ANALOG DEVICES

±0.5°C Accurate, 16-Bit Digital I2C Temperature Sensor

Preliminary Technical Data

ADT7410

FEATURES

16-bit temperature-to-digital converter
Temperature accuracy ±0.5°C from 0°C to 70°C
Power saving 1 Sample Per Second mode
I²C-compatible interface
Operating temperature range : −55°C to +150°C
Operating voltage range: 2.7 V to 5.5 V
Critical overtemperature indicator
Programmable overtemperature/undertemperature interrupt
Shutdown mode for low power consumption
Power consumption 1 mW typical at 3.3 V
Standard 8-lead narrow SOIC RoHS-compliant package

APPLICATIONS

Medical equipment
Isolated sensors
Environmental control systems
Computer thermal monitoring
Thermal protection
Industrial process control
Power system monitors
Hand-held applications

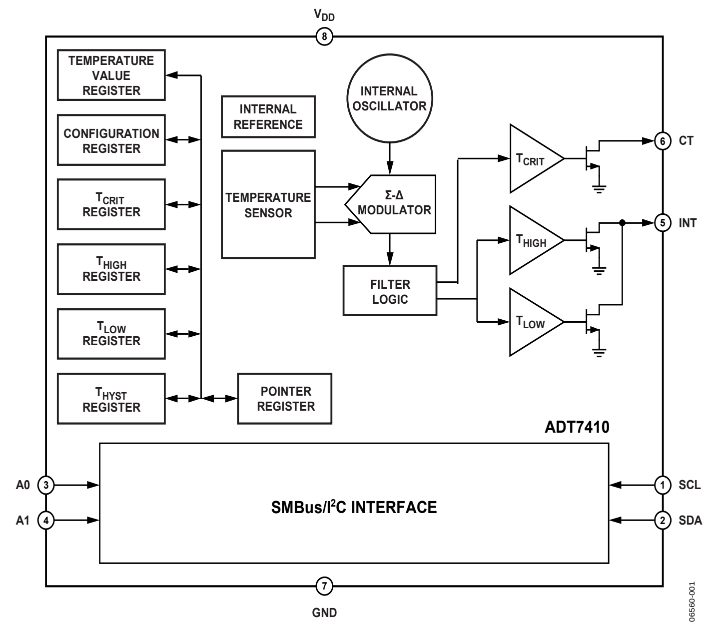

Figure 1.

FUNCTIONAL BLOCK DIAGRAM

GENERAL DESCRIPTION

The ADT7410 is a high accuracy digital temperature sensor in a narrow SOIC package. It contains a band gap temperature sensor and a13-bit ADC, to monitor and digitize the temperature to a resolution of 0.0625°C. The resolution can be changed to 16 bits by setting a bit in the configuration register, to give a 0.0078°C resolution. The default resolution is 13 bits.

The ADT7410 is guaranteed to operate at supply voltages from 2.7 V to 5.5 V. Operating at 3.3 V, the average supply current is typically 250 µA. The ADT7410 offers a shutdown mode that powers down the device and gives a shutdown current of typically 0.8 µA. The ADT7410 is rated for operation over the −55°C to +150°C temperature range.

Pins A0 and A1 are available for address selection, giving the ADT7410 4 possible I²C addresses. The CT pin is an open-drain output that becomes active when the temperature exceeds a programmable critical temperature limit. The default critical temperature limit is 147°C. The INT pin is also an open-drain output that becomes active when the temperature exceeds a programmable limit. The INT and CT pins can operate in either comparator or interrupt mode.

Rev. PrE
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PRODUCT HIGHLIGHTS

- An on-chip temperature sensor allows an accurate measurement of the ambient temperature. The measurable temperature range is −55°C to +150°C.
- Supply voltage is 2.7 V to 5.5 V.
- Available in an 8-lead narrow SOIC package.
- Temperature accuracy is ±0.5°C maximum.
- Default temperature resolution is 0.0625°C.
- First conversion on power-up is a fast conversion to ensure fast CT and INT pin activation in overtemperature situations.
- Programmable temperature interrupt limits.
- Shutdown mode reduces the current consumption to 0.8 µA typical.
- Connect up to four ADT7410 devices to a single I^2C® bus.

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TABLE OF CONTENTS

REVISION HISTORY

08/08 - Revision PrE: Preliminary Version E

04/08 - Revision PrD: Preliminary Version D

12/07 – Revision PrC: Preliminary Version C

11/07—Revision PrB: Preliminary Version B

08/07—Revision PrA: Preliminary Version A

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SPECIFICATIONS

T_A = −55°C to +150°C, V_{DD} = 2.7 V to 5.5 V, unless otherwise noted.

Table 1.

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
TEMPERATURE SENSOR AND ADC					
Accuracy			±0.5	°C	T_A = 0°C to +70°C
			±0.5	°C	T_A = -20°C to +100°C, V_{DD} = 3.3 V
			±1.5	°C	T_A = −40°C to +125°C
			±2	°C	T_A = −55°C to +150°C
ADC Resolution		13		Bits	Twos complement temperature value of sign bit plus 12 ADC bits (power-up default resolution)
		16		Bits	Twos complement temperature value of sign bit plus 15 ADC bits (D7 = 1 in the configuration register)
Temperature Resolution					
13 Bits		0.0625		°C	13-bits (Sign + 12-bit)
16 Bits		0.0078125		°C	16-bit (Sign + 15-bit)
Temperature Conversion Time		240		ms	Continuous conversion mode and one-shot conversion mode
Fast Temperature Conversion Time		6	10	ms	First conversion on power-up only
1 SPS Conversion Time		60		ms	Conversion time for one sample per second mode
Fast Temperature Conversion Accuracy		±TBD	±TBD	°C	T_A = 0°C to +70°C
		±TBD	±TBD	°C	T_A = −40°C to +125°C
		±TBD	±TBD	°C	T_A = −55°C to +150°C
Long-Term Drift		0.08		°C	Drift over 10 years, if part is operated at 55°C
Temperature Hysteresis		0.02		°C	Temperature cycl = 25°C to 125°C, and back to 25°C
Repeatability		0.01	?	°C	T_A = +25°C
DC PSRR		TBD		°C/V	T_A = +25°C
DIGITAL OUTPUTS (OPEN DRAIN)					
High Output Leakage Current, I_{OH}		0.1	5	µA	CT and INT pins pulled up to 5.5 V
Output High Current, I_{OH}			1	mA	V_{OH} = 5 V
Output Low Voltage, V_{OL}			0.4	V	I_{OL} = 3 mA
Output High Voltage, V_{OH}	0.7 × V_{DD}			V	
Output Capacitance, C_{OUT}	3		10	pF	
R_{ON} Resistance (Low Output)		15		Ω	Supply and temperature dependent
DIGITAL INPUTS					
Input Current			±1	µA	V_{IN} = 0 V to V_{DD}
Input Low Voltage, V_{IL}			0.3 × V_{DD}	V	
Input High Voltage, V_{IH}	0.7 × V_{DD}			V	
SCL, SDA Glitch Rejection			50	ns	Input filtering suppresses noise spikes of less than 50 ns
Pin Capacitance	3		10	pF	
POWER REQUIREMENTS					
Supply Voltage	2.7		5.5	V	
Supply Current at 3.3 V		TBD	TBD	µA	Peak current while converting and I²C interface inactive
Supply Current at 5.0 V		TBD	350	µA	Peak current while converting and I²C interface inactive
Shutdown Mode at 3.3 V		TBD	TBD	µA	Supply current in shutdown mode
Shutdown Mode at 5.0 V		TBD	1	µA	Supply current in shutdown mode
Power Dissipation		TBD		µW	V_{DD} = 3.3 V, normal mode at 25°C
1 Sample Per Second		150		µW	Power dissipated for V_{DD} = 3.3 V at 25°C
1 Sample Per Second		315		µW	Power dissipated for V_{DD} = 5.0 V at 25°C

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I²C TIMING SPECIFICATIONS

T_A = −55°C to +150°C, V_{DD} = 2.7 V to 5.5 V, unless otherwise noted. All input signals are specified with t_R (rise time) = t_F (fall time) = 5 ns (10% to 90% of V_{DD}) and timed from a voltage level of 1.6 V.

Table 2.

