

LM56

Dual Output Low Power Thermostat

General Description

The LM56 is a precision low power thermostat. Two stable temperature trip points (V_{T1} and V_{T2}) are generated by dividing down the LM56 1.250V bandgap voltage reference using 3 external resistors. The LM56 has two digital outputs. OUT1 goes LOW when the temperature exceeds $T1$ and goes HIGH when the the temperature goes below ($T1 - T_{HYST}$). Similarly, OUT2 goes LOW when the temperature exceeds $T2$ and goes HIGH when the temperature goes below ($T2 - T_{HYST}$). T_{HYST} is an internally set 5°C typical hysteresis. The LM56 is available in an 8-lead Mini-SO8 surface mount package and an 8-lead small outline package.

Applications

- Microprocessor Thermal Management
- Appliances
- Portable Battery Powered 3.0V or 5V Systems
- Fan Control
- Industrial Process Control
- HVAC Systems
- Remote Temperature Sensing
- Electronic System Protection

Features

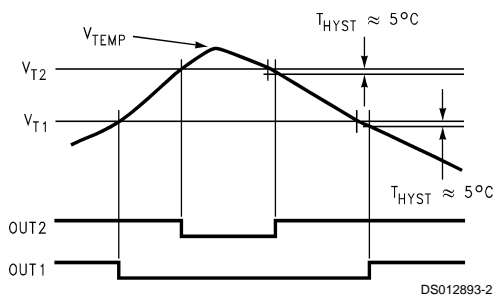
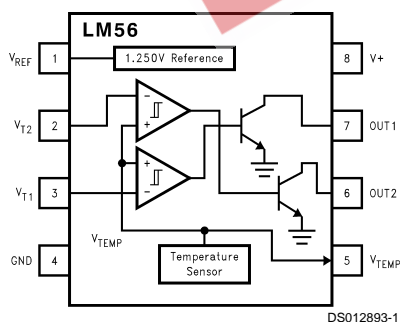
- Digital outputs support TTL logic levels
- Internal temperature sensor
- 2 internal comparators with hysteresis
- Internal voltage reference
- Currently available in 8-pin SO plastic package
- Future availability in the 8-pin Mini-SO8 package

Key Specifications

- Power Supply Voltage 2.7V–10V
- Power Supply Current 230 μ A (max)
- V_{REF} 1.250V \pm 1% (max)
- Hysteresis Temperature 5°C
- Internal Temperature Sensor Output Voltage (+6.20 mV/°C x T) +395 mV
- Temperature Trip Point Accuracy:

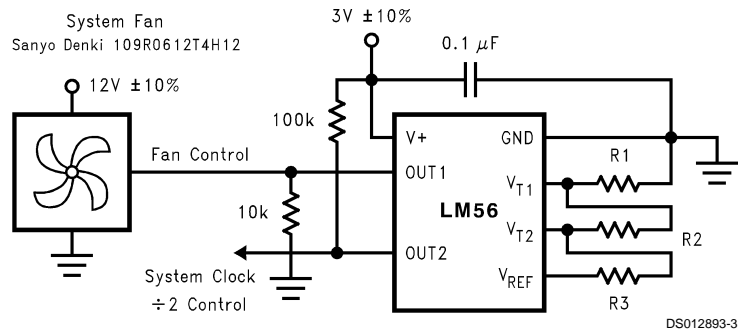
| | LM56BIM | LM56CIM |
|-----------------|-----------------|-----------------|
| +25°C | \pm 2°C (max) | \pm 3°C (max) |
| +25°C to +85°C | \pm 2°C (max) | \pm 3°C (max) |
| -40°C to +125°C | \pm 3°C (max) | \pm 4°C (max) |

Simplified Block Diagram and Connection Diagram



| Order Number | LM56BIM | LM56BIMX | LM56CIM | LM56CIMX | LM56BIMM | LM56BIMMX | LM56CIMM | LM56CIMMX |
|-------------------|---------|---------------------------|---------|---------------------------|----------|---------------------------|----------|---------------------------|
| NS Package Number | M08A | M08A | M08A | M08A | MUA08A | MUA08A | MUA08A | MUA08A |
| | SOP-8 | SOP-8 | SOP-8 | SOP-8 | MSOP-8 | MSOP-8 | MSOP-8 | MSOP-8 |
| Transport Media | Rail | 2500 Units Tape & Reel | Rail | 2500 Units Tape & Reel | Rail | 3500 Units Tape & Reel | Rail | 3500 Units Tape & Reel |
| Package Marking | LM56BIM | LM56BIM | LM56CIM | LM56CIM | T02B | T02B | T02C | T02C |

Typical Application



$$V_{T1} = 1.250V \times (R1)/(R1 + R2 + R3)$$

$$V_{T2} = 1.250V \times (R1 + R2)/(R1 + R2 + R3)$$

where:

$$(R1 + R2 + R3) = 27 \text{ k}\Omega \text{ and}$$

$$V_{T1 \text{ or } T2} = [6.20 \text{ mV}/^\circ\text{C} \times T] + 395 \text{ mV} \text{ therefore:}$$

$$R1 = V_{T1}/(1.25V) \times 27 \text{ k}\Omega$$

$$R2 = (V_{T2}/(1.25V) \times 27 \text{ k}\Omega) - R1$$

$$R3 = 27 \text{ k}\Omega - R1 - R2$$

FIGURE 1. Microprocessor Thermal Management

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Absolute Maximum Ratings (Note 1)

| | |
|--|--------|
| Input Voltage | 12V |
| Input Current at any pin (Note 2) | 5 mA |
| Package Input Current (Note 2) | 20 mA |
| Package Dissipation at $T_A = 25^\circ\text{C}$ (Note 3) | 900 mW |
| ESD Susceptibility (Note 4) | |
| Human Body Model | 1000V |
| Machine Model | 200V |
| Soldering Information | |
| SO Package (Note 5) : | |

| | |
|--------------------------|-----------------|
| Vapor Phase (60 seconds) | 215°C |
| Infrared (15 seconds) | 220°C |
| Storage Temperature | -65°C to +150°C |

