August 2004

N *National Semiconductor*

LM95071
SPI/MICROWIRE™ 13-Bit Plus Sign Temperature Sensor

General Description

The LM95071 is a low-power, high-resolution digital temperature sensor with an SPI and MICROWIRE compatible interface, available in the 5-pin SOT23. The host can query the LM95071 at any time to read temperature. Its low operating current is useful in systems where low power consumption is critical.

The LM95071 has 13-bit plus sign temperature resolution (0.03125˚C per LSB) while operating over a temperature range of −40˚C to +150˚C.

The LM95071's 2.4V to 5.5V supply voltage range, fast conversion rate, low supply current, and simple SPI interface make it ideal for a wide range of applications.

Applications

- System Thermal Management
- Portable Electronic Devices
- Personal Computers
- Disk Drives
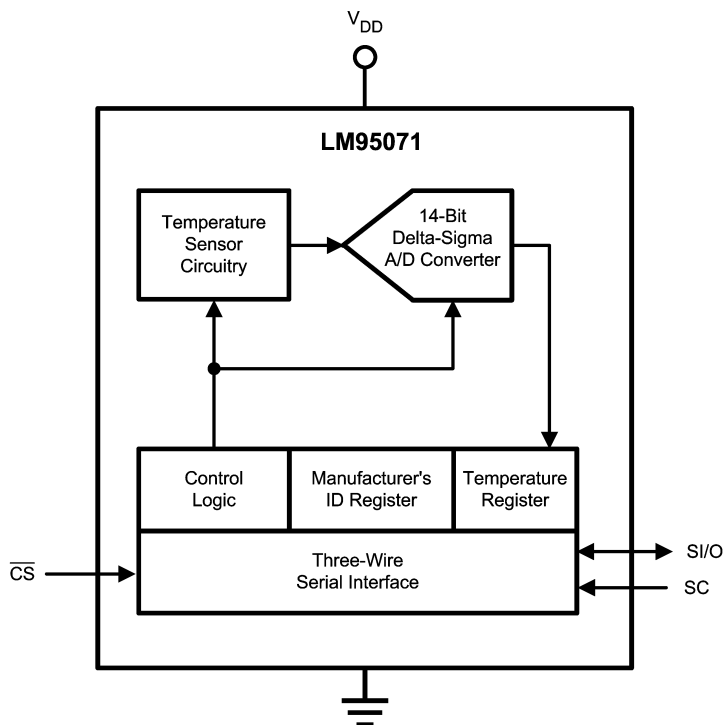- Office Electronics
- Electronic Test Equipment

Features

- Small SOT23-5 package saves space
- Shutdown mode conserves power between temperature readings
- Operates over a full −40˚C to +150˚C range
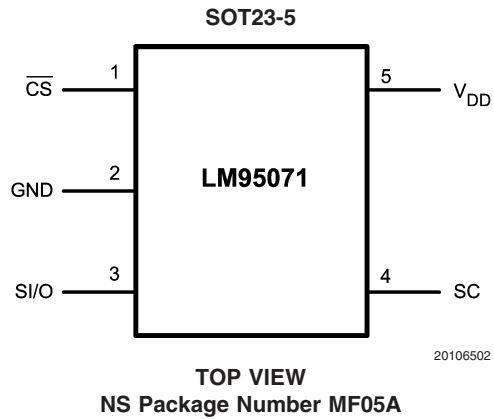- SPI and MICROWIRE Bus interface

Key Specifications

■ Supply Voltage		2.4V to 5.5V
■ Supply Current	operating	280 µA (typ)
	shutdown	6 µA (typ)
■ Temperature Accuracy	0˚C to 70˚C	±1˚C (max)
	−40˚C to 150˚C	±2˚C (max)
■ Temperature Resolution		0.03125 ˚C

Simplified Block Diagram

20106501

Connection Diagram

SOT23-5

$\overline{CS}$ — 1

GND — 2

SI/O — 3

LM95071

5 — V$_{DD}$

4 — SC

20106502

TOP VIEW
NS Package Number MF05A

Ordering Information

Order Number	Top Mark	NS Package Number	Supply Voltage	Transport Media
LM95071CIMFX	T18C	MF05A	2.4V to 5.5V	3000 Units in Tape and Reel