Parameter[1]	Symbol	Min	Typ	Max	Unit	Comments
Serial Clock Period	t_1	2.5			µs	Fast mode I²C. See Figure 2.
Data In Setup Time to SCL High	t_2	50			ns	See Figure 2.
Data Out Stable After SCL Low	t_3	0		0.9[2]	ns	Fast mode I²C. See Figure 2.
Data Out Stable After SCL Low	t_3	0		3.45[2]	µs	Standard mode I²C. See Figure 2.
SDA Low Setup Time to SCL Low (Start Condition)	t_4	50			ns	See Figure 2.
SDA High Hold Time After SCL High (Stop Condition)	t_5	50			ns	See Figure 2.
SDA and SCL Rise Time	t_6			300	ns	Fast mode I²C. See Figure 2.
SDA and SCL Rise Time	t_6			1000	ns	Standard mode I²C. See Figure 2.
SDA and SCL Fall Time	t_7			300	ns	See Figure 2.
Capacitive Load for each Bus Line	C_B			400	pF	

[1] Guaranteed by design and characterization; not production tested.
[2] This time has to be met only if the master does not stretch the low period of the SCL signal.

TIMING DIAGRAM

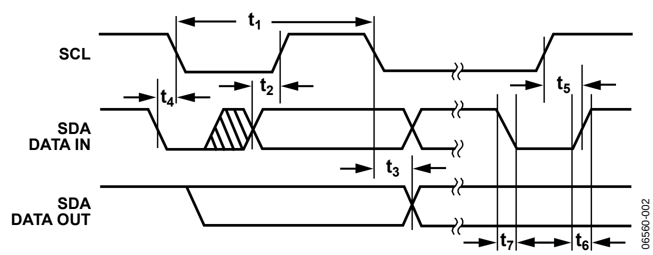

Figure 2 I²C Timing Diagram

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ABSOLUTE MAXIMUM RATINGS

Table 3.

Parameter	Rating
V_{DD} to GND	−0.3 V to +7 V
SDO Input Voltage to GND	−0.3 V to V_{DD} + 0.3 V
SDO Output Voltage to GND	−0.3 V to V_{DD} + 0.3 V
SCL Input Voltage to GND	−0.3 V to V_{DD} + 0.3 V
CT and INT Output Voltage to GND	−0.3 V to V_{DD} + 0.3 V
Operating Temperature Range	−55°C to +150°C
Storage Temperature Range	−65°C to +160°C
Maximum Junction Temperature, T_{JMAX}	150.7°C
8-Lead N-SOIC (R-8)	
Power Dissipation[1]	$W_{MAX} = (T_{JMAX} - T_A$[2]$)/\theta_{JA}$
Thermal Impedance[3]	
θ_{JA}, Junction-to-Ambient (Still Air)	157°C/W
θ_{JC}, Junction-to-Case	56°C/W
IR Reflow Soldering	
Peak Temperature (RoHS-Compliant Package)	260°C (+0°C)
Time at Peak Temperature	20 sec to 40 sec
Ramp-Up Rate	3°C/sec maximum
Ramp-Down Rate	−6°C/sec maximum
Time from 25°C to Peak Temperature	8 minutes maximum

[1] Values relate to package being used on a standard 2-layer PCB. This gives a worst-case θ_{JA} and θ_{JC}. Refer to Figure 3 for a plot of maximum power dissipation vs. ambient temperature (T_A).
[2] T_A = ambient temperature.
[3] Junction-to-case resistance is applicable to components featuring a preferential flow direction, for example, components mounted on a heat sink. Junction-to-ambient is more useful for air-cooled, PCB-mounted components.

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.

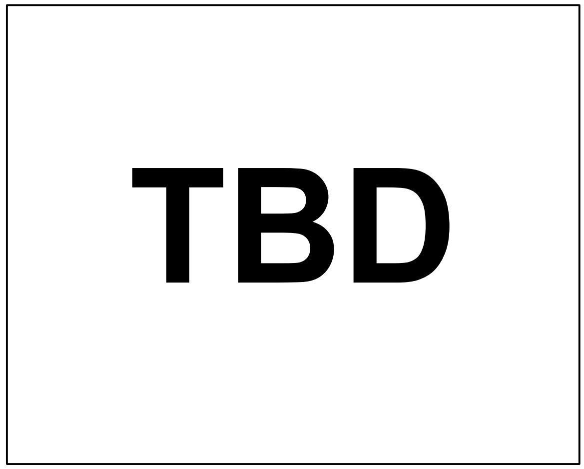
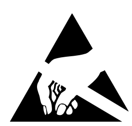


Figure 3. SOIC_N Maximum Power Dissipation vs. Temperature

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

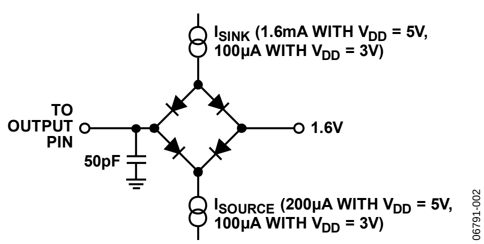


Figure 4. Load Circuit for Timing Characterization

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PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

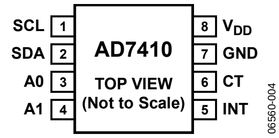

Figure 5. Pin Configuration

Table 4. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	SCL	Serial Clock Input. This is the clock input for the serial port. The serial clock is used to clock in and clock out data to and from any register of the ADT7410. Open-drain configuration; needs a pull-up resistor.
2	SDA	I^2C Serial Data Input/Output. Serial data to and from the part is provided on this pin. Open-drain configuration; needs a pull-up resistor.
3	A0	I^2C Serial Bus Address Selection Pin. Logic input. Connect to GND or V_{DD} to set I^2C address.
4	A1	I^2C Serial Bus Address Selection Pin. Logic input. Connect to GND or V_{DD} to set I^2C address.
5	INT	Overtemperature and Undertemperature Indicator. Power-up default setting is as an active low comparator interrupt. Open-drain configuration; needs a pull-up resistor.
6	CT	Critical Overtemperature Indicator. Power-up default polarity is active low. Open-drain configuration; needs a pull-up resistor.
7	GND	Analog and Digital Ground.
8	V_{DD}	Positive Supply Voltage, 2.7 V to 5.5 V. The supply should be decoupled to ground.

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TYPICAL PERFORMANCE CHARACTERISTICS

TBD

Figure 6. Temperature Accuracy at 3.3 V and 5 V

TBD

Figure 7. Operating Supply Current vs. Temperature

TBD

Figure 8. Average Operating Supply Current vs. Supply Voltage at 30°C

TBD

Figure 9. Shutdown Current vs. Supply Voltage at 30°C

TBD

Figure 10. Temperature Accuracy vs. Supply Ripple Frequency

TBD

Figure 11. Response to Thermal Shock

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THEORY OF OPERATION

CIRCUIT INFORMATION

The ADT7410 is a 16-bit digital temperature sensor with the 16th bit acting as the sign bit. An on-board temperature sensor generates a voltage precisely proportional to absolute temperature, which is compared to an internal voltage reference and input to a precision digital modulator. Overall accuracy for the ADT7410 is ±0.5°C from 0°C to +70°C. The serial interface is I²C compatible and the open-drain outputs of the ADT7410, INT and CT, are capable of sinking 2 mA.

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

The sensor output is digitized by a Σ-Δ 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 16 bits of effective accuracy in an extremely compact circuit.

The measured temperature value is compared with a critical temperature limit stored in the 16-bit T_{CRIT} read/write register, a high temperature limit stored in the 16-bit T_{HIGH} read/write register and a low temperature limit stored in the 16-bit T_{LOW} read/write register. If the measured value exceeds these limits, the INT pin is activated, and if it exceeds the T_{CRIT} limit, the CT pin is activated. The INT and CT pins are programmable for polarity via the configuration register while the INT and CT pins are also programmable for mode operation via the configuration register.

Configuration register functions consist of:

- Switching between normal operation and full power-down.
- Switching between comparator and interrupt event modes on the INT and CT pins.
- Setting the CT and INT pins active polarity.
- Setting the number of faults that activate the CT and INT pins.
- Enabling the standard one-shot mode and one sample per second mode.

CONVERTER DETAILS

The Σ-Δ modulator consists of an input sampler, a summing network, an integrator, a comparator, and a 1-bit DAC. This architecture creates a negative feedback loop and minimizes 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 oversampling spreads the quantization noise over a much wider band than that of the input signal, improving overall noise performance and increasing accuracy.

The modulated output of the comparator is encoded using a circuit technique that results in I²C temperature data.

