



# SMBus/I<sup>2</sup>C<sup>®</sup> Compatible, ±0.5°C Accurate 12-Bit Digital Temperature Sensor with Daisy Chain

Preliminary Technical Data

**ADT7401**

## FEATURES

**12-Bit Temperature-to-Digital Converter**

**±0.5°C Accuracy at 25°C**

**±1°C Accuracy from 0°C to +70°C**

**Operation from -40°C to 150°C**

**Operation from 2.7V to 5.5V**

**Power Consumption TBD mW Max at 5.5V**

**Power Saving One Shot Mode**

**Pin Selectable Addressing via AS pin**

**Sub-SMBus/I<sup>2</sup>C Bus via DC pin**

**Small Low Cost 6-Pin SOT-23 Package and 8-Pin MSOP**

**MSOP**

## APPLICATIONS

**Isolated Sensors**

**Environmental Control Systems**

**Refrigeration Systems**

**Thermal Protection**

**Industrial Process Control**

**Power System Monitors**

**Automotive**

**Medical**

## GENERAL DESCRIPTION

The ADT7401 is a complete temperature monitoring system that outputs a 12-bit digital word corresponding to the temperature of the ADT7401's silicon. The device offers a high temperature accuracy of ±1°C from 0°C to +70°C, with excellent transducer linearity. The digital output of the ADT7401 is SMBus/I<sup>2</sup>C compatible.

The ADT7401 is specified for operation at supply voltages from 2.7 V to 5.5 V. Operating at 3.3 V the supply current is typically 230 µA.

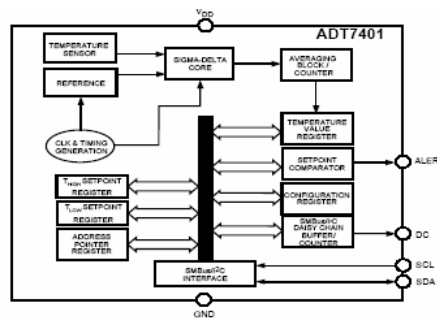
The ADT7401 is rated for operation over the -40°C to +150°C temperature range. It is packaged in a low cost, low area SOT-23 package and mini-SOIC package. The SMBus ALERT pin is an open-drain output that is used as an out of limit temperature indicator. It can be wired-AND with other SMBus ALERT pins and is used in conjunction with the SMBus General Call Address.

The DC (Daisy Chain) pin creates a sub-SMBus/I<sup>2</sup>C bus where a multiple of ADT7401's can be used. The DC pin has the advantage of freeing up the address options on the root bus as only one ADT7401 root address needs to be used by the SMBus/I<sup>2</sup>C controller but still being able to address a number of ADT7401 temperature sensors.

## PRODUCT HIGHLIGHTS

1. The ADT7401 has an on-chip temperature sensor that allows an accurate measurement of the ambient temperature. The measurable temperature range is -40°C to +150°C.
2. Supply voltage of 2.7 V to 5.5 V.
3. Space-saving 6-lead SOT-23 package and 8-lead MSOP.
4. Temperature accuracy of ±0.5°C.
5. 0.0625°C temperature resolution.
6. The ADT7401 features a one shot mode that reduces the power consumption to 2.57 µW at one sample per second.

## FUNCTIONAL BLOCK DIAGRAM



SOT-23 FUNCTIONAL BLOCK DIAGRAM

Figure 1. SOT-23 Functional Block Diagram

## Rev. PrE

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## SPECIFICATIONS

All specifications apply for -40°C to +150°C unless otherwise stated.  $T_A = T_{MIN}$  to  $T_{MAX}$ ,  $V_{DD} = +2.7$  V to +5.5 V, unless otherwise noted

Table 1.

