

SPI/MICROWIRE 13-Bit Plus Sign Temperature Sensor

Check for Samples: [LM95071](#)

FEATURES

- Small SOT-23 Package Saves Space
- Shutdown Mode Conserves Power Between Temperature Readings
- Operates Over a Full -40°C to $+150^{\circ}\text{C}$ Range
- SPI and MICROWIRE Bus Interface

APPLICATIONS

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

DESCRIPTION

The LM95071 is a low-power, high-resolution digital temperature sensor with an SPI and MICROWIRE compatible interface, available in the 5-pin SOT-23. 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 $+150^{\circ}\text{C}$.

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.

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	$\pm 1^{\circ}\text{C}$ (max)
	-40°C to 150°C	$\pm 2^{\circ}\text{C}$ (max)
Temperature Resolution		0.03125 $^{\circ}\text{C}$

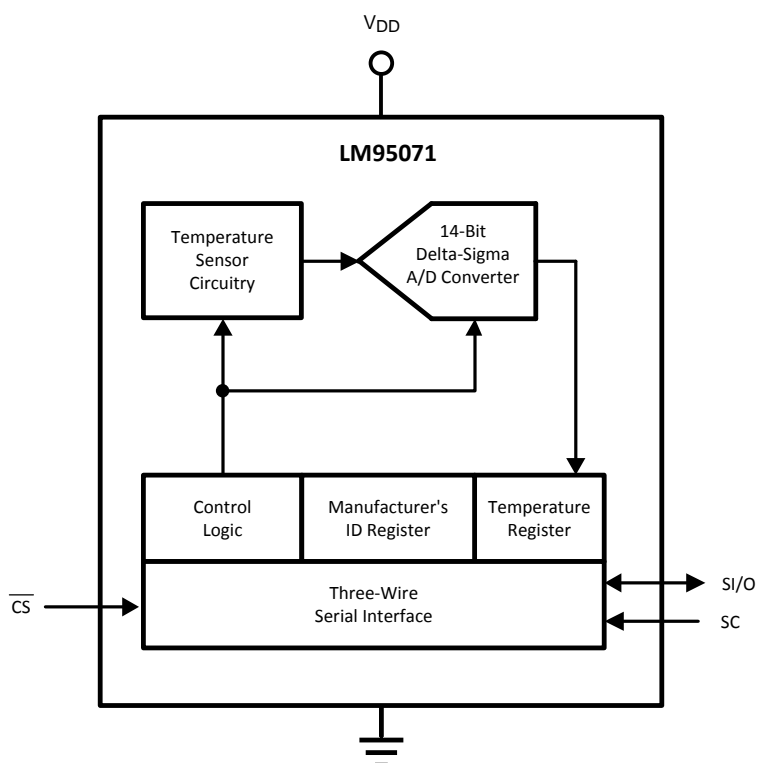


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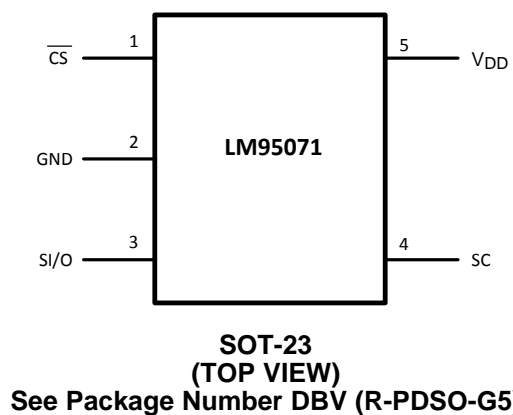
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Simplified Block Diagram



Connection Diagram



Pin Description

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, bidirectional, 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 μ F ceramic capacitor to ground.

