

November 2000

LM135/LM235/LM335, LM135A/LM235A/LM335A Precision Temperature Sensors

General Description

The LM135 series are precision, easily-calibrated, integrated circuit temperature sensors. Operating as a 2-terminal zener, the LM135 has a breakdown voltage directly proportional to absolute temperature at +10 mV/°K. With less than 1Ω dynamic impedance the device operates over a current range of 400 μA to 5 mA with virtually no change in performance. When calibrated at 25°C the LM135 has typically less than 1°C error over a 100°C temperature range. Unlike other sensors the LM135 has a linear output.

Applications for the LM135 include almost any type of temperature sensing over a -55°C to +150°C temperature range. The low impedance and linear output make interfacing to readout or control circuitry especially easy.

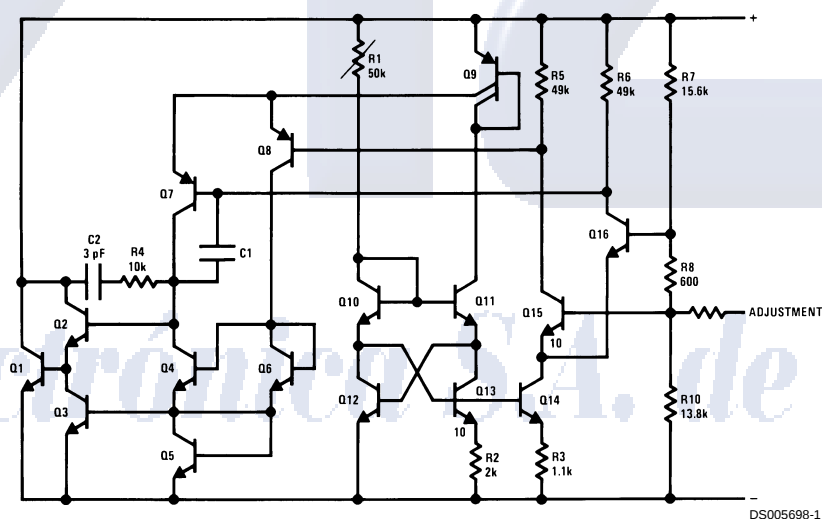
The LM135 operates over a -55°C to +150°C temperature range while the LM235 operates over a -40°C to +125°C

temperature range. The LM335 operates from -40°C to +100°C. The LM135/LM235/LM335 are available packaged in hermetic TO-46 transistor packages while the LM335 is also available in plastic TO-92 packages.

Features

- Directly calibrated in °Kelvin
- 1°C initial accuracy available
- Operates from 400 μA to 5 mA
- Less than 1Ω dynamic impedance
- Easily calibrated
- Wide operating temperature range
- 200°C overrange
- Low cost

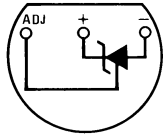
Schematic Diagram



LM135/LM235/LM335, LM135A/LM235A/LM335A Precision Temperature Sensors

Connection Diagrams

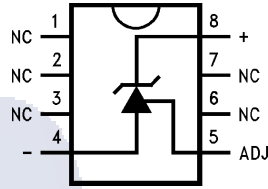
TO-92
Plastic Package



DS005698-8

Bottom View
Order Number LM335Z
or LM335AZ
See NS Package
Number Z03A

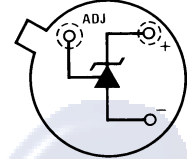
SO-8
Surface Mount Package



DS005698-25

Order Number LM335M
See NS Package
Number M08A

TO-46
Metal Can Package*



DS005698-26

*Case is connected to negative pin

Bottom View
Order Number LM135H,
LM135H-MIL, LM235H,
LM335H, LM135AH,
LM235AH or LM335AH
See NS Package
Number H03H

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Absolute Maximum Ratings (Note 4)

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

Reverse Current	15 mA
Forward Current	10 mA
Storage Temperature	
TO-46 Package	-60°C to +180°C
TO-92 Package	-60°C to +150°C
SO-8 Package	-65°C to +150°C

