Jameco Part Number 1992401

November 2000

# *N*ational *Semiconductor*

# 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.
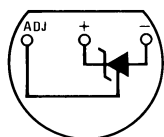
## Features

- 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
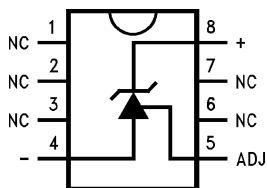- 200˚C overrange
- Low cost

## Schematic Diagram
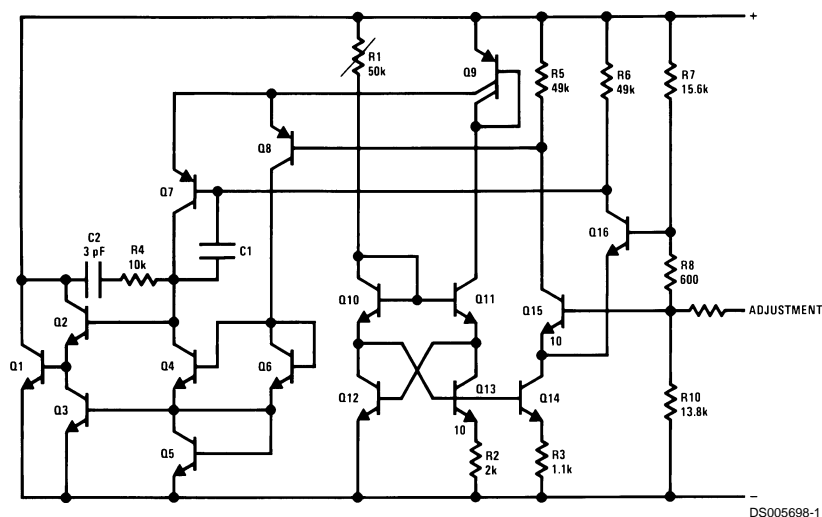


DS005698-1

# Connection Diagrams

**TO-92**
**Plastic Package**



DS005698-8

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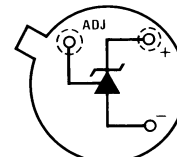**Number Z03A**

**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**

2

## 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) | |
|---|---|
| TO-92 Package: | $260°C$ |
| 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 | $T_C = 25°C$, $I_R = 1$ 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 | $T_{MIN} \leq T_C \leq T_{MAX}$, $I_R = 1$ mA | | 1.3 | 2.7 | | 2 | 5 | °C |
| Temperature Error with 25°C Calibration | $T_{MIN} \leq T_C \leq T_{MAX}$, $I_R = 1$ mA | | 0.3 | 1 | | 0.5 | 1.5 | °C |
| Calibrated Error at Extended Temperatures | $T_C = T_{MAX}$ (Intermittent) | | 2 | | | 2 | | °C |
| Non-Linearity | $I_R = 1$ 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 | $T_C = 25°C$, $I_R = 1$ 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 | $T_{MIN} \leq T_C \leq T_{MAX}$, $I_R = 1$ mA | | 2 | 5 | | 4 | 9 | °C |
| Temperature Error with 25°C Calibration | $T_{MIN} \leq T_C \leq T_{MAX}$, $I_R = 1$ mA | | 0.5 | 1 | | 1 | 2 | °C |
| Calibrated Error at Extended Temperatures | $T_C = T_{MAX}$ (Intermittent) | | 2 | | | 2 | | °C |
| Non-Linearity | $I_R = 1$ 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 Change with Current | $400\ \mu A \leq I_R \leq 5$ mA At Constant Temperature | | 2.5 | 10 | | 3 | 14 | mV |
| Dynamic Impedance | $I_R = 1$ mA | | 0.5 | | | 0.6 | | $\Omega$ |
| 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 | $T_C = 125°C$ | | 0.2 | | | 0.2 | | °C/khr |

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## 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.
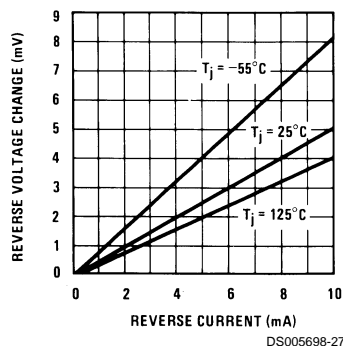
**Note 3:**

| Thermal Resistance | TO-92 | TO-46 | SO-8 |
|---|---|---|---|
| $\theta_{JA}$ (junction to ambient) | 202˚C/W | 400˚C/W | 165˚C/W |
| $\theta_{JC}$ (junction to case) | 170˚C/W | N/A | N/A |

