SPI/I²C® Compatible, 10-Bit Digital Temperature Sensor and Eight Channel ADC

Preliminary Technical Data — ADT7411

FEATURES

10-Bit Temperature to Digital Converter
10-Bit Eight Channel ADC :
- **DC Input Bandwidth**
- **Input Range: 0 V to 2.25 V and 0 V to V_{DD}**

Temperature range: -40°C to +125°C
Temperature Sensor Accuracy of ±0.5°C
Supply Range : + 2.7 V to + 5.5 V

Power-Down Current 1µA
Internal 2.25 V_{Ref} Option
Double-Buffered Input Logic

I²C®, SPI™, QSPI™, MICROWIRE™ and DSP-Compatible 4-wire Serial Interface
16-Lead QSOP Package

APPLICATIONS

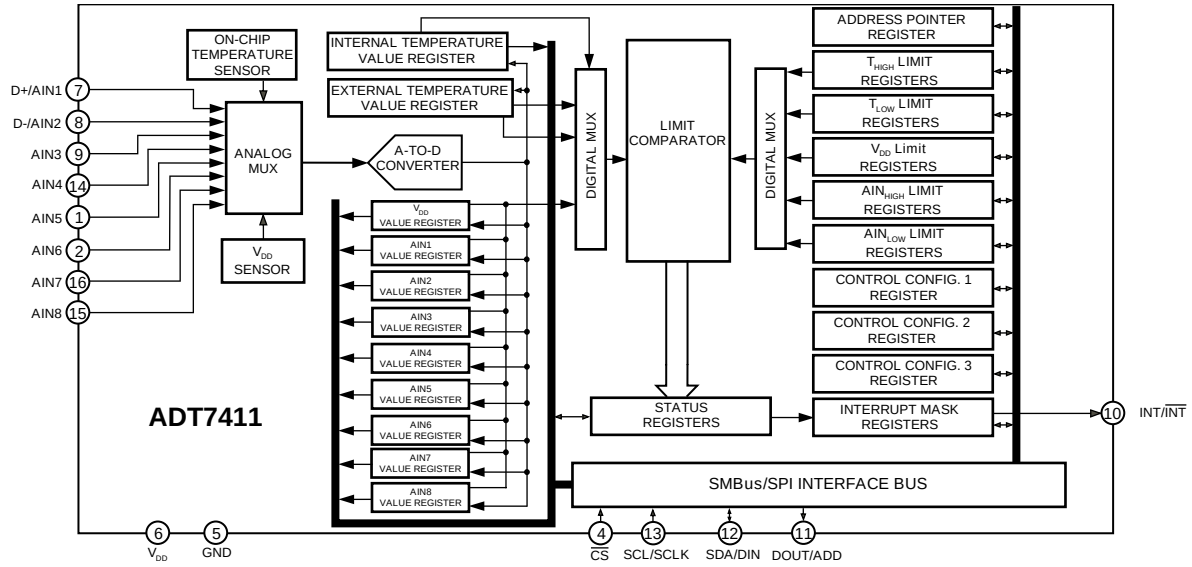
Portable Battery Powered Instruments
Personal Computers
Smart Battery Chargers
Telecommunications Systems
Electronic Test Equipment
Domestic Appliances
Process Control

GENERAL DESCRIPTION

The ADT7411 combines a 10-Bit Temperature-to-Digital Converter and a 10-Bit Eight Channel ADC, in a 16-Lead QSOP package. This includes a bandgap temperature sensor and a 10-bit ADC to monitor and digitize the temperature reading to a resolution of 0.25 °C. The ADT7411 operates from a single +2.7 V to + 5.5 V supply. The input voltage range on the ADC channels has a range of 0V to 2.25V and the input bandwidth is DC. The reference for the ADC channels is derived internally. The ADT7411 provides two serial interface options, a four-wire serial interface which is compatible with SPI™, QSPI™, MICROWIRE™ and DSP interface standards; and a two-wire SMBus/I²C interface. It features a standby mode that is controlled via the serial interface.

The ADT7411's wide supply voltage range, low supply current and SPI/I²C-compatible interface, make it ideal for a variety of applications, including personal computers, office equipment and domestic appliances.

FUNCTIONAL BLOCK DIAGRAM



I²C is a registered trademark of Philips Corporation
SPI and QSPI are trademarks of Motorola, INC.
MICROWIRE is a trademark of National Semiconductor Corporation.
The ADT7411 is protected by the following U.S. patent numbers and by other intellectual property rights :
6,169,442 6,097,239 US Patent Pending
5,867,012 5,764174

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One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781/329-4700 World Wide Web Site: http://www.analog.com
Fax: 781/326-8703

ADT7411

ADT7411-SPECIFICATIONS[1]

(V_{DD}=2.7 V to 5.5 V, GND=0 V, unless otherwise noted)

Parameter[2]	Min	Typ	Max	Units	Conditions/Comments
ADC DC ACCURACY					Max V_{DD} = 5 V
Resolution			10	Bits	
Integral Nonlinearity			±2	LSB	
Differential Nonlinearity			±0.9	LSB	
Offset Error			±2	% of FSR	
Offset Error Match			±0.5	LSB	
Gain Error			±2	% of FSR	
Gain Error Match			±0.5	LSB	
ADC Bandwidth			DC	Hz	
ANALOG INPUTS					
Input Voltage Range	0		2.25	V	AIN1 to AIN8. C4 = 0 in Control Config. 3.
	0		V_{DD}	V	AIN1 to AIN8. C4 = 1 in Control Config. 3.
AIN Conversion Time		712		µs	Averaging (16 samples) on.
		44.5		µs	Averaging off.
DC Leakage Current			±1	µA	
Input Capacitance		tbd	tbd	pF	
Input Resistance		tbd		Ω	
THERMAL CHARACTERISTICS					Internal Reference used. Averaging on.
INTERNAL TEMPERATURE SENSOR					
Accuracy @ V_{DD}=3.3V ±10%			±0.5	°C	T_A = 40°C
		±0.5	±2	°C	T_A = 0°C to +85°C
		±2	±3	°C	T_A = -40°C to +125°C
Accuracy @ V_{DD}=5V ±5%			±1	°C	T_A = 40°C
		±2	±3	°C	T_A = 0°C to +85°C
		±3	±4	°C	T_A = -40°C to +125°C
Resolution			10	Bits	Equivalent to 0.25°C
Long Term Drift		0.5		°C/1000hrs	
Conversion Time		25.92		ms	Averaging (16 samples) on.
		1.62		ms	Averaging off.
EXTERNAL TEMPERATURE SENSOR					External Transistor = 2N3906.
Accuracy @ V_{DD}=3.3V ±10%			±1	°C	T_A = 40°C
			±2	°C	T_A = 0°C to +85°C.
			±3	°C	T_A = -40°C to +125°C
Accuracy @ V_{DD}=5V ±5%			±1.5	°C	T_A = 40°C
		±2	±3	°C	T_A = 0°C to +85°C
		±3	±4	°C	T_A = -40°C to +125°C
Resolution			10	Bits	Equivalent to 0.25°C
Conversion Time		16.8		ms	Averaging (16 samples) on.
		1.05		ms	Averaging off.
Output Source Current		180		µA	High Level
		11		µA	Low Level
ROUND ROBIN UPDATE RATE[3]					Time to complete one measurement cycle.
Averaging On		32.33		ms	Pins 7 and 8 configured for AIN1 and AIN2
Averaging Off		2.02		ms	Pins 7 and 8 configured for AIN1 and AIN2
Averaging On		47.7		ms	Pins 7 and 8 configured for D+ and D-
Averaging Off		2.98		ms	Pins 7 and 8 configured for D+ and D-
ON-CHIP REFERENCE[4]					
Reference Voltage		2.25		V	
Temperature Coefficient		80		ppm/°C	
DIGITAL INPUTS[4]					
Input Current			±1	µA	V_{IN} = 0V to V_{DD}

Parameter[2]	Min	Typ	Max	Units	Conditions/Comments
V_{IL}, Input Low Voltage			0.8	V	
V_{IH}, Input High Voltage	1.89			V	
Pin Capacitance		3	10	pF	All Digital Inputs
SCL, SDA Glitch Rejection			50	ns	Input Filtering Suppresses Noise Spikes of Less than 50 ns
DIGITAL OUTPUT					
Output High Voltage, V_{OH}	2.4			V	I_{SOURCE} = I_{SINK} = 200 µA
Output Low Voltage, V_{OL}			0.4	V	I_{OL} = 3 mA
Output High Current, I_{OH}			1	mA	V_{OH} = 5 V
Output Capacitance, C_{OUT}			50	pF	
INT/$\overline{INT}$ Output Saturation Voltage			0.8	V	I_{OUT} = 4 mA
I^2C TIMING CHARACTERISTICS[5,6]					
Serial Clock Period, t_1	2.5			µs	Fast-Mode I^2C. See Figure 1
Data In Setup Time to SCL High, t_2					
Data Out Stable after SCL Low, t_3	0			ns	See Figure 1
SDA Low Setup Time to SCL Low (Start Condition), t_4	50			ns	See Figure 1
SDA High Hold Time after SCL High (Stop Condition), t_5	50			ns	See Figure 1
SDA and SCL Fall Time, t_6			90	ns	See Figure 1
SPI TIMING CHARACTERISTICS[7,8]					
$\overline{CS}$ to SCLK Setup Time, t_1	0			ns	See Figure 2
SCLK High Pulsewidth, t_2	50			ns	See Figure 2
SCLK Low Pulse, t_3	50			ns	See Figure 2
Data Access Time after SCLK Falling edge, t_4[9]			35	ns	See Figure 2
Data Setup Time Prior to SCLK Rising Edge, t_5	20			ns	See Figure 2
Data Hold Time after SCLK Rising Edge, t_6	0			ns	See Figure 2
$\overline{CS}$ to SCLK Hold Time, t_7	0			ns	See Figure 2
$\overline{CS}$ to DOUT High Impedance, t_8			40	ns	See Figure 2
POWER REQUIREMENTS					
V_{DD}	2.7		5.5	V	
V_{DD} Settling Time			50	ms	V_{DD} settles to within 10% of it's final voltage level
I_{DD} (Normal Mode)[10]			2	mA	V_{DD} = +3.3 V, V_{IH} = V_{DD} and V_{IL} = GND
			2.2	mA	V_{DD} = +5 V, V_{IH} = V_{DD} and V_{IL} = GND
I_{DD} (Power Down Mode)		TBD	3	µA	V_{DD} = +3.3 V, V_{IH}=V_{DD} and V_{IL}=GND
		TBD	10	µA	V_{DD} = +5 V, V_{IH}=V_{DD} and V_{IL}=GND
Power Dissipation		tbd	6.6	µW	V_{DD} = +3.3 V. Using Normal Mode
		tbd	10	µW	V_{DD} = +3.3 V. Using Shutdown Mode

Notes:
[1] Temperature ranges are as follows: A Version: -40°C to +125°C.
[2] See Terminology.
[3] Round Robin is the continuous sequential measurement of the following channels : V_{DD}, Internal Temperature, External Temperature/ (AIN1, AIN2), AIN3, AIN4, AIN5, AIN6, AIN7 and AIN8.
[4] Guaranteed by Design and Characterization, not production tested
[5] The SDA & SCL timing is measured with the input filters turned on so as to meet the Fast-Mode I^2C specification. Switching off the input filters improves the transfer rate but has a negative affect on the EMC behaviour of the part.
[6] Guaranteed by design. Not tested in production.
[7] Guaranteed by design and characterization, not production tested.
[8] All input signals are specified with tr = tf = 5 ns (10% to 90% of V_{DD}) and timed from a voltage level of 1.6 V.
[9] Measured with the load circuit of Figure 3.
[10] I_{DD} spec. is valid for fullscale analog input voltages. Interface inactive. ADC active. Load currents excluded.
Specifications subject to change without notice.

