

LM70

SPI/MICROWIRE™ 10-Bit plus Sign Digital Temperature Sensor

General Description

The LM70 is a temperature sensor, Delta-Sigma analog-to-digital converter with an SPI and MICROWIRE compatible interface available in LLP and MSOP 8-pin packages. The host can query the LM70 at any time to read temperature. A shutdown mode decreases power consumption to less than 10 μ A. This mode is useful in systems where low average power consumption is critical.

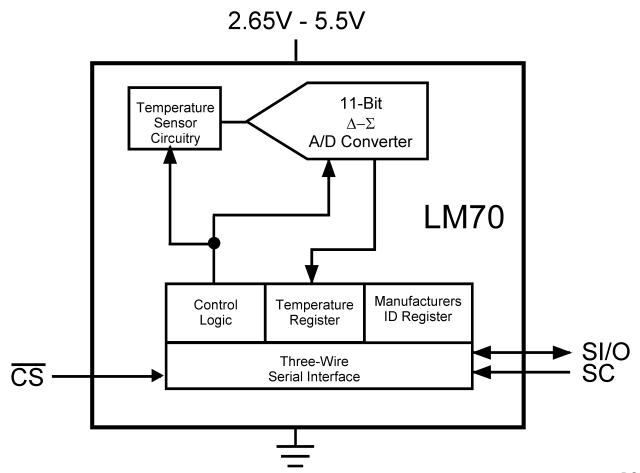
The LM70 has 10-bit plus sign temperature resolution (0.25°C per LSB) while operating over a temperature range of -55°C to +150°C.

The LM70's 2.65V to 5.5V supply voltage range, low supply current and simple SPI interface make it ideal for a wide range of applications. These include thermal management and protection applications in hard disk drives, printers, electronic test equipment, and office electronics.

Applications

- System Thermal Management
- Personal Computers
- Disk Drives
- Office Electronics

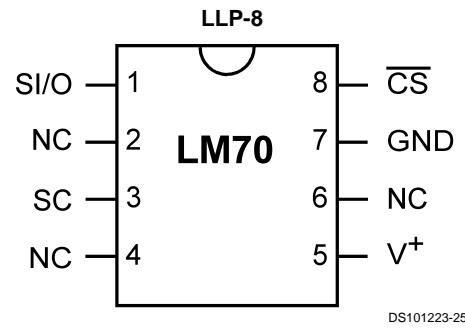
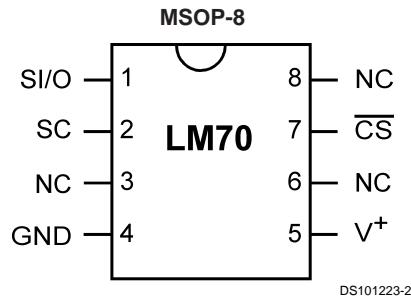
Simplified Block Diagram



DS101223-1

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Connection Diagrams



Ordering Information

Order Number	Package Marking	NS Package Number	Supply Voltage	Transport Media
LM70CILD-3	T33	LLP-8, LDA08A	2.65V to 3.6V	_ Units in Rail
LM70CILDX-3	T33	LLP-8, LDA08A	2.65V to 3.6V	_ Units in Rail
LM70CILD-5	T35	LLP-8, LDA08A	4.5V to 5.5V	_ Units in Tape and Reel
LM70CILDX-5	T35	LLP-8, LDA08A	4.5V to 5.5V	_ Units in Tape and Reel
LM70CIMM-3	T04C	MSOP-8, MUA08A	2.65V to 3.6V	250 Units in Rail
LM70CIMMX-3	T04C	MSOP-8, MUA08A	2.65V to 3.6V	3500 Units in Tape and Reel
LM70CIMM-5	T03C	MSOP-8, MUA08A	4.5V to 5.5V	250 Units in Rail
LM70CIMMX-5	T03C	MSOP-8, MUA08A	4.5V to 5.5V	3500 Units in Tape and Reel

Pin Descriptions

Label	SOP-8 Pin #	LLP-8 Pin #	Function	Typical Connection
SI/O	1	1	Input/Output - Serial bus bi-directional data line. Schmitt trigger input.	From and to Controller
SC	2	3	Clock - Serial bus clock Schmitt trigger input line.	From Controller
GND	4	7	Power Supply Ground	Ground
V ⁺	5	5	Positive Supply Voltage Input	DC Voltage from 2.65V to 5.5V. Bypass with a 0.1 μ F ceramic capacitor.
CS	7	8	Chip Select input.	From Controller
NC	3, 6, 8	2, 4, 6	No Connect	These pins are not connected to the LM70 die in any way.