Typical Application

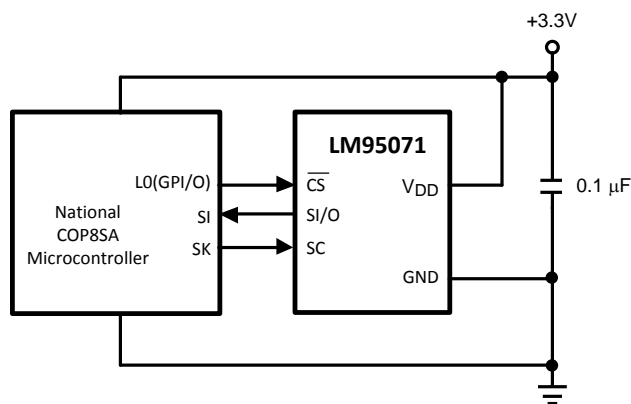


Figure 1. COP Microcontroller Interface



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Absolute Maximum Ratings ⁽¹⁾⁽²⁾

Supply Voltage	–0.3V to 6.0V	
Voltage at any Pin	–0.3V to V _{DD} + 0.3V	
Input Current at any Pin ⁽³⁾	5 mA	
Storage Temperature	–65°C to +150°C	
ESD Susceptibility ⁽⁴⁾	Human Body Model	2000V
	Machine Model	200V

- (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.
- (2) Soldering process must comply with National Semiconductor's Reflow Temperature Profile specifications. Refer to www.national.com/packaging.
- (3) 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.
- (4) Human body model, 100 pF discharged through a 1.5 k Ω resistor. Machine model, 200 pF discharged directly into each pin.

Operating Ratings

Specified Temperature Range ⁽¹⁾ , T _{MIN} to T _{MAX}	–40°C to +150°C
Supply Voltage Range (V _{DD})	2.4V to +5.5V

- (1) 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.

Thermal Characteristics

Device Number	Package Number	Thermal Resistance (θ_{JA})
LM95071CIMF	MF05A	250°C/W

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	Test Conditions	Typical ⁽¹⁾	Limits ⁽²⁾	Unit (Limit)
Temperature Error ⁽³⁾	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 (max)
	V _{DD} = 3.0V to 2.4V; T _A = 0°C to +70°C		–0.6	
Resolution		14 0.03125		Bits °C
Temperature Conversion Time	⁽⁴⁾	130	228	ms (max)
Quiescent Current	Operating, Serial Bus Inactive	280	520	µA (max)
	Shutdown	6	28	µA (max)

- (1) Typicals are at T_A = 25°C and represent most likely parametric norm.
 (2) Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).
 (3) The LM95071 will operate properly over the V_{DD} supply voltage range of 2.4V to 5.5V.
 (4) 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.

LOGIC ELECTRICAL CHARACTERISTICS

DIGITAL DC CHARACTERISTICS

Unless otherwise noted, these specifications apply for V_{DD} = 2.4 to 5.5V⁽¹⁾. **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	Test Conditions	Typical ⁽²⁾	Limits ⁽³⁾	Unit (Limit)
V _{IN(1)}	Logical "1" Input Voltage			0.7 × V_{DD}	V (min)
				V_{DD} + 0.3	V (max)
V _{IN(0)}	Logical "0" Input Voltage			–0.3	V (min)
				0.3 × 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 V _O = V _{DD}		–1 +1	µA (min) µA (max)

- (1) The LM95071 will operate properly over the V_{DD} supply voltage range of 2.4V to 5.5V.
 (2) Typicals are at T_A = 25°C and represent most likely parametric norm.
 (3) Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

SERIAL BUS DIGITAL SWITCHING CHARACTERISTICS

Unless otherwise noted, these specifications apply for $V_{DD} = 2.4V$ to $5.5V$ ⁽¹⁾; 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 $T_A = T_J = +25^\circ C$, unless otherwise noted.

Symbol	Parameter	Test Conditions	Typical ⁽²⁾	Limits ⁽³⁾	Unit (Limit)
t_1	SC (Clock) Period			0.16 DC	μs (min) (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)

(1) The LM95071 will operate properly over the V_{DD} supply voltage range of 2.4V to 5.5V.

(2) Typicals are at $T_A = 25^\circ C$ and represent most likely parametric norm.