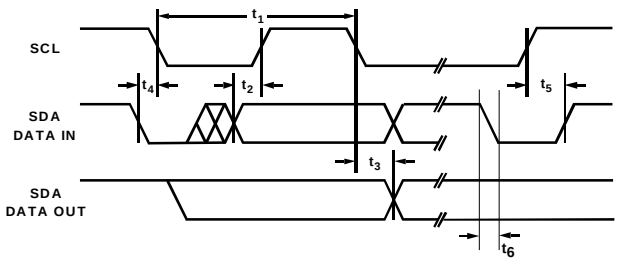


Figure 1. Diagram for I²C Bus Timing

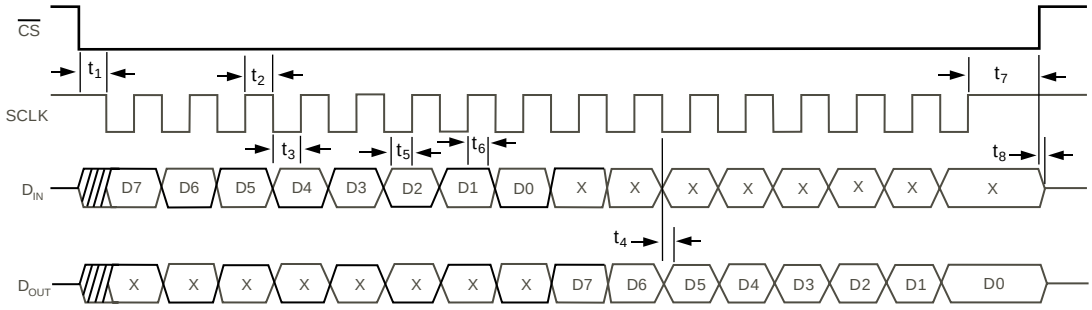


Figure 2. Diagram for SPI Bus Timing

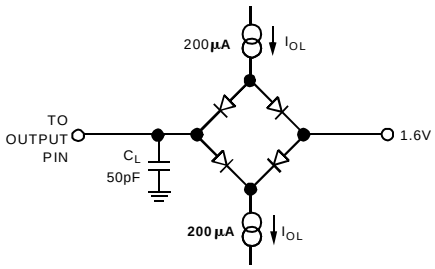


Figure 3. Load Circuit for Access Time and Bus Relinquish Time

ABSOLUTE MAXIMUM RATINGS*

V_{DD} to GND	–0.3 V to +7 V
Analog Input Voltage to GND	–0.3 V to V_{DD} + 0.3 V
Digital Input Voltage to GND	–0.3 V to V_{DD} + 0.3 V
Operating Temperature Range	–40°C to +125°C
Storage Temperature Range	–65°C to +150°C
Junction Temperature	+150°C
16-Lead QSOP Package	
Power Dissipation[2]	(T_j max - T_A) / θ_{JA}
Thermal Impedance[3]	
θ_{JA} Junction-to-Ambient	105.44 °C/W
θ_{JC} Junction-to-Case	38.8 °C/W
IR Reflow Soldering	
Peak Temperature	+220°C (-0/+5°C)
Time at Peak Temperature	10 to 20 secs
Ramp-up Rate	2-3°C/sec
Ramp-down Rate	-6°C/sec

Notes:

[1]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.

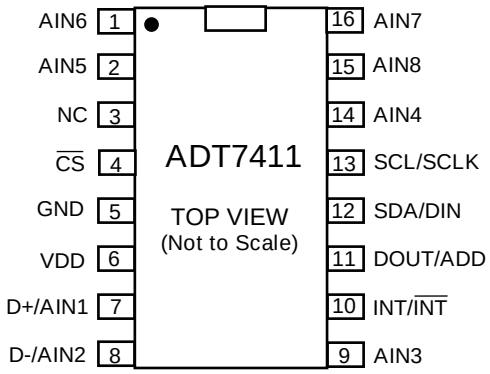
[2]Values relate to package being used on a 4-layer board.

[3]Junction-to-Case resistance is applicable to components featuring a preferential flow direction, eg. components mounted on a heat sink. Junction-to-Ambient resistance is more useful for air-cooled PCB-mounted components.

Table 1. I^2C Address Selection

ADD Pin	I^2C Address
Low	1001 000
Float	1001 010
High	1001 011

PIN CONFIGURATION
QSOP



ORDERING GUIDE

Model	Temperature Range	Package Description	Package Options
ADT7411ARQ	–40°C to +125°C	16-Lead QSOP	RQ-16

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 ADT7411 feature 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.

ADT7411 PIN FUNCTION DESCRIPTION

Pin	Mnemonic	Description
1	AIN6	Analog input. Single ended analog input channel. Input range is 0 V to 2.25 V or 0 V to V_{DD}.
2	AIN5	Analog input. Single ended analog input channel. Input range is 0 V to 2.25 V or 0 V to V_{DD}.
3	NC	No connection to this pin.
4	$\overline{CS}$	SPI - Active low control Input. This is the frame synchronization signal for the input data. When $\overline{CS}$ goes low, it enables the input register and data is transferred in on the rising edges and out on the falling edges of the subsequent serial clocks. It is recommended that this pin be tied high to V_{DD} when operating the serial interface in I^2C mode.
5	GND	Ground Reference Point for All Circuitry on the part. Analog and Digital Ground.
6	V_{DD}	Positive Supply Voltage, +2.7 V to +5.5 V. The supply should be decoupled to ground.
7	D+/AIN1	D+. Positive connection to external temperature sensor. AIN1. Analog Input. Single ended analog input channel. Input range is 0 V to 2.25 V or 0 V to 5 V.
8	D-/AIN2	D-. Negative connection to external temperature sensor. AIN2. Analog Input. Single ended analog input channel. Input range is 0 V to 2.25 V or 0 V to 5 V.
9	AIN3	Analog input. Single ended analog input channel. Input range is 0 V to 2.25 V or 0 V to V_{DD}.
10	INT/$\overline{INT}$	Over Limit Interrupt. The output polarity of this pin can be set to give an active low or active high interrupt when temperature, V_{DD} or AIN limits are exceeded. Default is active low.
11	DOUT/ADD	SPI Serial Data Output. Logic Output. Data is clocked out of any register at this pin. Data is clocked out on the falling edge of SCLK. Open Drain output - needs a pullup resistor. ADD - I^2C serial bus address selection pin. Logic input. A low on this pin gives the address 1001 000, leaving it floating gives the address 1001 010 and setting it high gives the address 1001 011. The I^2C address set up by the ADD pin is not latched by the device until after this address has been sent twice. On the 8^{th} SCL cycle of the second valid communication, the serial bus address is latched in. Any subsequent changes on this pin will have no affect on the I^2C serial bus address.
12	SDA/DIN	SDA. I^2C Serial Data Input. I^2C serial data to be loaded into the parts registers is provided on this input. DIN. SPI Serial Data Input. Serial data to be loaded into the parts registers is provided on this input. Data is clocked into a register on the rising edge of SCLK.
13	SCL/SCLK	Serial Clock Input. This is the clock input for the serial port. The serial clock is used to clock data out of any register of the ADT7411 and also to clock data into any register that can be written to.
14	AIN4	Analog input. Single ended analog input channel. Input range is 0 V to 2.25 V or 0 V to V_{DD}.
15	AIN8	Analog input. Single ended analog input channel. Input range is 0 V to 2.25 V or 0 V to V_{DD}.
16	AIN7	Analog input. Single ended analog input channel. Input range is 0 V to 2.25 V or 0 V to V_{DD}.

TERMINOLOGY

RELATIVE ACCURACY

Relative accuracy or integral nonlinearity (INL) is a measure of the maximum deviation, in LSBs, from a straight line passing through the endpoints of the ADC transfer function. Typical INL versus Code plot can be seen in TPC 4.

DIFFERENTIAL NONLINEARITY

Differential Nonlinearity (DNL) is the difference between the measured change and the ideal 1 LSB change between any two adjacent codes. A specified differential nonlinearity of ±1 LSB maximum ensures monotonicity. The ADC is guaranteed monotonic by design. Typical DNL versus Code plot can be seen in TPC 3.

OFFSET ERROR

This is a measure of the offset error of the ADC. It can be negative or positive. It is expressed in mV.

OFFSET ERROR MATCH

This is the difference in Offset Error between any two channels

GAIN ERROR

This is a measure of the span error of the ADC. It is the deviation in slope of the actual ADC transfer characteristic from the ideal expressed as a percentage of the full-scale range.

GAIN ERROR MATCH

This is the difference in Gain error between any two channels.

OFFSET ERROR DRIFT

This is a measure of the change in offset error with changes in temperature. It is expressed in (ppm of full-scale range)/°C.

GAIN ERROR DRIFT

This is a measure of the change in gain error with changes in temperature. It is expressed in (ppm of full-scale range)/°C.

LONG TERM TEMPERATURE DRIFT

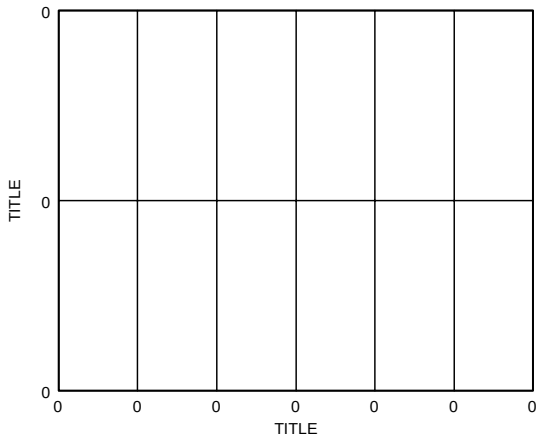
This is a measure of the change in temperature error with the passage of time. It is expressed in °C/1000hrs. The concept of long-term stability has been used for many years to describe by what amount an IC's parameter would shift during its lifetime. This is a concept that has been typically applied to both voltage references and monolithic temperature sensors. Unfortunately, integrated circuits cannot be evaluated at room temperature (25°C) for 10 years or so to determine this shift. As a result, manufacturers very typically perform accelerated life-time testing of integrated circuits by operating ICs at elevated temperatures (between 125°C and 150°C) over a shorter period of time (typically, between 500 and 1000 hours). As a result of this operation, the lifetime of an integrated circuit is significantly accelerated due to the increase in rates of reaction within the semiconductor material. As a result of this operation, the lifetime of an integrated circuit is significantly accelerated due to the increase in rates of reaction within the semiconductor material.

DC POWER-SUPPLY REJECTION RATIO (PSRR)

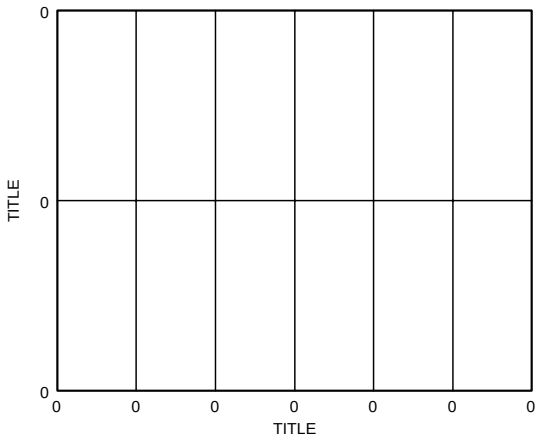
This is the dc change in the output level of one DAC in response to a change in the output of another DAC. It is measured with a full-scale output change on one DAC while monitoring another DAC. It is expressed in µV.

ROUND ROBIN

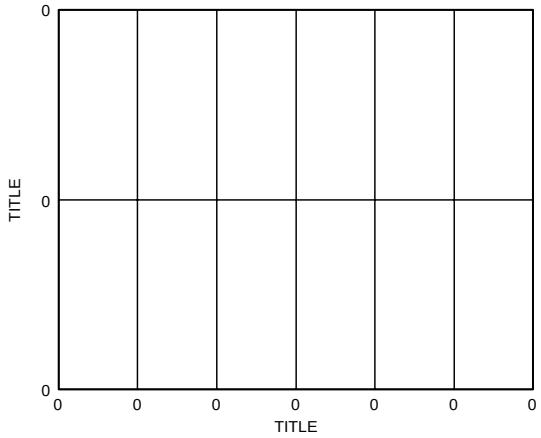
This term is used to describe the ADT7411 cycling through the available measurement channels in sequence, taking a measurement on each channel.