Typical Application

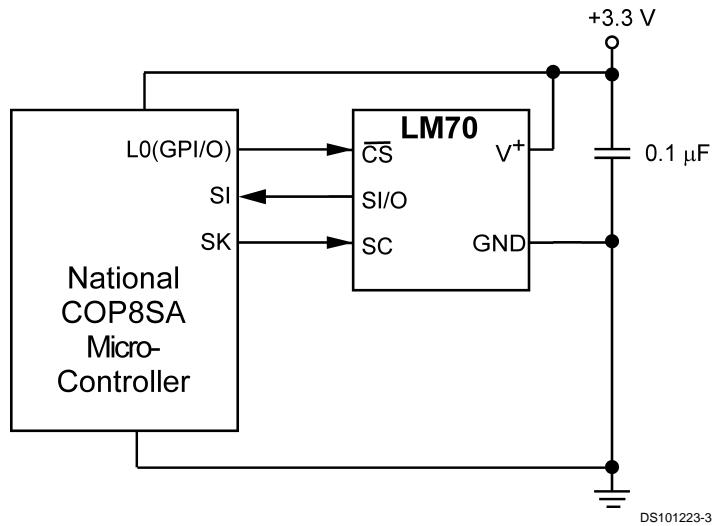


FIGURE 1. COP Microcontroller Interface

Absolute Maximum Ratings (Note 1)

Supply Voltage	-0.3V to 6.0V
Voltage at any Pin	-0.3V to $V^+ + 0.3V$
Input Current at any Pin (Note 2)	5 mA
Package Input Current (Note 2)	20 mA
Storage Temperature	-65°C to +150°C
Soldering Information, Lead Temperature (Note 3)	MSOP-8 and LLP-8 Packages Vapor Phase (60 seconds) Infrared (15 seconds)
	215°C 220°C

ESD Susceptibility (Note 4)

Human Body Model	3000V
Machine Model	300V

Operating Ratings

Specified Temperature Range (Note 5)	T_{MIN} to T_{MAX}
Supply Voltage Range ($+V_S$)	-55°C to +150°C +2.65V to +5.5V

Temperature-to-Digital Converter Characteristics

Unless otherwise noted, these specifications apply for $V^+ = 2.65V$ to 3.6V for the LM70-3 and $V^+ = 4.5V$ to 5.5V for the LM70-5 (Note 6). **Boldface** limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX} ; all other limits $T_A = T_J = +25^\circ C$, unless otherwise noted.

Parameter	Conditions	Typical (Note 7)	LM70-5 Limits (Note 8)	LM70-3 Limits (Note 8)	Units (Limit)
Temperature Error (Note 6)	$T_A = -10^\circ C$ to $+65^\circ C$		+1.5/-2.0	+1.5/-2.0	°C (max)
	$T_A = -40^\circ C$ to $+85^\circ C$		±2.0	±2.0	°C (max)
	$T_A = -55^\circ C$ to $+125^\circ C$		+3.0/-2.0	+3.0/-2.0	°C (max)
	$T_A = -55^\circ C$ to $+150^\circ C$		+3.5/-2.0	+3.5/-2.0	°C (max)
Resolution		11 0.25			Bits °C
Temperature Conversion Time	(Note 9)	140	210	210	ms (max)
Quiescent Current	Serial Bus Inactive	260	490	490	µA (max)
	Serial Bus Active	260			µA
	Shutdown Mode	12			µA

Logic Electrical Characteristics**DIGITAL DC CHARACTERISTICS**

Unless otherwise noted, these specifications apply for $V^+ = 2.65V$ to 3.6V for the LM70-3 and $V^+ = 4.5V$ to 5.5V for the LM70-5. **Boldface** limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX} ; all other limits $T_A = T_J = +25^\circ C$, unless otherwise noted.

Symbol	Parameter	Conditions	Typical (Note 7)	Limits (Note 8)	Units (Limit)
$V_{IN(1)}$	Logical "1" Input Voltage			$V^+ \times 0.7$ $V^+ + 0.3$	V (min) V (max)
$V_{IN(0)}$	Logical "0" Input Voltage			-0.3 $V^+ \times 0.3$	V (min) V (max)
	Input Hysteresis Voltage	$V^+ = 2.65V$ to 3.6V $V^+ = 4.5V$ to 5.5V	0.8 0.8	0.27 0.35	V (min) V (min)
$I_{IN(1)}$	Logical "1" Input Current	$V_{IN} = V^+$	0.005	3.0	µA (max)
$I_{IN(0)}$	Logical "0" Input Current	$V_{IN} = 0V$	-0.005	-3.0	µA (min)
C_{IN}	All Digital Inputs		20		pF
V_{OH}	High Level Output Voltage	$I_{OH} = -400 \mu A$		2.4	V (min)
V_{OL}	Low Level Output Voltage	$I_{OL} = +2 mA$		0.4	V (max)
$I_{O_TRI-STATE}$	TRI-STATE Output Leakage Current	$V_O = GND$ $V_O = V^+$		-1 +1	µA (min) µA (max)

Logic Electrical Characteristics (Continued)

SERIAL BUS DIGITAL SWITCHING CHARACTERISTICS

Unless otherwise noted, these specifications apply for $V^+ = 2.65V$ to $3.6V$ for the LM70-3 and $V^+ = 4.5V$ to $5.5V$ for the LM70-5, C_L (load capacitance) on output lines = 100 pF unless otherwise specified. **Boldface limits apply for $T_A = T_J = T_{\text{MIN}} \text{ to } T_{\text{MAX}}$** ; all other limits $T_A = T_J = +25^\circ\text{C}$, unless otherwise noted.

