

### FEATURES

- 12-bit temperature-to-digital converter
- ±2°C accuracy typ
- Operation from -20°C to +125°C
- Operation from 3 V to 3.6 V
- Average supply current (500µA max)
- Selectable 0, 1.5°C, 3°C, 6°C Hysteresis
- SMBus- /I2C- compatible interface
- Dual purpose event pin: Comparator or Interrupt
- 8-pin LFCSP 3mm x 3mm (JEDEC MO-229 VEED-4) package
- Complies with JEDEC standard JC-42.4 Memory Module Thermal Sensor Component Specification

### APPLICATIONS

- Memory module temperature monitoring
- Isolated sensors
- Environmental control systems
- Computer thermal monitoring
- Thermal protection
- Industrial process control
- Power-system monitors
- Hand Held Applications

### GENERAL DESCRIPTION

The ADT7408 is the first digital temperature sensor that complies with JEDEC standard JC-42.4 for Mobile Platform Memory Module. The ADT7408 contains a band gap temperature sensor and 12-bit ADC to monitor and digitize the temperature to a resolution of 0.0625°C.

There is an open-drain Event# output that is active when the monitoring temperature exceeds a critical programmable limit or the temperature falls above or below an alarm window. This pin can operate in either comparator or interrupt mode. There are three slave-device address pins that allows up to eight

### FUNCTIONAL BLOCK DIAGRAM

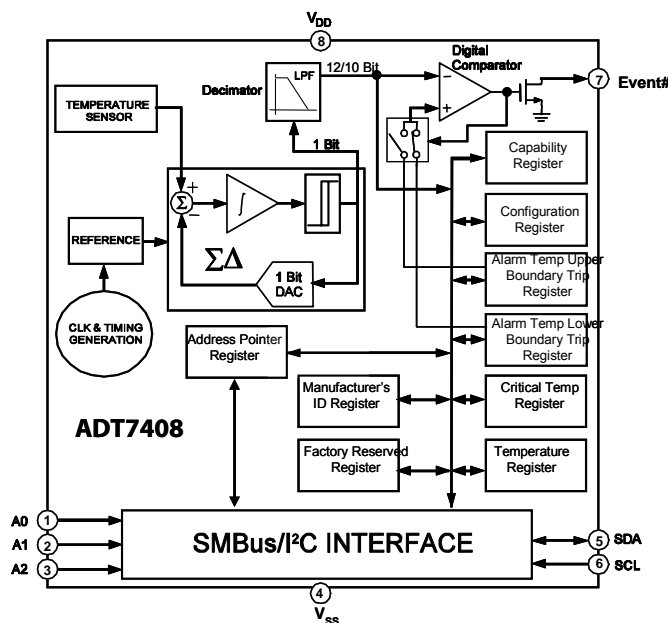


Figure 1.

ADT7408s to be used in a system that monitors temperature of various components and subsystems.

The ADT7408 is specified for operation at supply voltages from 3.0 V to 3.6 V. Operating at 3.3 V, the average supply current is less than typically 240µA. The ADT7408 offers a shutdown mode that powers down the device and gives a shutdown current of typically 3 µA. The ADT7408 is rated for operation over the -20°C to +125°C temperature range. The ADT7408 is available in lead-free 8-lead LFCSP 3mm x 3mm (JEDEC MO-229 VEED-4) package.

### Rev. PrC

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## Specifications

All specifications  $T_A = -20^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ ,  $V_{DD} = 3.0\text{ V}$  to  $3.6\text{ V}$ , unless otherwise noted.

Table 1.

Parameter	Symbol	Min	Typ	Max	Unit	Test Conditions/Comments
<b>TEMPERATURE SENSOR AND ADC</b>						
Local Sensor Accuracy (C grade)			$\pm 1.0$	$\pm 2.0$	$^{\circ}\text{C}$	$75^{\circ}\text{C} \leq T_A \leq 95^{\circ}\text{C}$ , $3.0\text{V} \leq V_{DD} \leq 3.6\text{V}$ Active Range
			$\pm 2.0$	$\pm 3.0$	$^{\circ}\text{C}$	$40^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$ , $3.0\text{V} \leq V_{DD} \leq 3.6\text{V}$ Monitor Range
			$\pm 3.0$	$\pm 4.0$	$^{\circ}\text{C}$	$-20^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$ , $3.0\text{V} \leq V_{DD} \leq 3.6\text{V}$
ADC Resolution			12		Bits	
Temperature Resolution			0.0625		$^{\circ}\text{C}$	
Temperature Conversion Time			15	30	ms	
Update Rate			100	125	ms	
Long Term Drift			0.081		$^{\circ}\text{C}$	Drift over 10 years, if part is operated at $55^{\circ}\text{C}$
<b>Event# OUTPUT (OPEN DRAIN)</b>						
Output Low Voltage, $V_{OL}$				0.4	V	$I_{OL} = 3\text{ mA}$
Sink Current, $I_{SINK}$				6	mA	
Pin Capacitance			10		pF	
High Output Leakage Current	$I_{OH}$		0.1	1	$\mu\text{A}$	Event# = 3.6 V
Rise Time <sup>1</sup>	$t_{LH}$		30		ns	
Fall Time <sup>1</sup>	$t_{HL}$		30		ns	
$R_{ON}$ Resistance (Low Output)			55		$\Omega$	Supply and temperature dependent
<b>DIGITAL INPUTS</b>						
Input Current,	$I_{IH}, I_{IL}$	-1		+1	$\mu\text{A}$	$V_{IN} = 0\text{ V}$ to $V_{DD}$
Input Low Voltage	$V_{IL}$			0.8	V	$3.0\text{ V} \leq V_{DD} \leq 3.6\text{ V}$
Input High Voltage	$V_{IH}$	2.1			V	$3.0\text{ V} \leq V_{DD} \leq 3.6\text{ V}$
SCL, SDA Glitch Rejection				50	ns	Input filtering suppresses noise spikes of less than 50 ns
Pin Capacitance		3		10	pF	
<b>DIGITAL OUTPUT (OPEN DRAIN)</b>						
Output Low Current,	$I_{OL}$	6			mA	SDA Forced to 0.6 V
Output Low Voltage	$V_{OL}$			0.4	V	$3.0\text{ V} \leq V_{DD} \leq 3.6\text{ V}$ at $I_{OPULL\_UP} = 350\ \mu\text{A}$
Output High Voltage	$V_{OH}$	2.1			V	
Output Capacitance	$C_{OUT}$	3		10	pF	
Hysteresis			500		mV	
<b>POWER REQUIREMENTS</b>						
Supply Voltage	$V_{DD}$	3.0	3.3	3.6	V	
Average Supply Current	$I_{DD}$		240	500	$\mu\text{A}$	
Supply Current	$I_{DD\_CONV}$		370	550	$\mu\text{A}$	Device current while converting
Quiescent Current	$I_{DD\_Q}$		35	40	$\mu\text{A}$	Device current between conversions
Shutdown Mode at 3.3 V			3	10	$\mu\text{A}$	
Average Power Dissipation	$P_D$		790		$\mu\text{W}$	$V_{DD} = 3.3\text{ V}$ , normal mode at $25^{\circ}\text{C}$

**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 behavior of the part.

T<sub>A</sub> = -20°C to +125°C, V<sub>DD</sub> = 3.0 V to 3.6 V, unless otherwise noted.

Table 2.