Specified Operating Temp. Range

	Continuous	Intermittent (Note 2)
LM135, LM135A	-55°C to +150°C	150°C to 200°C
LM235, LM235A	-40°C to +125°C	125°C to 150°C
LM335, LM335A	-40°C to +100°C	100°C to 125°C
Lead Temp. (Soldering, 10 seconds)		260°C
TO-92 Package:		300°C
TO-46 Package:		300°C
SO-8 Package:		300°C
Vapor Phase (60 seconds):		215°C
Infrared (15 seconds):		220°C

Temperature Accuracy (Note 1)

LM135/LM235, LM135A/LM235A

Parameter	Conditions	LM135A/LM235A			LM135/LM235			Units
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage	$T_C = 25^\circ\text{C}$, $I_R = 1\text{ mA}$	2.97	2.98	2.99	2.95	2.98	3.01	V
Uncalibrated Temperature Error	$T_C = 25^\circ\text{C}$, $I_R = 1\text{ mA}$		0.5	1		1	3	°C
Uncalibrated Temperature Error	$T_{\text{MIN}} \leq T_C \leq T_{\text{MAX}}$, $I_R = 1\text{ mA}$		1.3	2.7		2	5	°C
Temperature Error with 25°C Calibration	$T_{\text{MIN}} \leq T_C \leq T_{\text{MAX}}$, $I_R = 1\text{ mA}$		0.3	1		0.5	1.5	°C
Calibrated Error at Extended Temperatures	$T_C = T_{\text{MAX}}$ (Intermittent)		2			2		°C
Non-Linearity	$I_R = 1\text{ mA}$		0.3	0.5		0.3	1	°C

Temperature Accuracy (Note 1)

LM335, LM335A

Parameter	Conditions	LM335A			LM335			Units
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage	$T_C = 25^\circ\text{C}$, $I_R = 1\text{ mA}$	2.95	2.98	3.01	2.92	2.98	3.04	V
Uncalibrated Temperature Error	$T_C = 25^\circ\text{C}$, $I_R = 1\text{ mA}$		1	3		2	6	°C
Uncalibrated Temperature Error	$T_{\text{MIN}} \leq T_C \leq T_{\text{MAX}}$, $I_R = 1\text{ mA}$		2	5		4	9	°C
Temperature Error with 25°C Calibration	$T_{\text{MIN}} \leq T_C \leq T_{\text{MAX}}$, $I_R = 1\text{ mA}$		0.5	1		1	2	°C
Calibrated Error at Extended Temperatures	$T_C = T_{\text{MAX}}$ (Intermittent)		2			2		°C
Non-Linearity	$I_R = 1\text{ mA}$		0.3	1.5		0.3	1.5	°C

Electrical Characteristics (Note 1)

Parameter	Conditions	LM135/LM235 LM135A/LM235A			LM335 LM335A			Units
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage	$400\text{ }\mu\text{A} \leq I_R \leq 5\text{ mA}$		2.5	10		3	14	mV
Change with Current	At Constant Temperature							
Dynamic Impedance	$I_R = 1\text{ mA}$		0.5			0.6		Ω
Output Voltage Temperature Coefficient			+10			+10		mV/°C
Time Constant	Still Air		80			80		sec
	100 ft/Min Air		10			10		sec
	Stirred Oil		1			1		sec
Time Stability	$T_C = 125^\circ\text{C}$		0.2			0.2		°C/khr

LM135/LM235/LM335, LM135A/LM235A/LM335A

Electrical Characteristics (Note 1) (Continued)

Note 1: Accuracy measurements are made in a well-stirred oil bath. For other conditions, self heating must be considered.

Note 2: Continuous operation at these temperatures for 10,000 hours for H package and 5,000 hours for Z package may decrease life expectancy of the device.

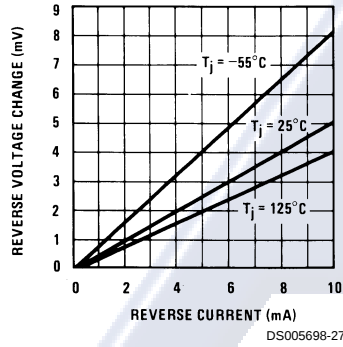
Note 3:

Thermal Resistance	TO-92	TO-46	SO-8
θ_{JA} (junction to ambient)	202°C/W	400°C/W	165°C/W
θ_{JC} (junction to case)	170°C/W	N/A	N/A

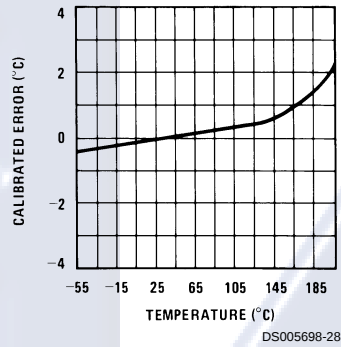
Note 4: Refer to RETS135H for military specifications.

