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◢ℕ *National Semiconductor*

LM75
Digital Temperature Sensor and Thermal WATCHDOG™ with Two-Wire Interface

General Description

The LM75 is a temperature sensor, Delta-Sigma analog-to-digital converter, and digital over-temperature detector with I²C® interface. The host can query the LM75 at any time to read temperature. The open-drain Overtemperature Shutdown (O.S.) output becomes active when the temperature exceeds a programmable limit. This pin can operate in either "Comparator" or "Interrupt" mode.

The host can program both the temperature alarm threshold (T_{OS}) and the temperature at which the alarm condition goes away (T_{HYST}). In addition, the host can read back the contents of the LM75's T_{OS} and T_{HYST} registers. Three pins (A0, A1, A2) are available for address selection. The sensor powers up in Comparator mode with default thresholds of 80˚C T_{OS} and 75˚C T_{HYST}.

The LM75's 3.0V to 5.5V supply voltage range, low supply current and I²C interface make it ideal for a wide range of applications. These include thermal management and protection applications in personal computers, electronic test equipment, and office electronics.

Features

■ SOP-8 and Mini SOP-8 (MSOP) packages save space
■ I²C Bus interface
■ Separate open-drain output pin operates as interrupt or comparator/thermostat output
■ Register readback capability
■ Power up defaults permit stand-alone operation as thermostat
■ Shutdown mode to minimize power consumption
■ Up to 8 LM75s can be connected to a single bus

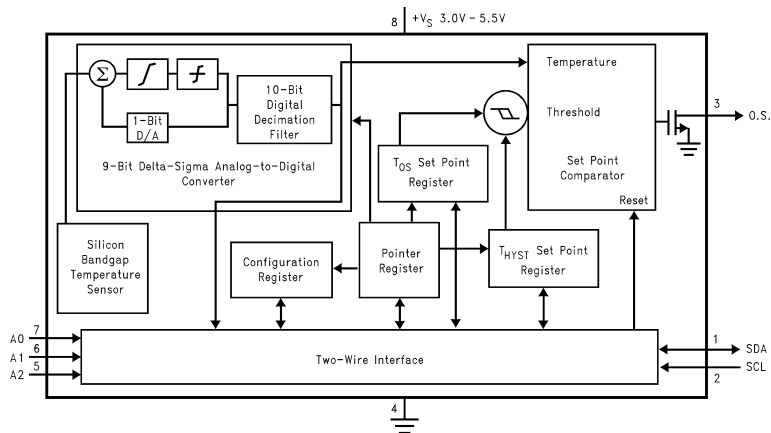## Key Specifications

■ Supply Voltage   3.0V to 5.5V
■ Supply Current   operating   250 µA (typ)
                                                    1 mA (max)
                             shutdown   4 µA (typ)
■ Temperature Accuracy   −25˚C to 100˚C   ±2˚C(max)
                          −55˚C to 125˚C   ±3˚C(max)

Applications

■ System Thermal Management
■ Personal Computers
■ Office Electronics
■ Electronic Test Equipment

Simplified Block Diagram
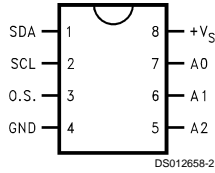

DS012658-1

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I²C® is a registered trademark of Philips Corporation.

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Connection Diagram

SOP-8 and Mini SOP-8

```
        ┌────────┐
SDA  1 ─┤        ├─ 8  +Vs
SCL  2 ─┤        ├─ 7  A0
O.S. 3 ─┤        ├─ 6  A1
GND  4 ─┤        ├─ 5  A2
        └────────┘
         DS012658-2
```

Ordering Information

Order Number	NS Package Number	Supply Voltage	Transport Media
LM75CIM-3	M08A (SOP-8)	3.3V	
LM75CIMX-3	M08A (SOP-8)	3.3V	2500 Units on Tape and Reel
LM75CIMM-3	MUA08A (MSOP-8)	3.3V	250 Units in Rail
LM75CIMMX-3	MUA08A (MSOP-8)	3.3V	3500 Units on Tape and Reel
LM75CIM-5	M08A (SOP-8)	5V	
LM75CIMX-5	M08A (SOP-8)	5V	2500 Units on Tape and Reel
LM75CIMM-5	MUA08A (MSOP-8)	5V	250 Units in Rail
LM75CIMMX-5	MUA08A (MSOP-8)	5V	3500 Units on Tape and Reel