Operating Ratings (Note 1)

| | |
|---|--|
| Operating Temperature Range | $T_{\text{MIN}} \leq T_A \leq T_{\text{MAX}}$ |
| LM56BIM, LM56CIM | $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$ |
| Positive Supply Voltage (V^+) | +2.7V to +10V |
| Maximum V_{OUT1} and V_{OUT2} | +10V |

LM56 Electrical Characteristics

The following specifications apply for $V^+ = 2.7 V_{\text{DC}}$, and V_{REF} load current = 50 μA unless otherwise specified. **Boldface limits apply for $T_A = T_J = T_{\text{MIN}}$ to T_{MAX}** ; all other limits $T_A = T_J = 25^\circ\text{C}$ unless otherwise specified.

| Symbol | Parameter | Conditions | Typical (Note 6) | LM56BIM Limits (Note 7) | LM56CIM Limits (Note 7) | Units (Limits) |
|--|---|---|---------------------|-------------------------------|-------------------------------|-------------------------|
| Temperature Sensor | | | | | | |
| | Trip Point Accuracy (Includes V_{REF} , Comparator Offset, and Temperature Sensitivity errors) | $+25^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$ | | ± 2 | ± 3 | $^\circ\text{C}$ (max) |
| | | $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$ | | ± 2 | ± 3 | $^\circ\text{C}$ (max) |
| | | | | ± 3 | ± 4 | $^\circ\text{C}$ (max) |
| | Trip Point Hysteresis | $T_A = -40^\circ\text{C}$ | 4 | 3 | 3 | $^\circ\text{C}$ (min) |
| | | | | 6 | 6 | $^\circ\text{C}$ (max) |
| | | $T_A = +25^\circ\text{C}$ | 5 | 3.5 | 3.5 | $^\circ\text{C}$ (min) |
| | | | | 6.5 | 6.5 | $^\circ\text{C}$ (max) |
| | | $T_A = +85^\circ\text{C}$ | 6 | 4.5 | 4.5 | $^\circ\text{C}$ (min) |
| | | | 7.5 | 7.5 | $^\circ\text{C}$ (max) | |
| | | $T_A = +125^\circ\text{C}$ | 6 | 4 | 4 | $^\circ\text{C}$ (min) |
| | | | | 8 | 8 | $^\circ\text{C}$ (max) |
| | Internal Temperature Sensitivity | | +6.20 | | | mV/ $^\circ\text{C}$ |
| | Temperature Sensitivity Error | | | ± 2 | ± 3 | $^\circ\text{C}$ (max) |
| | | | | ± 3 | ± 4 | $^\circ\text{C}$ (max) |
| | Output Impedance | $-1 \mu\text{A} \leq I_L \leq +40 \mu\text{A}$ | | 1500 | 1500 | Ω (max) |
| | Line Regulation | $+3.0\text{V} \leq V^+ \leq +10\text{V}$, $+25^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$ | | ± 0.36 | ± 0.36 | mV/V (max) |
| | | $+3.0\text{V} \leq V^+ \leq +10\text{V}$, $-40^\circ\text{C} \leq T_A < 25^\circ\text{C}$ | | ± 0.61 | ± 0.61 | mV/V (max) |
| | | $+2.7\text{V} \leq V^+ \leq +3.3\text{V}$ | | ± 2.3 | ± 2.3 | mV (max) |
| V_{T1} and V_{T2} Analog Inputs | | | | | | |
| I_{BIAS} | Analog Input Bias Current | | 150 | 300 | 300 | nA (max) |
| V_{IN} | Analog Input Voltage Range | | $V^+ - 1$ | | | V |
| | | | GND | | | V |
| V_{OS} | Comparator Offset | | 2 | 8 | 8 | mV (max) |
| V_{REF} Output | | | | | | |
| V_{REF} | V_{REF} Nominal | | 1.250V | | | V |
| | V_{REF} Error | | | ± 1 | ± 1 | % (max) |
| | | | | ± 12.5 | ± 12.5 | mV (max) |
| $\Delta V_{\text{REF}}/\Delta V^+$ | Line Regulation | $+3.0\text{V} \leq V^+ \leq +10\text{V}$ | 0.13 | 0.25 | 0.25 | mV/V (max) |
| | | $+2.7\text{V} \leq V^+ \leq +3.3\text{V}$ | 0.15 | 1.1 | 1.1 | mV (max) |
| $\Delta V_{\text{REF}}/\Delta I_L$ | Load Regulation Sourcing | $+30 \mu\text{A} \leq I_L \leq +50 \mu\text{A}$ | | 0.15 | 0.15 | mV/ μA (max) |

LM56 Electrical Characteristics

The following specifications apply for $V^+ = 2.7 V_{DC}$, and V_{REF} load current = 50 μA unless otherwise specified. **Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX}** ; all other limits $T_A = T_J = 25^\circ C$ unless otherwise specified.

| Symbol | Parameter | Conditions | Typical (Note 6) | Limits (Note 7) | Units (Limits) |
|-----------------------------------|------------------------------------|-----------------------|---------------------|--------------------|-------------------|
| V⁺ Power Supply | | | | | |
| I_S | Supply Current | $V^+ = +10V$ | | 230 | μA (max) |
| | | $V^+ = +2.7V$ | | 230 | μA (max) |
| Digital Outputs | | | | | |
| $I_{OUT("1")}$ | Logical "1" Output Leakage Current | $V^+ = +5.0V$ | | 1 | μA (max) |
| $V_{OUT("0")}$ | Logical "0" Output Voltage | $I_{OUT} = +50 \mu A$ | | 0.4 | V (max) |

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

Note 2: When the input voltage (V_I) at any pin exceeds the power supply ($V_I < GND$ or $V_I > V^+$), the current at that pin should be limited to 5 mA. The 20 mA maximum package input current rating limits the number of pins that can safely exceed the power supplies with an input current of 5 mA to four.

Note 3: The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{Jmax} (maximum junction temperature), θ_{JA} (junction to ambient thermal resistance) and T_A (ambient temperature). The maximum allowable power dissipation at any temperature is $P_D = (T_{Jmax} - T_A) / \theta_{JA}$ or the number given in the Absolute Maximum Ratings, whichever is lower. For this device, $T_{Jmax} = 125^\circ C$. For this device the typical thermal resistance (θ_{JA}) of the different package types when board mounted follow:

| Package Type | θ_{JA} |
|--------------|---------------|
| M08A | 110°C/W |
| MUA08A | 250°C/W |

Note 4: The human body model is a 100 pF capacitor discharge through a 1.5 k Ω resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin.