Symbol	Parameter	Conditions	Typical (Note 7)	Limits (Note 8)	Units (Limit)
t_1	SC (Clock) Period			0.16 DC	μs (min) (max)
t_2	$\overline{\text{CS}}$ Low to SC (Clock) High Set-Up Time			100	ns (max)
t_3	$\overline{\text{CS}}$ Low to Data Out (SO) Delay			70	ns (max)
t_4	SC (Clock) Low to Data Out (SO) Delay			70	ns (max)
t_5	$\overline{\text{CS}}$ High to Data Out (SO) TRI-STATE			200	ns (min)
t_6	SC (Clock) High to Data In (SI) Hold Time			60	ns (min)
t_7	Data In (SI) Set-Up Time to SC (Clock) High			30	ns (min)

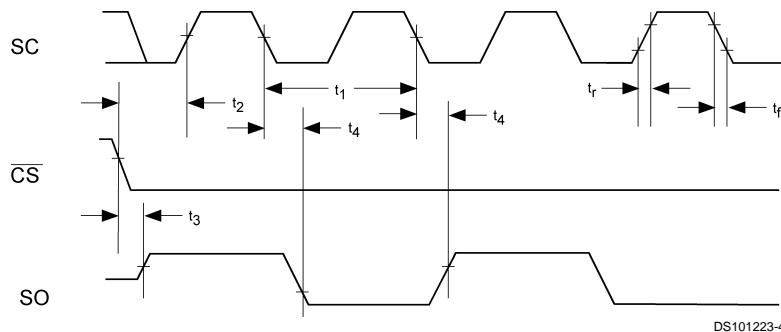


FIGURE 2. Data Output Timing Diagram

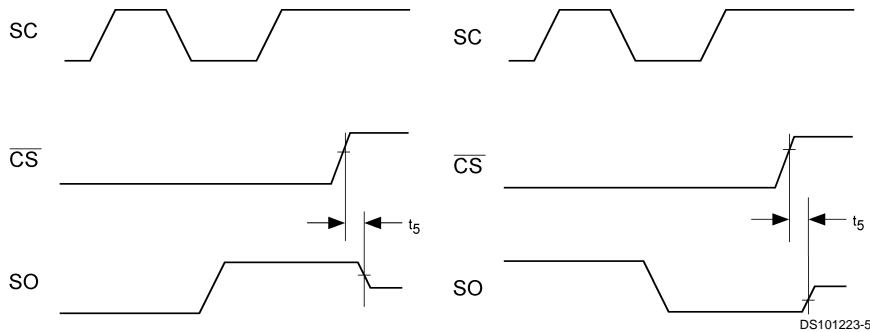


FIGURE 3. TRI-STATE Data Output Timing Diagram

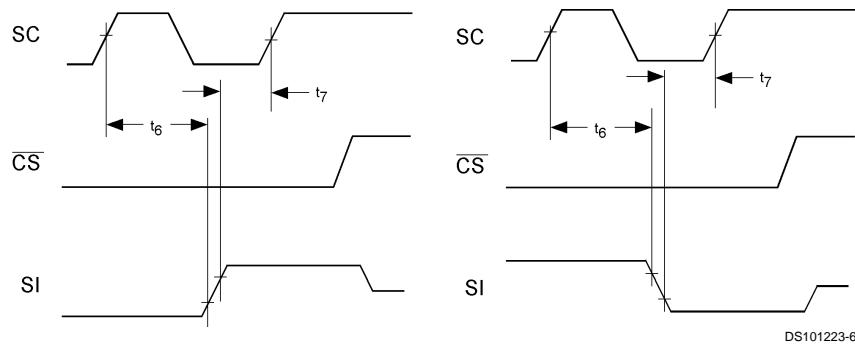


FIGURE 4. Data Input Timing Diagram

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 ($V_I < GND$ 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 kΩ resistor. Machine model, 200 pF discharged directly into each pin.

Note 5: The life expectancy of the LM70 will be reduced when operating at elevated temperatures. LM70 θ_{JA} (thermal resistance, junction-to-ambient) when attached to a printed circuit board with 2 oz. foil is summarized in the table below:

Device Number	NS Package Number	Thermal Resistance (θ_{JA})
LM70CILD	LDA08A	51.3°C/W
LM70CIMM	MUA08A	200°C/W

Note 6: Both part numbers of the LM70 will operate properly over the V^+ supply voltage range of 2.65V to 5.5V. The temperature error for temperature ranges of $-10^{\circ}C$ to $+65^{\circ}C$, $-40^{\circ}C$ to $+85^{\circ}C$, $-55^{\circ}C$ to $+125^{\circ}C$ and $-55^{\circ}C$ to $+150^{\circ}C$ include error induced by power supply variation of $\pm 5\%$ from the nominal value. Temperature error will increase by $\pm 0.3^{\circ}C$ for a power supply voltage (V^+) variation of $\pm 10\%$ from the nominal value.

