



January 2000

## LM76

# ±0.5°C, ±1°C, 12-Bit + Sign Digital Temperature Sensor and Thermal Window Comparator with Two-Wire Interface

## General Description

The LM76 is a digital temperature sensor and thermal window comparator with an I<sup>2</sup>C™ Serial Bus interface with an accuracy of ±1°C. This accuracy for the LM76CHM is specified for a -10°C to 45°C temperature range, while for the LM76CNM the temperature range is 70°C to 100°C. The LM76CHM is specified with an accuracy ±0.5°C at 25°C. The window-comparator architecture of the LM76 eases the design of temperature control systems conforming to the ACPI (Advanced Configuration and Power Interface) specification for personal computers. The open-drain Interrupt (INT) output becomes active whenever temperature goes outside a programmable window, while a separate Critical Temperature Alarm (T\_CRIT\_A) output becomes active when the temperature exceeds a programmable critical limit. The INT output can operate in either a comparator or event mode, while the T\_CRIT\_A output operates in comparator mode only.

The host can program both the upper and lower limits of the window as well as the critical temperature limit. Programmable hysteresis as well as a fault queue are available to minimize false tripping. Two pins (A0, A1) are available for address selection. The sensor powers up with default thresholds of 2°C T<sub>HYST</sub>, 10°C T<sub>LOW</sub>, 64°C T<sub>HIGH</sub>, and 80°C T\_CRIT.

The LM76's 3.3V and 5.0V supply voltage, Serial Bus interface, 12-bit + sign output, and full-scale range of over 127°C make it ideal for a wide range of applications. These include thermal management and protection applications in personal computers, electronic test equipment, office electronics and bio-medical applications.

## Features

- Window comparison simplifies design of ACPI compatible temperature monitoring and control.
- Serial Bus interface
- Separate open-drain outputs for Interrupt and Critical Temperature shutdown
- Shutdown mode to minimize power consumption
- Up to 4 LM76s can be connected to a single bus
- 12-bit + sign output; full-scale reading of over 127°C

## Key Specifications

|                        |                |              |
|------------------------|----------------|--------------|
| ■ Supply Voltage       |                | 3.3V or 5.0V |
| ■ Supply Current       | operating      | 250 µA (typ) |
|                        |                | 450 µA (max) |
|                        | shutdown       | 8 µA (max)   |
| ■ Temperature Accuracy | +25°C          | ±0.5°C(max)  |
|                        | -10°C to +45°C | ±1.0°C(max)  |
|                        | 70°C to 100°C  | ±1.0°C(max)  |
| ■ Resolution           |                | 0.0625°C     |

## Applications

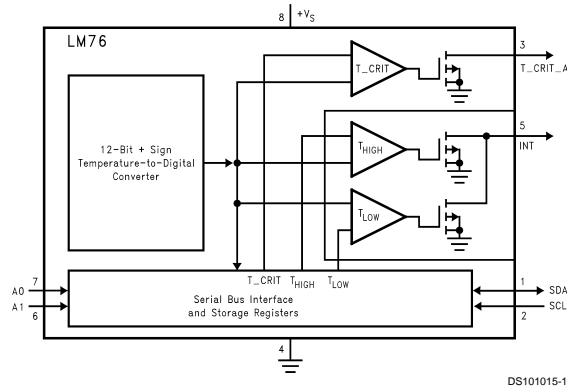
- System Thermal Management
- Personal Computers
- Office Electronics
- HVAC

LM76 ±0.5°C, ±1°C, 12-Bit + Sign Digital Temperature Sensor and Thermal Window Comparator with Two-Wire Interface

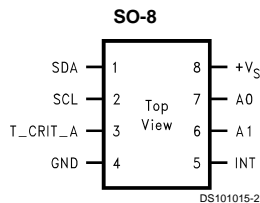
I<sup>2</sup>C® is a registered trademark of Philips Corporation.



Simplified Block Diagram



Connection Diagram



LM76 See NS Package Number M08A

Ordering Information

| Order Number | Supply Voltage | Accuracy         | Temperature Range for Accuracy | Transport Media             |
|--------------|----------------|------------------|--------------------------------|-----------------------------|
| LM76CHM-5    | 5.0V           | ±0.5°C<br>±1.0°C | 25°C<br>–10°C to 45°C          | 95 units in Rail            |
| LM76CHMX-5   | 5.0V           | ±0.5°C<br>±1.0°C | 25°C<br>–10°C to 45°C          | 2500 Units on Tape and Reel |
| LM76CNM-3    | 3.3V           | ±1°C             | 70°C to 100°C                  | 95 units in Rail            |
| LM76CNMX-3   | 3.3V           | ±1°C             | 70°C to 100°C                  | 2500 Units on Tape and Reel |

Pin Description

| Label           | Pin # | Function   | Typical Connection  |
|-----------------|-------|--|---|
| SDA             | 1     | Serial Bi-Directional Data Line, Open Drain Output, CMOS Logic Level | Pull Up Resistor, Controller I <sup>2</sup> C Data Line                 |
| SCL             | 2     | Serial Bus Clock Input, CMOS Logic Level                             | From Controller I <sup>2</sup> C Clock Line                             |
| T_CRIT_A        | 3     | Critical Temperature Alarm, Open Drain Output                        | Pull Up Resistor, Controller Interrupt Line or System Hardware Shutdown |
| GND             | 4     | Power Supply Ground  | Ground  |
| INT             | 5     | Interrupt, Open Drain Output   | Pull Up Resistor, Controller Interrupt Line                             |
| +V <sub>S</sub> | 8     | Positive Supply Voltage Input  | DC Voltage from 3.3V power supply or 5V.                                |
| A0–A1           | 7,6   | User-Set Address Inputs, TTL Logic Level                             | Ground (Low, “0”) or +V <sub>S</sub> (High, “1”)                        |