Pin Descriptions

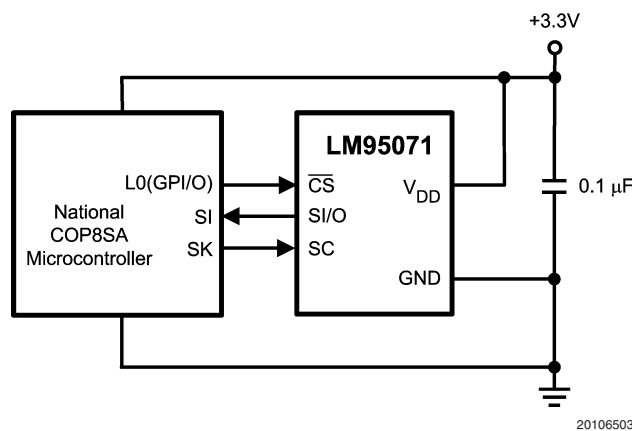| Pin Number	Symbol	Name	Description
1	$\overline{CS}$	Chip Select input	This pin receives an active-low signal from the controller to select the device.
2	GND	Ground	This is the power and signal ground return.
3	SI/O	Serial Input/Output	This serial, bi-directional, data bus pin transmits and receives signals to and from the controller. Schmitt trigger input in the input mode.
4	SC	Serial bus clock	This serial clock signal comes from the controller. Schmitt trigger input.
5	V$_{DD}$	Positive Supply Voltage	Supply a DC voltage from 2.4V to 5.5V to this pin and bypass with a 0.1 µF ceramic capacitor to ground.

Typical Application

+3.3V

National COP8SA Microcontroller

L0(GPI/O)
SI
SK

LM95071

$\overline{CS}$ V$_{DD}$
SI/O
SC
GND

0.1 µF

20106503

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_{DD} + 0.3V
Input Current at any Pin (Note 2)	5 mA
Storage Temperature	−65°C to +150°C
ESD Susceptibility (Note 4)	
Human Body Model	2000V
Machine Model	200V

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

Operating Ratings

Specified Temperature Range	
(Note 5)	T_{MIN} to T_{MAX}
LM95071CIMF	−40°C to +150°C
Supply Voltage Range (V_{DD})	
LM95071CIMF	2.4V to +5.5V

Temperature-to-Digital Converter Characteristics

Unless otherwise noted, these specifications apply for V_{DD} = 3.3V . **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 7)	LM95071CIMF Limits (Note 8)	Units (Limit)
Temperature Error (Note 6)	V_{DD} = 3.0V to 3.6V; T_A = 0°C to +70°C		**±1.0**	°C (max)
	V_{DD} = 3.0V to 3.6V; T_A = −40°C to +150°C		**±2.0**	°C (max)
Line Regulation	V_{DD} = 3.6V to 5.5V; T_A = 0°C to +70°C		+0.3	°C/V
	V_{DD} = 3.0V to 2.4V; T_A = 0°C to +70°C		-0.6	(max)
Resolution		14 / 0.03125		Bits / °C
Temperature Conversion Time	(Note 9)	130	**228**	ms (max)
Quiescent Current	Operating, Serial Bus Inactive	280	**520**	µA (max)
	Shutdown	6	**28**	µA (max)

Logic Electrical Characteristics

DIGITAL DC CHARACTERISTICS Unless otherwise noted, these specifications apply for V_{DD} = 2.4 to 5.5V (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.

| Symbol	Parameter	Conditions	Typical (Note 7)	Limits (Note 8)	Units (Limit)
$V_{IN(1)}$	Logical "1" Input Voltage			**0.7 x V_{DD}**	V (min)
				V_{DD} + 0.3	V (max)
$V_{IN(0)}$	Logical "0" Input Voltage			**−0.3**	V (min)
				0.3 x V_{DD}	V (max)
	Input Hysteresis Voltage	V_{DD} = 3.0V to 3.6V	0.4	**0.33**	V (min)
$I_{IN(1)}$	Logical "1" Input Current	$V_{IN} = V_{DD}$	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 µA		**2.25**	V (min)
V_{OL}	Low Level Output Voltage	I_{OL} = +1.6 mA		**0.4**	V (max)
$I_{O\_TRI-STATE}$	TRI-STATE ®Output Leakage Current	V_O = GND		**−1**	µA (min)
		$V_O = V_{DD}$		**+1**	µA (max)