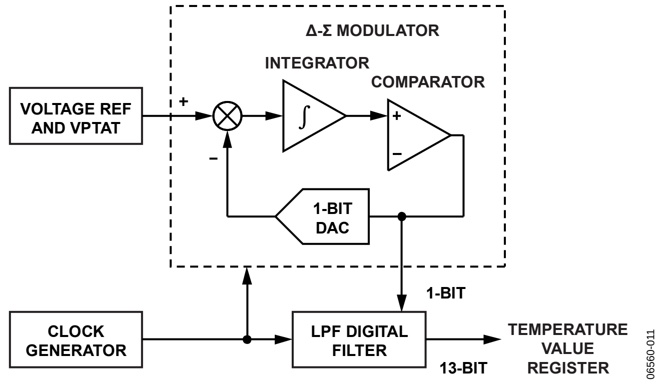

Figure 12. Σ-Δ Modulator

TEMPERATURE MEASUREMENT

In normal mode, the ADT7410 runs an automatic conversion sequence. During this automatic conversion sequence, a conversion takes 240 ms to complete and the ADT7410 is continuously converting. This means that as soon as one temperature conversion is completed another temperature conversion begins. Each temperature conversion result is stored in the temperature value register and is available through the I²C interface.

On power-up, the first conversion is a fast conversion, taking typically 6 ms. Therefore, the CT and INT pins are activated very quickly after power-up if an overtemperature event is present at power-up.

The conversion clock for the part is generated internally. No external clock is required except when reading from and writing to the serial port.

In continuous conversion mode, the internal clock is reset after every read or write operation. This causes the device to start a temperature conversion after every read or write, the result of which is typically available 240 ms later. Reading from the device before a conversion is complete causes the ADT7410 to finish converting and store the result in a shadow temperature value register. The read operation provides the previous conversion result. As soon as communication to the ADT7410 is complete, the result in the temporary temperature value register is moved into the live temperature value register that can be accessed by the I²C interface.

The measured temperature value is compared with a critical temperature limit, stored in the 16-bit T_{CRIT} read/write register, a high temperature limit, stored in the 16-bit T_{HIGH} read/write register, and a low temperature limit, stored in the 16-bit T_{LOW} read/write register. If the measured value exceeds these limits, the INT pin is activated and if it exceeds the T_{CRIT} limit, the CT pin is activated. This INT and CT pins are programmable for polarity

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via the configuration register while the INT and CT pins are also programmable for interrupt mode via the configuration register.

ONE-SHOT MODE

Setting Bit 5 = 1 and Bit 6 = 0 of the configuration register enables the one-shot mode. When this mode is enabled, the ADT7410 immediately does a conversion and then goes into shutdown mode.

Wait for a minimum of 240 ms after writing to the one-shot bits before reading back the temperature from the temperature value register. This time ensures that the ADT7410 has time to power up and do a conversion.

The one-shot mode is useful when one of the circuit design priorities is to reduce power consumption.

One Sample Per Second Mode

In this mode, the part does a conversion taking 60mS and then goes to an idle state for 0.94 Secs, then wakes up and does another conversion taking 60 mS and goes to the idle state again, and so on... The temperature accuracy is also reduced but this can be compensated by greatly reduced current consumption. The current consumption is reduced to typically 45 µA when V_{DD} is 3.3 V and 50 µA when V_{DD} is 5 V. This mode is enabled by writing Bit 5 = 0 and Bit 6 = 1. As soon as Bit D5 and Bit D6 are configured, the ADT7410 does a temperature conversion, and powers down.

CT & INT Operation in One-Shot Mode

Both the one sample per second and standard one-shot temperature measurements cause the INT and CT pins to go active if the temperature exceeds their corresponding temperature limits. Therefore, it is quite possible that the temperature can exceed the interrupt limits for quite some time before a one-shot conversion is activated. Refer to Figure 13 for more information on one-shot CT pin operation for T_{CRIT} overtemperature events when one of the limits is exceeded. Note that in interrupt mode, a read from any register resets the INT and CT pins after it is activated by a write to the one-shot or 1 SPS bits.

For the INT pin, in the comparator mode, once the temperature drops below the $T_{HIGH} - T_{HYST}$ value or goes above the $T_{LOW} + T_{HYST}$ value, a write to the one-shot or 1 SPS bits resets the INT pin.

For the CT pin, in the comparator mode, once the temperature drops below the $T_{CRIT} - T_{HYST}$ value, a write to the one-shot or 1 SPS bits resets the CT pin. See Fig 13.

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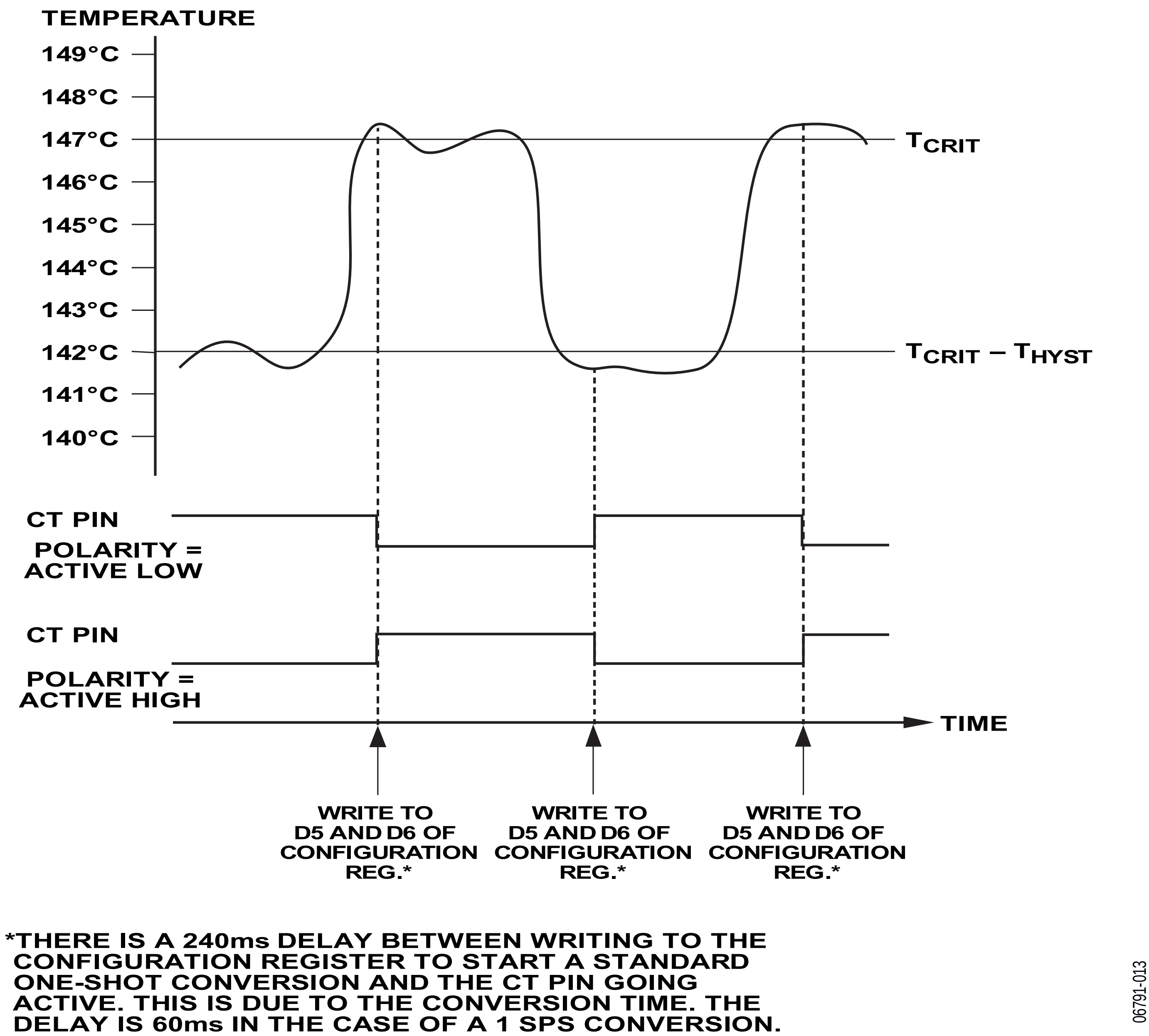

Figure 13. One-Shot CT Pin

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SHUTDOWN

The ADT7410 can be placed in shutdown mode via the configuration register, in which case the entire IC is shut down and no further conversions are initiated until the ADT7410 is taken out of shutdown mode. The ADT7410 can be taken out of shutdown mode by writing 00 to Bit 5 and Bit 6 in the configuration register. The ADT7410 typically takes TBD ms to come out of shutdown mode. The conversion result from the last conversion prior to shutdown can still be read from the ADT7410 even when it is in shutdown mode. When the part is taken out of shutdown mode, the internal clock is started and a conversion is initiated.

