

LM88

Factory Programmable Dual Remote-Diode Thermostat

General Description

The LM88 is a dual remote-diode temperature sensor with 3 digital comparators. The LM88 has 3 open-drain outputs ($\overline{O_SP0}$, $\overline{O_SP1}$ and $\overline{O_CRIT}$) that can be used as interrupts or to signal system shutdown. The digital comparators can be factory programmed to make a greater than or less than comparison. When programmed for a greater than comparison outputs:

$\overline{O_SP0}$ and $\overline{O_SP1}$ activate when the temperatures measured by D0 or D1 exceed the associated setpoints of T_SP0 or T_SP1 .

$\overline{O_CRIT}$ activates when the temperature measured by either D0 or D1 exceeds setpoint T_CRIT .

T_CRIT can be set at 1°C intervals from -40°C to +125°C. T_SP0 and T_SP1 can be set at 4°C intervals in the range of $T_CRIT +127^\circ\text{C}/-128^\circ\text{C}$. Hysteresis for all comparators is set to 1°C. $\overline{O_CRIT}$, in conjunction with T_CRIT , could be used to prevent catastrophic damage to key subsystems such as notebook Card Bus cards while $\overline{O_SP0}$ and $\overline{O_SP1}$, in conjunction with T_SP0 and T_SP1 , can warn of an impending failure.

The LM88 is available in an 8-lead mini-small-outline package.

Applications

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

Features

- 2 external remote diode input channels
- 3 digital comparator outputs, 1 per remote diode and one T_CRIT common to both
- Factory programmable greater than or less than comparisons
- 1°C comparator hysteresis
- 2 setpoints, T_SP0 and T_SP1 , factory programmable in 4°C intervals
- 1 setpoint, T_CRIT , factory programmable in 1°C intervals
- Active Low open-drain digital outputs
- 8-pin mini-SO plastic package

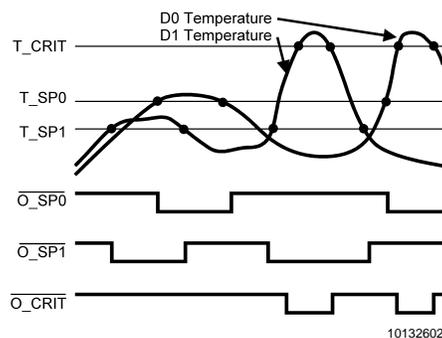
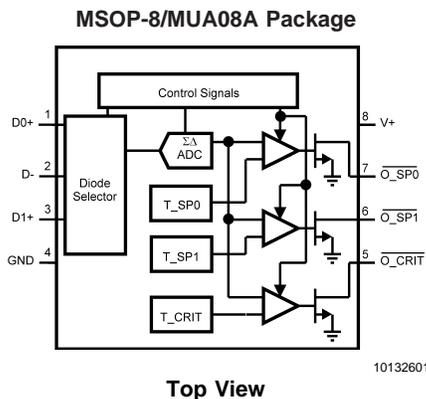
Key Specifications

- Power Supply Voltage 2.8V–3.8V
- Power Supply Current 1.5 mA (max)
- LM88 Temperature Range -40°C to +85°C
- Diode Setpoint Temperature Range 0°C to +125°C
- Temperature Trip Point Accuracy:

Diode Junction Temperature (T_{DJ})	LM88CIM Accuracy	LM88CIM Temperature Range
+45°C to +85°C	±3°C (max)	-40°C to +85°C
+60°C to +100°C	±3°C (max)	-40°C to +85°C

Note: These are sample ranges. Contact factory for other ranges.