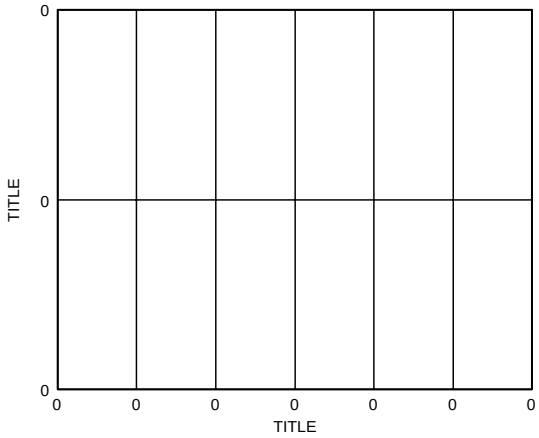
TPC 1. Supply Current vs. Supply Voltage



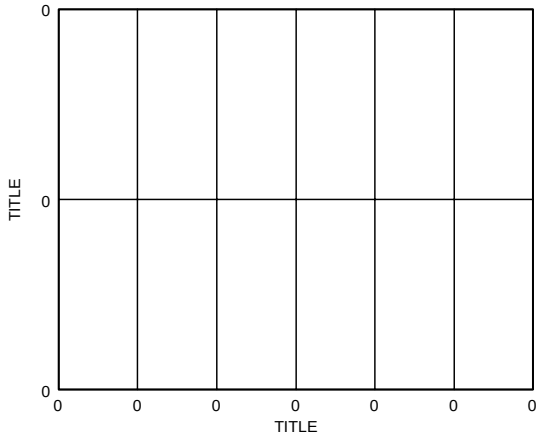
TPC 2. Power-Down Current vs. Supply Voltage



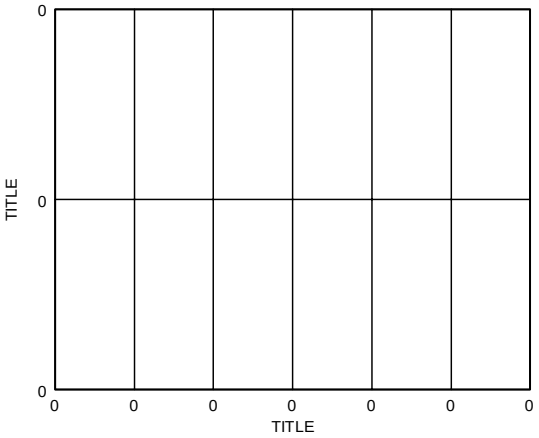
TPC 3. ADC DNL



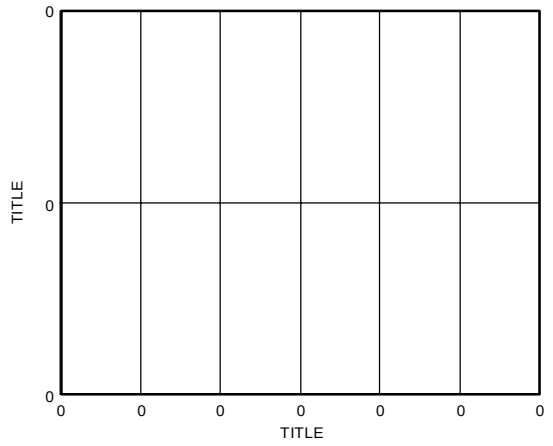
TPC 4. ADC INL



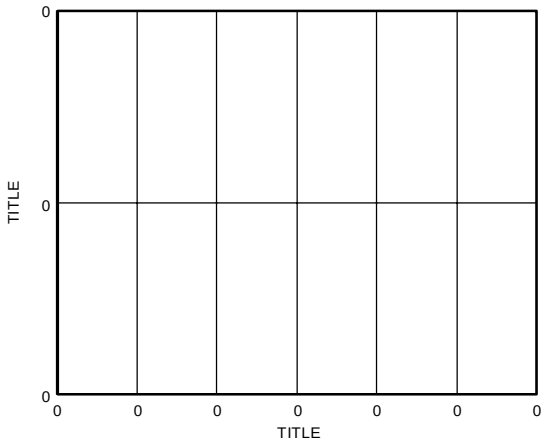
TPC 5. PSRR vs Supply Ripple Frequency



TPC 6. Temperature Error @ 3.3 V and 5 V



TPC 7. ADC Offset Error and Gain Error vs Temperature



TPC 8. ADC Offset Error and Gain Error vs V_{DD}

ADT7411 OPERATION

Directly after the power-up calibration routine the ADT7411 goes into idle mode. In this mode the device is not performing any measurements and is fully powered up.

To begin monitoring, write to Control Configuration 1 (address = 18h) register and set bit C0 = 1. The ADT7411 goes into it's power-up default measurement mode, which is Round Robin. The device proceeds to take measurements on the V_{DD} channel, internal temperature sensor channel, external temperature sensor channel or AIN1 and AIN2, AIN3, AIN4, AIN5, AIN6, AIN7 and finally AIN8 . Once it finishes taking measurements on the AIN8 channel the device immediately loops back to start taking measurements on the V_{DD} channel and repeats the same cycle as before. This loop continues until the monitoring is stopped by resetting bit C0 of Control Configuration 1 register to 0. It is also possible to continue monitoring as well as switching to Single channel mode by writing to Control Configuration 2 register (address = 19h) and setting bit C4 = 1. Further explanation of the Single channel and Round Robin measurement modes are given in later sections. All measurement channels have averaging enabled on them on power-up. Averaging forces the device to take an average of 16 readings before giving a final measured result. To disable averaging and consequently decrease the conversion time by a factor of 16, set C5 = 1 in Control Configuration 2 register.

There are eight single ended analog input channels on the ADT7411, AIN1 to AIN8. AIN1 and AIN2 are multiplexed with the external temperature sensors D+ and D- terminals. Bits C1 and C2 of Control Configuration 1 register (address = 18h) are used to select between AIN1/2 and external temperature sensor. The input range on the analog input channels is dependent on whether the ADC reference used is the internal V_{REF} or V_{DD}. To meet linearity specifications, it is recommended that the maximum V_{DD} value is 5 V. Bit C4 of Control Configuration 3 register is used to select between the internal reference or V_{DD} as the analog inputs ADC reference.

The dual serial interface defaults to the I^2C protocol on power-up. To select and lock in the SPI protocol please follow the selection process as described in the Serial Interface Selection section. The I^2C protocol cannot be locked in, while the SPI protocol on selection is automatically locked in. The interface can only be switched back to be I^2C when the device is powered off and on. When using I^2C the $\overline{CS}$ pin should be tied to either V_{DD} or GND.

There are a number of different operating modes on the ADT7411 devices and all of them can be controlled by the configuration registers. These features consist of the INT/$\overline{INT}$ pin, enabling and disabling interrupts, polarity of the INT/$\overline{INT}$ pin, enabling and disabling the averaging on the measurement channels, SMBus timeout and software reset.

POWER-UP CALIBRATION

It is recommended that no communication to the part is initiated until approximately 5ms after V_{DD} has settled to within 10% of it's final value. It is generally accepted that most systems take a maximum of 50ms to power-up. Power-up time is directly related to the amount of decoupling on the voltage supply line.

During this 5ms after V_{DD} has settled, the part is performing a calibration routine and any communication to the device will interrupt this routine and could cause erroneous temperature measurements. If it not possible to have V_{DD} at it's nominal value by the time 50ms has elapsed or that communication to the device has started prior to V_{DD} settling then it is recommended that a measurement be taken on the V_{DD} channel before a temperature measurement is taken. The V_{DD} measurement is used to calibrate out any temperature measurement error due to different supply voltage values.

FUNCTIONAL DESCRIPTION - ANALOG INPUTS

SINGLE-ENDED INPUTS

The ADT7411 offers eight single-ended analog input channels. The analog input range is between 0 V to 2.25 V or 0 V to V_{DD}. To maintain the linearity specification it is recommendated that the maximum V_{DD} value be set at 5 V. Selection between the two input ranges is done by Bit C4 of Control Congifuration 3 Register (Address = 1Ah). Setting this bit to 0 sets up the analog input ADC reference to be sourced from the internal voltage reference of 2.25 V. Setting the bit to 1 sets up the ADC reference to be sourced from V_{DD}.

The ADC resolution is 10 bits and is mostly suitable for DC input signals or very slow varying AC signals. Bits C1:2 of Control Configuration 1 register (Address = 18h) are used to set up pins 7 and 8 as AIN1 and AIN2. Figure 4 shows the overall view of the eight channel analog input path.

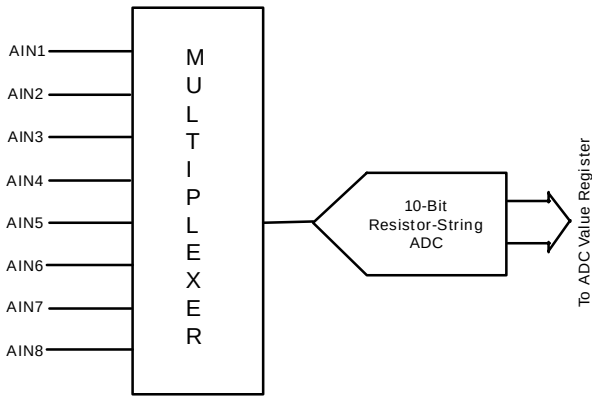


Figure 4. Octal Analog Input Path

CONVERTER OPERATION

The analog input channels use a successive approximation ADC based around a resistor-string DAC. Figures 6 and 7 show simplified schematics of the ADC. Figure 6 shows the ADC during acquisition phase. SW2 is closed and SW1 is in position A. The comparator is held in a balanced condition and the sampling capacitor acquires the signal on AIN.

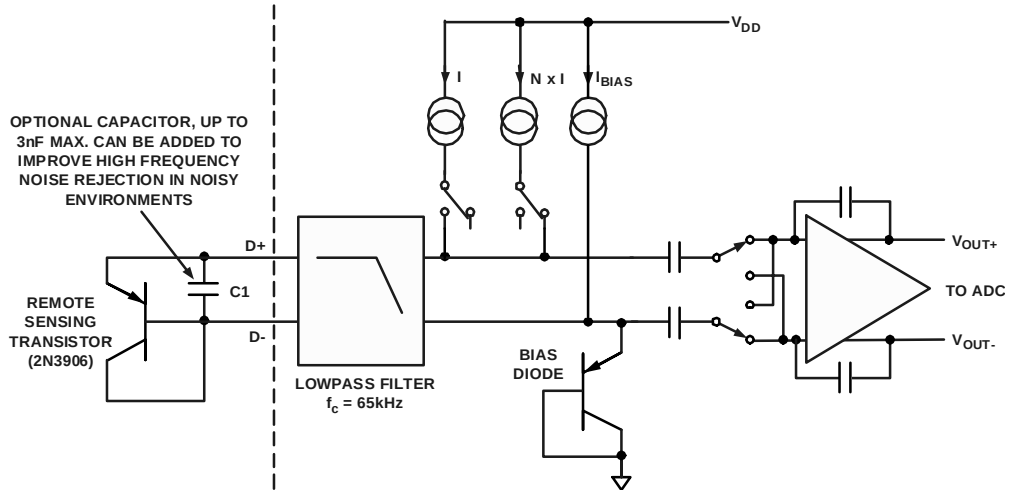


Figure 5. Signal Conditioning for External Diode Temperature Sensor

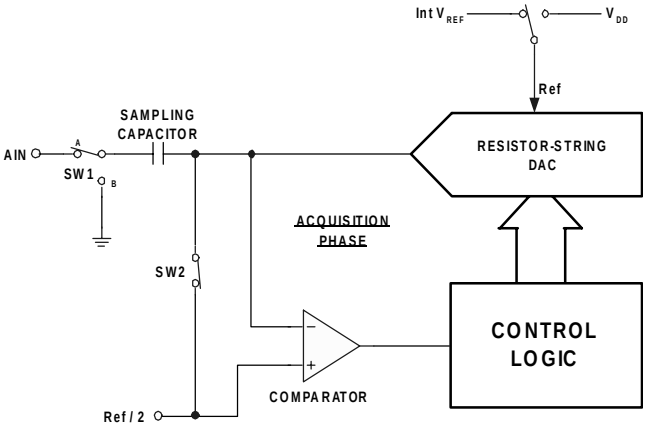


Figure 6. ADC Acquisition Phase

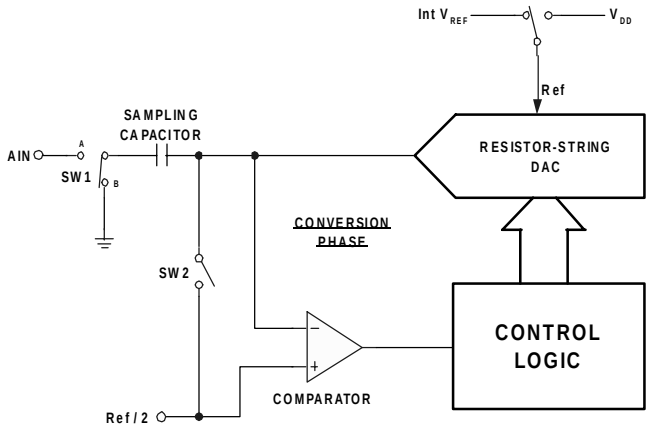


Figure 7. ADC Conversion Phase

When the ADC eventually goes into conversion phase, see Figure 7, SW2 opens and SW1 moves to position B causing the comparator to become unbalanced. The control logic and the DAC are used to add and subtract fixed amounts of charge from the sampling capacitor to bring the comparator back into a balanced condition. When the comparator is rebalanced the conversion is complete. The control logic generates the ADC output code. Figure 8 shows the ADC transfer function for single-ended analog inputs.