(3) Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

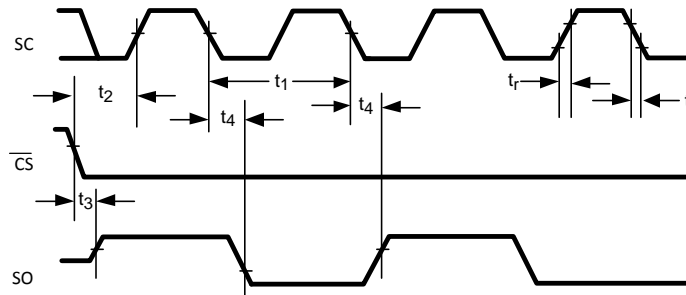


Figure 2. Data Output Timing Diagram

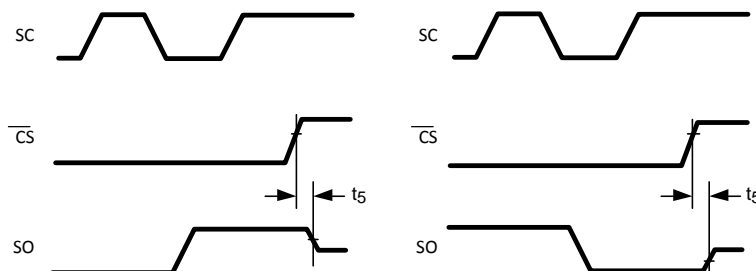


Figure 3. TRI-STATE Data Output Timing Diagram

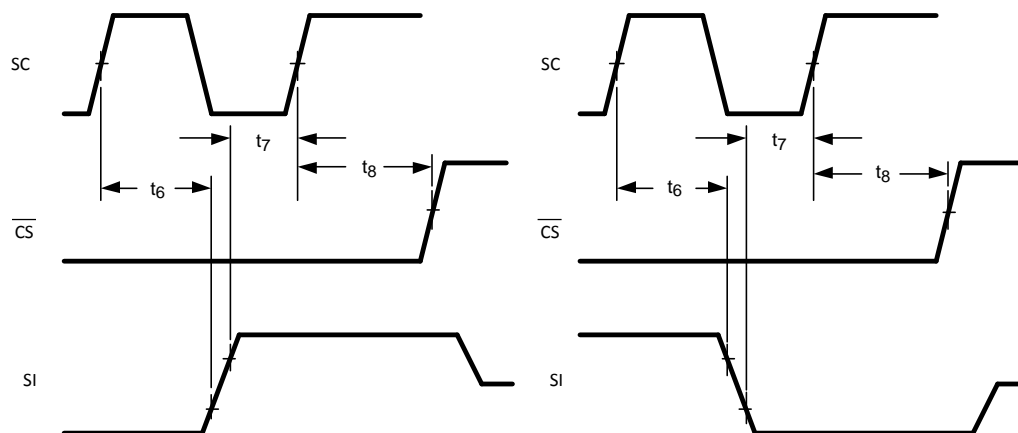


Figure 4. Data Input Timing Diagram

Electrical Characteristics

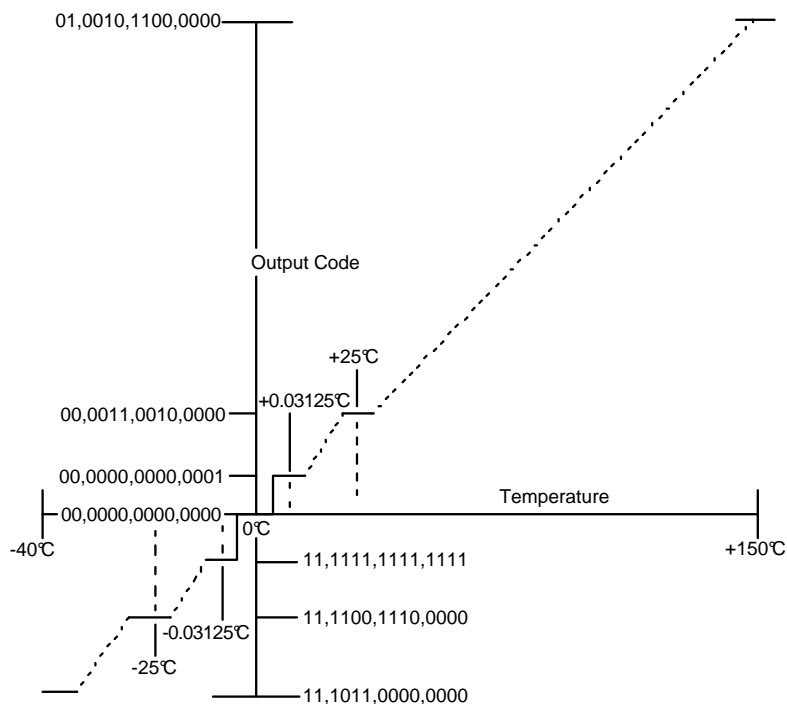
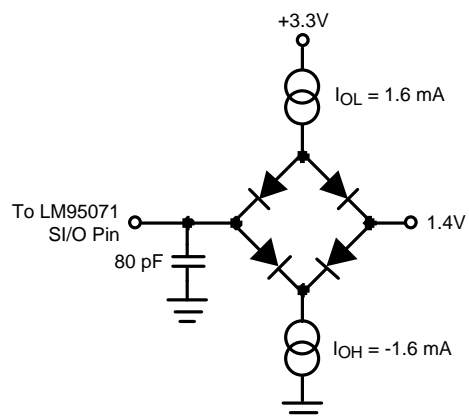