Simplified Block Diagram and Connection Diagram



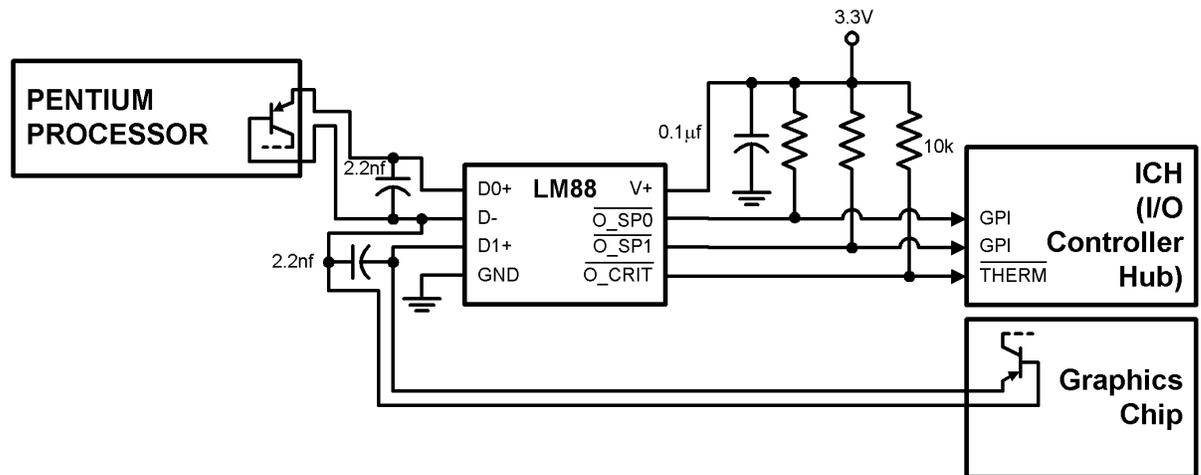
For simplicity, the effects of the hysteresis are not shown in the temperature response diagram.

Simplified Block Diagram and Connection Diagram (Continued)

Order Number	Device Marking	NS Package Number	Transport Media	T_SP0 (°C)	T_SP1 (°C)	T_CRIT (°C)	Setpoint Accuracy (°C)
LM88C1MM-A	T08A	MUA08A or MSOP-8	Rail	61	49	80	±3
LM88C1MMX-A			Tape and Real				
LM88C1MM-B	T08A	MUA08A or MSOP-8	Rail	41	49	60	±3
LM88C1MMX-B			Tape and Real				

For other setpoints please contact the factory. Performance is dependent on temperature range.

Typical Application



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FIGURE 1. Thermal Protection for Pentium® Processor and Graphics Chip

Absolute Maximum Ratings (Note 1)

Input Voltage	6V
Input Current at any pin (Note 2)	5mA
Package Input Current (Note 2)	20mA
Package Dissipation at $T_A = 25^\circ\text{C}$ (Note 4)	900mW
Soldering Information	
MSOP Package (Note 6) :	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
Storage Temperature	-65°C to + 150°C
ESD Susceptibility (Note 5)	
Human Body Model	2500V
Machine Model	250V

Operating Ratings(Note 1)

Operating Temperature Range	$T_{\text{MIN}} \leq T \leq T_{\text{MAX}}$
LM88C1MM	$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$
Remote Diode Junction	$0^\circ\text{C} \leq T_{\text{DJ}} \leq +125^\circ\text{C}$
Positive Supply Voltage (V^+)	+2.8V to +3.8V
Maximum $V_{\text{O_CRIT}}$, $V_{\text{O_SP0}}$ and $V_{\text{O_SP1}}$	+5.5V

LM88 Electrical Characteristics

The following specifications apply for $2.8V_{\text{DC}} \leq V^+ \leq 3.8V_{\text{DC}}$ 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 7)	LM88C1MM Limits (Note 8)	Units (Limits)
Temperature Sensor					
	Setpoint Temperature Accuracy (Note 9)	+60°C ≤ T_{DJ} ≤ +100°C +45°C ≤ T_{DJ} ≤ +85°C +30°C ≤ T_{DJ} ≤ +70°C		±3	°C (max)
	Setpoint Hysteresis			1 1	°C (min) °C (max)
	Output Update Rate			920	ms (max)
$V_{\text{D-}}$, V_{D0} and V_{D1} Analog Inputs					
$I_{\text{D+SOURCE}}$	Diode Source Current	(D+ – D–)=0.65; high level	120	210	μA (max)
				46	μA (min)
		(D+ – D–)=0.65; low level	12	21	μA (max)
				4.6	μA (min)
$V_{\text{D-Out}}$	D– Output Source Voltage		0.7		V