## Pin Description (Continued)

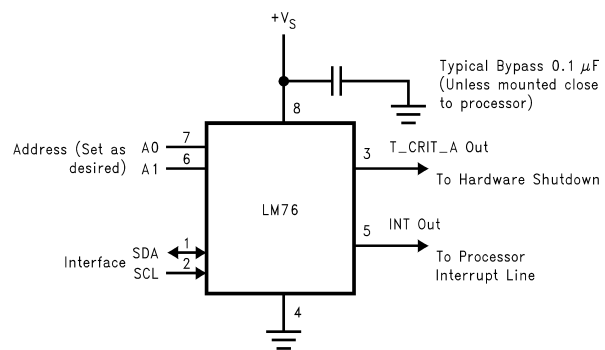


FIGURE 1. Typical Application

**Absolute Maximum Ratings** (Note 1)

|                                      |                                   |
|--------------------------------------|-----------------------------------|
| Supply Voltage                       | –0.3V to 6.5V                     |
| Voltage at any Pin                   | –0.3V to (+V <sub>S</sub> + 0.3V) |
| Input Current at any Pin             | 5mA                               |
| Package Input Current (Note 2)       | 20mA                              |
| T_CRIT_A and INT Output Sink Current | 10mA                              |
| T_CRIT_A and INT Output Voltage      | 6.5V                              |
| Storage Temperature                  | –65°C to +125°C                   |

Soldering Information, Lead Temperature

SOP Package (Note 3)

Vapor Phase (60 seconds) 215°C

Infrared (15 seconds) 220°C

ESD Susceptibility (Note 4)

Human Body Model 3000V

Machine Model 250V

**Operating Ratings**(Notes 1, 5)

Operating Temperature Range –55°C to +150°C

Specified Temperature Range

(Note 6)

T<sub>MIN</sub> to T<sub>MAX</sub>

LM76CHM-5 –20°C to +85°C

LM76CNM-3 –55°C to +125°C

Supply Voltage Range (+V<sub>S</sub>)(Note 7)

+3.0V to +5.5V

**Temperature-to-Digital Converter Characteristics**

Unless otherwise noted, these specifications apply for +V<sub>S</sub>=+3.3 Vdc ±5% for the LM76CNM-3 and for +V<sub>S</sub>=+5.0 Vdc ±10% for the LM76CHM-5. (Note 7). **Boldface limits apply for T<sub>A</sub> = T<sub>J</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>**; all other limits T<sub>A</sub>= T<sub>J</sub>=+25°C, unless otherwise noted.

| Parameter                             | Conditions                                     | Typical<br>(Note 8) | LM76CNM-3<br>Limits<br>(Note 9) | LM76CHM-5<br>Limits<br>(Note 9) | Units<br>(Limit) |
|---------------------------------------|--|---------------------|---------------------------------|---------------------------------|------------------|
| Accuracy (Note 7)                     | T <sub>A</sub> = –25°C to +125°C for LM76CNM-3 | ±2.5                |                                 |                                 | °C (max)         |
|                                       | T <sub>A</sub> = +70°C to +100°C               |                     | <b>±1.0</b>                     |                                 |                  |
|                                       | T <sub>A</sub> = –20°C to +85°C for LM76CHM-5  | ±1.5                |                                 |                                 |                  |
|                                       | T <sub>A</sub> = –10°C to +45°C                |                     |                                 | <b>±1.0</b>                     |                  |
|                                       | T <sub>A</sub> = +25°C                         |                     |                                 | <b>±0.5</b>                     |                  |
| Resolution                            | (Note 10)                                      | 13<br>0.0625        |                                 |                                 | Bits<br>°C       |
| Temperature Conversion Time           | (Note 11)                                      | 400                 | <b>500</b>                      | <b>1000</b>                     | ms               |
| Quiescent Current                     | I <sup>2</sup> C Inactive                      | 0.25                |                                 |                                 | mA               |
|                                       | I <sup>2</sup> C Active                        | 0.25                | <b>0.5</b>                      | <b>0.45</b>                     | mA (max)         |
|                                       | Shutdown Mode:                                 | 5                   |                                 |                                 | µA               |
|                                       |  |                     | <b>12</b>                       | <b>18</b>                       | µA (max)         |
|                                       | T <sub>A</sub> =+85°C                          |                     | <b>8</b>                        |                                 | µA (max)         |
|                                       | T <sub>A</sub> =+25°C                          |                     |                                 | 12                              | µA (max)         |
| T <sub>HYST</sub> Default Temperature | (Notes 13, 14)                                 | 2                   |                                 |                                 | °C               |
| T <sub>LOW</sub> Default Temperature  | (Note 14)                                      | 10                  |                                 |                                 | °C               |
| T <sub>HIGH</sub> Default Temperature | (Note 14)                                      | 64                  |                                 |                                 | °C               |
| T <sub>CRIT</sub> Default Temperature | (Note 14)                                      | 80                  |                                 |                                 | °C               |

**Logic Electrical Characteristics**

**DIGITAL DC CHARACTERISTICS** Unless otherwise noted, these specifications apply for +V<sub>S</sub>=+3.3 Vdc ±5% for the LM76CNM-3 and for +V<sub>S</sub>=+5.0 Vdc ±10% for the LM76CHM-5. **Boldface limits apply for T<sub>A</sub> = T<sub>J</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>**; all other limits T<sub>A</sub>= T<sub>J</sub>=+25°C, unless otherwise noted.

| Symbol             | Parameter                             | Conditions | Typical<br>(Note 8) | Limits<br>(Note 9)          | Units<br>(Limit) |
|--------------------|---------------------------------------|------------|---------------------|-----------------------------|------------------|
| V <sub>IN(1)</sub> | SDA and SCL Logical "1" Input Voltage |            |                     | <b>+V<sub>S</sub> x 0.7</b> | V (min)          |
|                    |                                       |            |                     | <b>+V<sub>S</sub>+0.3</b>   | V (max)          |

## Logic Electrical Characteristics (Continued)

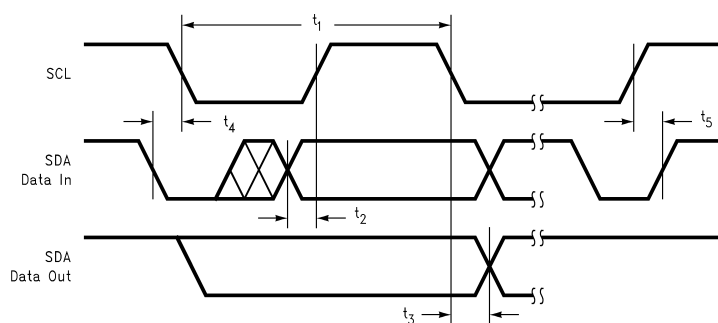
**DIGITAL DC CHARACTERISTICS** Unless otherwise noted, these specifications apply for for  $+V_S=+3.3$  Vdc  $\pm 5\%$  for the LM76CNM-3 and for  $+V_S=+5.0$  Vdc  $\pm 10\%$  for the LM76CHM-5. **Boldface limits apply for  $T_A = T_J = T_{MIN}$  to  $T_{MAX}$** ; all other limits  $T_A = T_J = +25^\circ\text{C}$ , unless otherwise noted.