ADC TRANSFER FUNCTION

The output coding of the ADT7411 analog inputs is straight binary. The designed code transitions occur midway between successive integer LSB values (i.e. 1/2LSB, 3/2LSB, etc.). The LSB is V_{DD}/1024 or Int V_{REF}/1024, Int V_{REF} = 2.25 V. The ideal transfer characteristic is shown in figure 8 below.

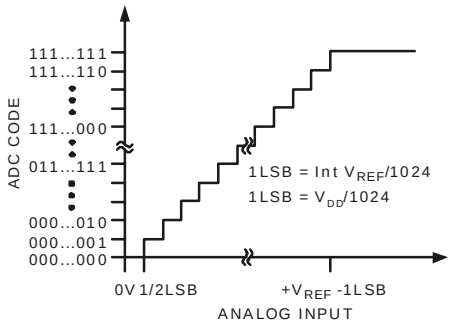


Figure 8. Transfer Function

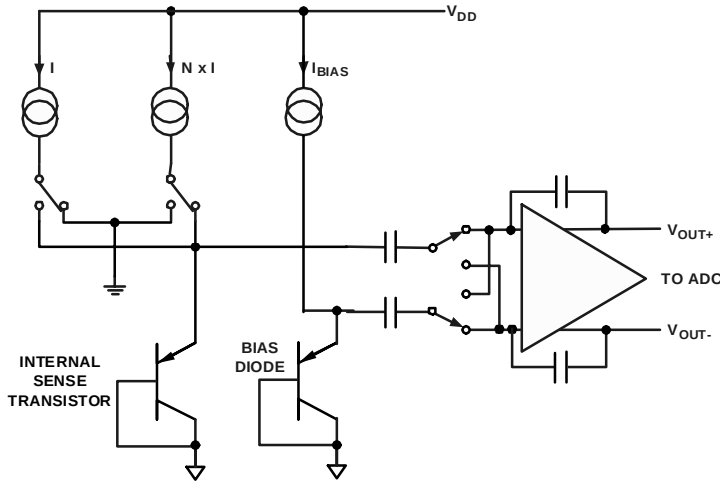


Figure 9. Top Level Structure of Internal Temperature Sensor

To work out the voltage on any analog input channel, the following method can be used:

1 LSB = Reference (v) / 1024

Convert value read back from AIN Value register into decimal.

AIN Voltage = AIN Value (d) x LSB size

d = decimal

Example:

Internal Reference used. Therefore Vref = 2.25 V.

AIN Value = 512d

1 LSB size = 2.25 V / 1024 = 2.197×10^{-3}

AIN Voltage = 512 x 2.197×10^{-3}

= 1.125 V

ANALOG INPUT ESD PROTECTION

Figure 10 shows the input structure on any of the analog input pins that provides ESD protection. The diode provides the main ESD protection for the analog inputs. Care must be taken that the analog input signal never drops below the GND rail by more than 200mV. If this happens then the diode will become forward biased and start conducting current into the substrate. The 4pF capacitor is the typical pin capacitance and the resistor is a lumped component made up of the on-resistance of the multiplexer switch.

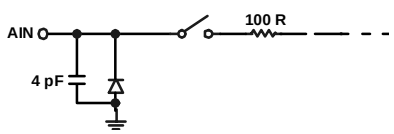


Figure 10. Equivalent Analog Input ESD Circuit

AIN INTERRUPTS

The measured results from the AIN inputs are compared with the AIN V_{HIGH} (greater than comparsion) and V_{LOW} (less than and equal to comparsion) limits. An interrupt occurs if the AIN inputs exceed or equal the limit registers. These voltage limits are stored in on-chip registers. Please note that the limit registers are 8 bits long while the AIN conversion result is 10 bits long. If the voltage limits are not masked out then any out of limit comparisons generate flags that are stored in Interrupt Status 1 Register (address = 00h) and one or more out-of limit results will cause the INT/$\overline{\text{INT}}$ output to pull either high or low depending on the output polarity setting. It is good design practice to mask out interrupts for channels that are of no concern to the application.

Figure 11 showes the interrupt structure for the ADT7411. It gives a block diagram representation of how the various measurement channels affect the INT/$\overline{\text{INT}}$ pin.

FUNCTIONAL DESCRIPTION - MEASUREMENT

TEMPERATURE SENSOR

The ADT7411 contains an A-D converter with special input signal conditioning to enable operation with external and on-chip diode temperature sensors. When the ADT7411 is operating in single channel mode, the A to D converter continually processes the measurement taken on one channel only. This channel is preselected by bits C0:C3 in Control Configuration 2 Register (address 19h). When in Round Robin mode the analog input multiplexer sequently selects the V_{DD} input channel, on-chip temperature sensor to measure its internal temperature, the external temperature sensor or an AIN channel and then the rest of the AIN channels. These signals are digitized by the ADC and the results stored in the various Value Registers.

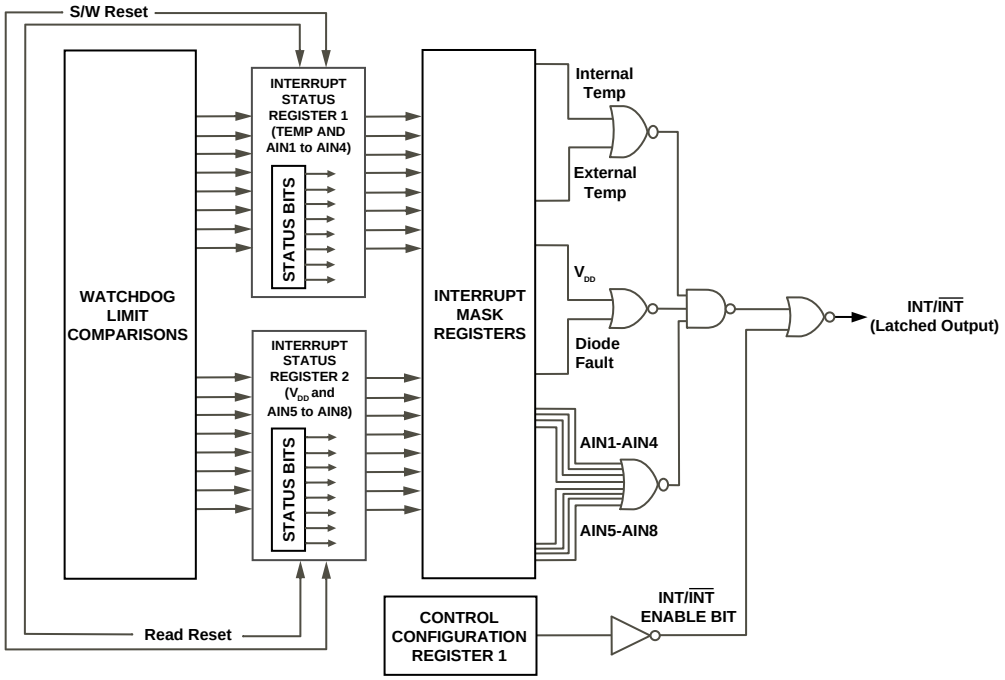


Figure 11. ADT7411 Interrupt Structure

The measured results from the temperature sensors are compared with the Internal and External, T_{HIGH}, T_{LOW} limits. These temperature limits are stored in on-chip registers. If the temperature limits are not masked out then any out of limit comparisons generate flags that are stored in Interrupt Status 1 Register. One or more out-of limit results will cause the INT/$\overline{INT}$ output to pull either high or low depending on the output polarity setting.

Theoretically, the temperature sensor and ADC can measure temperatures from -128°C to +127°C with a resolution of 0.25°C. However, temperatures outside T_A are outside the guaranteed operating temperature range of the device. Temperature measurement from -128°C to +127°C is possible using an external sensor.

Temperature measurement is initiated by three methods. The first method is applicable when the part is in single channel measurement mode. The temperature is measured 16 times and internally averaged to reduce noise. The total time to measure a temperature channel is typically 25.92ms (1.62ms x 16) for the internal temperature sensor and 16.8ms (1.05ms x 16) for the external temperature sensor. The new temperature value is loaded into the Temperature Value Register and ready for reading by the I^2C or SPI interface. The user has the option of disabling the averaging by setting a bit (Bit 5) in the Control Configuration Register 2 (address 19h). The ADT7411 defaults on power-up with the averaging enabled.

The second method is applicable when the part is in Round Robin measurement mode. The part measures both the internal and external temperature sensors as it cycles through all possible measurement channels. The two temperature channels are measured each time the part runs a round robin sequence. In round robin mode the part is continuously measuring all channels.

Temperature measurement is also initiated after every read or write to the part when the part is in either single channel measurement mode or Round Robin measurement mode. Once serial communication has started, any conversion in progress is stopped and the ADC reset. Conversion will start again immediately after the serial communication has finished. The temperature measurement proceeds normally as described above.

V_{DD} MONITORING

The ADT7411 also has the capability of monitoring it's own power supply. The part measures the voltage on it's V_{DD} pin to a resolution of 10 bits. The resultant value is stored in two 8-bit registers, the two LSBs stored in register address 03h and the eight MSBs are stored in register address 06h. This allows the user to have the option of just doing a one byte read if 10-bit resolution is not important. The measured result is compared with V_{HIGH} and V_{LOW} limits. If the V_{DD} interrupt is not masked out then any out-of-limit comparison generates a flag in Interrupt Status 2 Register and one or more out-of-limit results will cause the INT/$\overline{INT}$ output to pull either high or low depending on the output polarity setting.

Measuring the voltage on the V_{DD} pin is regarded as monitoring a channel along with the Internal, External and AIN channels. You can select the V_{DD} channel for single channel measurement by setting Bit C4 = 1 and setting Bit C0 to Bit C 2 to all 0's in Control Configuration 2 register.

When measuring the V_{DD} value the reference for the ADC is sourced from the Internal Reference. Table 2 shows the data format. As the max V_{CC} voltage measurable is 7 V, internal scaling is performed on the V_{CC} voltage to match the 2.25V internal reference value. Below is an example of how the transfer function works.

V_{DD} = 5 V

ADC Reference = 2.25 V

1 LSB = ADC Reference / 2^10 = 2.25 / 1024 = 2.197mV

Scale Factor = Fullscale V_{CC} / ADC Reference = 7 / 2.25 = 3.11

Conversion Result = V_{DD} / ((7/Scale Factor) x LSB size)

= 5 / (3.11 x 2.197mV)

= 2DBh

TABLE 2. V_{DD} Data Format, V_{REF} = 2.25 V

V_{DD} Value	Digital Output	
	Binary	Hex
2.5 V	01 0110 1110	16E
2.7 V	01 1000 1011	18B
3 V	01 1011 0111	1B7
3.5 V	10 0000 0000	200
4 V	10 0100 1001	249
4.5 V	10 1001 0010	292
5 V	10 1101 1011	2DB
5.5 V	11 0010 0100	324
6 V	11 0110 1101	36D
6.5 V	11 1011 0110	3B6
7 V	11 1111 1111	3FF

ON-CHIP REFERENCE

The ADT7411 has an on-chip 1.125 V band-gap refernece which is gained up by a switched capacitor amplifier to give an output of 2.25 V. The amplifier is powered up for the duration of the device monitoring phase and is powered down once monitoring is disabled. This saves on current consumption. On power-up the default mode is to have the internal reference selected as the reference for the ADC. The internal reference is always used when measuring V_{DD}, the internal and external temperature sensors.