LM88 Electrical Characteristics

The following specifications apply for $2.8V_{\text{DC}} \leq V^+ \leq 3.8V_{\text{DC}}$ 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 7)	Limits (Note 8)	Units (Limits)
V+ Power Supply					
I_{S}	Supply Current			1.5	mA (max)
Digital Outputs					
$I_{\text{OUT("1")}}$	Logical "1" Output Leakage Current (Note 10)	$V_{\text{OUT}}=V^+ - 0.6\text{V}$ where $V^+=3.8\text{V}$ to 2.8V		2	μA (max)
		$V_{\text{OUT}}=V^+ = 3.8\text{V}$ to 2.8V		40	μA (max)
$V_{\text{OUT("0")}}$	Logical "0" Output Voltage	$I_{\text{OUT}} = +3\text{mA}$		0.4	V (max)

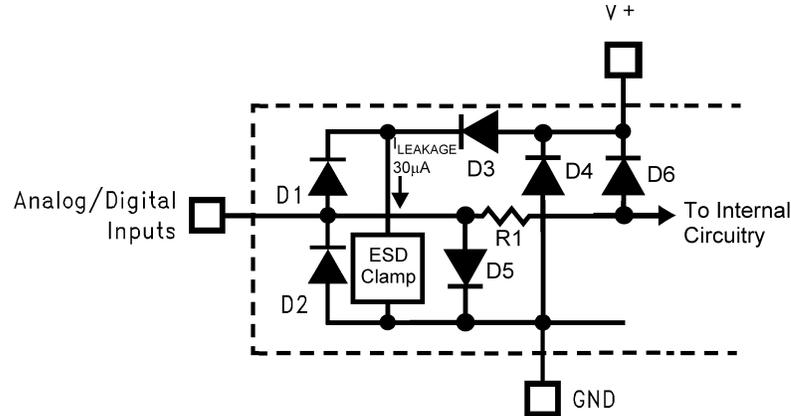
Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. 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.

LM88 Electrical Characteristics (Continued)

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

Note 3: Parasitics or ESD protection circuitry are shown in the diagram found below. The ESD Clamp circuitry is triggered on when there is an ESD event. The table maps what devices appear on the different pins.

Pin Name	D1	D2	D3	D4	D5	D6	R1
D0+	X	X	X	X		X	50Ω
D-	X	X	X	X	X	X	50Ω
D1+	X	X	X	X		X	50Ω
$\overline{\text{O_CRIT}}$	X	X	X	X			0Ω
$\overline{\text{O_SP1}}$	X	X	X	X			0Ω
$\overline{\text{O_SP0}}$	X	X	X	X			0Ω



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Note 4: 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, $T_{Jmax} = 125^\circ\text{C}$. For this device the typical thermal resistance (θ_{JA}) of the different package types when board mounted follow:

Package Type	θ_{JA}
MUA08A	250°C/W

Note 5: The human body model is a 100pF capacitor discharged through a 1.5kΩ resistor into each pin. The machine model is a 200pF capacitor discharged directly into each pin.

Note 6: See the URL "<http://www.national.com/packaging/>" for other recommendations and methods of soldering surface mount devices.

Note 7: Typical values are at $T_J = T_A = 25^\circ\text{C}$ and represent most likely parametric norm.

Note 8: Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 9: These are sample temperature ranges, contact the factory for other temperature ranges. Performance is dependent on temperature range.

Note 10: The two I_{OH} specifications are intended to describe two operating regions of the output voltage. In Region 1, $V^+ - 0.6\text{V}$ and below, there is normal leakage current, 2µA (max). In Region 2, $V^+ - 0.6\text{V}$ to V^+ , there is additional current flowing caused by the ESD protection circuitry (see Figure in Note 3). The maximum current flow is under short circuit conditions as specified at 40µA (max). Under normal operating conditions a pull-resistor (R) will be used. The voltage drop across this pull-up resistor caused by the 2µA normal leakage current with large values of R (much greater than 100k) will bias diode D1 into the cutoff region causing the additional current to be negligible in the voltage drop calculation. With low values of R more current will flow as in the case of a 1.1k pull-up, 20µA may flow causing less than 22mV of voltage drop.

