Analog Temperature Sensor – LM335

Single-supply linear-output temperature sensor in bare die form

Description

The LM335 precision linear-output temperature sensor is designed for simple calibration and ease of use. Output is derived from an integrated 2-terminal Zener with a breakdown voltage directly proportional to absolute temperature at 10mV/°K. Calibrated at +25°C, the LM335 has an accuracy of 1°C over a wide -40°C to 100°C temperature range. With less than 1Ω dynamic impedance, performance is consistent across a current range of 450μA to 5mA. The device suits use as a general purpose sensor where its small size, low impedance and linear output enables simple circuit integration.

Features:

- Wide temperature range: -40 to +100°C
- 1% typical accuracy at 25°C
- Single-point calibration for high precision
- Operates from 450μA to 5mA
- <1Ω dynamic impedance
- Linear output
- Small size for high integration

Ordering Information

The following part suffixes apply:


For High Reliability versions of this product please see

LM135 and LM135A

For higher precision commercial grade product please see

LM335A

Supply Formats:

- Default – Die in Waffle Pack (400 per tray capacity)
- Sawn Wafer on Tape – On request
- Unsawn Wafer – On request
- Die Thickness <> 350μm(14 Mil) – On request
- Assembled into Hermetic Package – On request

Die Dimensions in µm (mils)

![Die Dimensions Diagram]

Die Size (Unsawn) 1500 x 1050 59 x 41

Minimum Bond Pad Size 104 x 104 4.09 x 4.09

Die Thickness 350 (±20) 13.78 (±0.79)

Top Metal Composition Al 1%Si 1.1µm

Back Metal Composition N/A – Bare Si

Mechanical Specification

<table>
<thead>
<tr>
<th>Die Size (Unsawn)</th>
<th>1500 x 1050</th>
<th>59 x 41</th>
<th>µm</th>
<th>mils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Bond Pad Size</td>
<td>104 x 104</td>
<td>4.09 x 4.09</td>
<td>µm</td>
<td>mils</td>
</tr>
<tr>
<td>Die Thickness</td>
<td>350 (±20)</td>
<td>13.78 (±0.79)</td>
<td>µm</td>
<td>mils</td>
</tr>
<tr>
<td>Top Metal Composition</td>
<td>Al 1%Si 1.1µm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back Metal Composition</td>
<td>N/A – Bare Si</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Calibration methodology and schematic

The LM335 response is proportional to absolute temperature with the extrapolated output of sensor going to 0V at 0°K (-273.15°C). Errors in output voltage versus temperature are only slope. Thus a calibration of the slope at one temperature corrects errors at all temperatures. The circuit output (calibrated or not) is given by the equation:

\[ V_{OUT_T} + V_{OUT_{T0}} \times \frac{T}{T_0} \]

Where:

- \( T \) is the unknown temperature
- \( T_0 \) is the reference temperature (in °K).

Nominally, the output is calibrated at 10mV/°K.

Application Note:

Self-heating can decrease accuracy; LM335 should be operated at low current but sufficient enough to drive the sensor and calibration circuit to the maximum operating temperature. If used in surroundings where the thermal resistance is constant, the errors due to self-heating can be externally calibrated. This is possible if the circuit is biased with a temperature stable current. Heating will then be proportional to Zener voltage and therefore temperature. In this way, the error due to self-heating is proportional to the absolute temperature as scale factor errors.
Analog Temperature Sensor – LM335

Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>VALUE</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse Current</td>
<td>I_R</td>
<td>15</td>
<td>mA</td>
</tr>
<tr>
<td>Forward Current</td>
<td>I_F</td>
<td>10</td>
<td>mA</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>T_OPER</td>
<td>Continuous</td>
<td>-40 to +100</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>T_STG</td>
<td>-65 to +150</td>
<td>°C</td>
</tr>
</tbody>
</table>

1. Operation above the absolute maximum rating may cause device failure. Operation at the absolute maximum ratings, for extended periods, may reduce device reliability.

