

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

 Check for Samples: [LM135](#), [LM135A](#), [LM235](#), [LM235A](#), [LM335](#), [LM335A](#)

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

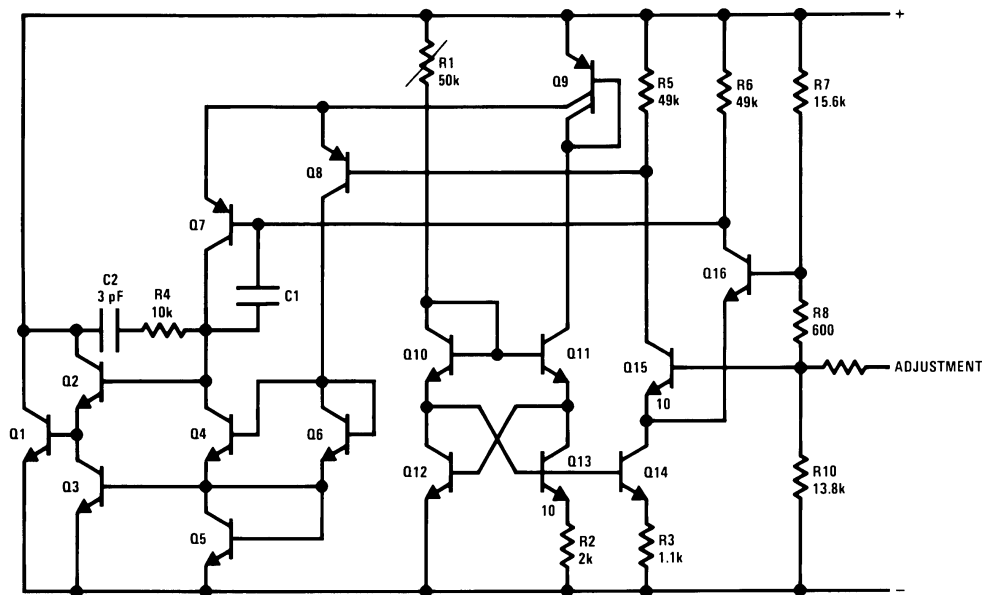
DESCRIPTION

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.

SCHEMATIC DIAGRAM



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.



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Absolute Maximum Ratings ⁽¹⁾

Reverse Current		15 mA
Forward Current		10 mA
Storage Temperature		
8-Pin SOIC Package		-65°C to 150°C
TO-92 Package		-60°C to 150°C
TO-46 Package		-60°C to 180°C
Specified Operating Temp. Range		
	Continuous	Intermittent ⁽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)		
8-Pin SOIC Package:		300°C
Vapor Phase (60 seconds):		215°C
Infrared (15 seconds):		220°C
TO-92 Package:		260°C
TO-46 Package:		300°C

(1) Refer to RETS135H for military specifications.

(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.

Temperature Accuracy ⁽¹⁾

LM135/LM235, LM135A/LM235A

Parameter	Conditions	LM135A/LM235A			LM135/LM235			Units
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage	T _C = 25°C, I _R = 1 mA	2.97	2.98	2.99	2.95	2.98	3.01	V
Uncalibrated Temperature Error	T _C = 25°C, I _R = 1 mA		0.5	1		1	3	°C
Uncalibrated Temperature Error	T _{MIN} ≤ T _C ≤ T _{MAX} , I _R = 1 mA		1.3	2.7		2	5	°C
Temperature Error with 25°C	T _{MIN} ≤ T _C ≤ T _{MAX} , I _R = 1 mA		0.3	1		0.5	1.5	°C
Calibration								
Calibrated Error at Extended	T _C = T _{MAX} (Intermittent)		2			2		°C
Temperatures								
Non-Linearity	I _R = 1 mA		0.3	0.5		0.3	1	°C

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

Temperature Accuracy ⁽¹⁾

LM335, LM335A

Parameter	Conditions	LM335A			LM335			Units
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage	T _C = 25°C, I _R = 1 mA	2.95	2.98	3.01	2.92	2.98	3.04	V
Uncalibrated Temperature Error	T _C = 25°C, I _R = 1 mA		1	3		2	6	°C
Uncalibrated Temperature Error	T _{MIN} ≤ T _C ≤ T _{MAX} , I _R = 1 mA		2	5		4	9	°C
Temperature Error with 25°C	T _{MIN} ≤ T _C ≤ T _{MAX} , I _R = 1 mA		0.5	1		1	2	°C
Calibration								
Calibrated Error at Extended	T _C = T _{MAX} (Intermittent)		2			2		°C
Temperatures								
Non-Linearity	I _R = 1 mA		0.3	1.5		0.3	1.5	°C

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

Electrical Characteristics (1)