FAULT QUEUE

Bit D0 and Bit D1 of the configuration register is used to set up a fault queue. Up to four faults is provided to prevent false tripping of the INT and CT pins when the ADT7410 is used in a noisy temperature environment. The number of faults set in the queue must occur consecutively to set the INT and CT outputs. For example, if the number of faults set in the queue is four, then four consecutive temperature conversions must occur with each result exceeding a temperature limit in any of the limit registers before the INT and CT pins are activated. If two consecutive temperature conversions exceed a temperature limit and the third conversion does not, the fault count is reset back to zero.

TEMPERATURE DATA FORMAT

One LSB of the ADC corresponds to 0.0625°C. The ADC can theoretically measure a temperature range of 255°C, but the ADT7410 is guaranteed to measure a low value temperature limit of −55°C to a high value temperature limit of +150°C. The temperature measurement result is stored in the 16-bit temperature value register and is compared with the high temperature limits stored in the T_{CRIT} setpoint register and the T_{HIGH} setpoint register. It is also compared with the low temperature limit stored in the T_{LOW} setpoint register.

Temperature data in the temperature value register, the T_{CRIT} setpoint register, the T_{HIGH} setpoint register and the T_{LOW} setpoint register is represented by a 13-bit twos complement word. The MSB is the temperature sign bit. The three LSBs, Bit D0 to Bit D2, on power-up default, are not part of the temperature conversion result and are flag bits for T_{CRIT}, T_{HIGH} and T_{LOW}. Table 5 shows the 13-bit temperature data format without Bit D0 to Bit D2.

The number of bits in the temperature data word can be extended to 16 bits, twos complement, by setting D7 = 1 in the configuration register. When using a16-bit temperature data value, Bit D0 to Bit D2 are not used as flag bits and are now the LSB bits of the temperature value. The power-on default setting is to have a 13-bit temperature data value.

Reading back the temperature from the temperature value register requires a 2-byte read. Designers that use a 9-bit temperature data format can still use the ADT7410 by ignoring the last four LSBs of the 13-bit temperature value. These four LSBs are Bit D3 to Bit D6 in Table 5.

Table 5. 13-Bit Temperature Data Format

Temperature	Digital Output (Binary) D15 to D3	Digital Output (Hex)
−55°C	1 1100 1001 0000	0x1C90
−50°C	1 1100 1110 0000	0x1CE0
−25°C	1 1110 0111 0000	0x1E70
−0.0625°C	1 1111 1111 1111	0x1FFF
0°C	0 0000 0000 0000	0x000
+0.0625°C	0 0000 0000 0001	0x001
+10°C	0 0000 1010 0000	0x0A0
+25°C	0 0001 1001 0000	0x190
+50°C	0 0011 0010 0000	0x320
+75°C	0 0100 1011 0000	0x4B0
+100°C	0 0110 0100 0000	0x640
+125°C	0 0111 1101 0000	0x7D0
+150°C	0 1001 0110 0000	0x960

Temperature Conversion Formulas

16-Bit Temperature Data Format

- Positive Temperature = ADC Code(d)/128
- Negative Temperature = (ADC Code(d)[1]– 65536)/128
- Negative Temperature = (ADC Code(d)[2] – 32768)/128

13-Bit Temperature Data Format

- Positive Temperature = ADC Code(d)/16
- Negative Temperature = (ADC Code(d)[1]– 8192)/16
- Negative Temperature = (ADC Code(d)[2] – 4096)/16

10-Bit Temperature Data Format

- Positive Temperature = ADC Code(d)/2
- Negative Temperature = (ADC Code(d)[3] – 1024)/2
- Negative Temperature = (ADC Code(d)[4] – 512)/2

9-Bit Temperature Data Format

- Positive Temperature = ADC Code(d)
- Negative Temperature = ADC Code(d)[5] – 512
- Negative Temperature = ADC Code(d)[6] – 256

[1] For ADC Code, use all 13 bits of the data byte, including the sign bit.
[2] For ADC Code, Bit D15 (sign bit) is removed from the ADC code.
[3] For ADC Code, use all 10 bits of the data byte, including the sign bit.
[4] Bit D9 (sign bit) is removed from the ADC code.
[5] For the ADC Code, use all nine bits of the data byte, including the sign bit.
[6] Bit D8 (sign bit) is removed from the ADC code.

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REGISTERS

The ADT7410 contains thirteen registers:

- Nine temperature registers
- One status register
- One ID register
- One configuration register
- One address pointer register

All registers are 8 bits wide. The temperature value register, the status register, and the ID register are read-only. Both a read and write can be performed on the rest of the registers. On power-up, the address pointer register is loaded with 0x00 and points to the to the temperature value register MSB.

Table 6. ADT7410 Registers

Address Pointer	Description	Power-On Default
0x00	Temperature value MSB	0x00
0x01	Temperature value LSB	0x00
0x02	Status	0x00
0x03	Configuration	0x00
0x04	T_{HIGH} MSB	0x20 (+64°C)
0x05	T_{HIGH} LSB	0x00 (+64°C)
0x06	T_{LOW} MSB	0X05 (+10°C)
0x07	T_{LOW} LSB	0x00 (+10°C)
0x08	T_{CRIT} MSB	0x49 (+147°C)
0x09	T_{CRIT} LSB	0x80 (+147°C)
0x0A	T_{HYST}	0x05 (5°C)
0x0B	ID	0x00

ADDRESS POINTER REGISTER

This 8-bit write-only register is used as a pointer to the other registers on the ADT7410. This register is always the first register written to during a write to the ADT7410. It should be set to the address of the register to which the write or read transaction is intended. Table 7 shows the register address of each register on the ADT7410. The default value of the address pointer register is 0x00.

Table 7. Address Pointer Register

P7	P6	P5	P4	P3	P2	P1	P0
ADD 7	ADD 6	ADD 5	ADD 4	ADD 3	ADD 2	ADD 1	ADD 0

TEMPERATURE VALUE REGISTERS

The Temperature Value MSB and Temperature Value LSB registers store the temperature measured by the internal temperature sensor. The temperature is stored in twos complement format with the MSB being the temperature sign bit. When reading from these registers, the eight MSBs (Bit D15 to Bit D8) are read first from Register Address 0x00 and then the eight LSBs (Bit D7 to Bit D0) are read from Register Address 0x01. Only the register address 0x00 (temperature value MSB) needs to be loaded into the address pointer register as the address pointer autoincrements to Address 0x01 (temperature value LSB).

Bit D0 to Bit D2 are event alarm flags. Bit D0 to Bit D2 are event alarm flags for T_{CRIT}, T_{HIGH}, and T_{LOW}. When the ADC is configured to convert the temperature to a 15-bit digital value then D0 to D2 are no longer used as flag bits and are instead used as the LSB bits for the extended digital value.

Table 8. Temperature Value MSB Register

Address	Data Bit	Default Value	Type	Name	Description
0x00	[14:8]	0	R	Temp	Temperature Value in 2s complement format
	[15]	0	R	Sign	Sign Bit. Indicates if temperature value is negative or positive

Table 9. Temperature Value LSB Register

Address	Data Bit	Default Value	Type	Name	Description
0x01	[0]	0	R	T_{LOW} Flag/ LSB0	Flags T_{LOW} event. While temperature value is below T_{LOW}, this bit is set to 1. If Configuration register[7] = 1, this contains the LSB0 of the 15 bit temperature value
	[1]	0	R	T_{HIGH} Flag/ LSB1	Flags T_{HIGH} event. While temperature value is above T_{HIGH}, this bit is set to 1. If Configuration register[7] = 1, this contains the LSB1 of the 15 bit temperature value
	[2]	0	R	T_{CRIT} Flag/LSB2	Flags T_{CRIT} event. While temperature value exceeds T_{CRIT}, this bit is set to 1. If Configuration register[7] = 1, this contains the LSB2 of the 15 bit temperature value
	[7:3]	0	R	Temp	Temperature Value in 2s complement format

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STATUS REGISTER

This 8-bit read-only register reflects the status of the over temperature and under temperature interrupts that can cause the CT and INT pins to go active. It also reflects the status of a temperature conversion operation. The interrupt flags in this register are reset by a read operation to the status register and/or when the temperature value returns within the temperature limits, less the hysteresis value. The RDYB bit is reset after a read from the temperature value register. In one-shot and 1 SPS modes, the RDYB bit is reset after a write to the one-shot bits.