| Symbol         | Parameter                             | Conditions                                   | Typical<br>(Note 8) | Limits<br>(Note 9)                                 | Units<br>(Limit)     |
|----------------|---------------------------------------|--|---------------------|--|----------------------|
| $V_{IN(0)}$    | SDA and SCL Logical "0" Input Voltage |  |                     | <b>-0.3</b><br><b><math>+V_S \times 0.3</math></b> | V (min)<br>V (max)   |
| $V_{IN(HYST)}$ | SDA and SCL Digital Input Hysteresis  |  | 500                 | <b>250</b>   | mV (min)             |
| $V_{IN(1)}$    | A0 and A1 Logical "1" Input Voltage   |  |                     | <b>2.0</b><br><b><math>+V_S+0.3</math></b>         | V (min)<br>V (max)   |
| $V_{IN(0)}$    | A0 and A1 Logical "0" Input Voltage   |  |                     | <b>-0.3</b><br><b>0.8</b>                          | V (min)<br>V (max)   |
| $I_{IN(1)}$    | Logical "1" Input Current             | $V_{IN} = +V_S$                              | 0.005               | <b>1.0</b>   | $\mu\text{A}$ (max)  |
| $I_{IN(0)}$    | Logical "0" Input Current             | $V_{IN} = 0\text{V}$                         | -0.005              | <b>-1.0</b>  | $\mu\text{A}$ (max)  |
| $C_{IN}$       | Capacitance of All Digital Inputs     |  | 20                  |  | pF                   |
| $I_{OH}$       | High Level Output Current             | $V_{OH} = +V_S$                              |                     | <b>10</b>  | $\mu\text{A}$ (max)  |
| $V_{OL}$       | Low Level Output Voltage              | $I_{OL} = 3\text{ mA}$                       |                     | <b>0.4</b>   | V (max)              |
|                | T_CRIT_A Output Saturation Voltage    | $I_{OUT} = 4.0\text{ mA}$<br>(Note 12)       |                     | <b>0.8</b>   | V (max)              |
|                | T_CRIT_A Delay                        |  |                     | <b>1</b>   | Conversions<br>(max) |
| $t_{OF}$       | Output Fall Time                      | $C_L = 400\text{ pF}$<br>$I_O = 3\text{ mA}$ |                     | <b>250</b>   | ns (max)             |

**SERIAL BUS DIGITAL SWITCHING CHARACTERISTICS** Unless otherwise noted, these specifications apply for  $+V_S=+3.3$  Vdc  $\pm 5\%$  for the LM76CNM-3 and for  $+V_S=+5.0$  Vdc  $\pm 10\%$  for the LM76CHM-5,  $C_L$  (load capacitance) on output lines = 80 pF unless otherwise specified. **Boldface limits apply for  $T_A = T_J = T_{MIN}$  to  $T_{MAX}$** ; all other limits  $T_A = T_J = +25^\circ\text{C}$ , unless otherwise noted.

The switching characteristics of the LM76 fully meet or exceed the published specifications of the I<sup>2</sup>C bus. The following parameters are the timing relationship between SCL and SDA signal related to the LM76. They are not the I<sup>2</sup>C bus specifications.

| Symbol | Parameter  | Conditions | Typical<br>(Note 8) | Limits<br>(Note 9) | Units<br>(Limit)    |
|--------|--|------------|---------------------|--------------------|---------------------|
| $t_1$  | SCL (Clock) Period                                 |            |                     | <b>2.5</b>         | $\mu\text{s}$ (min) |
| $t_2$  | Data in Set-Up Time to SCL High                    |            |                     | <b>100</b>         | ns(min)             |
| $t_3$  | Data Out Stable after SCL Low                      |            |                     | <b>0</b>           | ns(min)             |
| $t_4$  | SDA Low Set-Up Time to SCL Low (Start Condition)   |            |                     | <b>100</b>         | ns(min)             |
| $t_5$  | SDA High Hold Time after SCL High (Stop Condition) |            |                     | <b>100</b>         | ns(min)             |



DS101015-4

## Logic Electrical Characteristics (Continued)

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

**Note 2:** When the input voltage ( $V_I$ ) at any pin exceeds the power supplies ( $V_I < \text{GND}$  or  $V_I > +V_S$ ) 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:** See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

**Note 4:** Human body model, 100 pF discharged through a 1.5 k $\Omega$  resistor. Machine model, 200 pF discharged directly into each pin.

**Note 5:** LM76  $\theta_{JA}$  (thermal resistance, junction-to-ambient) when attached to a printed circuit board with 2 oz. foil is 200°C/W.

**Note 6:** While the LM76 has a full-scale-range in excess of 128°C, prolonged operation at temperatures above 125°C is not recommended.

**Note 7:** The LM76 will operate properly over the  $+V_S$  supply voltage range of 3V to 5.5V for the LM76CNM-3 and the LM76CHM-5. The LM76CNM-3 is tested and specified for rated accuracy at the nominal supply voltage of 3.3V. Accuracy of the LM76CNM-3 will degrade 0.2°C for a  $\pm 1\%$  variation in  $+V_S$  from the nominal value. The LM76CHM-5 is tested and specified for a rated accuracy at the nominal supply voltage of 5.0V. Accuracy of the LM76CHM-5 will degrade 0.08°C for a  $\pm 1\%$  variation in  $+V_S$  from the nominal value.

**Note 8:** Typicals are at  $T_A = 25^\circ\text{C}$  and represent most likely parametric norm.

**Note 9:** Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

**Note 10:** 12 bits + sign, two's complement

**Note 11:** This specification is provided only to indicate how often temperature data is updated. The LM76 can be read at any time without regard to conversion state (and will yield last conversion result). If a conversion is in process it will be interrupted and restarted after the end of the read.

**Note 12:** For best accuracy, minimize output loading. Higher sink currents can affect sensor accuracy with internal heating. This can cause an error of 0.64°C at full rated sink current and saturation voltage based on junction-to-ambient thermal resistance.