**Note 4:** Refer to RETS135H for military specifications.

## Typical Performance Characteristics

**Reverse Voltage Change**



DS005698-27

**Calibrated Error**



DS005698-28
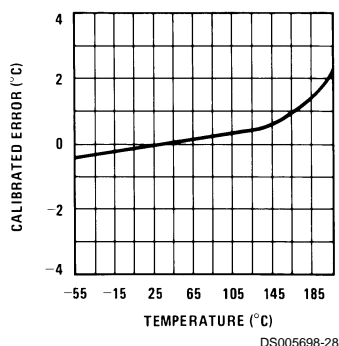
**Reverse Characteristics**



DS005698-29

**Response Time**



DS005698-30

**Dynamic Impedance**



DS005698-31

**Noise Voltage**



DS005698-32
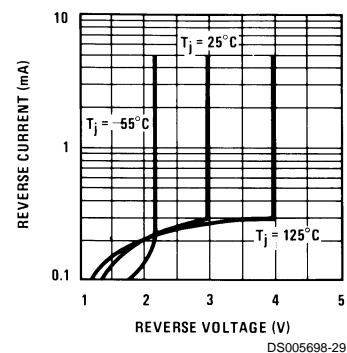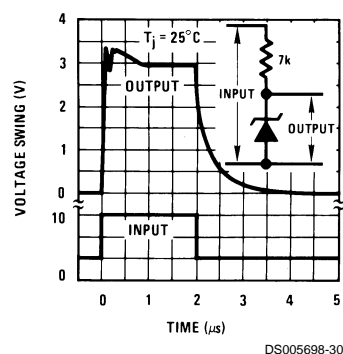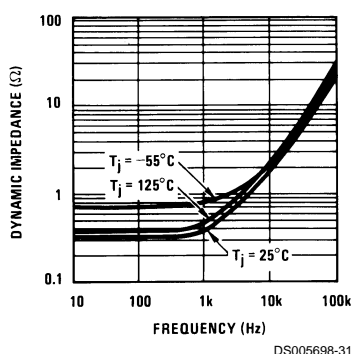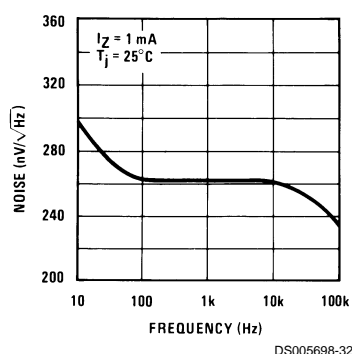
**Thermal Resistance Junction to Air**



DS005698-33
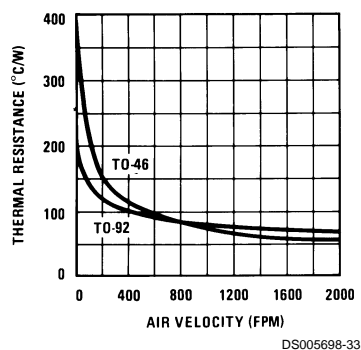
**Thermal Time Constant**



DS005698-34
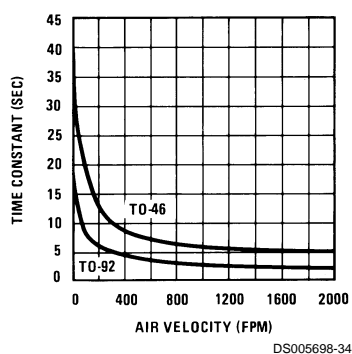
**Thermal Response in Still Air**



DS005698-35
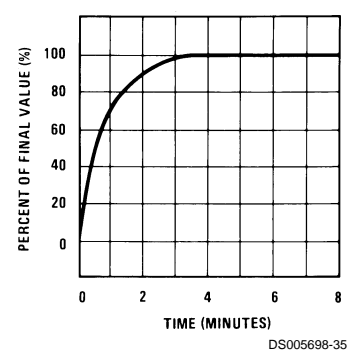
# Typical Performance Characteristics (Continued)

