



12-Bit, $\pm 0.5^{\circ}\text{C}$ Accurate, MicroPower Digital Temperature Sensor in 6-Lead SOT-23

Preliminary Technical Data

ADT7301

FEATURES

12-Bit Temperature-to-Digital Converter
 -55°C to $+125^{\circ}\text{C}$ Operating Temperature Range
 Capable of operating up to 150°C
 $\pm 0.5^{\circ}\text{C}$ Accuracy
 Operating Current of $1\ \mu\text{A}$
 SPI- and DSP-Compatible Serial Interface
 Shutdown Mode
 Space-Saving SOT-23 Package

APPLICATIONS

Medical Equipment
 Automotive
 Cell Phone
 Hard Disk Drives
 Personal Computers
 Electronic Test Equipment
 Office Equipment
 Domestic Appliances
 Process Control

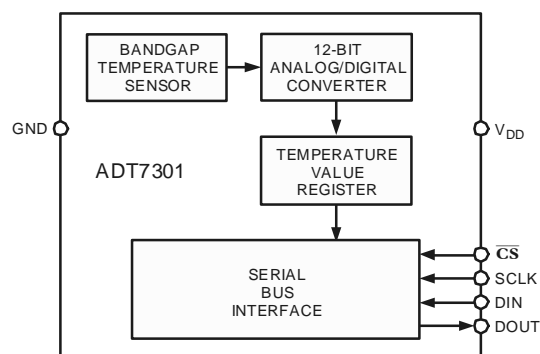
GENERAL DESCRIPTION

The ADT7301 is a complete temperature monitoring system in an SOT-23 package. It contains a bandgap temperature sensor and a 12-bit ADC to monitor and digitize the temperature reading to a resolution of $+0.0625^{\circ}\text{C}$.

The ADT7301 has a flexible serial interface that allows easy interfacing to most microcontrollers. The interface is compatible with SPI™, QSPI and MICROWIRE™ protocol and is also compatible with DSPs. The part features a standby mode that is controlled via the serial interface.

The ADT7301's wide supply voltage range, low supply current and SPI-compatible interface, make it ideal for a variety of applications, including personal computers, office equipment, automotive and domestic appliances.

FUNCTIONAL BLOCK DIAGRAM



PRODUCT HIGHLIGHTS

1. The ADT7301 has an on-chip temperature sensor that allows an accurate measurement of the ambient temperature. The measurable temperature range is -55°C to $+125^{\circ}\text{C}$.
2. Supply voltage of $+2.7\ \text{V}$ to $+5.5\ \text{V}$.
3. Space-saving 6-lead SOT-23 package.
4. Temperature accuracy of $\pm 0.5^{\circ}\text{C}$.
4. 12-bit temperature reading to $+0.0625^{\circ}\text{C}$ resolution.
5. The ADT7301 features a standby mode that reduces the power consumption to $\text{tbd}\ \mu\text{W}$.

REV. PrC 11/02

Information furnished by Analog Devices is believed to be accurate and reliable. However, no responsibility is assumed by Analog Devices for its use, nor for any infringements of patents or other rights of third parties which may result from its use. No license is granted by implication or otherwise under any patent or patent rights of Analog Devices.

SPI is a trademark of Motorola, Inc.

MICROWIRE is a trademark of National Semiconductor, Inc.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
 Tel: 781/329-4700
 Fax: 781/326-8703
 www.analog.com
 Analog Devices, Inc., 2002