ROUND ROBIN MEASUREMENT

On power-up the ADT7411 goes into Round Robin mode but monitoring is disabled. Setting Bit C0 of Configuration Register 1 to a 1 enables conversions. It sequences through all the available channels taking a measurement from each in the following order of V_{DD} , Internal temperature sensor, External temperature sensor/(AIN1 and AIN2), AIN3, AIN4, AIN5, AIN6, AIN7 and AIN8. Pin 7 and pin 8 can be configured to be either external temperature sensor pins or stand alone analog input pins. Once conversion is completed on the AIN8 channel, the device loops around for another measurement cycle. This method of taking a measurement on all the channels in one cycle is called Round Robin. Setting Bit 4 of Control Configuration 2 (address 19h) disables the Round Robin mode and in turn sets up the single channel mode. The single channel mode is where only one channel, eg. Internal temperature sensor, is measured in each conversion cycle.

The time taken to monitor all channels will normally not be of interest, as the most recently measured value can be read at any time.

For applications where the Round Robin time is important, it can be easily calculated.

As mentioned previously a conversion on the internal temperature channel takes 25.92 ms, on the external temperature channel it takes 16.8ms, on the V_{DD} and AIN channels it takes 712 us. These values are typical times and the channels have averaging on. This means that each channel is measured 16 times and internally averaged to reduce noise.

The total cycle time for V_{DD}, AIN1 to AIN8 and internal temperature is therefore nominally :

712µs + (8 x 712µs) + 25.92ms = 32.33 ms

The total cycle time with averaging off is:

32.33 ms / 16 = 2.02 ms

The total cycle time for V_{DD}, AIN3 to AIN8, internal temperature and external temperature is therefore nominally :

712µs + (6 x 712µs) + 25.92ms + 16.8ms = 47.7 ms

The total cycle time with averaging off is:

47.7 ms / 16 = 2.98 ms

SINGLE CHANNEL MEASUREMENT

Setting C4 of Control Configuration 2 register enables the single channel mode and allows the ADT7411 to focus on one channel only. A channel is selected by writing to Bits C0:C3 in register Control Configuration 2 register. For example, to select the V_{DD} channel for monitoring write to the Control Configuration 2 register and set C4 to 1 (if not done so already), then write all 0's to bits C0 to C3 . All subsequent conversions will be done on the V_{DD} channel only. To change the channel selection to the Internal temperature channel, write to the Control Configuration 2 register and set C0 = 1. When measuring in single channel mode, conversions on the channel selected occur directly after each other. Any communication to the ADT7411 stops the conversions but they are restarted once the read or write operation is completed.

MEASUREMENT METHOD

INTERNAL TEMPERATURE MEASUREMENT

The ADT7411 contains an on-chip bandgap temperature sensor, whose output is digitized by the on-chip ADC. The temperature data is stored in the Internal Tempera-

ture Value Register. As both positive and negative temperatures can be measured, the temperature data is stored in two's complement format, as shown in Table 3. The thermal characteristics of the measurement sensor could change and therefore an offset is added to the measured value to enable the transfer function to match the thermal characteristics. This offset is added before the temperature data is stored. The offset value used is stored in the Internal Temperature Offset Register.

EXTERNAL TEMPERATURE MEASUREMENT

The ADT7411 can measure the temperature of one external diode sensor or diode-connected transistor.

The forward voltage of a diode or diode-connected transistor, operated at a constant current, exhibits a negative temperature coefficient of about -2mV/°C. Unfortunately, the absolute value of V_{be}, varies from device to device, and individual calibration is required to null this out, so the technique is unsuitable for mass-production.

The time taken to measure the external temperature can be reduced by setting C0 of Control Config. 3 register (1Ah). This increases the ADC clock speed from 1.4KHz to 22KHz but the analog filters on the D+ and D- input pins are switched off to accommodate the higher clock speeds. Running at the slower ADC speed, the time taken to measure the external temperature is TBD while on the fast ADC this time is reduced to TBD.

The technique used in the ADT7411 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 carrier

T is absolute temperature in Kelvins

N is ratio of the two currents

Figure 5 shows the input signal conditioning used to measure the output of an external temperature sensor. This figure shows the external sensor as a substrate transistor, provided for temperature monitoring on some microprocessors, but it could equally well be a discrete transistor.

If a discrete transistor is used, the collector will not be grounded, and should be linked to the base. If a PNP transistor is used the base is connected to the D- input and the emitter to the D+ input. If an NPN transistor is used, the emitter is connected to the D- input and the base to the D+ input.

We recommend that a 2N3906 be used as the external transistor.

To prevent ground noise interfering with the measurement, the more negative terminal of the sensor is not referenced to ground, but is biased above ground by an internal diode at the D- input. As the sensor is operating in a noisy environment, C1 is provided as a noise filter. See the section on layout considerations for more information on C1.

To measure ΔV_{be}, the sensor is switched between operating currents of I and N x I. The resulting waveform is passed through a lowpass filter to remove noise, thence to 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 measured by the ADC to give a temperature output in 10-bit two's complement format. To further reduce the effects of noise, digital filtering is performed by averaging the results of 16 measurement cycles.

LAYOUT CONSIDERATIONS

Digital boards can be electrically noisy environments, and care must be taken to protect the analog inputs from noise, particularly when measuring the very small voltages from a remote diode sensor. The following precautions should be taken:

1. Place the ADT7411 as close as possible to the remote sensing diode. Provided that the worst noise sources such as clock generators, data/address buses and CRTs are avoided, this distance can be 4 to 8 inches.
2. Route the D+ and D- tracks close together, in parallel, with grounded guard tracks on each side. Provide a ground plane under the tracks if possible.
3. Use wide tracks to minimize inductance and reduce noise pickup. 10 mil track minimum width and spacing is recommended.

Figure 12. Arrangement of Signal Tracks

4. Try to minimize the number of copper/solder joints, which can cause thermocouple effects. Where copper/solder joints are used, make sure that they are in both the D+ and D- path and at the same temperature.

   Thermocouple effects should not be a major problem as 1°C corresponds to about 240µV, and thermocouple voltages are about 3µV/°C of temperature difference. Unless there are two thermocouples with a big temperature differential between them, thermocouple voltages should be much less than 200mV.
5. Place 0.1µF bypass and 2200pF input filter capacitors close to the ADT7411.
6. If the distance to the remote sensor is more than 8 inches, the use of twisted pair cable is recommended. This will work up to about 6 to 12 feet.
7. For really long distances (up to 100 feet) use shielded twisted pair such as Belden #8451 microphone cable. Connect the twisted pair to D+ and D- and the shield

to GND close to the ADT7411. Leave the remote end of the shield unconnected to avoid ground loops.

Because the measurement technique uses switched current sources, excessive cable and/or filter capacitance can affect the measurement. When using long cables, the filter capacitor may be reduced or removed.

Cable resistance can also introduce errors. 1Ω series resistance introduces about 0.5°C error.

TEMPERATURE VALUE FORMAT

One LSB of the ADC corresponds to 0.25°C. The ADC can theoretically measure a temperature span of 255 °C. The internal temperature sensor is guaranteed to a low value limit of -40 °C. It is possible to measure the full temperature span using the external temperature sensor. The temperature data format is shown in Table 3.

The result of the internal or external temperature measurements is stored as 2's complement format in the temperature value registers, and is compared with limits programmed into the Internal or External High and Low Registers.

TABLE 3. Temperature Data Format (Internal and External Temperature)

Temperature	Digital Output
-40 °C	11 0110 0000
-25 °C	11 1001 1100
-10 °C	11 1101 1000
-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
+105 °C	01 1010 0100
+125 °C	01 1111 0100

Temperature Conversion Formula:

1. Positive Temperature = ADC Code/4
2. Negative Temperature = (ADC Code* - 512)/4

*DB9 is removed from the ADC Code

INTERRUPTS

The measured results from the internal temperature sensor, external temperature sensor, V_{DD} pin and the AIN inputs are compared with their T_{HIGH}/V_{HIGH} (greater than comparison) and T_{LOW}/V_{LOW} (greater than or equal to comparison) limits. An interrupt occurs if the measurement exceeds or equals the limit registers. These limits are stored in on-chip registers. Please note that the limit registers are 8 bits long while the conversion results are 10 bits long. If the limits are not masked out then any out-of-limit comparisons generate flags that are stored in Interrupt Status 1 Register (address = 00h) and Interrupt Status 2 Register (address = 01h). One or more out-of limit results will cause the INT/$\overline{INT}$ output to pull either high or low depending on the output polarity setting. It is good design practice to mask out interrupts for channels that are of no concern to the application.

Figure 11 shows the interrupt structure for the ADT7411. It gives a block diagram representation of how the various measurement channels affect the INT/$\overline{INT}$ pin.

ADT7411 REGISTERS

The ADT7411 contains registers that are used to store the results of external and internal temperature measurements, V_{DD} value measurements, analog input measurements, high and low temperature limits, supply voltage and analog input limits, configure multipurpose pins and generally control the device. A detailed description of these registers is given below.

The register map is divided into registers of 8-bits long. Each register has it's own indvidual address but some consist of data that is linked with other registers. These registers hold the 10-bit conversion results of measurements taken on the Temperature, V_{DD} and AIN channels. For example, the 8 MSBs of the V_{DD} measurement are stored in register address 06h while the 2 LSBs are stored in register address 03h. The link involved between these types of registers is that when the LSB register is read first then the MSB registers associated with that LSB register are locked to prevent any updates. To unlock these MSB registers the user has only to read to any one of them which will have the affect of unlocking all previously locked MSB registers. So for the example given above if register 03h was read first then MSB registers 06h and 07h would be locked to prevent any updates to them. If register 06h was read then this register and register 07h would be subsequently unlocked.

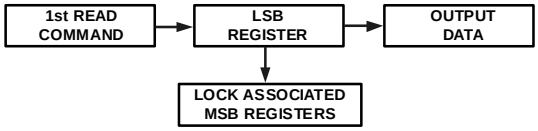


Figure 13. Phase 1 of 10-Bit Read

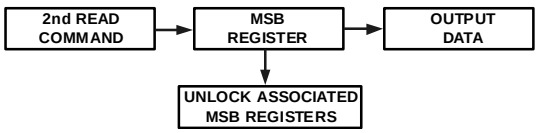


Figure 14. Phase 2 of 10-Bit Read

If an MSB register is read first, it's corresponding LSB register is not locked thus leaving the user with the option of just reading back 8 bits (MSB) of a 10-bit conversion result. Reading an MSB register first does not lock up

other MSB registers and likewise reading an LSB register first does not lock up other LSB registers.