Parameter	Conditions	LM135/LM235			LM335			Units
		LM135A/LM235A			LM335A			
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage	$400 \mu A \leq I_R \leq 5 \text{ mA}$		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

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

Thermal Resistance	8-Pin SOIC	TO-92	TO-46
θ_{JA} (Junction to Ambient)	165°C/W	202°C/W	400°C/W
θ_{JC} (Junction to Case)	N/A	170°C/W	N/A

CONNECTION DIAGRAMS

*Case is connected to negative pin

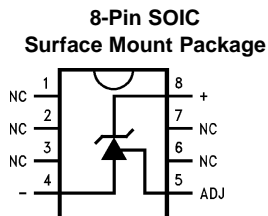


Figure 1. Top View

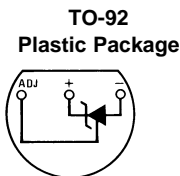


Figure 2. Bottom View

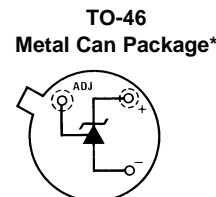
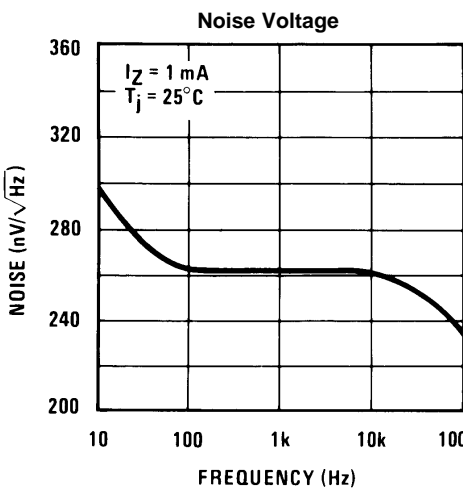
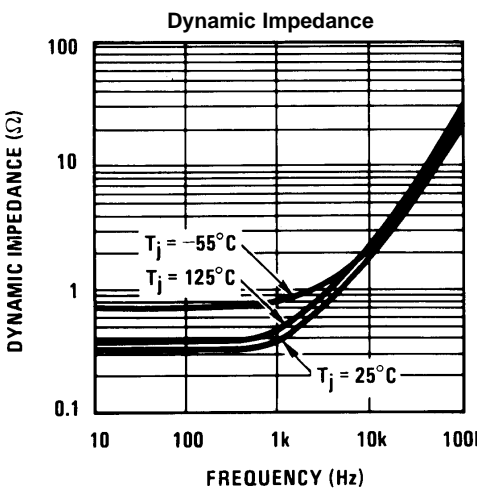