Typical Performance Characteristics

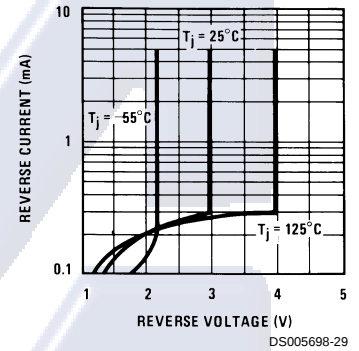
Reverse Voltage Change



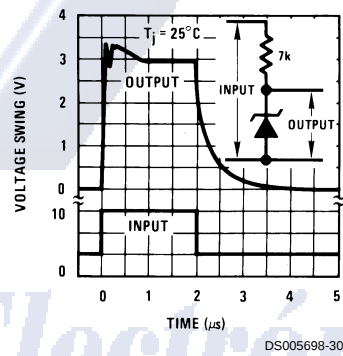
Calibrated Error



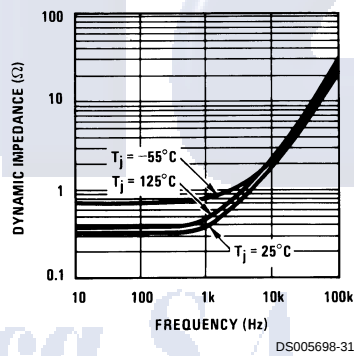
Reverse Characteristics



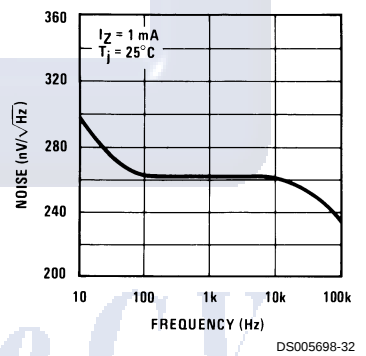
Response Time



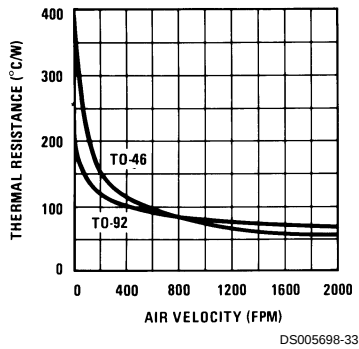
Dynamic Impedance



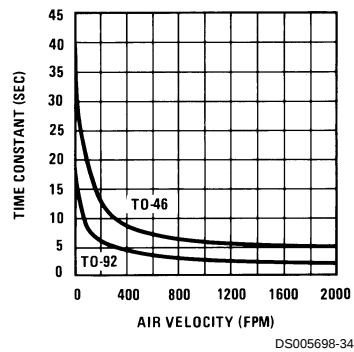
Noise Voltage



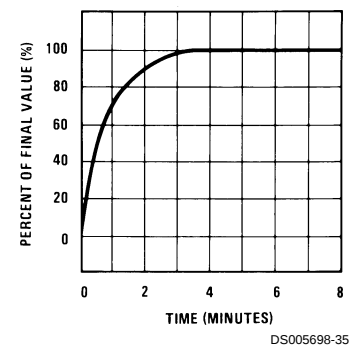
Thermal Resistance
Junction to Air



Thermal Time Constant

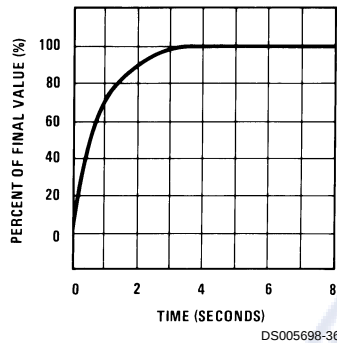


Thermal Response in Still Air

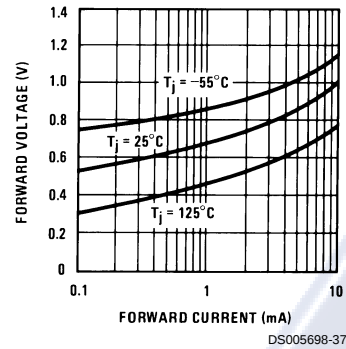


Typical Performance Characteristics (Continued)