1.0 Functional Description

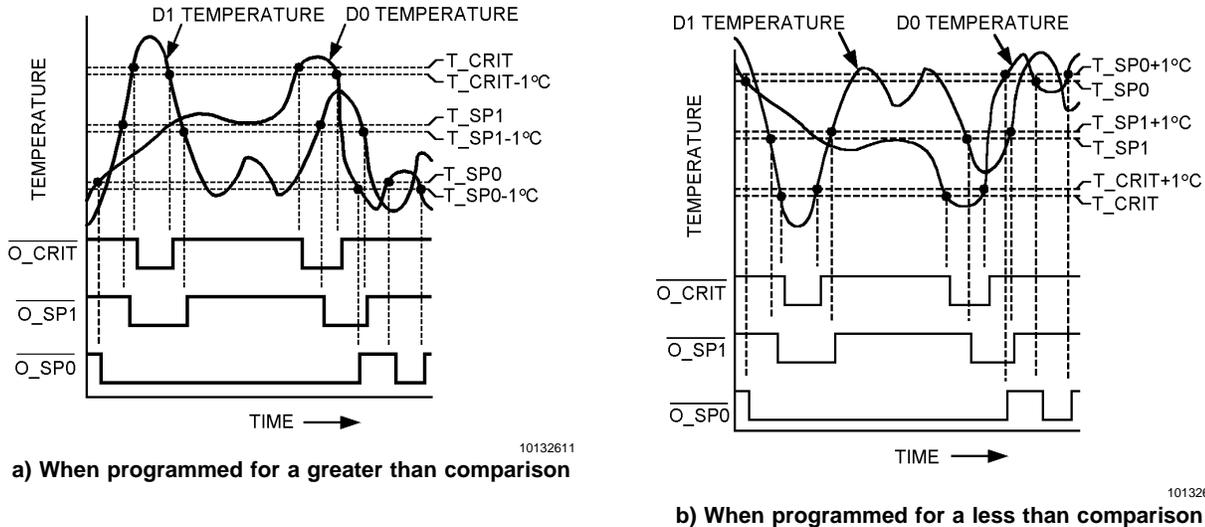


FIGURE 2. Comparator output temperature response diagrams

1.1 PIN DESCRIPTIONS

- V⁺** This is the positive supply voltage pin, which has a range of 2.8 to 3.8 volts. This pin should be bypassed with a 0.1 μ F capacitor to ground.
- GND** This is the ground pin.
- D0+, D1+** These pins connect to the positive terminal of the diodes (e.g. a 2N3904 collector base shorted or a Pentium thermal diode anode) and provide the source current for forward biasing the diodes for the temperature measurement. During a temperature conversion, the current source switches between 120 μ A and 12 μ A. The diodes are sampled sequentially.
- D-** This pin should be connected to the negative pin of each diode (e.g. a 2N3904 emitter or a Pentium thermal diode cathode). A star connection is recommended. Separate traces should be routed from this pin to each diode cathode. This pin biases the negative diode terminals to approximately 0.7V.
- $\overline{O_CRIT}$** This is an active-low open-drain digital output. It goes LOW when a comparison of either diode temperature reading to the setpoint T_CRIT is true. It returns to HIGH when the comparison of the diode temperature, that caused the true con-

dition, to $T_CRIT \pm 1^\circ\text{C}$ is false. The CRIT comparator can be factory programmed to make a greater than or less than comparison. (See Section 1.3 LM88 OPTIONS)

$\overline{O_SP1}$ This is an active-low open-drain digital output. It goes LOW when the comparison of the temperature reading of diode one to the value of T_SP1 is true. The SP1 comparator has a built in hysteresis of 1°C . Therefore, $\overline{O_SP1}$ returns to HIGH when diode one's temperature comparison to the value of $T_SP1 \pm 1^\circ\text{C}$ is false. The SP1 comparator can be factory programmed to make a greater than or less than comparison. (See Section 1.3 LM88 OPTIONS)