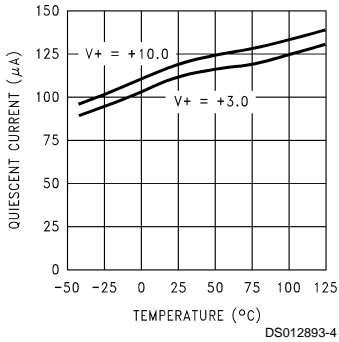
Note 5: See AN450 "Surface Mounting Methods and Their Effects on Product Reliability" or the section titled "Surface Mount" found in any post 1986 National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Note 6: Typical values are at $T_J = T_A = 25^\circ C$ and represent most likely parametric norm.

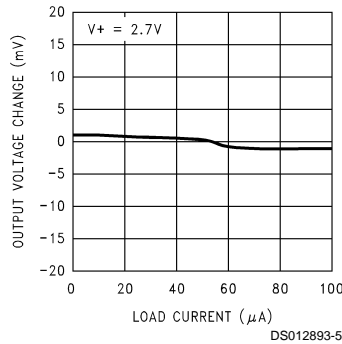
Note 7: Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

Typical Performance Characteristics

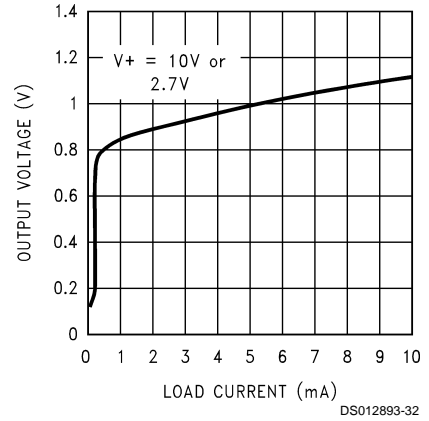
Quiescent Current vs Temperature



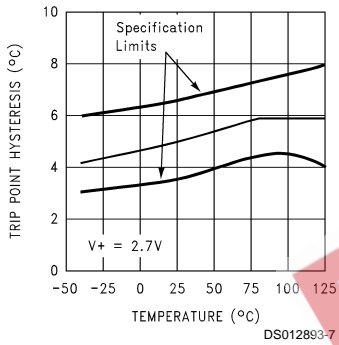
V_{REF} Output Voltage vs Load Current



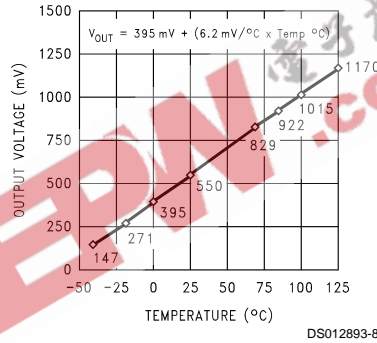
OUT1 and OUT2 Voltage Levels vs Load Current



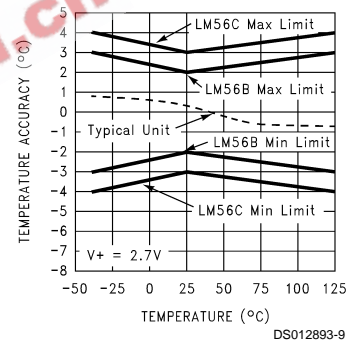
Trip Point Hysteresis vs Temperature



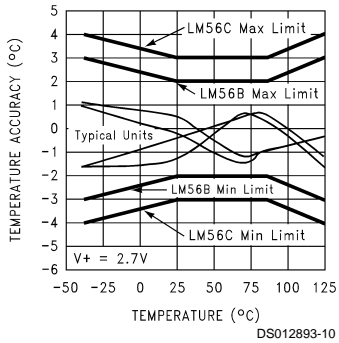
Temperature Sensor Output Voltage vs Temperature



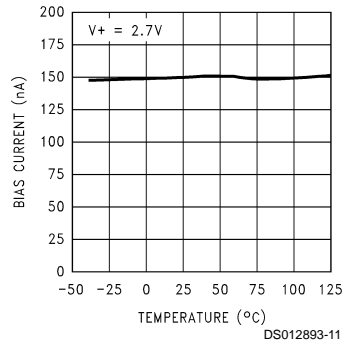
Temperature Sensor Output Accuracy vs Temperature



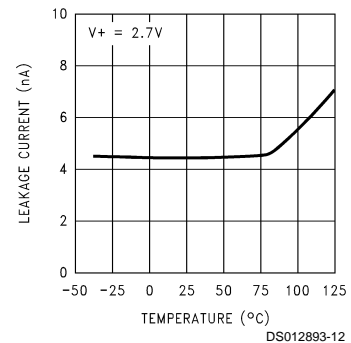
Trip Point Accuracy vs Temperature



Comparator Bias Current vs Temperature

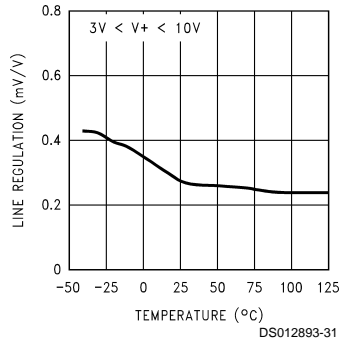


OUT1 and OUT2 Leakage Current vs Temperature

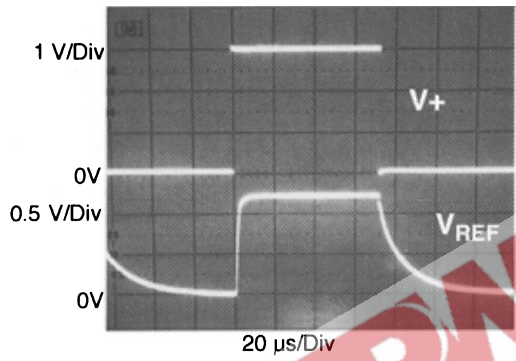


Typical Performance Characteristics (Continued)