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

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

Note 9: This specification is provided only to indicate how often temperature data is updated. The LM70 can be read at any time without regard to conversion state (and will yield last conversion result). A conversion in progress will not be interrupted. The output shift register will be updated at the completion of the read and a new conversion restarted.

Note 10: For best accuracy, minimize output loading. Higher sink currents can affect sensor accuracy with internal heating. This can cause an error of $0.64^{\circ}C$ at full rated sink current and saturation voltage based on junction-to-ambient thermal resistance.

Electrical Characteristics

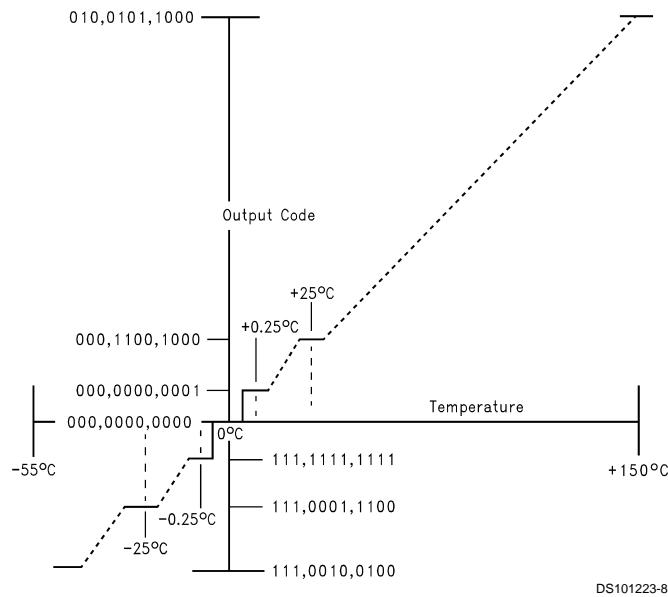
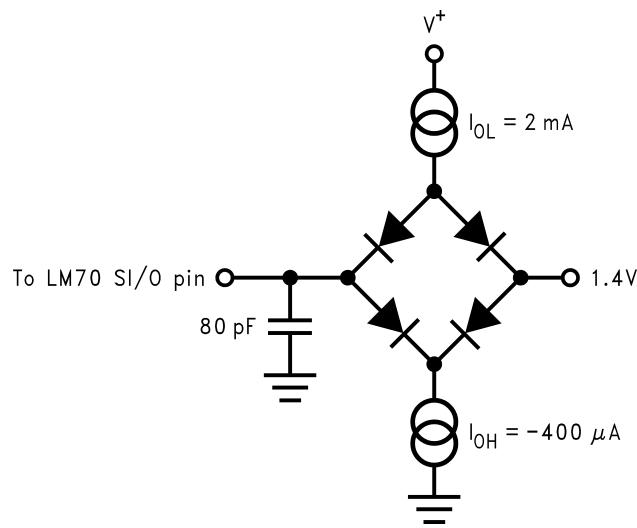


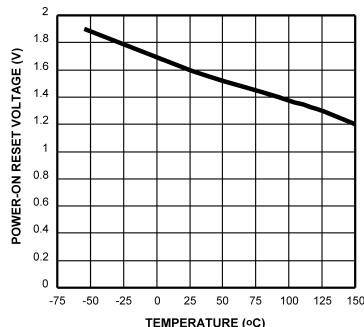
FIGURE 5. Temperature-to-Digital Transfer Function (Non-linear scale for clarity)

TRI-STATE Test Circuit



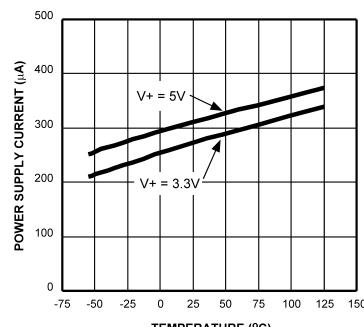
Typical Performance Characteristics

Average Power-On Reset Voltage vs Temperature



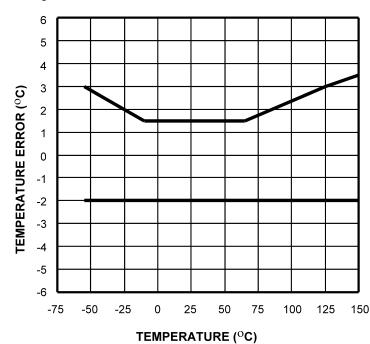
DS101223-23

Static Supply Current vs Temperature



DS101223-21

Temperature Error



DS101223-22

1.0 Functional Description

The LM70 temperature sensor incorporates a band-gap type temperature sensor and 10-bit plus sign $\Delta\Sigma$ ADC (Delta-Sigma Analog-to-Digital Converter). Compatibility of the LM70's three wire serial interface with SPI and MICROWIRE allows simple communications with common microcontrollers and processors. Shutdown mode can be used to optimize current drain for different applications. A manufacturer's ID register identifies the LM70 as National Semiconductor product.

