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**

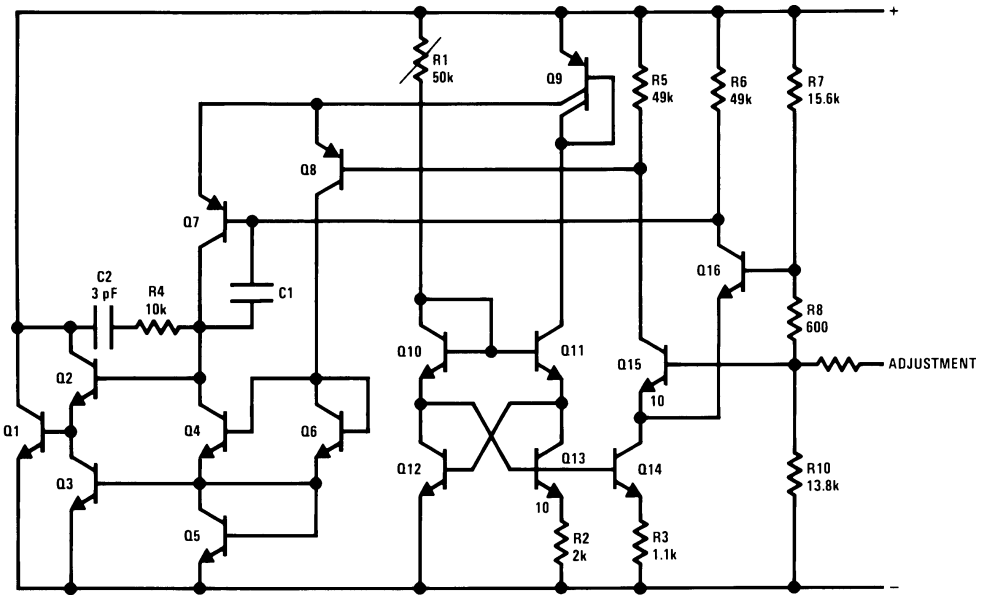
DESCRIPTION

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 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][2]

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 Package		−60°C to 180°C
Specified Operating Temp. Range		
	Continuous	**Intermittent**[3]
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 Package:		300°C

(1) Refer to RETS135H for military specifications.
(2) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
(3) Continuous operation at these temperatures for 10,000 hours for NDV package and 5,000 hours for LP 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	$T_{MIN} \le T_C \le T_{MAX}$, I_R = 1 mA		1.3	2.7		2	5	°C
Temperature Error with 25°C	$T_{MIN} \le T_C \le T_{MAX}$, 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	$T_{MIN} \le T_C \le T_{MAX}$, I_R = 1 mA		2	5		4	9	°C
Temperature Error with 25°C	$T_{MIN} \le T_C \le T_{MAX}$, 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.

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Electrical Characteristics (1)

Parameter	Conditions	LM135/LM235 LM135A/LM235A			LM335 LM335A			Units
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage	400 µA ≤ I_R ≤ 5 mA		2.5	10		3	14	mV
Change with Current	At Constant Temperature							
Dynamic Impedance	I_R = 1 mA		0.5			0.6		Ω
Output Voltage Temperature			+10			+10		mV/°C
Coefficient								
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

(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
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

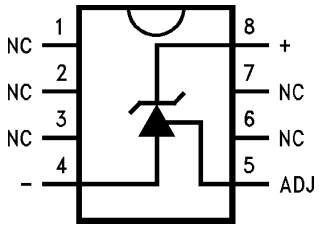


Figure 1. 8-Pin SOIC Surface Mount Package Top View Package Number M08A

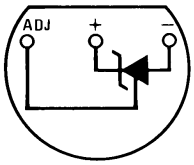


Figure 2. TO-92 Plastic Package Bottom View Package Z03A

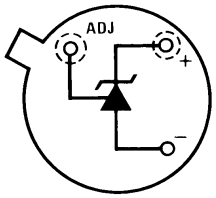


Figure 3. TO Metal Can Package (1) Bottom View Package Number H03H

(1) Case is connected to negative pin.

Typical Performance Characteristics

Reverse Voltage Change

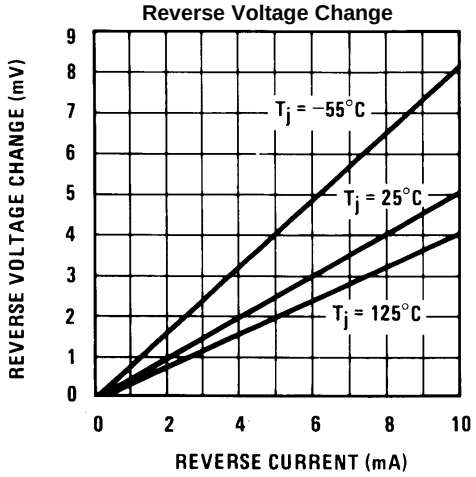


Figure 4.

Calibrated Error

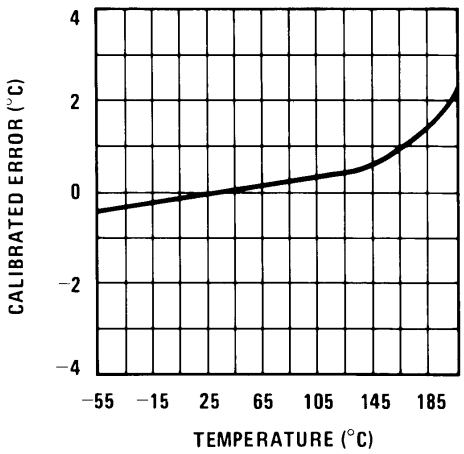


Figure 5.

Reverse Characteristics

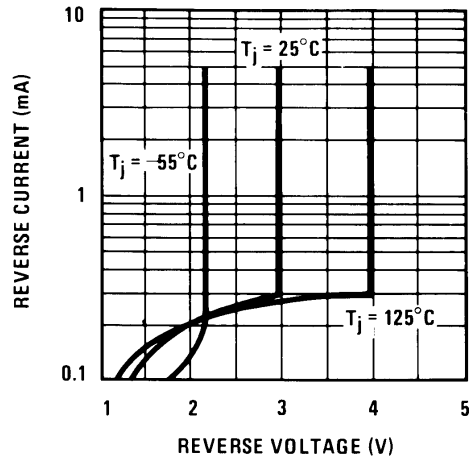


Figure 6.