Pin Description

| Label	Pin #	Function	Typical Connection
SDA	1	I^2C Serial Bi-Directional Data Line. Open Drain.	From Controller
SCL	2	I^2C Clock Input	From Controller
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 3V to 5.5V
A0–A2	7,6,5	User-Set I^2C Address Inputs	Ground (Low, "0") or $+V_S$ (High, "1")
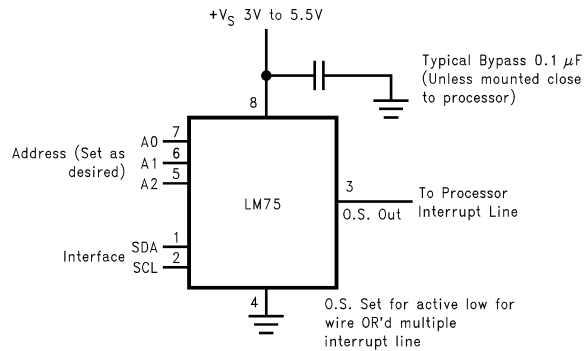
FIGURE 1. Typical Application

Absolute Maximum Ratings (Note 1)

Supply Voltage	−0.3V to 6.5V
Voltage at any Pin	−0.3V to +V_S + 0.3V
Input Current at any Pin (Note 2)	5 mA
Package Input Current (Note 2)	20 mA
O.S. Output Sink Current	10 mA
O.S. Output Voltage	6.5V
Storage Temperature	−65˚C to +150˚C
Soldering Information, Lead Temperature	
SOP and MSOP Package (Note 3)	
Vapor Phase (60 seconds)	215˚C
Infrared (15 seconds)	220˚C

ESD Susceptibility (Note 4)	
Human Body Model	950V
Machine Model	100V

Operating Ratings

Specified Temperature Range	T_{MIN} to T_{MAX}
(Note 5)	−55˚C to +125˚C
Supply Voltage Range (+V_S)	+3.0V to +5.5V

Temperature-to-Digital Converter Characteristics

Unless otherwise noted, these specifications apply for +V_S=+5 Vdc for LM75CIM-5 and LM75CIMM-5 and +V_S=+3.3 Vdc for LM75CIM-3 and LM75CIMM-3 (Note 6). **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 12)	Limits (Note 7)	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 8)	100		ms
Quiescent Current	I²C Inactive	0.25		mA
	I²C Active		**1.0**	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 (Note 9)		**0.8**	V (max)
O.S. Delay	(Note 10)		**1**	Conversions (min)
			6	Conversions (max)
T_{OS} Default Temperature	(Note 11)	80		˚C
T_{HYST} Default Temperature	(Note 11)	75		˚C

Logic Electrical Characteristics

DIGITAL DC CHARACTERISTICS

Unless otherwise noted, these specifications apply for +V_S=+5 Vdc for LM75CIM-5 and LM75CIMM-5 and +V_S=+3.3 Vdc for LM75CIM-3 and LM75CIMM-3. **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 12)	Limits (Note 7)	Units (Limit)
$V_{IN(1)}$	Logical "1" Input Voltage			**+V_S x 0.7**	V (min)
				+V_S+0.5	V (max)
$V_{IN(0)}$	Logical "0" Input Voltage			**−0.3**	V (min)
				+V_S x 0.3	V (max)
$I_{IN(1)}$	Logical "1" Input Current	V_{IN} = 5V	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		20		pF
I_{OH}	High Level Output Current	V_{OH} = 5V		**100**	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)

.   .

Logic Electrical Characteristics (Continued)

I²C DIGITAL SWITCHING CHARACTERISTICS

Unless otherwise noted, these specifications apply for+V_S=+5 Vdc for LM75CIM-5 and LM75CIMM-5 and +V_S=+3.3 Vdc for LM75CIM-3 and LM75CIMM-3 , 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˚C, unless otherwise noted.

The switching characteristics of the LM75 fully meet or exceed the published specifications of the I²C bus. The following parameters are the timing relationships between SCL and SDA signals related to the LM75. They are not the I²C bus specifications.

Symbol	Parameter	Conditions	Typical (Note 12)	Limits (Note 7)	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)
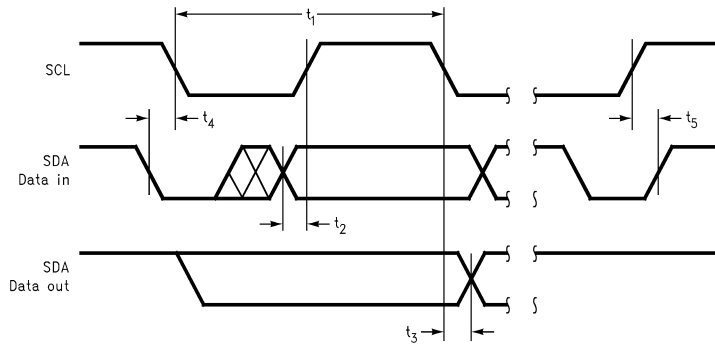
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Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

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 5 mA. The 20 mA maximum package input current rating limits the number of pins that can safely exceedthe 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 kΩ resistor. Machine model, 200 pF discharged directly into each pin.