Parameter	Min	Typ	Max	Units	Test Conditions/Comments
<b>TEMPERATURE SENSOR AND ADC</b>					
Accuracy @ $V_{DD} = +3.3$ V ( $\pm 10\%$ )			$\pm 0.5$	°C	$T_A = 25^\circ\text{C}$ .
			$\pm 1$	°C	$T_A = 0^\circ\text{C}$ to $70^\circ\text{C}$ .
			$\pm 2$	°C	$T_A = -40^\circ\text{C}$ to $+85^\circ\text{C}$ .
			$\pm 3$	°C	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$ .
			$\pm 4^1$	°C	$T_A = -40^\circ\text{C}$ to $+150^\circ\text{C}$ .
Accuracy @ $V_{DD} = +5$ V ( $\pm 10\%$ )			$\pm 0.5$	°C	$T_A = 25^\circ\text{C}$ .
			$\pm 1$	°C	$T_A = 0^\circ\text{C}$ to $70^\circ\text{C}$ .
			$\pm 2$	°C	$T_A = -40^\circ\text{C}$ to $+85^\circ\text{C}$ .
			$\pm 3$	°C	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$ .
			$\pm 4^1$	°C	$T_A = -40^\circ\text{C}$ to $+150^\circ\text{C}$ .
Temperature Resolution		0.0625		°C	Equivalent to 12 Bits Sigma Delta ADC
Temperature Conversion Time		200		ms	
Temperature Update Rate		1		s	Time between each conversion
Long Term Drift		0.25		°C	Drift over 10 years if part is operated at $+55^\circ\text{C}$ .
Power Supply Rejection Ratio		0.3	0.6	°C/V	$T_A = +25^\circ\text{C}$
<b>DIGITAL INPUTS<sup>2</sup></b>					
Input Current			$\pm 1$	$\mu\text{A}$	$V_{IN} = 0$ V to $V_{DD}$
$V_{IL}$ , Input Low Voltage			$0.3 \times V_{DD}$	V	
$V_{IH}$ , Input High Voltage	$0.7 \times V_{DD}$			V	
Pin Capacitance		3	10	pF	All digital inputs
SCL, SDA Glitch Rejection			50	ns	Input filtering suppresses noise spikes of less than 50 ns.
<b>DIGITAL OUTPUTS<sup>2</sup></b>					
$V_{OH}$ , Output High Voltage	2.4			V	$I_{SOURCE} = I_{SINK} = 200 \mu\text{A}$
$V_{OL}$ , Output Low Voltage			0.4	V	$I_{OL} = 3$ mA
$I_{OH}$ , Output High Current			1	mA	$V_{OH} = 5$ V
$C_{OUT}$ , Output Capacitance			50	pF	
<b>SUPPLIES</b>					
Supply Voltage	2.7		5.5	V	
Supply Current					Serial Bus Inactive.
Normal Mode <sup>6</sup> @ 3.3 V		230	450	$\mu\text{A}$	Device Converting.
Normal Mode <sup>6</sup> @ 5 V		300	500	$\mu\text{A}$	Device Converting.
Quiescent <sup>6</sup> @ 3.3 V		3	8	$\mu\text{A}$	Device not converting.
Quiescent <sup>6</sup> @ 5.5 V		5	10	$\mu\text{A}$	Device not converting.
One Shot Mode @ 1 sps		21.16		$\mu\text{A}$	Average Current @ $V_{DD} = 2.7$ V to 3.6 V.
One Shot Mode @ 1 sps		28.6		$\mu\text{A}$	Average Current @ $V_{DD} = 4.5$ V to 5.5 V.
Shutdown Current		0.3	1	$\mu\text{A}$	
Power Dissipation		759		$\mu\text{W}$	$V_{DD} = +3.3$ V, Continuously Converting
Power Dissipation					
1 sps		69.83		$\mu\text{W}$	Average Power Dissipated for $V_{DD} = +3.3$ V. One Shot Mode.
1 sps		143		$\mu\text{W}$	Average Power Dissipated for $V_{DD} = +5$ V. One Shot Mode.

<sup>1</sup> It is not recommended to operate the device at temperatures above  $+125^\circ\text{C}$  for greater than a total of 5% of the lifetime of the device. Any exposure beyond this limit will affect device reliability.

<sup>2</sup> Guaranteed by design and characterization, not production tested.

## TIMING CHARACTERISTICS

Guaranteed by design and characterization, not production tested. The SDA & SCL timing is measured with the input filters turned on so as to meet the Fast-Mode I<sup>2</sup>C specification. Switching off the input filters improves the transfer rate but has a negative affect on the EMC behaviour of the part. T<sub>A</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>, V<sub>DD</sub> = +2.7 V to +5.5 V, unless otherwise noted.

Table 2.

