



SMBus/I²C Compatible, 10-bit Digital Temperature Sensor in 5 Pin SOT-23

Preliminary Technical Data

AD7415

FEATURES

10-Bit Temperature to Digital Converter.

Temperature range:

-55°C to +135°C

-55°C to +125°C

Accuracy of $\pm 2^\circ\text{C}$

SMBusTM/I²C^R Compatible Serial Interface

25 μA Supply Current

Temperature Conversion Time - 25 μs typ

Space Saving 5-pin SOT-23 Package

Pin-Selectable Addressing via AS

Four Versions Allow Eight I²C Addresses

APPLICATIONS

Hard Disk Drives

Personal Computers

Electronic Test Equipment

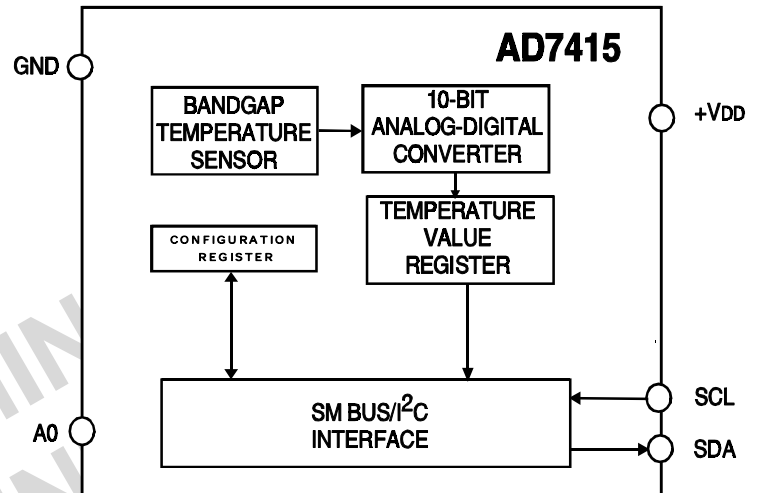
Office Equipment

Domestic Appliances

Process Control

Cellular Phones

FUNCTIONAL BLOCK DIAGRAM



GENERAL DESCRIPTION

The AD7415 is a complete temperature monitoring system in a 5-pin SOT-23 package. It contains a bandgap temperature sensor and a 10-bit ADC to monitor and digitize the temperature reading to a resolution of 0.25°C.

The AD7415 provides a two-wire serial interface which is compatible with SMBus and I²C interfaces. The part comes in four versions, AD7415-0, AD7415-1, AD7415-2 and the AD7415-3. The AD7415-0 & AD7415-1 versions allow for the choice of three different SMBus addresses for each version. All four versions give the possibility of eight different I²C addresses for the AD7415.

The AD7415's 3.3V supply voltage, low supply current, serial interface and small package size, make it ideal for a variety of applications, including personal computers, cellular phones, office equipment and domestic appliances.

PRODUCT HIGHLIGHTS

1. The AD7415 has an on chip temperature sensor that allows an accurate measurement of the ambient temperature to be made. The measurable temperature range is -55°C to +135°C with a $\pm 3^\circ\text{C}$ temperature accuracy over the full temperature range.
2. SMBus/I²C Compatible Serial Interface with pin selectable choice of three addresses per version of the AD7415, eight address options in total.
3. Supply voltage of 2.7V to 5.5V.
4. Space saving 5-Pin SOT-23 package.
5. 10-bit temperature reading to 0.25°C resolution.