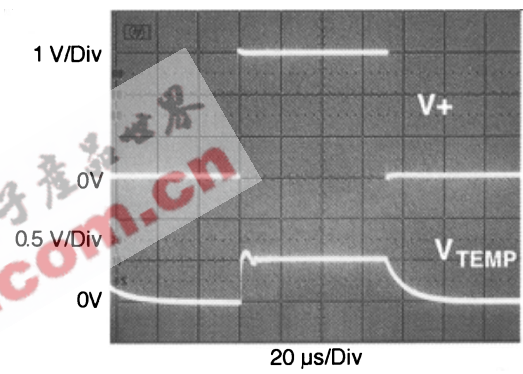
V_{TEMP} Output
Line Regulation vs Temperature



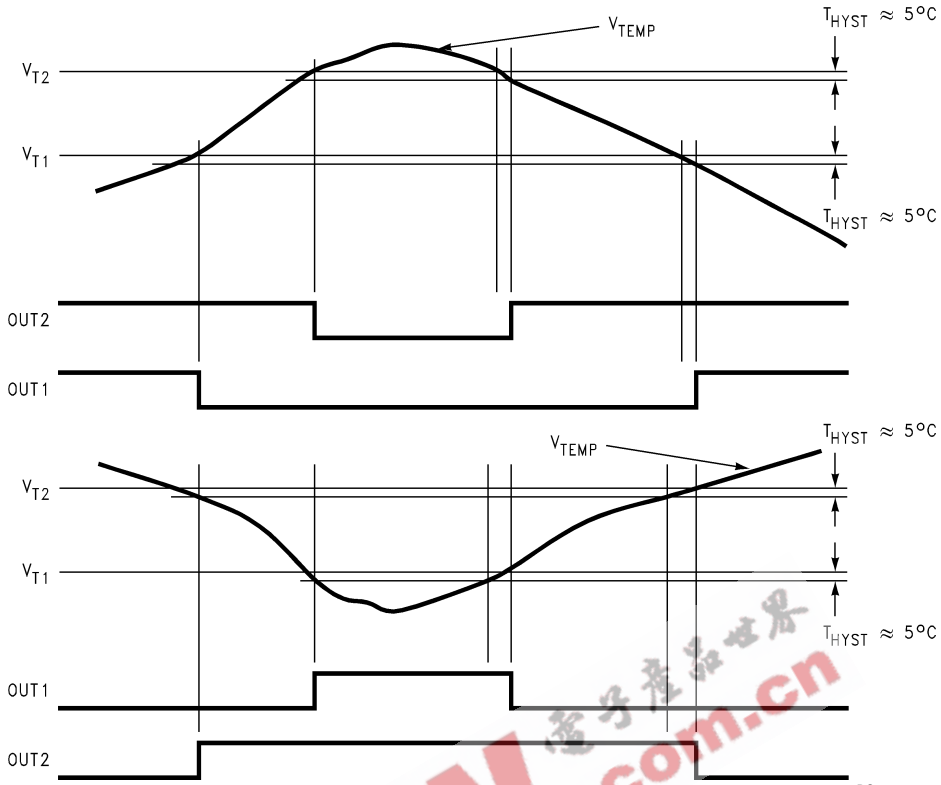
V_{REF} Start-Up Response



V_{TEMP} Start-Up Response



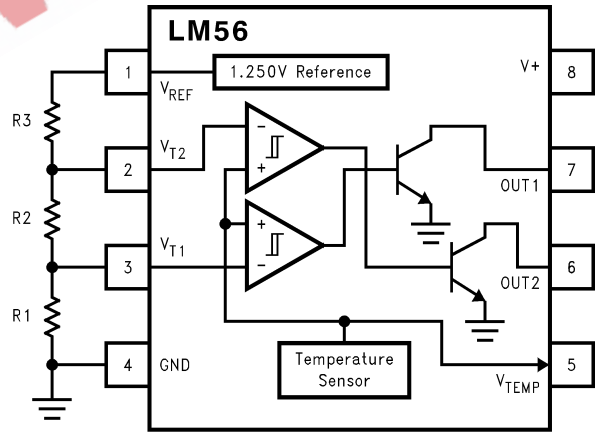
Functional Description



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1.0 PIN DESCRIPTION

- V⁺** This is the positive supply voltage pin. This pin should be bypassed with 0.1 μF capacitor to ground.
- GND** This is the ground pin.
- V_{REF}** This is the 1.250V bandgap voltage reference output pin. In order to maintain trip point accuracy this pin should source a 50 μA load.
- V_{TEMP}** This is the temperature sensor output pin.
- OUT1** This is an open collector digital output. OUT1 is active LOW. It goes LOW when the temperature is greater than T₁ and goes HIGH when the temperature drops below T₁-5°C. This output is not intended to directly drive a fan motor.
- OUT2** This is an open collector digital output. OUT2 is active LOW. It goes LOW when the temperature is greater than the T₂ set point and goes HIGH when the temperature is less than T₂-5°C. This output is not intended to directly drive a fan motor.
- V_{T1}** This is the input pin for the temperature trip point voltage for OUT1.
- V_{T2}** This is the input pin for the low temperature trip point voltage for OUT2.



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$$V_{T1} = 1.250V \times (R1)/(R1 + R2 + R3)$$

$$V_{T2} = 1.250V \times (R1 + R2)/(R1 + R2 + R3)$$

where:

$$(R1 + R2 + R3) = 27 \text{ k}\Omega$$

V_{T1} or $T_2 = [6.20 \text{ mV}/^\circ\text{C} \times T] + 395 \text{ mV}$ therefore:

$$R1 = V_{T1}/(1.25V) \times 27 \text{ k}\Omega$$

$$R2 = (V_{T2}/(1.25V) \times 27 \text{ k}\Omega) - R1$$

$$R3 = 27 \text{ k}\Omega - R1 - R2$$

Application Hints

2.0 LM56 TRIP POINT ACCURACY SPECIFICATION

For simplicity the following is an analysis of the trip point accuracy using the single output configuration show in *Figure 2* with a set point of 82°C.