**Thermal Response in Stirred Oil Bath**



DS005698-36
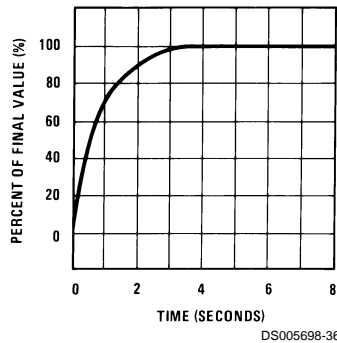
**Forward Characteristics**



DS005698-37
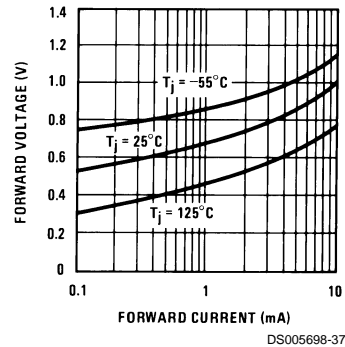
# Application Hints

### 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:

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

where T is the unknown temperature and $T_o$ 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.
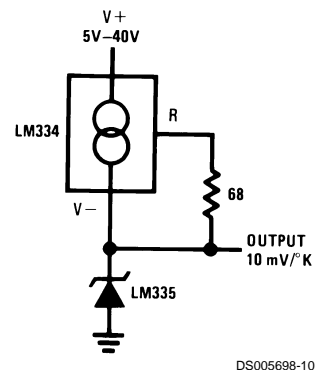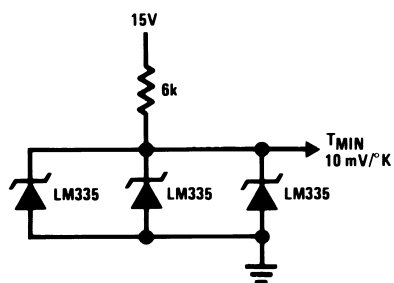
# Typical Applications

**Basic Temperature Sensor**
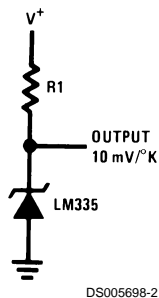


DS005698-2

**Calibrated Sensor**
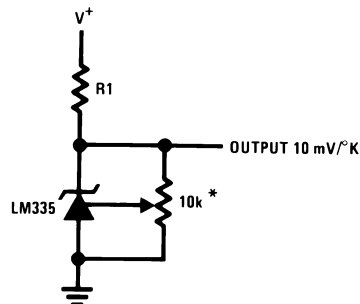


DS005698-9

*Calibrate for 2.982V at 25°C

**Wide Operating Supply**



DS005698-10

# Typical Applications (Continued)

### Minimum Temperature Sensing

15V

6k

$T_{MIN}$
10 mV/°K

LM335    LM335    LM335

DS005698-4

### Average Temperature Sensing

15V

6k

$T_{AVG}$ (30 mV/°K)

LM335

LM335

LM335
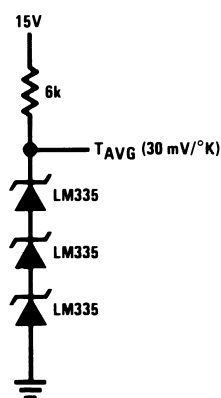
DS005698-18

### Remote Temperature Sensing

I

OUTPUT

LM335    10k
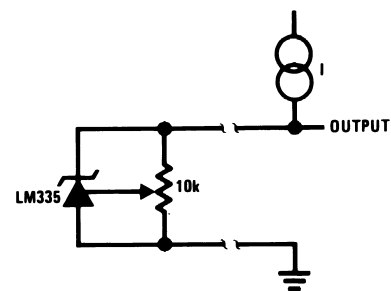
DS005698-19

Wire length for 1°C error due to wire drop

| AWG | $I_R$ = 1 mA FEET | $I_R$ = 0.5 mA* 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

15V    50k    LM335

3k    BOURNS
4258−0007    15V

0.1 μF    1N457    0.1 μF

0.1 μF    8    5    2k

3    6
−    LM311
1N914    2k
510    1N914    10k    3    LF398    5
7    6    OUTPUT
1k    2    1    10 mV/°K
+    4    7