Response Time

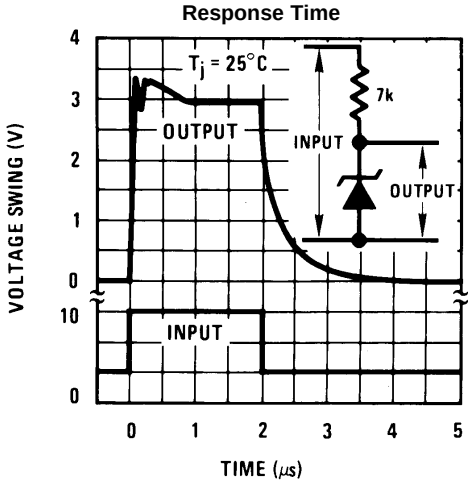


Figure 7.

Dynamic Impedance

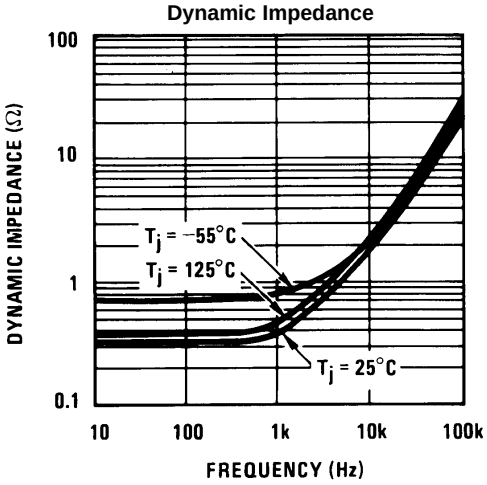


Figure 8.

Noise Voltage

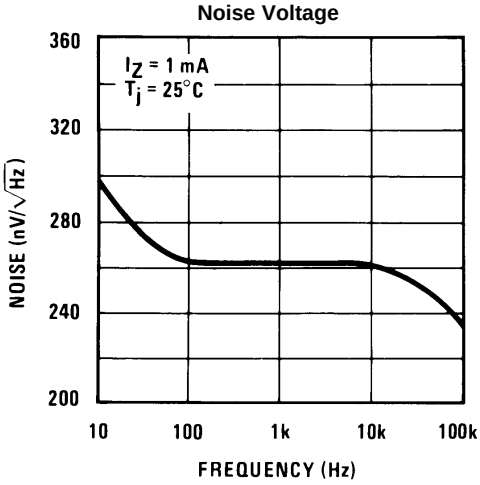


Figure 9.

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Typical Performance Characteristics (continued)

Thermal Resistance Junction to Air

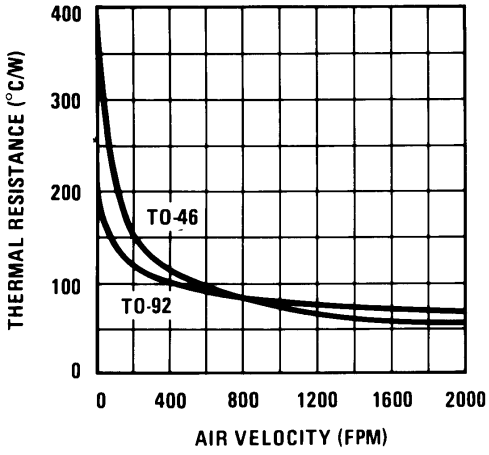


Figure 10.

Thermal Time Constant

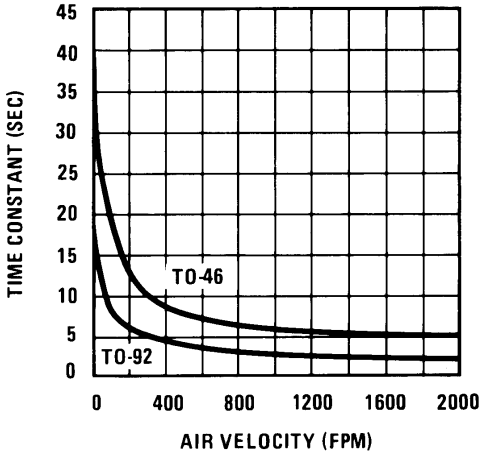


Figure 11.

Thermal Response in Still Air

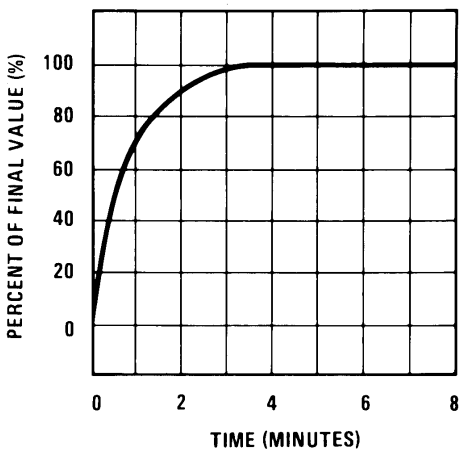


Figure 12.

Thermal Response in Stirred Oil Bath

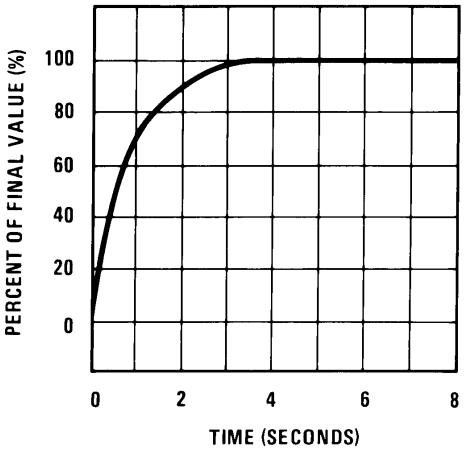


Figure 13.