Trip Point Error Voltage = V_{TPE} ,

Comparator Offset Error for V_{T1E}

Temperature Sensor Error = V_{TSE}

Reference Output Error = V_{RE}

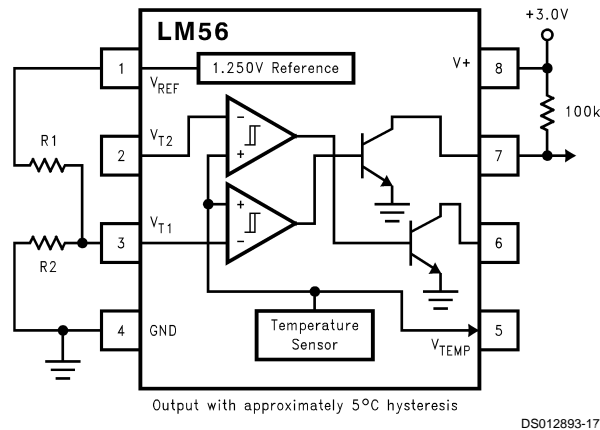


FIGURE 2. Single Output Configuration

$$1. V_{TPE} = \pm V_{T1E} - V_{TSE} + V_{RE}$$

Where:

$$2. V_{T1E} = \pm 8 \text{ mV (max)}$$

$$3. V_{TSE} = (6.20 \text{ mV/}^\circ\text{C}) \times (\pm 3^\circ\text{C}) = \pm 18.6 \text{ mV}$$

$$4. V_{RE} = 1.250\text{V} \times (\pm 0.01) R2/(R1 + R2)$$

Using Equations from page 1 of the datasheet.

$$V_{T1} = 1.25\text{V} \times R2/(R1 + R2) = (6.20 \text{ mV/}^\circ\text{C})(82^\circ\text{C}) + 395 \text{ mV}$$

$$\text{Solving for } R2/(R1 + R2) = 0.7227$$

then,

$$5. V_{RE} = 1.250\text{V} \times (\pm 0.01) R2/(R1 + R2) = (0.0125) \times (0.7227) = \pm 9.03 \text{ mV}$$

The individual errors do not add algebraically because, the odds of all the errors being at their extremes are rare. This is proven by the fact the specification for the trip point accuracy stated in the Electrical Characteristic for the temperature

range of -40°C to $+125^\circ\text{C}$, for example, is specified at $\pm 3^\circ\text{C}$ for the LM56BIM. Note this trip point error specification does not include any error introduced by the tolerance of the actual resistors used, nor any error introduced by power supply variation.

If the resistors have a $\pm 0.5\%$ tolerance, an additional error of $\pm 0.4^\circ\text{C}$ will be introduced. This error will increase to $\pm 0.8^\circ\text{C}$ when both external resistors have a $\pm 1\%$ tolerance.

3.0 BIAS CURRENT EFFECT ON TRIP POINT ACCURACY

Bias current for the comparator inputs is 300 nA (max) each, over the specified temperature range and will not introduce considerable error if the sum of the resistor values are kept to about 27 k Ω as shown in the typical application of *Figure 1*. This bias current of one comparator input will not flow if the temperature is well below the trip point level. As the temperature approaches trip point level the bias current will start to flow into the resistor network. When the temperature sensor output is equal to the trip point level the bias current will be 150 nA (max). Once the temperature is well above the trip point level the bias current will be 300 nA (max). Therefore, the first trip point will be affected by 150 nA of bias current. The leakage current is very small when the comparator input transistor of the different pair is off (see *Figure 3*).

The effect of the bias current on the first trip point can be defined by the following equations:

$$K1 = \frac{R1}{R1 + R2 + R3}$$

$$V_{T1} = K1 \times V_{REF} + K1 \times (R2 + R3) \times \frac{I_B}{2}$$

where $I_B = 300 \text{ nA}$ (the maximum specified error).

The effect of the bias current on the second trip point can be defined by the following equations:

$$K2 = \frac{R1 + R2}{R1 + R2 + R3}$$

$$V_{T2} = K2 \times V_{REF} + \left(K1 + \frac{K2}{2} \right) \times R3 \times I_B$$

where $I_B = 300 \text{ nA}$ (the maximum specified error).

The closer the two trip points are to each other the more significant the error is. Worst case would be when $V_{T1} = V_{T2} = V_{REF}/2$.

Application Hints (Continued)

