National Semiconductor

November 1996

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 will be available in an 8-lead Mini-SO8 surface mount package and is currently available in 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

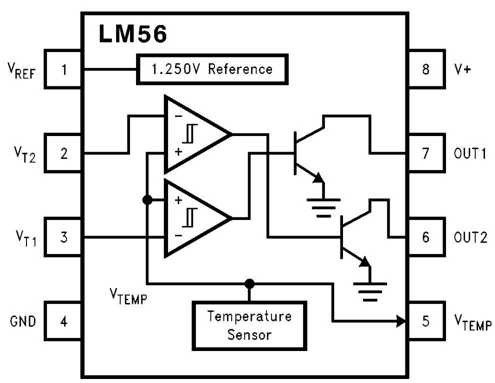
- Digital outputs support TTL logic levels
- Internal temperature sensor
- 2 internal comparators with hysteresis
- Internal voltage reference
- Future availability in 8-pin Mini-SO8 plastic package
- Currently Available in 8-pin SO plastic package

Key Specifications

- Power Supply Voltage: 2.7V−10V
- Power Supply Current: 230 μA (max)
- V_{REF}: 1.250V ±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	±2°C (max)	±3°C (max)
+25°C to +85°C	±2°C (max)	±3°C (max)
−40°C to +125°C	±3°C (max)	±4°C (max)

Simplified Block Diagram and Connection Diagram



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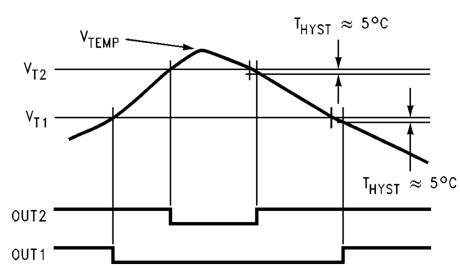

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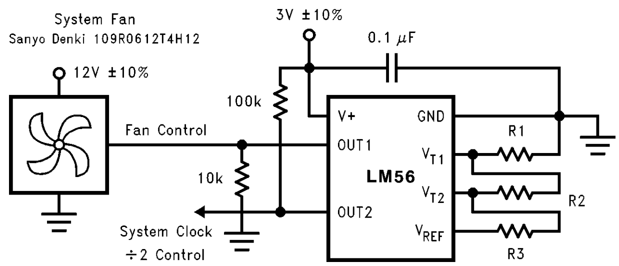
Order Number	LM56BIM	LM56BIMX	LM56CIM	LM56CIMX	LM56BIMM*	LM56CIMM*
NS Package Number	M08A	M08A	M08A	M08A	NMMSO008*	NMMSO008*
Transport Media	Bulk Rail	2500 Units Tape & Reel	Bulk Rail	2500 Units Tape & Reel		

*The Mini-SO8 package option is not available yet.

Typical Application



$V_{T1} = 1.250V \times (R1)/(R1 + R2 + R3)$
$V_{T2} = 1.250V \times (R1 + R2)/(R1 + R2 + R3)$

where:

$(R1 + R2 + R3) = 27\ k\Omega$ and
$V_{T1\ or\ T2} = [6.20\ mV/°C \times T] + 395\ mV$ therefore:
$R1 = V_{T1}/(1.25V) \times 27\ k\Omega$
$R2 = (V_{T2}/(1.25V) \times 27\ k\Omega) - R1$
$R3 = 27\ k\Omega - R1 - R2$