Note 5: LM75 θ_{JA} (thermal resistance, junction-to-ambient) when attached to a printed circuit board with 2 oz. foil similar to the one shown in *Figure 3* is summarized in the table below:

Device Number	NS Package Number	Thermal Resistance (θ_{JA})
LM75CIM-3, LM75CIM-5	M08A	200˚C/W
LM75CIMM-3, LM75CIMM-5	MUA08A	250˚C/W

Note 6: Both part numbers of the LM75 will operate properly over the +V_S supply voltage range of 3V to 5.5V. The devices are tested and specified for rated accuracy at their nominal supply voltage. Accuracy will typically degrade 1˚C/V of variation in +V_S as it varies from the nominal value.

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

Note 8: This specification is provided only to indicate how often temperature data is updated. The LM75 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 9: 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 10: 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 11: Default values set at power up.

Note 12: Typicals are at T_A = 25˚C and represent most likely parametric norm.

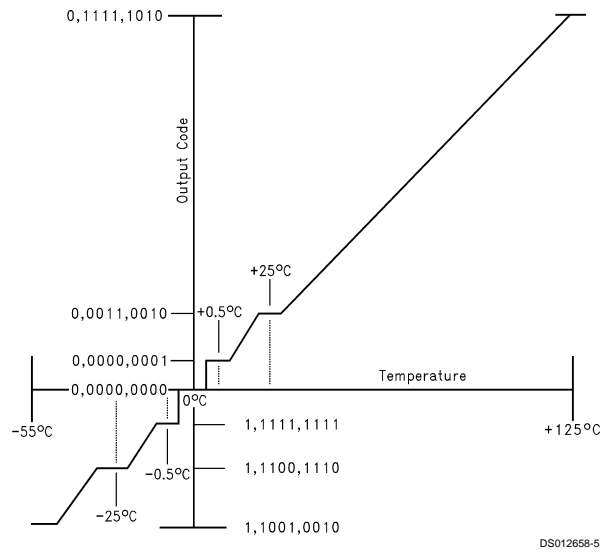## Logic Electrical Characteristics (Continued)

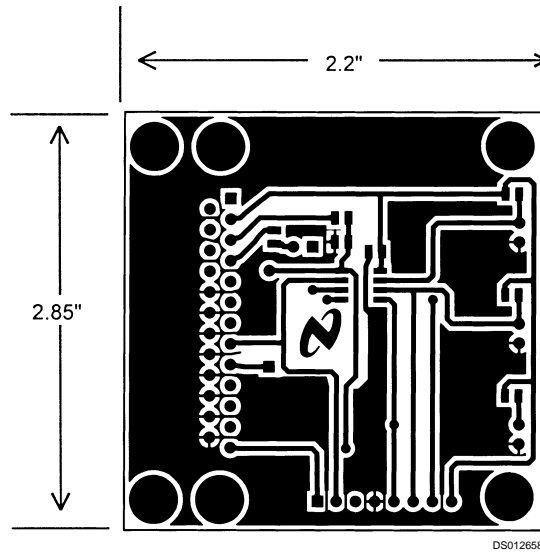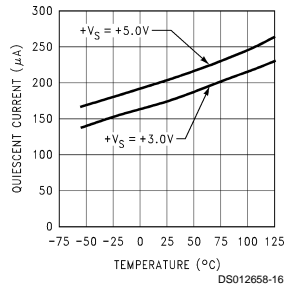**FIGURE 2. Temperature-to-Digital Transfer Function (Non-linear scale for clarity)**
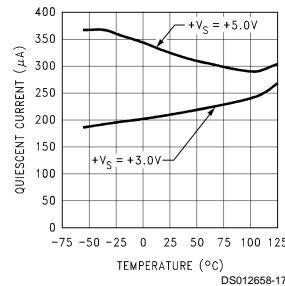

FIGURE 3. Printed Circuit Board Used for Thermal Resistance Specifications

Typical Performance Characteristics

Static Quiescent Current vs Temperature

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Dynamic Quiescent Current vs Temperature

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Accuracy vs Temperature

DS012658-18
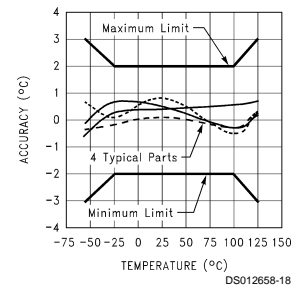
1.0 Functional Description

The LM75 temperature sensor incorporates a band-gap type temperature sensor and 9-bit ADC (Delta-Sigma Analog-to-Digital Converter). The temperature data output of the LM75 is available at all times via the I^{2}C 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.

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 I^{2}C 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 LM75 in shutdown mode also resets the O.S. Output.