Parameter	Symbol	MIN	TYP	MAX	Units	Comments
SCL Clock Frequency	f <sub>SCL</sub>	10		100	kHz	
Bus Free Time between a STOP (P) and START (S) condition	t <sub>BUF</sub>	4.7			μs	
Hold Time after (Repeated) START condition. After this period, the first clock is generated	t <sub>HD:STA</sub>	4.0			μs	
Repeated Start Condition Setup Time	t <sub>SU:STA</sub>	4.7			μs	
High Period of the SCL Clock	t <sub>HIGH</sub>	4.0		50	μs	
Low Period of the SCL Clock	t <sub>LOW</sub>	4.7			μs	
Fall Time of Both SDA and SCL Signals	t <sub>F</sub>			300	ns	
Rise Time of Both SDA and SCL Signals	t <sub>R</sub>			1000	ns	
Data Setup Time	t <sub>SU:DAT</sub>	250			ns	
Data Hold Time	t <sub>HD:DAT</sub>	300			ns	
Setup Time for STOP Condition	t <sub>SU:STO</sub>	4.0			μs	
Capacitive Load for each Bus Line, C <sub>B</sub>				400	pF	

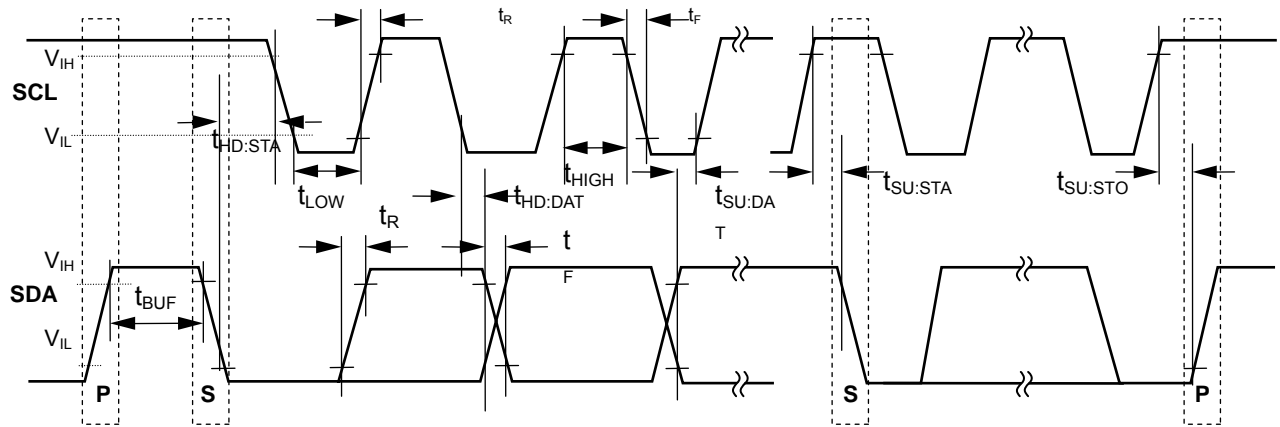


Figure 2. SMBus/I<sup>2</sup>C Timing Diagram

## ABSOLUTE MAXIMUM RATINGS

Table 3.

Parameter	Rating
$V_{DD}$ to $V_{SS}$	-0.3 V to +7 V
SDA Input Voltage to $V_{SS}$	-0.3 V to $V_{DD} + 0.3$ V
SDA Output Voltage to $V_{SS}$	-0.3 V to $V_{DD} + 0.3$ V
SCL Input Voltage to $V_{SS}$	-0.3 V to $V_{DD} + 0.3$ V
Event# Output Voltage to $V_{SS}$	-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°C
Power Dissipation <sup>1</sup>	$P_{MAX} = (T_{JMAX} - T_A^2)/\theta_{JA}$
Thermal Impedance <sup>3</sup>	
$\theta_{JA}$ , Junction-to-Ambient (still air)	TBD
$\theta_{JC}$ , Junction-to-Case	TBD
IR Reflow Soldering	
Peak Temperature	TBD
Time at Peak Temperature	TBD
Ramp-Up Rate	TBD
Ramp-Down Rate	TBD
Time 25°C to Peak Temperature	TBD
IR Reflow Soldering – Pb-Free Package	
Peak Temperature	TBD
Time at Peak Temperature	TBD
Ramp-Up Rate	TBD
Ramp-Down Rate	TBD
Time 25°C to Peak Temperature	TBD

<sup>1</sup> Values relate to package being used on a standard 2-layer PCB.

<sup>2</sup>  $T_A$  = ambient temperature.

<sup>3</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.



Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only and 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.

## PIN CONFIGURATIONS AND FUNCTION DESCRIPTIONS

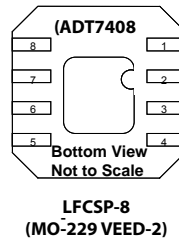


Figure 3. LFCSP-8 (Bottom View) Pin Configurations

Table 4. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	A0	SMBus/I <sup>2</sup> C Serial Bus Address Selection Pin. Logic input. Can be set to V <sub>SS</sub> or V <sub>DD</sub> .
2	A1	SMBus/I <sup>2</sup> C Serial Bus Address Selection Pin. Logic input. Can be set to V <sub>SS</sub> or V <sub>DD</sub> .
3	A2	SMBus/I <sup>2</sup> C Serial Bus Address Selection Pin. Logic input. Can be set to V <sub>SS</sub> or V <sub>DD</sub> .
4	V <sub>SS</sub>	Negative Supply, Ground.
5	SDA	SMBus/I <sup>2</sup> C Serial Data Input/Output. Serial data to be loaded into the part's registers and read from these registers is provided on this pin. Open-drain configuration - needs a pullup resistor.
6	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 ADT7408. Open-drain configuration - needs a pullup resistor.
7	Event#	Active Low. Open Drain event output pin. Driven low on comparator level, or Alert Interrupt
8	V <sub>DD</sub>	Positive Supply, Power. The supply should be decoupled to ground.

## THEORY OF OPERATION

### CIRCUIT INFORMATION

The ADT7408 is a 12-bit digital temperature sensor. Its output is Two's complement that the 12<sup>th</sup> bit is the sign bit. An on-board sensor generates a voltage precisely proportional to absolute temperature, which is compared to an internal voltage reference and is input to a precision digital modulator. Overall accuracy for the ADT7408 is  $\pm 2^{\circ}\text{C}$  from  $75^{\circ}\text{C}$  to  $95^{\circ}\text{C}$ ,  $\pm 3^{\circ}\text{C}$  from  $40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ , and  $\pm 4^{\circ}\text{C}$  from  $-20^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  with excellent transducer linearity. The serial interface is SMBus/I<sup>2</sup>C-compatible and the open-drain output of the ADT7408 is capable of sinking 6 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 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. This architecture creates a negative feedback loop that 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, called oversampling. Oversampling spreads the quantization noise over a much wider band than that of the input signal, improving overall noise performance and increasing accuracy.

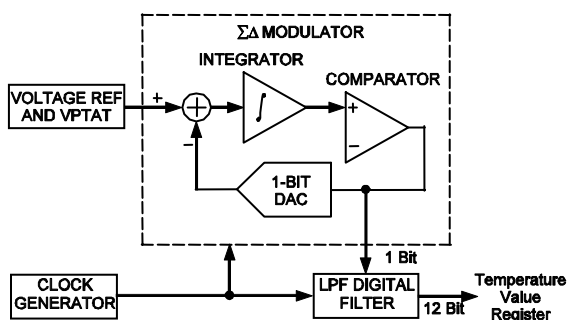


Figure 4. First-Order  $\Sigma$ - $\Delta$  Modulator

The modulated output of the comparator is encoded using a circuit technique that results in SMBus/I<sup>2</sup>C temperature data.

### FUNCTIONAL DESCRIPTION

The conversion clock for the part is internally generated. No external clock is required except when reading from and writing to the serial port. In normal mode, the internal clock oscillator runs an automatic conversion sequence. During this automatic conversion sequence, a conversion is initiated every 100 ms. At this time, the part powers up its analog circuitry and performs a temperature conversion. This temperature conversion typically takes 60 ms, after which time the analog circuitry of the part automatically shuts down. The analog circuitry powers up again 40 ms later, when the 100 ms timer times out and the next conversion begins. The result of the most recent temperature conversion is always available in the temperature value register as the SMBus/I<sup>2</sup>C circuitry never shuts down.

The ADT7408 can be placed in a shutdown mode via the configuration register, in which case the on-chip oscillator is shut down and no further conversions are initiated until the ADT7408 is taken out of shutdown mode. The ADT7408 can be taken out of shutdown mode by writing zero to Bit D8 in the configuration register. The conversion result from the last conversion prior to shut-down can still be read from the ADT7408 even when it is in shutdown mode.

In normal conversion mode, the internal clock oscillator is reset after every read or write operation. This causes the device to start a temperature conversion, the result of which is typically available 60 ms later. Similarly, when the part is taken out of shutdown mode, the internal clock oscillator is started and a conversion is initiated. The conversion result is typically available 60 ms later. Reading from the device before a conversion is complete causes the ADT7408 to stop converting; the part starts again when serial communication is finished. This read operation provides the previous result.