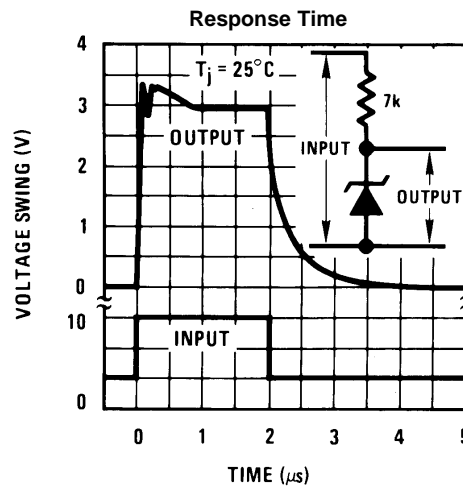
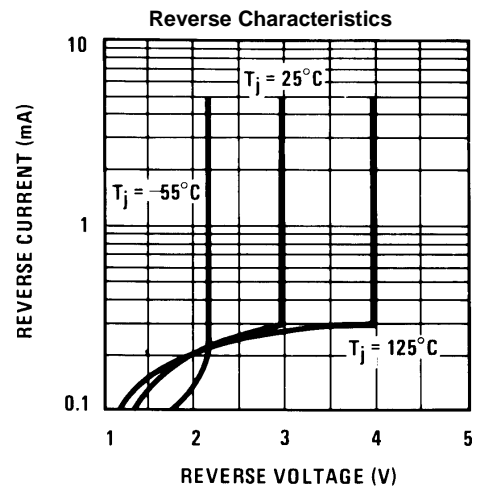
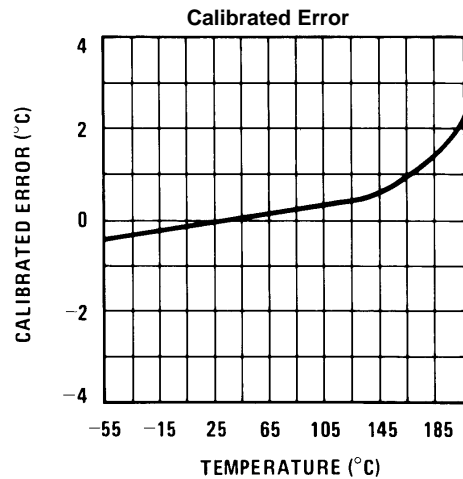
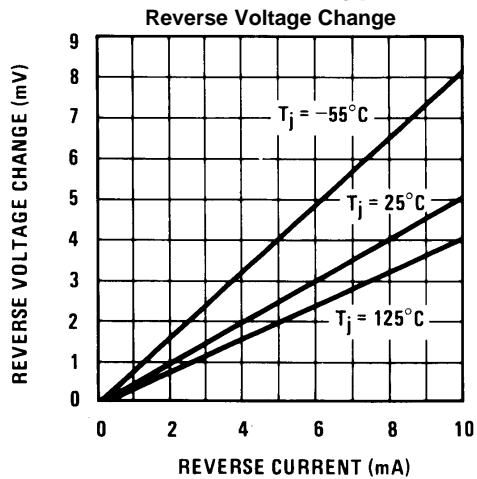
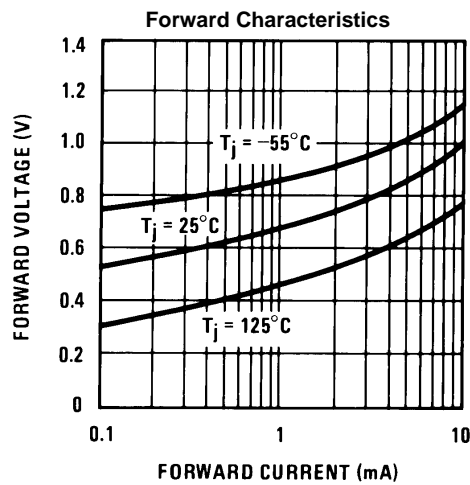
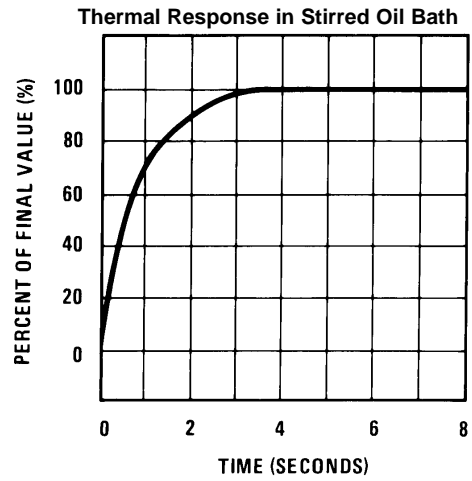
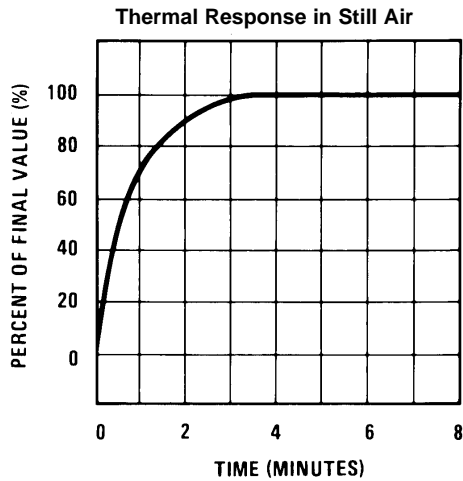
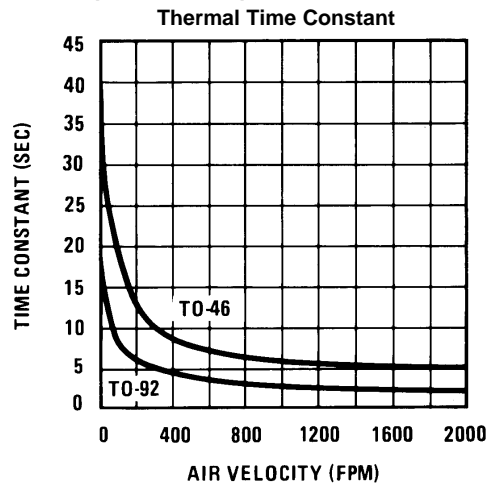
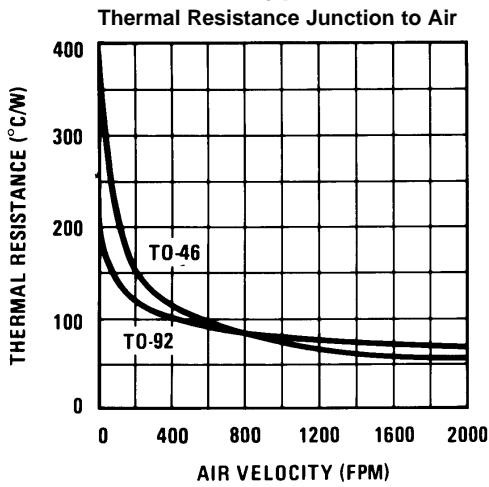


Figure 3. Bottom View

Typical Performance Characteristics



Typical Performance Characteristics (continued)



APPLICATION INFORMATION

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:

$$V_{OUT_T} = V_{OUT_{T_0}} \times \frac{T}{T_0} \quad (1)$$

where T is the unknown temperature and T₀ 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.