Figure 5. Temperature-to-Digital Transfer Function (Non-linear scale for clarity)

TRI-STATE Test Circuit



TYPICAL PERFORMANCE CHARACTERISTICS

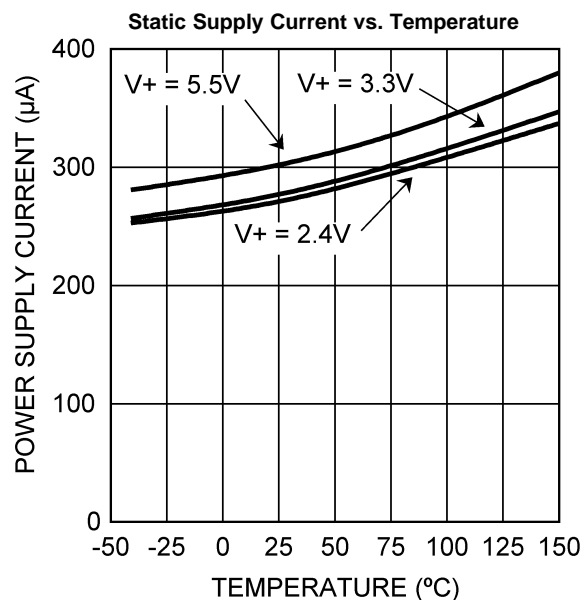


Figure 6.

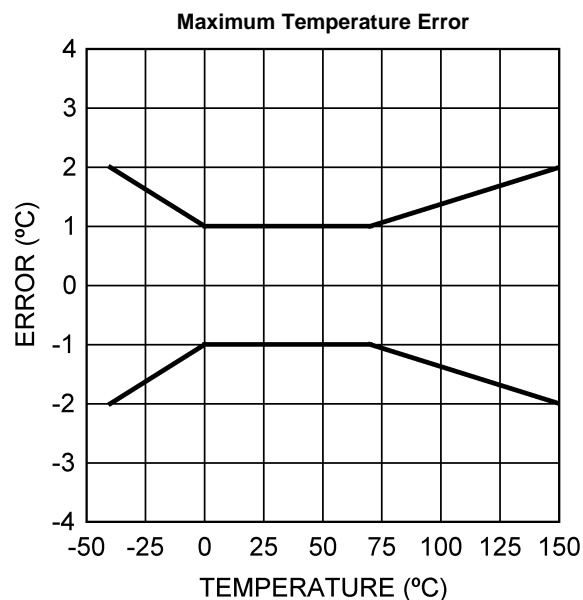


Figure 7.

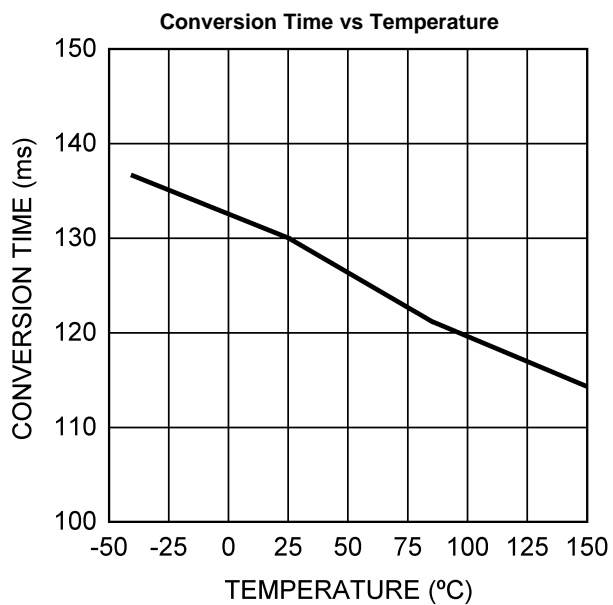


Figure 8.