FIGURE 1. Microprocessor Thermal Management

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°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	$\mathbf{T_{MIN} \le T_A \le T_{MAX}}$
LM56BIM, LM56CIM	−40°C ≤ T_A ≤ +125°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_{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°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°C ≤ T_A ≤ +85°C −40°C ≤ T_A ≤ +125°C		±2 ±2 ±**3**	±3 ±3 ±**4**	°C (max) °C (max) °C (max)
	Trip Point Hysteresis	T_A = −40°C	4	3 6	3 6	°C (min) °C (max)
		T_A = +25°C	5	3.5 6.5	3.5 6.5	°C (min) °C (max)
		T_A = +85°C	6	4.5 7.5	4.5 7.5	°C (min) °C (max)
		T_A = +125°C	6	4 8	4 8	°C (min) °C (max)
	Internal Temperature Sensitivity		+6.20			mV/°C
	Temperature Sensitivity Error			±2 ±**3**	±3 ±**4**	°C (max) °C (max)
	Output Impedance	−1 µA ≤ I_L ≤ +40 µA		**1500**	**1500**	Ω (max)
	Line Regulation	+3.0V ≤ V^+ ≤ +10V		±**0.3**	±**0.3**	mV/V (max)
		+2.7V ≤ V^+ ≤ +3.3V		±**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 GND			V 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** ±**12.5**	±**1** ±**12.5**	% (max) mV (max)
$\Delta V_{REF}/\Delta V^+$	Line Regulation	+3.0V ≤ V^+ ≤ +10V +2.7V ≤ V^+ ≤ +3.3V	0.13 0.15	**0.20** **1.45**	**0.20** **1.45**	mV/V (max) mV (max)
$\Delta V_{REF}/\Delta I_L$	Load Regulation Sourcing	+30 µA ≤ I_L ≤ + 50 µA		**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 $T_A = T_J = 25°C$ unless otherwise specified. (Continued)

Symbol	Parameter	Conditions	Typical (Note 6)	Limits (Note 7)	Units (Limits)
V^+ Power Supply					
I_S	Supply Current	$V^+ = +10V$ $V^+ = +2.7V$		**230** **230**	µA (max) µA (max)
Digital Output(s)					
$I_{OUT(``1")}$	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, $T_{Jmax} = 125°C$. For this device the typical thermal resistance (Θ_{JA}) of the different package types when board mounted follow:

Pacakge Type	Θ_{JA}
M08A	110°C/W

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

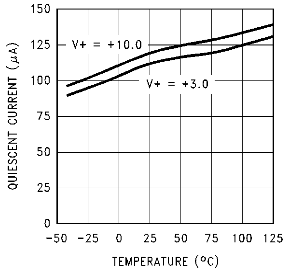
Note 5: See AN450 "Surface Mounting Methods and Their Effects on Product Reliability" or the section titled "Surface Mount" found in any post 1986 National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Note 6: Typicals are at $T_J = T_A = 25°C$ 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



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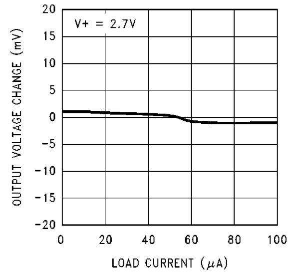
V_{REF} Output Voltage vs Load Current



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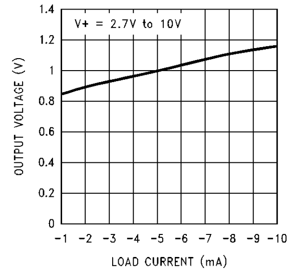
OUT1 and OUT2 Voltage Levels vs Load Current



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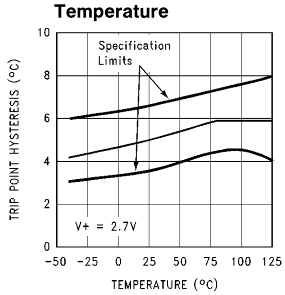
Trip Point Hysteresis vs Temperature



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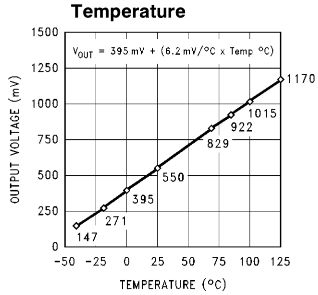
Temperature Sensor Output Voltage vs Temperature



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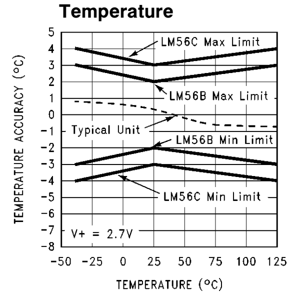
Temperature Sensor Output Accuracy vs Temperature



