May 4, 2012

![Texas Instruments logo] **TEXAS INSTRUMENTS**

LM75A

Digital Temperature Sensor and Thermal Watchdog with Two-Wire Interface

General Description

The LM75A is an industry-standard digital temperature sensor with an integrated Sigma-Delta analog-to-digital converter and I2C® interface. The LM75A provides 9-bit digital temperature readings with an accuracy of ±2°C from -25°C to 100°C and ±3°C over -55°C to 125°C.

The LM75A operates with a single supply from +2.7V to +5.5V. Communication is accomplished over a 2-wire interface which operates up to 400kHz. The LM75A has three address pins, allowing up to eight LM75A devices to operate on the same 2-wire bus. The LM75A has a dedicated over-temperature output (O.S.) with programmable limit and hysteresis. This output has programmable fault tolerance, which allows the user to define the number of consecutive error conditions that must occur before O.S. is activated.

The wide temperature and supply range and I2C interface make the LM75A ideal for a number of applications including base stations, electronic test equipment, office electronics, personal computers, and any other system where thermal management is critical to performance. The LM75A is available in an SOP-8 package and an MSOP-8 package.

Applications

- General System Thermal Management
- Communications Infrastructure
- Electronic Test Equipment
- Environmental Monitoring

Features

- No external components required
- Shutdown mode to minimize power consumption
- Up to eight LM75As can be connected to a single bus
- Power up defaults permit stand-alone operation as thermostat

Key Specifications

- Supply Voltage   LM75A   2.7V to 5.5V
- Supply Current   operating   280 µA (typ)
                    shutdown   4 µA (typ)
- Temperature Accuracy   −25°C to 100°C   ±2°C (max)
                          −55°C to 125°C   ±3°C (max)

Simplified Block Diagram
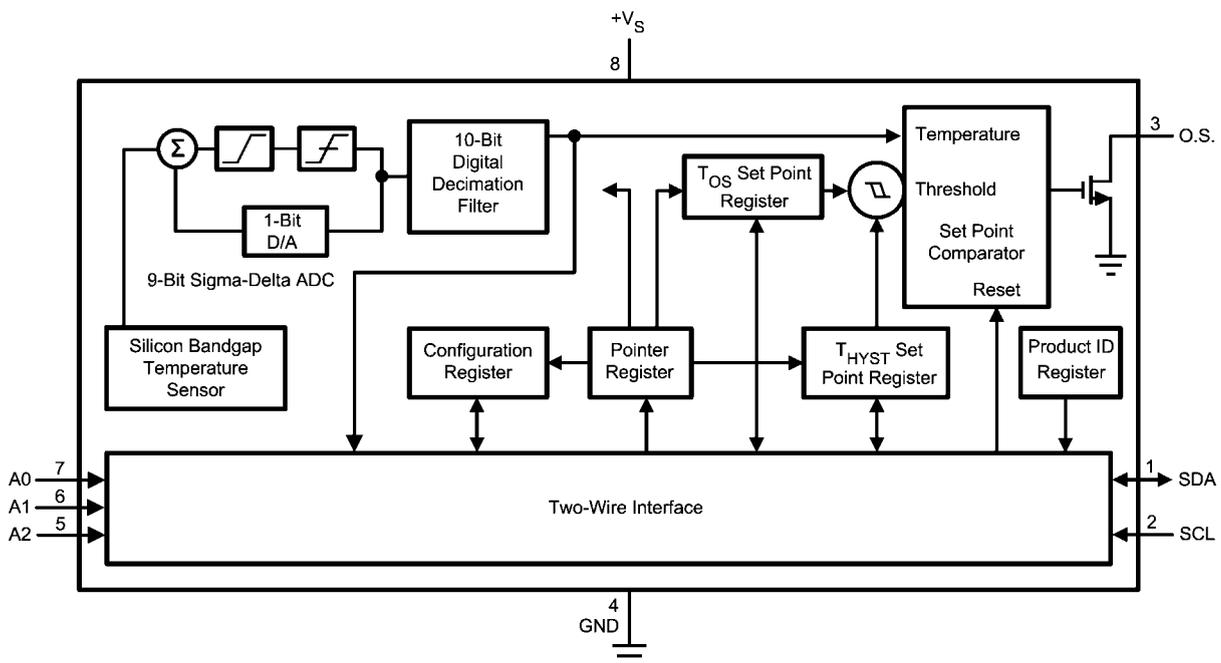
Connection Diagram

LM75A SOP-8 and MSOP-8
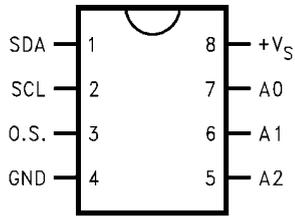

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SDA ──┤ 1        8 ├── +V_S
SCL ──┤ 2        7 ├── A0
O.S. ─┤ 3        6 ├── A1
GND ──┤ 4        5 ├── A2
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Pin Descriptions

Label	Pin #	Function	Typical Connection
SDA	1	I2C Serial Bi-Directional Data Line, Open Drain	From Controller, tied to a pull-up resistor or current source
SCL	2	I2C Clock Input	From Controller, tied to a pull-up resistor or current source
O.S.	3	Overtemperature Shutdown, Open Drain Output	Pull–up Resistor, Controller Interrupt Line
GND	4	Power Supply Ground	Ground
+V$_S$	8	Positive Supply Voltage Input	DC Voltage from 2.7V to 5.5V 100 nF bypass capacitor with 10 µF bulk capacitance in the near vicinity
A0–A2	7,6,5	User-Set I2C Address Inputs	Ground (Low, "0") or +V$_S$ (High, "1")

Typical Application
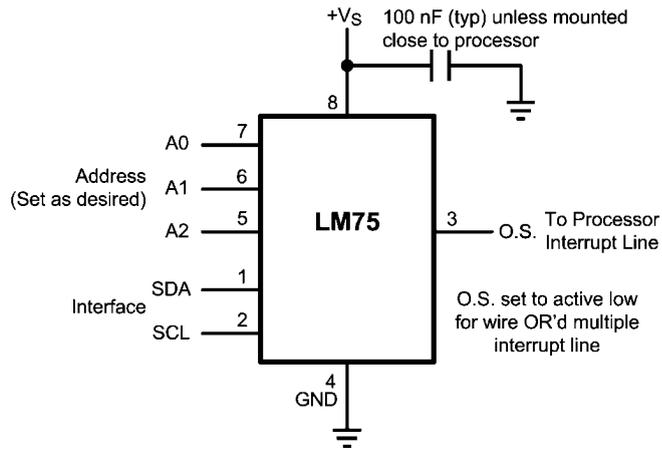
FIGURE 1. Typical Application