The measured temperature value is compared with the temperature set at the Alarm Temp Upper Boundary Trip Register, the Alarm Temp Lower Boundary Trip Register, and the Critical Temp Trip Register. If the measured value exceeds these limits then the EVENT# pin is activated. This EVENT# output is programmable for interrupt mode, comparator mode, and also the output polarity via the configuration register.

**TEMPERATURE DATA FORMAT**

The 16-bit value used in the three Temperature Trip Point Registers and Temperature Register is in Two's complement format. The Temperature Register has a 12-bit resolution with 256°C range with one LSB = 0.0625 °C (256°C/2<sup>12</sup>). The temperature data in the three Temperature Trip Point Registers (Alarm Upper, Alarm Lower and Critical), is a 10-bit format with 256°C range with one LSB = 0.25 °C. D12 in all these registers represent the sign bit such that 0 = positive and 1 = negative. In Two's Complement format, the data bits are inverted and add 1 if the sign bit is negative.

For example if the following values are read in the Temperature Register:

1. A T<sub>1</sub> value of 0x019C is 0000 0001 1001 1100 in binary, thus T<sub>1</sub> = + 0x19C \* 0.0625 = +25.75°C
2. A T<sub>2</sub> value of 0x07C0 is 0000 0111 1100 0000 in binary, thus T<sub>2</sub> = 0x7C0 \* 0.0625 = +124°C
3. A T<sub>3</sub> value of 0x1E74 is 0001 1110 0111 0100 in binary. Since the sign bit is negative, the data becomes 0001 1000 1100, thus T<sub>3</sub> = - 0x18C \* 0.0625 = -24.75°C

If the following value is read from the Critical Temperature Register

1. A value of 0x07C0 is 0000 0111 1100 0000 in binary, thus the critical temperature = + 0x1F0 \* 0.25 = +124°C

The temperature calculations above are cumbersome, the more convenient temperature conversion formula can be found in equations (1) to (4) later.

Although one LSB of the ADC corresponds to 0.0625°C. The ADC can theoretically measure a temperature range of 255°C (-128°C to +127°C ), but the ADT7408 is guaranteed to measure a low value temperature limit of -55°C to a high value temperature limit of +125°C.

Reading back the temperature from the temperature value register requires a two byte read unless only a 1°C (8-bits) resolution is required, then a one byte read is required. Designers used to using a 9-bit temperature data format can still use the ADT7408 by ignoring the last three LSBs of the 12-bit temperature value. These three LSBs are Bit D4 to Bit D6 in Table 5.

**Table 5. 12-Bit Temperature Data Format**

Temperature	Digital Output (Binary) D11 to D0	Digital Output (Hex)
-55°C	1100 1001 0000	C90
-50°C	1100 1110 0000	CE0
-25°C	1110 0110 1111	E6F
-0.0625°C	1111 1111 1111	FFF

0°C	0000 0000 0000	000
+0.0625°C	0000 0000 0001	0x001
+10°C	0000 1010 0000	0x0A0
+25°C	0001 1001 0000	0x190
+50°C	0011 0010 0000	0x320
+75°C	0100 1011 0000	0x4B0
+100°C	0110 0100 0000	0x640
+125°C	0111 1101 0000	0x7D0

**Temperature Conversion Formulas**

**12-Bit Temperature Data Format**

Positive Temperature = ADC Code(d)/16 (1)

Negative Temperature = (ADC Code(d) – 4096)/16 (2)

For ADC Code, Bit D12 (sign bit) is removed from the ADC code.

**10-Bit Temperature Data Format**

Positive Temperature = ADC Code(d)/4 (3)

Negative Temperature = (ADC Code(d) – 1024)/4 (4)

For ADC Code, Bit D12 (sign bit) is removed from the ADC code

## DESCRIPTION

The thermal sensor continuously monitors the temperature and updates the temperature data ten times per second.

Temperature data is latched internally by the device and may be read by software from the bus host at any time.

SMBus/I2C slave address selection pins allow up to 8 such devices to co-exist on the same bus. This means that up to 8 memory modules can be supported given each module has one such slave device address slot.

After initial power-on, the configuration registers are set to the default values. Software can write to the configuration register to set bits as per the bit-definitions in the following section.

## ADT7408 REGISTERS

The ADT7408 contains sixteen accessible registers shown in Table 6. The address pointer register is the only register that is 8 bits while the rest are 16 bits wide. On power-up, the Address Pointer Register is loaded with 0x00 and points to the Capability Register.

**Table 6. ADT7408 Registers**

Pointer Address	Name	Power-On Default	Read/Write
Not Applicable	Address Pointer	0x00	Write
0x00	Capability Register	0x001D	Read
0x01	Configuration Register	0x0000	Read/Write
0x02	Alarm Temp Upper Boundary Trip Register	0x0000	Read/Write
0x03	Alarm Temp Lower Boundary Trip Register	0x0000	Read/Write
0x04	Critical Temp Trip Register	0x0000	Read/Write
0x05	Temperature Register	Undefined	Read
0x06	Manufacturer's ID Register	0x11D4	Read
0x07	Device ID/Revision Register	0x0800	Read
0x08-0x0F	Vendor-defined Registers	0x0000	Reserved

### Address Pointer Register (write only)

This 8-bit write only register selects which of the 16-bit registers is accessed in subsequent read/write operations. Address space between 0x08 and 0x0F are reserved for factory usage or test registers.

**Table 7. Address Pointer Register**

Bits	D7	D6	D5	D4	D3	D2	D1	D0
Content	0	0	0	0	Register Select	Register Select	Register Select	Register Select

**Table 8. Address Pointer Selected Registers**

D2	D1	D0	Register Selected
0	0	0	Capability Register
0	0	1	Configuration Register
0	1	0	Alarm Temp Upper Boundary Trip Register
0	1	1	Alarm Temp Lower Boundary Trip Register
1	0	0	Critical Temp Trip Register
1	0	1	Temperature Register
1	1	0	Manufacturer ID
1	1	1	Device ID/Revision



**Capability Register (read only)**

This 16-bit read only register indicates the capabilities of the thermal sensor.

**Table 9. Capability Register**

Bits	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
<b>Content</b>	RFU	RFU	RFU	RFU	RFU	RFU	RFU	RFU	RFU	RFU	RFU	TRES1	TRES0	Wider Range	Higher Precision	Has Alarm & Critical Trips

\*RFU=Reserved For Future Use

**Table 10. Capability Mode Description**

Bits	Description
D0	Basic Capability 1 – Has Alarm & Critical Trips Capability (Required)
D1	Accuracy 0 – Default, accuracy +/-2°C over the active and +/-3°C monitor ranges
D2	Wider Range 0 – Values lower than 0°C will be clamped and represented as binary value 0 1 – Can read temperature below 0°C and set sign bit accordingly (Default)
D4:D3	Temperature Resolution 00 – 0.5°C LSB 01 – 0.25°C LSB 10 – 0.125°C LSB 11 – 0.0625°C LSB (Default)
D15:D5	0 – Reserved for future use. Must be zero

**Configuration Register (read/write)**

This 16-bit read/write register stores various configuration modes for the ADT7408 and are shown in Tables 11 and 12.