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REV. PrB 01/00

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AD7415–SPECIFICATIONS¹ ($T_A = T_{MIN}$ to T_{MAX} , $V_{DD} = 2.7V$ to $5.5V$, unless otherwise noted)

Parameter	A Version	S Version	Units	Test Conditions/Comments
TEMPERATURE SENSOR AND ADC				
Accuracy	±2.0		°C max	$T_A = -55^{\circ}\text{C}$ to $+125^{\circ}\text{C}$ $T_A = -55^{\circ}\text{C}$ to $+135^{\circ}\text{C}$
Resolution	10	±3.0	°C max	
Update Rate, t_R	400	10	Bits	
Temperature Conversion Time	25	400	µs typ	
	25	25	µs typ	
POWER SUPPLIES				
Supply Current	1.2	1.2	mA max	Peak current when part is converting.
Supply Current ²	25	25	µA	Average Supply Current with serial bus inactive. Not converting.
Supply Current ³	60	60	µA	Average Supply Current with serial bus active. Not converting
DIGITAL INPUT				
Input High Voltage, V_{IH}	2.4	2.4	V min	$V_{IN} = 0V$ to V_{DD} All Digital Inputs
Input Low Voltage, V_{IL}	0.8	0.8	V max	
Input Current, I_{IN}	±1	±1	µA max	
Input Capacitance, C_{IN}	10	10	pF max	
DIGITAL OUTPUT				
Output High Current, I_{OH}	1	1	µA max	$V_{OH} = 5V$ $I_{OL} = 1.6mA$
Output Low Voltage, V_{OL}	0.4	0.4	V max	
Output Capacitance, C_{OUT}	50	50	pF max	
AC ELECTRICAL CHARACTERISTICS⁴				
Serial Clock Period, t_1	2.5	2.5	µs min	See Figure 1
Data In Setup Time to SCL High, t_2	50	50	ns min	See Figure 1
Data Out Stable after SCL Low, t_3	0	0	ns min	See Figure 1
SDA Low Setup Time to SCL Low (Start Condition), t_4	50	50	ns min	See Figure 1
SDA High Hold Time after SCL High (Stop Condition), t_5	50	50	ns min	See Figure 1
SDA and SCL Fall Time, t_6	90	90	ns max	See Figure 1

Specifications subject to change without notice.

NOTES

- 1 Temperature Ranges as follows: A Version = -55°C to $+125^{\circ}\text{C}$, B Version = -55°C to $+135^{\circ}\text{C}$.
- 2 Peak supply current is approximately 1.2mA with serial bus inactive and part converting. This peak supply current is required for 25µs (the conversion time) out of every 400µs (the conversion rate).
- 3 Peak supply current is approximately 1.2mA with serial bus active and part converting. The 60µA average current is derived assuming a 400kHz serial clock being active for 16 serial clock cycles every 400µs. If the temperature read is at a lower rate, the average current will reduce accordingly.
- 4 The SDA & SCL timing is measured with the input filters turned on so as to meet the Fast-Mode I²C specification. Switching off the input filters improves the transfer rate but has a negative affect on the EMC behaviour of the part.

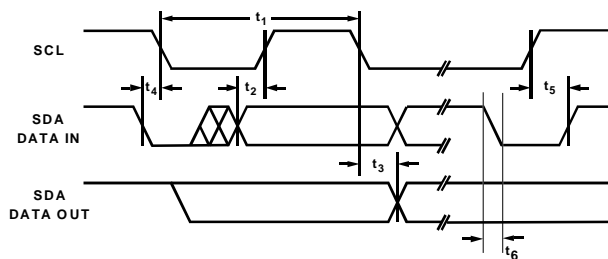
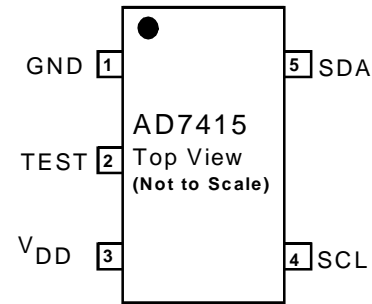


Figure 1. Diagram for Serial Bus Timing

AD7415 PIN FUNCTION DESCRIPTION

Mnemonic	Description
GND	Analog and Digital Ground.
AS	Logic Input. Address Select Input which selects one of three I ² C addresses for the AD7415 (See Table 1).
VDD	Positive Supply Voltage, +2.7V to +5.5V.
SCL	Digital Input. Serial Bus Clock.
SDA	Digital I/O. Serial Bus Bi-directional Data. Open-drain output.