Ordering Information

Order Number	Package Marking	NS Package Number	Supply Voltage	Transport Media	Noise Filter on SDA and SCL
LM75AIM	LM75AIM	M08A (SOP-8)	3.3V, 5V	95 units in Rail	Yes
LM75AIMX	LM75AIM	M08A (SOP-8)	3.3V, 5V	2500 units on Tape and Reel	Yes
LM75AIMM	T00A	MUA08A (MSOP-8)	3.3V, 5V	1000 units on Tape and Reel	Yes
LM75AIMMX	T00A	MUA08A (MSOP-8)	3.3V, 5V	3500 units on Tape and Reel	Yes
LM75AIMME	T00A	MUA08A (MSOP-8)	3.3V, 5V	250 units on Tape and Reel	Yes

Absolute Maximum Ratings (*Note 1*)

Supply Voltage Pin (+V_S)	−0.3V to 6.5V
Voltage at A0, A1and A2 Pins	−0.3V to (+V_S + 0.3V) and must be ≤ 6.5V
Voltage at OS, SCL and SDA Pins	−0.3V to 6.5V
Input Current at any Pin (*Note 2*)	5 mA
Package Input Current (*Note 2*)	20 mA
Storage Temperature	−65°C to +150°C
ESD Susceptibility (*Note 4*)	LM75A
Human Body Model	2500V
Machine Model	250V
Charged Device Model	1000V
O.S. Output Sink Current	10 mA
O.S. Output Voltage	6.5V

Operating Ratings

Specified Temperature Range (*Note 5*)	T_{MIN} to T_{MAX} −55°C to +125°C
Supply Voltage Range (+V_S)	
LM75A	+2.7V to +5.5V

Soldering process must comply with National Semiconductor's Reflow Temperature Profile specifications. Refer to www.national.com/packaging.(Note 3)

Temperature-to-Digital Converter Characteristics

Unless otherwise noted, these specifications apply for: +V_S = +2.7 to 5.5 Vdc for LM75AIM. **Boldface limits apply for T_A = T_J = T_{MIN} to T_{MAX}**; all other limits T_A = T_J = +25°C, unless otherwise noted.

Parameter		Conditions	Typical (*Note 11*)	Limits (*Note 6*)	Units (Limit)
Accuracy		T_A = −25°C to +100°C		**±2.0**	°C (max)
		T_A = −55°C to +125°C		**±3.0**	
Resolution			9		Bits
Temperature Conversion Time		(*Note 7*)	100	**300**	ms (max)
Quiescent Current	LM75A	I²C Inactive	0.28	**0.5**	mA (max)
		Shutdown Mode, +V_S = 3V	4		µA
		Shutdown Mode, +V_S = 5V	6		µA
O.S. Output Saturation Voltage		I_{OUT} = 4.0 mA		**0.8**	V (max)
O.S. Delay		(*Note 9*)		**1**	Conversion (min)
				6	Conversions (max)
T_{OS} Default Temperature		(*Note 10*)	80		°C
T_{HYST} Default Temperature		(*Note 10*)	75		°C

# Logic Electrical Characteristics

DIGITAL DC CHARACTERISTICS

Unless otherwise noted, these specifications apply for $+V_S$ = +2.7 to 5.5 Vdc for LM75AIM and LM75AIMM. **Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX};** all other limits $T_A = T_J$ = +25°C, unless otherwise noted.

Symbol	Parameter		Conditions	Typical (*Note 11*)	Limits (*Note 6*)	Units (Limit)
$V_{IN(1)}$	Logical "1" Input Voltage				$+V_S \times 0.7$	V (min)
					$+V_S + 0.3$	V (max)
$V_{IN(0)}$	Logical "0" Input Voltage				**−0.3**	V (min)
					$+V_S \times 0.3$	V (max)
$I_{IN(1)}$	Logical "1" Input Current		$V_{IN} = +V_S$	0.005	**1.0**	µA (max)
$I_{IN(0)}$	Logical "0" Input Current		V_{IN} = 0V	−0.005	**−1.0**	µA (max)
C_{IN}	All Digital Inputs			5		pF
I_{OH}	High Level Output Current Open drain leakage	LM75A	V_{OH} = 5V		**1**	µA (max)
V_{OL}	Low Level Output Voltage		I_{OL} = 3 mA		**0.4**	V (max)
t_{OF}	Output Fall Time		C_L = 400 pF I_O = 3 mA		**250**	ns (max)

I²C DIGITAL SWITCHING CHARACTERISTICS

Unless otherwise noted, these specifications apply for $+V_S$ = +2.7 to 5.5 Vdc for LM75AIM and LM75AIMM 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°C, unless otherwise noted.

Symbol	Parameter		Conditions	Typical (*Note 11*)	Limits (*Note 6*, *Note 13*)	Units (Limit)
t_1	SCL (Clock) Period				**2.5**	µs (min)
t_2	Data in Set-Up Time to SCL High				**100**	ns (min)
t_3	Data Out Stable after SCL Low				**0**	ns (min)
t_4	SDA Low Set-Up Time to SCL Low (Start Condition)				**100**	ns (min)
t_5	SDA High Hold Time after SCL High (Stop Condition)				**100**	ns (min)
$t_{TIMEOUT}$	SDA Time Low for Reset of Serial Interface (*Note 12*)	LM75A			**75** **325**	ms (min) ms (max)
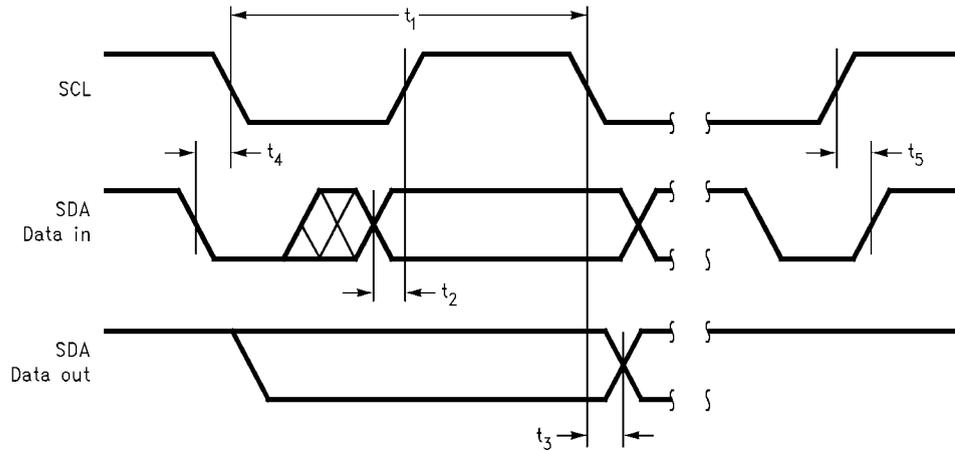
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Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

Note 2: When the input voltage (V_I) at any pin exceeds the power supplies ($V_I < GND$ or $V_I > +V_S$) 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: Reflow temperature profiles are different for lead-free and non-lead-free packages.