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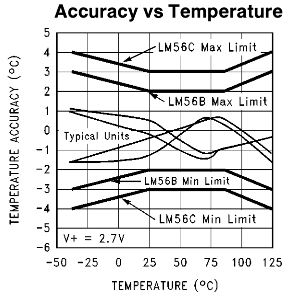
Trip Point Accuracy vs Temperature



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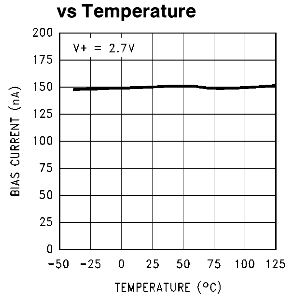
Comparator Bias Current vs Temperature



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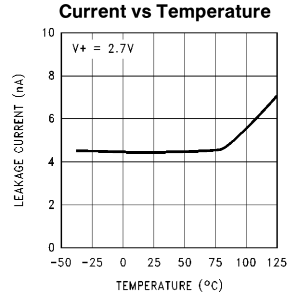
OUT1 and OUT2 Leakage Current vs Temperature



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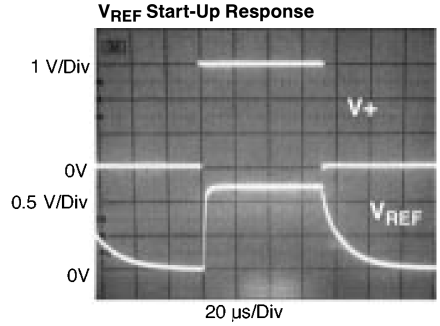
V_{REF} Start-Up Response



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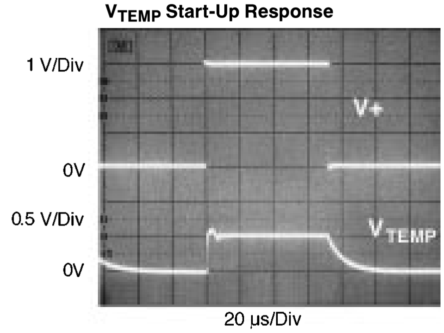
V_{TEMP} Start-Up Response



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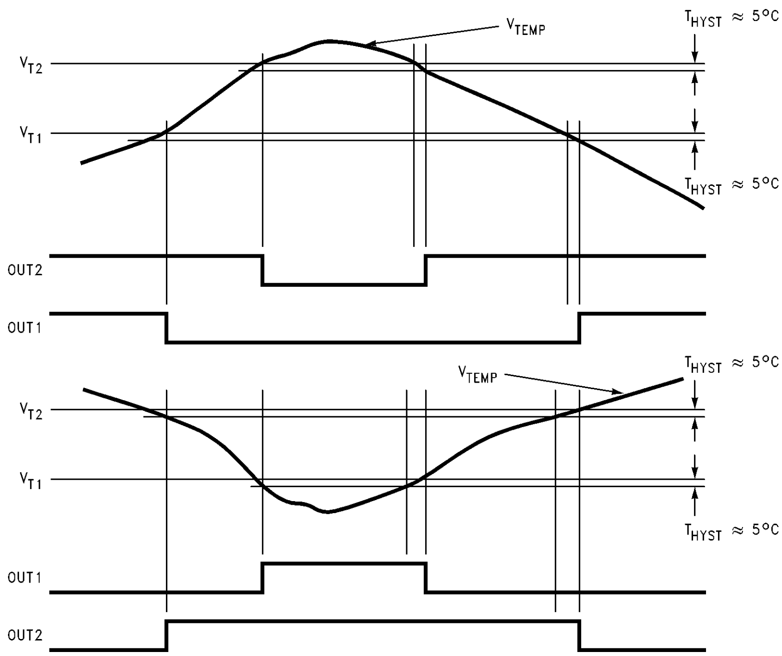
Functional Description