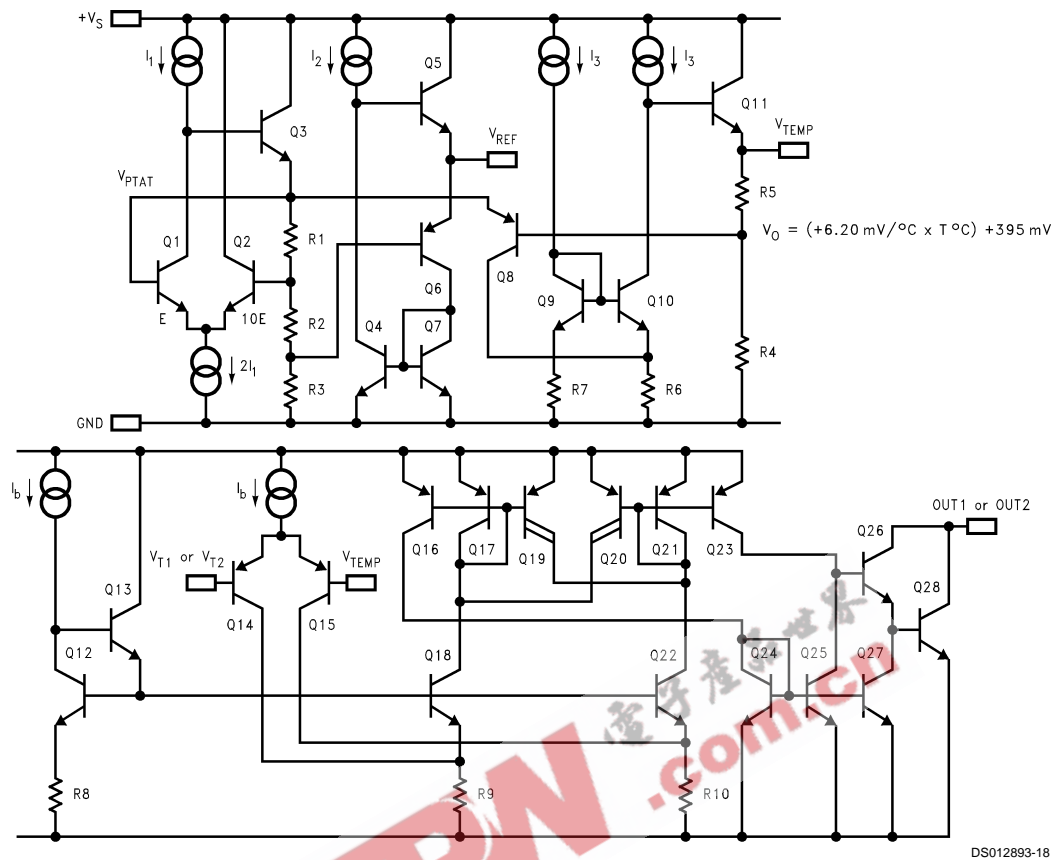


FIGURE 3. Simplified Schematic

4.0 MOUNTING CONSIDERATIONS

The majority of the temperature that the LM56 is measuring is the temperature of its leads. Therefore, when the LM56 is placed on a printed circuit board, it is not sensing the temperature of the ambient air. It is actually sensing the temperature difference of the air and the lands and printed circuit board that the leads are attached to. The most accurate temperature sensing is obtained when the ambient temperature is equivalent to the LM56's lead temperature.

As with any IC, the LM56 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to ensure that moisture cannot corrode the LM56 or its connections.

Application Hints (Continued)

5.0 V_{REF} AND V_{TEMP} CAPACITIVE LOADING

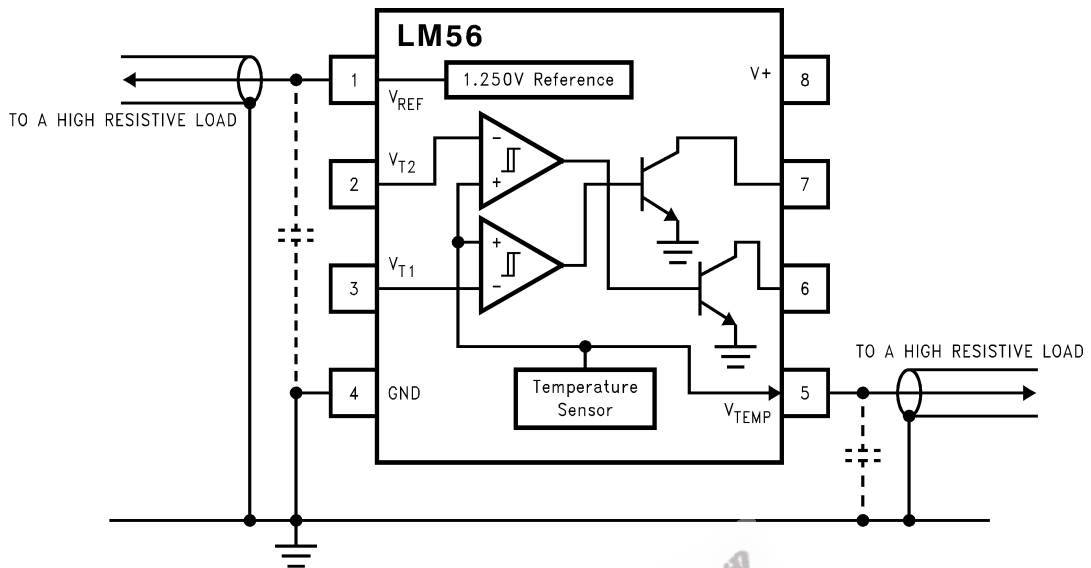


FIGURE 4. Loading of V_{REF} and V_{TEMP}

The LM56 V_{REF} and V_{TEMP} outputs handle capacitive loading well. Without any special precautions, these outputs can drive any capacitive load as shown in Figure 4.

6.0 NOISY ENVIRONMENTS

Over the specified temperature range the LM56 V_{TEMP} output has a maximum output impedance of 1500Ω. In an extremely noisy environment it may be necessary to add some filtering to minimize noise pickup. It is recommended that 0.1 μF be added from V^+ to GND to bypass the power supply voltage, as shown in Figure 4. In a noisy environment it may be necessary to add a capacitor from the V_{TEMP} output to ground. A 1 μF output capacitor with the 1500Ω output impedance will form a 106 Hz lowpass filter. Since the thermal time constant of the V_{TEMP} output is much slower than the 9.4 ms time constant formed by the RC, the overall response time of the V_{TEMP} output will not be significantly affected. For much larger capacitors this additional time lag will increase the overall response time of the LM56.

7.0 APPLICATIONS CIRCUITS

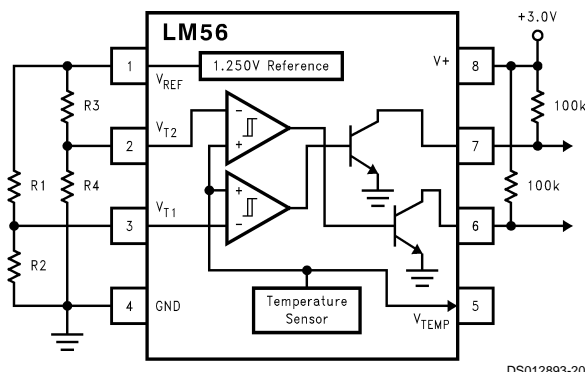


FIGURE 5. Reducing Errors Caused by Bias Current

The circuit shown in Figure 5 will reduce the effective bias current error for V_{T2} as discussed in Section 3.0 to be equivalent to the error term of V_{T1} . For this circuit the effect of the bias current on the first trip point can be defined by the following equations:

$$K1 = \frac{R2}{R1 + R2}$$

$$V_{T1} = K1 \times V_{REF} + K1 \times (R1) \times \frac{I_B}{2}$$

where $I_B = 300$ nA (the maximum specified error).

Similarly, bias current affect on V_{T2} can be defined by:

$$K2 = \frac{R4}{R3 + R4}$$

$$V_{T1} = K2 \times V_{REF} + K1 \times (R3) \times \frac{I_B}{2}$$

where $I_B = 300$ nA (the maximum specified error).