**Note 13:** Hysteresis value adds to the  $T_{\text{LOW}}$  setpoint value (e.g.: if  $T_{\text{LOW}}$  setpoint = 10°C, and hysteresis = 2°C, then actual hysteresis point is 10+2 = 12°C); and subtracts from the  $T_{\text{HIGH}}$  and  $T_{\text{CRIT}}$  setpoints (e.g.: if  $T_{\text{HIGH}}$  setpoint = 64°C, and hysteresis = 2°C, then actual hysteresis point is 64-2 = 62°C). For a detailed discussion of the function of hysteresis refer to Section 1.1, TEMPERATURE COMPARISON, and Figure 3.

**Note 14:** Default values set at power up.

## Electrical Characteristics

Continued

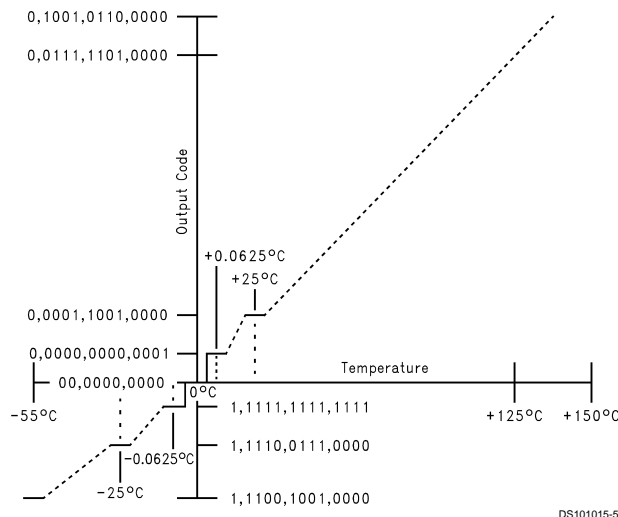


FIGURE 2. Temperature-to-Digital Transfer Function (Non-linear scale for clarity)

## 1.0 Functional Description

The LM76 temperature sensor incorporates a band-gap type temperature sensor, 13-bit ADC, and a digital comparator with user-programmable upper and lower limit values. The comparator activates either the INT line for temperatures outside the  $T_{\text{LOW}}$  and  $T_{\text{HIGH}}$  window, or the  $T_{\text{CRIT\_A}}$  line for temperatures which exceed  $T_{\text{CRIT}}$ . The lines are programmable for mode and polarity.

### 1.1 TEMPERATURE COMPARISON

LM76 provides a window comparison against a lower ( $T_{\text{LOW}}$ ) and upper ( $T_{\text{HIGH}}$ ) trip point. A second upper trip point ( $T_{\text{CRIT}}$ ) functions as a critical alarm shutdown. Figure 3 depicts the comparison function as well as the modes of operation.

#### 1.1.1 STATUS BITS

The internal Status bits operate as follows:

## 1.0 Functional Description (Continued)

**"True":** Temperature above a  $T_{HIGH}$  or  $T_{CRIT}$  is "true" for those respective bits. A "true" for  $T_{LOW}$  is temperature below  $T_{LOW}$ .

**"False":** Assuming temperature has previously crossed above  $T_{HIGH}$  or  $T_{CRIT}$ , then the temperature must drop below the points corresponding  $T_{HYST}$  ( $T_{HIGH} - T_{HYST}$  or  $T_{CRIT} - T_{HYST}$ ) in order for the condition to be false. For  $T_{LOW}$ , assuming temperature has previously crossed below  $T_{LOW}$ , a "false" occurs when temperature goes above  $T_{LOW} + T_{HYST}$ .

The Status bits are not affected by reads or any other actions, and always represent the state of temperature vs. setpoints.

### 1.1.2 HARDWARE OUTPUTS

The  $T_{CRIT\_A}$  hardware output mirrors the  $T_{CRIT\_A}$  flag, when the flag is true, the  $T_{CRIT\_A}$  output is asserted at all times regardless of mode. Reading the LM76 has no effect on the  $T_{CRIT\_A}$  output, although the internal conversion is restarted.

The behavior of the INT hardware output is as follows:

**Comparator Interrupt Mode (Default):** User reading part resets output until next measurement completes. If condition is still true, output is set again at end of next conversion cycle. For example, if a user never reads the part, and temperature goes below  $T_{LOW}$  then INT becomes active. It would stay that way until temperature goes above  $T_{LOW} + T_{HYST}$ . However if the user reads the part, the output would be reset. At the end of the next conversion cycle, if the condition is true, it is set again. If not, it remains reset.

**Event Interrupt Mode:** User reading part resets output until next condition "event" occurs (in other words, output is only set once for a true condition, if reset by a read, it remains reset until the next triggering threshold has been crossed). Conversely, if a user never read the part, the output would stay set indefinitely after the first event that set the output. An "event" for Event Interrupt Mode is defined as:

1. Transitioning upward across a setpoint, or
2. Transitioning downward across a setpoint's corresponding hysteresis (after having exceeded that setpoint).

For example, if a user never read the part, and temperature went below  $T_{LOW}$  then INT would become active. It would stay that way forever if a user never read the part.

However if the user read the part, the output would be reset. Even if the condition is true, it will remain reset. The temperature must cross above  $T_{LOW} + T_{HYST}$  to set the output again.

In either mode, reading any register in the LM76 restarts the conversion. This allows a designer to know exactly when the LM76 begins a comparison. This prevents unnecessary Interrupts just after reprogramming setpoints. Typically, system Interrupt inputs are masked prior to reprogramming trip points. By doing a read just after resetting trip points, but prior to unmasking, unexpected Interrupts are prevented.

Avoid programming setpoints so close that their hysteresis values overlap. An example would be that with a  $T_{HYST}$  value of 2°C then setting  $T_{HIGH}$  and  $T_{LOW}$  to within 4°C of each other will violate this restriction. To be more specific, with  $T_{HYST}$  set to 2°C assume  $T_{HIGH}$  set to 64°C. If  $T_{LOW}$  is set equal to, or higher than 60°C this restriction is violated.

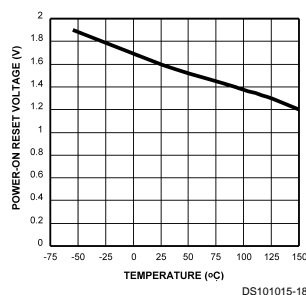
### 1.2 DEFAULT SETTINGS

The LM76 always powers up in a known state. LM76 power up default conditions are:

1. Comparator Interrupt Mode
2.  $T_{LOW}$  set to 10°C
3.  $T_{HIGH}$  set to 64°C
4.  $T_{CRIT}$  set to 80°C
5.  $T_{HYST}$  set to 2°C
6. INT and  $T_{CRIT\_A}$  active low
7. Pointer set to "00"; Temperature Register

The LM76 registers will always reset to these default values when the power supply voltage is brought up from zero volts as the supply crosses the voltage level plotted in the following curve. The LM76 registers will reset again when the power supply drops below the voltage plotted in this curve.