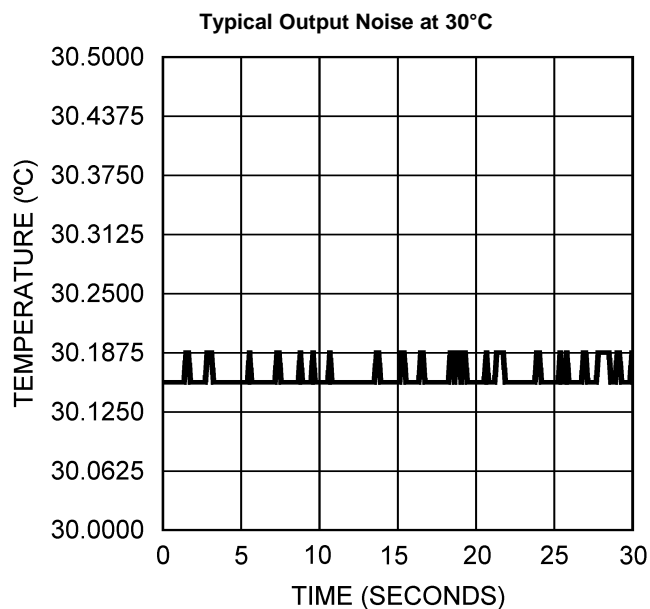


Figure 9.

FUNCTIONAL DESCRIPTION

The LM95071 temperature sensor incorporates a temperature sensor and 13-bit-plus-sign $\Delta\Sigma$ 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.

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.

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 (\overline{CS}) signal. The \overline{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 [SERIAL BUS TIMING DIAGRAMS](#)). 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.

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.

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 13c](#). 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.

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.

Configuration Register

(Selects shutdown or continuous conversion modes):

Table 1. (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 [SERIAL BUS INTERFACE](#) for a complete discussion.

Temperature Register

Table 2. (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	Bit 1	LSB	1	1

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

D2–D15: Temperature Data. One LSB = 0.03125°C. Two's complement format.

Manufacturer/Device ID Register

Table 3. (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/O.