Note 4: Human body model, 100pF discharged through a 1.5kΩ resistor. Machine model, 200pF discharged directly into each pin. The Charged Device Model (CDM) is a specified circuit characterizing an ESD event that occurs when a device acquires charge through some triboelectric (frictional) or electrostatic induction processes and then abruptly touches a grounded object or surface.

Note 5: LM75A θ_{JA} (thermal resistance, junction-to-ambient) when attached to a printed circuit board with 2oz. foil similar to the one shown in *Figure 3* is summarized in the table below:

Device Number	NS Package Number	Thermal Resistance (θ_{JA})
LM75AIM	M08A	200°C/W
LM75AIMM	MUA08A	250°C/W

Note 6: Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 7: The conversion-time specification is provided to indicate how often the temperature data is updated. The LM75A can be accessed at any time and reading the Temperature Register will yield result from the last temperature conversion. When the LM75A is accessed, the conversion that is in process will be interrupted and it will be restarted after the end of the communication. Accessing the LM75A continuously without waiting at least one conversion time between communications will prevent the device from updating the Temperature Register with a new temperature conversion result. Consequently, the LM75A should not be accessed continuously with a wait time of less than 300ms.

Note 8: 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 9: O.S. Delay is user programmable up to 6 "over limit" conversions before O.S. is set to minimize false tripping in noisy environments.

Note 10: Default values set at power up.

Note 11: Typicals are at $T_A = 25°C$ and represent most likely parametric norm.

Note 12: Holding the SDA line low for a time greater than $t_{TIMEOUT}$ will cause the LM75A to reset SDA to the IDLE state of the serial bus communication (SDA set High).

Note 13: Timing specifications are tested at the bus input logic levels (Vin(0)=0.3XVA for a falling edge and Vin(1)=0.7XVA for a rising edge) when the SCL and SDA edge rates are similar.
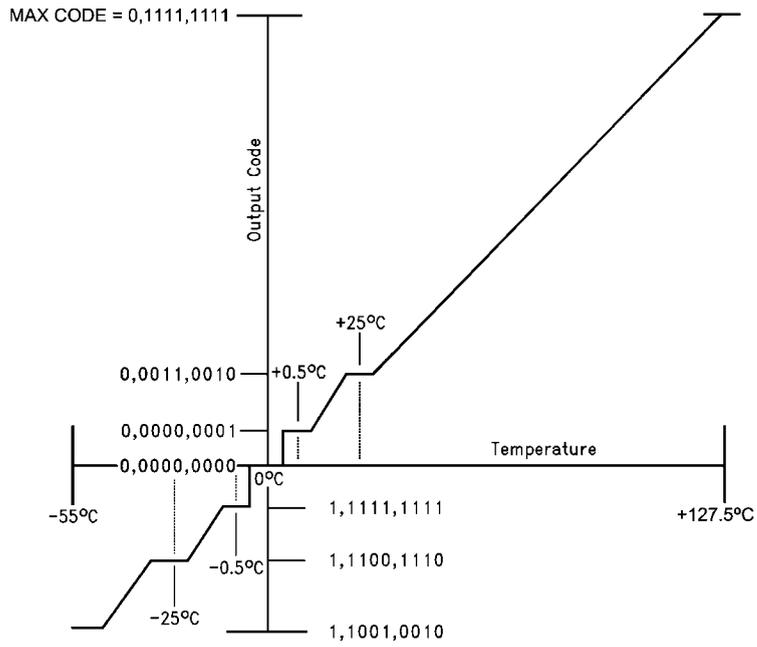
FIGURE 2. Temperature-to-Digital Transfer Function (Non-linear scale for clarity)
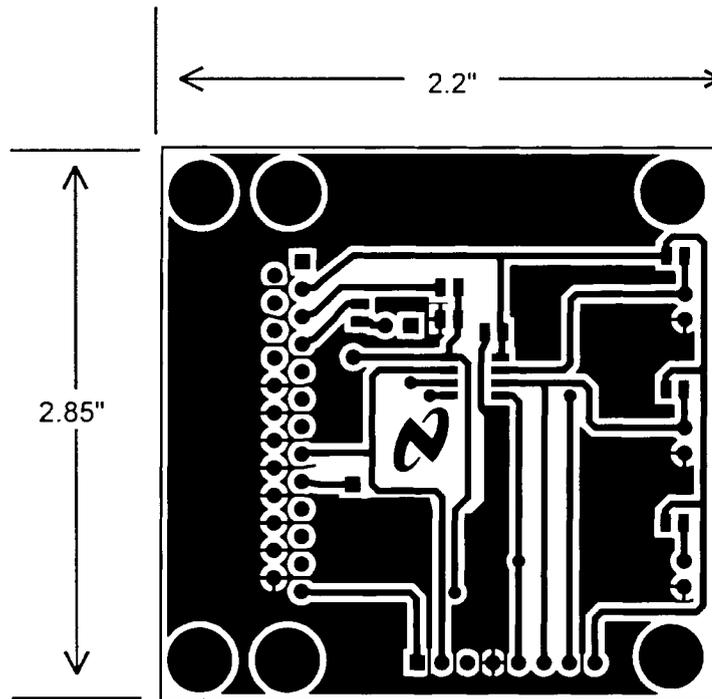
FIGURE 3. Printed Circuit Board Used for Thermal Resistance Specifications

Typical Performance Characteristics

Accuracy vs Temperature (LM75A)