Logic Electrical Characteristics (Continued)

SERIAL BUS DIGITAL SWITCHING CHARACTERISTICS Unless otherwise noted, these specifications apply for V_{DD} = 2.4V to 5.5V (Note 6); C_L (load capacitance) on output lines = 100 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 7)	Limits (Note 8)	Units (Limit)
t_1	SC (Clock) Period			**0.16**	μs (min)
				DC	(max)
t_2	$\overline{CS}$ Low to SC (Clock) High Set-Up Time			**100**	ns (min)
t_3	$\overline{CS}$ Low to Data Out (SO) Delay			**70**	ns (max)
t_4	SC (Clock) Low to Data Out (SO) Delay			**70**	ns (max)
t_5	$\overline{CS}$ High to Data Out (SO) TRI-STATE			**200**	ns (max)
t_6	SC (Clock) High to Data In (SI) Hold Time			**50**	ns (min)
t_7	Data In (SI) Set-Up Time to SC (Clock) High			**30**	ns (min)
t_8	SC (Clock) High to $\overline{CS}$ High Hold Time			**50**	ns (min)
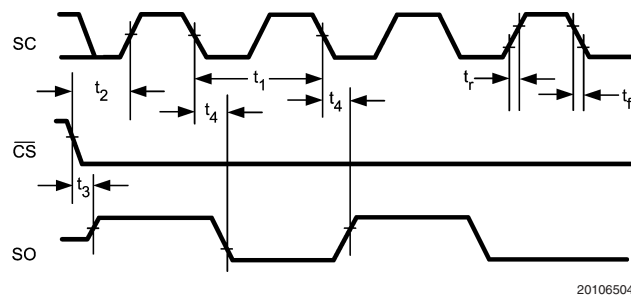
20106504

FIGURE 2. Data Output Timing Diagram
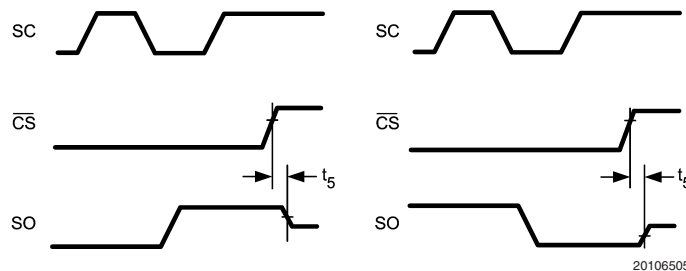
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FIGURE 3. TRI-STATE Data Output Timing Diagram
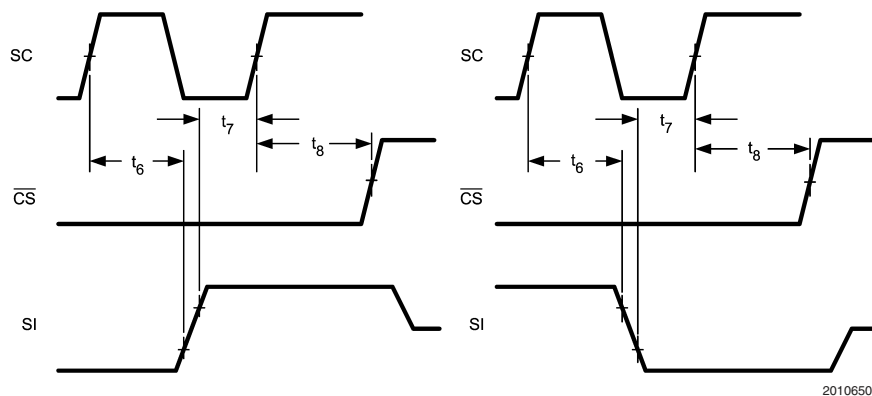
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FIGURE 4. Data Input Timing Diagram

Logic Electrical Characteristics (Continued)

Notes

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_{DD}) the current at that pin should be limited to 5 mA.

Note 3: Reflow temperature profiles are different for lead-free and non-lead-free packages.