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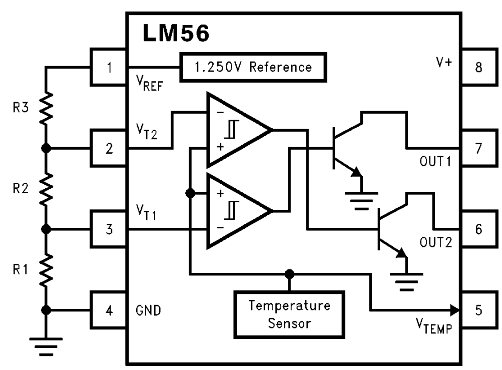
1.0 PIN DESCRIPTION

- 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 T_1 and goes HIGH when the temperature drops below T_1−4°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 T_2 set point and goes HIGH when the temperature is less than T_2−4°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 x (R1)/(R1 + R2 + R3)
V_{T2} = 1.250V x (R1 + R2)/(R1 + R2 + R3)

where:

(R1 + R2 + R3) = 27 kΩ and

$V_{T1 \text{ or } T2}$ = [6.20 mV/°C x T] + 395 mV therefore:
R1 = V_{T1}/(1.25V) x 27 kΩ
R2 = (V_{T2}/(1.25V) x 27 k)Ω−R1
R3 = 27 kΩ − 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}

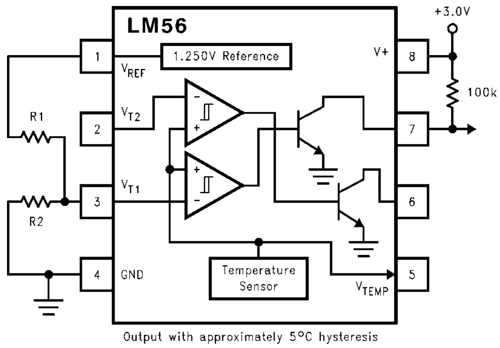

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FIGURE 2. Single Output Configuration

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

Where:

2. $V_{T1E} = \pm 8$ mV (max)
3. $V_{TSE} = (6.20$ mV/°C) x $(\pm 3°C) = \pm 18.6$ mV
4. $V_{RE} = 1.250V$ x (± 0.01) R2/(R1 + R2)

Using Equations from page 1 of the datasheet.

$V_{T1} = 1.25V$xR2/(R1 + R2) = (6.20 mV/°C)(82°C) + 395 mV

Solving for R2/(R1 + R2) = 0.7227

then,

5. $V_{RE} = 1.250V$ x (± 0.01) R2/(R1 + R2) = (0.0125) x (0.7227) = ± 9.03 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°C, for example, is specified at ±3°C for the LM56BIM. Note this trip point error specification does not include any error introduced by the tolerance of the actual resistors used.

If the resistors have a ±0.5% tolerance, an additional error of ±0.4°C will be introduced. This error will increase to ±0.8°C when both external resistors have a ±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 kΩ 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