$\overline{O_SP0}$ This is an active-low open-drain digital output. It goes LOW when the comparison of the temperature reading of diode one to the value of T_SP0 is true. The SP0 comparator has a built in hysteresis of 1°C . Therefore, $\overline{O_SP0}$ returns to HIGH when diode one's temperature comparison to the value of $T_SP0 \pm 1^\circ\text{C}$ is false. The SP0 comparator can be factory programmed to make a greater than or less than comparison. (See Section 1.3 LM88 OPTIONS)

1.0 Functional Description (Continued)

1.2 TYPICAL PIN CONNECTION

Pin Label	Pin Number	Typical Connection
D0+	1	3904-type transistor shorted-collector base or Pentium thermal diode anode; 2.2nF capacitor connected to D-
D-	2	3904-type transistor emitter or Pentium thermal diode cathode (individual traces are required to each diode; do not daisy chain); two 2.2nF capacitors connected to D0+ and D1+
D1+	3	3904-type transistor shorted collector-base or Pentium thermal diode anode; 2.2nF capacitor connected to D-
GND	4	a quiet system ground
$\overline{\text{O_CRIT}}$	5	2k pull-up; system shutdown or the THERM pin of the ICH (I/O Controller Hub found in PCs)
$\overline{\text{O_SP1}}$	6	2k pull-up; general purpose input (GPI), to determine which diode caused the THERM event
$\overline{\text{O_SP1}}$	7	2k pull-up; general purpose input (GPI), to determine which diode caused the THERM event
V+	8	3.3V; 0.1 μ F bypass capacitor

1.3 LM88 OPTIONS

1.3.1 Set-Point Values

T_SP0 and T_SP1 are dependent on the value of T_CRIT:

$$T_SP0 = T_CRIT + 4a + 1$$

$$T_SP1 = T_CRIT + 4b + 1$$

where:

a and b are any integer in the range of -32 to +31.

T_CRIT can be any value in the range of 0°C to +125°C with a resolution of 1°C.

1.3.2 Functionality

The LM88's comparators can be factory programmed to do a greater than or less than comparison. When programmed for a greater than comparison, the comparison result is true when the temperature measured is above the preprogrammed setpoint temperature. The comparison returns to false when the temperature measured is below or equal to the setpoint temperature minus one degree. For a less than comparison the comparison result is true when the temperature measured is below the preprogrammed limit. The result turns to false when the temperature measured is above or equal to the setpoint limit plus one degree. SP0, SP1 and CRIT comparisons can all be independently programmed to

be greater than or less than. All CRIT comparisons are required to be the same, either greater than or less than. The comparator hysteresis can also be factory set to one, two or three degrees. The hysteresis for all comparisons is required to be the same.

2.0 Application Hints

2.1 OPEN-DRAIN OUTPUTS

The $\overline{\text{O_SP0}}$, $\overline{\text{O_SP1}}$ and $\overline{\text{O_CRIT}}$ outputs are open-drain outputs and do not have internal pull-ups. A "high" level will not be observed on these pins until pull-up current is provided from some external source, typically a pull-up resistor. Choice of resistor value depends on many system factors but, in general, the pull-up resistor should be as large as possible. This will minimize any internal temperature reading errors due to internal heating of the LM88. The maximum resistance of the pull-up needed to provide a 2.1V high level, based on LM88 specification for High Level Output Current with the supply voltage at 3.0V, is 430k Ω .

2.2 THERMAL DIODE MOUNTING CONSIDERATIONS

To measure temperature the LM88 uses two remote diodes. These diodes can be located on the die of a target IC, allowing measurement of the IC's temperature, independent

2.0 Application Hints (Continued)

of the LM88's temperature. The LM88 has been optimized to measure the remote diode of a Pentium type processor as shown in *Figure 3*. A discrete diode can also be used to sense the temperature of external objects or ambient air. Remember that a discrete diode's temperature will be affected, and often dominated, by the temperature of its leads.

As with any IC, the LM88 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 LM88 or its connections. Moisture may also cause leakage on the diode wiring and therefore affect the accuracy of the temperature set-points.