Thermal Response in Stirred Oil Bath



Forward Characteristics



Application Hints

CALIBRATING THE LM135

Included on the LM135 chip is an easy method of calibrating the device for higher accuracies. A pot connected across the LM135 with the arm tied to the adjustment terminal allows a 1-point calibration of the sensor that corrects for inaccuracy over the full temperature range.

This single point calibration works because the output of the LM135 is proportional to absolute temperature with the extrapolated output of sensor going to 0V output at 0°K (-273.15°C). Errors in output voltage versus temperature are only slope (or scale factor) errors so a slope calibration at one temperature corrects at all temperatures.

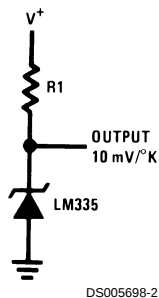
The output of the device (calibrated or uncalibrated) can be expressed as:

$$V_{OUT_T} = V_{OUT_{T_0}} \times \frac{T}{T_0}$$

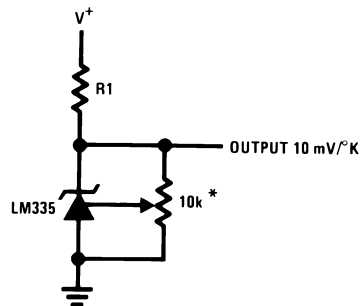
where T is the unknown temperature and T_0 is a reference temperature, both expressed in degrees Kelvin. By calibrating the output to read correctly at one temperature the output at all temperatures is correct. Nominally the output is calibrated at 10 mV/°K.

Typical Applications

Basic Temperature Sensor

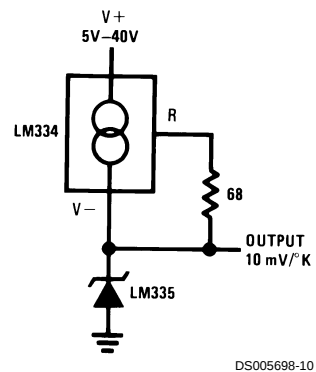


Calibrated Sensor



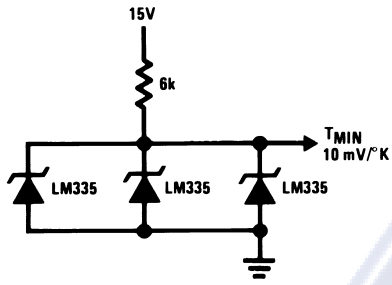
*Calibrate for 2.982V at 25°C

Wide Operating Supply



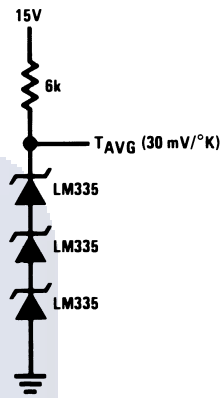
Typical Applications (Continued)