1.2 POWER UP AND POWER DOWN

The LM75 always powers up in a known state. The power up default conditions are:

1. Comparator mode
2. T$_{OS}$ = 80˚C
3. T$_{HYST}$ = 75˚C
4. O.S. active low
5. Pointer = "00"

If the LM75 is not connected to the I^{2}C bus on power up, it will act as a stand-alone thermostat with the above temperature settings.

When the supply voltage is less than about 1.7V, the LM75 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.

1.3 I^{2}C BUS INTERFACE

The LM75 operates as a slave on the I^{2}C bus, so the SCL line is an input (no clock is generated by the LM75) and the SDA line is a bi-directional serial data path. According to I^{2}C bus specifications, the LM75 has a 7-bit slave address. The four most significant bits of the slave address are hard wired inside the LM75 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

1.0 Functional Description (Continued)

Temperature response
shown for O.S. set for
active low.

Time
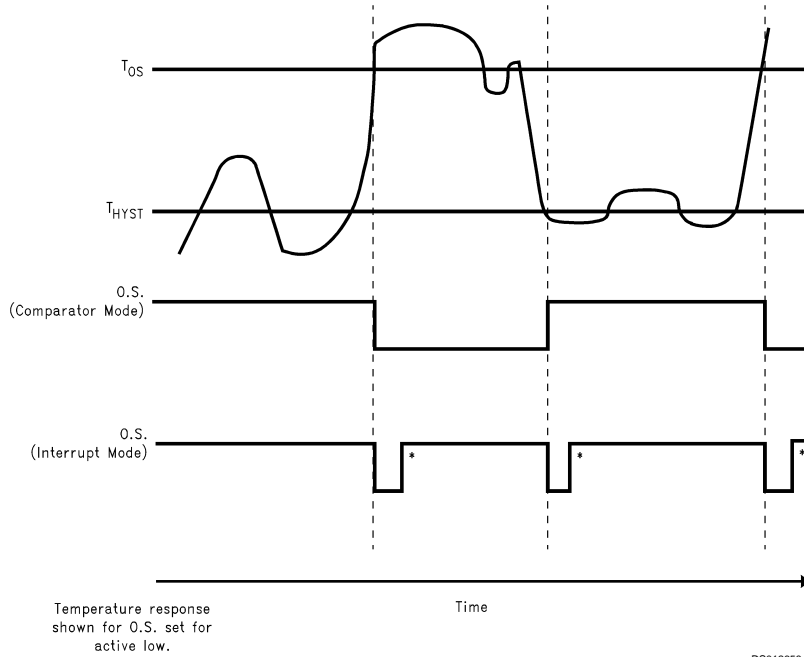
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Note 13: These interrupt mode resets of O.S. occur only when LM75 is read or placed in shutdown. Otherwise, O.S. would remain active indefinitely for any event.

FIGURE 4. O.S. Output Temperature Response Diagram

1.0 Functional Description (Continued)

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 to 1 µA typical. 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.

1.6 FAULT QUEUE

A fault queue of up to 6 faults is provided to prevent false tripping of O.S. when the LM75 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 LM75.

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 LM75. The maximum resistance of the pull up, based on LM75 specification for High Level Output Current, to provide a 2V high level, is 30 kΩ.

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.

1.0 Functional Description (Continued)

1.10 INTERNAL REGISTER STRUCTURE
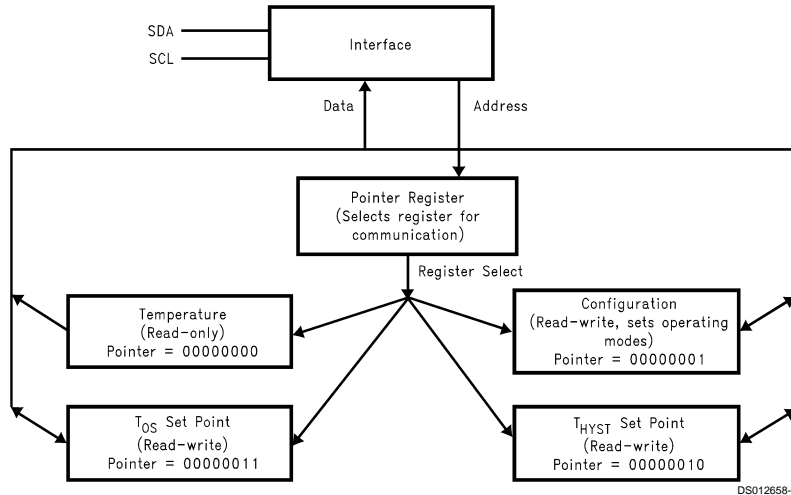
There are four data registers in the LM75, selected by the Pointer register. At power-up the Pointer is set to "00"; the location for the Temperature Register. The Pointer register latches whatever the last location it was set to. In Interrupt Mode, a read from the LM75, or placing the device in shutdown mode, resets the O.S. output. All registers are read and write, except the Temperature register which is read only.