1.1 POWER UP AND POWER DOWN

The LM70 always powers up in a known state. The power up default condition is continuous conversion mode. Immediately after power up the LM70 will output an erroneous code until the first temperature conversion has completed.

When the supply voltage is less than about 1.6V (typical), the LM70 is considered powered down. As the supply voltage rises above the nominal 1.6V power up threshold, the internal registers are reset to the power up default state described above.

1.2 SERIAL BUS INTERFACE

The LM70 operates as a slave and is compatible with SPI or MICROWIRE bus specifications. Data is clocked out on the falling edge of the serial clock (SC), while data is clocked in on the rising edge of SC. A complete transmit/receive communication will consist of 32 serial clocks. The first 16 clocks comprise the transmit phase of communication, while the second 16 clocks are the receive phase.

When \overline{CS} is high SI/O will be in TRISTATE®. Communication should be initiated by taking chip select (\overline{CS}) low. This should not be done when SC is changing from a low to high state. Once \overline{CS} is low the serial I/O pin (SI/O) will transmit the first bit of data. The master can then read this bit with the rising edge of SC. The remainder of the data will be clocked out by the falling edge of SC. Once the 14 bits of data (one sign bit, ten temperature bits and 3 high bits) are transmitted the SI/O line will go into TRI-STATE. \overline{CS} can be taken high at any time during the transmit phase. If \overline{CS} is brought low in the middle of a conversion the LM70 will complete the conversion and the output shift register will be updated after \overline{CS} is brought back high.

The receive phase of a communication starts after 16 SC periods. \overline{CS} can remain low for 32 SC cycles. The LM70 will read the data available on the SI/O line on the rising edge of the serial clock. Input data is to an 8-bit shift register. The

part will detect the last eight bits shifted into the register. The receive phase can last up to 16 SC periods. All ones must be shifted in order to place the part into shutdown. A zero in any location will take the LM70 out of shutdown. The following codes only should be transmitted to the LM70:

- 00 hex (normal operation)
- 01 hex (normal operation)
- 03 hex (normal operation)
- 07 hex (normal operation)
- 0F hex (normal operation)
- 1F hex (normal operation)
- 3F hex(normal operation)
- 7F hex(normal operation)
- FF hex (Shutdown, transmit manufacturer's ID)

any others may place the part into a Test Mode. Test Modes are used by National Semiconductor to thoroughly test the function of the LM70 during production testing. Only eight bits have been defined above since only the last eight transmitted, before \overline{CS} is taken HIGH, are detected by the LM70

The following communication can be used to determine the Manufacturer's/Device ID and then immediately place the part into continuous conversion mode. With \overline{CS} continuously low:

- Read 16 bits of temperature data
- Write 16 bits of data commanding shutdown
- Read 16 bits of Manufacture's/Device ID data
- Write 8 to 16 bits of data commanding Conversion Mode
- Take \overline{CS} HIGH.

Note that 250 ms will have to pass for a conversion to complete before the LM70 actually transmits temperature data.

1.0 Functional Description (Continued)

1.3 TEMPERATURE DATA FORMAT

Temperature data is represented by a 11-bit, two's complement word with an LSB (Least Significant Bit) equal to 0.25°C:

Temperature	Digital Output	
	Binary	Hex
+150°C	0100 1011 0001 1111	4B 1Fh
+125°C	0011 1110 1001 1111	3E 9Fh
+25°C	0000 1100 1001 1111	0B 9Fh
+0.25°C	0000 0000 0011 1111	00 3Fh
0°C	0000 0000 0001 1111	00 1Fh
-0.25°C	1111 1111 1111 1111	FF FFh
-25°C	1111 0011 1001 1111	F3 9Fh
-55°C	1110 0100 1001 1111	E4 9Fh

1.5 INTERNAL REGISTER STRUCTURE

The LM70 has three registers, the temperature register, the configuration register and the manufacturer's/device identification register. The temperature and manufacturer's/device identification registers are read only. The configuration register is write only.

1.5.1 CONFIGURATION REGISTER

(Selects shutdown or continuous conversion modes):

(Write Only):

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
X	X	X	X	X	X	X	X								Shutdown

D0-D15 set to XX FF hex enables shutdown mode.

D0-D15 set to XX 00 hex enables continuous conversion mode.

Note: setting D0-D15 to any other values may place the LM70 into a manufacturer's test mode, upon which the LM70 will stop responding as described. These test modes are to be used for National Semiconductor production testing only. See Section 1.2 Serial Bus Interface for a complete discussion.

1.5.2 TEMPERATURE REGISTER

(Read Only):

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

D0-D1: Undefined. TRI-STATE will be output on SI/0.

D2-D4: Always set high.

D5-D15: Temperature Data. One LSB = 0.25°C. Two's complement format.

1.5.3 MANUFACTURER'S/DEVICE ID REGISTER

(Read Only):

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
1	0	0	0	0	0	0	1	0	0	0	0	0	0	X	X

D0-D1: Undefined. TRI-STATE will be output on SI/0.