ADT7301–SPECIFICATIONS¹

($T_A = T_{MIN}$ to T_{MAX} , $V_{DD} = +2.7$ V to $+5.5$ V, unless otherwise noted)

| Parameter | Min | Typ | Max | Units | Test Conditions/Comments |
|---|------------------|--------|--|--|---|
| TEMPERATURE SENSOR AND ADC | | | | | |
| Accuracy @ $V_{DD} = +3.3$ V ($\pm 10\%$) | | | ± 0.5 ± 1 | $^{\circ}\text{C}$ $^{\circ}\text{C}$ | $T_A = 0^{\circ}\text{C}$ to 70°C . $T_A = -40^{\circ}\text{C}$ to $+85^{\circ}\text{C}$. |
| Accuracy @ $V_{DD} = +5$ V ($\pm 10\%$) | | | ± 2 ± 0.5 ± 1 ± 2 | $^{\circ}\text{C}$ $^{\circ}\text{C}$ $^{\circ}\text{C}$ $^{\circ}\text{C}$ | $T_A = -55^{\circ}\text{C}$ to $+125^{\circ}\text{C}$. $T_A = 0^{\circ}\text{C}$ to 70°C . $T_A = -40^{\circ}\text{C}$ to $+85^{\circ}\text{C}$. $T_A = -55^{\circ}\text{C}$ to $+125^{\circ}\text{C}$. |
| Temperature Resolution | | 0.0625 | | $^{\circ}\text{C}$ | |
| Autoconversion Update Rate, t_R | | 1 | | sec | |
| Temperature Conversion Time | | 208 | | μs | |
| SUPPLIES | | | | | |
| Supply Voltage | 2.7 | | 5.5 | V | For Specified Performance |
| Supply Current | | | | | |
| Normal Mode @ 3 V | | 100 | 200 | μA | |
| Normal Mode @ 5 V | | 250 | 400 | μA | |
| Shutdown Mode @ 2.7V to 3.3V | | 0.04 | 1 | μA | |
| Shutdown Mode @ 4.5V to 5.5V | | 1 | 3 | μA | |
| Power Dissipation | | 80 | | μW | $V_{DD} = +3$ V - Normal Mode |
| Power Dissipation | | | | | |
| 1 sps | | 3 | | μW | $V_{DD} = +3$ V - Shutdown Mode |
| 10 sps | | 3.3 | | μW | $V_{DD} = +3$ V - Shutdown Mode |
| 100 sps | | 6 | | μW | $V_{DD} = +3$ V - Shutdown Mode |
| DIGITAL INPUT ² | | | | | |
| Input High Voltage, V_{IH} | 2.4 | | | V | |
| Input Low Voltage, V_{IL} | | | 0.8 | V | |
| Input Current, I_{IN} | | | ± 1 | μA | $V_{IN} = 0$ V to V_{DD} |
| Input Capacitance, C_{IN} | | | 10 | pF | All Digital Inputs |
| DIGITAL OUTPUT ² | | | | | |
| Output High Voltage, V_{OH} | $V_{DD} - 0.3$ V | | | | $I_{SOURCE} = I_{SINK} = 200$ μA |
| Output Low Voltage, V_{OL} | | | 0.4 | V | $I_{OL} = 200$ μA |
| Output Capacitance, C_{OUT} | | | 50 | pF | |

NOTES

¹All specifications apply for -55°C to $+125^{\circ}\text{C}$ unless otherwise stated.

²Guaranteed by design and characterization, not production tested.

Specifications subject to change without notice.

TIMING CHARACTERISTICS^{1, 2, 3} ($T_A = T_{MIN}$ to T_{MAX} , $V_{DD} = +2.7$ V to $+5.5$ V, unless otherwise noted)

| Parameter | Limit | Units | Comments |
|-----------|-------|--------|---|
| t_1 | 0 | ns min | $\overline{\text{CS}}$ to SCLK Setup Time |
| t_2 | 25 | ns min | SCLK High Pulsewidth |
| t_3 | 25 | ns min | SCLK Low Pulsewidth |
| t_4^4 | 35 | ns max | Data Access Time After SCLK Falling Edge |
| t_5 | 20 | ns min | Data Setup Time Prior to SCLK Rising Edge |
| t_6 | 0 | ns min | Data Hold Time After SCLK Rising Edge |
| t_7 | 0 | ns min | $\overline{\text{CS}}$ to SCLK Hold Time |
| t_8^4 | 40 | ns max | $\overline{\text{CS}}$ to DOUT High Impedance |

NOTES

¹Guaranteed by design and characterization, not production tested.