**Table 11. Configuration Register**

Bits	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
<b>Content</b>	RFU	RFU	RFU	RFU	RFU	Hysteresis		Shut-down Mode	Critical Lock Bit	Alarm Lock Bit	Clear Event	Event Output Status	Event Output Control	Critical Event Only	Event Polarity	Event Mode

**Table 12. Configuration Mode Description**

Bits	Description
D0	Event Mode 0 – Comparator output mode (default) 1 – interrupt mode When either of the lock bits is set, this bit cannot be altered until unlocked.
D1	Event Polarity 0 – Active Low (default) 1 – Active High When either of the lock bits is set, this bit cannot be altered until unlocked.
D2	Critical Event Only

	<p>0 – Event Output on Alarm or Critical temp event (default)  1 – Event only if temperature is above the value in the critical temp register  When either of the lock bits is set, this bit cannot be altered until unlocked.</p>
D3	<p>Event Output Control  0 – Event Output Disabled (default)  1 – Event Output Enabled  When either of the lock bits is set, this bit cannot be altered until unlocked.</p>
D4	<p>Event Status (read only)  0 – Event Output condition is not being asserted by this device  1 – Event Output pin is being asserted by this device due to Alarm Window or Critical trip condition  The actual event causing the event can be determined from the Read Temperature register. Interrupt Events can be cleared by writing to “Clear Event” bit. Writing to this bit will have no effect.</p>
D5	<p>Clear Event (write only)  0 – No effect  1 – Clears active event in Interrupt Mode. Writing to this register has no effect in Comparator Mode. When read, this bit will always return zero ‘0’. Once the DUT temperature is greater than the Critical Temperature, Event cannot be cleared.</p>
D6	<p>Alarm Window Lock bit  0 – Alarm Trips are not locked and can be altered (default)  1 – Alarm Trip register settings cannot be altered  This bit is initially cleared. When set this bit will return a 1, and remain locked until cleared by internal power on reset. These bits can be written with a single write and do not require double writes.</p>
D7	<p>Critical Trip Lock bit  0 – Critical Trip is not locked and can be altered (default)  1 – Critical Trip register settings cannot be altered  This bit is initially cleared. When set this bit will return a 1, and remain locked until cleared by internal power on reset. These bits can be written with a single write and do not require double writes.</p>
D8	<p>Shutdown Mode  0 – Enabled TS (default)  1 – Shutdown TS  When shutdown, the thermal sensing device and A/D converter are disabled to save power, no events will be generated. When either of the lock bits is set, this bit cannot be set until unlocked. However it can be cleared at any time.</p>
D10:9	<p>Hysteresis Enable  00 – Disable Hysteresis  01 – Enable Hysteresis at 1.5°C  10 – Enable Hysteresis at 3°C  11 – Enable Hysteresis at 6°C  When enabled, hysteresis is applied to temperature movement around trigger points. For example, consider the behavior of the “Above Alarm Window” bit (Bit 14 of the Temperature Register) when the hysteresis is set to 3°C. As the temperature rises, Bit 14 will be set to 1 (temperature is above the alarm window) when the Temperature Register contains a value that is greater than the value in the Alarm Temperature Upper Boundary Register. If the temperature decreases, Bit 14 will remain set until the measured temperature is less than or equal to the value in the Alarm Temperature Upper Boundary Register minus 3°C. See Figure X for more detail.  Similarly, the “Below Alarm Window” bit (Bit 13 of the Temperature Register) will be set to 0 (temperature is equal to or above the Alarm window lower boundary trip temperature) when the value in the temperature register is equal to or greater than the value in the Alarm Temperature Lower Boundary Register. As the temperature decreases, Bit 13 will be set to 1 when the value in the Temperature Register is equal to or less than the value in the Alarm Temperature Lower Boundary Register minus 3°C.  Note that hysteresis is also applied to Event# pin functionality. When either of the lock bits is set, these bits cannot be altered.</p>

$T_U$  = Value stored in Alarm Temp Upper Boundary Trip Register.  
 $T_L$  = Value stored in Alarm Temp Lower Boundary Trip Register.  
 Hyst = Absolute value of selected hysteresis

	Below Alarm Window Bit		Above Alarm Window Bit	
	Temperature slope	Threshold Temperature	Temperature Slope	Temperature
Sets	Falling	$T_L - \text{Hyst}$	Rising	$T_H$
Clears	Rising	$T_L$	Falling	$T_H - \text{Hyst}$

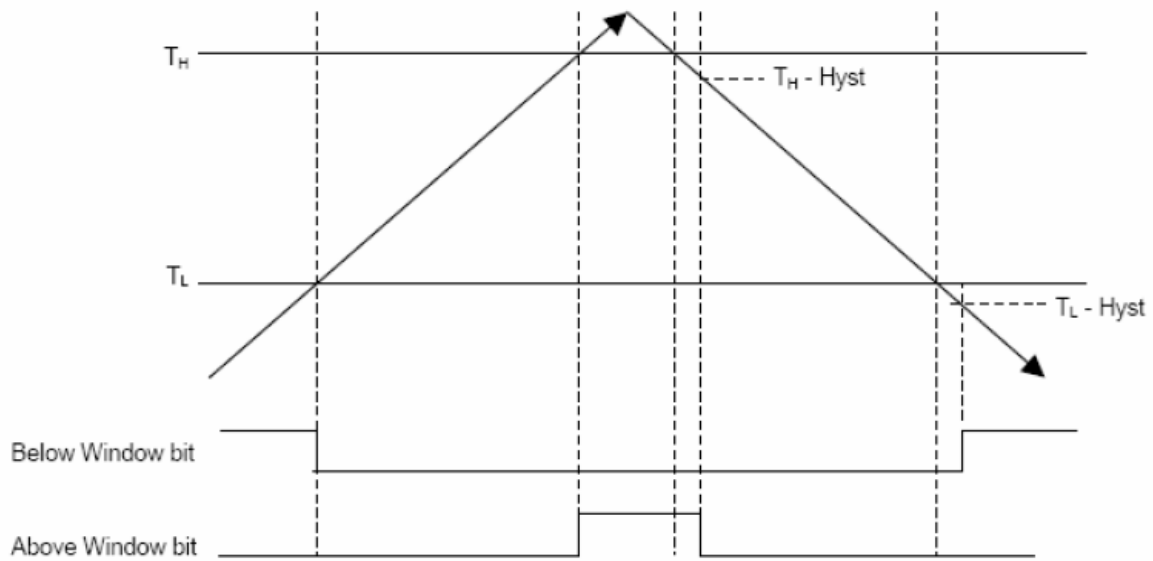


Figure 5. Hysteresis

### Temperature Trip Point Registers

There are three Temperature Trip Point Registers, they are the Alarm Temperature Upper Boundary Register, the Alarm Temperature Lower Boundary Register, and the Critical Temperature Register

#### Alarm Temperature Upper Boundary Register (read/write)

The value is the upper threshold temperature value for Alarm Mode. The data format is Two's complement with one LSB = 0.25°C. RFU (Reserved For Future Use) bits are not supported and will always report zero. Interrupts will respond to the presently programmed boundary values. If boundary values are being altered in-system, it is advised to turn off interrupts until a known state can be obtained to avoid superfluous interrupt activity. The format of this Register is shown in Table 13.

**Table 13 Alarm Temperature Upper Boundary Register**

Bits	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Content	0	0	0	Sign MSB									LSB	RFU	RFU	
				Alarm Window Upper Boundary Temperature												

#### Alarm Temperature Lower Boundary Register (read/write)

The value is the lower threshold temperature value for Alarm Mode. The data format is Two's complement with one LSB = 0.25°C. RFU bits are not supported and will always report zero. Interrupts will respond to the presently programmed boundary values. If boundary values are being altered in-system, it is advised to turn off interrupts until a known state can be obtained to avoid superfluous interrupt activity. The format of this Register is shown in Table 14.

**Table 14 Alarm Temperature Lower Boundary Register**

Bits	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Content	0	0	0	Sign MSB									LSB	RFU	RFU	
				Alarm Window Upper Boundary Temperature												

#### Critical Temperature Register (read/write)

The value is the critical temperature. The data format is Two's complement with one LSB = 0.25°C. RFU bits are not supported and will always report zero. The format of this Register is shown in Table 15.

**Table 15 Critical Temperature Register**

Bits	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Content	0	0	0	Sign MSB									LSB	RFU	RFU	
				Critical Temperature Trip Point												

#### Temperature Value Register (read only)

This 16-bit read only register stores the Trip Status and the temperature measured by the internal temperature sensor as shown in Table 16. The temperature is stored in 13-bit Two's complement format with the MSB being the temperature sign bit and the 12 LSBs represent temperature. One LSB = 0.0625°C. The most significant bit will have a resolution of 128°C.

When reading from this register the eight MSBs (Bit D15 to Bit D8) are read first and then the eight LSBs (Bit D7 to Bit D0) are read.

The Trip Status bits represent the internal temperature trip detection, and are not affected by the status of the Event or Configuration bits e.g. Event Output Control, Clear Event. If neither Above or Below are set (i.e. both are 0) then the current Temperature is exactly within the alarm window boundaries as defined in the Configuration Register. The format and descriptions are shown in Tables 16 and 17 respectively.