Minimum Temperature Sensing



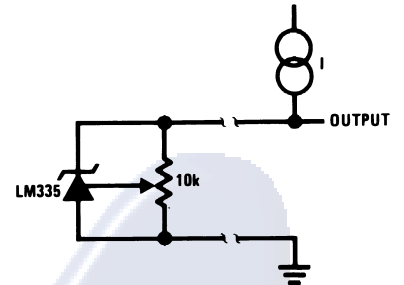
DS005698-4

Average Temperature Sensing



DS005698-18

Remote Temperature Sensing



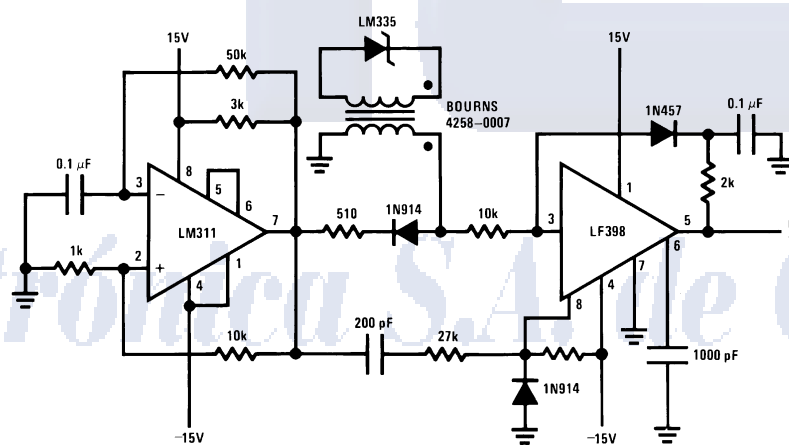
DS005698-19

Wire length for 1°C error due to wire drop

AWG	$I_R = 1$ mA	$I_R = 0.5$ mA*
	FEET	FEET
14	4000	8000
16	2500	5000
18	1600	3200
20	1000	2000
22	625	1250
24	400	800

*For $I_R = 0.5$ mA, the trim pot must be deleted.

Isolated Temperature Sensor



DS005698-20

*To calibrate adjust R2 for 2.554V across LM336.
Adjust R1 for correct output.

The circuit diagram shows a differential amplifier using an LM329B op-amp. The non-inverting input (+) is connected to a voltage divider consisting of a 4.7k resistor to +15V and a 12k resistor to -15V. The inverting input (-) is connected to a network of resistors: a 200k resistor to +15V, a 1M resistor to ground, and a 10k resistor (R2) to the non-inverting input. A 10k resistor (R1) connects the inverting input to the output. A 71.5k resistor (1% tolerance) connects the output to the non-inverting input. A 1% tolerance resistor (R3) is connected from the inverting input to ground. The output of the op-amp is connected to a 'METER' block. The meter's other terminals are connected to a thermocouple, which is also grounded. The thermocouple's polarity is indicated with '+' and '-' signs.

*Select R3 for proper thermocouple type

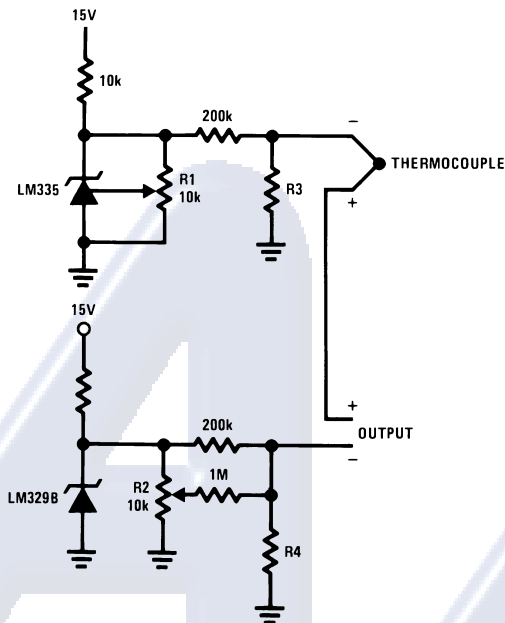
THERMO- COUPLE	R3 (±1%)	SEEBECK COEFFICIENT
J	377Ω	52.3 μV/°C
T	308Ω	42.8 μV/°C
K	293Ω	40.8 μV/°C
S	45.8Ω	6.4 μV/°C

2. Adjust R1 for Seebeck Coefficient times ambient temperature (in degrees K) across R3.
3. Short LM335 and adjust R2 for voltage across R3 corresponding to thermocouple type

J	14.32 mV	K	11.17 mV
T	11.79 mV	S	1.768 mV

Typical Applications (Continued)

Single Power Supply Cold Junction Compensation



*Select R3 and R4 for thermocouple type

DS005698-11

THERMO- COUPLE	R3	R4	SEEBECK COEFFICIENT
J	1.05K	385Ω	52.3 μV/°C
T	856Ω	315Ω	42.8 μV/°C
K	816Ω	300Ω	40.8 μV/°C
S	128Ω	46.3Ω	6.4 μV/°C

Adjustments:

1. Adjust R1 for the voltage across R3 equal to the Seebeck Coefficient times ambient temperature in degrees Kelvin.
2. Adjust R2 for voltage across R4 corresponding to thermocouple