PIN CONFIGURATIONS



SOT-23

ABSOLUTE MAXIMUM RATINGS*

(T_A = +25°C unless otherwise noted)

V _{DD} to GND.....	-0.3 V to +7 V
SDA Input Voltage to GND.....	-0.3 V to +7 V
SDA Output Voltage to GND.....	-0.3 V to +7 V
SCL Input Voltage to GND.....	-0.3 V to +7 V
Operating Temperature Range	-55°C to +150°C
Storage Temperature Range	-65°C to +150°C
Junction Temperature	+150°C
SOT-23, Power Dissipation	450 mW
θ _{JA} Thermal Impedance	240°C/W
Lead Temperature, Soldering	
Vapor Phase (60 sec)	+215°C
Infrared (15 sec)	+220°C

*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.

CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the AD7415 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.

ORDERING GUIDE

Model	Temperature Range	Temperature Error	Package Description	Branding Information for Silicon 1 samples	Min Qty's/ Reel
AD7415ART-0REEL7	-55°C to +125°C	±2°C	5-Pin SOT-23	CG1	3000
AD7415ART-0REEL	-55°C to +125°C	±2°C	5-Pin SOT-23	CG1	10000
AD7415ART-1REEL7	-55°C to +125°C	±2°C	5-Pin SOT-23	CG2	3000
AD7415ART-1REEL	-55°C to +125°C	±2°C	5-Pin SOT-23	CG2	10000
AD7415ART-2REEL7	-55°C to +125°C	±2°C	5-Pin SOT-23	CG3	3000
AD7415ART-2REEL	-55°C to +125°C	±2°C	5-Pin SOT-23	CG3	10000
AD7415ART-3REEL7	-55°C to +125°C	±2°C	5-Pin SOT-23	CG4	3000
AD7415ART-3REEL	-55°C to +125°C	±2°C	5-Pin SOT-23	CG4	10000
AD7415SRT-0REEL7	-55°C to +135°C	±3°C	5-Pin SOT-23	CG5	3000
AD7415SRT-1REEL7	-55°C to +135°C	±3°C	5-Pin SOT-23	CG6	3000
AD7415SRT-2REEL7	-55°C to +135°C	±3°C	5-Pin SOT-23	CG7	3000
AD7415SRT-3REEL7	-55°C to +135°C	±3°C	5-Pin SOT-23	CG8	3000

Table 1. I²C Address Selection

Part Number	AS Pin	I ² C Address
AD7415-0	Float	1001 000
AD7415-0	GND	1001 001
AD7415-0	VDD	1001 010
AD7415-1	Float	1001 100
AD7415-1	GND	1001 101
AD7415-1	VDD	1001 110
AD7415-2	N/A	1001 011
AD7415-3	N/A	1001 111

CIRCUIT INFORMATION

The AD7415 is a stand alone digital temperature sensor. The on-chip temperature sensor allows an accurate measurement of the ambient device temperature to be made. The 10-bit A/D converter converts the temperature measured into a two's complement format for storage in the Temperature Register. The A/D converter is made up of a conventional successive-approximation converter based around a capacitor DAC. The serial interface is I²C and SMBus compatible. The AD7415 requires a 2.7 V to 5.5 V power supply. The temperature sensor has a working measurement range of -55 °C to +125 °C for version A and -55 °C to +135 °C for version S.

FUNCTIONAL DESCRIPTION

Temperature measurement is initiated by a couple of methods. The first method uses an internal clock count-down of 400µs and then a conversion is performed. It takes typically 25µs for each conversion to be completed. The new temperature value is loaded into the Temperature Value Register and ready for reading by the I²C interface.

