices, as both a percent error and an equivalent temperature error. The LM134 operating current changes at a percent rate equal to $(100)\ (227\mu V/°C)/(67.7mV) = 0.336\%/°C$ at 25°C, so each 1% operating current error is equivalent to ≈3°C temperature error when the device is used as a temperature sensor. The slope accuracy (temperature coefficient) of the LM134 is expressed as a ratio compared to unity. The LM134-3, for instance, is specified at 0.98T to 1.02T, indicating that the maximum slope error of the device is ±2% when the room temperature current is set to the exact desired value.

Supply Voltage Slew Rate

At slew rates above a given threshold (see curve), the LM134 may exhibit non-linear current shifts. The slewing rate at which this occurs is directly proportional to I_{SET}. At $I_{SET}=10\mu A$, maximum dv/dt is $0.01V/\mu s$; at $I_{SET}=1\ mA$, the limit is $1V/\mu s$. Slew rates above the limit do not harm the LM134, or cause large currents to flow.

Thermal Effects

Internal heating can have a significant effect on current regulation for I_{SET} greater than 100µA. For example, each 1V increase across the LM134 at $I_{SET}=1mA$ will increase junction temperature by ≈0.4°C in still air. Output current (I_{SET}) has a temperature coefficient of ≈0.33%/°C, so the change in current due to temperature rise will be (0.4) (0.33)=0.132%. This is a 10:1 degradation in regulation compared to true electrical effects. Thermal effects, therefore, must be taken into account when DC regulation is critical and I_{SET} exceeds 100µA. Heat sinking of the TO-46 package or the TO-92 leads can reduce this effect by more than 3:1.

Shunt Capacitance

In certain applications, the 15pF shunt capacitance of the LM134 may have to be reduced, either because of loading problems or because it limits the AC output impedance of the current source. This can be easily accomplished by buffering the LM134 with an FET, as shown in the applications. This can reduce capacitance to less than 3pF and improve regulation by at least an order of magnitude. DC characteristics (with the exception of minimum input voltage) are not affected.

APPLICATIONS INFORMATION

Noise

Current noise generated by the LM134 is approximately 4 times the shot noise of a transistor. If the LM134 is used as an active load for a transistor amplifier, input referred noise will be increased by about 12dB. In many cases, this is acceptable and a single stage amplifier can be built with a voltage gain exceeding 2000.

Lead Resistance

The sense voltage which determines the operating current of the LM134 is less than 100mV. At this level, thermocouple or lead resistance effects should be minimized by locating the current setting resistor physically close to the device. Sockets should be avoided if possible. It takes only 0.7Ω contact resistance to reduce output current by 1% at the 1mA level.

Start-Up Time

The LM134 is designed to operate at currents as low as 1μA. This requires that internal biasing current be well below that level because the device achieves its wide operating current range by using part of the operating current as bias current for the internal circuitry. To ensure start-up, however, a fixed trickle current must be provided internally. This is typically in the range of 20nA–200nA and is provided by the special ultra-low I_{DSS} FETs shown in the Schematic Diagram as Q7 and Q8. The start-up time of the LM134 is determined by the I_{DSS} of these FETs and the capacitor C1. This capacitor must charge to approximately 500mV before Q3 turns on to start normal circuit operation. This takes as long as (500mV) (50pF)/(20nA) = 1.25ms for very low I_{DSS} values.

Using the LM134 as a Temperature Sensor

Because it has a highly linear output characteristic, the LM134 makes a good temperature sensor. It is particularly useful in remote sensing applications because it is a current output device and is therefore not affected by long wire runs. It is easy to calibrate, has good long term stability, and can be interfaced directly with most data acquisition systems, eliminating the expensive preamplifiers required for thermocouples and platinum sensors.

A typical temperature sensor application is shown in Figure 2. The LM134 operating current at 25°C is set at 298μA by the 226Ω resistor, giving an output of 1μA/°K. The current flows through the twisted pair sensor leads to the 10kΩ termination resistor, which converts the current output to a voltage of 10mV/°K referred to ground. The voltage across the 10kΩ resistor will be 2.98V at 25°C, with a slope of 10mV/°C. The simplest way to convert this signal to a Centigrade scale is to subtract a constant 2.73V in software. Alternately, a hardware conversion can be used, as shown in Figure 3, using an LT1009 as a level shifter to offset the output to a Centigrade scale.