A write to the LM75 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 LM75 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 LM75), 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 over-temperature condition, the host processor could immediately take action to remedy the excessive temperatures. At the end of a read, the LM75 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 LM75 to stop in a state where the SDA line is held low as shown in *Figure 5*. 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 LM75.
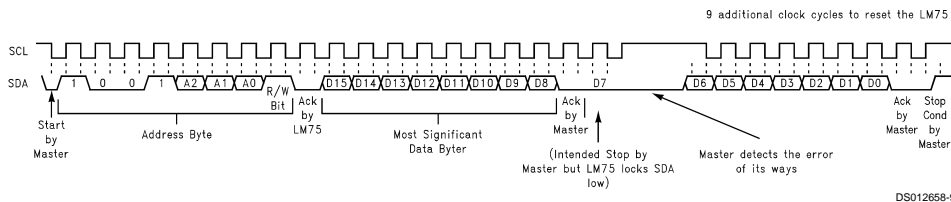
FIGURE 5. Inadvertent 8-Bit Read from 16-Bit Register where D7 is Zero ("0")

1.0 Functional Description (Continued)

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	0	Register Select	

P0-P1: Register Select:

P1	P0	Register
0	0	Temperature (Read only) (Power-up default)
0	1	Configuration (Read/Write)
1	0	T_{HYST} (Read/Write)
1	1	T_{OS} (Read/Write)

P2–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 LM75 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:

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.