**Table 16 Temperature Register**

Bits	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Contents	Above Critical Trip	Above Alarm Window	Below Alarm Window	Sign MSB	Temperature											LSB

**Table 17. Temperature Register Trip Status Description**

Bit	Definition
D13	Below Alarm Window 0 – Temp is equal to or above the Alarm window lower boundary temperature 1 – Temp is below the Alarm window lower boundary temperature
D14	Above Alarm Window 0 – Temp is equal to or below the Alarm window upper boundary temperature 1 – Temp is above the Alarm window upper boundary temperature
D15	Above Critical Trip 0 – Temp is below the critical temperature setting 1 – Temp is equal to or above the critical temperature setting

**Manufacturer ID Register (read only)**

This manufacturer ID matches that assigned to a vendor within the PCI SIG. This register may be used to identify the manufacturer of the device in order to perform manufacturer specific operations. Manufacturer IDs can be found at [www.pcisig.com](http://www.pcisig.com). The format of this Register is shown in Table 18.

**Table 17. Manufacturer ID Register**

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

**Device ID and Revision Register (read only)**

This Device ID and Device Revision are assigned by the manufacturer of the device. The Device Revision will start at 0 and be incremented by one whenever an update to the device is issued by the manufacturer of the device. The format of this Register is shown in Table 19.

**Table 18. Device ID and Device Revision Register**

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

### Event Pin Functionality

Figure 6 shows the 3 differently-defined outputs of Event# correspondent to the temperature change. Event# can be programmed to be one of the three output modes in the Configuration Register.

If in Interrupt Mode and the temperature reaches the critical temperature, the device switches to the comparator mode automatically and asserts the Event# output. When the temperature drops below the critical temperature, the part switches back to either Interrupt, or Comparator mode, as programmed in the Configuration Register. Note that Figure 6 is drawn with no hysteresis, but the values programmed into register 0x01 bits 10:9 affect the operation of the event trigger points. See Figure 5 and Table 12 for the explanation of hysteresis functionality.

### Event Thresholds

All event thresholds use hysteresis as programmed in register 0x01 bits 10:9 to set when they de-assert.

### Alarm Window Trip

The device provides a comparison window with an upper temperature trip point in the Alarm Upper Boundary Register, and a lower trip point in the Alarm Lower Boundary Register. When enabled, the Event# output will be triggered whenever

entering, or exiting (crossing above or below) the Alarm Window.

### Critical Trip

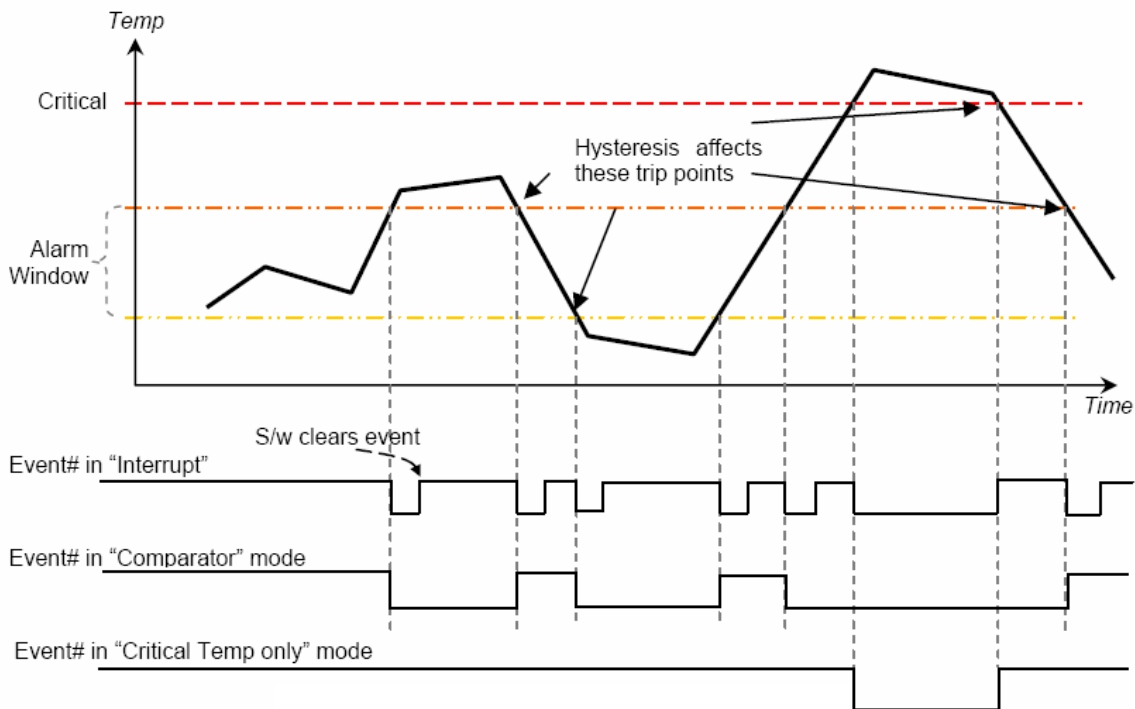
The device can be programmed in such a way that the Event output is only triggered when the temperature exceeds critical trip point. The Critical temperature setting is programmed in Critical Temperature Register. When the temperature sensor reaches the critical temperature value in this register, the device is automatically placed in comparator mode meaning that the Critical Event output cannot be cleared through software setting the “Clear Event” bit.

### Interrupt Mode

After an Event occurs, Software may write a one ('1') to the “Clear Event” bit in the Configuration Register to de-assert the Event# Interrupt output, until the next trigger condition occurs.

### Comparator Mode

Reads/writes on the device registers will not affect the Event# output in comparator mode. The Event# signal will remain asserted until the temperature drops outside the range, or the range is re-programmed such that the current temperature is outside the range.



Note: Event# cannot be cleared once the DUT temperature is greater than the Critical temperature.

**Figure 6. Temperature, Trip, and Events**

**ADT7408 SERIAL INTERFACE**

Control of the ADT7408 is carried out via the SMBus-/I<sup>2</sup>C-compatible serial interface. The ADT7408 is connected to this bus as a slave and is under the control of a master device.

Figure shows a typical SMBus-/I<sup>2</sup>C- interface connection.

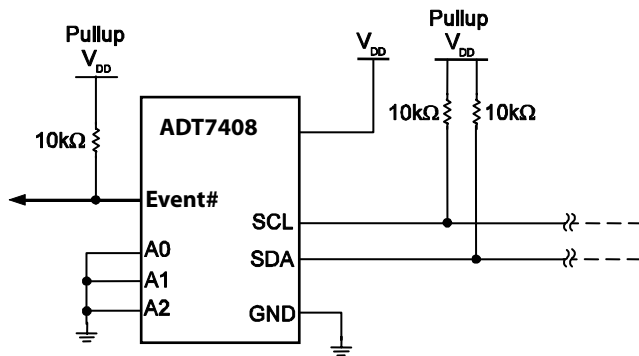


Figure 7. Typical SMBus/I<sup>2</sup>C Interface Connection

**Serial Bus Address**

Like all SMBus-/I<sup>2</sup>C- compatible devices, the ADT7408 has a 7-bit serial address. The four MSBs of this address for the ADT7408 are set to 0011. The three LSBs are set by Pin 1, Pin 2, and Pin 3 (A0, A1 and A2). These pins can be configured either low or high permanently or dynamically to give eight different address options. Table 20 shows the different bus address options available. Recommended pullup resistor value on the SDA and SCL lines is 2.2k $\Omega$  -10 k $\Omega$  .

**Table 20. SMBus/I<sup>2</sup>C Bus Address Options**

BINARY	HEX
A6 A5 A4 A3 A2 A1 A0	
0011 0 0 0	0x24
0011 0 0 1	0x25
0011 0 1 0	0x26
0011 0 1 1	0x27
0011 1 0 0	0x28
0011 1 0 1	0x29
0011 1 1 0	0x30
0011 1 1 1	0x31

The ADT7408 has been designed with a SMBus/I<sup>2</sup>C timeout. The SMBus/I<sup>2</sup>C interface will timeout after 75 ms to 325 ms of no activity on the SDA line. After this timeout the ADT7408 will reset the SDA line back to its idle state (SDA set to high impedance) and wait for the next start condition.