Forward Characteristics

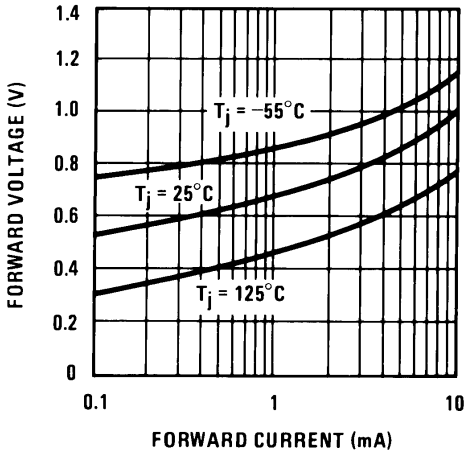


Figure 14.

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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:

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

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

Figure 15. Basic Temperature Sensor

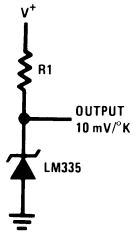
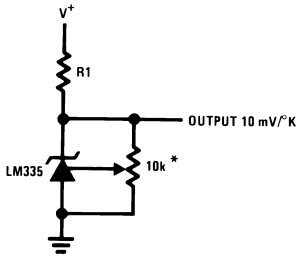
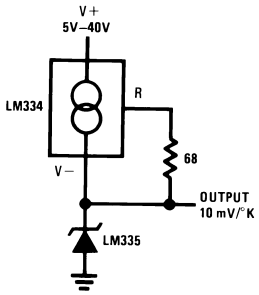


Figure 16. Calibrated Sensor



*Calibrate for 2.982V at 25°C

Figure 17. Wide Operating Supply



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Figure 18. Minimum Temperature Sensing

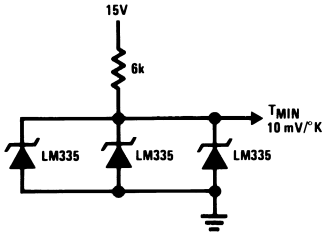


Figure 19. Average Temperature Sensing

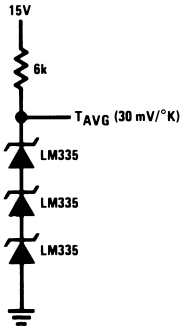
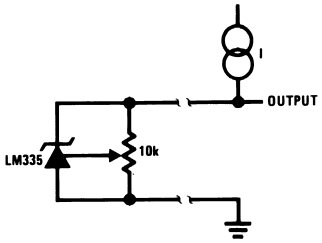


Figure 20. Remote Temperature Sensing



Wire length for 1°C error due to wire drop

	I_R = 1 mA	I_R = 0.5 mA (1)
AWG	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 mA, the trim pot must be deleted.

Figure 21. Isolated Temperature Sensor

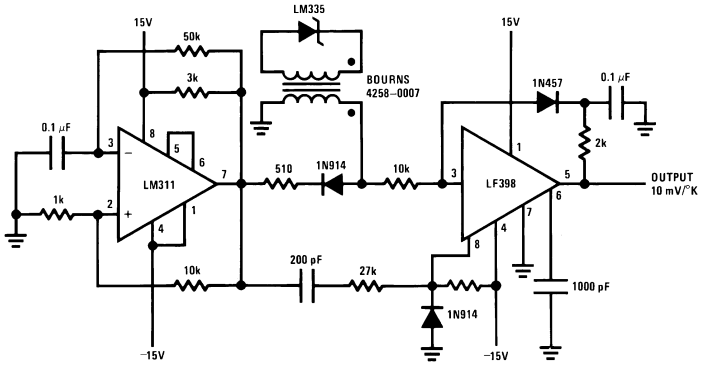


Figure 22. Simple Temperature Controller

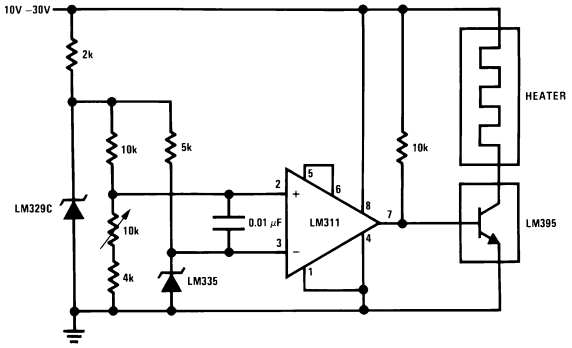


Figure 23. Simple Temperature Control

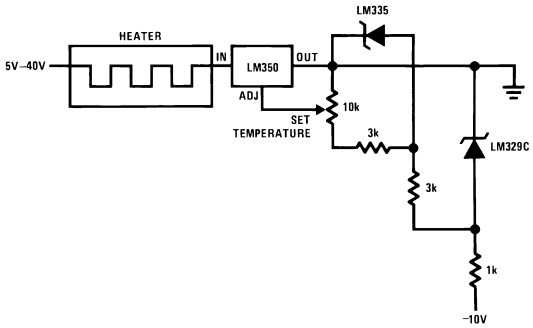
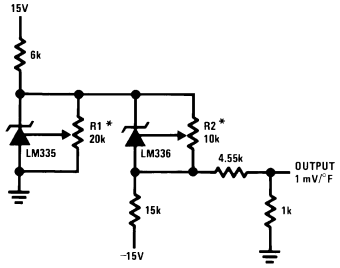
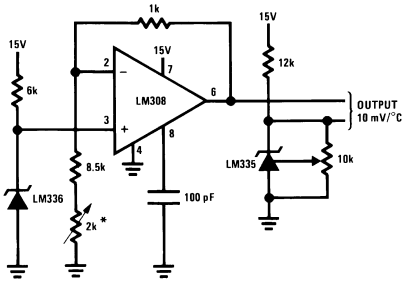