D2-D4: Always set LOW.

D5-D15: Manufacturer's ID Data. This register is accessed whenever the LM70 is in shutdown mode.

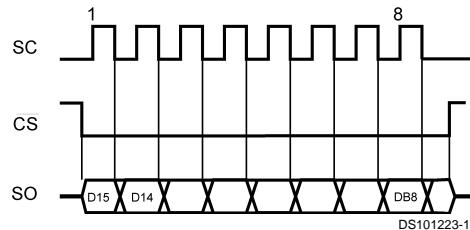
Note: The last two bits are TRI-STATE and depicted as one in the table.

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 indicate an over-temperature condition, the host processor could immediately take action to remedy the excessive temperatures.

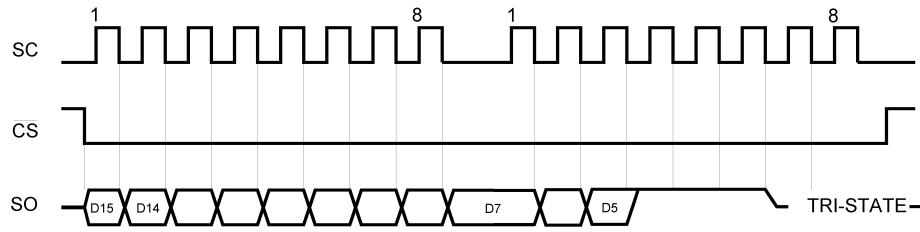
1.4 SHUTDOWN MODE/MANUFACTURER'S ID

Shutdown mode is enabled by writing XX FF to the LM70 as shown in Figure 7c and discussed in Section 1.2. The serial bus is still active when the LM70 is in shutdown. Current draw drops to less than 10 μ A between serial communications. When in shutdown mode the LM70 always will output 1000 0001 0000 00XX. This is the manufacturer's ID/Device ID information. The first 5-bits of the field (1000 0XXX) are reserved for manufacturer's ID.

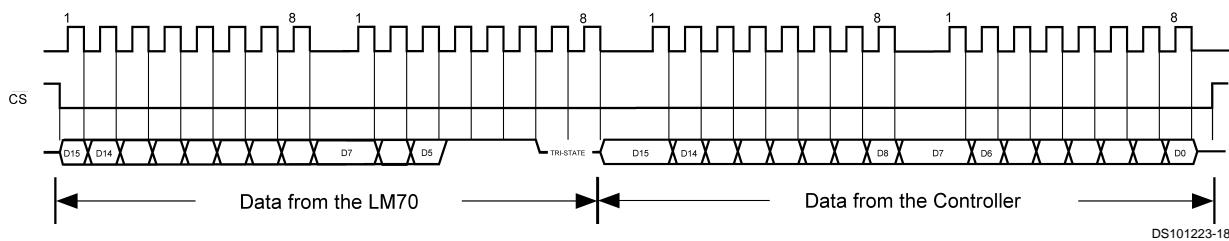
2.0 Serial Bus Timing Diagrams



a) Reading Continuous Conversion - Single Eight-Bit Frame



b) Reading Continuous Conversion - Two Eight-Bit Frames



c) Writing Shutdown Control

FIGURE 7. Timing Diagrams

3.0 Application Hints

To get the expected results when measuring temperature with an integrated circuit temperature sensor like the LM70, it is important to understand that the sensor measures its own die temperature. For the LM70, the best thermal path between the die and the outside world is through the LM70's pins. In the MSOP-8 package the ground pin is connected to the back side of the LM70 die and thus has the most effect on the die temperature. Although the other pins will also have some effect on the LM70 die temperature and therefore should not be discounted. The LM70 will provide an accurate measurement of the temperature of the printed circuit board on which it is mounted, because the pins represent a good thermal path to the die. A less efficient thermal path exists

between the plastic package and the LM70 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 LM70 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 LM70 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 LM70 or its connections.