Parameter	Limit	Units	Comments
Serial Clock Period, t <sub>1</sub>	2.5	μs	Fast Mode I <sup>2</sup> C. See Figure 2
Data In Setup Time to SCL High, t <sub>2</sub>	50	ns	
Data Out Stable after SCL Low, t <sub>3</sub>	0	ns	See Figure 2
SDA Low Setup Time to SCL Low (Start Condition), t <sub>4</sub>	50	ns	See Figure 2
SDA High Hold Time after SCL High (Stop Condition), t <sub>5</sub>	50	ns	See Figure 2
SDA and SCL Fall Time, t <sub>6</sub>	90	ns	See Figure 2

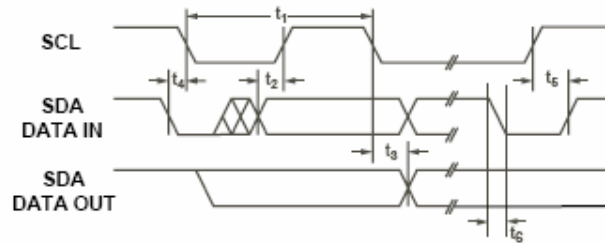


Figure 1. SMBus/I<sup>2</sup>C Timing Diagram

Figure 2. SMBus/I<sup>2</sup>C Timing Diagram



Figure 2. Load Circuit for Access Time and Bus Relinquish Time

Figure 3. Load Circuit for Access Time and Bus Relinquish Time

## ABSOLUTE MAXIMUM RATINGS

Table 3.

Parameter	Rating
V <sub>DD</sub> to GND	-0.3 V to +7 V
Digital Input Voltage to GND	-0.3 V to V <sub>DD</sub> + 0.3 V
Maximum Output Current (OUT)	±10 mA
Operating Temperature Range <sup>3</sup>	-40°C to +150°C
Storage Temperature Range	-65°C to +160°C
Max Junction Temperature, T <sub>JMAX</sub>	+150°C
6-Lead SOT-23	
Power Dissipation <sup>4</sup>	$W_{MAX} = (T_{JMAX} - T_A^5) / \theta_{JA}$
Thermal Impedance <sup>6</sup>	
θ <sub>JA</sub> , Junction-to-Ambient (still air)	229.6°C/W
θ <sub>JC</sub> , Junction-to-Case	91.99°C/W
8-Lead MSOP (RM-8)	
Power Dissipation <sup>2</sup>	$W_{MAX} = (T_{JMAX} - T_A^3) / \theta_{JA}$
Thermal Impedance <sup>4</sup>	
θ <sub>JA</sub> , Junction-to-Ambient (still air)	205.9°C/W
θ <sub>JC</sub> , Junction-to-Case	43.74°C/W
IR Reflow Soldering	
Peak Temperature	+220°C (-0/+5°C)
Time at Peak Temperature	10 to 20 secs
Ramp-up Rate	2-3°C/sec
Ramp-down Rate	-6°C/sec

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.

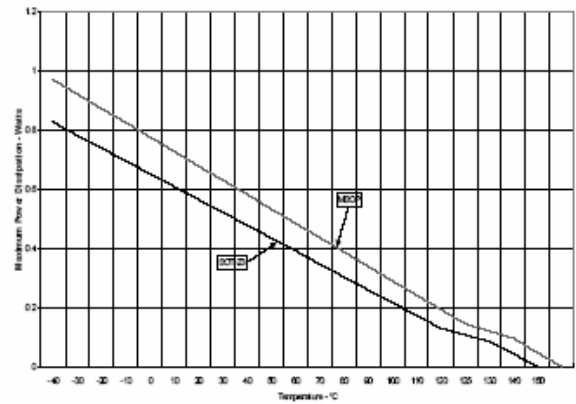


Figure 4. Plot of Maximum Power Dissipation vs. Temperature

Figure 4. Plot of Maximum Power Dissipation vs. Temperature

<sup>3</sup> It is not recommended to operate the device at temperatures above +125°C for greater than a total of 5% of the lifetime of the device. Any exposure beyond this limit will affect device reliability.

<sup>4</sup> Values relate to the package being used on a 2-layer PCB. See Figure 4. for a plot of max power dissipation vs. ambient temperature (T<sub>A</sub>).

<sup>5</sup> T<sub>A</sub> = Ambient Temperature.

<sup>6</sup> Junction-to-Case resistance is applicable to components featuring a preferential flow direction, e.g. components mounted on a heat sink. Junction-to-Ambient resistance is more useful for air-cooled PCB mounted components.