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 LM95071 will be reduced when operating at elevated temperatures. LM95071 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})
LM95071CIMF	MF05A	250˚C/W

Note 6: The LM95071 will operate properly over the V_{DD} supply voltage range of 2.4V to 5.5V.

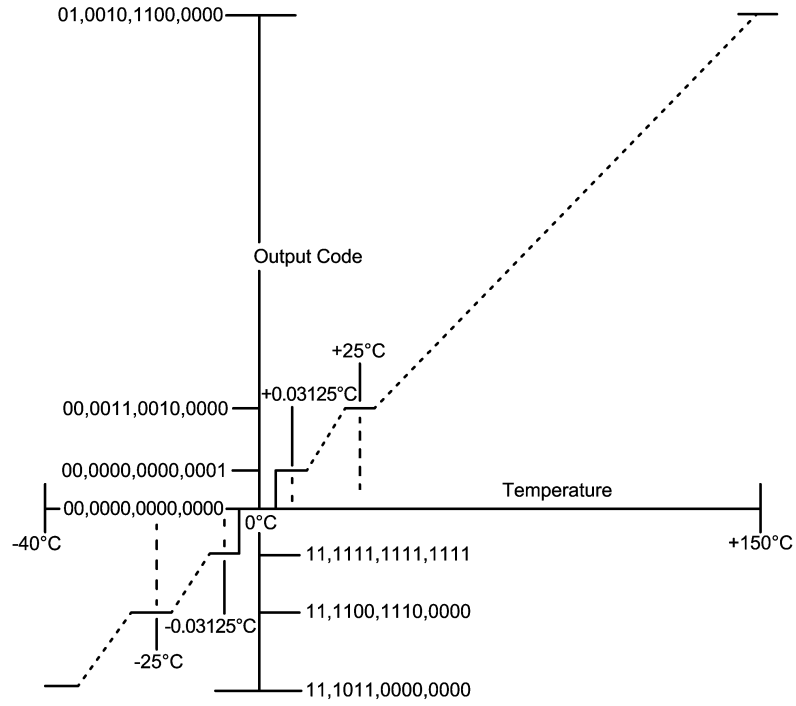**Note 7:** Typicals are at T_A = 25˚C and represent most likely parametric norm.

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 LM95071 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.

Electrical Characteristics

01,0010,1100,0000 —

Output Code

+25°C

+0.03125°C

00,0011,0010,0000 —

00,0000,0000,0001 —

00,0000,0000,0000

Temperature

-40°C

0°C

+150°C

11,1111,1111,1111

11,1100,1110,0000

-0.03125°C

-25°C

11,1011,0000,0000

20106508

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

TRI-STATE Test Circuit

+3.3V

I_{OL} = 1.6 mA

To LM95071
SI/O Pin

1.4V

80 pF

I_{OH} = -1.6 mA
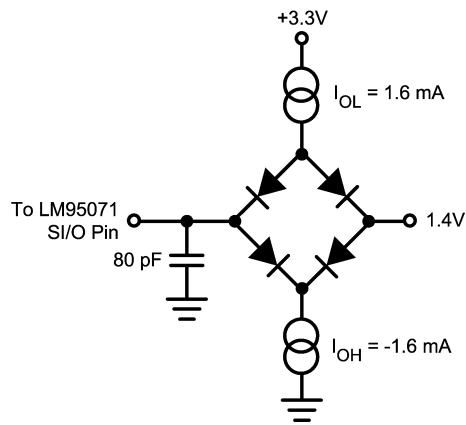
20106507

FIGURE 6.