J	14.32 mV
T	11.79 mV
K	11.17 mV
S	1.768 mV

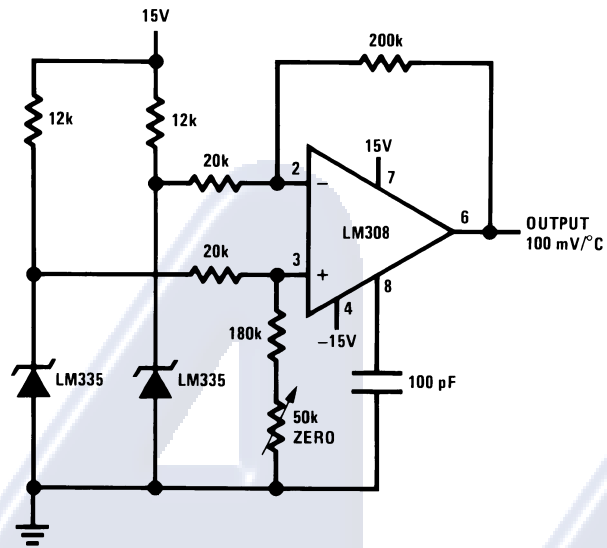
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The circuit diagram shows a precision centigrade thermocouple amplifier. The input stage consists of a thermocouple (CHROMEL and ALUMEL) connected to the non-inverting input (pin 3) of the LM308A op-amp. The op-amp is configured with a voltage divider at the inverting input (pin 2) connected to a 15V supply, and a feedback network (resistor and 100 pF capacitor) connected to the output (pin 6). The output voltage is labeled $V_{OUT} \cong 10 \text{ mV}/^{\circ}\text{C}$. The circuit also includes a reference voltage section using an LM335 precision centigrade centrabol, a 10k resistor (R1), and a 10k resistor (R2) connected to a 15V supply. The LM335 is connected to a 10k resistor (R1) and a 10k resistor (R2) connected to a 15V supply. The LM335 is also connected to a 10k resistor (R1) and a 10k resistor (R2) connected to a 15V supply. The LM335 is also connected to a 10k resistor (R1) and a 10k resistor (R2) connected to a 15V supply.

The diagram shows a temperature measurement circuit. A +V 15V supply is connected to a 10k resistor, which is in series with a thermally coupled diode D11 (LM335). The other end of D11 is connected to ground through a 20k resistor. The junction of the 10k resistor and D11 is connected to the non-inverting input (pin 3) of the LM308 op-amp. The inverting input (pin 2) is connected to a 10k resistor, which is in series with a 5k resistor connected to a START switch. The output of the switch is connected to pin 2. Pin 8 of the LM308 is connected to a 0.01μF capacitor to ground. Pin 4 is connected to ground through a 50k resistor. The output of the op-amp (pin 6) is connected to the anode of a diode, whose cathode is connected to ground. The output of the diode is connected to the ADJ pin of an LM317 voltage regulator. The LM317 is configured as a voltage follower, with its INPUT and OUTPUT pins connected together. The ADJ pin is also connected to a 10k resistor to ground. The output of the LM317 is labeled OUT and is connected to a 1.2V reference point, which is connected to ground through a 10k resistor. The ground reference is labeled 6V -12V.