### ESD 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 this product 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.



## PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

### PIN CONFIGURATIONS

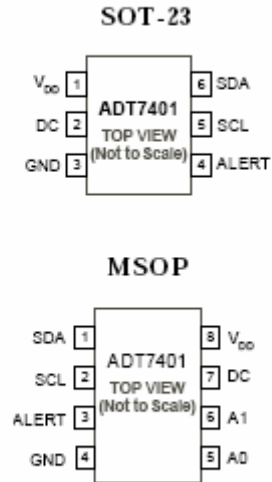
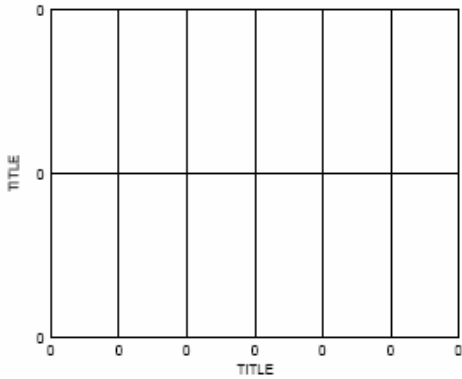


Figure 5. Pin Configurations

Table 4. Pin Function Description

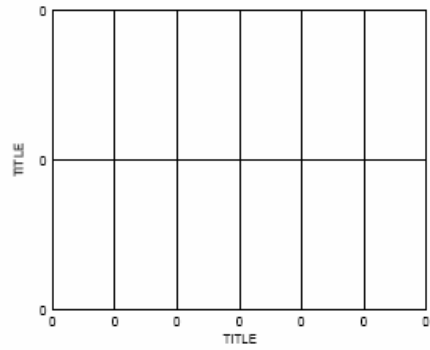
Mnemonic	SOT-23 Pin No.	MSOP Pin No.	Description
SDA	6	1	SMBus/I <sup>2</sup> C Serial Data Input/Output. Open-drain configuration needs a pullup resistor.
SCL	5	2	Serial clock input. Open-drain configuration.
ALERT	4	3	Digital open-drain output. Out of limit temperature indicator. This output becomes active when temperature exceeds T <sub>HIGH</sub> or T <sub>LOW</sub> limits. Can be programmed to be active low or active high
GND	3	4	Analog and Digital Ground.
DC	2	7	Daisy Chain Digital Input/Output. This pin acts as the input/output conduit for the sub-SMBus/I <sup>2</sup> C bus. Push-Pull configuration.
V <sub>DD</sub>	1	8	Positive Supply Voltage, 2.7 V to 5.5 V.
A0	-	5	Digital Input. User set programmable bit of the serial bus address.
A1	-	6	Digital Input. User set programmable bit of the serial bus address.

### TYPICAL PERFORMANCE CURVES



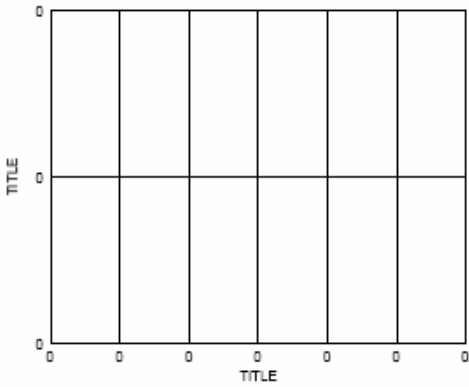
TPC 1. Supply Current vs. Supply Voltage @ +25°C