The current shown in Figure 6 is a simple overtemperature detector for power devices. In this example, an audio power amplifier IC is bolted to a heat sink and an LM56 Celsius temperature sensor is mounted on a PC board that is bolted to the heat sink near the power amplifier. To ensure that the sensing element is at the same temperature as the heat sink, the sensor's leads are mounted to pads that have feed throughs to the back side of the PC board. Since the LM56 is sensing the temperature of the actual PC board the back side of the PC board also has large ground plane to help conduct the heat to the device. The comparator's output goes low if the heat sink temperature rises above a threshold set by R1, R2, and the voltage reference. This fault detection output from the comparator now can be used to turn on a cooling fan. The circuit as shown in design to turn the fan on when heat sink temperature exceeds about 80°C, and to turn the fan off when the heat sink temperature falls below approximately 75°C.

Application Hints (Continued)

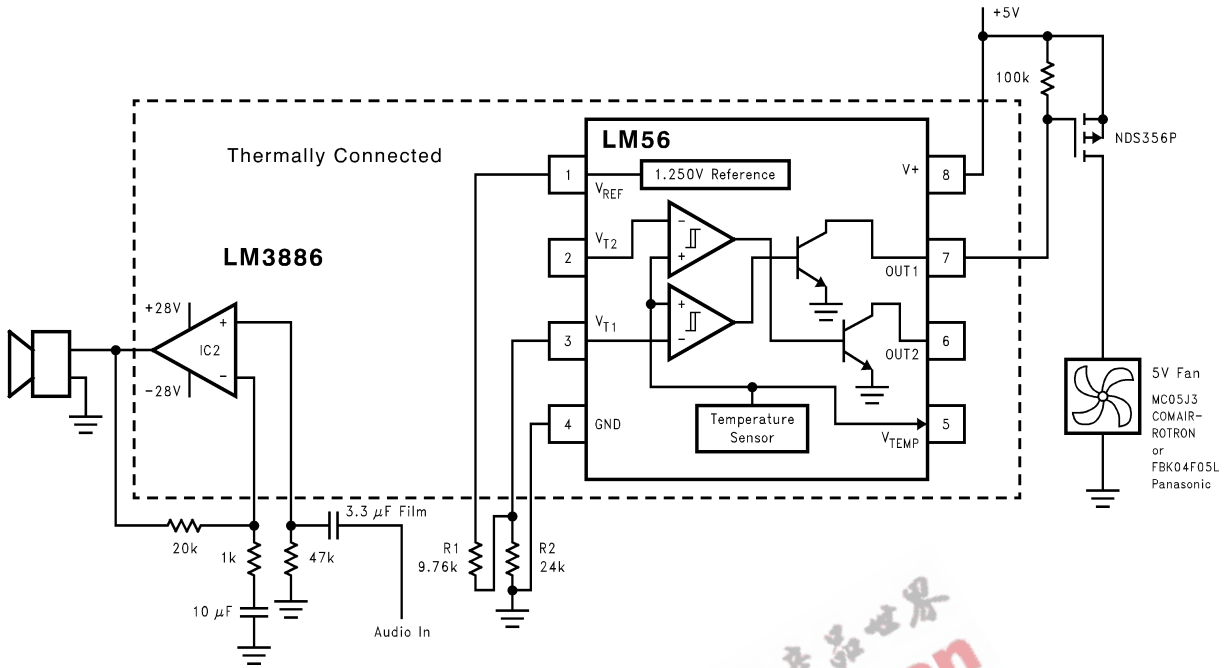


FIGURE 6. Audio Power Amplifier Overtemperature Detector

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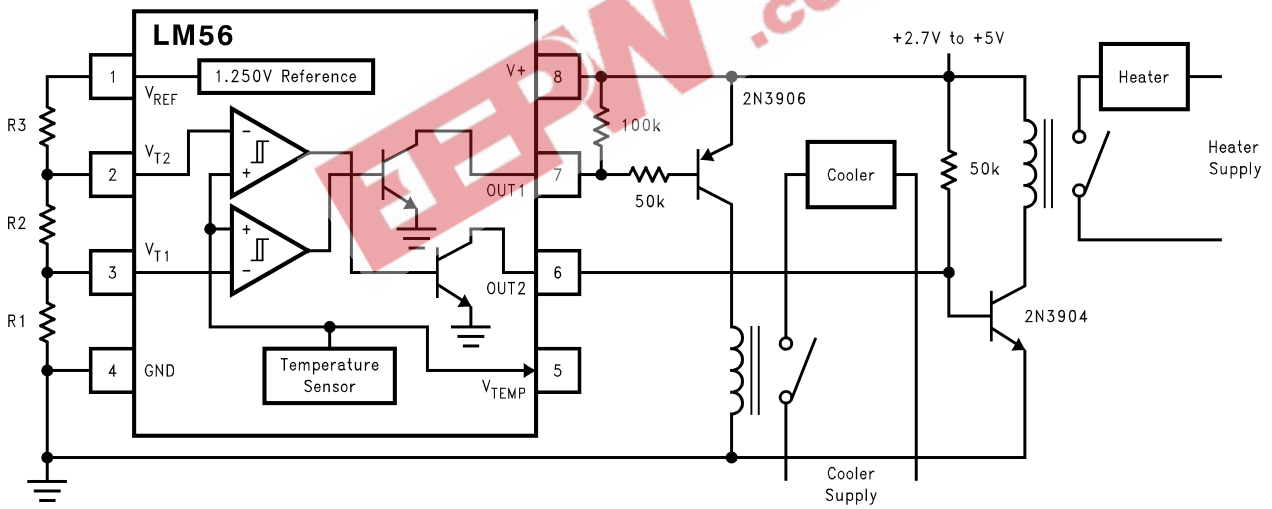
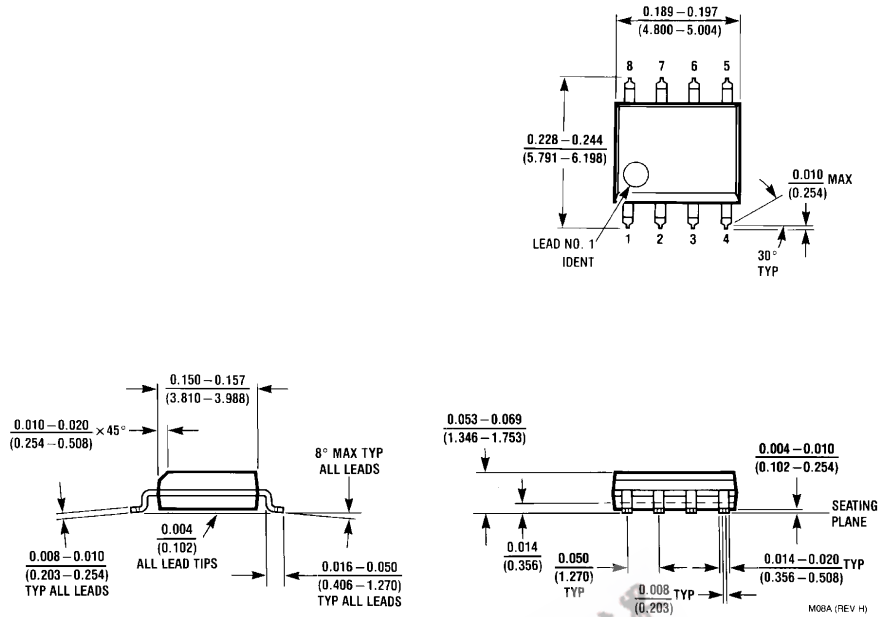