The resistor (R_{SET}) used to set the operating current of the LM134 in temperature sensing applications should have low temperature coefficient and good long term stability.

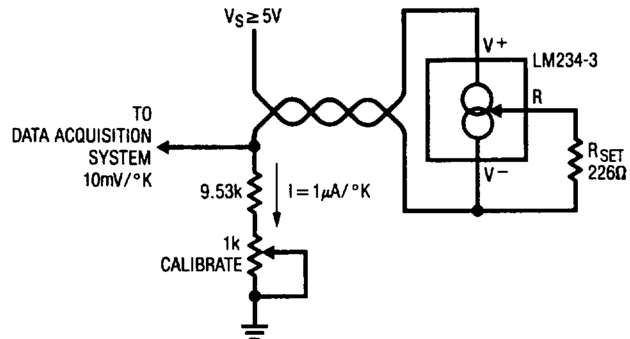


Figure 2. Kelvin Temperature Sensor

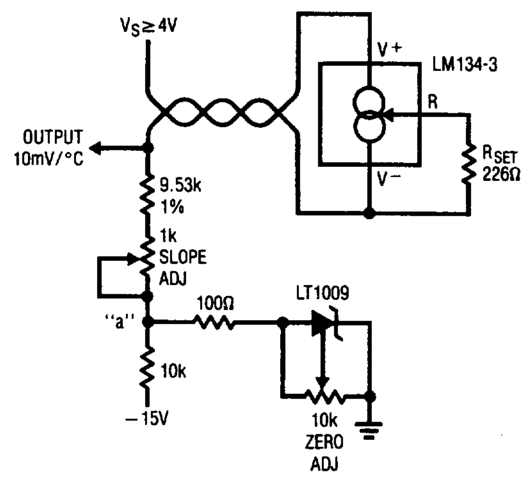


Figure 3. Centigrade Temperature Sensor

APPLICATIONS INFORMATION

30ppm/°C drift in the resistor will change the slope of the temperature sensor by 1%, assuming that the resistor is at the same temperature as the sensor, which is usually the case since the resistor should be located physically close to the LM134 to prevent errors due to wire resistance. A long term shift of 0.3% in the resistor will create a 1°C temperature error. The long term drift of the LM134 is typically much better than this, so stable resistors must be used for best long term performance.

Calibration of the LM134 as a temperature sensor is extremely easy. Referring to Figure 2, calibration is achieved by trimming the termination resistor. *This theoretically trims both zero and slope simultaneously for Centigrade and Fahrenheit applications.* The initial errors in the LM134 are directly proportional to absolute temperature, just like the actual output. This allows the sensor to be trimmed at any temperature and have the slope error be corrected at the same time. Residual slope error is typically less than 1% after this single trim is completed.

The two trims shown in Figure 3 are still intended to be a "one point" temperature calibration, where the zero and the slope are trimmed at a single temperature. The LT1009 reference is adjusted to give 2.700V at node "a" at $T_{SENSOR} = 25°C$. The 1k trimmer then adjusts the output for 0.25V, completing the calibration. If the calibration is to be done at a temperature other than 25°C, trim the LT1009 for $2.7025 - (1\mu A)[T_{SENSOR}\ (°C)](100\Omega)$ at node "a", then adjust the 1k trimmer for proper output.

If higher accuracy is required, a two point calibration technique can be used. In Figure 4, separate zero and slope trims are provided. Residual non-linearity is now the limitation on accuracy. Non-linearity of the LM134 in a 100°C span is typically less than 0.5°C. This particular method of trimming has the advantage that the slope trim does not interact with the zero trim. Trim procedure is to adjust for zero output with $T_{SENSOR} = 0°C$, then trim slope for proper output at some convenient second temperature. No further trimming is required.