Recommended Operating Conditions

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>MIN</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>T_A</td>
<td>-40</td>
<td>100</td>
<td>°C</td>
</tr>
<tr>
<td>Forward Current</td>
<td>I_F</td>
<td>0.45</td>
<td>5</td>
<td>mA</td>
</tr>
</tbody>
</table>

Temperature Parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>LIMITS</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage</td>
<td>V_OUT</td>
<td>T_J = 25°C, I_R = 1mA</td>
<td>2.92</td>
<td>2.98</td>
</tr>
<tr>
<td>Un-calibrated Temperature Error</td>
<td>ΔT_1</td>
<td>T_A = 25°C, I_R = 1mA</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ΔT_2</td>
<td>-40°C ≤ T_A ≤ +100°C, I_R = 1mA</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>25°C Calibrated Temperature Error</td>
<td>ΔT_3</td>
<td>-40°C ≤ T_A ≤ +100°C, I_R = 1mA</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Non-linearity</td>
<td>ΔT_4</td>
<td>-40°C ≤ T_A ≤ +100°C, I_R = 1mA</td>
<td>-</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Electrical Parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>LIMITS</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output voltage change with current</td>
<td>ΔV_OUT</td>
<td>450µA ≤ I_R ≤ 5mA, Constant temperature</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Dynamic impedance</td>
<td>ΔR_1</td>
<td>T_J = 25°C, I_R = 1mA</td>
<td>-</td>
<td>0.6</td>
</tr>
<tr>
<td>Temperature coefficient of output voltage</td>
<td>TC</td>
<td>T_J = 25°C, I_R = 1mA</td>
<td>-</td>
<td>+10</td>
</tr>
<tr>
<td>Time constant</td>
<td>τ_T</td>
<td>Still air</td>
<td>-</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Air 0.5m/s</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stirred oil</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Time stability</td>
<td>T_STAB</td>
<td>T_J = 125°C</td>
<td>-</td>
<td>0.2</td>
</tr>
</tbody>
</table>

2. Accuracy measurements are made in a well-stirred oil bath. For other conditions, self-heating must be considered.
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Typical Characteristics (TJ = 25°C unless otherwise specified)

FIGURE 1. Reverse Voltage Change

![Reverse Voltage Change](image)

FIGURE 2. Calibrated error

![Calibrated error](image)

FIGURE 3. Reverse characteristics

![Reverse characteristics](image)

FIGURE 4. Response time

![Response time](image)
Typical Characteristics\( (T_J = 25°C \text{ unless otherwise specified}) \)

**FIGURE 5.** Dynamic Impedance

**FIGURE 6.** Noise voltage

**FIGURE 8.** Thermal resistance, junction-to-air

**FIGURE 9.** Thermal time constant
Typical Characteristics \((T_J = 25^\circ C\) unless otherwise specified)
Typical Applications

FIGURE 13.
Average Temperature Sensing

FIGURE 14.
Minimum Temperature Sensing

FIGURE 15.
Wide operating supply

FIGURE 16.
Isolated Temperature Sensor
Typical Applications continued

**FIGURE 16.**
Temperature Controller

**FIGURE 17.**
Centigrade Thermometer

*Adjust for 2.7315V at output of LM308

**FIGURE 18.**
Differential Temperature Sensor
Thermocouple compensation

**FIGURE 19.** Thermocouple cold junction compensation (compensation for grounded thermocouple)

<table>
<thead>
<tr>
<th>Thermocouple</th>
<th>R3</th>
<th>SEEBECK Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>377Ω</td>
<td>52.3µV/°C</td>
</tr>
<tr>
<td>T</td>
<td>308Ω</td>
<td>42.8µV/°C</td>
</tr>
<tr>
<td>K</td>
<td>293Ω</td>
<td>40.8µV/°C</td>
</tr>
<tr>
<td>S</td>
<td>45.8Ω</td>
<td>6.4µV/°C</td>
</tr>
</tbody>
</table>

Adjustments:
1. Short 1N4568.
2. Adjust R1 for SEEBECK coefficient times ambient temperature in degrees Kelvin across R3.
3. Short LM135 and adjust R2 for voltage across R3 corresponding to thermocouple type as below:
   - J: 14.32mV
   - T: 11.9mV
   - K: 11.17mV
   - S: 1.768mV

**FIGURE 20.** Single power supply cold junction compensation

<table>
<thead>
<tr>
<th>Thermocouple</th>
<th>R3</th>
<th>R4</th>
<th>SEEBECK Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>1.05kΩ</td>
<td>365Ω</td>
<td>52.3µV/°C</td>
</tr>
<tr>
<td>T</td>
<td>856Ω</td>
<td>315Ω</td>
<td>42.8µV/°C</td>
</tr>
<tr>
<td>K</td>
<td>816Ω</td>
<td>300Ω</td>
<td>40.8µV/°C</td>
</tr>
<tr>
<td>S</td>
<td>128Ω</td>
<td>46.3Ω</td>
<td>6.4µV/°C</td>
</tr>
</tbody>
</table>

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 the thermocouple as below:
   - J: 14.32mV
   - T: 11.9mV
   - K: 11.17mV
   - S: 1.768mV
Circuit schematic

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