Figure 6. Supply Current vs. Supply Voltage @ +25°C



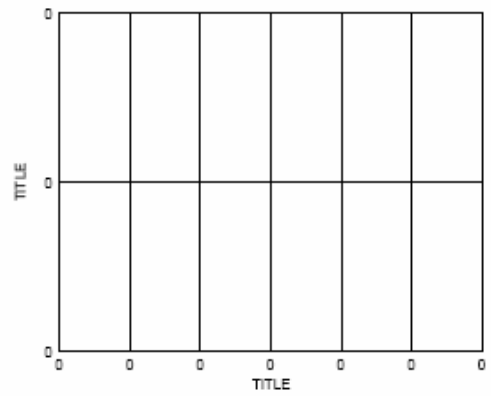
TPC 3. PSRR vs. Supply Ripple Frequency

Figure 8. PSRR vs. Supply Ripple Frequency



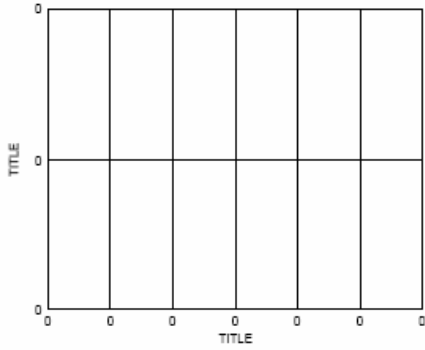
TPC 2. Shutdown Current vs. Supply Voltage @ +25°C

Figure 7. Shutdown Current vs. Supply Voltage @ +25°C



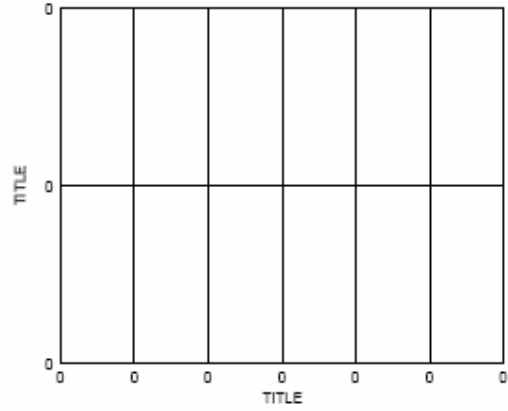
TPC 4. Temperature Error at 3.3 V and 5 V

Figure 9. Temperature Error at 3.3 V and 5 V



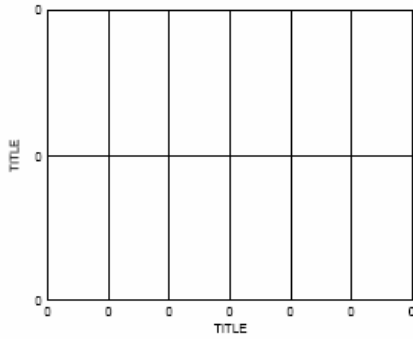
TPC 5. Temperature Error vs. Power Supply Noise Frequency

Figure 10. Temperature Error vs. Power Supply Noise Frequency



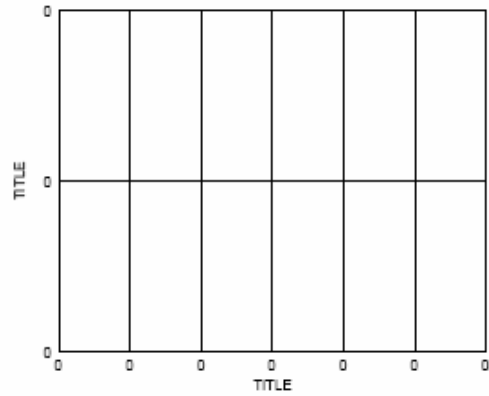
TPC 13. Supply Current vs. Temperature

Figure 12. Supply Current vs. Temperature



TPC 6. Temperature Sensor Response to Thermal Shock

Figure 11. Temperature Sensor Response to Thermal Shock



TPC 15. Power Supply Rejection vs. Temperature

Figure 13. Power Supply Rejection vs. Temperature



## CIRCUIT INFORMATION

The ADT7401 is a standalone temperature sensor that generates a 12-bit digital output in two's complement that varies in direct proportion with the temperature of the device. An onboard sensor generates a voltage precisely proportional to absolute temperature which is compared to an internal voltage reference and input to a precision digital modulator. The serial digital output is converted into a 12-bit digital word and stored in the Temperature Value Register. Overall accuracy is  $\pm 5^{\circ}\text{C}$  from  $0^{\circ}\text{C}$  to  $+70^{\circ}\text{C}$ , with excellent transducer linearity. The digital output of the ADT7401 is SMBus/I<sup>2</sup>C compatible, and is easily interfaced to most popular microcontrollers.

The onboard temperature sensor has excellent accuracy and linearity over the entire rated temperature range without correction or calibration by the user.

The sensor output is digitized by a first-order sigma-delta modulator, also known as the "charge balance" type analog-to-digital converter. This type of converter utilizes time-domain oversampling and a high accuracy comparator to deliver 12 bits of effective accuracy in an extremely compact circuit.