Figure 24. Ground Referred Fahrenheit Thermometer



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

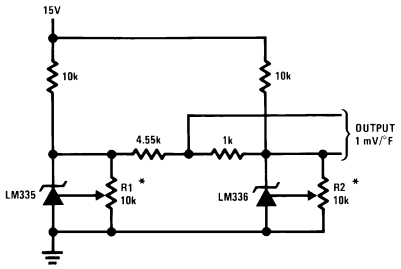
Figure 25. Centigrade Thermometer



*Adjust for 2.7315V at output of LM308

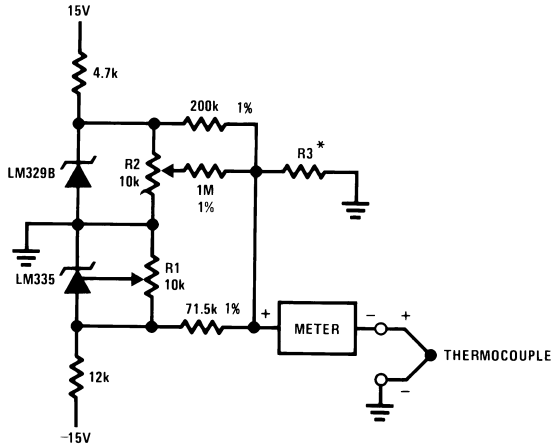
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Figure 26. Fahrenheit Thermometer



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

Figure 27. THERMOCOUPLE COLD JUNCTION COMPENSATION



Compensation for Grounded Thermocouple

*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

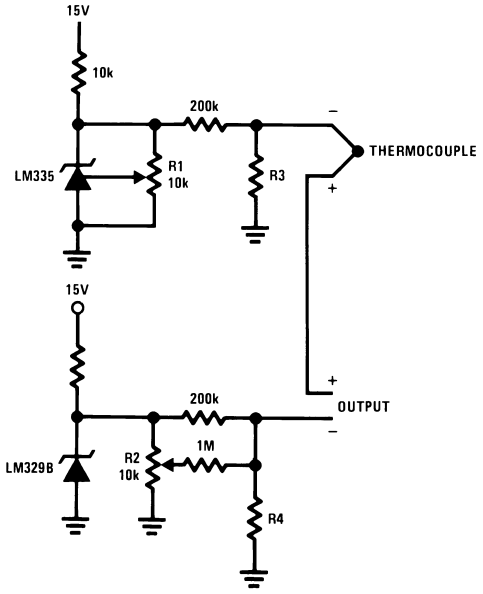
1. Short LM329B
2. Adjust R1 for Seebeck Coefficient times ambient temperature (in degrees K) across R3.
3. Short LM335 and adjust R2 for voltage across R3 corresponding to thermocouple type.

J 14.32 mV K 11.17 mV

T 11.79 mV S 1.768 mV

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Figure 28. Single Power Supply Cold Junction Compensation

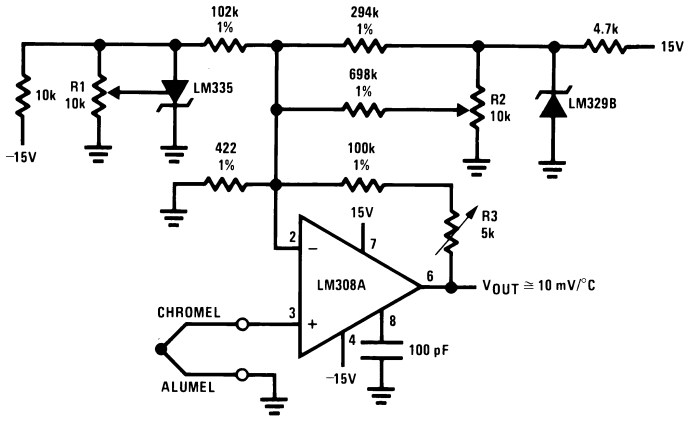


*Select R3 and R4 for thermocouple type

THERMO-COUPLE	R3	R4	SEEBECK COEFFICIENT
J	1.05K	385Ω	52.3 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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Figure 29. Centigrade Calibrated Thermocouple Thermometer

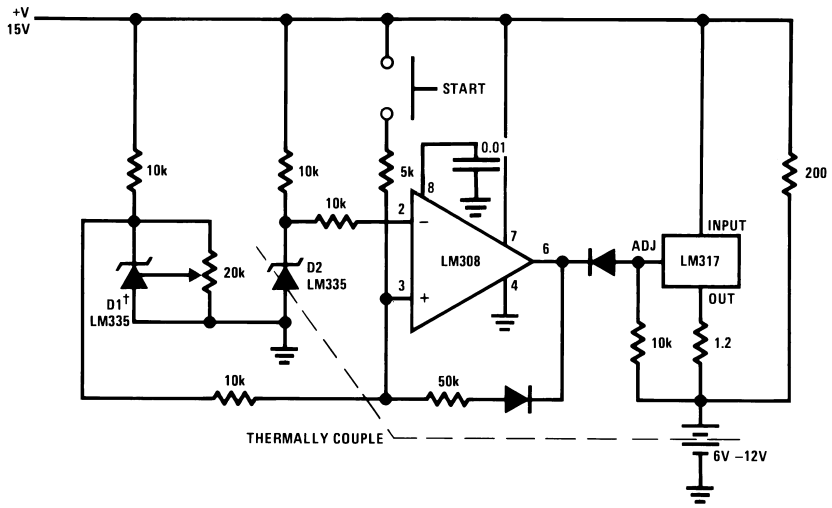


Terminate thermocouple reference junction in close proximity to LM335.

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

Figure 30. 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 31. Differential Temperature Sensor