Typical Performance Characteristics

Static Supply Current vs. Temperature
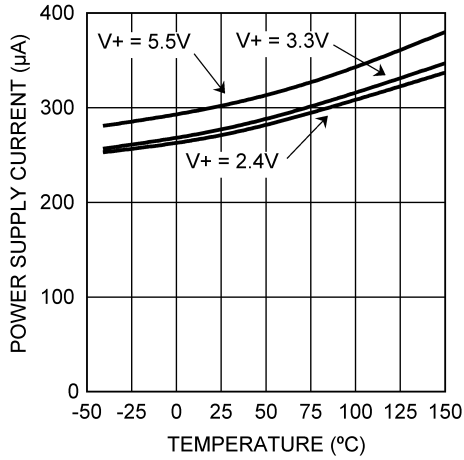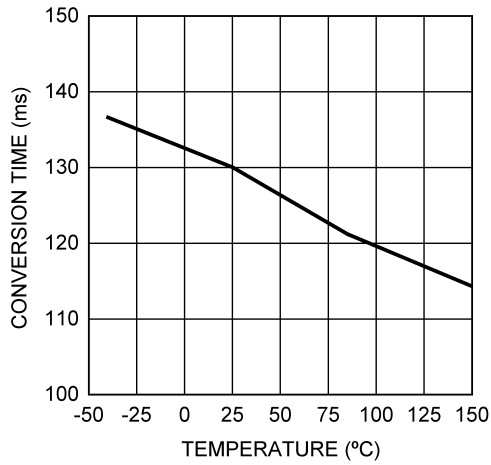

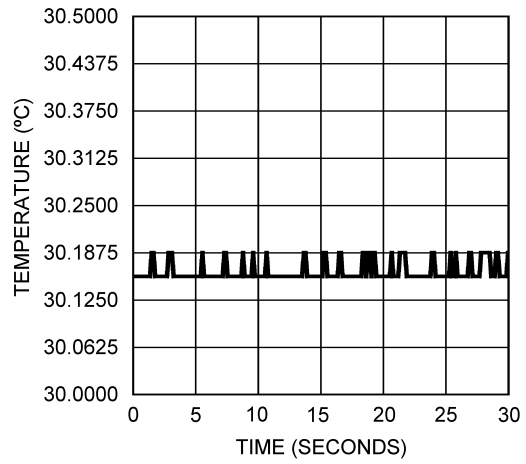20106525

MaximumTemperature Error
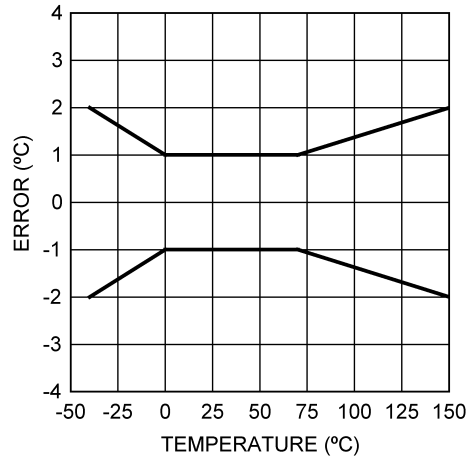
20106526

Conversion Time vs Temperature

20106527

Typical Output Noise at 30˚C

20106529

1.0 Functional Description

The LM95071 temperature sensor incorporates a temperature sensor and 13-bit-plus-sign ΔΣ ADC (Delta-Sigma Analog-to-Digital Converter). Compatibility of the LM95071'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/Device ID register identifies the LM95071 as a National Semiconductor product.

1.1 POWER UP AND POWER DOWN

The LM95071 always powers up in a known state and in the continuous conversion mode. Immediately after power up, the LM95071 will output an erroneous code until the first temperature conversion has completed.

When the supply voltage is less than about 1.6V (typical), the LM95071 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 LM95071 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 communication is framed by falling and rising chip select (CS) signal. The CS signal should be held high for at least one clock cycle (160 ns minimum) between communications. The transmit-only communication (register read) consists of 16 clock cycles. A complete transmit/receive communication will consist of 32 serial clocks (see Figure 7). 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 TRI-STATE. 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. $\overline{CS}$ can be taken high at any time during the transmit phase. If $\overline{CS}$ is brought low in the middle of a conversion the LM95071 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 LM95071 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. All zeros must be shifted in order to place the LM95071 into continuous conversion mode. Only the following codes should be transmitted to the LM95071:

- 00 hex for continuous conversion
- FF hex for shutdown

Another code may place the part into a test mode. Test modes are used by National Semiconductor to thoroughly test the function of the LM95071 during production testing. Only eight bits have been defined above since only the last eight transmitted are detected by the LM95071, before $\overline{CS}$ is taken HIGH.

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 228 ms (max) will have to pass for a conversion to complete before the LM95071 actually transmits temperature data.