A temperature measurement is also initiated every time a read or write operation to the AD7415 takes place. The track/hold goes into hold approximately 3µs after the STOP condition and a conversion is then initiated. Typically 25µs later the conversion is complete and the Temperature Value Register is loaded with a new temperature value.

Configuration functions consist of:

- switching between normal operation and full power-down.
- enabling or disabling the SCL and SDA filters.

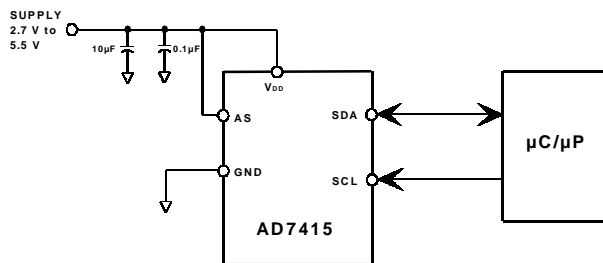


Figure 2. Typical Connection Diagram

MEASUREMENT TECHNIQUE

A common method of measuring temperature is to exploit the negative temperature coefficient of a diode, or the base-emitter voltage of a transistor, operated at constant current. Unfortunately, this technique requires calibration to null out the effect of the absolute value of V_{BE} , which varies from device to device.

The technique used in the AD7415 is to measure the change in V_{BE} when the device is operated at two different currents.

This is given by:

$$\Delta V_{BE} = KT/q \times \ln(N)$$

where:

K is Boltzmann's constant

q is charge on the electron (1.6×10^{-19} Coulombs).

T is absolute temperature in Kelvins.

N is the ration of the two currents.

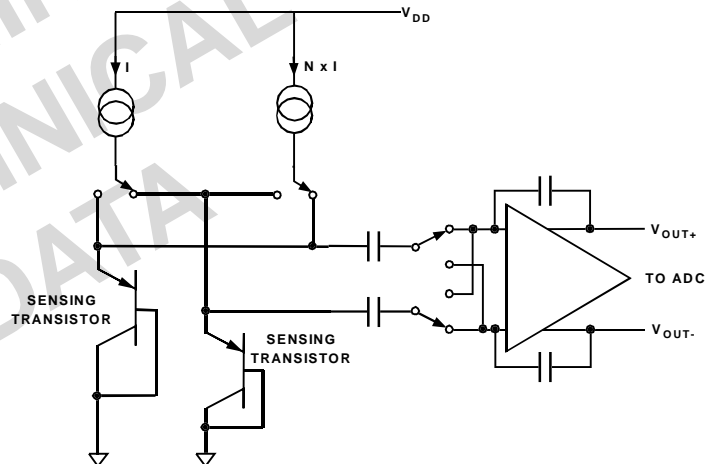


Figure 3. Temperature Measurement Technique

Figure 3 shows the method the AD7415 uses to measure the ambient device temperature. To measure ΔV_{BE} , the sensor (substrate transistor) is switched between operating currents of I and $N \times I$. The resulting waveform is passed through a chopper-stabilized amplifier that performs the functions of amplification and rectification of the waveform to produce a dc voltage proportional to ΔV_{BE} . This voltage is measure by the ADC to give a temperature output in 10-bit twos complement format.

TEMPERATURE DATA FORMAT

The temperature resolution of the ADC is 0.25°C which corresponds to one LSB of the ADC. The ADC can theoretically measure a temperature span of 255°C; the practical lowest value is limited to -55°C due to device maximum ratings. The S grade can measure a temperature range of -55°C to +135°C (temperature data format is shown in Table 2); the A grade can measure a temperature range of -55°C to +125°C (temperature data format is shown in Table 3).