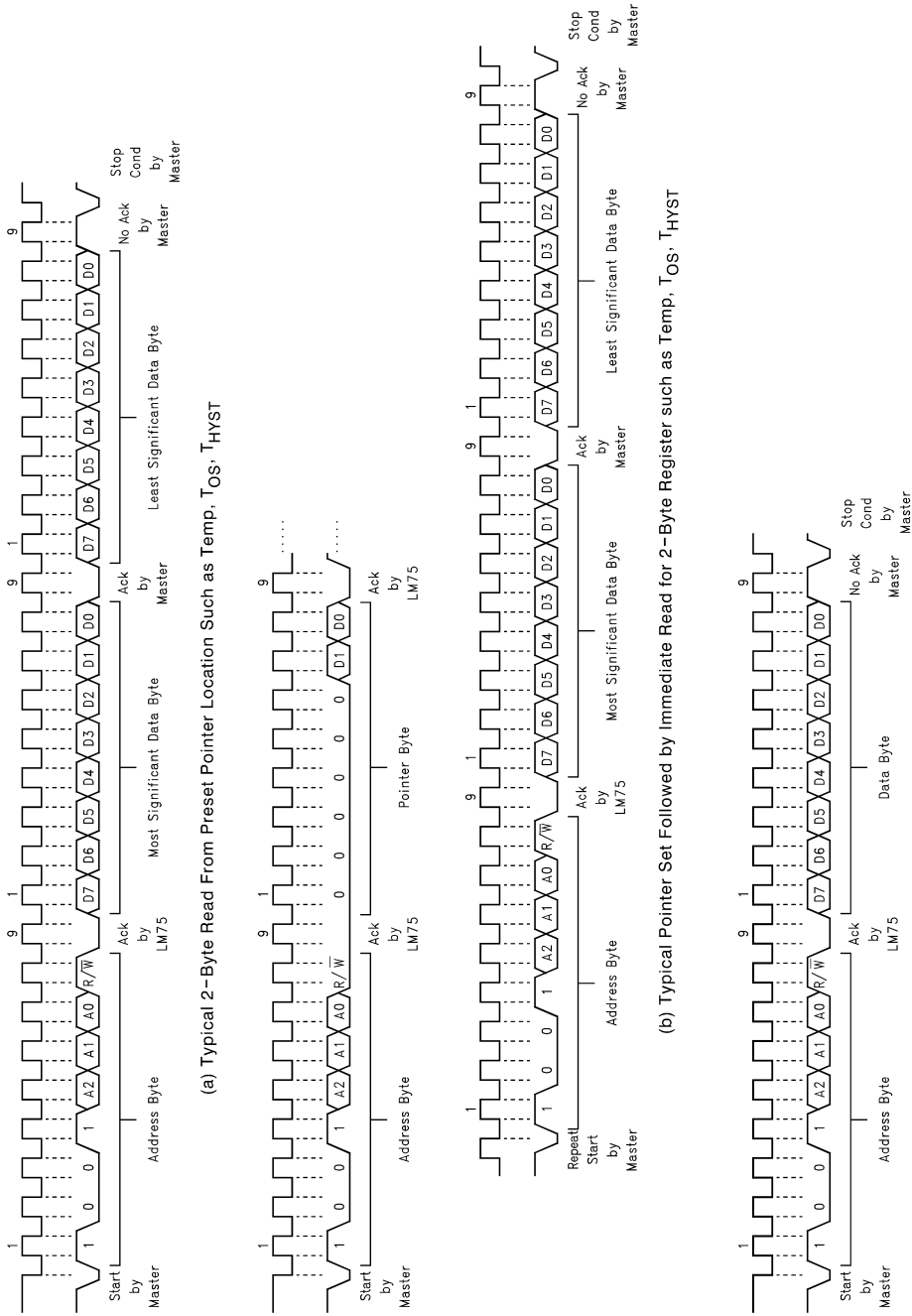### 1.14 T_{HYST} AND T_{OS} REGISTER

(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

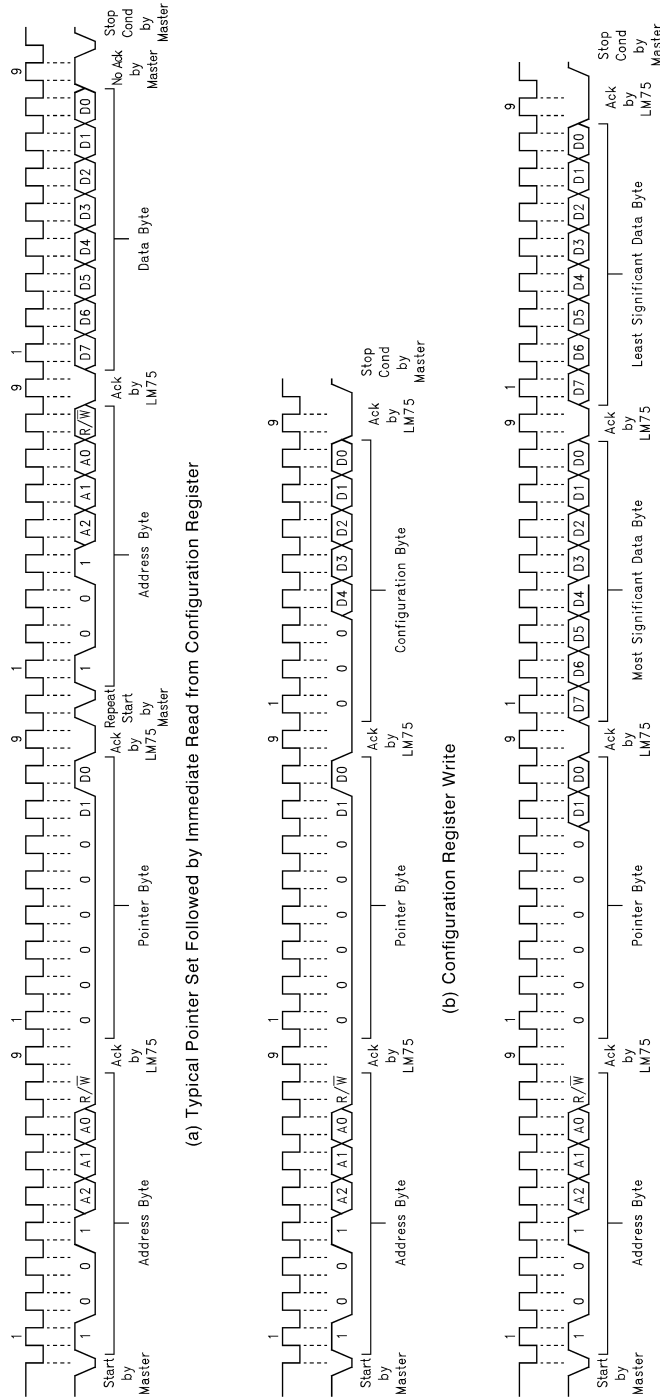D7–D15: T_{HYST} Or T_{OS} Trip Temperature Data. Power up default is T_{OS} = 80˚C, T_{HYST} = 75˚C.

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 6. Timing Diagram

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2.0 I²C Timing Diagrams (Continued)

DS012658-11

FIGURE 7. Timing Diagrams (Continued)