1.3 TEMPERATURE DATA FORMAT

Temperature data is represented by a 14-bit, two's complement word with an LSB (Least Significant Bit) equal to 0.03125˚C:

Temperature	Digital Output	
	Binary	**Hex**
+150˚C	0100 1011 0000 0011	4B03
+125˚C	0011 1110 1000 0011	3E83
+25˚C	0000 1100 1000 0011	0C83
+0.03125˚C	0000 0000 0000 0111	0007
0˚C	0000 0000 0000 0011	0003
−0.03125˚C	1111 1111 1111 1111	FFFF
−25˚C	1111 0011 1000 0011	F383
−40˚C	1110 1100 0000 0011	EC03

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 overtemperature condition, the host processor could immediately take action to remedy the excessive temperatures.

1.4 SHUTDOWN MODE/MANUFACTURER ID

The master controller may enable the shutdown mode for the purpose of reducing power consumption or for reading the Manufacturer/Device ID information. The shutdown mode is enabled by writing XX FF hex to the LM95071 as shown in *Figure 7*c. The serial bus is still active when the LM95071 is in shutdown. When in shutdown mode the LM95071 always will output 1000 0000 0000 1111. This is the Manufacturer/Device ID information. The first 5-bits of the field (1000 0XXX) are reserved for the manufacturer ID.

1.0 Functional Description (Continued)

1.5 INTERNAL REGISTER STRUCTURE

The LM95071 has three registers: the temperature register, the configuration register and the Manufacturer/Device identification register. The temperature and Manufacturer/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 sets continuous-conversion mode.

Note: setting D0-D15 to any other values may place the LM95071 into a manufacturer's test mode, upon which the LM95071 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 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit1	LSB	1	1

D0–D1: Logic 1 will be output on SI/0.

D2–D15: Temperature Data. One LSB = 0.03125˚C. Two's complement format.
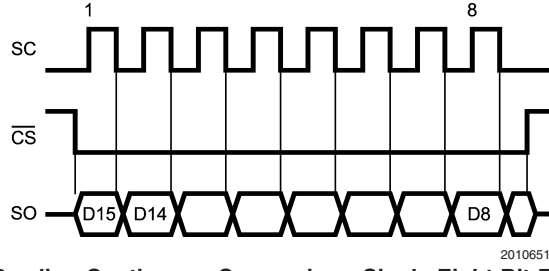
1.5.3 Manufacturer/Device ID Register

(Read Only):

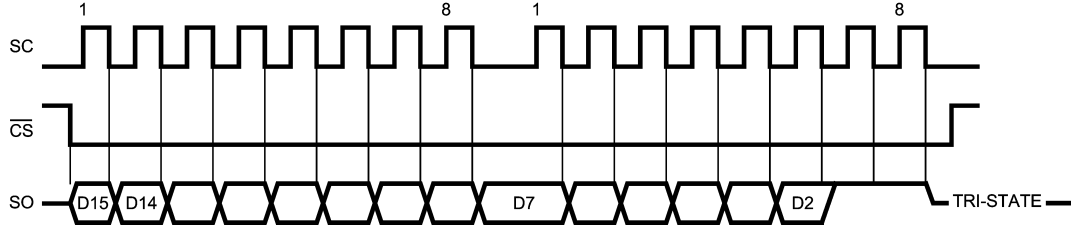| D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

D0–D1: Logic 1 will be output on SI/0.