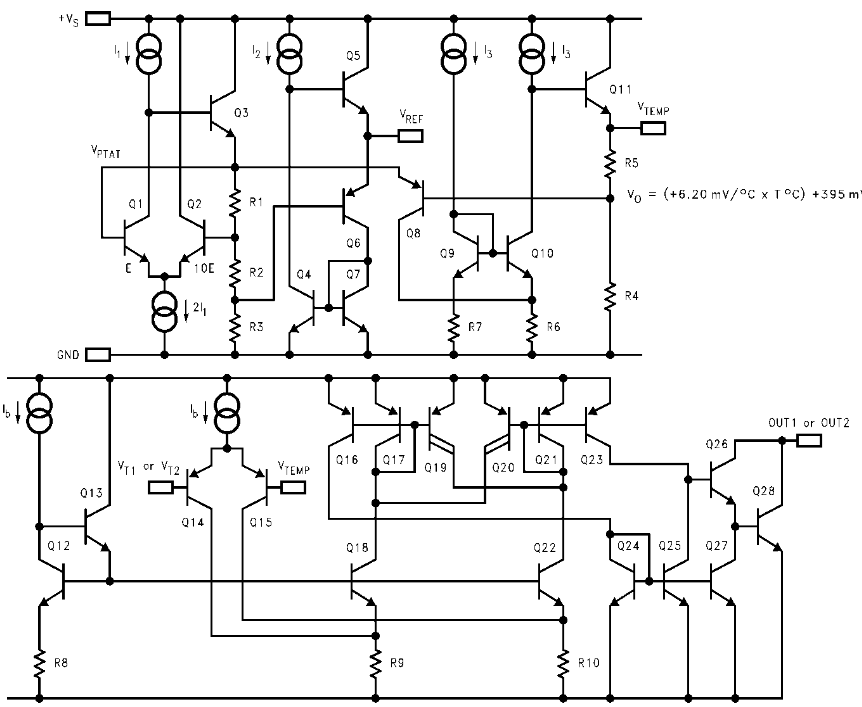

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FIGURE 3. Simplified Schematic

Application Hints (Continued)

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 $I_B = 300$ 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 $I_B = 300$ 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 $V_{T1} = V_{T2} = V_{REF}/2$.

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 cirucit 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.

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

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.

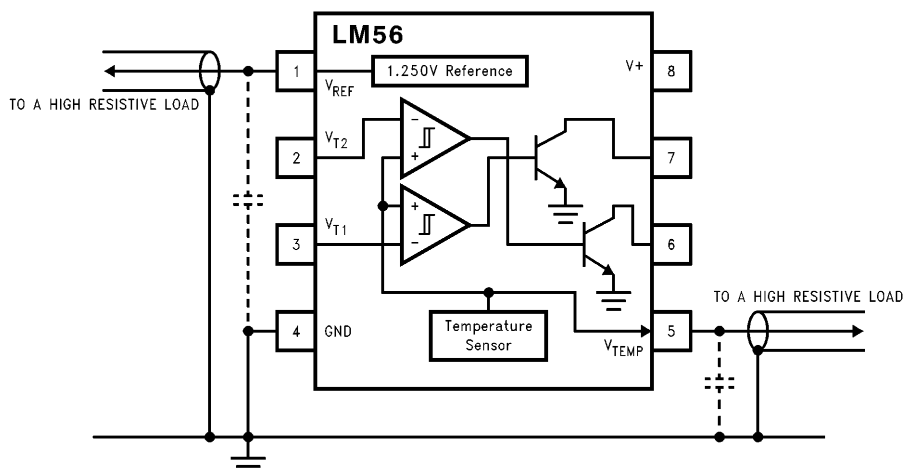

FIGURE 4. Loading of V_{REF} and V_{TEMP}

Application Hints (Continued)

7.0 APPLICATIONS CIRCUITS

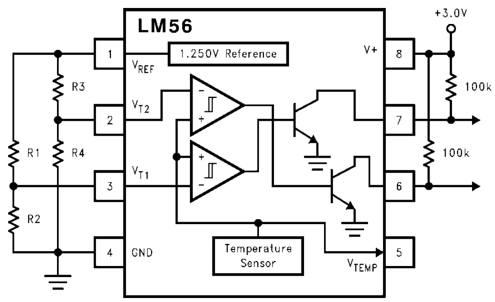

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FIGURE 5. Reducing Errors Caused by Bias Current

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:

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

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

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

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

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

$$V_{T1} = K2 \times V_{REF} + K1 \times (R4) \times \frac{I_B}{2}$$

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.