4.0 Typical Applications

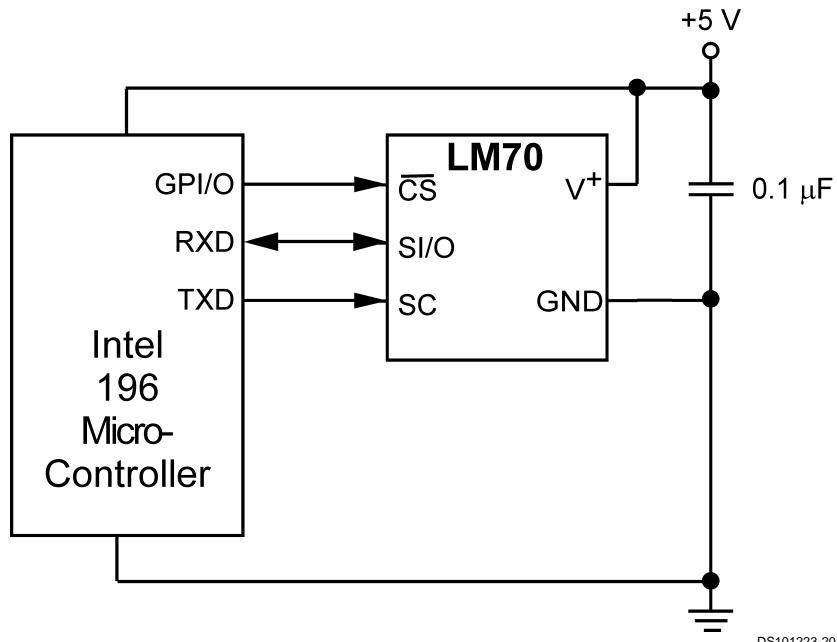


FIGURE 8. Temperature monitor using Intel 196 processor

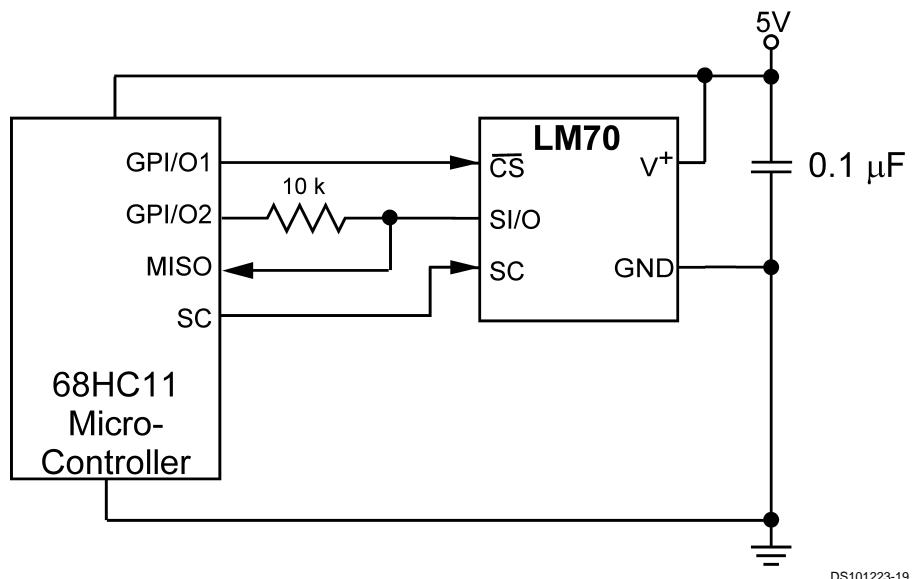
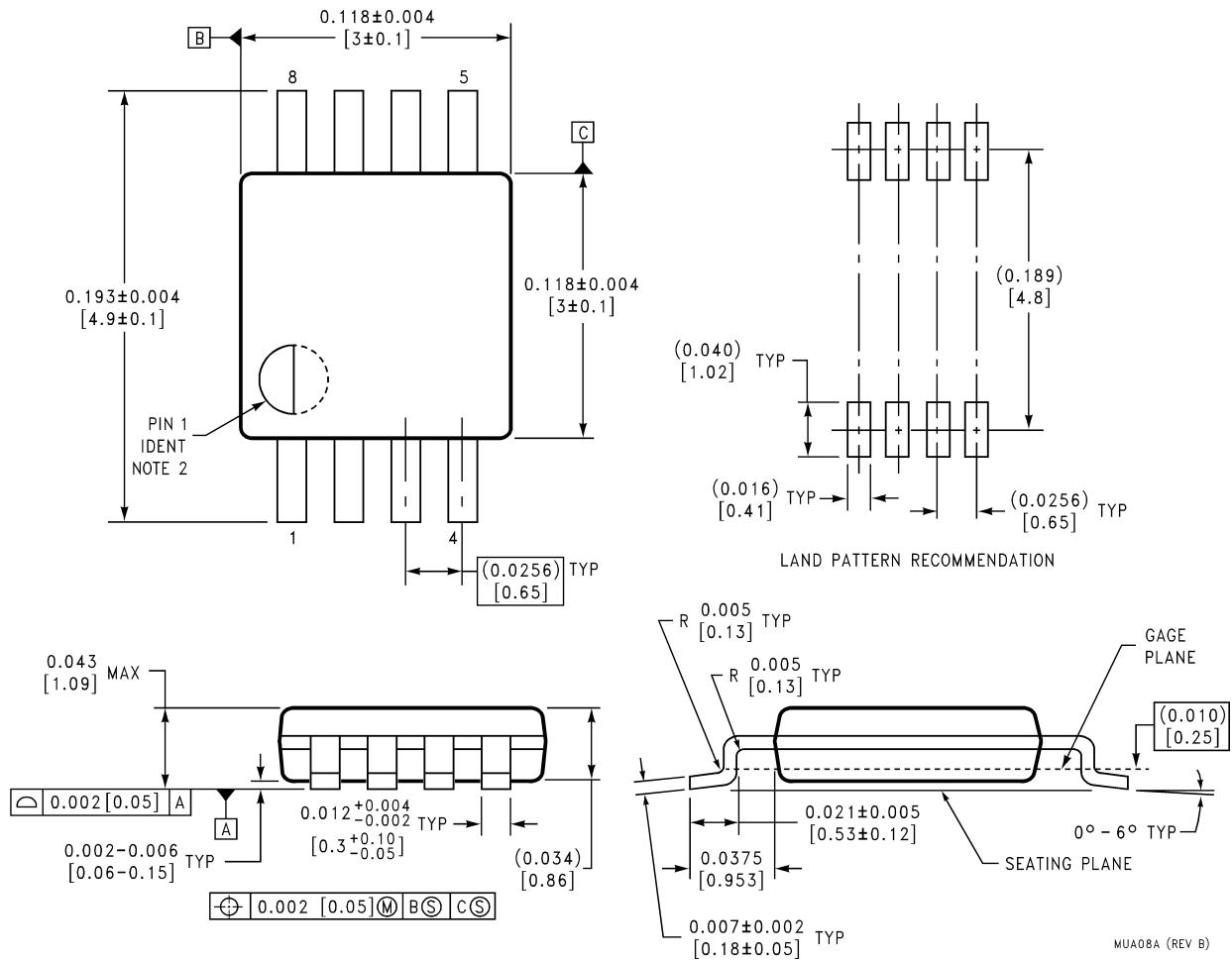