²All input signals are specified with $t_r = t_f = 5$ ns (10% to 90% of V_{DD}) and timed from a voltage level of 1.6 V.

³See Figure 2.

⁴Measured with the load circuit of Figure 1.

ABSOLUTE MAXIMUM RATINGS*

| | |
|---------------------------------------|----------------------------|
| V_{DD} to GND | -0.3 V to +7 V |
| Digital Input Voltage to GND | -0.3 V to $V_{DD} + 0.3$ V |
| Digital Output Voltage to GND | -0.3 V to $V_{DD} + 0.3$ V |
| Operating Temperature Range | -55°C to +125°C |
| Storage Temperature Range | -65°C to +150°C |
| Junction Temperature | +150°C |
| SOT-23, Power Dissipation | 450 mW |
| θ_{JA} Thermal Impedance | 240°C/W |
| Lead Temperature, Soldering | |
| Vapor Phase (60 sec) | +215°C |
| Infrared (15 sec) | +220°C |
| μ SOIC Package, Power Dissipation | 450 mW |
| θ_{JA} Thermal Impedance | 206°C/W |
| Lead Temperature, Soldering | |
| Vapor Phase (60 sec) | +215°C |
| Infrared (15 sec) | +220°C |

*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

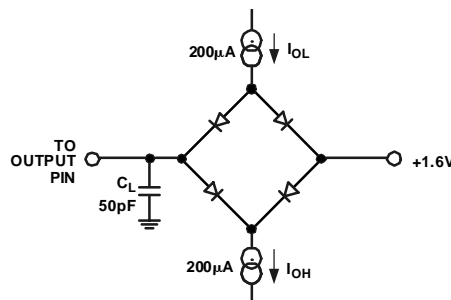


Figure 1. Load Circuit for Data Access Time and Bus Relinquish Time

ORDERING GUIDE

| Model | Temperature Range | Temperature Accuracy* | Package Description | Branding Information | Package Option |
|------------|-------------------|-----------------------|---------------------|----------------------|----------------|
| ADT7301ART | -55°C to +125°C | ±0.5°C | 6-Lead SOT-23 | | RT-6 |

*Temperature accuracy is over 0°C to +70°C temperature range.

CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the ADT7301 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



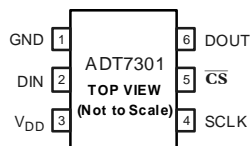
ADT7301

PIN FUNCTION DESCRIPTION

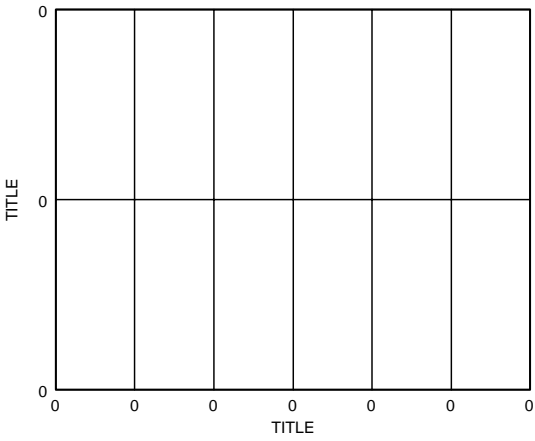
| Pin Mnemonic | SOT-23 Pin No. | Description |
|-----------------|----------------|--|
| GND | 1 | Analog and Digital Ground. |
| DIN | 2 | Serial Data Input. Serial data to be loaded to the part's control register is provided on this input. Data is clocked into the control register on the rising edge of SCLK. |
| V _{DD} | 3 | Positive Supply Voltage, +2.7 V to +5.5 V. |
| SCLK | 4 | Serial Clock Input. This is the clock input for the serial port. The serial clock is used to clock data out of the temperature value register of the ADT7301 and also to clock data into the control register on the part. |
| \overline{CS} | 5 | Chip Select Input. Logic Input. The device is selected when this input is low. The SCLK input is disabled when this pin is high. |
| DOUT | 6 | Serial Data Output. Logic output. Data is clocked out of the temperature value register at this pin. Data is clocked out on the falling edge of SCLK. |