Table 4. List of ADT7411 Registers

RD/WR Address	Name	Power-on Default
00h	Interrupt Status 1	00h
01h	Interrupt Status 2	00h
02h	RESERVED	
03h	Internal Temp & V_{DD} LSBs	00h
04h	External Temp & AIN 1-4 LSBs	00h
05h	AIN 5 - 8 LSBs	00h
06h	V_{DD} MSBs	00h
07h	Internal Temperature MSBs	00h
08h	External Temp MSBs/ AIN 1 MSBs	00h
09h	AIN 2 MSBs	00h
0Ah	AIN 3 MSBs	00h
0Bh	AIN 4 MSBs	00h
0Ch	AIN 5 MSBs	00h
0Dh	AIN 6 MSBs	00h
0Eh	AIN 7 MSBs	00h
0Fh	AIN 8 MSBs	00h
10h-17h	RESERVED	
18h	Control CONFIG 1	08h
19h	Control CONFIG 2	00h
1Ah	Control CONFIG 3	00h
1Bh-1Ch	RESERVED	
1Dh	Interrupt Mask 1	00h
1Eh	Interrput Mask 2	00h
1Fh	Internal Temp Offset	00h
20h	External Temp Offset	00h
21h	RESERVED	
22h	RESERVED	
23h	V_{DD} V_{HIGH} Limit	C7h
24h	V_{DD} V_{LOW} Limit	62h
25h	Internal T_{HIGH} Limit	64h
26h	Internal T_{LOW} Limit	C9h
27h	External T_{HIGH} / AIN1 V_{HIGH} Limits	FFh
28h	External T_{LOW} / AIN1 V_{LOW} Limits	00h
29h-2Ah	RESERVED	
2Bh	AIN 2 V_{HIGH} Limit	FFh
2Ch	AIN 2 V_{LOW} Limit	00h
2Dh	AIN 3 V_{HIGH} Limit	FFh
2Eh	AIN 3 V_{LOW} Limit	00h
2Fh	AIN 4 V_{HIGH} Limit	FFh
30h	AIN 4 V_{LOW} Limit	00h
31h	AIN 5 V_{HIGH} Limit	FFh
32h	AIN 5 V_{LOW} Limit	00h
33h	AIN 6 V_{HIGH} Limit	FFh
34h	AIN 6 V_{LOW} Limit	00h
35h	AIN 7 V_{HIGH} Limit	FFh
36h	AIN 7 V_{LOW} Limit	00h
37h	AIN 8 V_{HIGH} Limit	FFh
38h	AIN 8 V_{LOW} Limit	00h
39h-4Ch	RESERVED	
4Dh	Device ID	02h
4Eh	Manufacturer's ID	41h
4Fh	Silicon Revision	00h
50h-7Eh	RESERVED	00h
7F	SPI Lock Status	00h
80-FFh	RESERVED	00h

Interrupt Status 1 Register (Read only) [Add. = 00h]
This 8-bit read only register reflects the status of some of the interrupts that can cause the INT/$\overline{INT}$ pin to go active. This register is reset by a read operation provided that any out of limit event has been corrected. It is also reset by a software reset.

Table 5. Interrupt Status 1 Register

D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

Bit	Function

D0	1 when Internal Temp Value exceeds T_{HIGH} limit. Any internal temperature reading greater than the limit set will cause an out of limit event.
D1	1 when Internal Temp Value exceeds T_{LOW} limit. Any internal temperature reading less than or equal to the limit set will cause an out of limit event.
D2	This status bit is linked to the configuration of pins 7 and 8. If configured for External Temperature Sensor then this bit is 1 when External Temp Value exceeds T_{HIGH} limit. The default value for this limit register is -1°C so any external temperature reading greater than the limit set will cause an out of limit event. If configured for AIN1 and AIN2 then this bit is 1 when AIN1 Input Voltage exceeds V_{HIGH} or V_{LOW} limits.
D3	1 when External Temp Value exceeds T_{LOW} limit. The default value for this limit register is 0°C so any external temperature reading less than or equal to the limit set will cause an out of limit event.
D4	1 indicates a fault (open or short) for the external temperature sensor.
D5	1 when AIN2 voltage is greater than corresponding V_{HIGH} limit. 1 when AIN2 voltage is less than or equal to corresponding V_{LOW} limit.
D6	1 when AIN3 voltage is greater than corresponding V_{HIGH} limit. 1 when AIN3 voltage is less than or equal to corresponding V_{LOW} limit.
D7	1 when AIN4 voltage is greater than corresponding V_{HIGH} limit. 1 when AIN4 voltage is less than or equal to corresponding V_{LOW} limit.

Interrupt Status 2 Register (Read only) [Add. = 01h]
This 8-bit read only register reflects the status of the V_{DD} and AIN5-AIN8 interrupts that can cause the INT/$\overline{INT}$ pin to go active. This register is reset by a read operation provided that any out of limit event has been corrected. It is also reset by a software reset.

Table 6. Interrupt Status 2 Register

D7	D6	D5	D4	D3	D2	D1	D0
N/A	N/A	N/A	0*	N/A	N/A	N/A	N/A

*Default settings at Power-up.

Bit	Function
D0	1 when AIN5 voltage is greater than corresponding V_{HIGH} limit. 1 when AIN5 voltage is less than or equal to corresponding V_{LOW} limit.
D1	1 when AIN6 voltage is greater than corresponding V_{HIGH} limit. 1 when AIN6 voltage is less than or equal to corresponding V_{LOW} limit.
D2	1 when AIN7 voltage is greater than corresponding V_{HIGH} limit. 1 when AIN7 voltage is less than or equal to corresponding V_{LOW} limit.
D3	1 when AIN8 voltage is greater than corresponding V_{HIGH} limit. 1 when AIN8 voltage is less than or equal to corresponding V_{LOW} limit.
D4	1 when V_{DD} value is greater than corresponding V_{HIGH} limit. 1 when V_{DD} is less than or equal to corresponding V_{LOW} limit.
D5:D7	RESERVED

INTERNAL TEMPERATURE VALUE/V_{DD} VALUE REGISTER LSBs (Read only) [Add. = 03h]
This Internal Temperature Value and V_{DD} Value Register is a 8-bit read-only register. It stores the two LSBs of the 10-bit temperature reading from the internal temperature sensor and also the two LSBs of the 10-bit supply voltage reading.

Table 7. Internal Temp/V_{DD} LSBs

D7	D6	D5	D4	D3	D2	D1	D0
N/A	N/A	N/A	N/A	V1	LSB	T1	LSB
N/A	N/A	N/A	N/A	0*	0*	0*	0*

*Default settings at Power-up.

Bit	Function
D0	LSB of Internal Temperature Value
D1	B1 of Internal Temperature Value
D2	LSB of V_{DD} Value
D3	B1 of V_{DD} Value

EXTERNAL TEMPERATURE VALUE and ANALOG INPUTS 1-4 REGISTER LSBS (Read only) [Add. = 04h]
This is a 8-bit read-only register. Bits D2 - D7 store the two LSBs of the analog inputs AIN2 - AIN4. Bits D0 and D1 are used to store the two LSBs of either the External Temperature Value or AIN1 input value. The type of input for D0 and D1 is selected by Bits 1:2 of Control Configuration 1.

Table 8. External Temperature & AIN 1-4 LSBs

D7	D6	D5	D4	D3	D2	D1	D0

A4	$A4_{LSB}$	A3	$A3_{LSB}$	A2	$A2_{LSB}$	T/A	T/A_{LSB}
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

Bit	Function
D0	LSB of External Temperature Value or AIN 1 Value
D1	Bit 1 of External Temperature Value or AIN 1 Value
D2	LSB of AIN 2 Value
D3	Bit 1 of AIN 2 Value
D4	LSB of AIN 3 Value
D5	Bit 1 of AIN 3 Value
D6	LSB of AIN 4 Value
D7	Bit 1 of AIN 4 Value

ANALOG INPUTS 5-8 REGISTER LSBS (Read only) [Add. = 05h]
This is a 8-bit read-only register. Bits D0 - D7 store the two LSBs of the analog inputs AIN5 - AIN8. The MSBs are stored in registers 0Ch to 0Fh.

Table 9. External Temperature & AIN 1-4 LSBs

D7	D6	D5	D4	D3	D2	D1	D0
A8	$A8_{LSB}$	A7	$A7_{LSB}$	A6	$A6_{LSB}$	A5	$A5_{LSB}$
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

Bit	Function
D0	LSB of AIN 5 Value
D1	Bit 1 of AIN 5 Value
D2	LSB of AIN 6 Value
D3	Bit 1 of AIN 6 Value
D4	LSB of AIN 7 Value
D5	Bit 1 of AIN 7 Value
D6	LSB of AIN 8 Value
D7	Bit 1 of AIN 8 Value

V_{DD} VALUE REGISTER MSBS (Read only) [Add. = 06h]
This 8-bit read only register stores the supply voltage value. The 8 MSBs of the 10-bit value are stored in this register.

Table 10. V_{DD} Value MSBs

D7	D6	D5	D4	D3	D2	D1	D0
V9	V8	V7	V6	V5	V4	V3	V2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

INTERNAL TEMPERATURE VALUE REGISTER MSBS (Read only) [Add. = 07h]
This 8-bit read only register stores the Internal Temperature value from the internal temperature sensor in twos complement format. The 8 MSBs of the 10-bit value are stored in this register.

Table 11. Internal Temperature Value MSBs

D7	D6	D5	D4	D3	D2	D1	D0
T9	T8	T7	T6	T5	T4	T3	T2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

EXTERNAL TEMPERATURE VALUE OR ANALOG INPUT AIN 1 REGISTER MSBS (Read only) [Add. = 08h]
This 8-bit read only register stores, if selected, the External Temperature value or the Analog Input AIN 1 value. Selection is done in Control Configuration 1 register. The external temperature value is stored in twos complement format. The 8 MSBs of the 10-bit value are stored in this register.

Table 12. External Temperature Value/Analog Inputs MSBs

D7	D6	D5	D4	D3	D2	D1	D0
T/A9	T/A8	T/A7	T/A6	T/A5	T/A4	T/A3	T/A2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN 2 REGISTER MSBS (Read) [Add. = 09h]
This 8-bit read register contains the 8 MSBs of the AIN 2 analog input voltage word. The value in this register is combined with bits D2:3 of the External Temperature Value and Analog Inputs 1-4 Register LSBs, address 04h, to give the full 10-bit conversion result of the analog value on the AIN 2 pin.

Table 13. AIN 2 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN 3 REGISTER MSBS (Read) [Add. = 0Ah]
This 8-bit read register contains the 8 MSBs of the AIN 3 analog input voltage word. The value in this register is combined with bits D4:5 of the External Temperature Value and Analog Inputs 1-4 Register LSBs, address 04h, to give the full 10-bit conversion result of the analog value on the AIN 3 pin.

Table 14. AIN 3 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN 4 REGISTER MSBS (Read) [Add. = 0Bh]
This 8-bit read register contains the 8 MSBs of the AIN 4 analog input voltage word. The value in this register is combined with bits D6:7 of the External Temperature Value and Analog Inputs 1-4 Register LSBs, address 04h, to give the full 10-bit conversion result of the analog value on the AIN 4 pin.

Table 15. AIN 4 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN 5 REGISTER MSBS (Read) [Add. = 0Ch]
This 8-bit read register contains the 8 MSBs of the AIN 5 analog input voltage word. The value in this register is combined with bits D0:1 of the Analog Inputs 5-8 Register LSBs, address 05h, to give the full 10-bit conversion result of the analog value on the AIN 5 pin.

Table 16. AIN 5 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN 6 REGISTER MSBS (Read) [Add. = 0Dh]
This 8-bit read register contains the 8 MSBs of the AIN 6 analog input voltage word. The value in this register is combined with bits D2:3 of the Analog Inputs 5-8 Register LSBs, address 05h, to give the full 10-bit conversion result of the analog value on the AIN 6 pin.

Table 17. AIN 6 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN 7 REGISTER MSBS (Read) [Add. = 0Eh]
This 8-bit read register contains the 8 MSBs of the AIN 7 analog input voltage word. The value in this register is combined with bits D4:5 of the Analog Inputs 5-8 Register LSBs, address 05h, to give the full 10-bit conversion result of the analog value on the AIN 7 pin.

Table 18. AIN 7 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN 8 REGISTER MSBS (Read) [Add. = 0Fh]
This 8-bit read register contains the 8 MSBs of the AIN 8 analog input voltage word. The value in this register is combined with bits D6:7 of the Analog Inputs 5-8 Register LSBs, address 05h, to give the full 10-bit conversion result of the analog value on the AIN 8 pin.

Table 19. AIN 8 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

CONTROL CONFIGURATION 1 REGISTER (Read/ Write) [Add. = 18h]
This configuration register is an 8-bit read/write register that is used to setup some of the operating modes of the ADT7411.

Table 20. Control Configuration 1

D7	D6	D5	D4	D3	D2	D1	D0
PD	C6	C5	C4	C3	C2	C1	C0
0*	0*	0*	0*	1*	0*	0*	0*

*Default settings at Power-up.