## CONVERTER DETAILS

The sigma-delta modulator consists of an input sampler, a summing network, an integrator, a comparator, and a 1-bit DAC. Similar to the voltage-to-frequency converter, this architecture creates in effect a negative feedback loop whose intent is to minimize the integrator output by changing the duty

cycle of the comparator output in response to input voltage changes. The comparator samples the output of the integrator at a much higher rate than the input sampling frequency, this is called oversampling. This spreads the quantization noise over a much wider band than that of the input signal, improving overall noise performance and increasing accuracy.

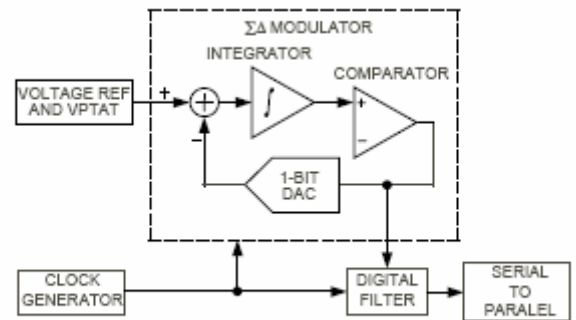


Figure 6. First-Order Sigma-Delta Modulator

Figure 14. First-Order Sigma-Delta Modulator

The modulated output of the comparator is encoded using a circuit technique, which results in a serial digital signal. This signal is then converted into a 12-bit digital word for storage into a register. The final output format is two's complement.

## APPLICATION HINTS

### THERMAL RESPONSE TIME

The time required for a temperature sensor to settle to a specified accuracy is a function of the thermal mass of, and the thermal conductivity between, the sensor and the object being sensed. Thermal mass is often considered equivalent to capacitance. Thermal conductivity is commonly specified using the symbol  $\theta$ , and can be thought of as thermal resistance. It is commonly specified in units of degrees per watt of power transferred across the thermal joint. Thus, the time required for the ADT7401 to settle to the desired accuracy is dependent on the package, the thermal contact established in that particular application, and the equivalent power of the heat source. In most applications, the settling time is probably best determined empirically.

### SELF-HEATING EFFECTS

The temperature measurement accuracy of the ADT7401 may be degraded in some applications due to self-heating. Errors introduced are from the quiescent dissipation and power dissipated when converting. The magnitude of these temperature errors is dependent on the thermal conductivity of the ADT7401 package, the mounting technique, and effects of airflow. Static dissipation in the ADT7401 is typically 10  $\mu$ W operating at 3.3 V with no load. In the 6 lead SOT-23 package mounted in free air, this accounts for a temperature increase due to self-heating of:

$$\Delta T = P_{DISS} \times \theta_{JA} = 143\mu W \times 229.6^{\circ}C/W = 0.0328^{\circ}C$$

It is recommended that current dissipated through the device is kept to a minimum as it has a proportional affect on the temperature error.

### SUPPLY DECOUPLING

The ADT7401 should be decoupled with a 0.1  $\mu$ F ceramic capacitor between  $V_{DD}$  and GND. This is particularly important if the ADT7401 is mounted remote from the power supply. Precision analog products, such as the ADT7401, require a well filtered power source. Since the ADT7401 operates from a single supply, it seems convenient to simply tap into the digital logic power supply. Unfortunately, the logic supply is often a switch-mode design, which generates noise in the 20 kHz to 1 MHz range. In addition, fast logic gates can generate glitches hundred of millivolts in amplitude due to wiring resistance and

inductance.

If possible, the ADT7401 should be powered directly from the system power supply. This arrangement, shown in Figure 15, will isolate the analog section from the logic switching transients. Even if a separate power supply trace is not available, however, generous supply bypassing will reduce supply-line induced errors. Local supply bypassing consisting of a 0.1  $\mu$ F ceramic capacitor is recommended.

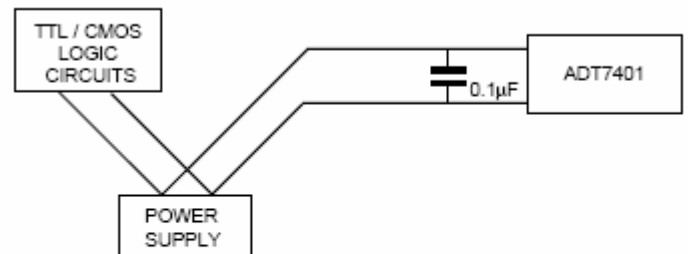


Figure TBD. Use Separate Traces to Reduce Power Supply Noise

Figure 15. Use Separate Traces to Reduce Power Supply Noise

### TEMPERATURE MONITORING

The ADT7401 is ideal for monitoring the thermal environment within electronic equipment. For example, the surface mounted package will accurately reflect the exact thermal conditions which affect nearby integrated circuits.