Table 2. S-Grade Temperature Data Format

Temperature	Digital Output DB9.....DB0
-55 °C	10 1100 0000
-50 °C	10 1101 0100
-25 °C	11 0011 1000
0 °C	11 1001 1100
+24.75 °C	11 1111 1111
+25 °C	00 0000 0000
+25.25 °C	00 0000 0001
+50 °C	00 0110 0100
+75 °C	00 1100 1000
+100 °C	01 0010 1100
+125 °C	01 1001 0000
+135 °C	01 1011 1000

S-Grade Temperature Conversion Formula :-

(1) $Temperature = +25^{\circ}C + (ADC\ Code^*/4)$

(2) $Temperature = (ADC\ Code^* - 412)/4$

* When DB9 = 0, use formula (1). Use DB0 - DB8 in formula.
When DB9 = 1, use formula (2). Use DB0 - DB8 in formula.

Table 3. A-Grade Temperature Data Format

Temperature	Digital Output DB9.....DB0
-128 °C	10 0000 0000
-125 °C	10 0000 1100
-100 °C	10 0111 0000
-75 °C	10 1101 0100
-50 °C	11 0011 1000
-25 °C	11 1001 1100
-0.25 °C	11 1111 1111
0 °C	00 0000 0000
+0.25 °C	00 0000 0001
+10 °C	00 0010 1000
+25 °C	00 0110 0100
+50 °C	00 1100 1000
+75 °C	01 0010 1100
+100 °C	01 1001 0000
+125 °C	01 1111 0100
+127 °C	01 1111 1100

A-Grade Temperature Conversion Formula :-

(1) $Positive\ Temperature = ADC\ Code/4$

(2) $Negative\ Temperature = (ADC\ Code^* - 512)/4$

*DB9 is removed from the ADC Code.

INTERNAL REGISTER STRUCTURE

The AD7415 has three internal registers as shown in Figure 4. Two are data registers and one is an address pointer register. Each data register has an address which is pointed to by the Address Pointer register when communicating with it. The Temperature Value register is the only data register that is read only.

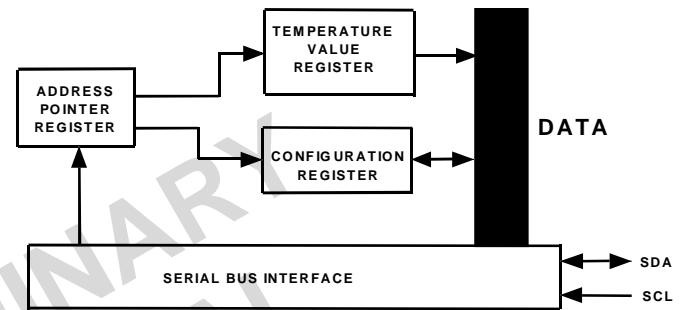


Figure 4. AD7415 Register Structure

ADDRESS POINTER REGISTER

The Address Pointer Register is an 8-bit register which stores an address that points to one of the two data registers. The first byte of every serial write operation to the AD7415 is the address of one of the data registers, which is stored in the Address Pointer Register, and selects the data register to which subsequent data bytes are written to or read from. Only the two LSBs of this register are used to select a data register.

Table 4. Address Pointer Register

P7*	P6*	P5*	P4*	P3*	P2*	P1	P0
0	0	0	0	0	0	Register Select	

Table 5. Register Address

P1	P0	Registers
0	0	Temperature Value Register (Read only)
0	1	Configuration Register (Read/Write)

CONFIGURATION REGISTER (ADDRESS 01H)

The Configuration Register is an 8-bit read/write register that is used to set the operating modes of the AD7415. Only four of the MSBs are used (D7 to D4) to set the operating modes, see Table 7. D0 to D5 are used for factory settings and must have zeros written to them during normal operation.

Table 6. Configuration Register

D7	D6	D5	D4	D3	D2	D1	D0
PD	FLTR	TEST MODE					
0*	1*	0's*					

*Default settings at Power-up.