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

SERIAL BUS TIMING DIAGRAMS

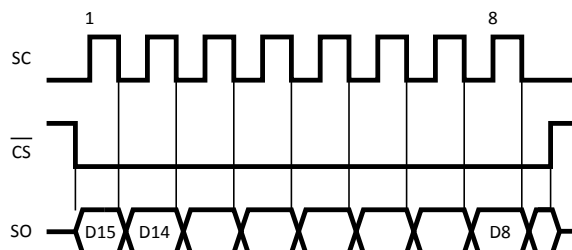


Figure 10. Reading Continuous Conversion - Single Eight-Bit Frame

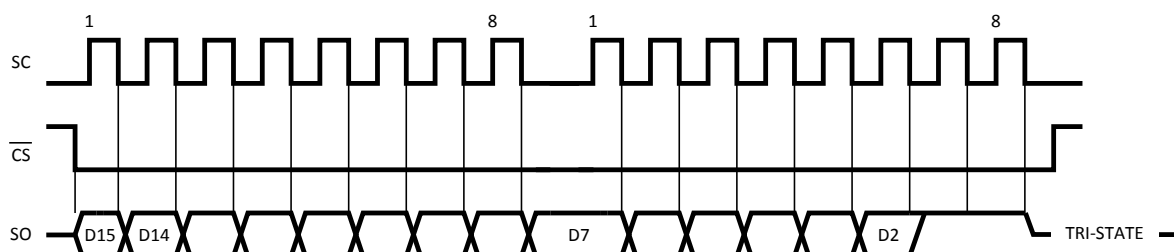


Figure 11. Reading Continuous Conversion - Two Eight-Bit Frames

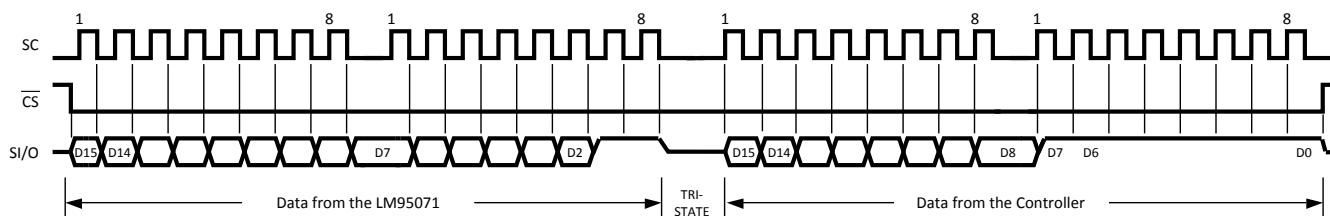


Figure 12. Writing Shutdown Mode

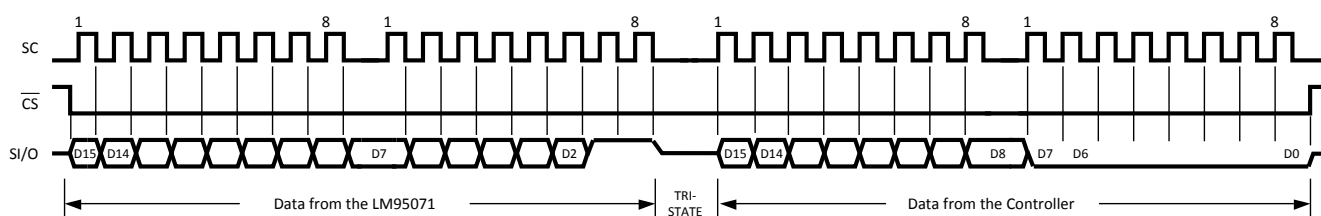


Figure 13. Writing Conversion Mode

APPLICATION HINTS

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 SOT-23 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.

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 its 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 [Figure 9](#) 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.

Typical Applications

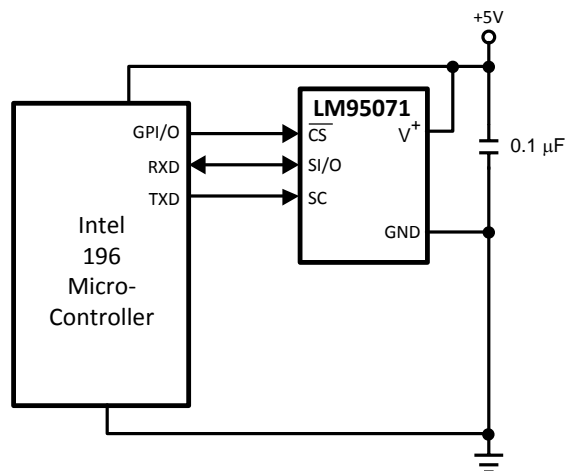


Figure 14. Temperature monitor using Intel 196 processor

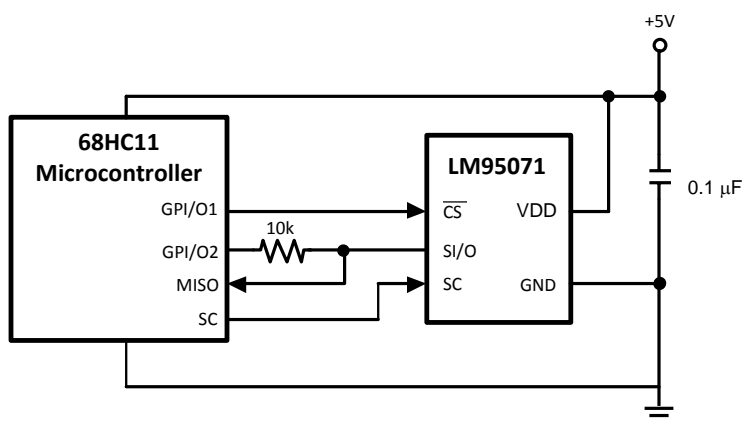


Figure 15. LM95071 digital input control using microcontroller's general purpose I/O.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
LM95071CIMF	ACTIVE	SOT-23	DBV	5	1000	TBD	Call TI	Call TI	-40 to 150	T18C	Samples
LM95071CIMF/NOPB	ACTIVE	SOT-23	DBV	5	1000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 150	T18C	Samples
LM95071CIMFX	ACTIVE	SOT-23	DBV	5	3000	TBD	Call TI	Call TI	-40 to 150	T18C	Samples
LM95071CIMFX/NOPB	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 150	T18C	Samples

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) Only one of markings shown within the brackets will appear on the physical device.