The ADT7401 measures and converts the temperature at the surface of their own semiconductor chip. When the ADT7401 is used to measure the temperature of a nearby heat source, the thermal impedance between the heat source and the ADT7401 must be considered. Often, a thermocouple or other temperature sensor is used to measure the temperature of the source while the ADT7401's temperature is monitored. Once the thermal impedance is determined, the temperature of the heat source can be inferred from the ADT7401 output.

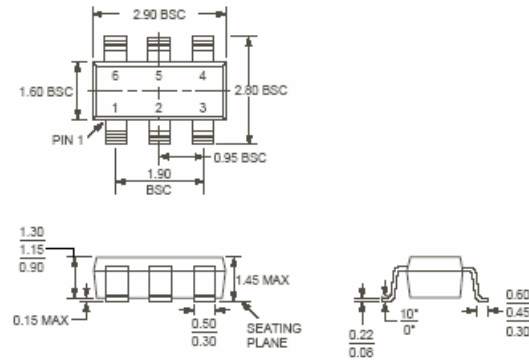
One example of using the ADT7401's unique properties is in monitoring a high power dissipation microprocessor. The adt7401, in a surface mount package, is mounted directly beneath the microprocessor's pin grid array (PGA) package.

# OUTLINE DIMENSIONS

## OUTLINE DIMENSIONS

Dimensions shown in mm.

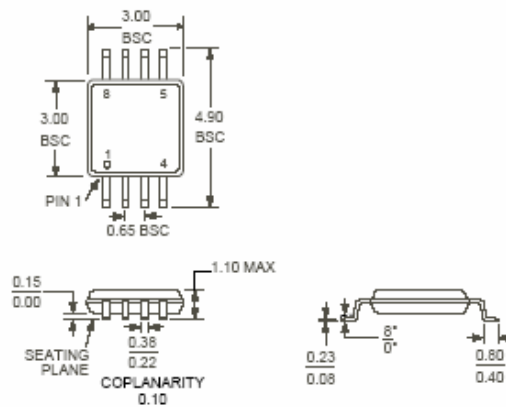
### 6-Lead Plastic Surface Mount SOT-23 (RT-6)



COMPLIANT TO JEDEC STANDARDS MO-178AB

Figure 16. 6-Lead Plastic Surface Mount SOT-23 (RT-6)  
Dimensions shown in Millimeters

### 8-Lead Plastic Surface Mount Mini/Micro SOIC (MSOP) (RM-8)



COMPLIANT TO JEDEC STANDARDS MO-187AA

Figure 17. 8-Lead Plastic Surface Mount Mini/Micro SOIC (MSOP) (RM-8)  
Dimensions shown in Millimeters

## ORDERING GUIDE

Model	Temperature Range <sup>1</sup>	Temperature Accuracy <sup>2</sup>	Package Description	Branding Information	Package Option	Minimum Quantities/Reel
ADT7401RT-500REEL7	-40°C to +150°C	±1°C	6-Lead SOT-23		RJ-6	500
ADT7401RT-REEL	-40°C to +150°C	±1°C	6-Lead SOT-23		RJ-6	10000
ADT7401RT-REEL7	-40°C to +150°C	±1°C	6-Lead SOT-23		RJ-6	3000
ADT7401RM-500REEL7	-40°C to +150°C	±1°C	8-Lead MSOP		RM-8	500
ADT7401RM-REEL	-40°C to +150°C	±1°C	8-Lead MSOP		RM-8	10000
ADT7401RM-REEL7	-40°C to +150°C	±1°C	8-Lead MSOP		RM-8	3000

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<sup>1</sup> It is not recommended to operate the device at temperatures above +125°C for greater than a total of 5% of the lifetime of the device. Any exposure beyond this limit will affect device reliability.

<sup>2</sup> Temperature accuracy is over 0°C to +70°C temperature range.