Table 7. Configuration Register Settings

D7	Full Power-down if = 1
D6	Bypass SDA & SCL filtering if = 0

TEMPERATURE VALUE REGISTER

The Temperature Value Register is a 10-bit read-only register which stores the temperature reading from the ADC in twos complement format. Two reads are necessary to read data from this register. The full theoretical span of the ADC is 255°C, but in practice the temperature measurement range is limited to the operating range of the device, -55°C to +125°C for A-grade and -55°C to +135°C for S-grade.

Table 8. Temperature Value Register

D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
MSB	B8	B7	B6	B5	B4	B3	B2	B1	LSB

AD7415 SERIAL INTERFACE

Control of the AD7415 is carried out via the I²C-compatible serial bus. The AD7415 is connected to this bus as a slave device, under the control of a master device, e.g. the processor.

SERIAL BUS ADDRESS

Like all I²C-compatible devices, the AD7415 has a 7-bit serial address. The four MSBs of this address for the AD7415 are set to 1001. The AD7415 comes in four versions, the AD7415-0, AD7415-1, AD7415-2 and the AD7415-3. The first two versions have three different I²C addresses available which are selected by either tying the AS pin to GND, to VDD or letting the pin float (see Table 1). By giving different addresses for the four versions, up to eight AD7415's can be connected to a single, serial bus, or the addresses can be set to avoid conflicts with other devices on the bus.

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 whilst 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 8 bits, consisting of a 7-bit address (MSB first) plus a R/ \bar{W} bit, which determines the direction of the data transfer, i.e. whether data will be written to or read from the slave device.

The peripheral whose address corresponds 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 whilst the selected device waits for data to be read from or written to it. If the R/ \bar{W} bit is a 0 then the master will write to the slave device. If the R/ \bar{W} bit is a 1 the master will read from the slave device.

2. 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.
3. 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, but 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.

WRITING TO THE AD7415

There are two different writes for the AD7415. One is for reading from either the Configuration Register or the Temperature Value Register. The other is for writing to the Configuration Register only.

Writing to the Address Pointer Register for a subsequent read.

In order 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 5. 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 a single byte of data to the Configuration Register

The Configuration register is an 8-bit register so only one byte of data can be written to it. Writing a single byte of data to the register 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 illustrated in Figure 6.

READING DATA FROM THE AD7415

Reading data from the AD7415 is a one or two byte operation. Reading back the contents of the Configuration Register is a single byte read operation as shown in Figure 7. The register address previously having been set up by a single byte write operation to the Address Pointer Register. Once the register address has been set up, any number of reads can be subsequently done from that register without having to write to the Address Pointer Register again. If you want to read from another register then you will have to write to the Address Pointer Register again to set up the relevant register address.

Reading data from the Temperature Value Register is a two byte operation as shown in Figure 8. The same rules apply for a two byte read as a single byte read.

POWER-ON DEFAULTS

The AD7415 always powers up with the following defaults.....

Address Pointer Register pointing to the Temperature Value Register.

Configuration Register loaded with 40 Hex.

OPERATING MODES

Mode 1

This is the power-on default mode of the AD7415. In this mode the AD7415 does a temperature conversion every 400 μ s and then partially powers down until the next conversion occurs.

If a read occurs during a conversion, the conversion aborts and a new one starts after the read operation has finished. The temperature value that is read is that of the previous

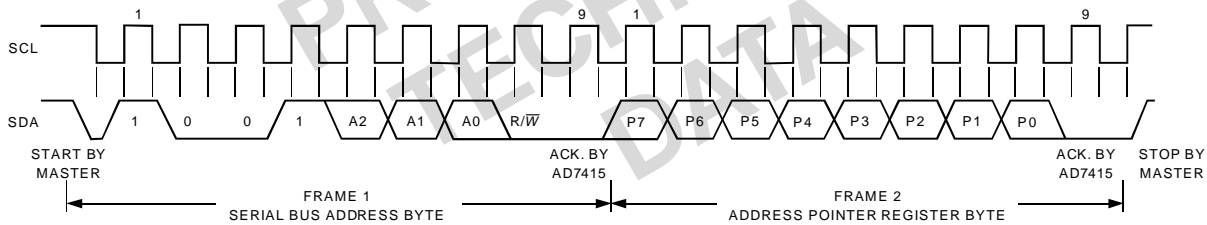


Figure 5. Writing to the Address Pointer Register to select a register for a subsequent Read operation