4
10k    200 pF    27k    8

1N914
−15V    −15V    1000 pF
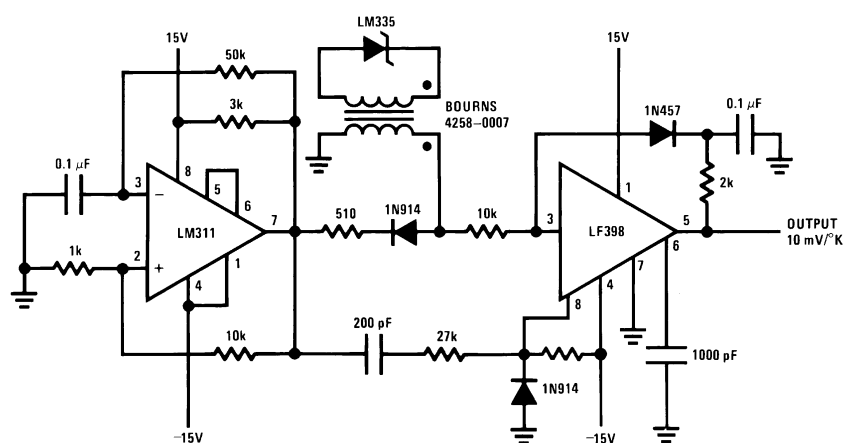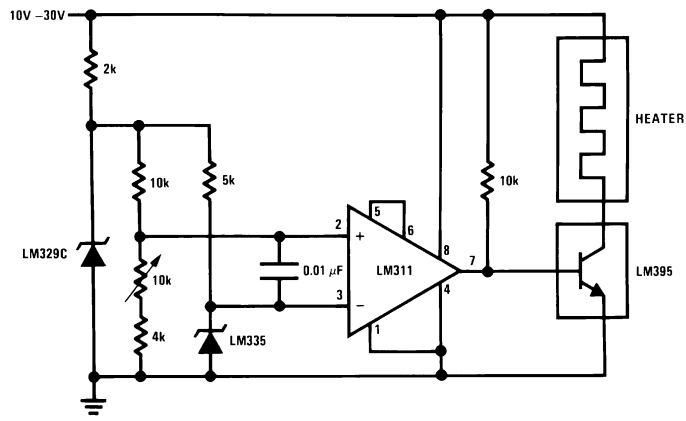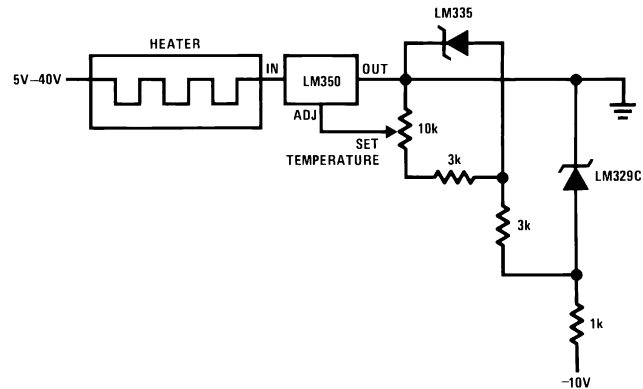
DS005698-20