**Average Power on Reset Voltage vs Temperature**



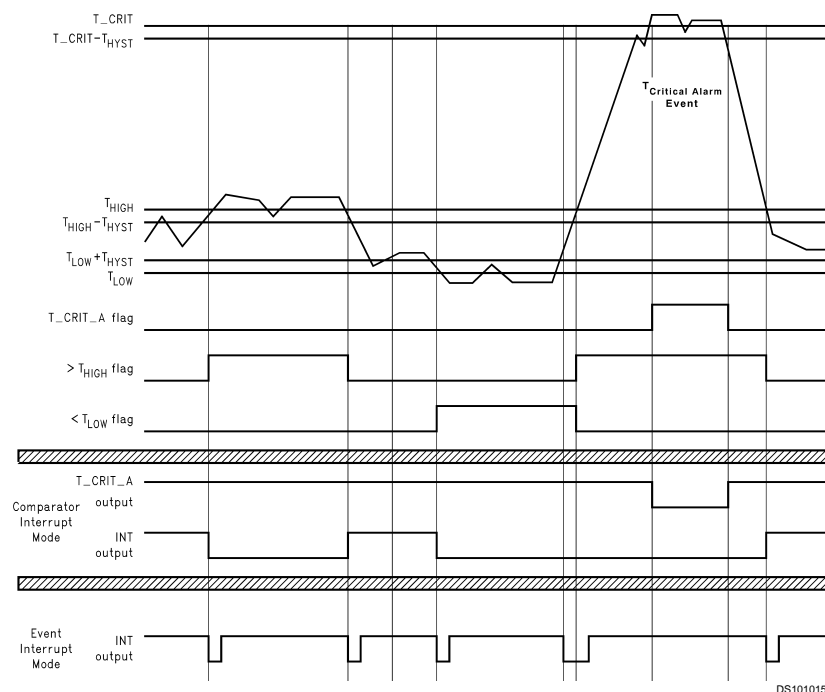
### 1.3 SERIAL BUS INTERFACE

The LM76 operates as a slave on the Serial Bus, so the SCL line is an input (no clock is generated by the LM76) and the SDA line is a bi-directional serial data line. According to Serial Bus specifications, the LM76 has a 7-bit slave address. The five most significant bits of the slave address are hard wired inside the LM76 and are "10010". The two least significant bits of the address are assigned to pins A1–A0, and are set by connecting these pins to ground for a low, (0); or to  $+V_S$  for a high, (1).

Therefore, the complete slave address is:

|     |   |   |   |   |     |    |
|-----|---|---|---|---|-----|----|
| 1   | 0 | 0 | 1 | 0 | A1  | A0 |
| MSB |   |   |   |   | LSB |    |

## 1.0 Functional Description (Continued)



**Note:** Event Interrupt mode is drawn as if the user is reading the part. If the user doesn't read, the outputs would go low and stay that way until the LM76 is read.

**FIGURE 3. Temperature Response Diagram**

### 1.4 TEMPERATURE DATA FORMAT

Temperature data can be read from the Temperature and Set Point registers; and written to the Set Point registers. Temperature data can be read at any time, although reading faster than the conversion time of the LM76 will prevent data from being updated. Temperature data is represented by a 13-bit, two's complement word with an LSB (Least Significant Bit) equal to 0.0625°C:

| Temperature | Digital Output    |        |
|-------------|-------------------|--------|
|             | Binary            | Hex    |
| +130°C      | 0 1000 0 010 0000 | 08 20h |
| +125°C      | 0 0111 1101 0000  | 07 D0h |
| +80°C       | 0 0101 1010 0000  | 05 90h |
| +64°C       | 0 0100 0000 0000  | 04 00h |
| +25°C       | 0 0001 1001 0000  | 01 90h |
| +10°C       | 0 0000 1010 0000  | 00 A0h |
| +2°C        | 0 0000 0010 0000  | 00 20h |
| +0.0625°C   | 0 0000 0000 0001  | 00 01h |
| 0°C         | 00 0000 0000      | 00 00h |
| -0.0625°C   | 1 1111 1111 1111  | 1F FFh |
| -25°C       | 1 1110 0111 0000  | 1E 70h |
| -55°C       | 1 1100 1001 0000  | 1C 90h |

### 1.5 SHUTDOWN MODE

Shutdown mode is enabled by setting the shutdown bit in the Configuration register via the Serial Bus. Shutdown mode reduces power supply current to 5 µA typical. T\_CRIT\_A is reset if previously set. Since conversions are stopped during shutdown, T\_CRIT\_A and INT will not be operational. The Serial Bus interface remains active. Activity on the clock and data lines of the Serial Bus may slightly increase shutdown mode quiescent current. Registers can be read from and written to in shutdown mode. The LM76 takes milliseconds to respond to the shutdown command.

### 1.6 INT AND T\_CRIT\_A OUTPUT

The INT and T\_CRIT\_A 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 errors due to internal heating of the LM76. The maximum resistance of the pull up, based on LM76 specification for High Level Output Current, to provide a 2 volt high level, is 30K ohms.

### 1.7 FAULT QUEUE

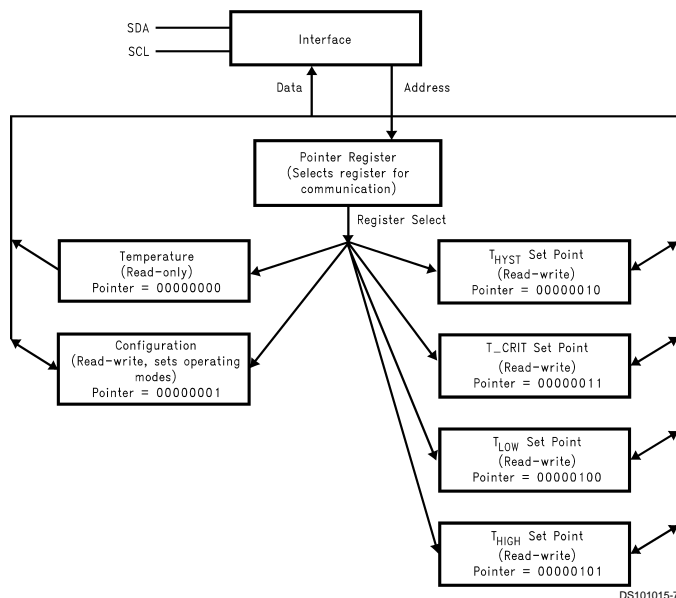
A fault queue of up to 4 faults is provided to prevent false tripping when the LM76 is used in noisy environments. The 4 faults must occur consecutively to set flags as well as INT



## 1.0 Functional Description (Continued)

and T\_CRIT\_A outputs. The fault queue is enabled by setting bit 4 of the Configuration Register high (see Section 1.11).