To insure good sensing accuracy several precautions must be taken. Like any temperature sensing device, self heating can reduce accuracy. The LM135 should be operated at the lowest current suitable for the application. Sufficient current, of course, must be available to drive both the sensor and the calibration pot at the maximum operating temperature as well as any external loads.

If the sensor is used in an ambient where the thermal resistance is constant, self heating errors can be calibrated out. This is possible if the device is run with a temperature stable current. Heating will then be proportional to zener voltage and therefore temperature. This makes the self heating error proportional to absolute temperature the same as scale factor errors.

WATERPROOFING SENSORS

Meltable inner core heat shrinkable tubing such as manufactured by Raychem can be used to make low-cost waterproof sensors. The LM335 is inserted into the tubing about ½" from the end and the tubing heated above the melting point of the core. The unfilled ½" end melts and provides a seal over the device.

Typical Applications

Figure 4. Basic Temperature Sensor

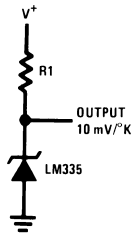
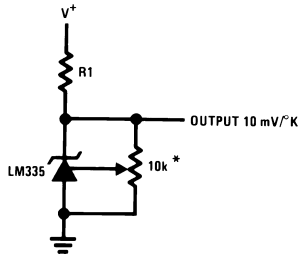


Figure 5. Calibrated Sensor



*Calibrate for 2.982V at 25°C

Figure 6. Wide Operating Supply

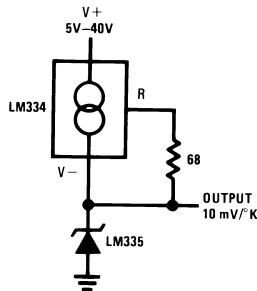


Figure 7. Minimum Temperature Sensing

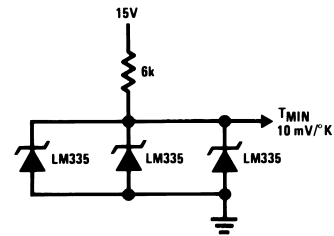


Figure 8. Average Temperature Sensing

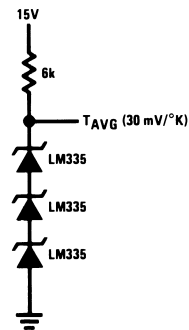
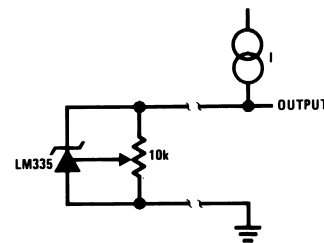


Figure 9. Remote Temperature Sensing



Wire length for 1°C error due to wire drop

AWG	$I_R = 1 \text{ mA}$	$I_R = 0.5 \text{ mA}^{(1)}$
	FEET	FEET
14	4000	8000
16	2500	5000
18	1600	3200
20	1000	2000
22	625	1250
24	400	800

(1) For $I_R = 0.5 \text{ mA}$, the trim pot must be deleted.