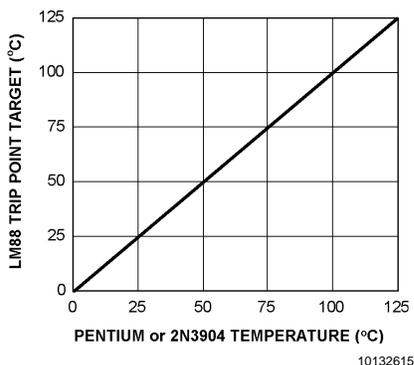


FIGURE 3. Pentium or 3904 Temperature vs LM88 Temperature Set-point

Most silicon diodes do not lend themselves well to this application. It is recommended that a 2N3904 transistor base emitter junction be used with the collector tied to the base.

A diode connected 2N3904 approximates the junction available on a Pentium III microprocessor for temperature measurement. Therefore, the LM88 can sense the temperature of this diode effectively.

2.3 EFFECTS OF THE DIODE NON-IDEALITY FACTOR ON ACCURACY

The technique used in today's remote temperature sensors is to measure the change in V_{BE} at two different operating points of a diode. For a bias current ratio of N:1, this difference is given as:

$$\Delta V_{BE} = \eta \frac{kT}{q} \ln(N)$$

where:

- η is the non-ideality factor of the process the diode is manufactured on,
- q is the electron charge,
- k is the Boltzmann's constant,
- N is the current ratio,
- T is the absolute temperature in °K.

The temperature sensor then measures ΔV_{BE} and converts to IT digital data. In this equation, k and q are well defined universal constants, and N is a parameter controlled by the

temperature sensor. The only other parameter is η , which depends on the diode that is used for measurement. Since ΔV_{BE} is proportional to both η and T , the variations in η cannot be distinguished from variations in temperature. Since the non-ideality factor is not controlled by the temperature sensor, it will directly add to the inaccuracy of the sensor. For the Pentium II, Intel specifies a $\pm 1\%$ variation in η from part to part. As an example, assume a temperature sensor has an accuracy specification of $\pm 3^\circ\text{C}$ at room temperature of 25°C and the process used to manufacture the diode has a non-ideality variation of $\pm 1\%$. The resulting accuracy of the temperature sensor at room temperature will be:

$$T_{ACC} = \pm 3^\circ\text{C} + (\pm 1\% \text{ of } 298^\circ\text{K}) = \pm 6^\circ\text{C}$$

The additional inaccuracy in the temperature measurement caused by η can be eliminated if each temperature sensor is calibrated with the remote diode that it will be paired with.

2.4 PCB LAYOUT to MINIMIZE NOISE

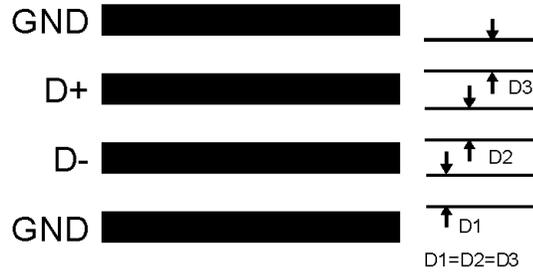
In a noisy environment, such as a processor motherboard, layout considerations are very critical. Noise induced on traces running between the remote temperature diode sensor and the LM88 can cause temperature conversion errors. The following guidelines should be followed:

1. Place a $0.1 \mu\text{F}$ power supply bypass capacitor as close as possible to the V_{DD} pin and the recommended 2.2 nF capacitor as close as possible to the D+ and D- pins. Make sure the traces to the two 2.2 nF capacitor are matched.
2. The recommended 2.2 nF diode bypass capacitor actually has a range of 200 pF to 3.3 nF . The average temperature accuracy will not change over that capacitance range. Increasing the capacitance will lower the corner frequency where differential noise error will start to affect the temperature reading thus producing a reading that is more stable. Conversely, lowering the capacitance will increase the corner frequency where differential noise error starts to affect the temperature reading thus producing a reading that is less stable.
3. Ideally, the LM88 should be placed within 10 cm of the remote diode pins with the traces being as straight, short and identical as possible. Trace resistance of 1Ω can cause as much as 1°C of error. This error can be compensated by using the Remote Temperature Offset Registers, since the value placed in these registers will automatically be subtracted or added to the remote temperature reading.
4. Diode traces should be surrounded by a GND guard ring to either side, above and below if possible. This GND guard should not go between the D+ and D- lines so that in the event that noise does couple to the diode lines, it would be coupled common mode and rejected. (See *Figure 4*)
5. Avoid routing diode traces in close proximity to power supply switching or filtering inductors.
6. Avoid running diode traces close to or parallel to high speed digital and bus lines. Diode traces should be kept at least 2 cm apart from the high speed digital traces.
7. If it is necessary to cross high speed digital traces, the diode traces and the high speed digital traces should cross at a 90° degree angle.