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TAPE AND REEL INFORMATION


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM95071CIMF	SOT-23	DBV	5	1000	178.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
LM95071CIMF/NOPB	SOT-23	DBV	5	1000	178.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
LM95071CIMFX	SOT-23	DBV	5	3000	178.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
LM95071CIMFX/NOPB	SOT-23	DBV	5	3000	178.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3

TAPE AND REEL BOX DIMENSIONS

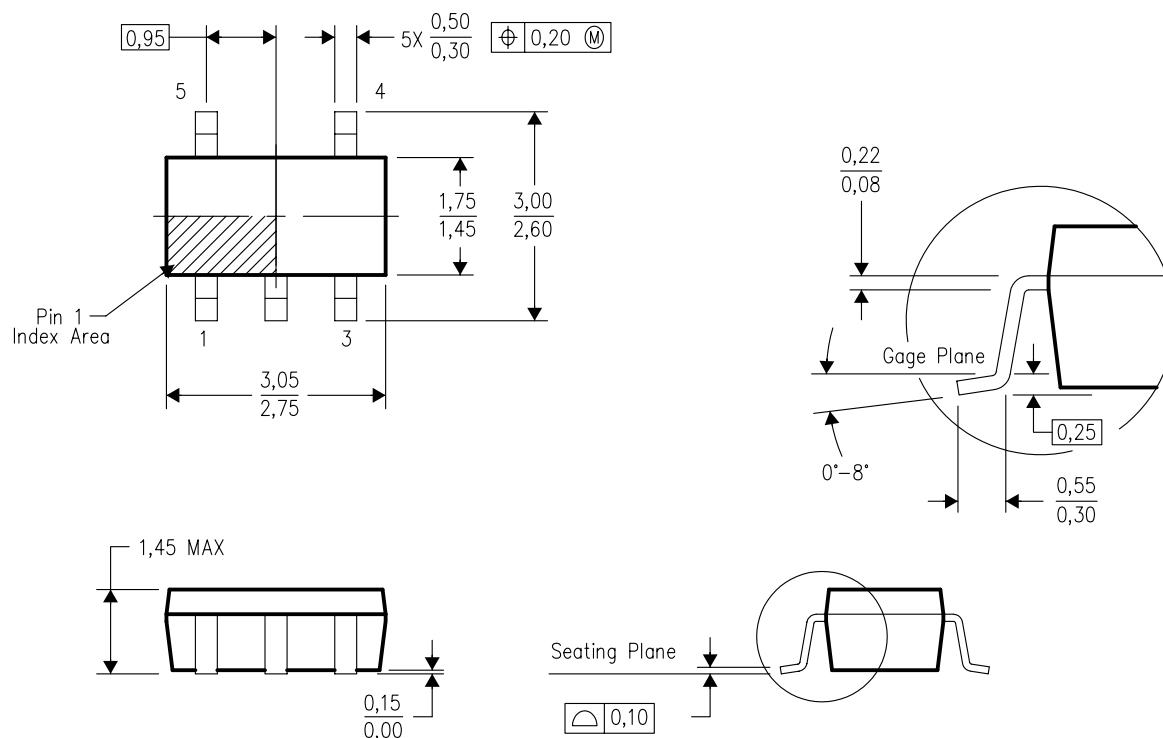


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM95071CIMF	SOT-23	DBV	5	1000	210.0	185.0	35.0
LM95071CIMF/NOPB	SOT-23	DBV	5	1000	210.0	185.0	35.0
LM95071CIMFX	SOT-23	DBV	5	3000	210.0	185.0	35.0
LM95071CIMFX/NOPB	SOT-23	DBV	5	3000	210.0	185.0	35.0

DBV (R-PDSO-G5)

PLASTIC SMALL-OUTLINE PACKAGE



4073253-4/K 03/2006

- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
 - D. Falls within JEDEC MO-178 Variation AA.

DBV (R-PDSO-G5)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
 - D. Publication IPC-7351 is recommended for alternate designs.
 - E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC-7525 for other stencil recommendations.

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