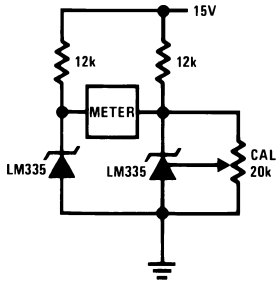


Figure 32. Differential Temperature Sensor

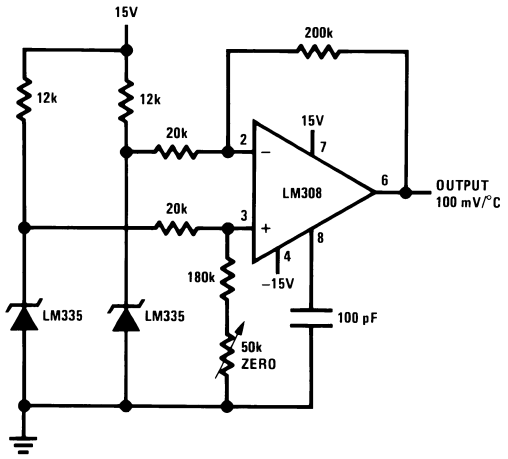
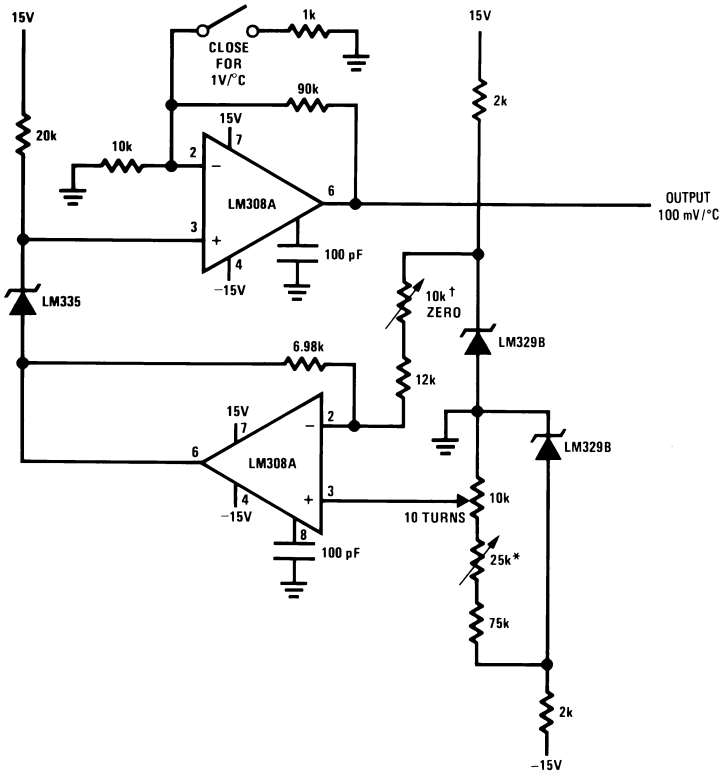


Figure 33. Variable Offset Thermometer‡



†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

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Figure 34. Ground Referred Centigrade Thermometer

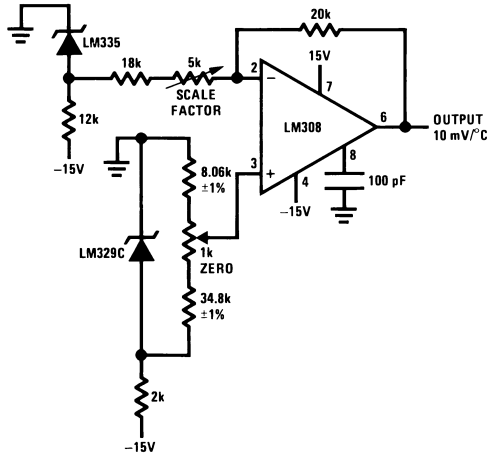
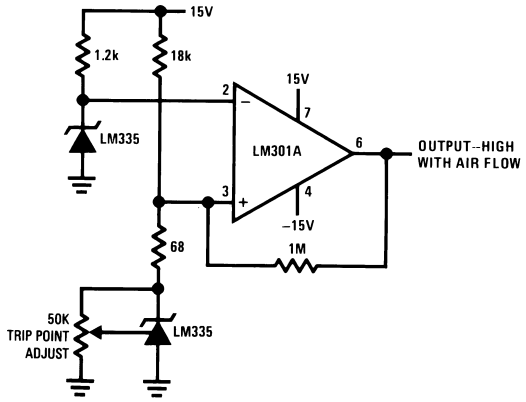


Figure 35. Air Flow Detector*



*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.

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REVISION HISTORY

Changes from Revision C (March 2013) to Revision D	Page
• Changed layout of National Data Sheet to TI format	13

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
LM135AH	ACTIVE	TO	NDV	3	1000	TBD	Call TI	Call TI	-55 to 150	LM135AH	Samples
LM135AH/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-55 to 150	LM135AH	Samples
LM135H	ACTIVE	TO	NDV	3	1000	TBD	Call TI	Call TI	-55 to 150	LM135H	Samples
LM135H/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-55 to 150	LM135H	Samples
LM235AH	ACTIVE	TO	NDV	3	1000	TBD	Call TI	Call TI	-40 to 125	LM235AH	Samples
LM235AH/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-40 to 125	LM235AH	Samples
LM235H	ACTIVE	TO	NDV	3	1000	TBD	Call TI	Call TI	-40 to 125	LM235H	Samples
LM235H/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-40 to 125	LM235H	Samples
LM335A MWC	ACTIVE	WAFERSALE	YS	0	1	Green (RoHS & no Sb/Br)	Call TI	Level-1-NA-UNLIM			Samples
LM335AH	ACTIVE	TO	NDV	3	1000	TBD	Call TI	Call TI	-40 to 100	LM335AH	Samples
LM335AH/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-40 to 100	LM335AH	Samples
LM335AM	ACTIVE	SOIC	D	8	95	TBD	Call TI	Call TI	-40 to 100	LM335 AM	Samples
LM335AM/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 100	LM335 AM	Samples
LM335AMX	ACTIVE	SOIC	D	8	2500	TBD	Call TI	Call TI	-40 to 100	LM335 AM	Samples
LM335AMX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 100	LM335 AM	Samples
LM335AZ/LFT1	ACTIVE	TO-92	LP	3	2000	TBD	Call TI	Call TI			Samples
LM335AZ/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	SNCU	Level-1-NA-UNLIM	-40 to 100	LM335 AZ	Samples
LM335H	ACTIVE	TO	NDV	3	1000	TBD	Call TI	Call TI	-40 to 100	LM335H	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
LM335H/NOPB	ACTIVE	TO	NDV	3	1000	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-40 to 100	LM335H	Samples
LM335M	ACTIVE	SOIC	D	8	95	TBD	Call TI	Call TI	-40 to 100	LM335 M	Samples
LM335M/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 100	LM335 M	Samples
LM335MX	ACTIVE	SOIC	D	8	2500	TBD	Call TI	Call TI	-40 to 100	LM335 M	Samples
LM335MX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 100	LM335 M	Samples
LM335Z/LFT7	ACTIVE	TO-92	LP	3	2000	Green (RoHS & no Sb/Br)	SNCU	Level-1-NA-UNLIM		LM335 Z	Samples
LM335Z/NOPB	ACTIVE	TO-92	LP	3	1800	Green (RoHS & no Sb/Br)	SNCU	Level-1-NA-UNLIM	-40 to 100	LM335 Z	Samples

(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.