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 will 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 R/W bit. The R/W bit determines whether data will be 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/W bit is a 0 then the master will write to the slave device. If the R/W bit is a 1 the master will read from the slave device.
3. Data is sent over the serial bus in sequences of 9 clock pulses, 8 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 may 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 will pull the data line high during the 10th clock pulse to assert a STOP condition. In READ mode, the master device will pull the data line high during the low period before the 9th clock pulse. This is known as no acknowledge. The master will then take 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.

Any number of bytes of data may be transferred over the serial bus in one operation. However, 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 I<sup>2</sup>C address set up by the three address pins is not latched by the device until after this address has been sent twice. On the 8th 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 I<sup>2</sup>C serial bus address. Any subsequent changes on this pin will have no effect on the I<sup>2</sup>C serial bus address.

**SMBus/I2C Communications**

The data registers in the ADT7408 are selected by the Pointer Register. At power-up the Pointer Register is set to 0x00, the location for the Capability Register. The Pointer Register latches the last location it was set to. Each data register falls into one of the three types of user accessibility:

1. Read only
2. Write only
3. Write/Read same address

A Write to the ADT7408 will always include the address byte and the pointer byte. A write to any register, other than the pointer register, requires two data bytes.

Reading data from the ADT7408 can take place either of two ways:

If the location latched in the Pointer Register is correct, then the read can simply consist of an address byte, followed by retrieving the two data bytes.

If the Pointer Register needs to be set, then an address byte, pointer byte, repeat start, and another address byte will accomplish a read.

The data byte has the most significant bit first. At the end of a read, the ADT7408 can accept either Acknowledge (Ack) or No Acknowledge (No Ack) from the Master (No Acknowledge is typically used as a signal for the slave that the Master has read its last byte). It takes the ADT7408 97ms to measure the temperature.

**Writing Data to a Register**

Except the Pointer Register, all other Registers are 16-bits wide so two bytes of data are written to these register. Writing two bytes of data to these Register consists of the serial bus address, the Data Register address written to the Pointer Register, followed by the two data bytes written to the selected Data Register. This is illustrated in

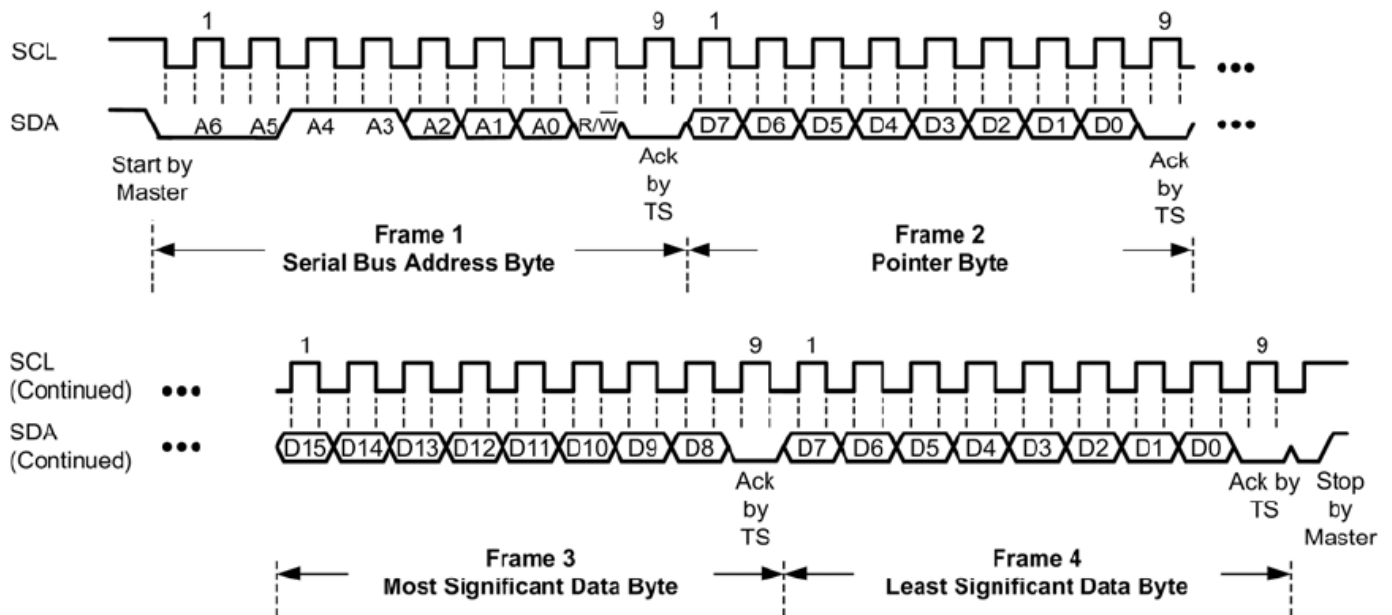


Figure . If more than the required number of data bytes is written to a register then the register will ignore these extra data bytes. To write to a different register, another START or repeated START is required.



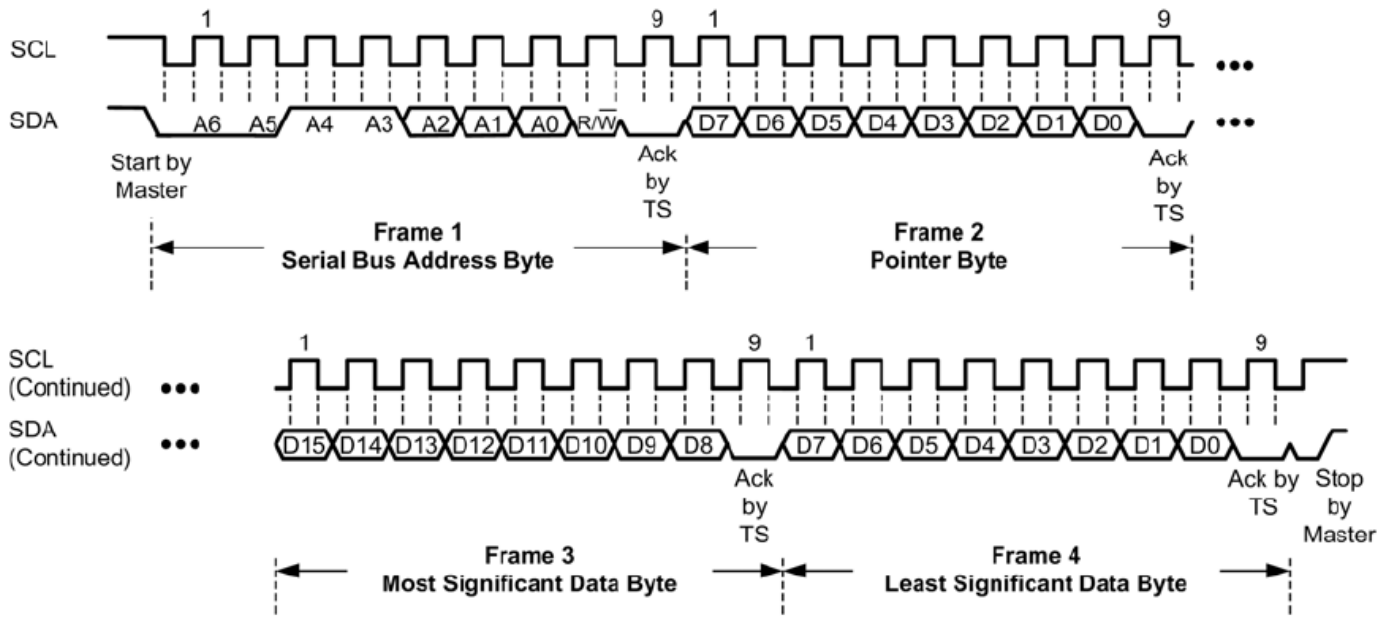


Figure 8. Writing to the Address Pointer Register Followed by two Bytes of Data

### Reading Data From the ADT7408

Reading data from the ADT7408 can take place in either of two ways:

#### Writing to the Pointer Register for a subsequent read

In order to read data from a particular register, the Pointer Register must contain the address of the data 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