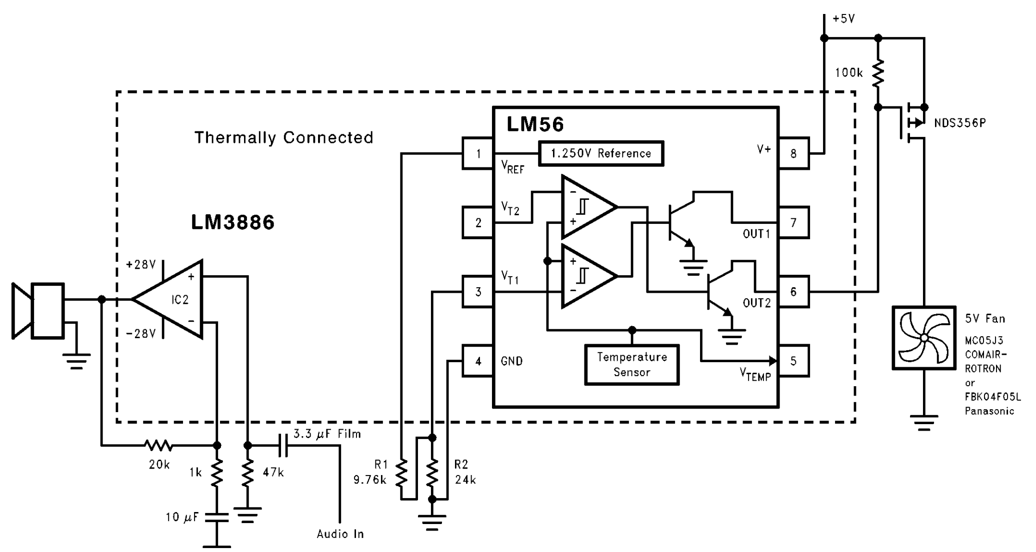

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FIGURE 6. Audio Power Amplifier Overtemperature Detector

Application Hints (Continued)

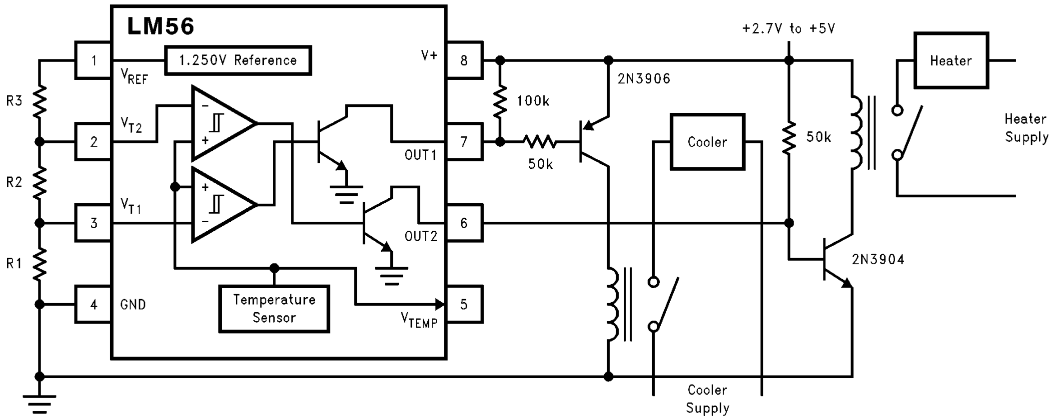

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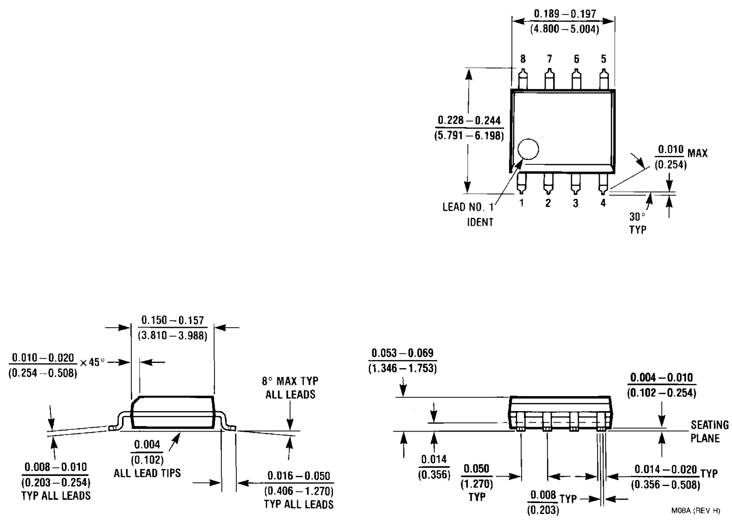
FIGURE 7. Simple Thermostat

Physical Dimensions inches (millimeters) unless otherwise specified



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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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.

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