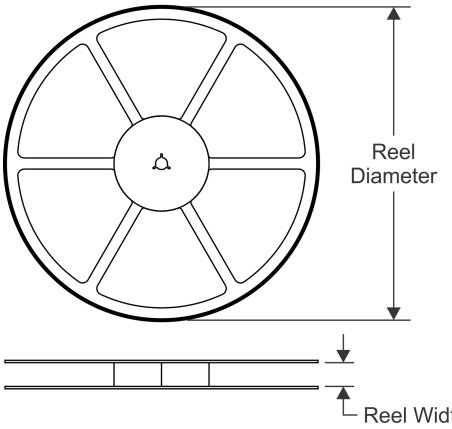
(4) Multiple Top-Side Markings will be inside parentheses. Only one Top-Side Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Top-Side Marking for that device.

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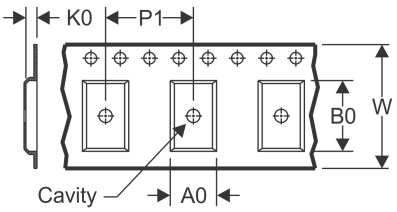
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TAPE AND REEL INFORMATION

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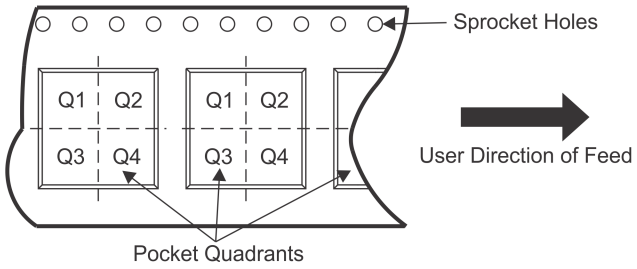


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

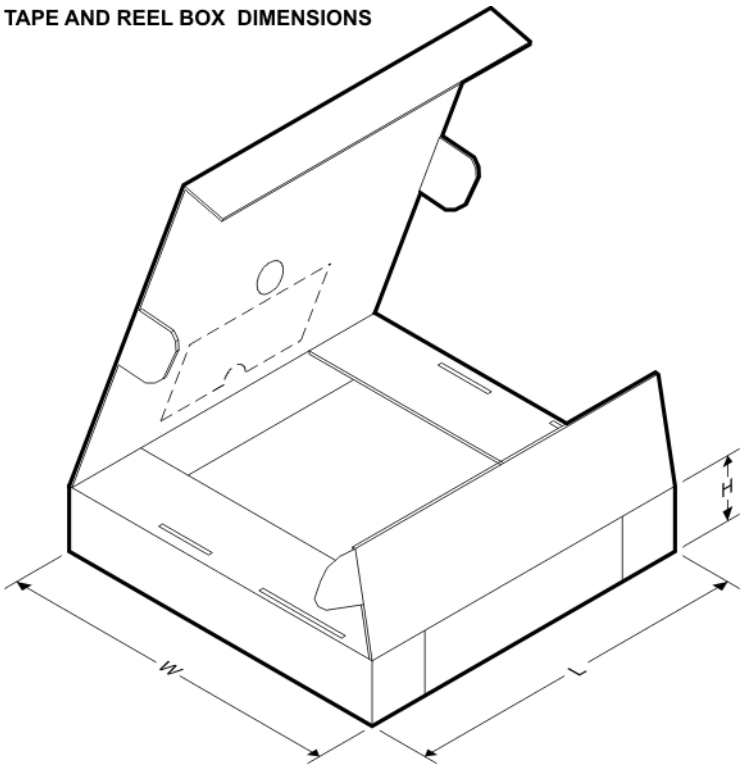
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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

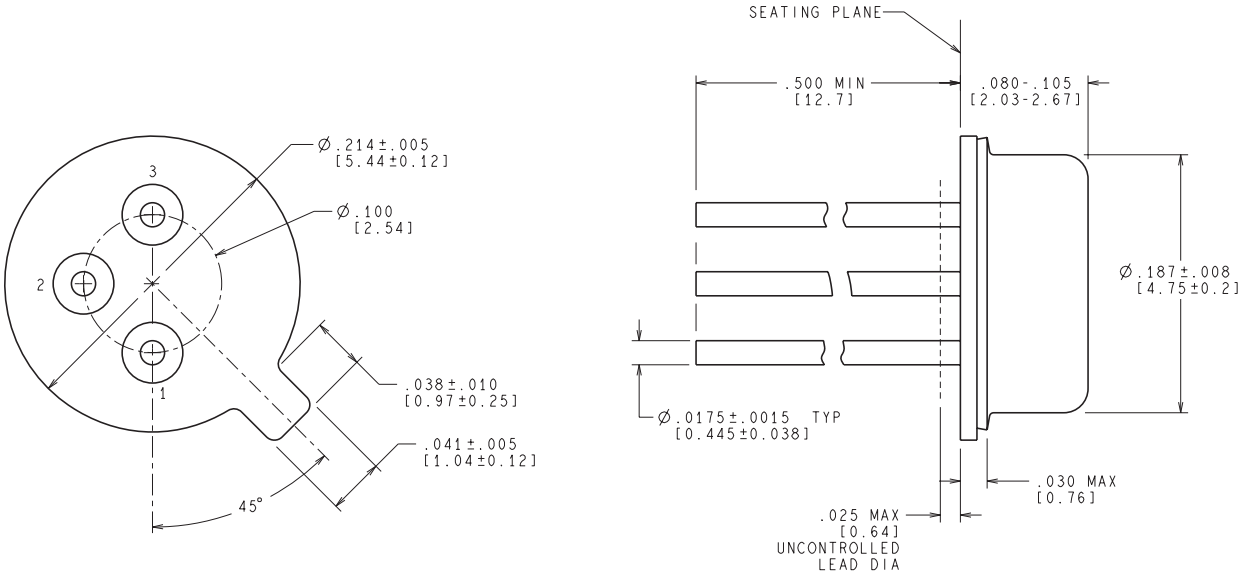
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM335AMX	SOIC	D	8	2500	367.0	367.0	35.0
LM335AMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM335MX	SOIC	D	8	2500	367.0	367.0	35.0
LM335MX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0