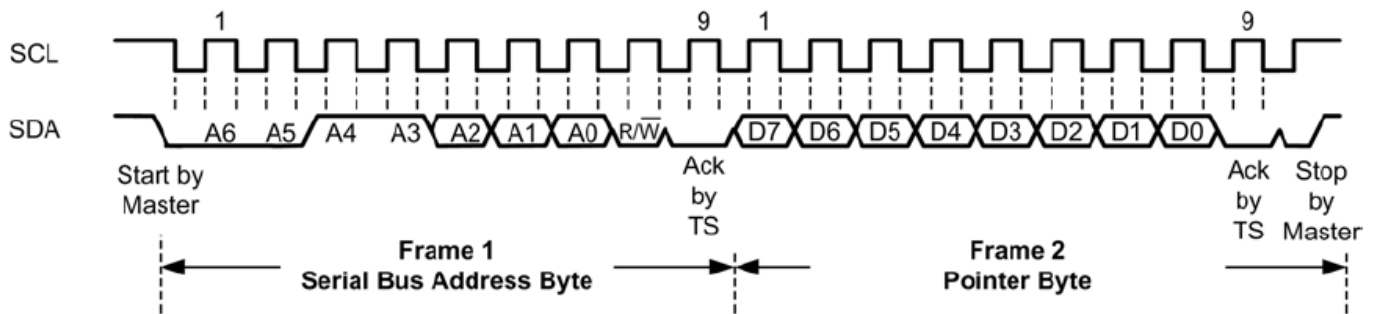


Figure 9. The write operation consists of the serial bus address followed by the pointer byte. No data is written to any of the data registers. Since the location latched in the Pointer Register is correct, then the read can simply consist of an address byte, followed by retrieving the two data bytes as shown in Figure 10.

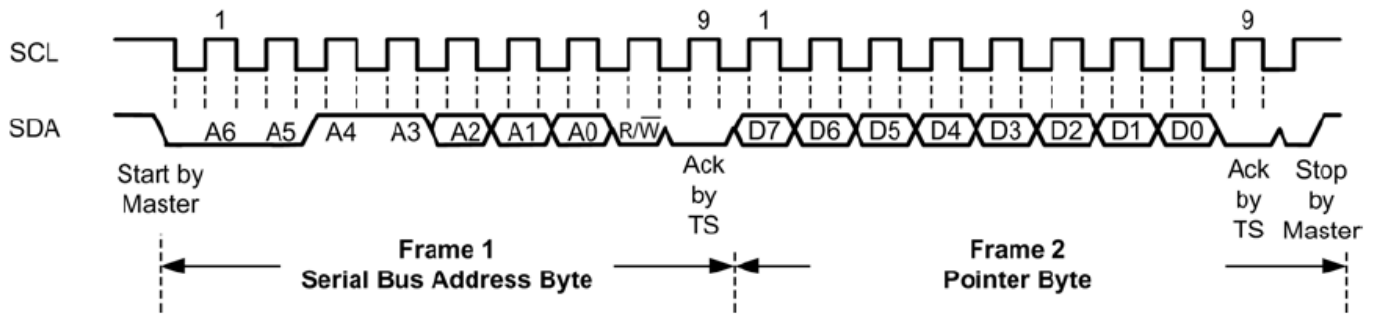


Figure 9. Writing to the Address Pointer Register to select a Register for a Subsequent Read Operation

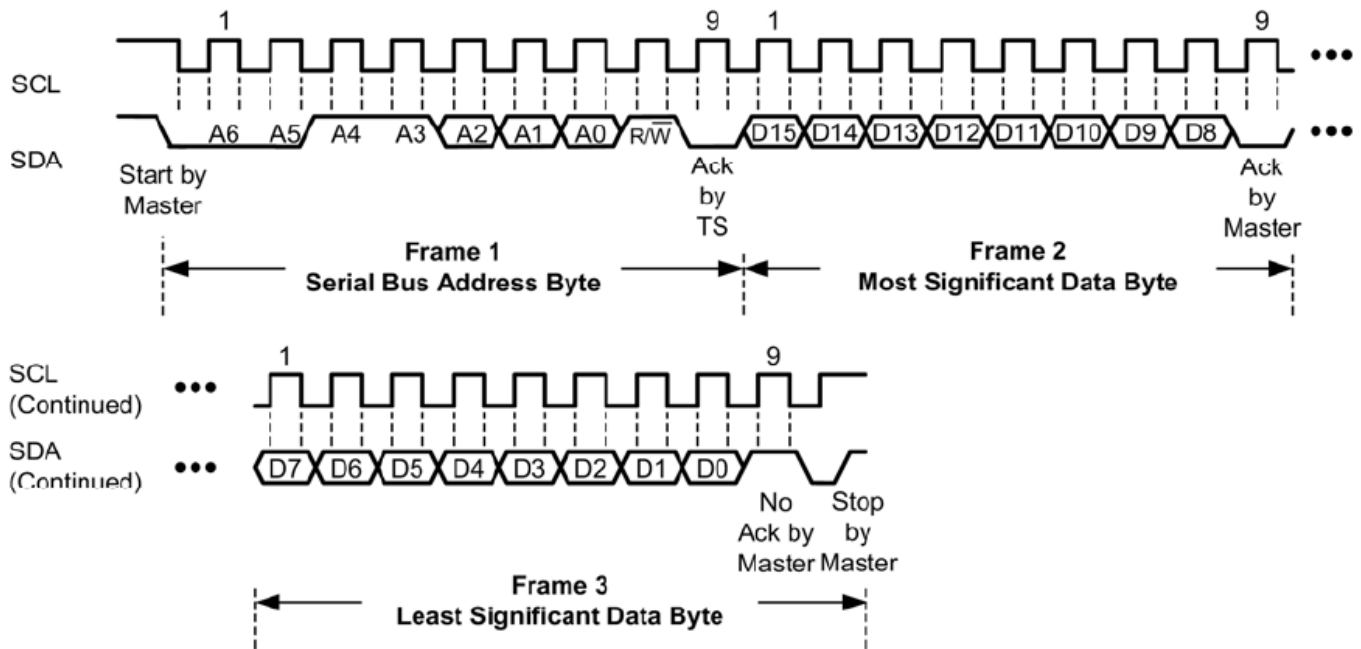


Figure 10. Reading back data from the Register with the preset pointer

**Reading from any Pointer Register**

On the other hand, if the Pointer Register needs to be set, then an address byte, pointer byte, repeat start, and another address byte will accomplish a read as shown in Figure 11.