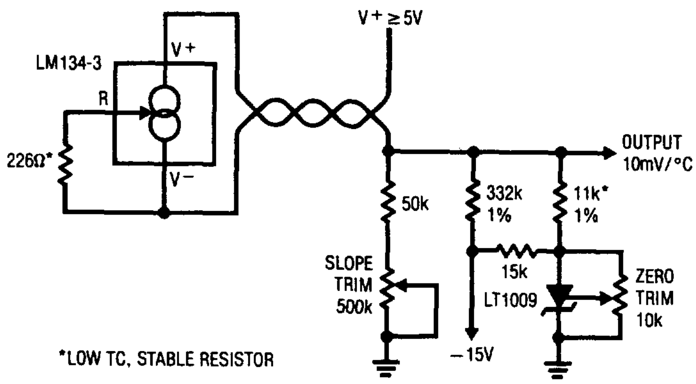
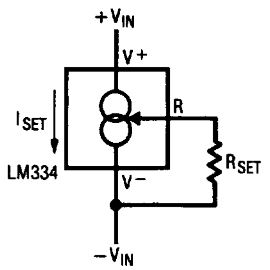


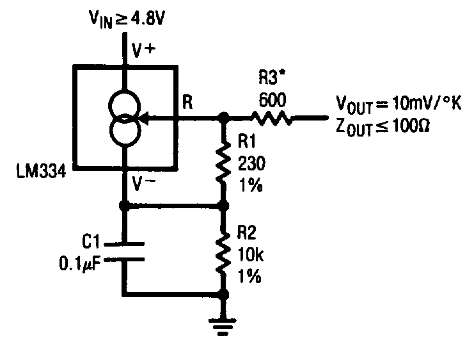
Figure 4. Centigrade Temperature Sensor with 2 Point Trim

TYPICAL APPLICATIONS

Basic 2-Terminal Current Source

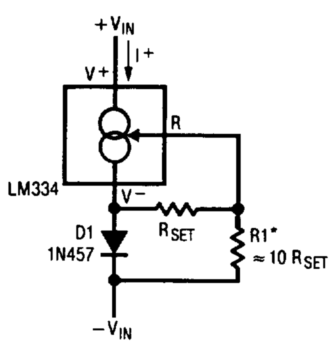


Low Output Impedance Thermometer (Kelvin Output)



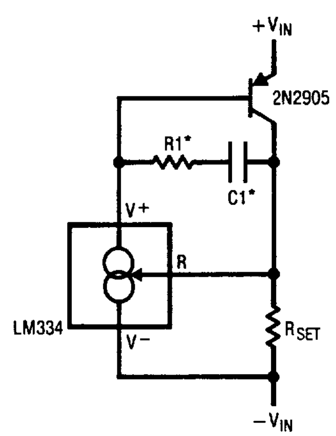
*OUTPUT IMPEDANCE OF THE LM134 AT THE "R" PIN IS APPROXIMATELY $\frac{-R_0}{16}\Omega$, WHERE R_0 IS THE EQUIVALENT EXTERNAL RESISTANCE CONNECTED TO THE V− PIN. THIS NEGATIVE RESISTANCE CAN BE REDUCED BY A FACTOR OF 5 OR MORE BY INSERTING AN EQUIVALENT RESISTOR IN SERIES WITH THE OUTPUT.

Zero Temperature Coefficient Current Source



*SELECT RATIO OF R1 TO R_{SET} TO OBTAIN ZERO DRIFT. $I^+ \approx 2\, I_{SET}$.