# Typical Applications (Continued)

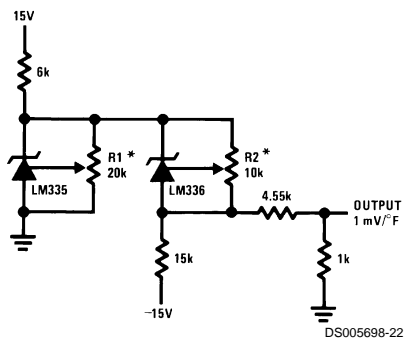## Simple Temperature Controller



DS005698-5

## Simple Temperature Control
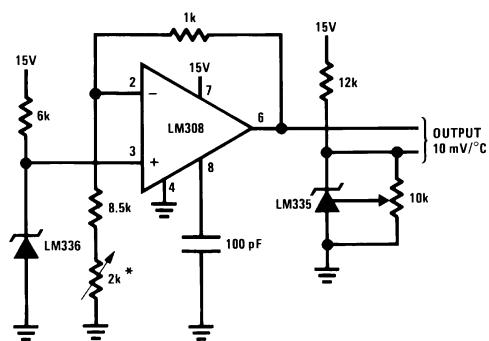


DS005698-21

## Ground Referred Fahrenheit Thermometer



DS005698-22

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

## Centigrade Thermometer



DS005698-23

*Adjust for 2.7315V at output of LM308

# Typical Applications (Continued)

**Fahrenheit Thermometer**



DS005698-24

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

**THERMOCOUPLE COLD JUNCTION COMPENSATION**
**Compensation for Grounded Thermocouple**



DS005698-6

*Select R3 for proper thermocouple type

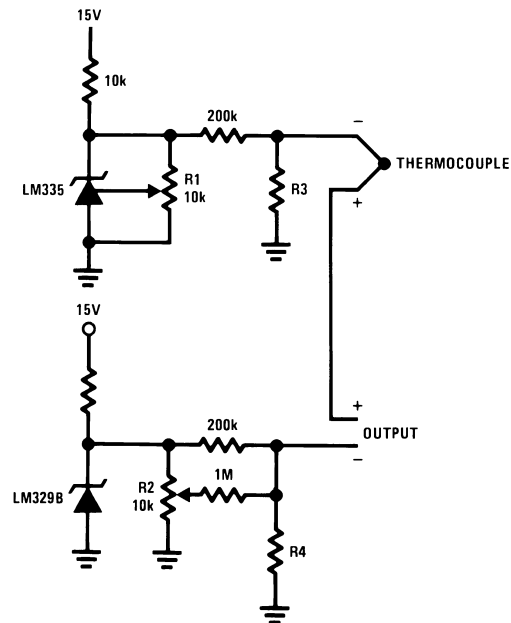| THERMO-COUPLE | R3 (±1%) | SEEBECK COEFFICIENT |
|---|---|---|
| J | 377Ω | 52.3 µV/°C |
| T | 308Ω | 42.8 µV/°C |
| K | 293Ω | 40.8 µV/°C |
| S | 45.8Ω | 6.4 µV/°C |

**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 |

# Typical Applications (Continued)

## Single Power Supply Cold Junction Compensation



DS005698-11

*Select R3 and R4 for thermocouple type

| 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 |

# Typical Applications (Continued)

## Centigrade Calibrated Thermocouple Thermometer
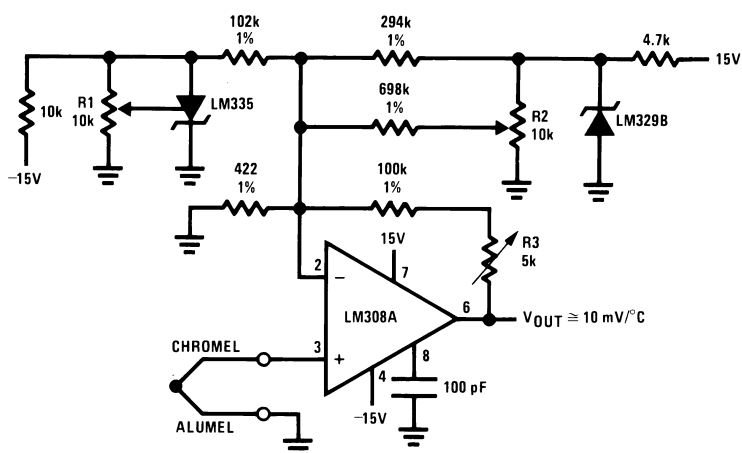


DS005698-12

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˚C.
4. Remove short across LM329B and adjust R2 so that $V_{OUT}$ = 246 mV @ 25˚C.
5. Remove short across thermocouple.