Table 10. Status Register

Address	Data Bit	Default Value	Type	Name	Description
0x02	[3:0]	000	R	Unused	Reads back 0
	[4]	0	R	T_{LOW}	This bit is set to 1 when the temperature goes below the T_{LOW} temperature limit. The bit is cleared to 0 when the status register is read and/or when the temperature measured goes back above the limit set in $T_{LOW} + T_{HYST}$ registers.
	[5]	0	R	T_{HIGH}	This bit is set to 1 when the temperature goes above the T_{HIGH} temperature limit. The bit is cleared to 0 when the status register is read and/or when the temperature measured goes back below the limit set in $T_{HIGH} – T_{HYST}$ registers
	[6]	0	R	T_{CRIT}	This bit is set to 1 when the temperature goes over the T_{CRIT} temperature limit. This bit clears to 0 when the status register is read and/or when the temperature measured goes back below the limit set in $T_{CRIT} – T_{HYST}$ registers.
	[7]	1	R	RDBY	This bit goes low when the temperature conversion result is written into the temperature value register. It is reset to 1 when the temperature value register is read. In one-shot and 1 SPS modes, this bit is reset after a write to the one-shot bits.

CONFIGURATION REGISTER

This 8-bit read/write register stores various configuration modes for the ADT7410, including shutdown, over temperature and under temperature interrupts, one-shot, continuous conversion, interrupt pins polarity, and overtemperature fault queues .

Table 11. Configuration Register

Address	Data Bit	Default Value	Type	Name	Description
0x03	[1:0]	00	R/$\overline{W}$	Fault queue	These two bits set the number of overtemperature faults that occur before setting the INT and CT pins. This helps to avoid false triggering due to temperature noise. 00 = 1 fault (default) 01 = 2 faults 10 = 3 faults 11= 4 faults
	[2]	0	R/$\overline{W}$	CT pin polarity	This bit selects the output polarity of the CT pin. 0 = active low; 1 = active high.
	[3]	0	R/$\overline{W}$	INT pin polarity	This bit selects the output polarity of the INT pin. 0 = active low; 1 = active high.
	[4]	0	R/$\overline{W}$	INT/CT mode	This bit selects between comparator and interrupt mode. 0 = interrupt mode; 1 = comparator mode
	[6:5]	00	R/$\overline{W}$	Operation mode	These two bits set the operational mode for the ADT7410. 00 = continuous conversion (default). Once one conversion is finished, the ADT7410 starts another 01 = One shot. Conversion time is typically 240 ms 10 = One Sample Per Sec (SPS) Mode. Conversion time is typically 60 ms. This operational mode reduces the average current consumption. 11= Shutdown. All circuitry except interface circuitry is powered down
	[7]	0	R/$\overline{W}$	Resolution	This bit sets up the resolution of the ADC when converting. 0 = 13-Bit resolution. Sign bit + 12 bits gives a temperature resolution of 0.0625°C 1 = 16-Bit resolution. Sign bit + 15 bits gives a temperature resolution of 0.0078125°C

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T_{HIGH} SETPOINT REGISTERS

The T_{HIGH} MSB and T_{HIGH} LSB registers store the over temperature limit value. An over temperature event occurs when the temperature value stored in the temperature value register exceeds the value stored in this register. The INT pin is activated if an over temperature event occurs The temperature is stored in twos complement format with the MSB being the temperature sign bit.

When reading from this register, the eight MSBs (Bit D15 to Bit D8) are read first from Register Address 0x04 and then the eight LSBs (Bit D7 to Bit D0) are read from Register Address 0x05. Only Register Address 0x04 (T_{HIGH} MSB) needs to be loaded into the address pointer register as the address pointer autoincrements to Address 0x05 (T_{HIGH} LSB).

The default setting for the T_{HIGH} setpoint is +64°C

Table 12. T_{HIGH} Setpoint MSB Register

Address	Data Bit	Default Value	Type	Name	Description
0x04	[15:8]	0x20	R/$\overline{W}$	T_{HIGH} MSB	MSBs of the over temperature limit, stored in 2's complement format.

Table 13. T_{HIGH} Setpoint LSB Register

Address	Data Bit	Default Value	Type	Name	Description
0x05	[7:0]	0x00	R/$\overline{W}$	T_{HIGH} LSB	LSBs of the over temperature limit, stored in 2's complement format.

T_{LOW} SETPOINT REGISTERS

The T_{LOW} MSB and T_{LOW} LSB registers store the under temperature limit value. An under temperature event occurs when the temperature value stored in the temperature value register is less than the value stored in this register. The INT pin is activated if an under temperature event occurs. The temperature is stored in twos complement format with the MSB being the temperature sign bit.

When reading from this register, the eight MSBs (Bit D15 to Bit D8) are read first from Register Address 0x06 and then the eight LSBs (Bit D7 to Bit D0) are read from Register Address 0x07. Only the register address 0x06 (T_{LOW} MSB) needs to be loaded into the address pointer register as the address pointer autoincrements to Address 0x07 (T_{LOW} LSB).

The default setting has the T_{LOW} setpoint is 10°C.

Table 14. T_{LOW} Setpoint MSB Register

Address	Data Bit	Default Value	Type	Name	Description
0x06	[15:8]	0x05	R/$\overline{W}$	T_{LOW} MSB	MSBs of the under temperature limit, stored in 2's complement format.

Table 15. T_{LOW} Setpoint LSB Register

Address	Data Bit	Default Value	Type	Name	Description
0x07	[7:0]]	0x00	R/$\overline{W}$	T_{LOW} LSB	LSBs of the under temperature limit, stored in 2's complement format.

T_{CRIT} SETPOINT REGISTERS

The T_{CRIT} MSB and T_{CRIT} LSB registers store the critical over temperature limit value. A critical over temperature event occurs when the temperature value stored in the temperature value register exceeds the value stored in this register. The CT pin is activated if a critical over temperature event occurs. The temperature is stored in twos complement format with the MSB being the temperature sign bit.

When reading from this register, the eight MSBs (Bit D15 to Bit D8) are read first from Register Address 0x08 and then the eight LSBs (Bit D7 to Bit D0) are read from Register Address 0x09. Only the register address 0x08 (T_{CRIT} MSB) needs to be loaded into the address pointer register as the address pointer autoincrements to Address 0x09 (T_{CRIT} LSB).

The default setting has the T_{CRIT} limit at +147°C.

Table 16. T_{CRIT} Setpoint MSB Register

Address	Data Bit	Default Value	Type	Name	Description
0X08	[15:8]	0x49	R/$\overline{W}$	T_{CRIT} MSB	MSBs of the critical over temperature limit, stored in 2's complement format.

Table 17. T_{CRIT} Setpoint LSB Register

Address	Data Bit	Default Value	Type	Name	Description
0X09	[7:0]	0x80	R/$\overline{W}$	T_{CRIT} LSB	LSBs of the critical over temperature limit, stored in 2's complement format.

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T_{HYST} SETPOINT REGISTER

This 8-bit read/write register stores the temperature hysteresis value for the T_{HIGH}, T_{LOW}, and T_{CRIT} temperature limits. The temperature hysteresis value is stored in straight binary format using the four LSBs. Increments are possible in steps of 1°C from 0°C to +15°C. The value in this register is added to the T_{HIGH} and T_{CRIT} values, and subtracted from the T_{LOW} value, to implement hysteresis,

Table 18. T_{HYST} Setpoint Register

Address	Data Bit	Default Value	Type	Name	Description
101	[3:0]	0x5	R/$\overline{W}$	T_{HYST}	Hysteresis value ,from0°C to +15°C. Stored in straight binary format. The default setting is 5°C
	[7:	X	R/$\overline{W}$	N/A	Not Used

MANUFACTURER ID REGISTER

This 8-bit read-only register stores the manufacturer ID in Bit D3 to Bit D7 and the silicon revision in Bit D0 to Bit D2

Table 19. Manufacturer ID Register

Address	Data Bit	Default Value	Type	Name	Description
0x0B	[2:0]	000	R	Rev ID	Contains the silicon revision identification number
	[7:3]	11001	R	Man ID	Contains the manufacturer identification number

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SERIAL INTERFACE

Control of the ADT7410 is carried out via the I²C/ SMBus-compatible serial interface. The ADT7410 is connected to this bus as a slave and is under the control of a master device.

Figure 14 shows a typical I²C interface connection.