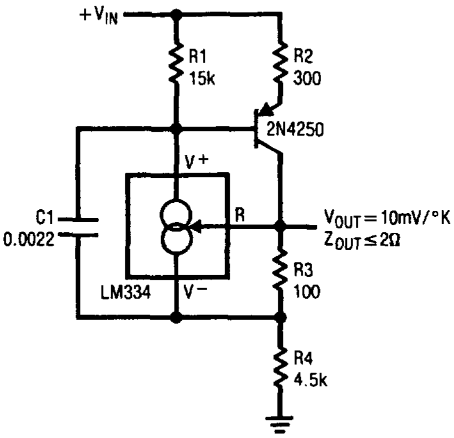
Higher Output Current



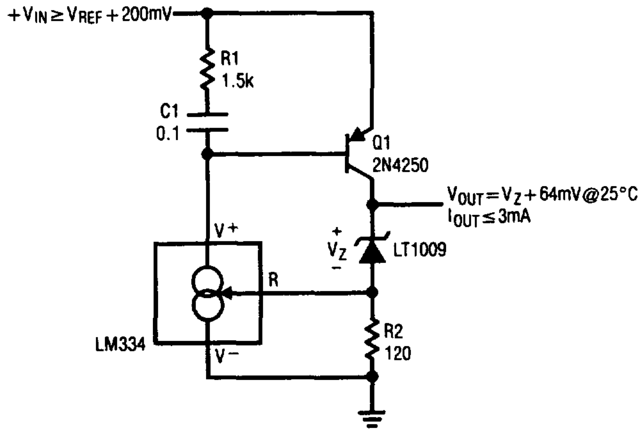
*SELECT R1 AND C1 FOR OPTIMUM STABILITY

TYPICAL APPLICATIONS

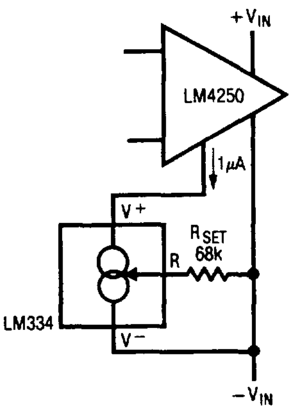
Low Output Impedance Thermometer



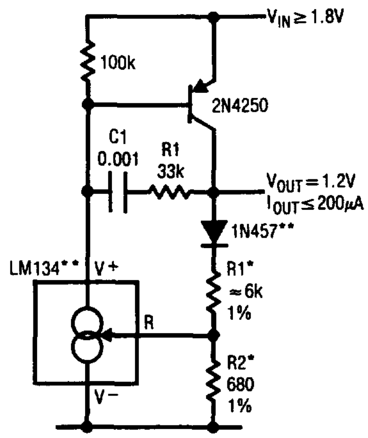
Low Input Voltage Reference Driver



Micropower Bias

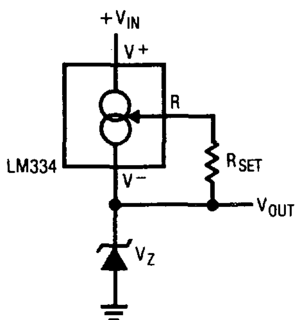


1.2V Regulator with 1.8V Minimum Input



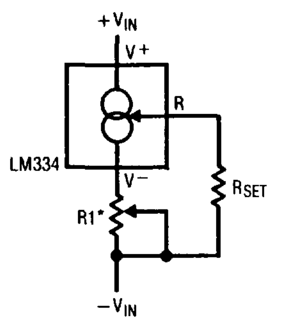
*SELECT RATIO OF R1 TO R2 FOR ZERO TEMPERATURE DRIFT
**LM134 AND DIODE SHOULD BE ISOTHERMAL