Figure 10. Isolated Temperature Sensor

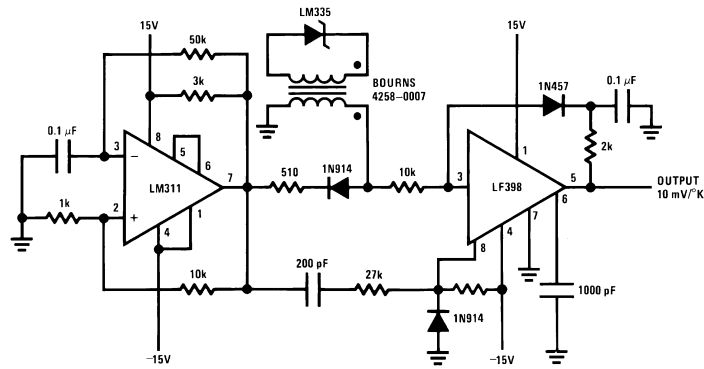


Figure 11. Simple Temperature Controller

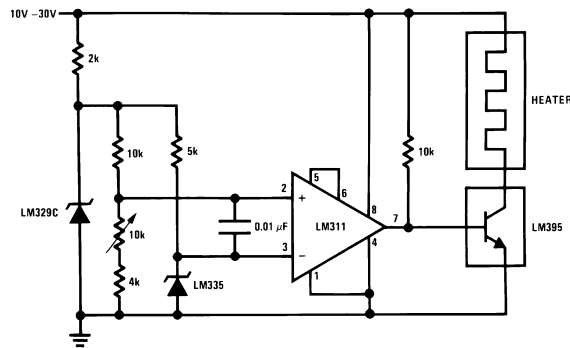


Figure 12. Simple Temperature Control

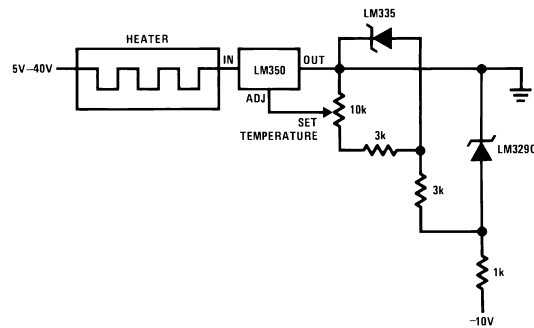
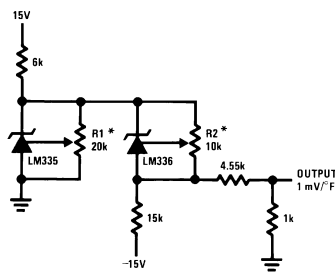
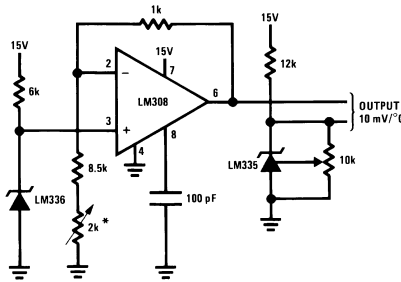


Figure 13. Ground Referred Fahrenheit Thermometer



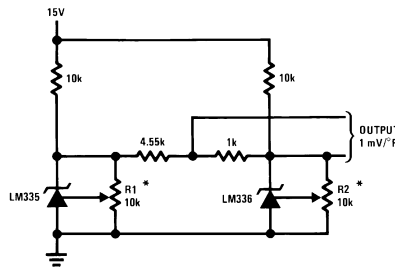
*Adjust R2 for 2.554V across LM336.
Adjust R1 for correct output.

Figure 14. Centigrade Thermometer



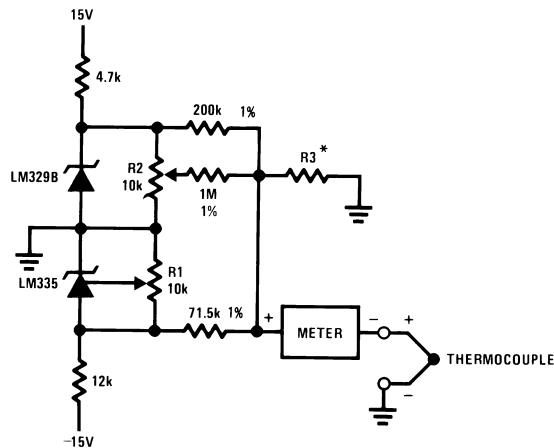
*Adjust for 2.7315V at output of LM308

Figure 15. Fahrenheit Thermometer



*To calibrate adjust R2 for 2.554V across LM3335.
Adjust R1 for correct output.

Figure 16. THERMOCOUPLE COLD JUNCTION COMPENSATION



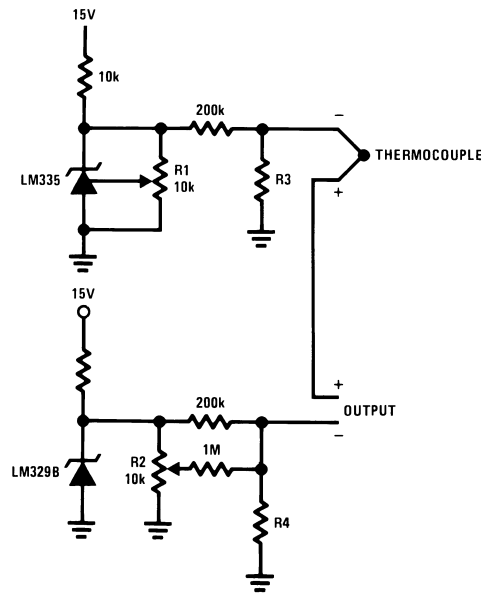
Compensation for Grounded Thermocouple

*Select R3 for proper thermocouple type

THERMO-COUPLE	R3 ($\pm 1\%$)	SEEBECK COEFFICIENT
J	377 Ω	52.3 $\mu\text{V}/^\circ\text{C}$
T	308 Ω	42.8 $\mu\text{V}/^\circ\text{C}$
K	293 Ω	40.8 $\mu\text{V}/^\circ\text{C}$
S	45.8 Ω	6.4 $\mu\text{V}/^\circ\text{C}$