### 1.8 INTERNAL REGISTER STRUCTURE



There are four data registers in the LM76, selected by the Pointer register. At power-up the Pointer is set to "00"; the location for the Temperature Register. The Pointer register latches the last location it was set to. In Interrupt Mode, a read from the LM76 resets the INT output. Placing the device in Shutdown mode resets the INT and T\_CRIT\_A outputs. All registers are read and write, except the Temperature register which is read only.

A write to the LM76 will always include the address byte and the Pointer byte. A write to the Configuration register requires one data byte, while the T\_LOW, T\_HIGH, and T\_CRIT registers require two data bytes.

Reading the LM76 can take place either of two ways: If the location latched in the Pointer is correct (most of the time it is expected that the Pointer will point to the Temperature register because it will be the data most frequently read from the LM76), then the read can simply consist of an address byte,

followed by retrieving the corresponding number of data bytes. If the Pointer needs to be set, then an address byte, pointer byte, repeat start, and another address byte plus required number of data bytes will accomplish a read.

The first data byte is the most significant byte with most significant bit first, permitting only as much data as necessary to be read to determine the temperature condition. For instance, if the first four bits of the temperature data indicates a critical condition, the host processor could immediately take action to remedy the excessive temperature. At the end of a read, the LM76 can accept either Acknowledge or No Acknowledge from the Master (No Acknowledge is typically used as a signal for the slave that the Master has read its last byte).

An inadvertent 8-bit read from a 16-bit register, with the D7 bit low, can cause the LM76 to stop in a state where the SDA line is held low as shown in Figure 4. This can prevent any further bus communication until at least 9 additional clock cycles have occurred. Alternatively, the master can issue clock cycles until SDA goes high, at which time issuing a "Stop" condition will reset the LM76.

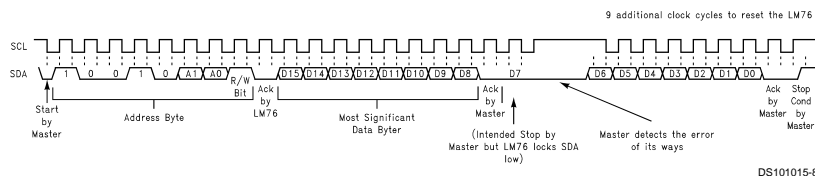


FIGURE 4. Inadvertent 8-Bit Read from 16-Bit Register where D7 is Zero ("0")

## 1.0 Functional Description (Continued)

### 1.9 POINTER REGISTER

(Selects which registers will be read from or written to):

| P7 | P6 | P5 | P4 | P3 | P2              | P1 | P0 |
|----|----|----|----|----|-----------------|----|----|
| 0  | 0  | 0  | 0  | 0  | Register Select |    |    |

P0–P2: Register Select:

| P2 | P1 | P0 | Register                                   |
|----|----|----|--|
| 0  | 0  | 0  | Temperature (Read only) (Power-up default) |
| 0  | 0  | 1  | Configuration (Read/Write)                 |
| 0  | 1  | 0  | T <sub>HYST</sub> (Read/Write)             |
| 0  | 1  | 1  | T <sub>CRIT</sub> (Read/Write)             |
| 1  | 0  | 0  | T <sub>LOW</sub> (Read/Write)              |
| 1  | 0  | 1  | T <sub>HIGH</sub> (Read/Write)             |

P3–P7: Must be kept zero.

### 1.10 TEMPERATURE REGISTER

(Read Only):

| D15  | D14 | D13    | D12   | D11   | D10   | D9    | D8    | D7    | D6    | D5    | D4    | D3    | D2          | D1   | D0  |
|------|-----|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------------|------|-----|
| Sign | MSB | Bit 10 | Bit 9 | Bit 8 | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | CRIT        | HIGH | LOW |
|      |     |        |       |       |       |       |       |       |       |       |       |       | Status Bits |      |     |

D0–D2: Status Bits

D3–D15: Temperature Data. One LSB = 0.0625°C. Two's complement format.

### 1.11 CONFIGURATION REGISTER

(Read/Write):

| D7 | D6 | D5 | D4          | D3           | D2                           | D1       | D0       |
|----|----|----|-------------|--------------|------------------------------|----------|----------|
| 0  | 0  | 0  | Fault Queue | INT Polarity | T <sub>CRIT_A</sub> Polarity | INT Mode | Shutdown |

D0: Shutdown - When set to 1 the LM76 goes to low power shutdown mode. Power up default of "0".

D1: Interrupt mode - 0 is Comparator Interrupt mode, 1 is Event Interrupt mode. Power up default of "0".

D2, D3: T<sub>CRIT\_A</sub> and INT Polarity - 0 is active low, 1 is active high. Outputs are open-drain. Power up default of "0"

D4: Fault Queue - When set to 1 the Fault Queue is enabled, see *Section 1.7*. Power up default of "0".

D5–D7: These bits are used for production testing and must be kept zero for normal operation.