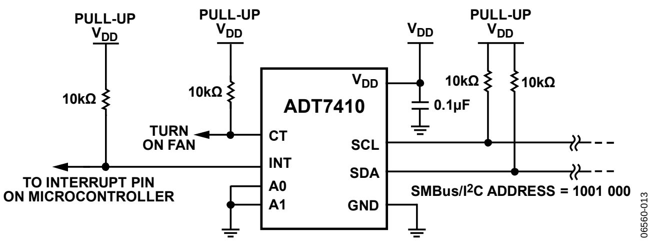

Figure 14. Typical II²C Interface Connection

Serial Bus Address

Like all I²C-compatible devices, the ADT7410 has a 7-bit serial address. The five MSBs of this address for the ADT7410 are set to 10010. Pin A1 and Pin A0 set the two LSBs. These pins can be configured two ways, low and high, to give four different address options. Table 20 shows the different bus address options available. The recommended pull-up resistor value on the SDA and SCL lines is 10 kΩ.

Table 20. SMBus/I²C Bus Address Options

Binary							
A6	**A5**	**A4**	**A3**	**A2**	**A1**	**A0**	**Hex**
1	0	0	1	0	0	0	0x48
1	0	0	1	0	0	1	0x49
1	0	0	1	0	1	0	0x4A
1	0	0	1	0	1	1	0x4B

The ADT7410 is designed with an I²C/SMBus timeout. The I²C interface times out after 75 ms to 325 ms of no activity on the SDA line. After this timeout, the ADT7410 resets the SDA line back to its idle state (SDA set to high impedance) and waits for the next start condition.

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The serial bus protocol operates as follows:

1. The master initiates data transfer by establishing a start condition, defined as a high to low transition on the serial data line SDA, while the serial clock line SCL remains high. This indicates that an address/data stream is going to follow. All slave peripherals connected to the serial bus respond to the start condition and shift in the next eight bits, consisting of a 7-bit address (MSB first) plus a read/write ($R/\overline{W}$) bit. The $R/\overline{W}$ bit determines whether data is written to, or read from, the slave device.
2. The peripheral with the address corresponding to the transmitted address responds by pulling the data line low during the low period before the ninth clock pulse, known as the acknowledge bit. All other devices on the bus now remain idle while the selected device waits for data to be read from or written to it. If the $R/\overline{W}$ bit is a zero, the master writes to the slave device. If the $R/\overline{W}$ bit is a one, the master reads from the slave device.
3. Data is sent over the serial bus in sequences of nine clock pulses, eight bits of data followed by an acknowledge bit from the receiver of data. Transitions on the data line must occur during the low period of the clock signal and remain stable during the high period as a low-to-high transition when the clock is high, which can be interpreted as a stop signal.
4. When all data bytes have been read or written, stop conditions are established. In write mode, the master pulls the data line high during the 10th clock pulse to assert a stop condition. In read mode, the master device pulls the data line high during the low period before the ninth clock pulse. This is known as a no acknowledge. The master takes the data line low during the low period before the 10th clock pulse, then high during the 10th clock pulse to assert a stop condition.

It is not possible to mix read and write in one operation because the type of operation is determined at the beginning and cannot subsequently be changed without starting a new operation.

The I²C address set up by the two address pins is not latched by the device until after this address has been sent twice. On the eighth SCL cycle of the second valid communication, the serial bus address is latched in. This is the SCL cycle directly after the device has seen its own I²C serial bus address. Any subsequent changes on this pin have no affect on the I²C serial bus address

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WRITING DATA

Depending on the register being written to, there are two different write transactions for the ADT7410.

Writing to the Address Pointer Register for a Subsequent Read

To read data from a particular register, the address pointer register must contain the address of that register. If it does not, the correct address must be written to the address pointer register by performing a single-byte write operation, as shown in Figure 15. The write operation consists of the serial bus address followed by the address pointer byte. No data is written to any of the data registers. A read operation is then performed to read the register.

Writing Data to a Register

It is possible to write either a single byte of data , or two bytes, to the ADT7410, depending on which registers are to be written.

Writing a single byte of data consists of the serial bus address, the data register address written to the address pointer register, followed by the data byte written to the selected data register. This is shown in Figure 16.

For the T_{HIGH}, T_{LOW}, and T_{CRIT} registers, it is possible to write to both the MSb and the LSDB registers in the same write transaction. Writing two bytes of data to these registers consists of the serial bus address, the data register address of the MSB register written to the address pointer register, followed by the two data bytes written to the selected data register. This is shown in Figure 17.

If more than the required number of data bytes is written to a register, the register ignores these extra data bytes. To write to a different register, a start or repeated start is required.

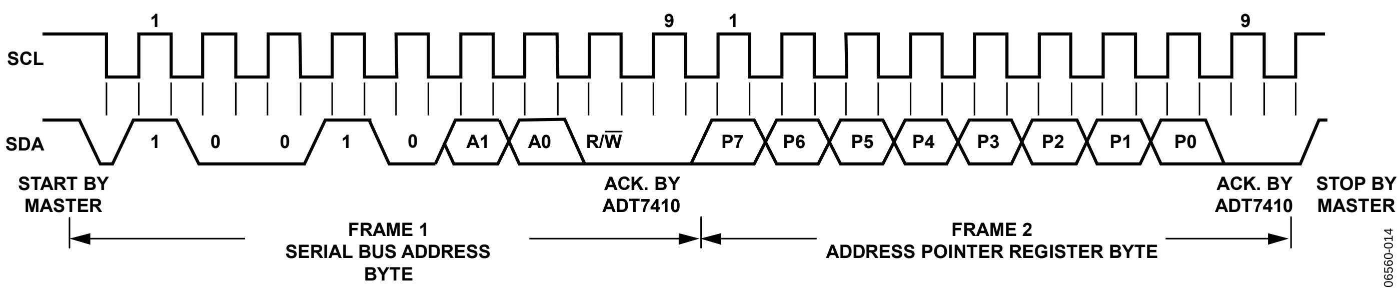

Figure 15. Writing to the Address Pointer Register to Select a Register for a Subsequent Read Operation

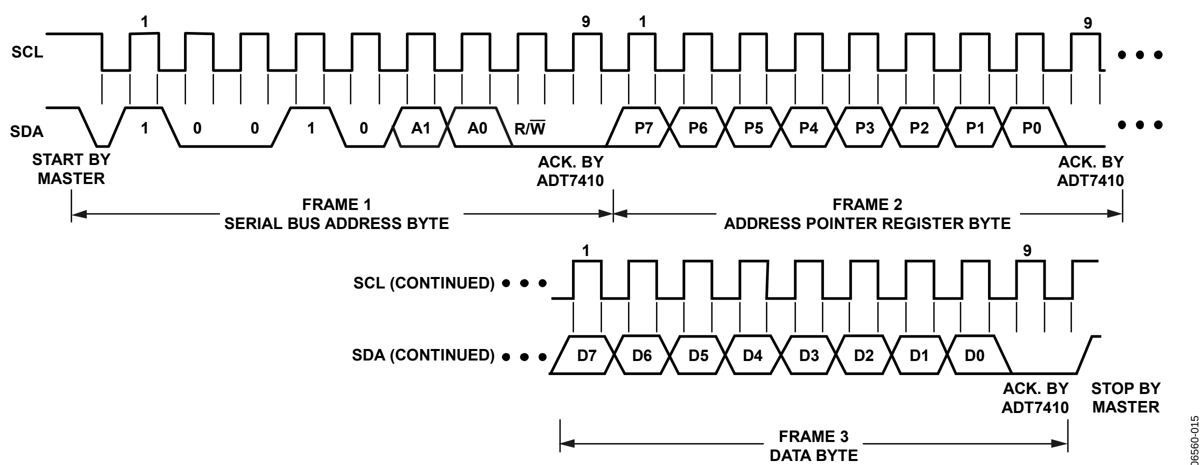

Figure 16. Writing to the Address Pointer Register Followed by a Single Byte of Data