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1. Comparator mode
2. $T_{OS} = 80°C$
3. $T_{HYST} = 75°C$
4. O.S. active low
5. Pointer = "00"
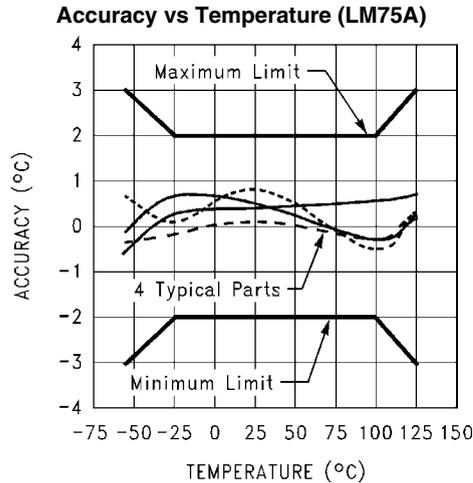
1.0 Functional Description

The LM75A temperature sensor incorporates a band-gap type temperature sensor and 9-bit ADC (Sigma-Delta Analog-to-Digital Converter). The temperature data output of the LM75A is available at all times via the I2C bus. If a conversion is in progress, it will be stopped and restarted after the read. A digital comparator is also incorporated that compares a series of readings, the number of which is user-selectable, to user-programmable setpoint and hysteresis values. The comparator trips the O.S. output line, which is programmable for mode and polarity. The LM75A has an integrated low-pass filter on both the SDA and the SCL line. These filters increase communications reliability in noisy environments.

The LM75A also has a bus fault timeout feature. If the SDA line is held low for longer than $t_{TIMEOUT}$ (see specification) the LM75A will reset to the IDLE state (SDA set to high impedance) and wait for a new start condition. The TIMEOUT feature is not functional in Shutdown Mode.

1.1 O.S. OUTPUT, T_{OS} AND T_{HYST} LIMITS

In Comparator mode the O.S. Output behaves like a thermostat. The output becomes active when temperature exceeds the T_{OS} limit, and leaves the active state when the temperature drops below the T_{HYST} limit. In this mode the O.S. output can be used to turn a cooling fan on, initiate an emergency system shutdown, or reduce system clock speed. Shutdown mode does not reset O.S. state in a comparator mode.

In Interrupt mode exceeding T_{OS} also makes O.S. active but O.S. will remain active indefinitely until reset by reading any register via the I2C interface. Once O.S. has been activated by crossing T_{OS}, then reset, it can be activated again only by Temperature going below T_{HYST}. Again, it will remain active indefinitely until being reset by a read. Placing the LM75A in shutdown mode also resets the O.S. Output.

1.2 POWER UP AND POWER DOWN

The LM75A always powers up in a known state. The power up default conditions are:

When the supply voltage is less than about 1.7V, the LM75A is considered powered down. As the supply voltage rises above the nominal 1.7V power up threshold, the internal registers are reset to the power up default values listed above.

1.2.1 Stand-Alone Thermostat Mode

If the LM75A is *not connected* to the I2C bus on power up, it will act as a stand-alone thermostat with the power up default conditions listed above. It is optional, but recommended, to connect the address pins (A2, A1, A0) and the SCL and SDA pins together and to a 10k pull-up resistor to +V_S for better noise immunity. Any of these pins may also be tied high separately through a 10k pull-up resistor.

1.3 I2C BUS INTERFACE

The LM75A operates as a slave on the I2C bus, so the SCL line is an input (no clock is generated by the LM75A) and the SDA line is a bi-directional serial data path. According to I2C bus specifications, the LM75A has a 7-bit slave address. The four most significant bits of the slave address are hard wired inside the LM75A and are "1001". The three least significant bits of the address are assigned to pins A2–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	A2	A1	A0
MSB						LSB
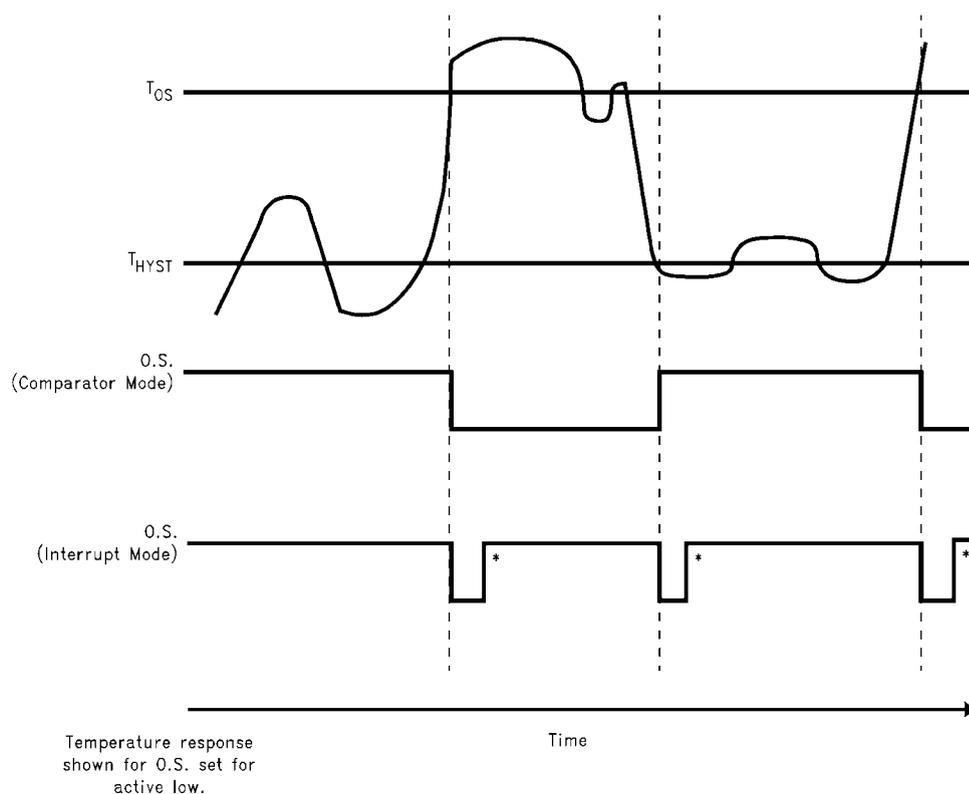
Note 14: These interrupt mode resets of O.S. occur only when LM75A is read or placed in shutdown. Otherwise, O.S. would remain active indefinitely for any event.