Bit	Function
C0	This bit enables/disables conversions in Round Robin and Single Channel mode. ADT7411 powers up in Round Robin mode but monitoring is not initiated until this bit is set. Default = 0. 0 = Stop monitoring. 1 = Start monitoring.
C2:C1	Selects between the two different analog inputs on pins 7 and 8. ADT7411 powers up with AIN1 and AIN2 selected. 00 AIN1 and AIN2 selected. 01 Undefined. 10 External TDM selected. 11 Undefined.
C3	RESERVED. Write 1 only to this bit.
C4	RESERVED. Write 0 only.
C5	0 Enable INT/$\overline{\text{INT}}$ Output 1 Disable INT/$\overline{\text{INT}}$ Output
C6 0 1	Configures INT/$\overline{\text{INT}}$ output polarity. Active low Active High

PD	Power-down Bit. Setting this bit to 1 puts the ADT7411 into standby mode. In this mode the analog circuitry is fully powered down, but serial interface is still operational. To power up the part again just write 0 to this bit.

CONTROL CONFIGURATION 2 REGISTER (Read/ Write) [Add. = 19h]

This configuration register is an 8-bit read/write register that is used to setup some of the operating modes of the ADT7411.

Table 21. Control Configuration 2

D7	D6	D5	D4	D3	D2	D1	D0
C7	C6	C5	C4	C3	C2	C1	C0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

Bit	Function
C3:0	In single channel mode these bits select between V_{DD}, the internal temperature sensor, external temperature sensor/AIN1, AIN2 to AIN8 for conversion. Default is V_{DD}. 0000 = V_{DD} 0001 = Internal Temperature Sensor. 0010 = External Temperature Sensor/AIN1 (Bits C1:C2 of Control Configuration 1 affect this selection) 0011 = AIN2 0100 = AIN3 0101 = AIN4 0110 = AIN5 0111 = AIN6 1000 = AIN7 1001 = AIN8 1010 - 1111 = RESERVED.
C4	Selects between single channel and Round Robin conversion cycle. Default is Round Robin. 0 = Round Robin. 1 = Single Channel.
C5	Default condition is to average every measurement on all channels 16 times. This bit disables this averaging. Channels affected are temperature, analog inputs and V_{DD}. 0 = Enable averaging. 1 = Disable averaging.
C6	SMBus timeout on the serial clock puts a 25ms limit on the pulse width of the clock. Ensures that a fault on the master SCL does not lock up the SDA line. 0 = Disable SMBus Timeout. 1 = Enable SMBus Timeout.
C7	Software Reset. Setting this bit to a 1 causes a software reset. All registers will reset to their default settings.

CONTROL CONFIGURATION 3 REGISTER (Read/ Write) [Add. = 1Ah]

This configuration register is an 8-bit read/write register that is used to setup some of the operating modes of the ADT7411.

Table 22. Control Configuration 3

D7	D6	D5	D4	D3	D2	D1	D0
C7	C6	C5	C4	C3	C2	C1	C0
0*	0*	0*	0*	1*	0*	0*	0*

*Default settings at Power-up.

Bit	Function
C0	Selects between fast and normal ADC conversion speeds. 0 = ADC clock at 1.4 KHz. 1 = ADC clock at 22.5 KHz. Analog filters are disabled.
C1:2	RESERVED. Only write 0's.
C3	RESERVED. Write only 1 to this bit.
C4	Selects the ADC reference to be either Internal V_{REF} or V_{DD} for analog inputs. 0 = Int V_{REF} 1 = V_{DD}
C5-C7	RESERVED. Only write 0's.

INTERRUPT MASK 1 REGISTER (Read/Write) [Add. = 1Dh]

This mask register is an 8-bit read/write register that can be used to mask out any interrupts that can cause the INT/$\overline{INT}$ pin to go active.

Table 23. Interrupt Mask 1

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

Bit	Function
D0	0 = Enable internal T_{HIGH} interrupt. 1 = Disable internal T_{HIGH} interrupt.
D1	0 = Enable internal T_{LOW} interrupt. 1 = Disable internal T_{LOW} interrupt.
D2	0 = Enable external T_{HIGH} interrupt or AIN1 interrupt. 1 = Disable external T_{HIGH} interrupt or AIN1 interrupt.
D3	0 = Enable external T_{low} interrupt. 1 = Disable external T_{low} interrupt.
D4	0 = Enable external temperature fault interrupt. 1 = Disable external temperature fault interrupt.

D5	0 = Enable AIN2 interrupt. 1 = Disable AIN2 interrupt.
D6	0 = Enable AIN3 interrupt. 1 = Disable AIN3 interrupt.
D7	0 = Enable AIN4 interrupt. 1 = Disable AIN4 interrupt.

INTERRUPT MASK 2 REGISTER (Read/Write) [Add. = 1Eh]

This mask register is an 8-bit read/write register that can be used to mask out any interrupts that can cause the INT/$\overline{INT}$ pin to go active.

Table 24. Interrupt Mask 2

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

Bit	Function
D0	0 = Enable AIN5 interrupt. 1 = Disable AIN5 interrupt.
D1	0 = Enable AIN6 interrupt. 1 = Disable AIN6 interrupt.
D2	0 = Enable AIN7 interrupt. 1 = Disable AIN7 interrupt.
D3	0 = Enable AIN8 interrupt. 1 = Disable AIN8 interrupt.
D4	0 = Enable V_{DD} interrupts. 1 = Disable V_{DD} interrupts.
D5:D7	RESERVED. Only write 0's.

INTERNAL TEMPERATURE OFFSET REGISTER (Read/Write) [Add. = 1Fh]

This register contains the Offset Value for the Internal Temperature Channel. A 2's complement number can be written to this register which is then 'added' to the measured result before it is stored or compared to limits. In this way a sort of one-point calibration can be done whereby the whole transfer function of the channel can be moved up or down. From a software point of view this may be a very simple method to vary the characteristics of the measurement channel if the thermal characteristics change. As it is an 8-bit register the temperature resolution is 1°C.

Table 25. Internal Temperature Offset

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

EXTERNAL TEMPERATURE OFFSET REGISTER (Read/Write) [Add. = 20h]

This register contains the Offset Value for the Internal Temperature Channel. A 2's complement number can be written to this register which is then 'added' to the measured result before it is stored or compared to limits. In this way a sort of one-point calibration can be done whereby the whole transfer function of the channel can be moved up or down. From a software point of view this may be a very simple method to vary the characteristics of the measurement channel if the thermal characteristics change. As it is an 8-bit register the temperature resolution is 1°C.

Table 26. External Temperature Offset

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

V_{DD} V_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 23h]

This limit register is an 8-bit read/write register which stores the V_{DD} upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured V_{DD} value has to be greater than the value in this register. Default value is 5.46 V.

Table 27. V_{DD} V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	0*	0*	0*	1*	1*	1*

*Default settings at Power-up.

V_{DD} V_{LOW} LIMIT REGISTER (Read/Write) [Add. = 24h]

This limit register is an 8-bit read/write register which stores the V_{DD} lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured V_{DD} value has to be less than or equal to the value in this register. Default value is 2.7 V.

Table 28. V_{DD} V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	1*	1*	0*	0*	0*	1*	0*

*Default settings at Power-up.

INTERNAL T_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 25h]

This limit register is an 8-bit read/write register which stores the 2's complement of the internal temperature upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured Internal Temperature Value has to be greater than the value in this register. As it is an 8-bit register the temperature resolution is 1°C. Default value is +100°C.

Table 29. Internal T_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	1*	1*	0*	0*	1*	0*	0*

*Default settings at Power-up.

INTERNAL T_{LOW} LIMIT REGISTER (Read/Write) [Add. = 26h]

This limit register is an 8-bit read/write register which stores the 2's complement of the internal temperature lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured Internal Temperature Value has to be more negative than or equal to the value in this register. As it is an 8-bit register the temperature resolution is 1°C. Default value is -55°C.

Table 30. Internal T_{LOW} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	0*	0*	1*	0*	0*	1*

*Default settings at Power-up.

EXTERNAL T_{HIGH} / AIN1 V_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 27h]

If pins 7 and 8 are configured for the external temperature sensor then this limit register is an 8-bit read/write register which stores the 2's complement of the external temperature upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured External Temperature Value has to be greater than the value in this register. As it is an 8-bit register the temperature resolution is 1°C. Default value = -1°C.

If pins 7 and 8 are configured for AIN1 and AIN2 single-ended inputs then this limit register is an 8-bit read/write register which stores the AIN1 input upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN1 value has to be greater than the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. As the power-up default settings for pins 7 and 8 is AIN1 and AIN2 single-ended inputs then the default value for this limit register is fullscale voltage.

Table 31. AIN1 V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	1*	1*	1*	1*	1*	1*

*Default settings at Power-up.

EXTERNAL T_{LOW} / AIN1 V_{LOW} LIMIT REGISTER (Read/Write) [Add. = 28h]

If pins 7 and 8 are configured for the external temperature sensor then this limit register is an 8-bit read/write register which stores the 2's complement of the external temperature lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured External Temperature Value has to be more negative than or equal to the value in this register. As it is an 8-bit register the temperature resolution is 1°C. Default value = 0°C.

If pins 7 and 8 are configured for AIN1 and AIN2 single-ended inputs then this limit register is an 8-bit read/write register which stores the AIN1 input lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN1 value has to be less than or equal to the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. As the power-up default settings for pins 7 and 8 is AIN1 and AIN2 single-ended inputs then the default value for this limit register is 0 V.

Table 32. AIN1 V_{LOW} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN2 V_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 2Bh]

This limit register is an 8-bit read/write register which stores the AIN2 input upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN2 value has to be greater than the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is fullscale voltage.

Table 33. AIN2 V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	1*	1*	1*	1*	1*	1*

*Default settings at Power-up.

AIN2 V_{LOW} LIMIT REGISTER (Read/Write) [Add. = 2Ch]

This limit register is an 8-bit read/write register which stores the AIN2 input lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN2 value has to be less than or equal to the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is 0 V.

Table 34. AIN2 V_{LOW} Limit

D7	D6	D5	D4	D3	D2	D1	D0

D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN3 V_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 2Dh]

This limit register is an 8-bit read/write register which stores the AIN3 input upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN3 value has to be greater than the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is fullscale voltage.

Table 35. AIN3 V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	1*	1*	1*	1*	1*	1*

*Default settings at Power-up.

AIN3 V_{LOW} LIMIT REGISTER (Read/Write) [Add. = 2Eh]

This limit register is an 8-bit read/write register which stores the AIN3 input lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN3 value has to be less than or equal to the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is 0 V.

Table 36. AIN3 V_{LOW} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN4 V_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 2Fh]

This limit register is an 8-bit read/write register which stores the AIN4 input upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN4 value has to be greater than the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is fullscale voltage.

Table 37. AIN4 V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	1*	1*	1*	1*	1*	1*

*Default settings at Power-up.

AIN4 V_{LOW} LIMIT REGISTER (Read/Write) [Add. = 30h]

This limit register is an 8-bit read/write register which stores the AIN4 input lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN4 value has to be less than or equal to the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is 0 V.

Table 38. AIN4 V_{LOW} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN5 V_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 31h]

This limit register is an 8-bit read/write register which stores the AIN5 input upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN5 value has to be greater than the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is fullscale voltage.

Table 39. AIN5 V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	1*	1*	1*	1*	1*	1*

*Default settings at Power-up.

AIN5 V_{LOW} LIMIT REGISTER (Read/Write) [Add. = 32h]

This limit register is an 8-bit read/write register which stores the AIN5 input lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN5 value has to be less than or equal to the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is 0 V.

Table 40. AIN5 V_{LOW} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN6 V_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 33h]

This limit register is an 8-bit read/write register which stores the AIN3 input upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN6 value has to be greater than the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is fullscale voltage.

Table 41. AIN6 V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0

D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	1*	1*	1*	1*	1*	1*

*Default settings at Power-up.

AIN6 V_{LOW} LIMIT REGISTER (Read/Write) [Add. = 34h]
This limit register is an 8-bit read/write register which stores the AIN6 input lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN6 value has to be less than or equal to the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is 0 V.

Table 42. AIN6 V_{LOW} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN7 V_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 35h]
This limit register is an 8-bit read/write register which stores the AIN7 input upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN7 value has to be greater than the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is fullscale voltage.

Table 43. AIN7 V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	1*	1*	1*	1*	1*	1*

*Default settings at Power-up.