### 1.12 T<sub>HYST</sub>, T<sub>LOW</sub>, T<sub>HIGH</sub> AND T<sub>CRIT\_A</sub> REGISTERS

(Read/Write):

| D15  | D14 | D13    | D12   | D11   | D10   | D9    | D8    | D7    | D6    | D5    | D4    | D3    | D2 | D1 | D0 |
|------|-----|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----|----|----|
| Sign | MSB | Bit 10 | Bit 9 | Bit 8 | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | X  | X  | X  |

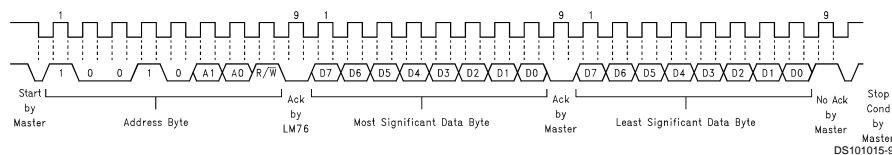
D0–D2: Undefined

D3–D15: T<sub>HYST</sub>, T<sub>LOW</sub>, T<sub>HIGH</sub> or T<sub>CRIT</sub> Trip Temperature Data. Power up default is T<sub>LOW</sub> = 10°C, T<sub>HIGH</sub> = 64°C, T<sub>CRIT</sub> = 80°C, T<sub>HYST</sub> = 2°C.

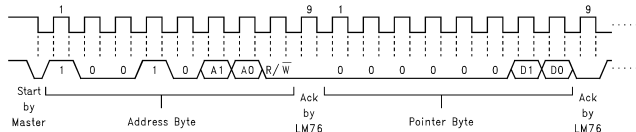
T<sub>HYST</sub> is subtracted from T<sub>HIGH</sub>, and T<sub>CRIT</sub>, and added to T<sub>LOW</sub>.

Avoid programming setpoints so close that their hysteresis values overlap. See *Section 1.1*.

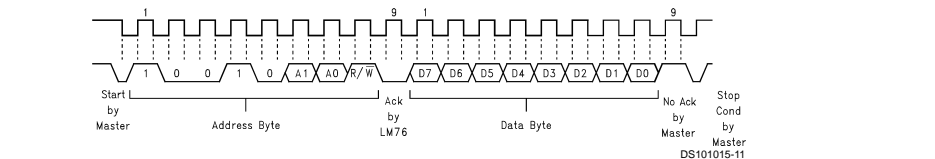
## 2.0 I<sup>2</sup>C Timing Diagrams



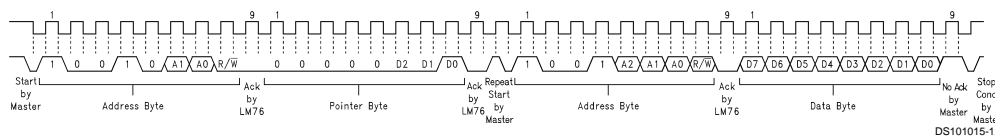
**Typical 2-Byte Read From Preset Pointer Location Such as Temp or Comparison Registers**



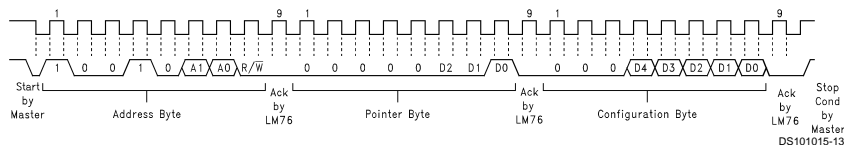
**Typical Pointer Set Followed by Immediate Read for 2-Byte Register such as Temp or Comparison Registers**



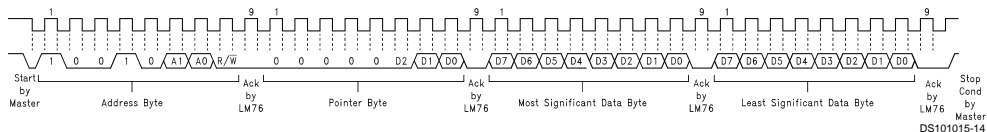
**Typical 1-Byte Read from Configuration Register with Preset Pointer**



**Typical Pointer Set Followed by Immediate Read from Configuration Register**



**Configuration Register Write**



**Comparison Register Write**

**FIGURE 6. Timing Diagrams**

### 3.0 Application Hints

The temperature response graph in *Figure 7* depicts a typical application designed to meet ACPI requirements. In this type of application, the temperature scale is given an arbitrary value of "granularity", or the window within which temperature notification events should occur. The LM76 can be programmed to the window size chosen by the designer, and will issue interrupts to the processor whenever the window limits have been crossed. The internal flags permit quick determination of whether the temperature is rising or falling.

The T\_CRIT limit would typically use its separate output to activate hardware shutdown circuitry separate from the processor. This is done because it is expected that if temperature has gotten this high that the processor may not be responding. The separate circuitry can then shut down the system, usually by shutting down the power supply.

Note that the INT and T\_CRIT\_A outputs are separate, but can be wire-or'd together. Alternatively the T\_CRIT\_A can be diode or'd to the INT line in such a way that a T\_CRIT\_A event activates the INT line, but an INT event does not activate the T\_CRIT\_A line. This may be useful in the event that it is desirable to notify both the processor and separate T\_CRIT\_A shutdown circuitry of a critical temperature alarm at the same time (maybe the processor is still working and can coordinate a graceful shutdown with the separate shutdown circuit).

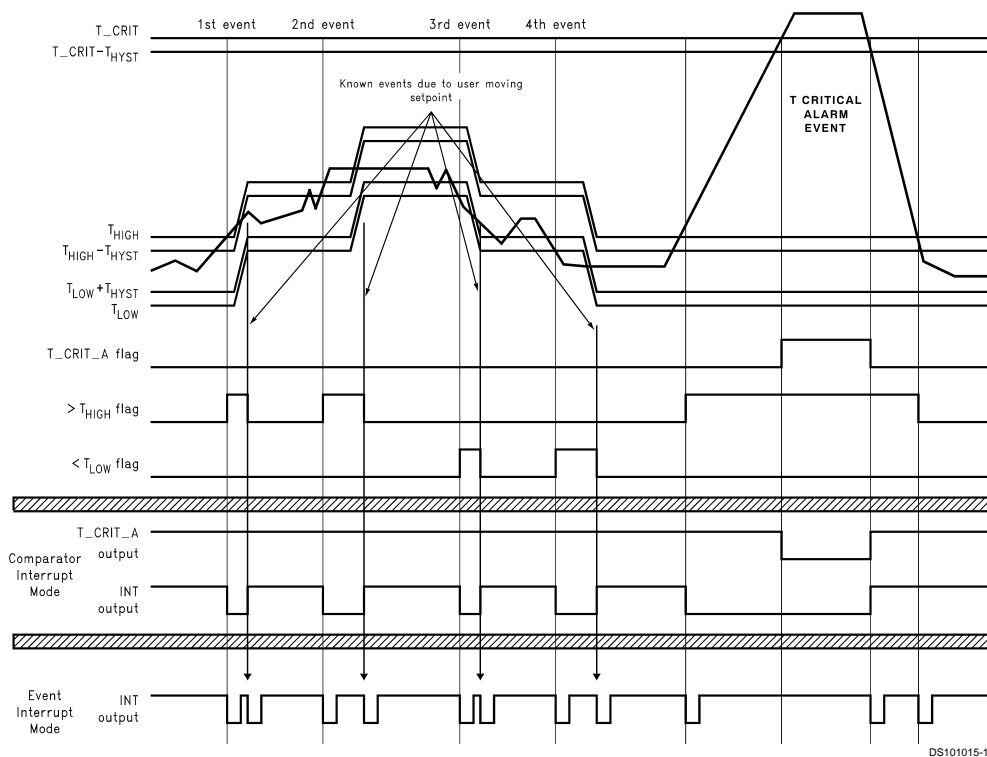
To implement ACPI compatible sensing it is necessary to sense whenever the temperature goes outside the window, issue an interrupt, service the interrupt, and reprogram the window according to the desired granularity of the temperature scale. The reprogrammed window will now have the current temperature inside it, ready to issue an interrupt whenever the temperature deviates from the current window.