FIGURE 4. O.S. Output Temperature Response Diagram

1.4 TEMPERATURE DATA FORMAT

Temperature data can be read from the Temperature, T_{OS} Set Point, and T_{HYST} Set Point registers; and written to the T_{OS} Set Point, and T_{HYST} Set Point registers. Temperature data is represented by a 9-bit, two's complement word with an LSB (Least Significant Bit) equal to 0.5°C:

Temperature	Digital Output	
	Binary	Hex
+125°C	0 1111 1010	0FAh
+25°C	0 0011 0010	032h
+0.5°C	0 0000 0001	001h
0°C	0 0000 0000	000h
−0.5°C	1 1111 1111	1FFh
−25°C	1 1100 1110	1CEh
−55°C	1 1001 0010	192h

1.5 SHUTDOWN MODE

Shutdown mode is enabled by setting the shutdown bit in the Configuration register via the I2C bus. Shutdown mode reduces power supply current significantly. See specified quiescent current specification in the electrical tables. In Interrupt mode O.S. is reset if previously set and is undefined in Comparator mode during shutdown. The I2C interface remains active. Activity on the clock and data lines of the I2C bus may slightly increase shutdown mode quiescent current. T_{OS}, T_{HYST}, and Configuration registers can be read from and written to in shutdown mode.

For the LM75A, the TIMEOUT feature is turned off in Shutdown Mode.

1.6 FAULT QUEUE

A fault queue of up to 6 faults is provided to prevent false tripping of O.S. when the LM75A is used in noisy environments. The number of faults set in the queue must occur consecutively to set the O.S. output.

1.7 COMPARATOR/INTERRUPT MODE

As indicated in the O.S. Output Temperature Response Diagram, Figure 4, the events that trigger O.S. are identical for either Comparator or Interrupt mode. The most important difference is that in Interrupt mode the O.S. will remain set indefinitely once it has been set. To reset O.S. while in Interrupt mode, perform a read from any register in the LM75A.

1.8 O.S. OUTPUT

The O.S. output is an open-drain output and does not have an internal pull-up. A "high" level will not be observed on this pin 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 LM75A. The maximum resistance of the pull up, based on LM75A specification for High Level Output Current, to provide a 2V high level, is 30kΩ.

1.9 O.S. POLARITY

The O.S. output can be programmed via the configuration register to be either active low (default mode), or active high. In active low mode the O.S. output goes low when triggered exactly as shown on the O.S. Output Temperature Response Diagram, *Figure 4*. Active high simply inverts the polarity of the O.S. output.

1.10 INTERNAL REGISTER STRUCTURE
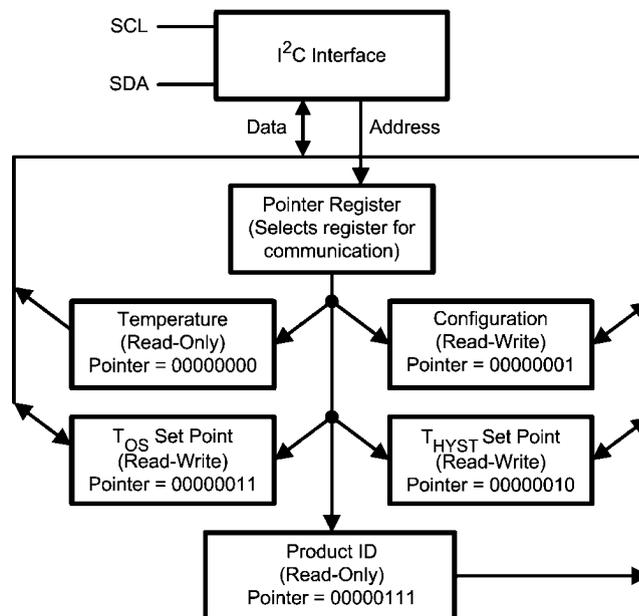
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There are four data registers in the LM75A and an additional Product ID register selected by the Pointer register. At power-up the Pointer is set to "000"; the location for the Temperature Register. The Pointer register latches whatever the last location it was set to. In Interrupt Mode, a read from the LM75A, or placing the device in shutdown mode, resets the O.S. output. All registers are read and write, except the Temperature register and the LM75A's Product ID register, which are read only.

A write to the LM75A will always include the address byte and the Pointer byte. A write to the Configuration register requires one data byte, and the T_{OS} and T_{HYST} registers require two data bytes.

Reading the LM75A 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 regis-ter because it will be the data most frequently read from the LM75A), 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 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 temperature condition. For instance, if the first four bits of the temperature data indicates an overtemperature condition, the host processor could immediately take action to remedy the excessive temperatures. At the end of a read, the LM75A 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).

1.11 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-P1: 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_{HYST} (Read/Write)
0	1	1	T_{OS} (Read/Write)
1	1	1	Product ID Register

P3–P7: Must be kept zero.

1.12 TEMPERATURE REGISTER (Read Only):

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
MSB	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	LSB	X	X	X	X	X	X	X

D0–D6: Undefined.   D7–D15: Temperature Data. One LSB = 0.5°C. Two's complement format.

1.13 CONFIGURATION REGISTER (Read/Write):

D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	Fault Queue		O.S. Polarity	Cmp/Int	Shutdown

Power up default is with all bits "0" (zero).

D0: Shutdown: When set to 1 the LM75A goes to low power shutdown mode.

D1: Comparator/Interrupt mode: 0 is Comparator mode, 1 is Interrupt mode.

D2: O.S. Polarity: 0 is active low, 1 is active high. O.S. is an open-drain output under all conditions.

D3–D4: Fault Queue: Number of faults necessary to detect before setting O.S. output to avoid false tripping due to noise. Faults are determine at the end of a conversion. See specified temperature conversion time in the electrical tables.

D4	D3	Number of Faults
0	0	1 (Power-up default)
0	1	2
1	0	4
1	1	6

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

1.14 T_{HYST} AND T_{OS} REGISTER (Read/Write):

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
MSB	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	LSB	X	X	X	X	X	X	X

D0–D6: Undefined   D7–D15: T_{HYST} Or T_{OS} Trip Temperature Data. Power up default is T_{OS} = 80°C, T_{HYST} = 75°C

1.15 PRODID: PRODUCT ID REGISTER

(Read Only) Pointer Address: 07h

D7	D6	D5	D4	D3	D2	D1	D0
1	0	1	0	0	0	0	1

D4--D7 Product Identification Nibble. Always returns Ah to uniquely identify this part as the LM75A.

D0--D3 Die Revision Nibble. Returns 1h to uniquely identify the revision level as one.