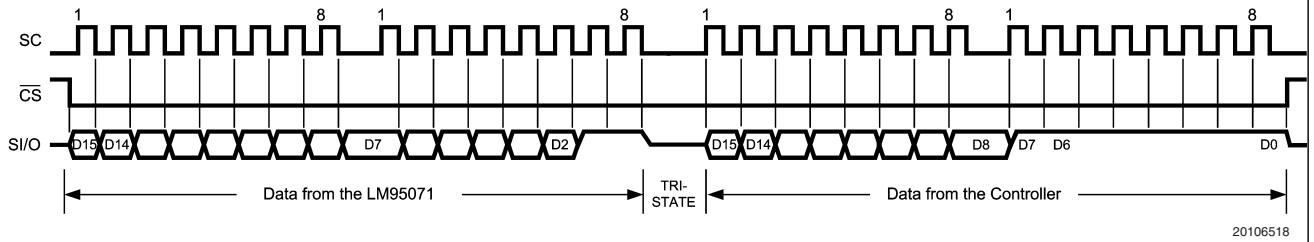D2–D15: Manufacturer/Device ID Data. This register is accessed whenever the LM95071 is in shutdown mode.
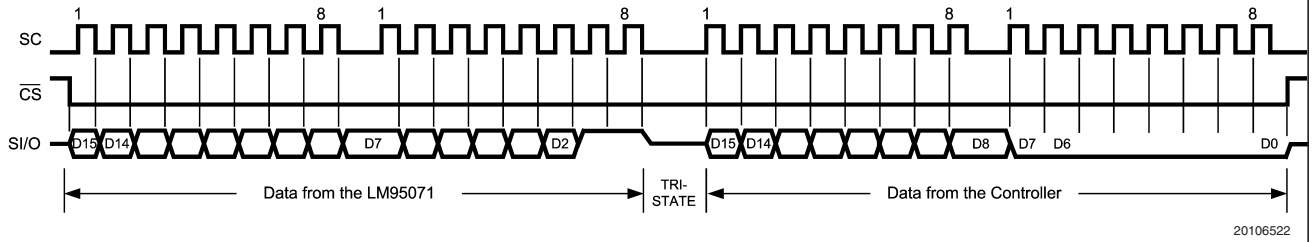
2.0 Serial Bus Timing Diagrams

a) Reading Continuous Conversion - Single Eight-Bit Frame

b) Reading Continuous Conversion - Two Eight-Bit Frames

c) Writing Shutdown Mode

d) Writing Conversion Mode

FIGURE 7. Timing Diagrams

3.0 Application Hints

3.1 THERMAL PATH CONSIDERATIONS

To get the expected results when measuring temperature with an integrated circuit temperature sensor like the LM95071, it is important to understand that the sensor measures its own die temperature. For the LM95071, the best thermal path between the die and the outside world is through the LM95071's pins. In the SOT23 package, all the pins on the LM95071 will have an equal effect on the die temperature. Because the pins represent a good thermal path to the LM95071 die, the LM95071 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 LM95071 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.

3.2 OUTPUT CONSIDERATIONS: TIGHT ACCURACY, FINE RESOLUTION AND LOW NOISE

The LM95071 is well suited for applications that require tight temperature measurement accuracy. In many applications, from process control to HVAC, the low temperature error can mean better system performance and, by eliminating a system calibration step, lower production cost.

With it's fine digital resolution the LM95071 senses and reports very small changes in its temperature, making it ideal for applications where temperature sensitivity is important. For example, the LM95071 enables the system to quickly identify the direction of temperature change, allowing the processor to take compensating action before the system reaches a critical temperature.

The LM95071 has very low output noise (see the Output Noise plot in the Typical Performance section), which makes it ideal for applications where stable thermal compensation is a priority. For example, in a temperature-compensated oscillator application, the very small deviation in successive temperature readings translates to a stable frequency output from the oscillator.
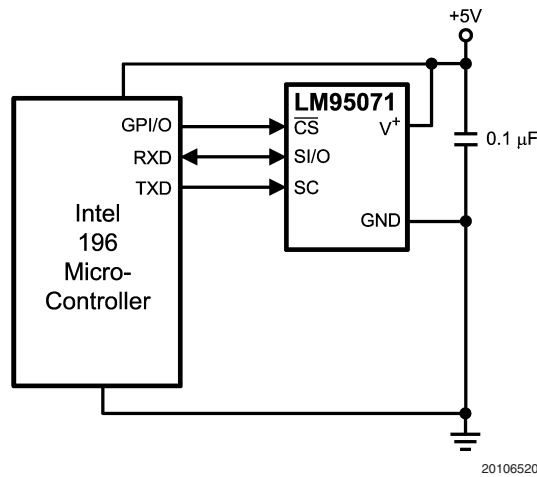
4.0 Typical Applications