PIN CONFIGURATIONS

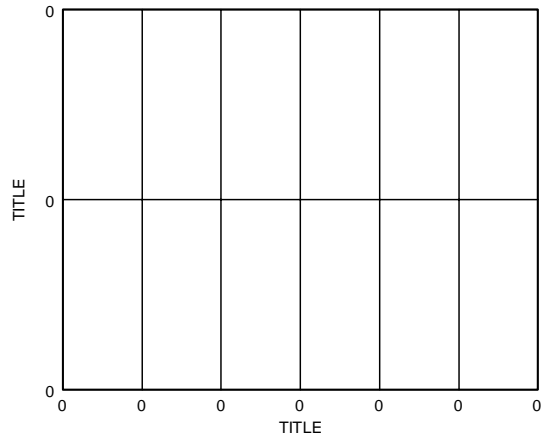
SOT-23



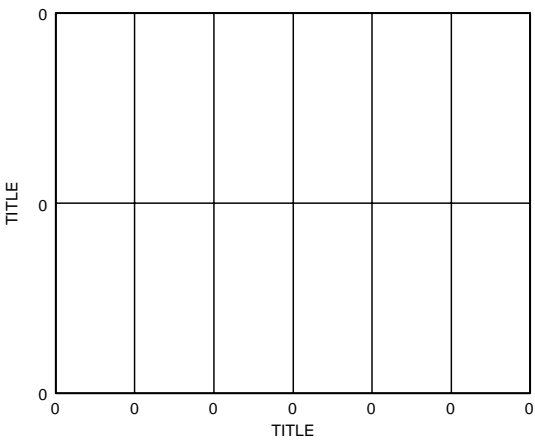
TYPICAL PERFORMANCE CURVES



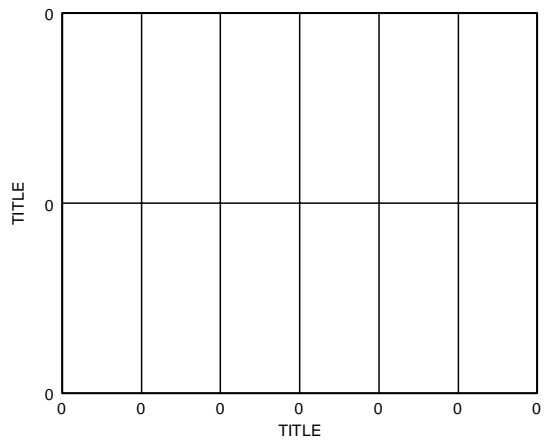
TPC 1. Temperature Accuracy @ 3.3 V and 5 V



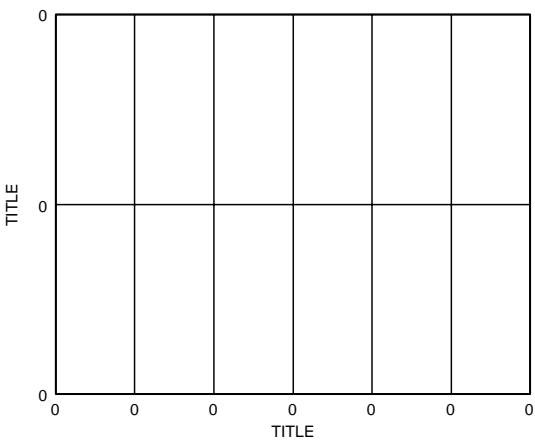
TPC 2. Operating Supply Current vs Temperature



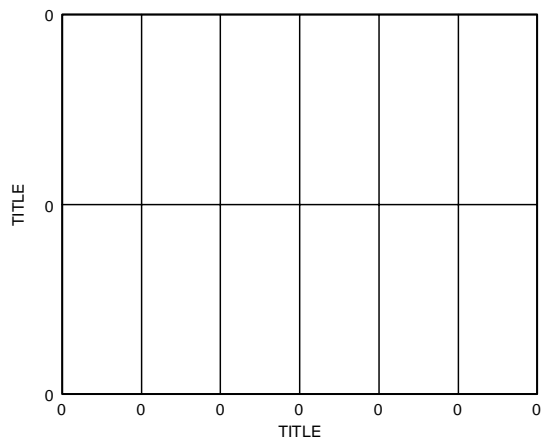
TPC 3. Operating Supply Current vs Supply Voltage