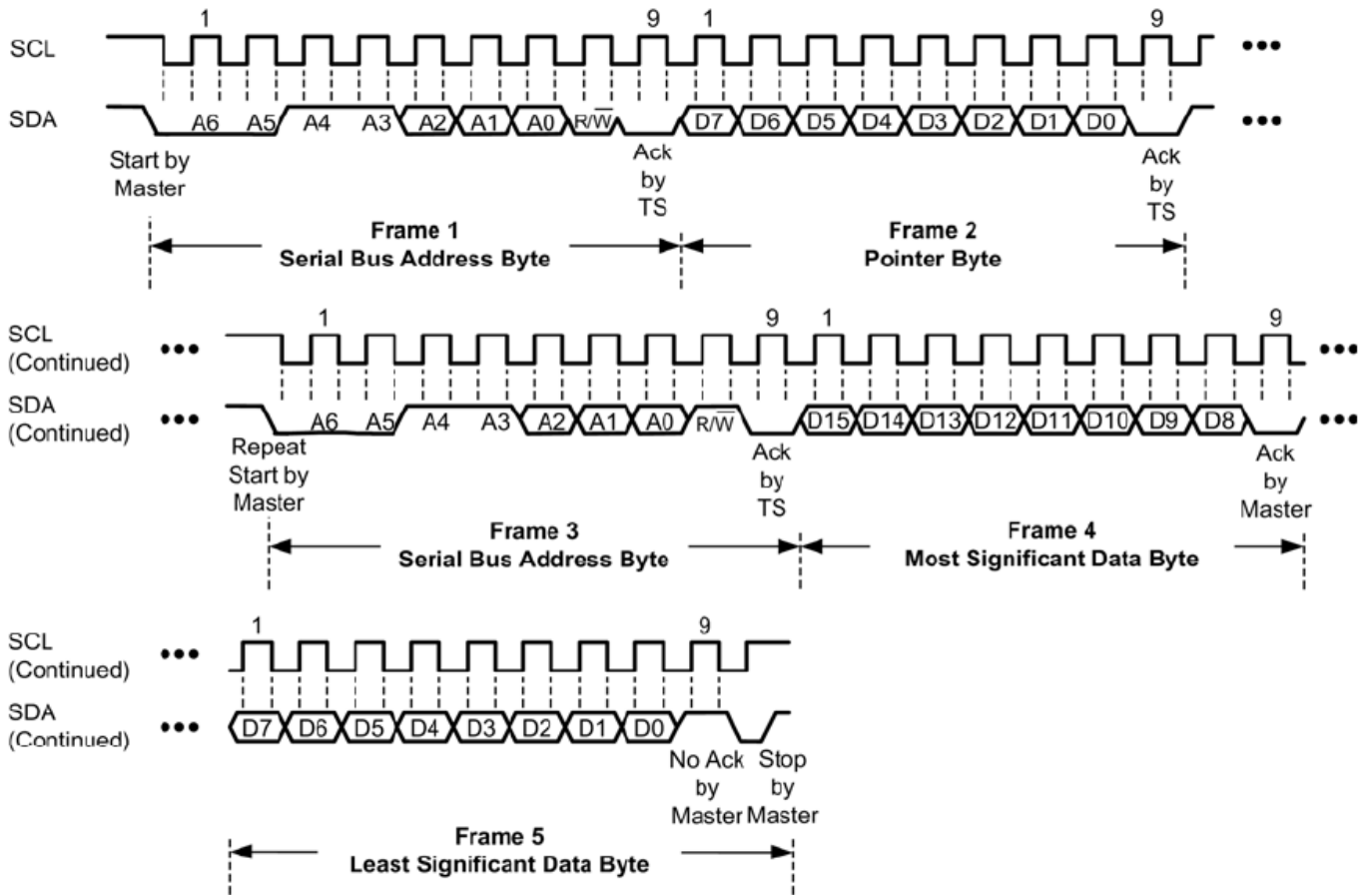


Figure 11. Write to the pointer register followed by a repeat start and an immediate data word read

## 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 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 ADT7408 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.

### SELF-HEATING EFFECTS

The temperature measurement accuracy of the ADT7408 might be degraded in some applications due to self-heating. Errors can be introduced from the quiescent dissipation and power dissipated when converting. The magnitude of these temperature errors is dependent on the thermal conductivity of the ADT7408 package, the mounting technique, and the effects of airflow. At 25°C, static dissipation in the ADT7408 is typically 778  $\mu\text{W}$  operating at 3.3 V. In the 8-lead LFCSP package mounted in free air, this accounts for a temperature increase due to self-heating of

$$\Delta T = P_{DISS} \times \theta_{JA} = 778 \mu\text{W} \times \text{???}^\circ\text{C}/\text{W} = \text{???}^\circ\text{C}$$

It is recommended that current dissipated through the device be kept to a minimum, because it has a proportional effect on the temperature error.

Using the shutdown mode can reduce the current dissipated through the ADT7408 subsequently reducing the self-heating effect. When the ADT7408 is in shutdown mode and operating at 25°C, static dissipation in the ADT7408 is typically 33  $\mu\text{W}$  with  $V_{DD} = 3.3$  V. In the 8-lead LFCSP package mounted in free air, this accounts for a temperature increase due to self-heating of

$$\Delta T = P_{DISS} \times \theta_{JA} = 33 \mu\text{W} \times \text{???}^\circ\text{C}/\text{W} = \text{???}^\circ\text{C}$$

### SUPPLY DECOUPLING

The ADT7408 should be decoupled with a 0.1  $\mu\text{F}$  ceramic capacitor between  $V_{DD}$  and GND. This is particularly important when the ADT7408 is mounted remotely from the power supply. Precision analog products such as the ADT7408 require a well-filtered power source. Because the ADT7408 operates from a single supply, it might seem 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 hundreds of mV in amplitude due to wiring resistance and inductance.

If possible, the ADT7408 should be powered directly from the system power supply. This arrangement, shown in Figure 4, isolates the analog section from the logic switching transients. Even if a separate power supply trace is not available, however, generous supply bypassing reduces supply-line-induced errors. Local supply bypassing consisting of a 0.1  $\mu\text{F}$  ceramic capacitor is critical for the temperature accuracy specifications to be achieved. This decoupling capacitor must be placed as close as possible to the ADT7408  $V_{DD}$  pin.

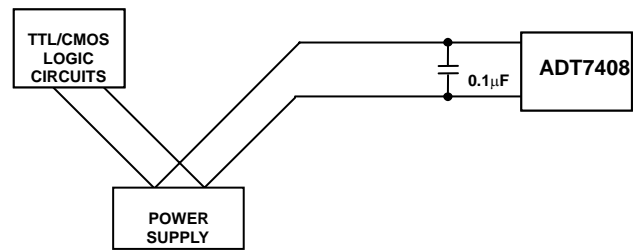


Figure 4. Use Separate Traces to Reduce Power Supply Noise

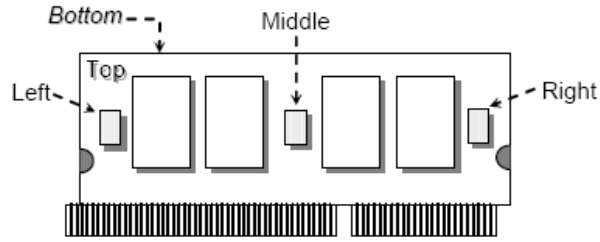
### TEMPERATURE MONITORING

The ADT7408 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 ADT7408 measures and converts the temperature at the surface of its own semiconductor chip. When the ADT7408 is used to measure the temperature of a nearby heat source, the thermal impedance between the heat source and the ADT7408 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 ADT7408's temperature value register.

Once the thermal impedance is determined, the temperature of the heat source can be inferred from the ADT7408 output. As much as 60% of the heat transferred from the heat source to the thermal sensor on the ADT7408 die is discharged via the copper tracks, the package pins and the bond pads. Of the pins on the ADT7408, 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 ADT7408 GND pin and the GND of the heat source is reduced as much as possible.

One example of using the ADT7408's unique properties is in monitoring a high power dissipation DIMM module. Ideally the ADT7408 device should be mounted in the middle between the two memory chips major heat sources as shown in Figure 13. The ADT7408 produces a linear temperature output while needing only two I/O pins and requiring no external characterization.



**SO-DIMM Thermal Sensor locations**

*Figure 13. Locations of ADT7408 on Dimm module*

### Outline Dimensions

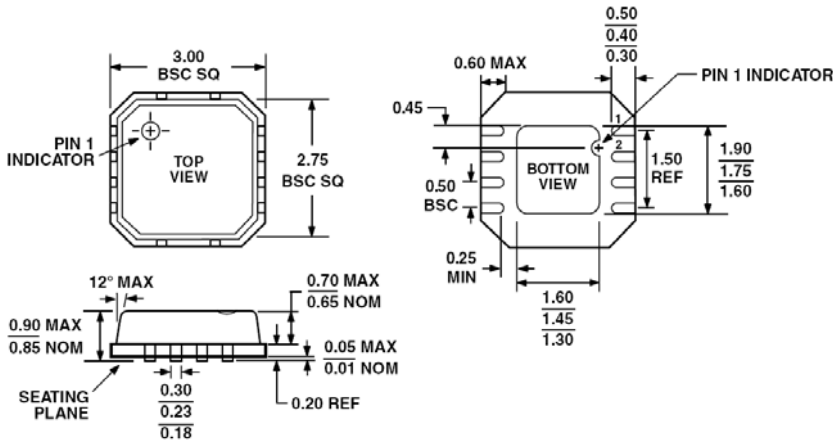


Figure 14. 8-Lead Frame Chip Scale Package [LFCSP]  
 3 x 3 mm Body  
 (CP-8)  
 Dimensions shown in millimeters

### ORDERING GUIDE

Model	Temperature Range	Temperature Accuracy <sup>1</sup>	Package Description	Package Option	Ordering Quantity	Branding
ADT7408CCPZ <sup>2</sup> -r2	-20°C to +125°C	±2°C	8-Lead LFCSP	CP-8	250	T1M
ADT7408CCPZ <sup>2</sup> -reel	-20°C to +125°C	±2°C	8-Lead LFCSP	CP-8	5,000	T1M
ADT7408CCPZ <sup>2</sup> -reel7	-20°C to +125°C	±2°C	8-Lead LFCSP	CP-8	1,500	T1M

<sup>1</sup> Temperature accuracy is over the -20°C to +100°C temperature range.

<sup>2</sup> Pb-free part

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