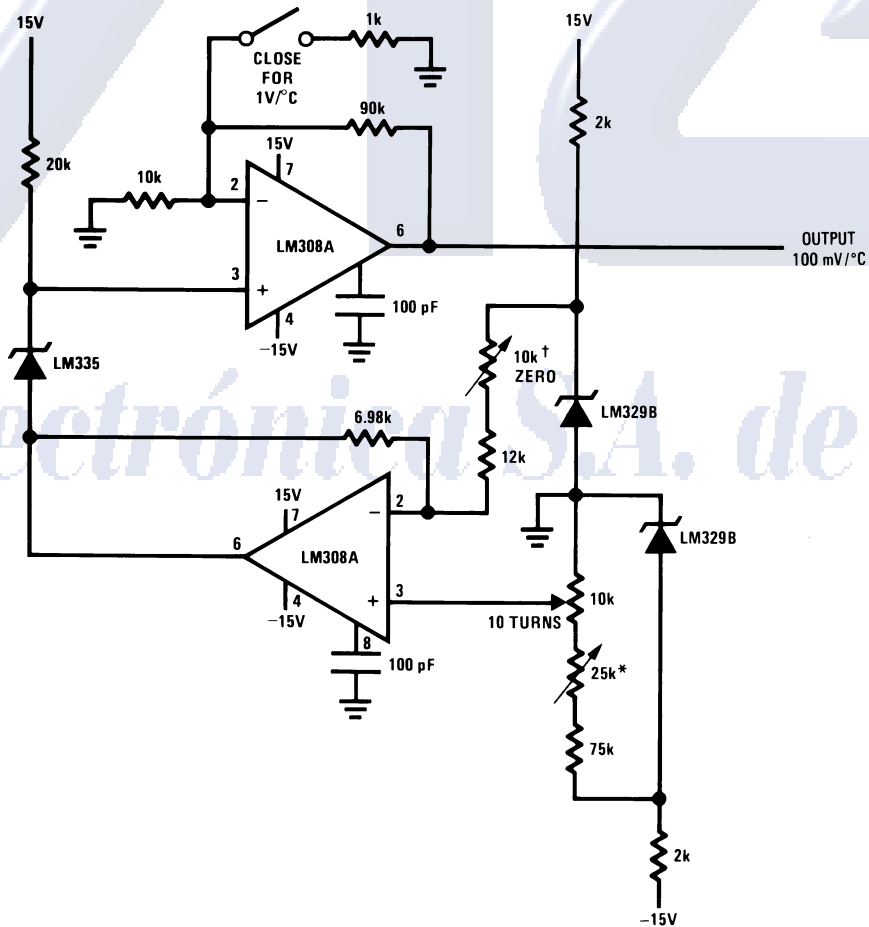
Typical Applications (Continued)

Differential Temperature Sensor



DS005698-14

Variable Offset Thermometer



DS005698-15

†Adjust for zero with sensor at 0°C and 10T pot set at 0°C

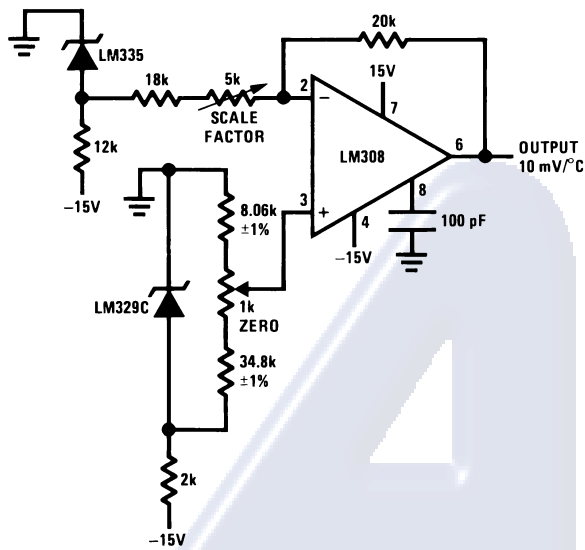
*Adjust for zero output with 10T pot set at 100°C and sensor at 100°C

Output reads difference between temperature and dial setting of 10T pot

LM135/LM235/LM335, LM135A/LM235A/LM335A

Typical Applications (Continued)

Ground Referred Centigrade Thermometer



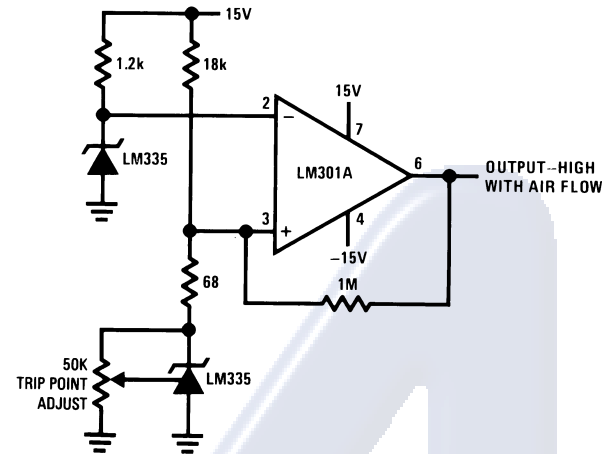
DS005698-16

Definition of Terms

Operating Output Voltage: The voltage appearing across the positive and negative terminals of the device at specified conditions of operating temperature and current.