TPC 4. Power-Down Current vs Supply Voltage



TPC 5. Temperature Accuracy vs Supply Ripple Frequency



TPC 6. Response to Thermal Shock

ADT7301

CIRCUIT INFORMATION

The ADT7301 is a 12-bit digital temperature sensor with a 13th bit as a sign bit. The part houses an on-chip temperature sensor, a 12-bit A/D converter, a reference and serial interface logic functions in an SOT-23 package. The A/D converter section consists of a conventional successive-approximation converter based around a capacitor DAC. The parts are capable of running on a +2.7 V to +5.5 V power supply.

The on-chip temperature sensor allows an accurate measurement of the ambient device temperature to be made. The specified measurement range of the ADT7301 is -55°C to +125°C. The ADT7301 is capable of measuring up to 150°C but for limited time periods. The structural integrity of the device will start to deteriorate when operated at voltage and temperature maximum specifications.

CONVERTER DETAILS

The conversion clock for the part is internally generated so no external clock is required except when reading from and writing to the serial port. In normal mode, an internal clock oscillator runs the automatic conversion sequence. A conversion is initiated every 1 sec. At this time, the part wakes up and performs a temperature conversion. This temperature conversion typically takes 208 μs, at which time the analog circuitry of the part automatically shuts down. The analog circuitry powers up again when the 1 sec timer times out and the next conversion begins. The result of the most recent temperature conversion is always available in the serial output register as the serial interface circuitry never shuts down. The ADT7301 can be placed in a shutdown mode, via the Control Register, in which case, the on-chip oscillator is shut down and no further conversions are initiated until the ADT7301 is taken out of shutdown mode. The conversion result from the last conversion prior to shutdown can still be read from the ADT7301 even when it is in shutdown mode.

In the automatic conversion mode, every time read or write operation takes place, the internal clock oscillator is restarted at the end of the read or write operation. The result of the conversion is available, typically 208 μs later. Similarly, when the part is taken out of shutdown mode, the internal clock oscillator is restarted and the conversion result is available, typically 208 μs later. Reading from the device again before conversion is complete will again provide the same set of data.

TEMPERATURE VALUE REGISTER

The temperature value register is a 13-bit read-only register that stores the temperature reading from the ADC in 12-bit twos complement format plus a sign bit. The MSB (DB12) is the sign bit. The ADC can theoretically measure a temperature span of 255 °C. The internal temperature sensor is guaranteed to a low value limit of -55 °C and a high limit of +125 °C. The temperature data format is shown in Table I. This table shows the temperature measurement range of the device (-55°C to +150°C). A typical performance curve is shown in TPC 1.

Table I. Temperature Data Format

| Temperature | Digital Output DB12 . . . DB0 |
|-------------|----------------------------------|
| -55°C | 1, 1100 1001 0000 |
| -50°C | 1, 1100 1110 0000 |
| -40°C | 1, 1101 1000 0000 |
| -30°C | 1, 1110 0010 0000 |
| -25°C | 1, 1110 0111 0000 |
| -10°C | 1, 1111 0110 0000 |
| -0.0625°C | 1, 1111 1111 1111 |
| 0°C | 0, 0000 0000 0000 |
| +0.0625°C | 0, 0000 0000 0001 |
| +10°C | 0, 0000 1010 0000 |
| +25°C | 0, 0001 1001 0000 |
| +50°C | 0, 0011 0010 0000 |
| +75°C | 0, 0100 1011 0000 |
| +100°C | 0, 0110 0100 0000 |
| +125°C | 0, 0111 1101 0000 |
| +150°C | 0, 1001 0110 0000 |

Temperature Conversion Formula:

1. Positive Temperature = ADC Code(d)/16
 2. Negative Temperature = (ADC Code*(d) - 8192)/16
- *Using all 12 bits of the data byte plus the sign bit.

$$\text{Negative Temperature} = (\text{ADC Code}(d) * - 4096) / 16$$

*DB12 (sign bit) is removed from the ADC Code

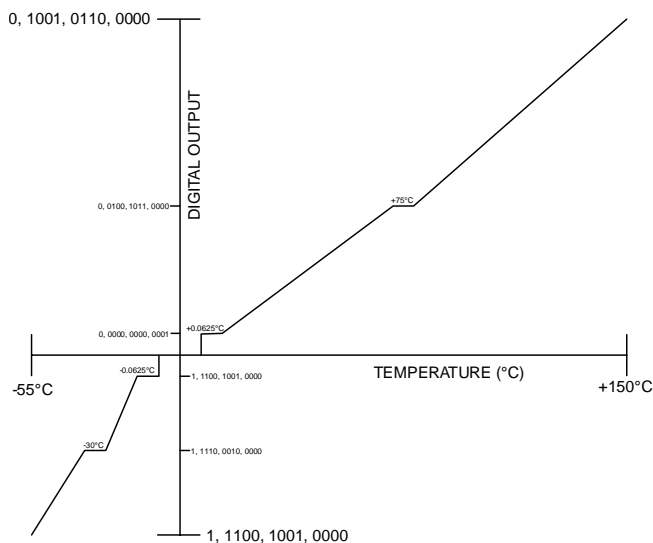


Figure 2. Temperature to Digital Transfer Function

SERIAL INTERFACE

The serial interface on the ADT7301 consists of four wires, \overline{CS} , SCLK, DIN and DOUT. The interface can be operated in 2-wire mode with \overline{CS} and DIN tied to Ground, in which case the interface has read-only capability, with data being read from the data register via the DOUT line. It is advisable to utilise \overline{CS} so as to

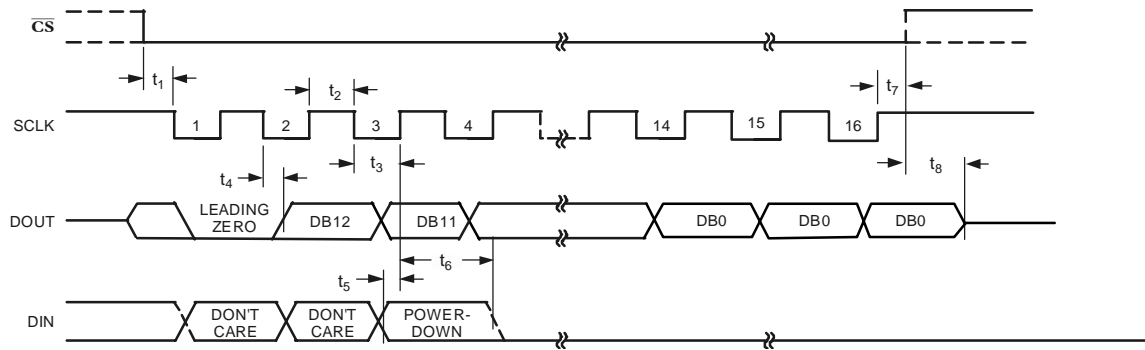


Figure 3. Serial Interface Timing Diagram

improve synchronisation between the ADT7301 and the master device. The DIN line is used to write the part into standby mode, if required. The \overline{CS} line is used to select the device when more than one device is connected to the serial clock and data lines.

The part operates in a slave mode and requires an externally applied serial clock to the SCLK input to access data from the data register. The serial interface on the ADT7301 is designed to allow the part to be interfaced to systems that provide a serial clock that is synchronized to the serial data, such as the 80C51, 87C51, 68HC11, 68HC05 and PIC16Cxx microcontrollers as well as DSP processors.

A read operation from the ADT7301 accesses data from the Temperature Value Register while a write operation to the part writes data to the Control Register.