2.0 I²C Timing Diagrams
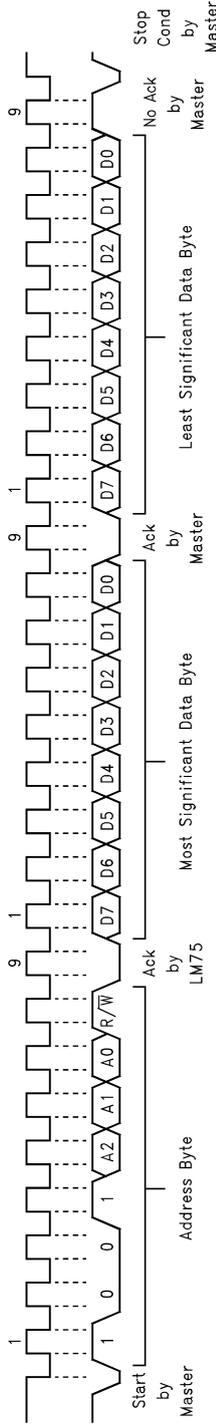
(a) Typical 2−Byte Read From Preset Pointer Location Such as Temp, T_OS, T_HYST
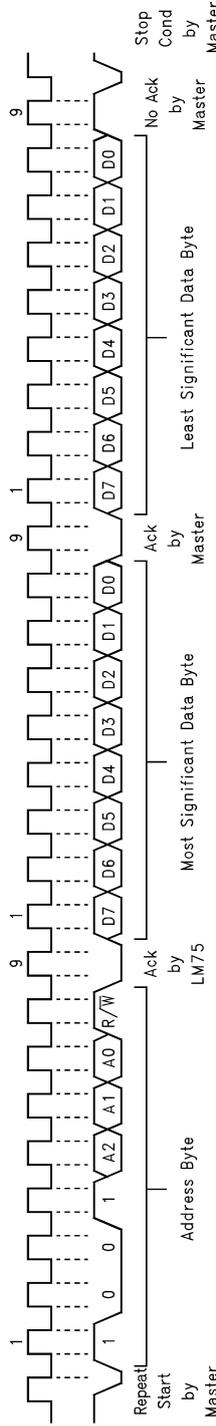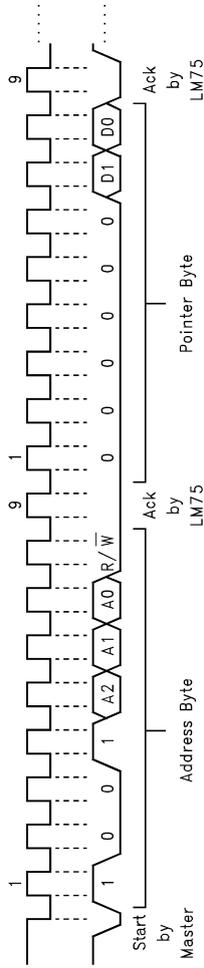
(b) Typical Pointer Set Followed by Immediate Read for 2−Byte Register such as Temp, T_OS, T_HYST
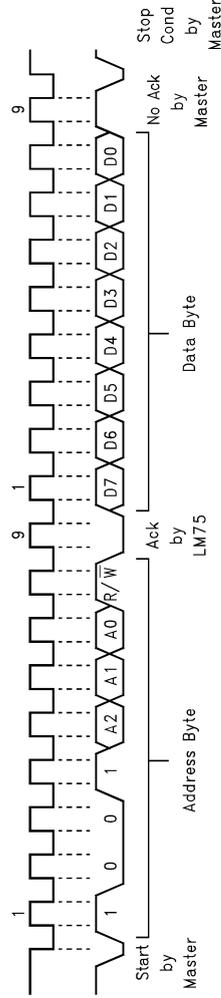
(c) Typical 1−Byte Read From Configuration Register With Preset Pointer

FIGURE 5. Timing Diagram
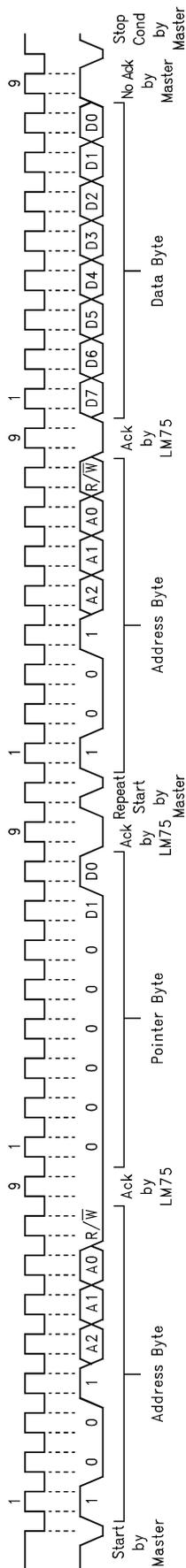
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(a) Typical Pointer Set Followed by Immediate Read from Configuration Register
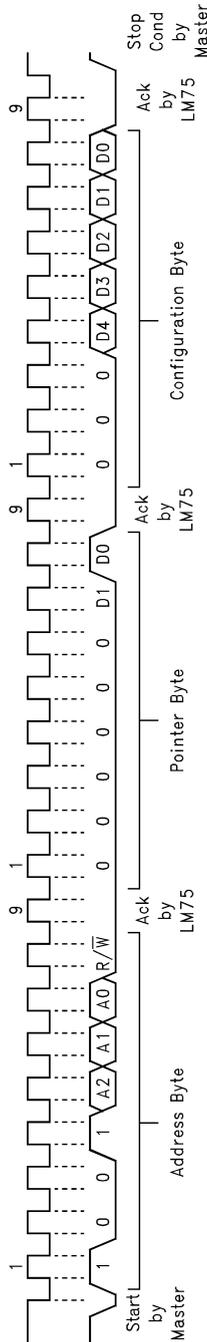
(b) Configuration Register Write
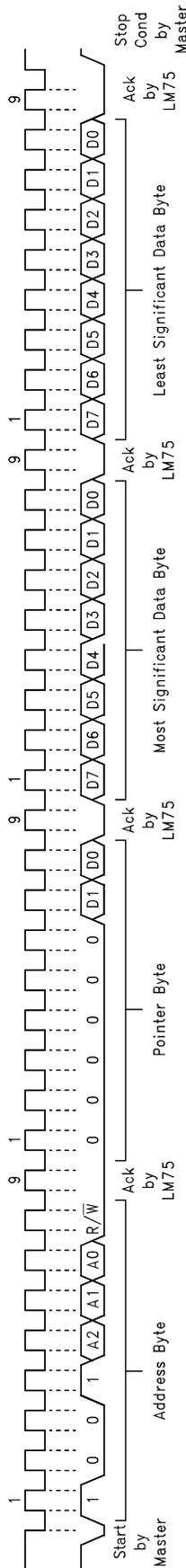
(c) T_{OS} and T_{HYST} Write