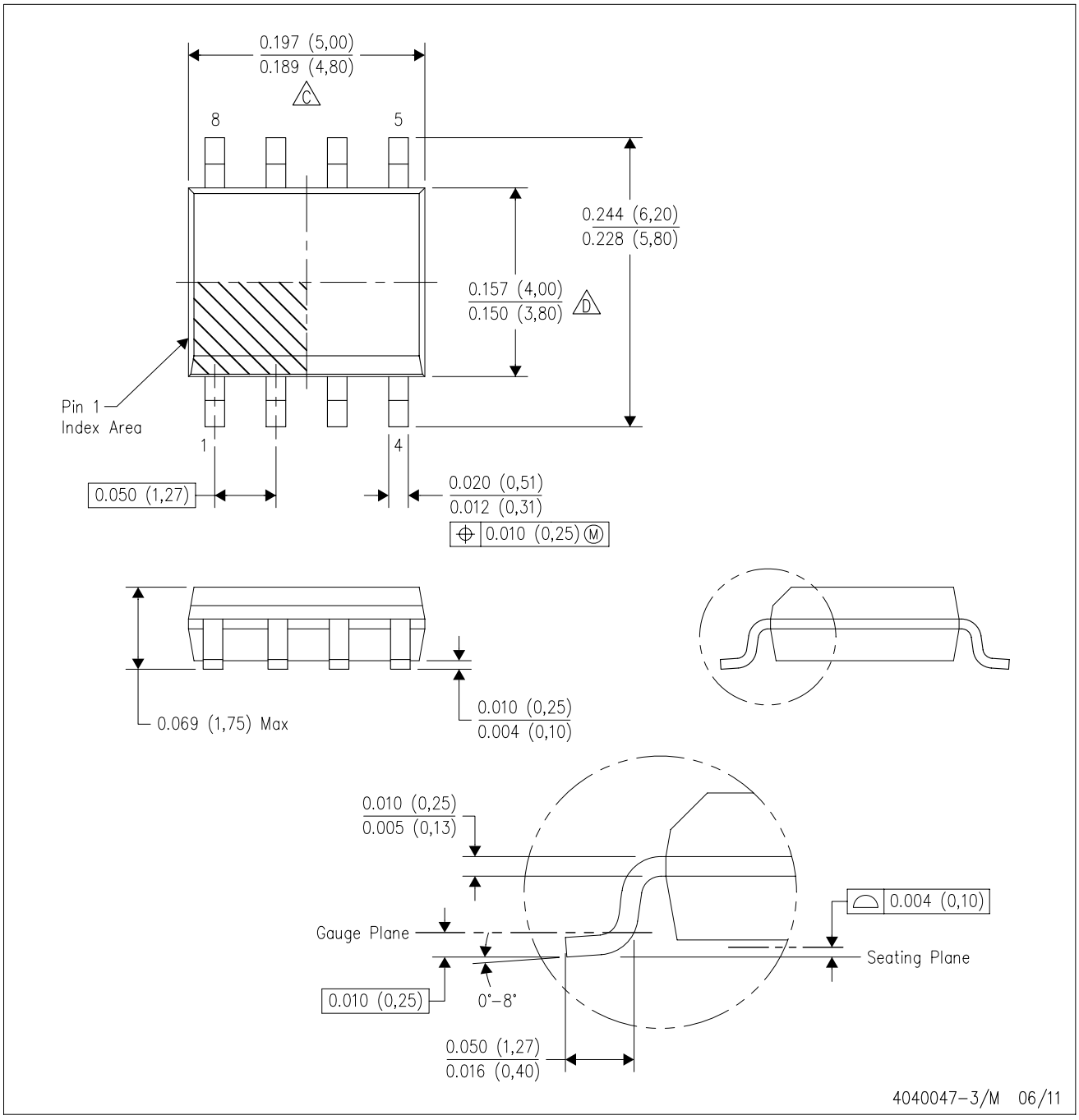
NDV0003H



CONTROLLING DIMENSION IS INCH
VALUES IN [ ] ARE IN MILLIMETERS

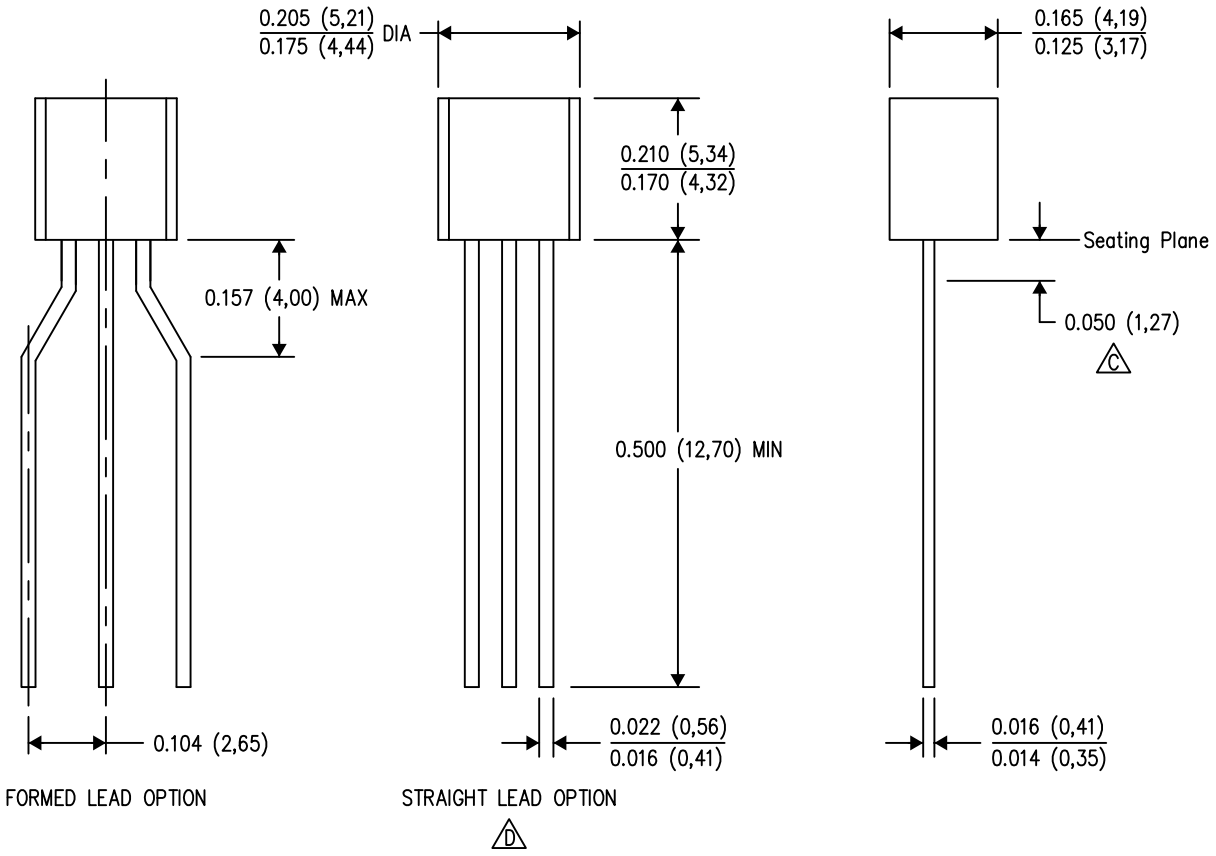
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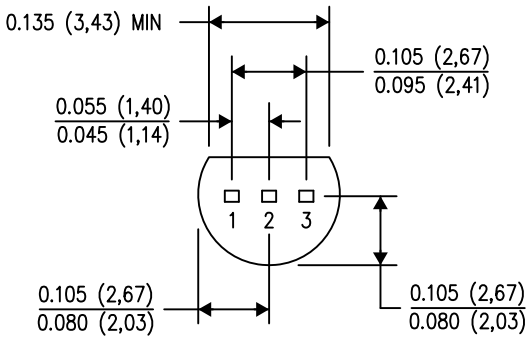
D (R–PDSO–G8) PLASTIC SMALL OUTLINE



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

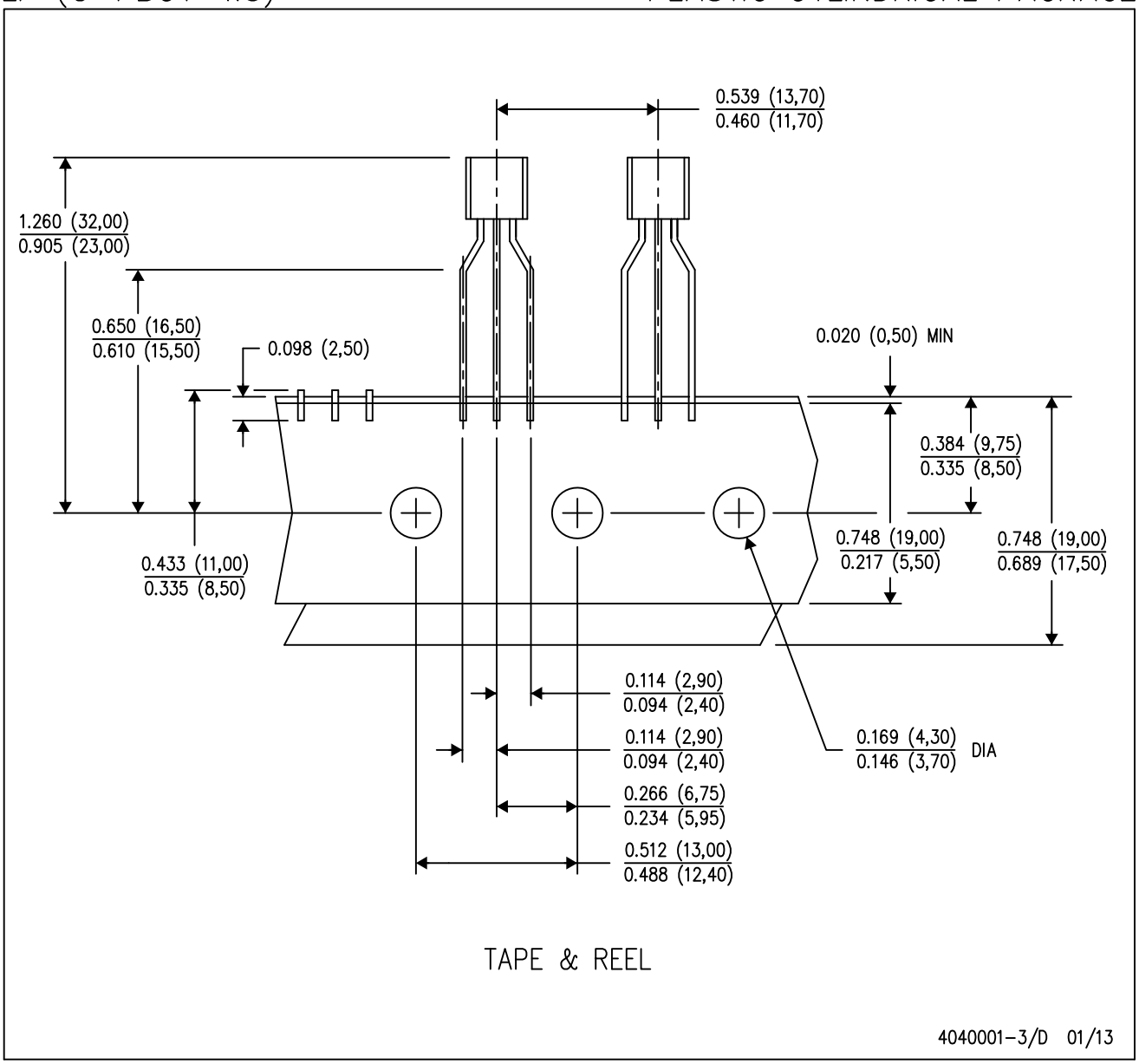




4040001–2/D 01/13

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 either bulk pack or tape & reel.
Formed lead option available in tape & reel or ammo pack.
Specific products can be offered in limited combinations of shipping mediums and lead options.
Consult product folder for more information on available options.

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 Formed Lead Option package.

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