Read Operation

Figure 3 shows the timing diagram for a serial read from the ADT7301. The \overline{CS} line enables the SCLK input. Twelve bits of data plus a sign bit are transferred during a read operation. Read operations occur during streams of 16 clock pulses. The first bit out is the Leading Zero and at the end of the read operation, the DOUT line remains in the same state as the last bit, DB0. It is clocked out of the ADT7301 until \overline{CS} returns high, at which time the DOUT line goes into three-state. Data is clocked out onto the DOUT line on the falling edge of SCLK.

Write Operation

Figure 3 also shows the timing diagram for a serial write to the ADT7301. The write operation takes place at the same time as the read operation. Only the third bit in the data stream provides a user-controlled function. This third bit is the power-down bit which, when set to a 1, puts the ADT7301 into shutdown mode. The first two bits of the data stream are don't cares while all other bits in the data stream other, than the power-down bit, should be 0 to ensure correct operation of the ADT7301. Data is loaded into the Control Register on the fifteenth falling SCLK edge and the data takes effect at this time i.e., if the part is programmed to go into shutdown, it does so at this point. If the \overline{CS} is brought high before this fifteenth SCLK edge, the Control Register will not be loaded and the power-down status of the part will not change. Data is clocked into the ADT7301 on the rising edge of SCLK.

MICROPROCESSOR INTERFACING

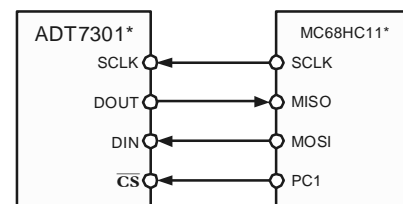
The ADT7301's serial interface allows for easy interface to most microcomputers and microprocessors. Figures 4 through 7 show some typical interface circuits.

The serial interface on the ADT7301 consists of four wires: \overline{CS} , DIN, DOUT and SCLK. All interface circuits shown utilize all four interface lines. However, it is possible to operate the interface with three wires. If the application does not require the power-down facility offered by the ADT7301, the DIN line can be tied permanently low. Thus, the interface can be operated from just three wires, SCLK, \overline{CS} , and DOUT.

The serial data transfer to and from the ADT7301 requires a 16-bit read operation. Many 8-bit microcontrollers have 8-bit serial ports and this 16-bit data transfer is handled as two 8-bit transfers. Other microcontrollers and DSP processors transfer 16 bits of data in a serial data operation.

ADT7301 to MC68HC11 Interface

Figure 4 shows an interface between the ADT7301 and the MC68HC11 microcontroller. The MC68HC11 is configured in the master mode with its CPOL bit set to a logic one and its CPHA bit set to a logic one. When the MC68HC11 is configured like this, its SCLK line idles high between data transfers. Data is transferred to and from the ADT7301 in two 8-bit serial data operations. The diagram shows the full (four-wire) interface. PC1 of the MC68HC11 is configured as an output and used to drive the \overline{CS} input.



*ADDITIONAL PINS OMITTED FOR CLARITY

Figure 4. ADT7301 to MC68HC11 Interface

ADT7301 to 8051

InterfaceAn interface circuit between the ADT7301 and the micro-controller is shown in Figure 5. The 8xC51 is configured in its Mode 0 serial interface mode. The serial clock line of the 8xC51 (on P3.1) idles high between data transfers. Data is transferred to and from the ADT7301 in

ADT7301

two 8-bit serial data operations. The ADT7301 outputs the MSB of its data stream as the first valid bit while the 8xC51 expects the LSB first. Thus, the data read into the serial buffer needs to be rearranged before the correct data word from the ADT7301 is available in the accumulator.

In the example shown, the ADT7301 is connected to the serial port of the 8051. Because the serial interface of the 8xC51 contains only one data line, the DIN line of the ADT7301 is tied low in the interface example given in Figure 5.