FIGURE 9. LM70 digital input control using micro-controller's general purpose I/O.

Physical Dimensions

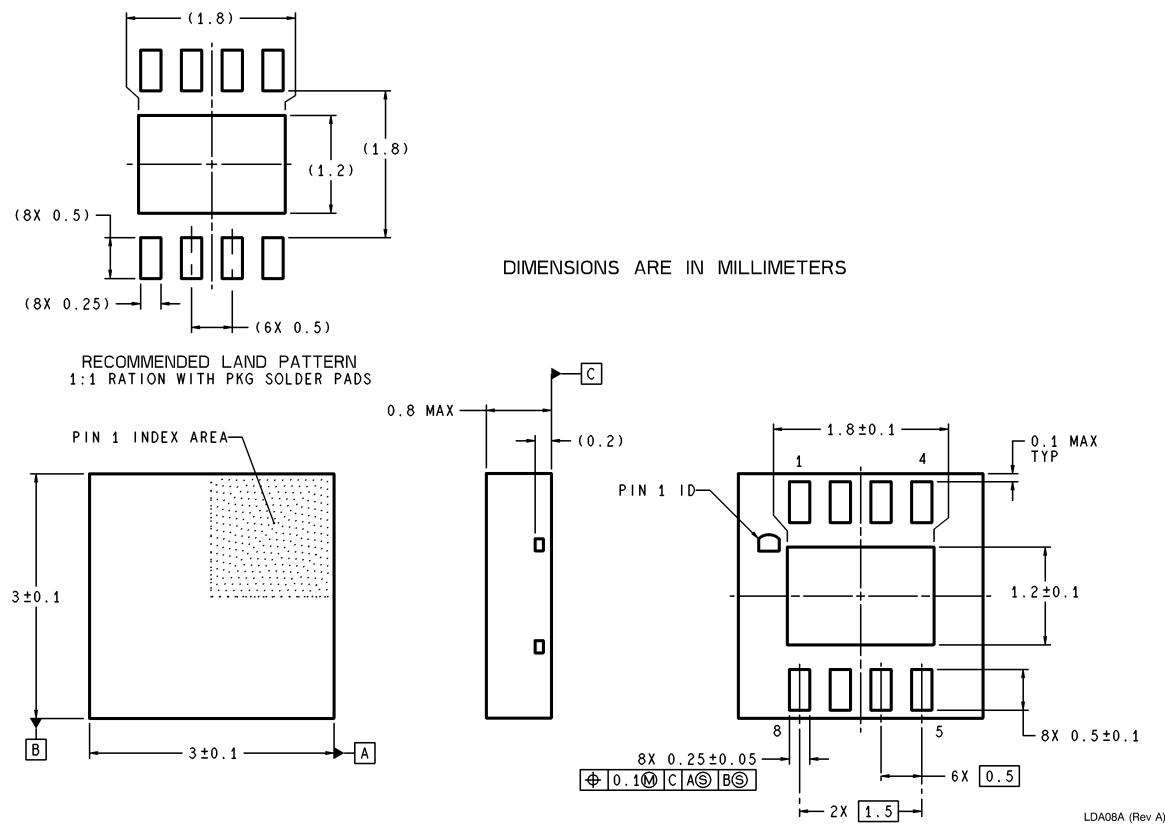
inches (millimeters) unless otherwise noted



8-Lead Molded Mini Small Outline Package (MSOP)
(JEDEC REGISTRATION NUMBER M0-187)

Order Number LM70CIMM-3, LM70CIMMX-3, LM70CIMM-5 or LM70CIMMX-5
NS Package Number MUA08A

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



8-Lead Molded Lead Less Package
Order Number LM70CILD-3, LM70CILDX-3, LM70CILD-5 or LM70CILDX-5
NS Package Number LDA08A

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