THERMO-COUPLE	R3 ($\pm 1\%$)	SEEBECK COEFFICIENT
Adjustments: Compensates for both sensor and resistor tolerances		
1. Short LM329B		
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

Figure 17. Single Power Supply Cold Junction Compensation

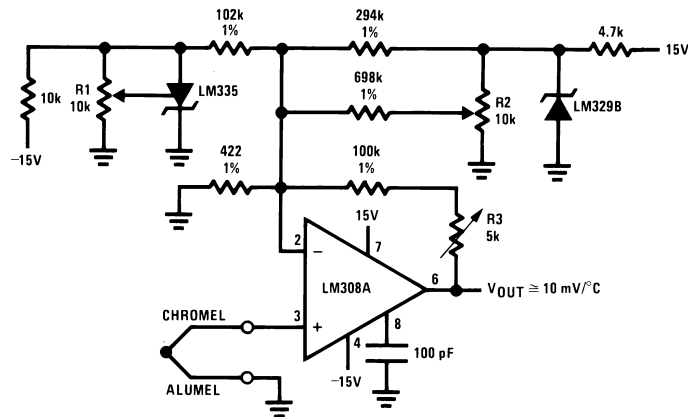


*Select R3 and R4 for thermocouple type

THERMO-COUPLE	R3	R4	SEEBECK COEFFICIENT
J	1.05K	385Ω	52.3 $\mu\text{V}/^\circ\text{C}$
T	856Ω	315Ω	42.8 $\mu\text{V}/^\circ\text{C}$
K	816Ω	300Ω	40.8 $\mu\text{V}/^\circ\text{C}$
S	128Ω	46.3Ω	6.4 $\mu\text{V}/^\circ\text{C}$

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	

Figure 18. Centigrade Calibrated Thermocouple Thermometer

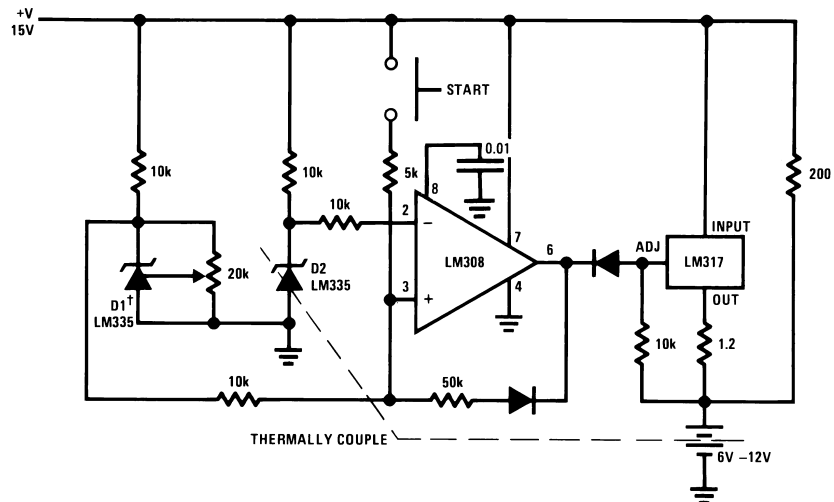


Terminate thermocouple reference junction in close proximity to LM335.

Adjustments:

1. Apply signal in place of thermocouple and adjust R3 for a gain of 245.7.
2. Short non-inverting input of LM308A and output of LM329B to ground.
3. Adjust R1 so that $V_{OUT} = 2.982V @ 25^{\circ}C$.
4. Remove short across LM329B and adjust R2 so that $V_{OUT} = 246 mV @ 25^{\circ}C$.
5. Remove short across thermocouple.

Figure 19. Fast Charger for Nickel-Cadmium Batteries



†Adjust D1 to 50 mV greater V_Z than D2.
Charge terminates on 5°C temperature rise. Couple D2 to battery.