For applications that require the use of the power-down feature of the ADT7301, the serial interface should be implemented using data port lines on the 8051. This allows a full-duplex serial interface to be implemented. The method involves 'bit-banging' a port line to generate a serial clock while using two other port lines to shift data in and out with the fourth port line connecting to \overline{CS} . Port lines 1.0 through 1.3 (with P1.1 configured as an input) can be used to connect to SCLK, DOUT, DIN and \overline{CS} , respectively, to implement this scheme.

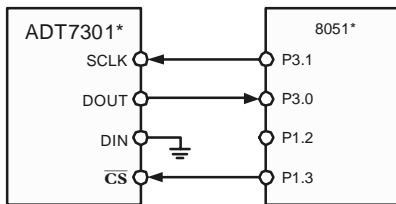


Figure 5. ADT7301 to 8051 Interface

ADT7301 to PIC16C6x/7x Interface

Figure 6 shows an interface circuit between the ADT7301 and the PIC16C6x/7x microcontroller. The PIC16C6x/7x Synchronous Serial Port (SSP) is configured as an SPI master with the Clock Polarity bit set to a logic one. In this mode, the serial clock line of the PIC16C6x/7x idles high between data transfers. Data is transferred to and from the ADT7301 in two 8-bit serial data operations. In the example shown, port line RA1 is being used to generate the \overline{CS} for the ADT7301.

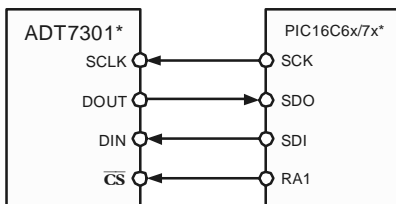


Figure 6. ADT7301 to PIC16C6x/7x Interface

ADT7301 to ADSP-21xx Interface

Figure 7 shows an interface between the ADT7301 and the ADSP-21xx DSP processor. To ensure correct operation of the interface the SPORT Control Register should be set up as follows:

TFSW = RFSW = 1, Alternate Framing
 INVRFS = INVTFS = 1, Active Low Framing Signal
 DTYPE = 00, Right Justify Data

SLEN = 1111, 16-Bit Data Words
 ISCLK = 1, Internal Serial Clock
 TFSR = RFS = 1, Frame Every Word
 IRFS = 0, RFS Configured As Input
 ITFS = 1, TFS Configured As Output

The interface requires an inverter between the SCLK line of the ADSP-21xx and the SCLK input of the ADT7301. The ADSP-21xx has the TFS and RFS of the SPORT tied together with TFS set as an output and RFS set as an input. The DSP operates in Alternate Framing Mode and the SPORT Control Register is set up as described above.

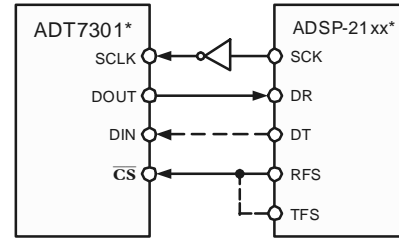


Figure 7. ADT7301 to ADSP-21xx Interface

MOUNTING THE ADT7301

The ADT7301 can be used for surface or air-temperature sensing applications. If the device is cemented to a surface with thermally conductive adhesive, the die temperature will be within about 0.1°C of the surface temperature, thanks to the device's low power consumption. Care should be taken to insulate the back and leads of the device from the air, if the ambient air temperature is different from the surface temperature being measured.

The ground pin provides the best thermal path to the die, so the temperature of the die will be close to that of the printed circuit ground track. Care should be taken to ensure that this is in good thermal contact with the surface being measured.

As with any IC, the ADT7301 and its associated wiring and circuits must be kept free from moisture to prevent leakage and corrosion, particularly in cold conditions where condensation is more likely to occur. Water-resistant varnishes and conformal coatings can be used for protection. The small size of the ADT7301 package allows it to be mounted inside sealed metal probes, which provide a safe environment for the device.

SUPPLY DECOUPLING

The ADT7301 should be decoupled with a 0.1 µF ceramic capacitor between V_{DD} and GND. This is particularly important if the ADT7301 is mounted remote from the power supply.

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

6-Lead Plastic Surface Mount SOT-23 (RT-6)