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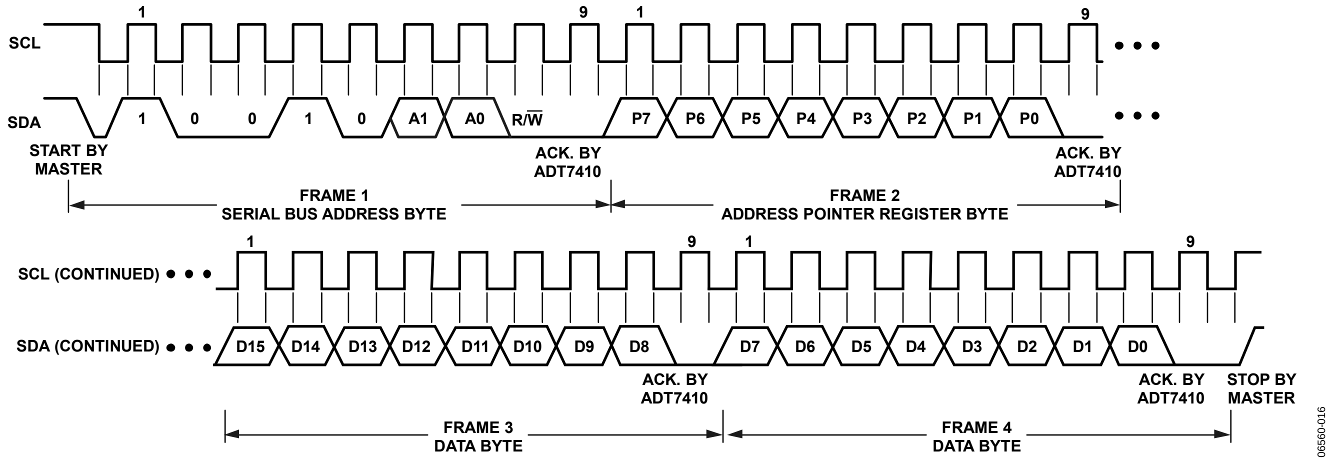

Figure 17. Writing to the Address Pointer Register Followed by Two Bytes of Data

READING DATA

Reading data from the ADT7410 is done in a 1-data byte operation for the configuration register, the status register, the T_{HYST} register and the ID register. A 2-data byte read operation is needed for the temperature value register, T_{HIGH} register, T_{LOW} register, and the T_{CRIT} register. Reading back the contents of the configuration register is shown in Figure 18. Reading back the contents of the temperature value register is shown in Figure 19.

Reading back from any register first requires a single-byte write operation to the address pointer register to set up the address of the register that is going to be read from. In the case of reading back from the 2-byte registers, the address pointer automatically increments from the MSB register address to the LSB register address.

To read from another register, execute another write to the address pointer register to set up the relevant register address. Thus, block reads are not possible, that is, there is no I^2C address pointer autoincrement except when reading back from a 16-bit register. If the address pointer register has previously been set up with the address of the register that is going to receive a read command, there is no need to repeat a write operation to set up the register address again.

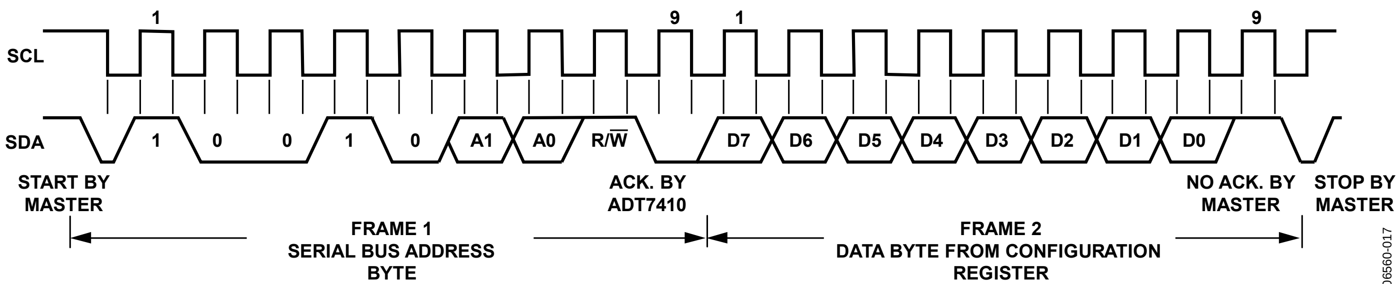

Figure 18. Reading Back Data from the Configuration Register

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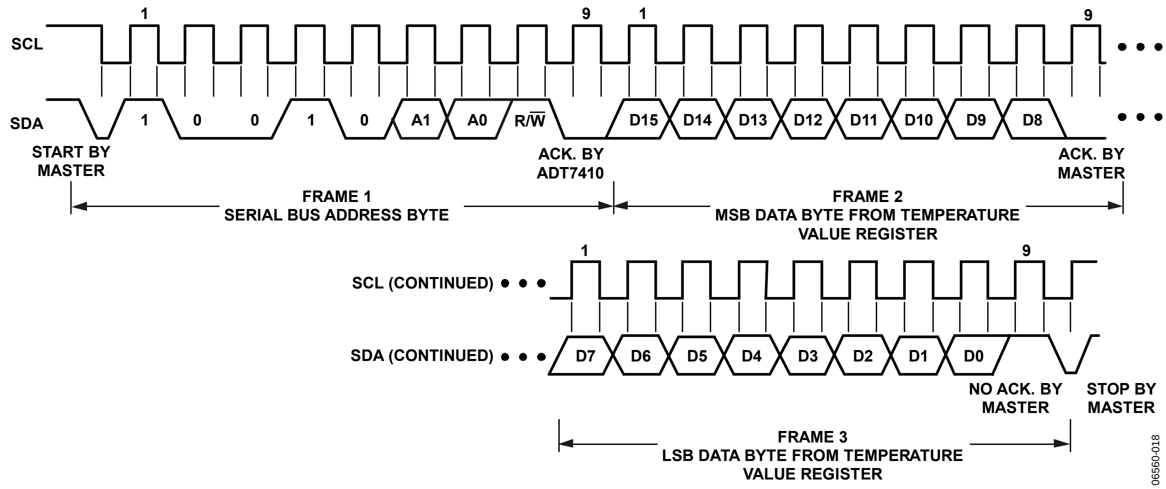

Figure 19. Reading Back Data from the Temperature Value Register

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INT & CT OUTPUTS

The INT and CT pins are open drain and require a pull-up resistor to VCC.

INT OVERTEMPERATURE MODES

The ADT7410 INT and CT pins have two temperature interrupt modes, comparator mode and interrupt mode. The interrupt mode is the default power-up overtemperature mode. The INT output pin becomes active when the temperature is greater than the temperature stored in the T_{HIGH} setpoint register or less than the temperature stored in the T_{LOW} setpoint register. How this pin reacts after this event depends on the overtemperature mode selected.

Figure 20 illustrates the comparator and interrupt modes for events exceeding the T_{HIGH} limit with both pin polarity settings. Figure 21 illustrates the comparator and interrupt modes for events exceeding the T_{LOW} limit with both pin polarity settings.

Comparator Mode

In comparator mode, the INT pin returns to its inactive status when the temperature measured drops below the $T_{HIGH} - T_{HYST}$ limit or rises above the $T_{LOW} + T_{HYST}$ limit.

Putting the ADT7410 into shutdown mode does not reset the INT state in comparator mode.

Interrupt Mode

In interrupt mode, the INT pin goes inactive when any ADT7410 register is read. Once the INT pin is reset, it goes active again only when the temperature is greater than the temperature stored in the T_{HIGH} setpoint register or less than the temperature stored in the T_{LOW} setpoint register.

Placing the ADT7410 into shutdown mode resets the INT pin in the interrupt mode.