2.0 Application Hints (Continued)

8. The ideal place to connect the LM88's GND pin is as close as possible to the processor GND associated with the sense diode.
9. Leakage current between D+ and GND should be kept to a minimum. One nano-ampere of leakage can cause

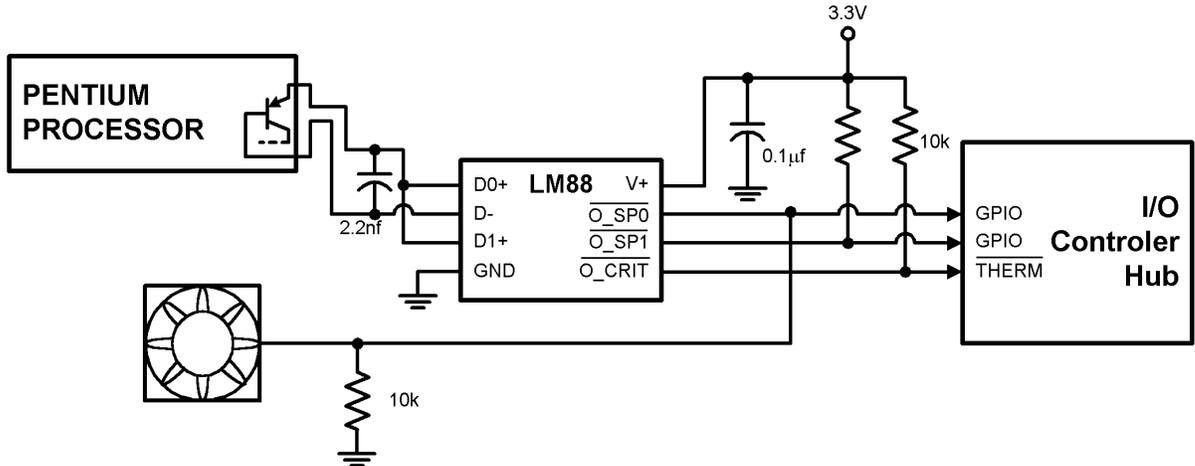
as much as 1°C of error in the diode temperature reading. Keeping the printed circuit board as clean as possible will minimize leakage current.



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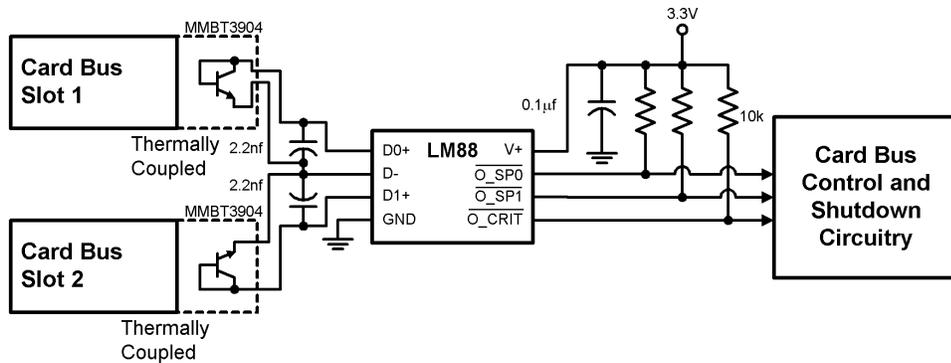
FIGURE 4. Ideal Diode Trace Layout

3.0 Applications Circuits



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FIGURE 5. Pentium processor Thermal Management with Fan Control



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FIGURE 6. Card Bus Thermal Management