FIGURE 6. Timing Diagrams (Continued)

2.0 Application Hints

To get the expected results when measuring temperature with an integrated circuit temperature sensor like the LM75A, it is important to understand that the sensor measures its own die temperature. For the LM75A, the best thermal path between the die and the outside world is through the LM75A's pins. In the MSOP-8 package, the GND pin is directly connected to the die, so the GND pin provides the best thermal path. If the other pins are at different temperatures (unlikely, but possible), they will affect the die temperature, but not as strongly as the GND pin. In the SO-8 package, none of the pins is directly connected to the die, so they will all contribute similarly to the die temperature. Because the pins represent a good thermal path to the LM75A die, the LM75A will provide an accurate measurement of the temperature of the printed circuit board on which it is mounted. There is a less efficient thermal path between the plastic package and the LM75A die. If the ambient air temperature is significantly different from the printed circuit board temperature, it will have a small effect on the measured temperature.

In probe-type applications, the LM75A can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM75A 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 insure that moisture cannot corrode the LM75A or its connections.

2.1 DIGITAL NOISE ISSUES

The LM75A features an integrated low-pass filter on both the SCL and the SDA digital lines to mitigate the effects of bus noise. Although this filtering makes the LM75A communication robust in noisy environments, good layout practices are always recommended. Minimize noise coupling by keeping digital traces away from switching power supplies. Also, ensure that digital lines containing high-speed data communications cross at right angles to the SDA and SCL lines.

Excessive noise coupling into the SDA and SCL lines on the LM75A—specifically noise with amplitude greater than 400 mV$_{pp}$ (the LM75A's typical hysteresis), overshoot greater than 300mV above +V$_s$, and undershoot more than 300 mV below GND—may prevent successful serial communication with the LM75A. Serial bus no-acknowledge is the most common symptom, causing unnecessary traffic on the bus. Although the serial bus maximum frequency of communication is only 400 kHz, care must be taken to ensure proper termination within a system with long printed circuit board traces or multiple parts on the bus.

3.0 Typical Applications
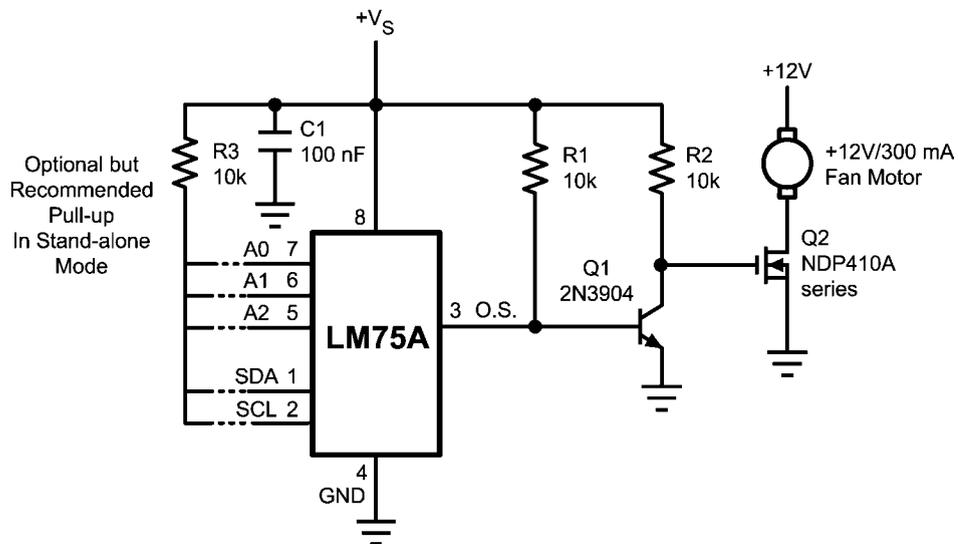
When using the two-wire interface: program O.S. for active high and connect O.S. directly to Q2's gate.

FIGURE 7. Simple Fan Controller, Interface Optional
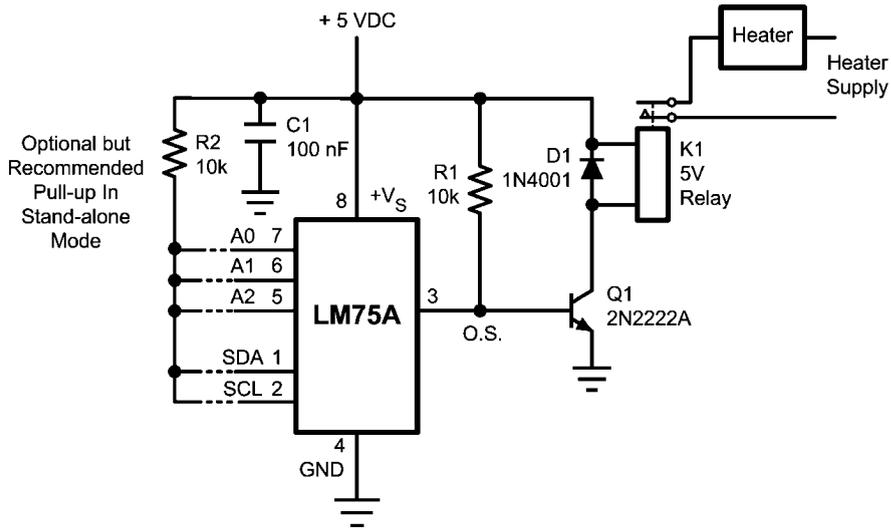
FIGURE 8. Simple Thermostat, Interface Optional
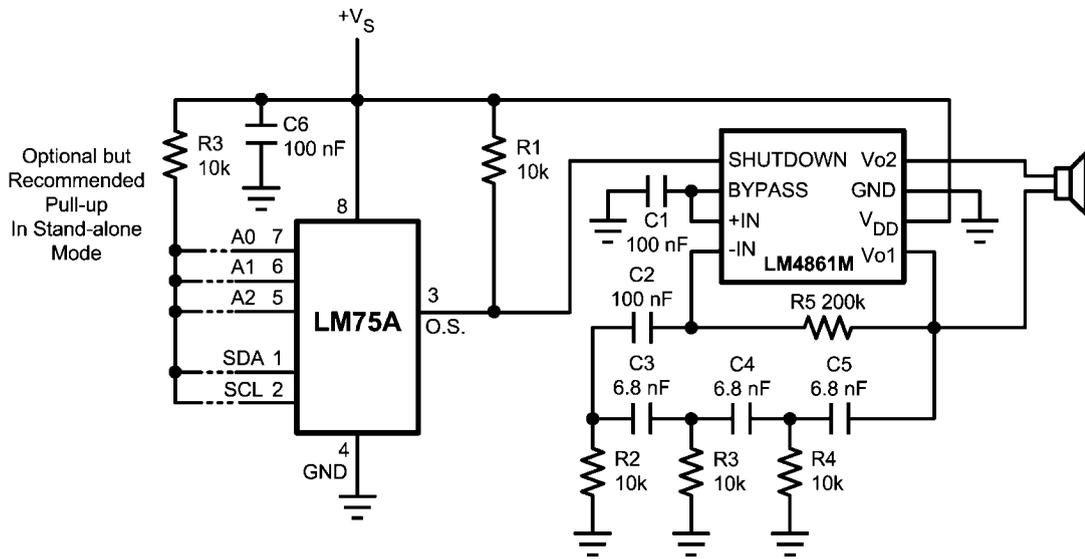
FIGURE 9. Temperature Sensor with Loudmouth Alarm (Barking Watchdog)