Figure 20. Differential Temperature Sensor

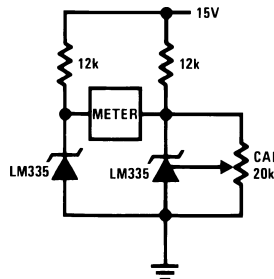


Figure 21. Differential Temperature Sensor

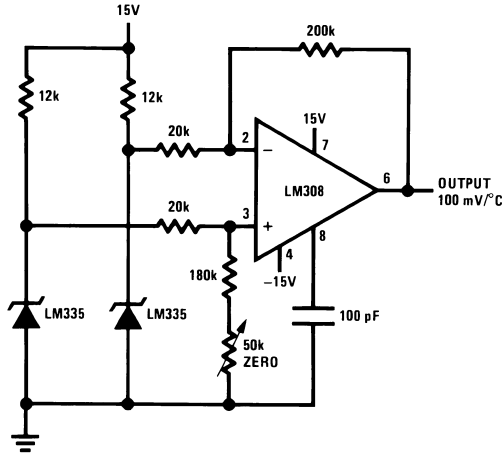
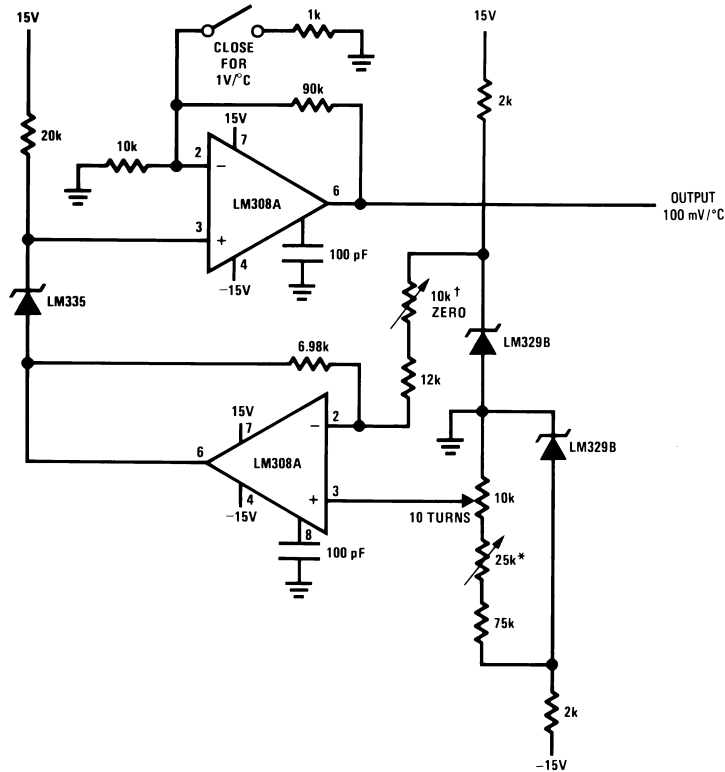


Figure 22. Variable Offset Thermometer†



†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

Figure 23. Ground Referred Centigrade Thermometer

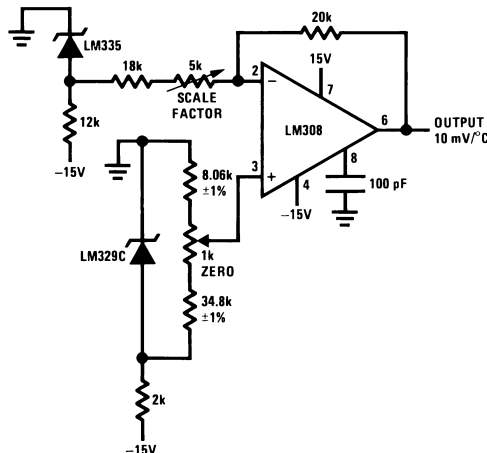
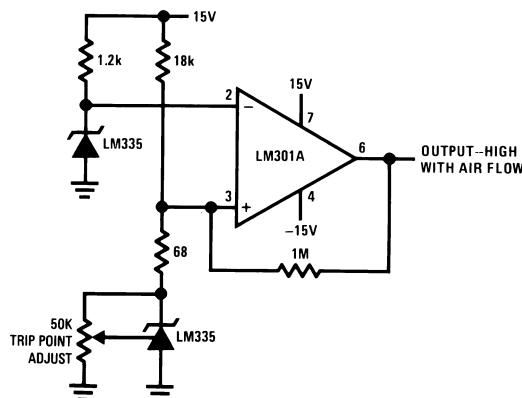


Figure 24. Air Flow Detector*



*Self heating is used to detect air flow

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.

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.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
LM135AH	ACTIVE	TO	NDV	3	1000	TBD	POST-PLATE	Level-1-NA-UNLIM	
LM135AH/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	
LM135H	ACTIVE	TO	NDV	3	1000	TBD	POST-PLATE	Level-1-NA-UNLIM	
LM135H/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	
LM235AH	ACTIVE	TO	NDV	3	1000	TBD	POST-PLATE	Level-1-NA-UNLIM	
LM235AH/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	
LM235H	ACTIVE	TO	NDV	3	1000	TBD	POST-PLATE	Level-1-NA-UNLIM	
LM235H/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	
LM335AH	ACTIVE	TO	NDV	3	1000	TBD	POST-PLATE	Level-1-NA-UNLIM	
LM335AH/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	
LM335AM	ACTIVE	SOIC	D	8	95	TBD	CU SNPB	Level-1-235C-UNLIM	
LM335AM/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	
LM335AMX	ACTIVE	SOIC	D	8	2500	TBD	CU SNPB	Level-1-235C-UNLIM	
LM335AMX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	
LM335AZ/LFT1	ACTIVE	TO-92	LP	3	2000	TBD	Call TI	Call TI	
LM335AZ/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	Call TI	Level-1-NA-UNLIM	
LM335H	ACTIVE	TO	NDV	3	1000	TBD	POST-PLATE	Level-1-NA-UNLIM	
LM335H/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	
LM335M	ACTIVE	SOIC	D	8	95	TBD	CU SNPB	Level-1-235C-UNLIM	
LM335M/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	
LM335MX	ACTIVE	SOIC	D	8	2500	TBD	CU SNPB	Level-1-235C-UNLIM	
LM335MX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
LM335Z/LFT7	ACTIVE	TO-92	LP	3	2000	Green (RoHS & no Sb/Br)	Call TI	Level-1-NA-UNLIM	
LM335Z/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	Call TI	Level-1-NA-UNLIM	