## Fast Charger for Nickel-Cadmium Batteries
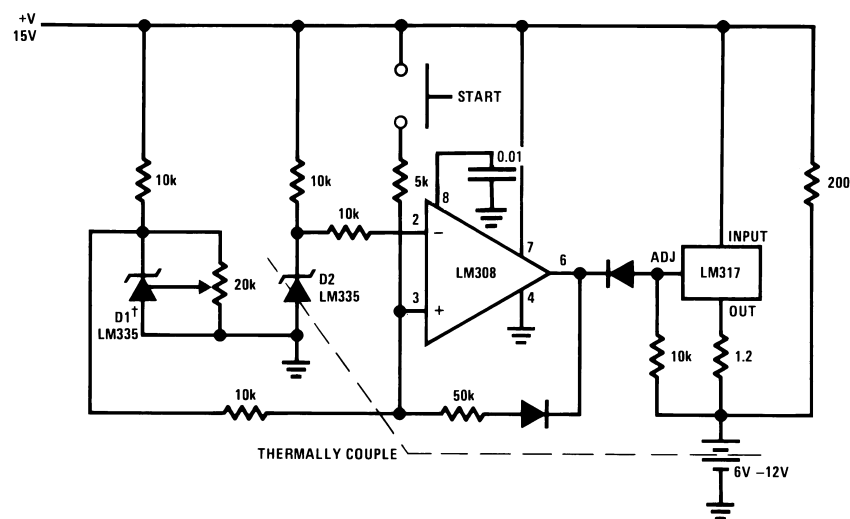


DS005698-13

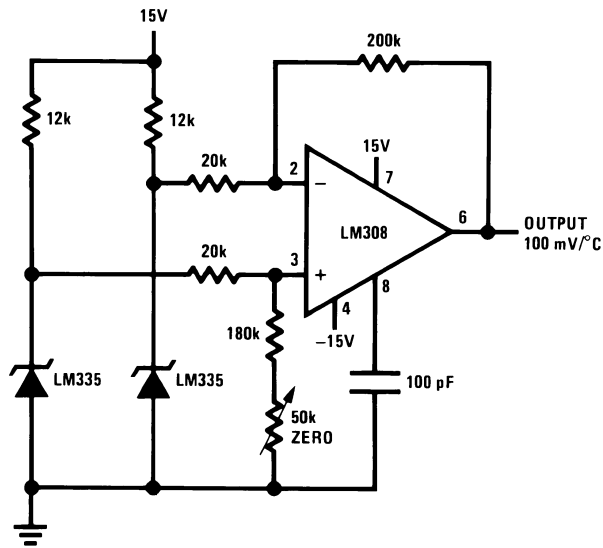## Differential Temperature Sensor
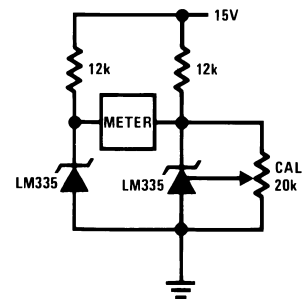


DS005698-7

†Adjust D1 to 50 mV greater $V_Z$ than D2.
Charge terminates on 5˚C temperature rise. Couple D2 to battery.
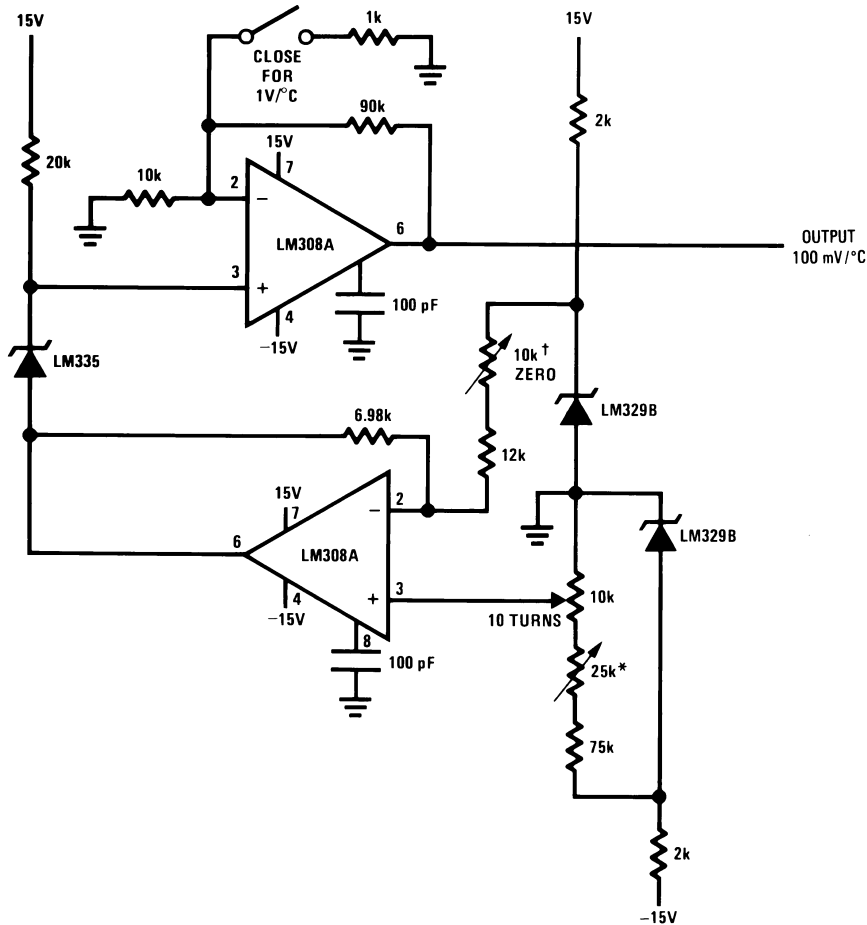
## Typical Applications (Continued)