20106520
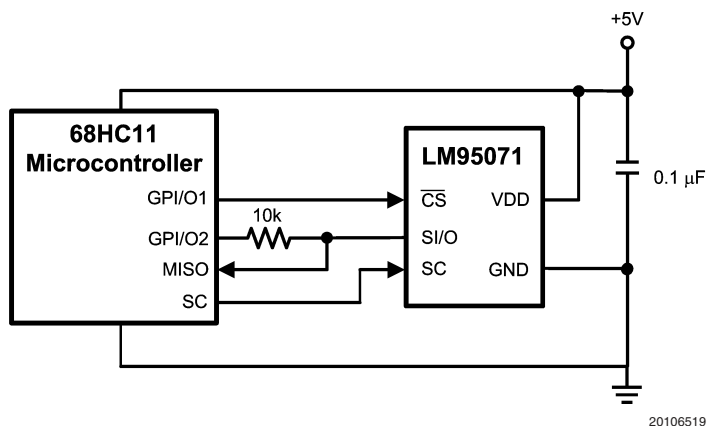
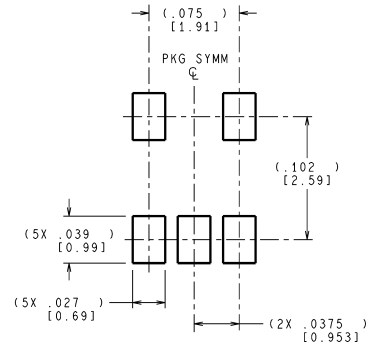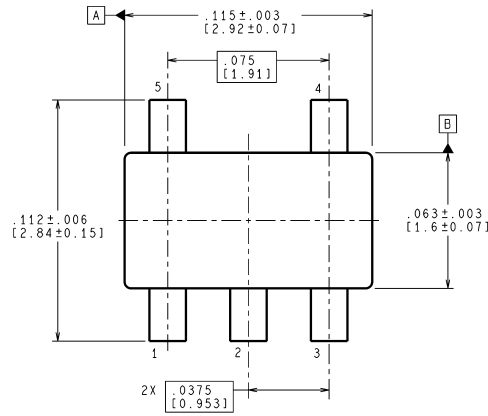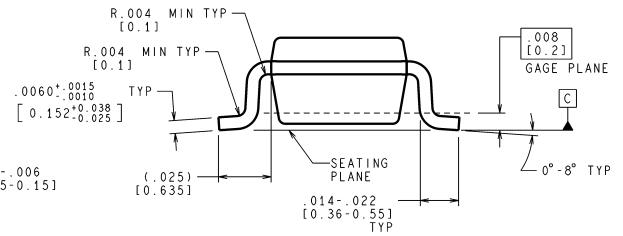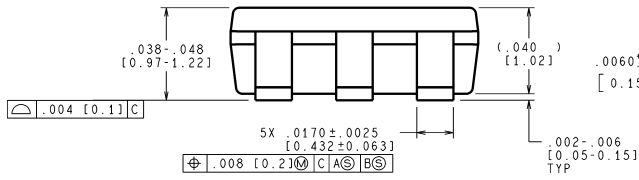**FIGURE 8. Temperature monitor using Intel 196 processor**

20106519

FIGURE 9. LM95071 digital input control using microcontroller's general purpose I/O.

Physical Dimensions inches (millimeters) unless otherwise noted

.115±.003
[2.92±0.07]

A

.075
[1.91]

5   4

B

.112±.006
[2.84±0.15]

.063±.003
[1.6±0.07]

1   2   3

2X .0375
[0.953]

(.075)
[1.91]

PKG SYMM

(.102)
[2.59]

(5X .039)
[0.99]

(5X .027)
[0.69]

(2X .0375)
[0.953]

LAND PATTERN RECOMMENDATION

.038-.048
[0.97-1.22]

(.040)
[1.02]

.004 [0.1] C

5X .0170±.0025
[0.432±0.063]

.008 [0.2] M C A S B S

.002-.006
[0.05-0.15]
TYP

R.004 MIN TYP
[0.1]

R.004 MIN TYP
[0.1]

.0060+.0015
-.0010
[0.152+0.038
-0.025]
TYP

TYP

(.025)
[0.635]

SEATING
PLANE

.014-.022
[0.36-0.55]
TYP

.008
[0.2]
GAGE PLANE

C

0°-8° TYP

**CONTROLLING DIMENSION IS INCH
VALUES IN [ ] ARE MILLIMETERS**

MF05A (Rev B)

**LM95071Top View
SOT23-5 Package
NS Package Number MF05A**

LIFE SUPPORT POLICY

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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