Physical Dimensions inches (millimeters) unless otherwise noted

RECOMMENDED LAND PATTERN
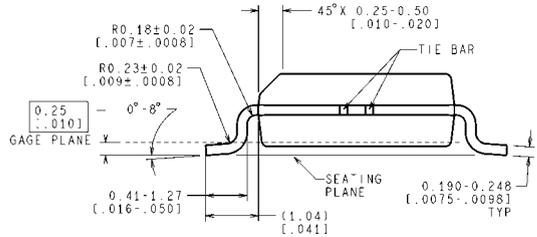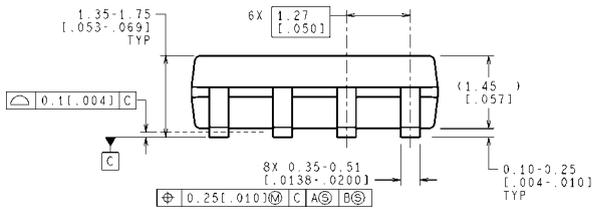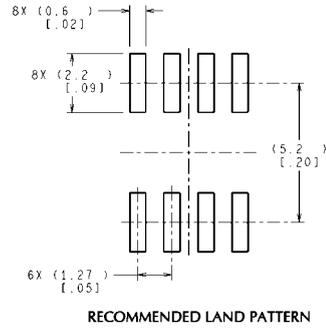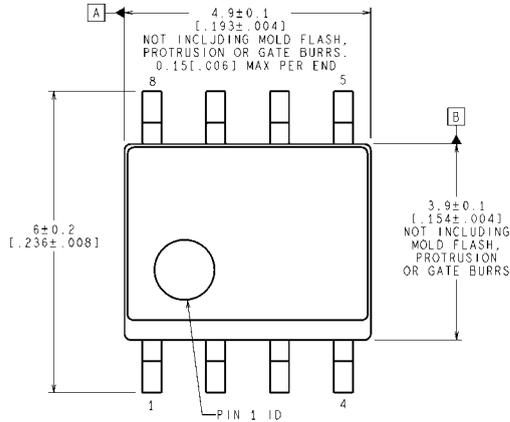
M08A (Rev M)

CONTROLLING DIMENSION IS MILLIMETER
VALUES IN [ ] ARE INCHES
DIMENSIONS IN ( ) FOR REFERENCE ONLY

8-Lead (0.150 Wide) Molded Small Outline Package (SOP), JEDEC
Order Number LM75AIM, LM75AIMX
NS Package Number M08A

RECOMMENDED LAND PATTERN
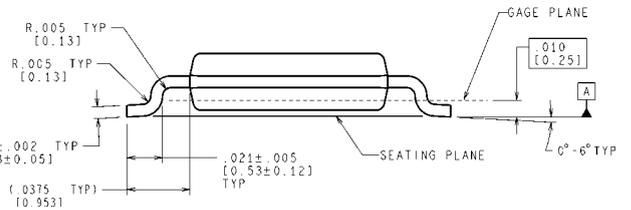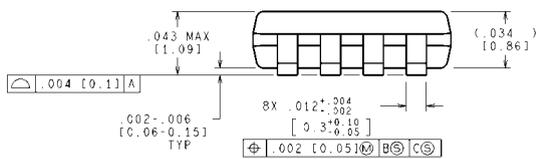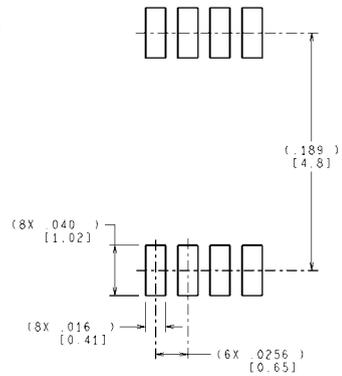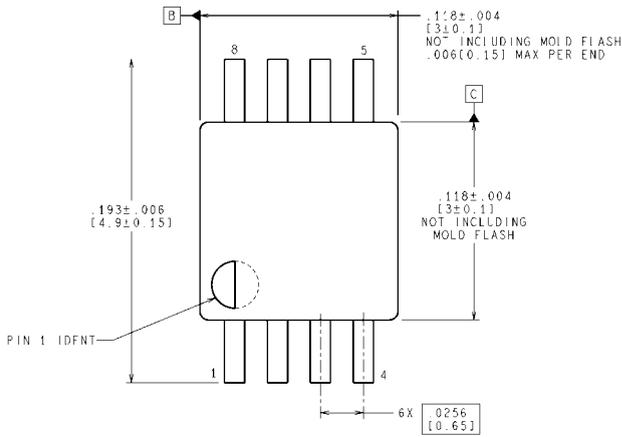
MUA08A (Rev F)

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8-Lead (0.118 Wide) Molded Mini SOIC Wide Package
Order Number LM75AIMM, LM75AIMMX
NS Package Number MUA08A

Notes

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IMPORTANT NOTICE