**Differential Temperature Sensor**



DS005698-14

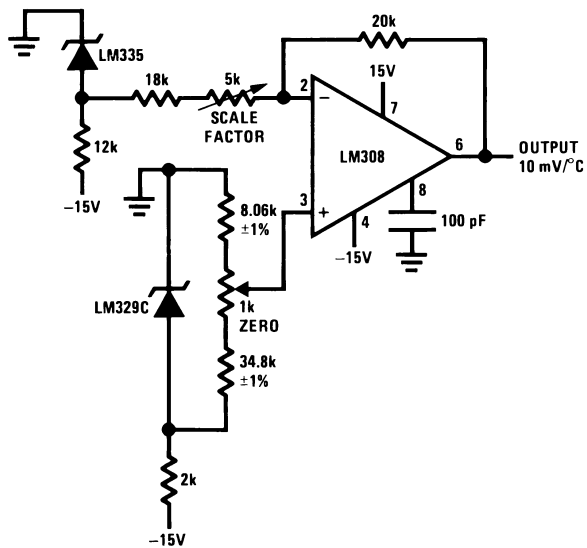**Variable Offset Thermometer**



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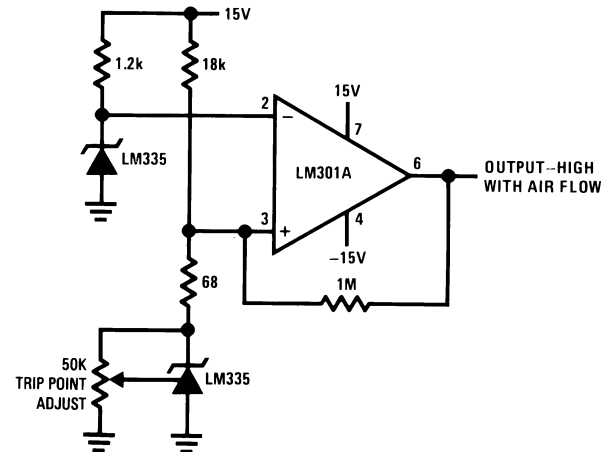 Output reads difference between temperature and dial setting of 10T pot

## Typical Applications (Continued)

**Ground Referred Centigrade Thermometer**



DS005698-16

**Air Flow Detector***



DS005698-17

*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.

# Physical Dimensions inches (millimeters) unless otherwise noted
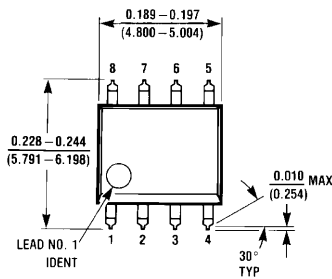


0.209−0.219 DIA
(5.308−5.563)

0.178−0.195 DIA
(4.521−4.953)

SEATING PLANE

0.025 MAX
(0.635)

UNCONTROLLED LEAD DIA

0.080 − 0.105
(2.032 − 2.667)

0.500 MIN
(12.70)

0.016−0.019 DIA TYP
(0.406−0.483)