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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TAPE AND REEL INFORMATION

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE


*All dimensions are nominal

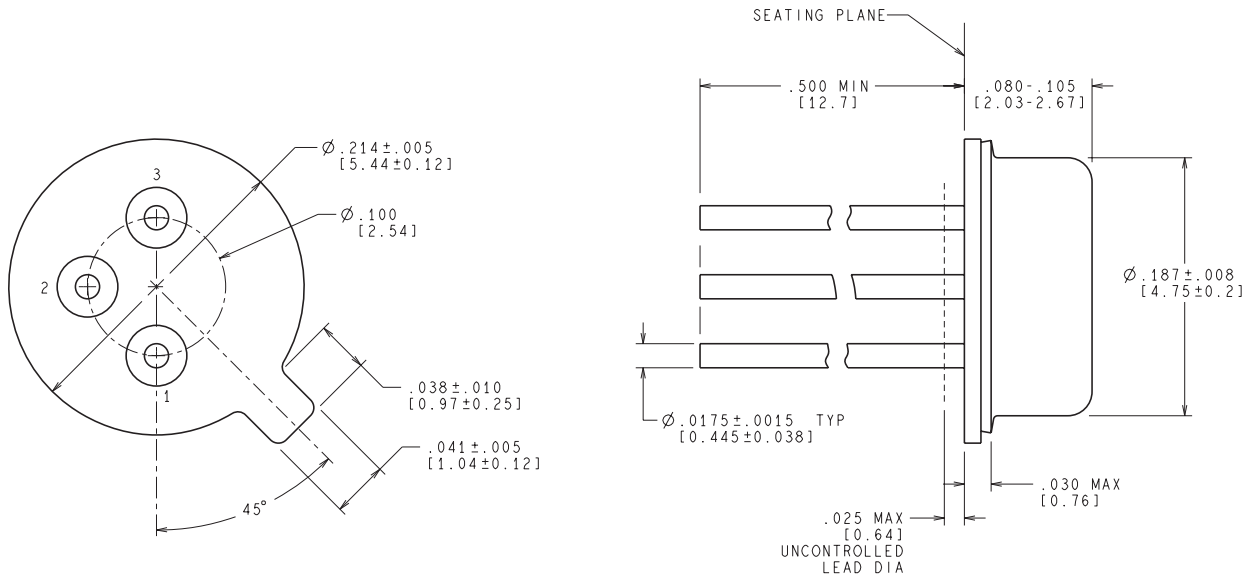
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM335AMX	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM335AMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM335MX	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM335MX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM335AMX	SOIC	D	8	2500	349.0	337.0	45.0
LM335AMX/NOPB	SOIC	D	8	2500	349.0	337.0	45.0
LM335MX	SOIC	D	8	2500	349.0	337.0	45.0
LM335MX/NOPB	SOIC	D	8	2500	349.0	337.0	45.0

NDV0003H



CONTROLLING DIMENSION IS INCH
VALUES IN [] ARE IN MILLIMETERS

H03H (Rev F)

D (R-PDSO-G8)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
 - D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
 - E. Reference JEDEC MS-012 variation AA.

LP (O-PBCY-W3)

PLASTIC CYLINDRICAL PACKAGE



- NOTES: A. All linear dimensions are in inches (millimeters).
 B. This drawing is subject to change without notice.
 C. Lead dimensions are not controlled within this area
 D. Falls within JEDEC TO -226 Variation AA (TO-226 replaces TO-92)
 E. Shipping Method:
 Straight lead option available in bulk pack only.
 Formed lead option available in tape & reel or ammo pack.

MECHANICAL DATA

MSOT002A – OCTOBER 1994 – REVISED NOVEMBER 2001

LP (O-PBCY-W3)

PLASTIC CYLINDRICAL PACKAGE



- NOTES: A. All linear dimensions are in inches (millimeters).
 B. This drawing is subject to change without notice.
 C. Tape and Reel information for the Format Lead Option package.

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