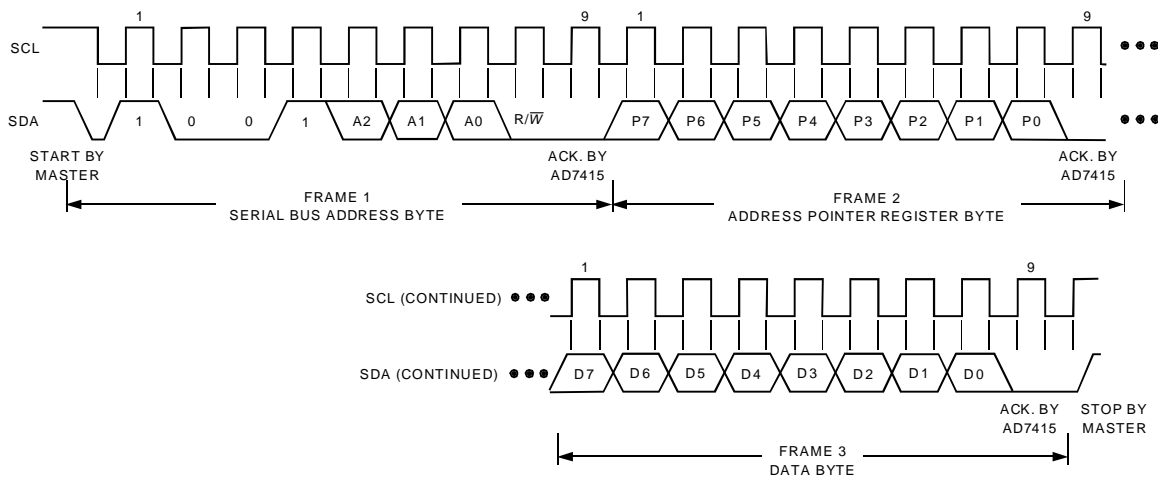


Figure 6. Writing to the Address Pointer Register followed by a single byte of data to the Configuration Register

completed conversion. The next conversion will typically occur 400 μ s after the new conversion has begun.

If a read is performed between conversions, a conversion is initiated right after the read operation. After this conversion, the part returns to performing a conversion every 400 μ s.

Mode 2

The only other mode the AD7415 operates in is the full power-down mode. This mode is usually used when temperature measurements are required at a very slow rate. The power consumption of the part can be greatly reduced in this mode by writing to the part to go to a full power-down. Full power-down is initiated right after D7 of the Configuration Register set to a 1.

When a temperature measurement is required, a write operation can be performed to power-up the part. The part then performs a conversion and is returned to full power-down. The temperature value can be read in the full power-down mode as the serial interface is still powered up.