0.030 MAX
(0.762)

0.100 TYP
(2.540)

0.050 TYP
(1.270)

0.036−0.046
(0.914−1.168)

45°

0.028−0.048
(0.711−1.219)

H03H (REV C)
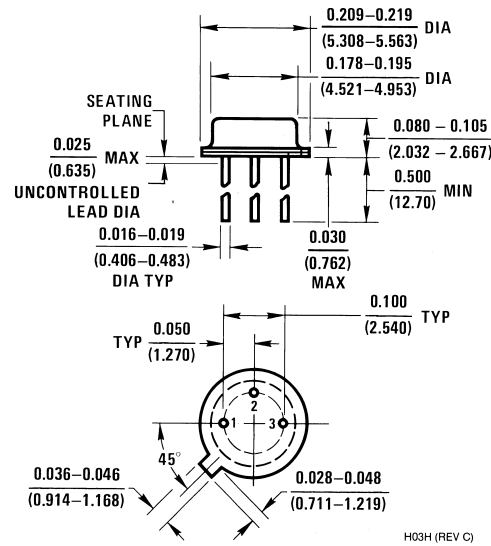
**Metal Can Package (H)**
**Order Number LM135H, LM235H, LM335H, LM135AH, LM235AH or LM335AH**
**NS Package Number H03H**



0.189−0.197
(4.800−5.004)

0.228−0.244
(5.791−6.198)

0.010 MAX
(0.254)

LEAD NO. 1 IDENT

30° TYP



0.150−0.157
(3.810−3.988)

0.010−0.020 × 45°
(0.254−0.508)

8° MAX TYP ALL LEADS

0.004
(0.102)
ALL LEAD TIPS

0.008−0.010
(0.203−0.254)
TYP ALL LEADS

0.016−0.050
(0.406−1.270)
TYP ALL LEADS

0.053−0.069
(1.346−1.753)

0.004 − 0.010
(0.102−0.254)

SEATING PLANE

0.014
(0.356)

0.050 TYP
(1.270)

0.008 TYP
(0.203)

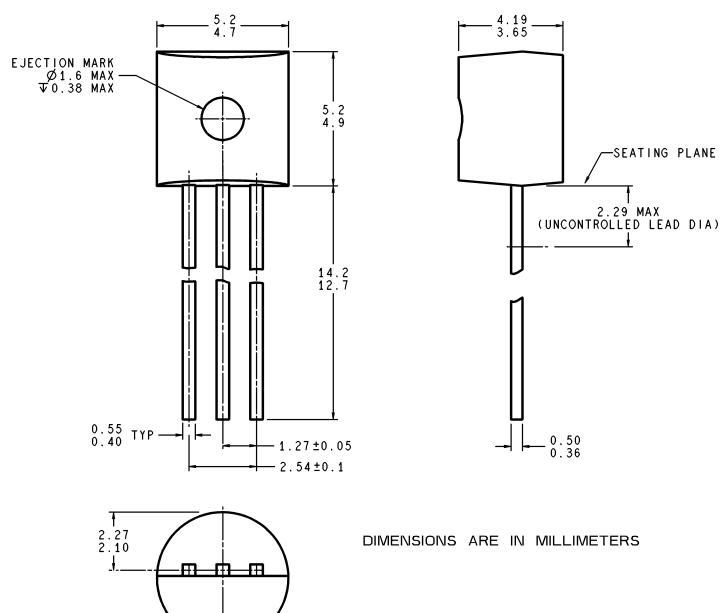0.014−0.020 TYP
(0.356−0.508)

M08A (REV H)

**8-Lead Molded Small Outline Package (M)**
**Order Number LM335M**
**NS Package Number M08A**

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

EJECTION MARK
Ø1.6 MAX
▽0.38 MAX

5.2
4.7

5.2
4.9

4.19
3.65

SEATING PLANE

2.29 MAX
(UNCONTROLLED LEAD DIA)

14.2
12.7

0.55
0.40 TYP

1.27±0.05

2.54±0.1

0.50
0.36

2.27
2.10

DIMENSIONS ARE IN MILLIMETERS

Z03A (Rev G)

**Plastic Package
Order Number LM335Z or LM335AZ
NS Package Z03A**

## LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.

2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.