FIGURE 7. Simple Thermostat

DS012893-22

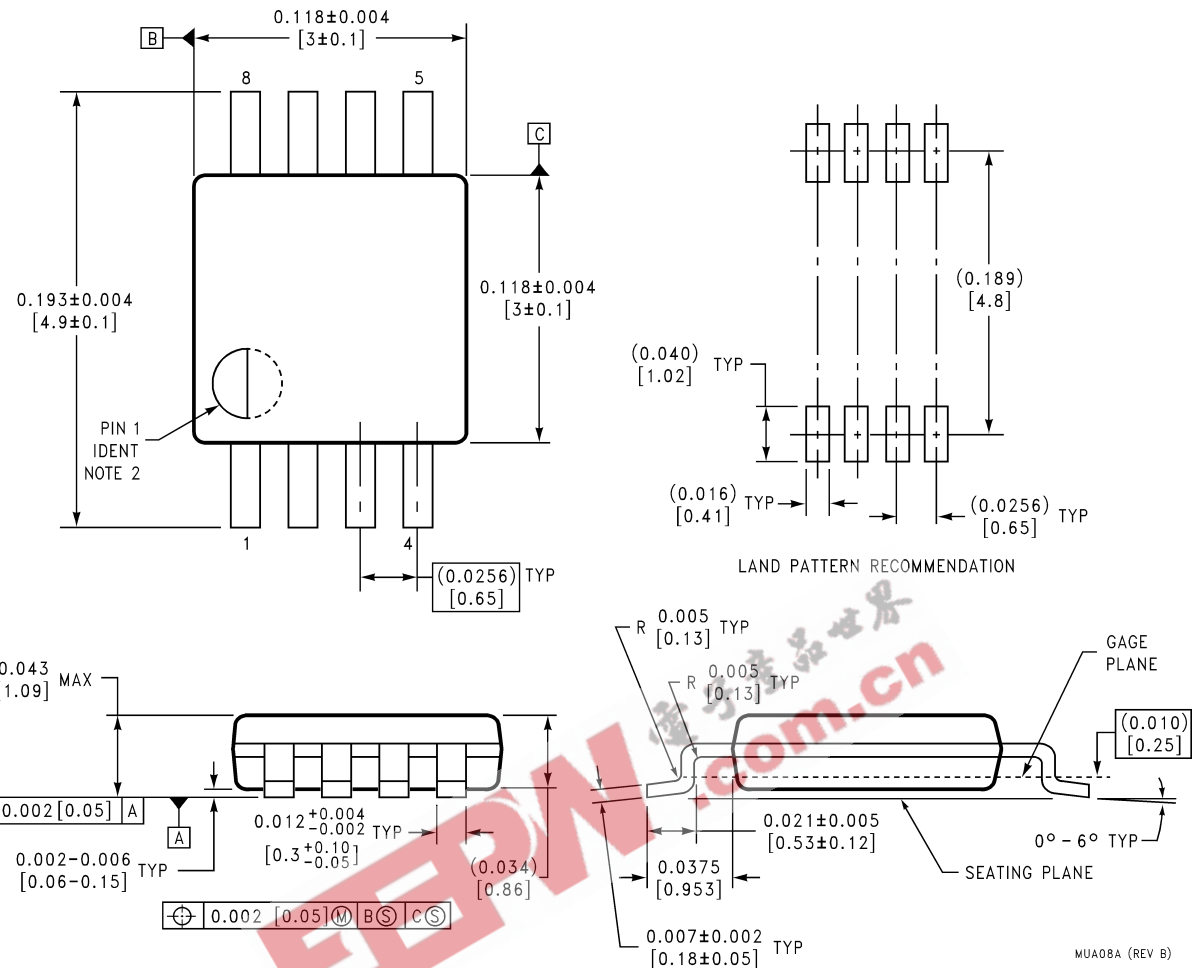
Physical Dimensions inches (millimeters) unless otherwise noted



**8-Lead (0.150" Wide) Molded Small Outline Package, JEDEC
Order Number LM56BIM, LM56BIMX, LM56CIM or LM56CIMX
NS Package Number M08A**

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



8-Lead Moulded Mini Small Outline Package (MSOP)
(JEDEC REGISTRATION NUMBER M0-187)
Order Number LM56BIMM, LM56BIMMX, LM56CIMM, or LM56CIMMX
NS Package Number MUA08A

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National Semiconductor Corporation
 Americas
 Tel: 1-800-272-9959
 Fax: 1-800-737-7018
 Email: support@nsc.com
 www.national.com

National Semiconductor Europe
 Fax: +49 (0) 180-530 85 86
 Email: europe.support@nsc.com
 Deutsch Tel: +49 (0) 69 9508 6208
 English Tel: +44 (0) 870 24 0 2171
 Français Tel: +33 (0) 1 41 91 8790

National Semiconductor Asia Pacific Customer Response Group
 Tel: 65-2544466
 Fax: 65-2504466
 Email: ap.support@nsc.com

National Semiconductor Japan Ltd.
 Tel: 81-3-5639-7560
 Fax: 81-3-5639-7507