Uncalibrated Temperature Error: The error between the operating output voltage at 10 mV/°K and case temperature at specified conditions of current and case temperature.

Air Flow Detector*



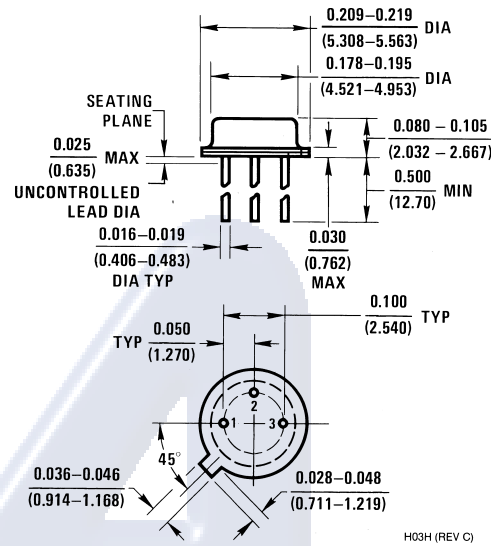
DS005698-17

*Self heating is used to detect air flow

Calibrated Temperature Error: The error between operating output voltage and case temperature at 10 mV/°K over a temperature range at a specified operating current with the 25°C error adjusted to zero.

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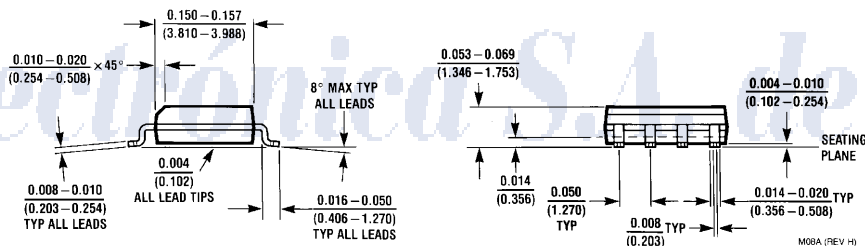
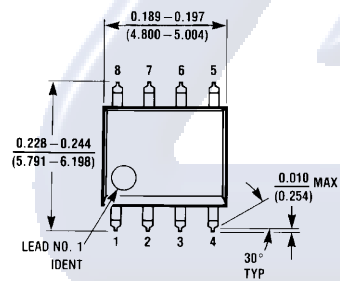
Physical Dimensions inches (millimeters) unless otherwise noted



Metal Can Package (H)

Order Number LM135H, LM235H, LM335H, LM135AH, LM235AH or LM335AH

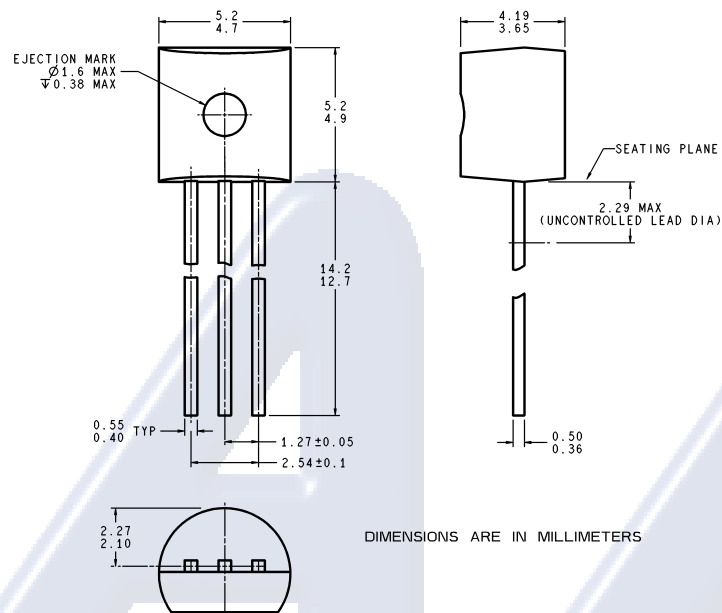
NS Package Number H03H



8-Lead Molded Small Outline Package (M)

Order Number LM335M

NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

Plastic Package
Order Number LM335Z or LM335AZ
NS Package Z03A

Z03A (Rev G)

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