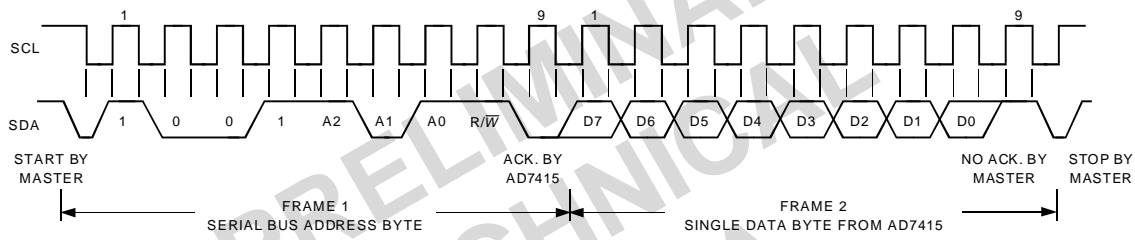


Figure 7. Reading a single byte of data from the Configuration register

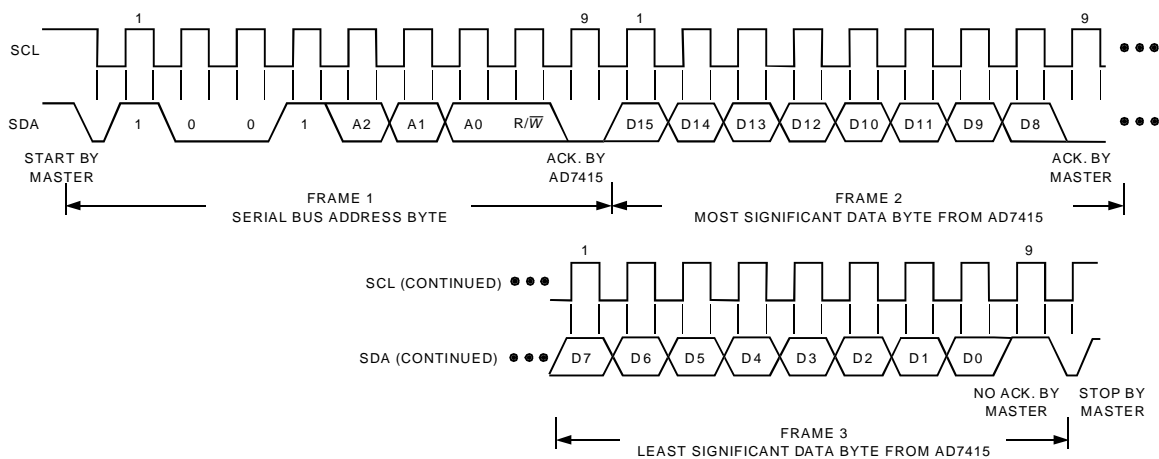
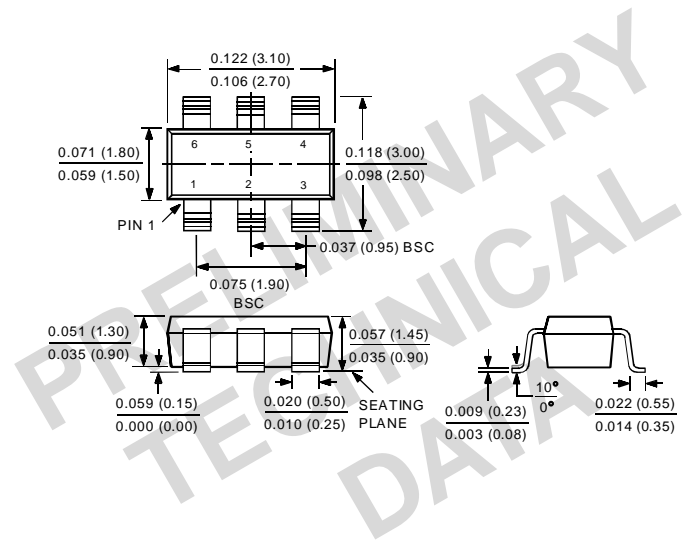


Figure 8. Reading two bytes of data from the Temperature Value Register

OUTLINE DIMENSIONS
 Dimensions shown in inches and (mm).

6-LEAD PLASTIC SURFACE MOUNT SOT-23

(RT-6)



ADDENDUM

This AD7415 Rev PrB preliminary datasheet is specific to Rev A sample silicon. The Rev B sample silicon will differ from Rev A in the following way:-

1. Oneshot Mode. When a 1 is written to the D2 bit of the Configuration register, a single temperature conversion is performed. A temperature conversion will not be initiated after each read or write.
2. Rate of Temperature Conversions. Rev A sample silicon does a temperature conversion every 400 μ s while Rev B sample silicon will have a temperature conversion every 800ms.