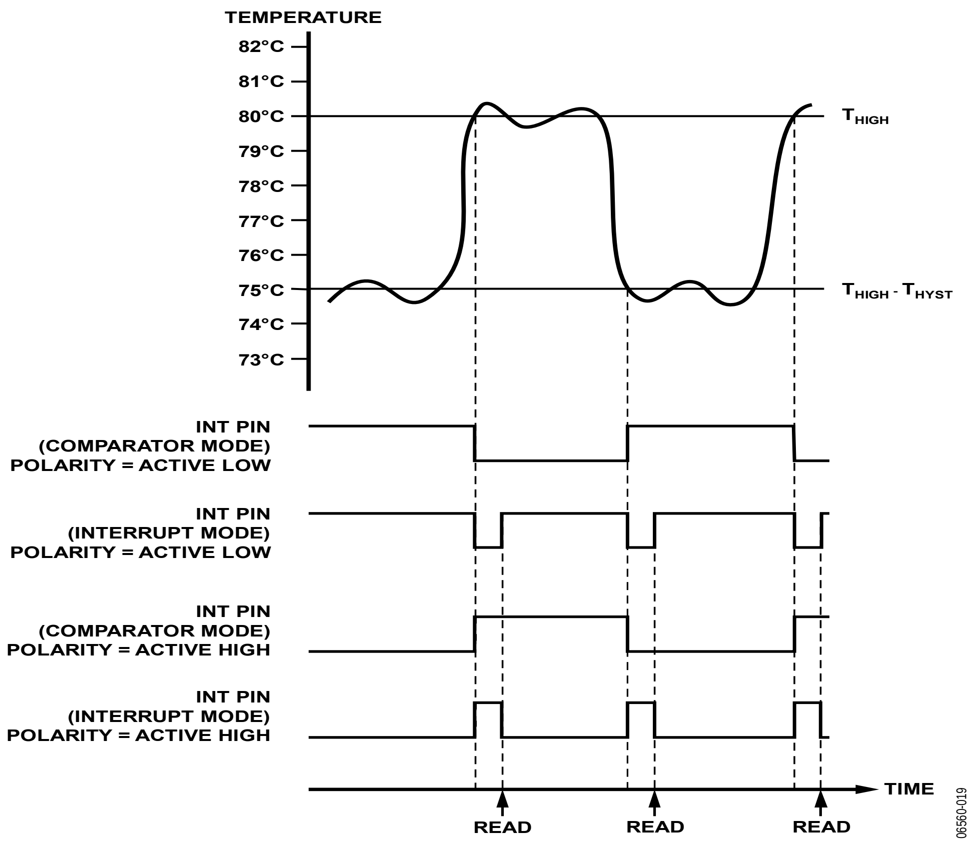

Figure 20. INT Output Temperature Response Diagram for T_{HIGH} Overtemperature Events

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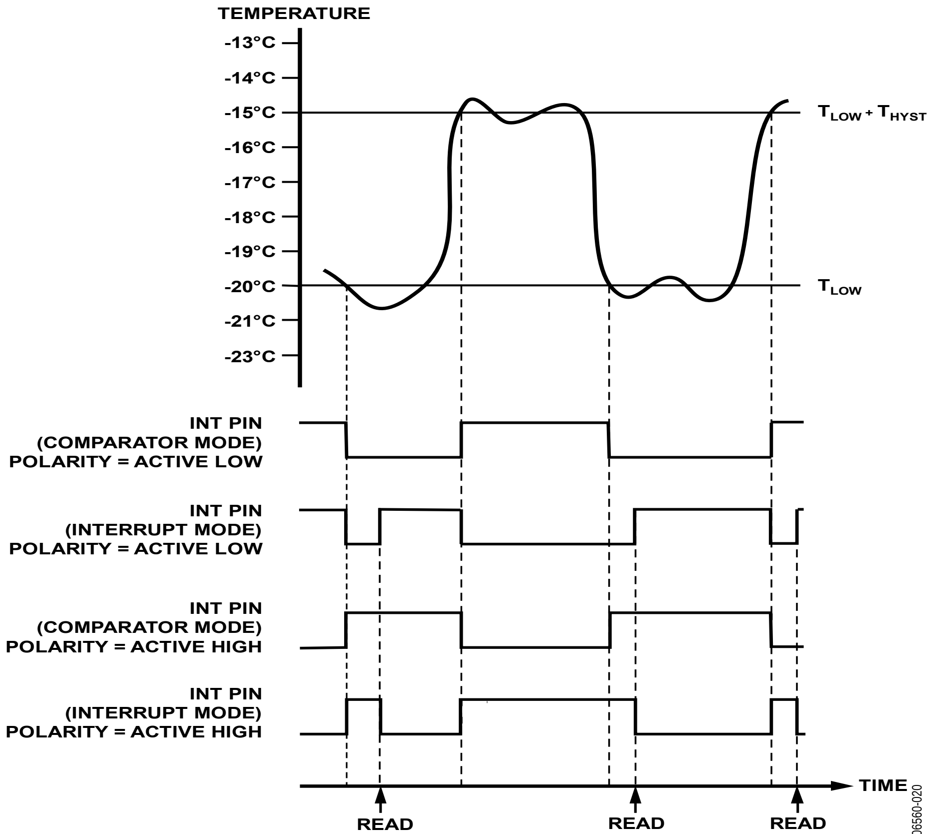

Figure 21. INT Output Temperature Response Diagram for T_{LOW} Overtemperature Events

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APPLICATION INFORMATION

THERMAL RESPONSE TIME

The time required for a temperature sensor to settle to a specified accuracy is a function of the thermal mass of the sensor 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 Q, 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 ADT7410 to settle to the desired accuracy is dependent on the package selected, 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.

SUPPLY DECOUPLING

The ADT7410 should be decoupled with a 0.1 μF ceramic capacitor between V_{DD} and GND. This is particularly important when the ADT7410 is mounted remotely from the power supply. Precision analog products, such as the ADT7410, require a well-filtered power source. Because the ADT7410 operates from a single supply, it might seem convenient to 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 hundreds of mV in amplitude due to wiring resistance and inductance.

If possible, the ADT7410 should be powered directly from the system power supply. This arrangement, shown in Figure 22, isolates the analog section from the logic switching transients. Even if a separate power supply trace is not available, generous supply bypassing reduces supply-line induced errors. Local supply bypassing consisting of a 0.1 μF ceramic capacitor is critical for the temperature accuracy specifications to be achieved. This decoupling capacitor must be placed as close as possible to the ADT7410 V_{DD} pin.

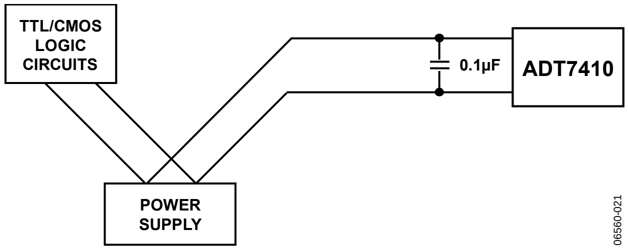

Figure 22. Use Separate Traces to Reduce Power Supply Noise

TEMPERATURE MONITORING

The ADT7410 is ideal for monitoring the thermal environment within electronic equipment. For example, the surface-mounted package accurately reflects the exact thermal conditions that affect nearby integrated circuits.

The ADT7410 measures and converts the temperature at the surface of its own semiconductor chip. When the ADT7410 is used to measure the temperature of a nearby heat source, the thermal impedance between the heat source and the ADT7410 must be considered. Often a thermocouple or other temperature sensor is used to measure the temperature of the source, while the temperature is monitored by reading back from the ADT7410 temperature value register.

Once the thermal impedance is determined, the temperature of the heat source can be inferred from the ADT7410 output. As much as 60% of the heat transferred from the heat source to the thermal sensor on the ADT7410 die is discharged via the copper tracks, the package pins, and the bond pads. Of the pins on the ADT7410, the GND pin transfers most of the heat. Therefore, to measure the temperature of a heat source, it is recommended that the thermal resistance between the ADT7410 GND pin and the GND of the heat source is reduced as much as possible.

For example, use the unique properties of the ADT7410 to monitor a high power dissipation microprocessor. The ADT7410 device, in a surface-mounted package, is mounted directly beneath the pin grid array (PGA) package of the microprocessor. The ADT7410 produces a linear temperature output while needing only two I/O pins and requiring no external characterization.

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OUTLINE DIMENSIONS

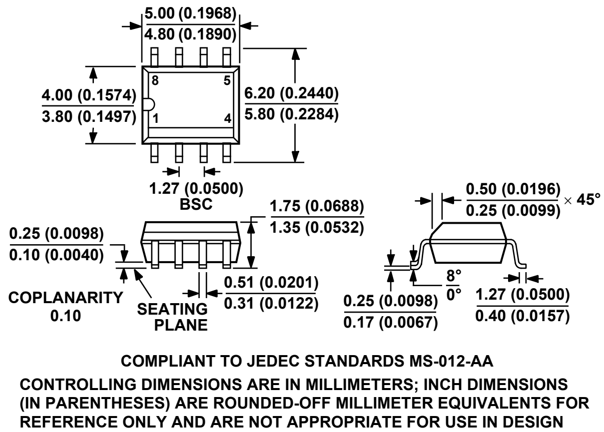

Figure 23. 8-Lead Standard Small Outline Package [SOIC_N]
(R-8)
Dimensions shown in millimeters

ORDERING GUIDE

Model	Temperature Range	Temperature Accuracy[1]	Package Description	Package Option
ADT7410Z[2]	–55°C to +150°C	±0.5°C	8-Lead SOIC_N	R-8

[1] Temperature accuracy is over the 0°C to +70°C temperature range.
[2] Z = RoHS Compliant Part.

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NOTES

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