Zener Biasing



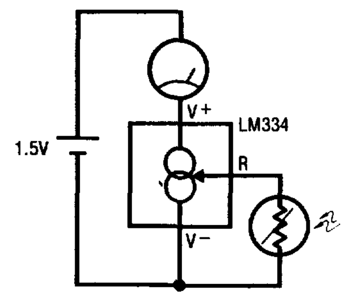
TYPICAL APPLICATIONS

Alternate Trimming Technique

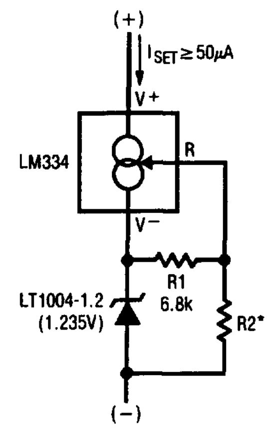


*FOR ±10% ADJUSTMENT, SELECT R_{SET} 10% HIGH AND MAKE R1 ≈ $3R_{SET}$

Buffer for Photoconductive Cell



High Precision Low TC Current Source

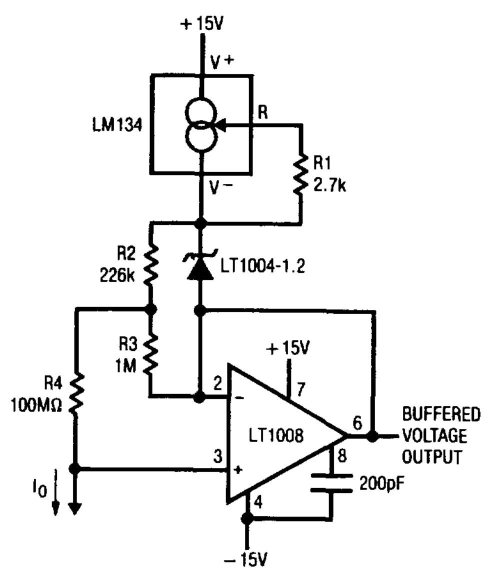


$*I_{SET} = \frac{1.37V}{R2} + 10\mu A$

I_{SET} TC = 0.016%/°C + 33nA/°C

REGULATION ≈ 0.001%/V

Precision 10nA Current Source

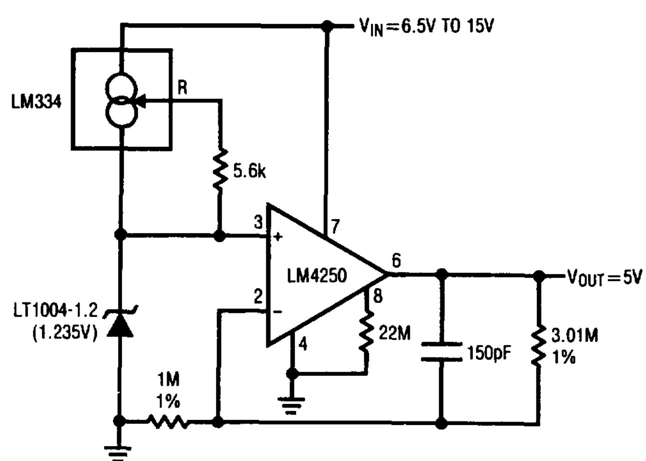


I_O = 10nA

$Z_O \geq 10^{12}\Omega$

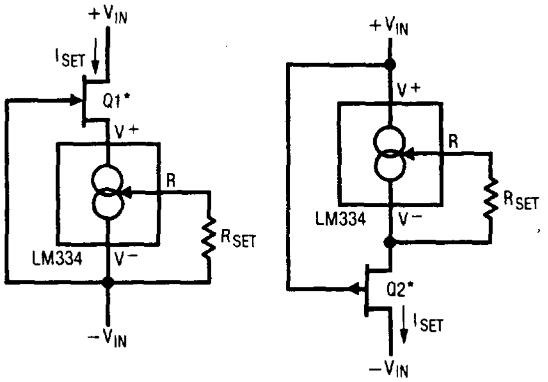
COMPLIANCE = −14V TO +12.5V

Micropower 5V Reference



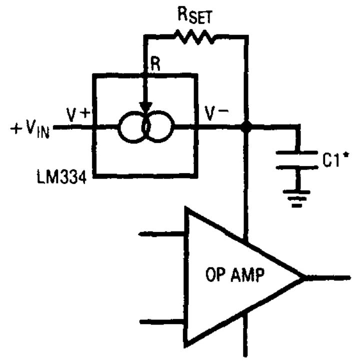
TYPICAL APPLICATIONS

FET Cascoding for Low Capacitance and/or Ultra High Output Impedance



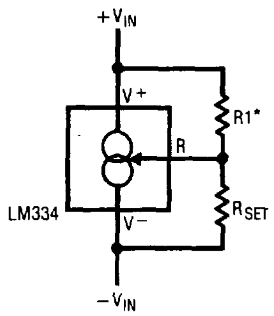
*SELECT Q1 OR Q2 TO ENSURE AT LEAST 1V ACROSS THE LM134. $V_P(1-I_{SET}/I_{DSS}) \geq 1.2V$.

In-Line Current Limiter



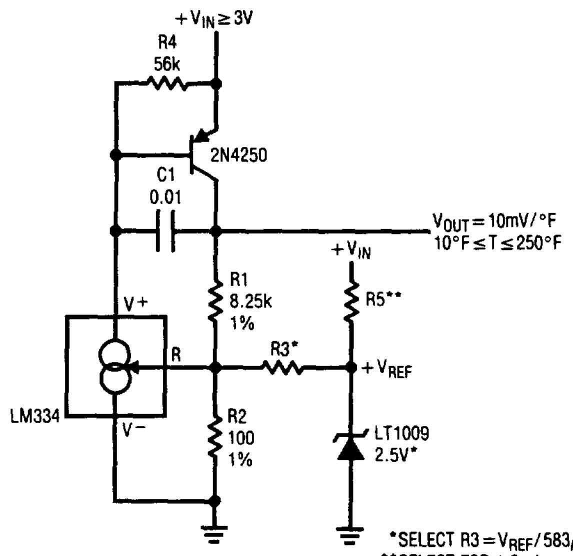
*USE MINIMUM VALUE REQUIRED TO ENSURE STABILITY OF PROTECTED DEVICE. THIS MINIMIZES INRUSH CURRENT TO A DIRECT SHORT.