(a) Typical Pointer Set Followed by Immediate Read from Configuration Register

(b) Configuration Register Write

(c) T_OS and T_HYST Write

3.0 Application Hints

To get the expected results when measuring temperature with an integrated circuit temperature sensor like the LM75, it is important to understand that the sensor measures its own die temperature. For the LM75, the best thermal path between the die and the outside world is through the LM75'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 LM75 die, the LM75 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 LM75 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 LM75 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 LM75 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 LM75 or its connections.
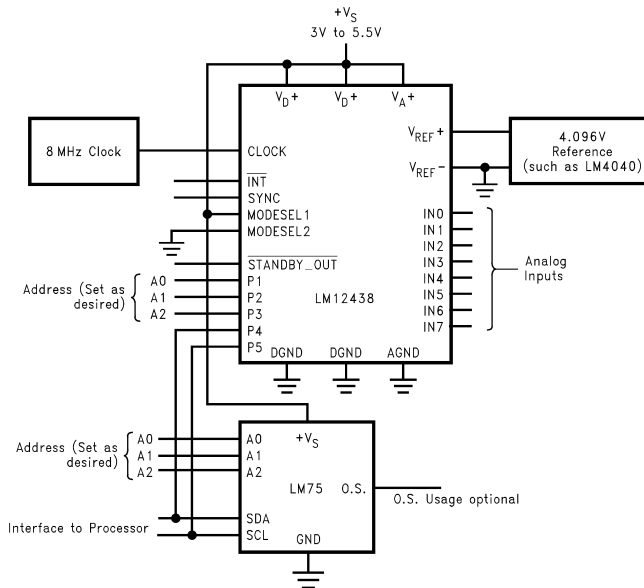
4.0 Typical Applications
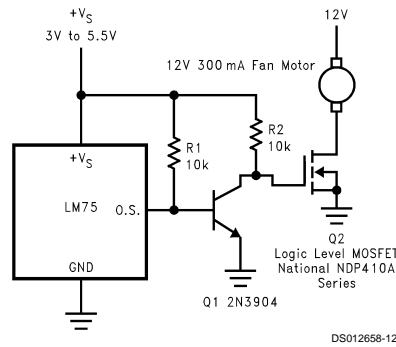
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When using the two-wire interface: program O.S. for active high and connect O.S. directly to Q2's gate.

FIGURE 8. Simple Fan Controller, Interface Optional

DS012658-13

FIGURE 9. Data Acquisition System with Temperature Input via I²C Bus
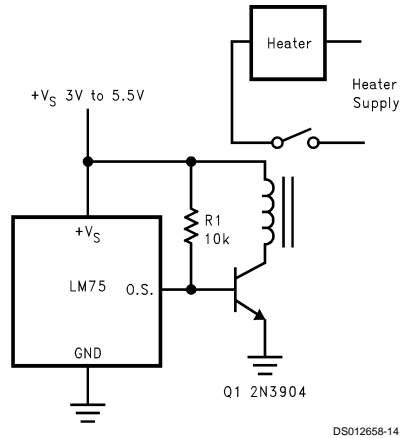
4.0 Typical Applications (Continued)