To understand this graph, assume that at the left hand side the system is at some nominal temperature. For the 1st event temperature rises above the upper window limit,  $T_{HIGH}$ , causing INT to go active. The system responds to the interrupt by querying the LM76's status bits and determines that  $T_{HIGH}$  was exceeded, indicating that temperature is rising. The system then reprograms the temperature limits to a value higher by an amount equal to the desired granularity. Note that in Event Interrupt Mode, reprogramming the limits has caused a second, known, interrupt to be issued since temperature has been returned within the window. In Comparator Interrupt Mode, the LM76 simply stops issuing interrupts.

The 2nd event is another identical rise in temperature. The 3rd event is typical of a drop in temperature. This is one of the conditions that demonstrates the power of the LM76, as the user receives notification that a lower limit is exceeded in such a way that temperature is dropping.

The Critical Alarm Event activates the separate T\_CRIT\_A output. Typically, this would feed circuitry separate from the processor on the assumption that if the system reached this temperature, the processor might not be responding.

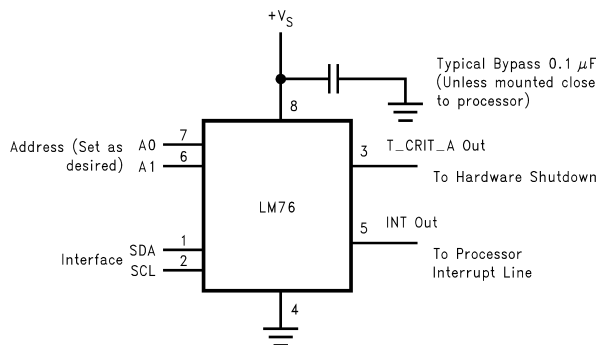
### 3.0 Application Hints (Continued)



**Note:** Event Interrupt mode is drawn as if the user is reading the part. If the user doesn't read, the outputs would go low and stay that way until the LM76 is read.

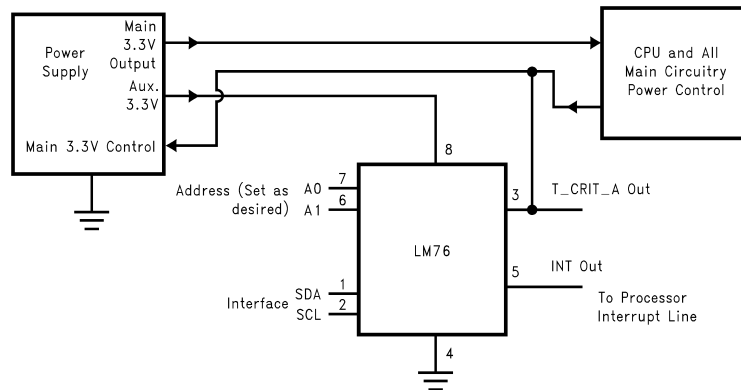
**FIGURE 7. Temperature Response Diagram for ACPI Implementation**

### 4.0 Typical Applications



**FIGURE 8. Typical Application**

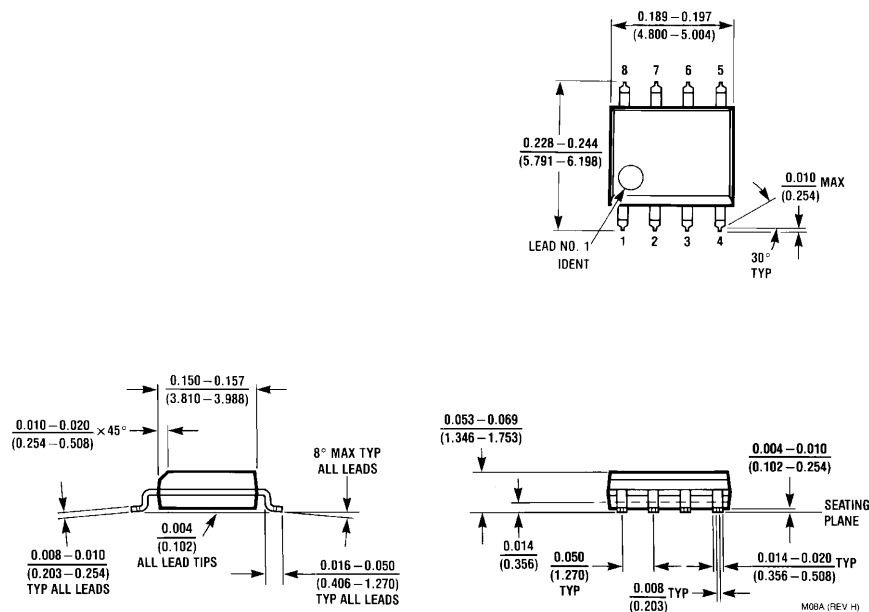
## 4.0 Typical Applications (Continued)



DS101015-19

**FIGURE 9. ACPI Compatible Terminal Alarm Shutdown.** By powering the LM76 from auxiliary output of the power supply, a non-functioning overheated computer can be powered down to preserve as much of the system as possible.

## Physical Dimensions inches (millimeters) unless otherwise noted



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