Generating Negative Output Impedance



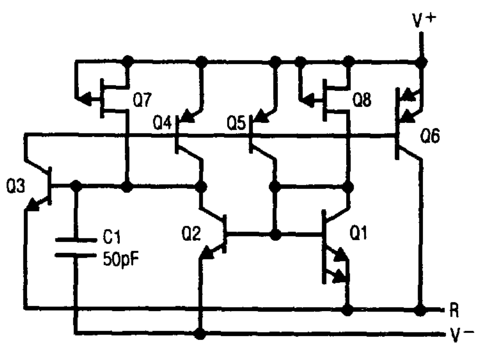
*$Z_{OUT} \approx -16 \bullet R1$ ($R1/V_{IN}$ MUST NOT EXCEED I_{SET}).

Ground Referred Fahrenheit Thermometer



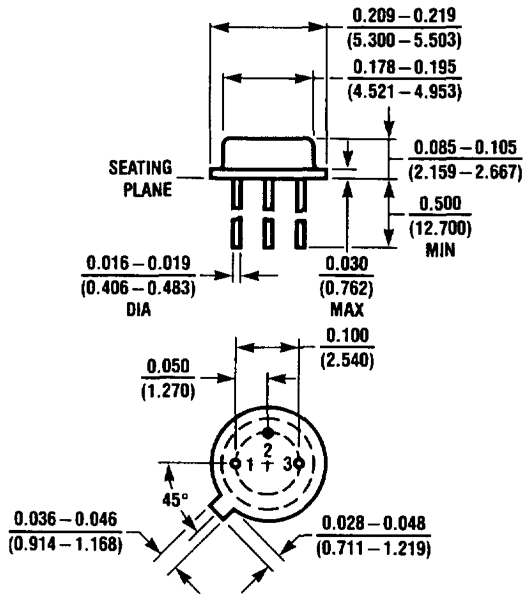
*SELECT $R3 = V_{REF}/583\mu A$.
**SELECT FOR 1.2mA

SCHEMATIC DIAGRAM



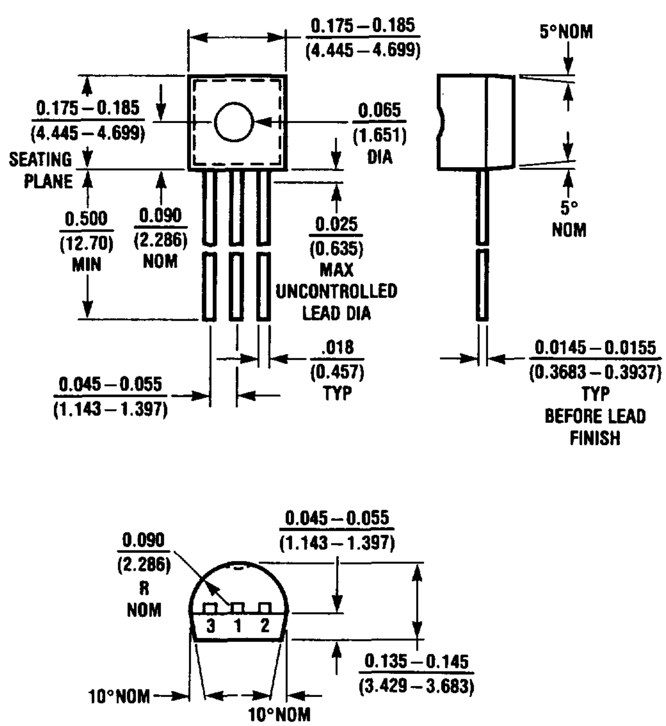
PACKAGE DESCRIPTION

H Package
Metal Can



T_jmax	θ_{ja}	θ_{jc}
150°C	440°C/W	80°C/W

Z Package
Plastic



T_jmax	θ_{ja}
100°C	160°C/W