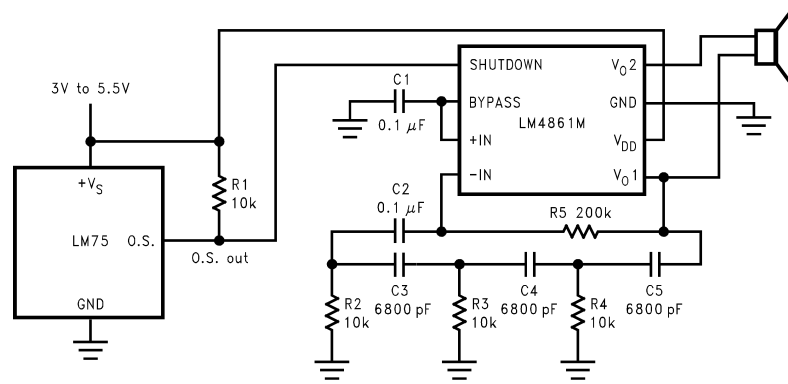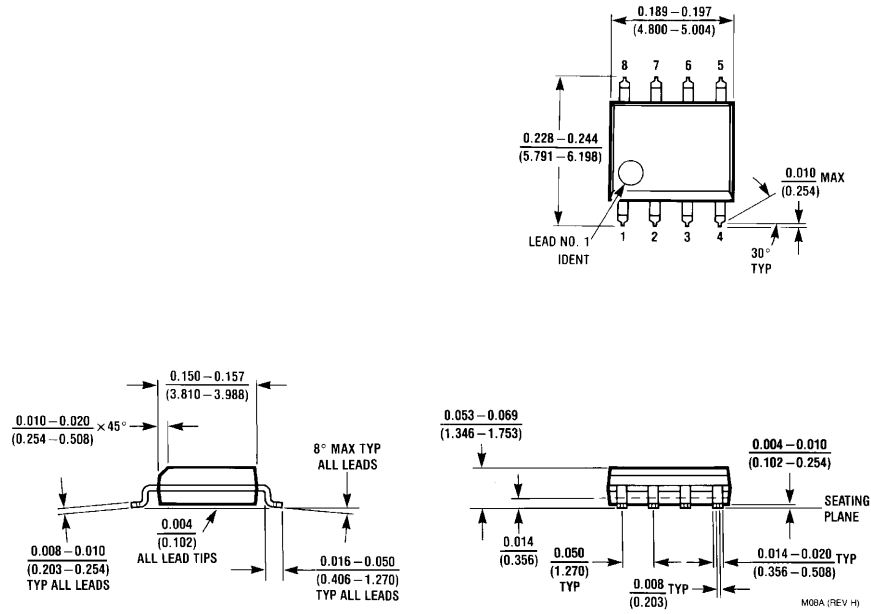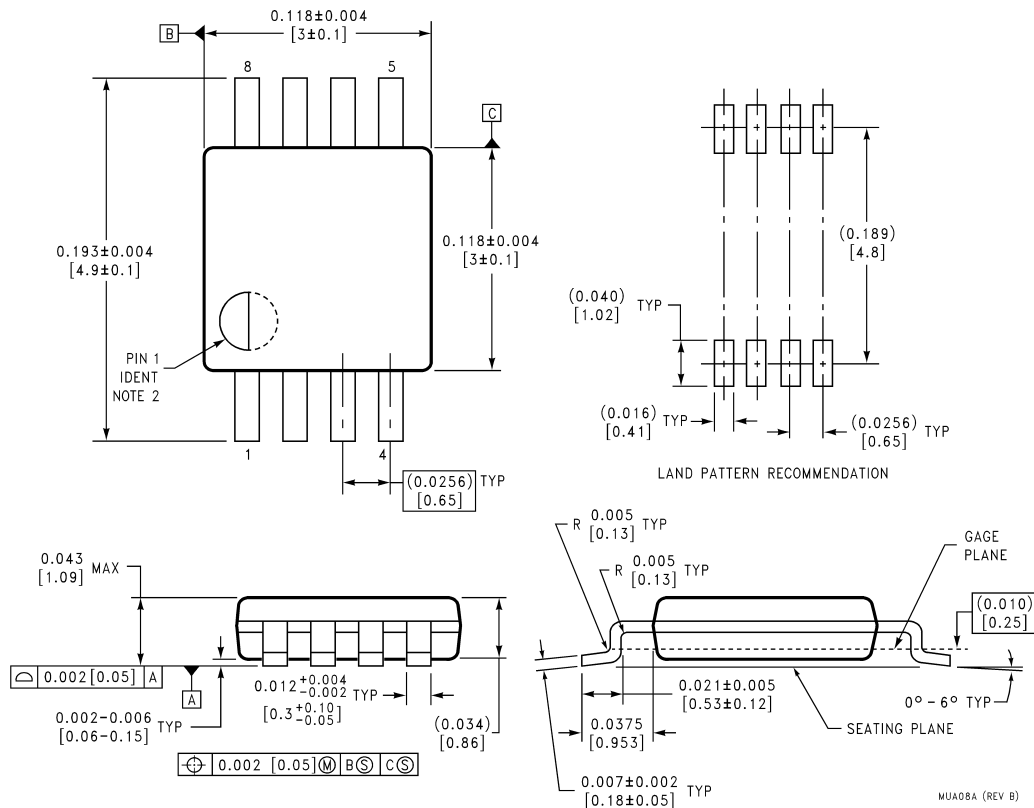FIGURE 10. Simple Thermostat, Interface Optional

FIGURE 11. Temperature Sensor with Loudmouth Alarm (Barking Watchdog)

Physical Dimensions inches (millimeters) unless otherwise noted

8-Lead (0.150" Wide) Molded Small Outline Package (SOP), JEDEC
Order Number LM75CIM-3, LM75CIMX-3, LM75CIM-5 or LM75CIMX-5
NS Package Number M08A

LM75 Digital Temperature Sensor and Thermal WATCHDOG with Two-Wire Interface

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

0.118±0.004
[3±0.1]

B

8   5

C

0.193±0.004
[4.9±0.1]

0.118±0.004
[3±0.1]

PIN 1
IDENT
NOTE 2

1   4

(0.0256) TYP
[0.65]

(0.189)
[4.8]

(0.040) TYP
[1.02]

(0.016) TYP
[0.41]

(0.0256) TYP
[0.65]

LAND PATTERN RECOMMENDATION

0.043 MAX
[1.09]

0.002[0.05] A

0.002−0.006 TYP
[0.06−0.15]

A

0.012 +0.004 −0.002 TYP
[0.3 +0.10 −0.05]

(0.034)
[0.86]

0.002 [0.05] M B S C S

R 0.005 TYP
[0.13]

R 0.005 TYP
[0.13]

GAGE
PLANE

(0.010)
[0.25]

0.021±0.005
[0.53±0.12]

0° − 6° TYP

0.0375
[0.953]

SEATING PLANE

0.007±0.002 TYP
[0.18±0.05]

MUA08A (REV B)

8-Lead Molded Mini Small Outline Package (MSOP)
(JEDEC REGISTRATION NUMBER M0-187)
Order Number LM75CIMM-3, LM75CIMMX-3,
LM75CIMM-5 or LM75CIMMX-5
NS Package Number MUA08A

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