AIN7 V_{LOW} LIMIT REGISTER (Read/Write) [Add. = 36h]
This limit register is an 8-bit read/write register which stores the AIN7 input lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN7 value has to be less than or equal to the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is 0 V.

Table 44. AIN7 V_{LOW} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

AIN8 V_{HIGH} LIMIT REGISTER (Read/Write) [Add. = 37h]
This limit register is an 8-bit read/write register which stores the AIN8 input upper limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN8 value has to be greater than the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is fullscale voltage.

Table 45. AIN8 V_{HIGH} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
1*	1*	1*	1*	1*	1*	1*	1*

*Default settings at Power-up.

AIN8 V_{LOW} LIMIT REGISTER (Read/Write) [Add. = 38h]
This limit register is an 8-bit read/write register which stores the AIN8 input lower limit that will cause an interrupt and activate the INT/$\overline{INT}$ output (if enabled). For this to happen the measured AIN8 value has to be less than or equal to the value in this register. As it is an 8-bit register the resolution is four times less than the resolution of the 10-Bit ADC. Default value is 0 V.

Table 46. AIN8 V_{LOW} Limit

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0*	0*	0*	0*	0*	0*	0*	0*

*Default settings at Power-up.

DEVICE ID REGISTER (Read only) [Add. = 4Dh]
This 8-bit read only register gives an unique identification number for this part. ADT7411 = 02h.

MANUFACTURER'S ID REGISTER (Read only) [Add. = 4Eh]
This register contains the manufacturers identification number. ADI's is 41h.

SILICON REVISION REGISTER (Read only) [Add. = 4Fh]
This register is divided into the four lsbs representing the Stepping and the four msbs representing the Version. The Stepping contains the manufacturers code for minor revisions or steppings to the silicon. The Version is the ADT7411 version number. The ADT7411's version number is 0100b (4h).

SPI LOCK STATUS REGISTER (Read only) [Add. = 7Fh]
Bit D0 (LSB) of this read only register indicates whether the SPI interface is locked or not. Writing to this register will cause the device to malfunction. Default value is 00h.
0 = I^2C interface
1 = SPI interface selected and locked.

ADT7411 SERIAL INTERFACE
There are two serial interfaces that can be used on this part, I^2C and SPI. The device will power up with the serial interface in I^2C mode but it is not locked into this mode. To stay in I^2C mode it is recommended that the

user ties the $\overline{CS}$ line to either V_{CC} or GND. It is not possible to lock the I^2C mode but it is possible to select and lock the SPI mode.

To select and lock the interface into the SPI mode, a number of pulses must be sent down the $\overline{CS}$ (pin 4) line. The following section describes how this is done.

Once the SPI communication protocol has been locked in, it cannot be unlocked while the device is still powered up. Bit D0 of SPI Lock Status register (address = 7Fh) is set to 1 when a successful SPI interface lock has been acomplished. To reset the serial interface the user must power down the part and power up again. A software reset does not reset the serial interface.

SERIAL INTERFACE SELECTION

The $\overline{CS}$ line controls the selection between I^2C and SPI. Figure 16 shows the selection process necessary to lock the SPI interface mode.

If the user wants to communicate to the ADT7411 using the SPI protocol, send three pulses down the $\overline{CS}$ line as shown in figure 16(a) and 16(b). On the third rising edge (marked as C in figure 16) the part selects and locks the SPI interface. The user is now limited to communicating to the device using the SPI protocol.

As per most SPI standards, the $\overline{CS}$ line must be low during every SPI communication to the ADT7411 and high all other times. Typical examples of how to connect up the dual interface as I^2C or SPI is shown in figures 15(a) and 15(b).

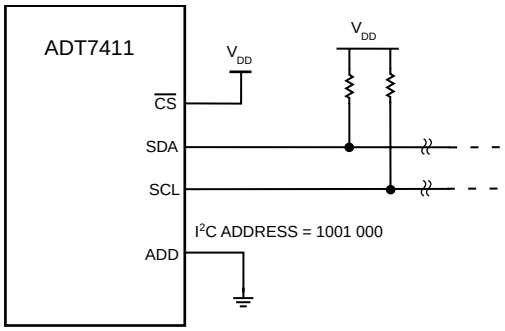


Figure 15(a). Typical I^2C Interface Connection

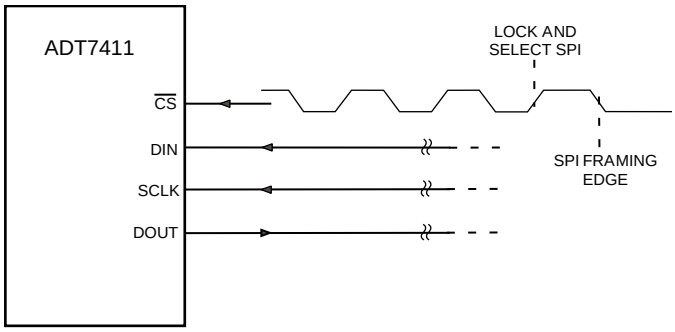


Figure 15(b). Typical SPI Interface Connection

The following sections describe in detail how to use the I^2C and SPI protocols associated with the ADT7411.

I^2C SERIAL INTERFACE

Like all I^2C-compatible devices, the ADT7411 has an 7-bit serial address. The four MSBs of this address for the

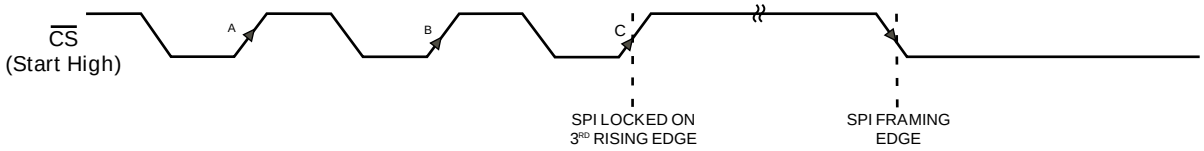


Figure 16(a). Serial Interface - Selecting and Locking SPI Protocol

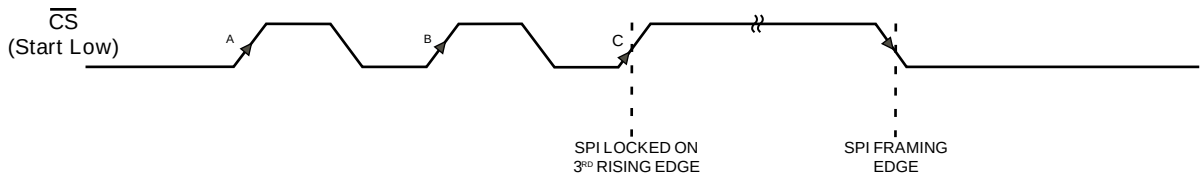


Figure 16(b). Serial Interface - Selecting and Locking SPI Protocol

ADT7411 are set to 1001. The three LSBs are set by pin 11, ADD. The ADD pin can be configured three ways to give three different address options; low, floating and high. Setting the ADD pin low gives a serial bus address of 1001 000, leaving it floating gives the address 1001 010 and setting it high gives the address 1001 011.

There is an enable/disable bit for the SMBus timout. When this is enabled the SMBus will timeout after 25 ms of no activity. To enable it, set Bit 6 of Control Configuration 2 register. The power-up default is with the SMBus timeout disabled.

The ADT7411 supports SMBus Packet Error Checking (PEC) and it's use is optional. It is triggered by supplying the extra clocks for the PEC byte. The PEC is calculated using CRC-8. The Frame Clock Sequence (FCS) conforms to CRC-8 by the polynominal :

$$C(x) = x^8 + x^2 + x^1 + 1$$

Consult SMBus specification (www.smbus.org) for more information.

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/$\overline{W}$ 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/$\overline{W}$ bit is a 0 then the master will write to the slave device. If the R/$\overline{W}$ 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

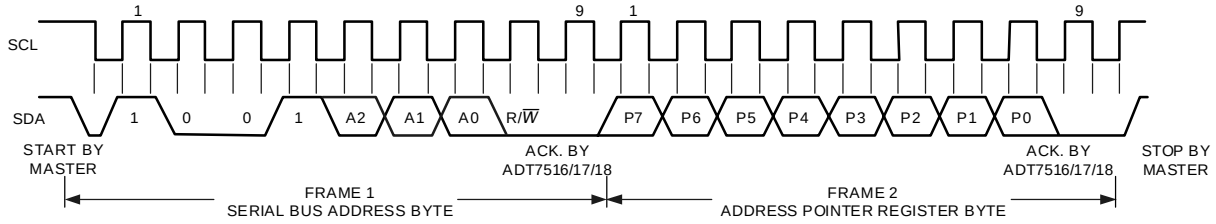


Figure 17. I²C - Writing to the Address Pointer Register to select a register for a subsequent Read operation

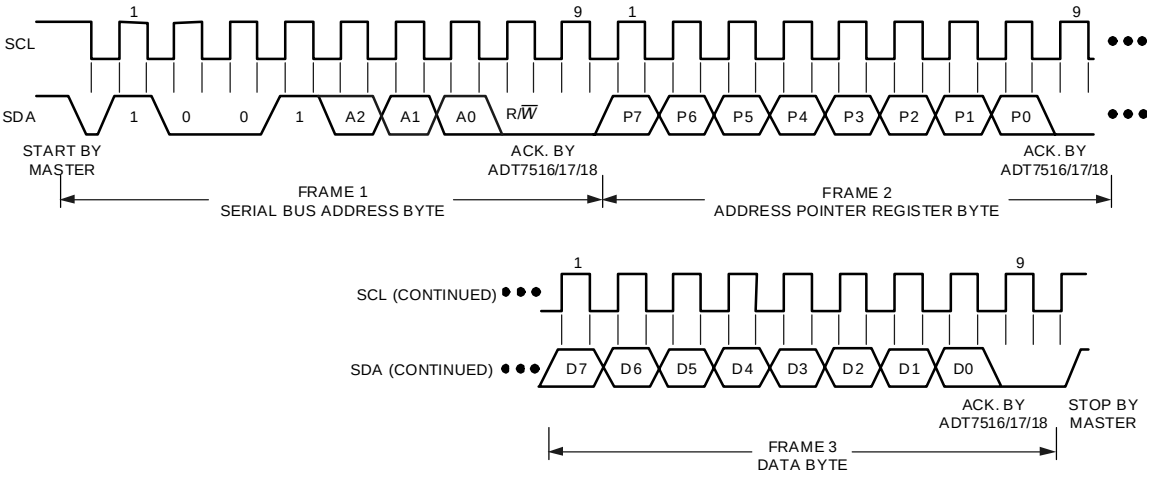


Figure 18. I²C - Writing to the Address Pointer Register followed by a single byte of data to the selected register

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.

The I^2C address set up by the ADD pin 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 it's own I^2C serial bus address. Any subsequent changes on this pin will have no affect on the I^2C serial bus address.

WRITING TO THE ADT7411

Depending on the register being written to, there are two different writes for the ADT7411. It is not possible to do a block write to this part i.e no I^2C auto-increment.

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 17. 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.

All registers are 8-bit registers so only one byte of data can be written to each register. Writing a single byte of data to one of these Read/Write registers 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 18. To write to a different register, another START or repeated START is required. If more than one byte of data is sent in one communication operation, the ad-

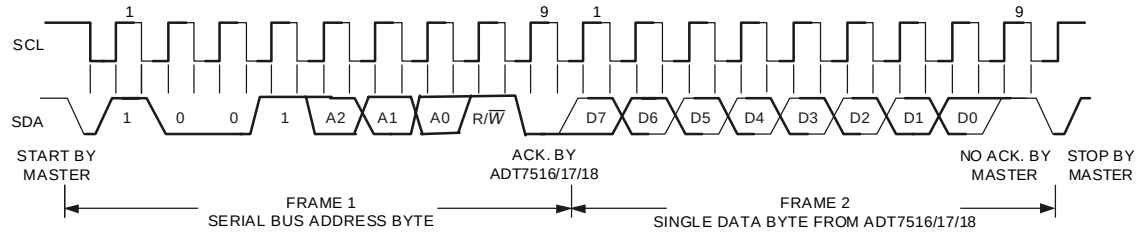


Figure 19. I^2C - Reading a single byte of data from a selected register

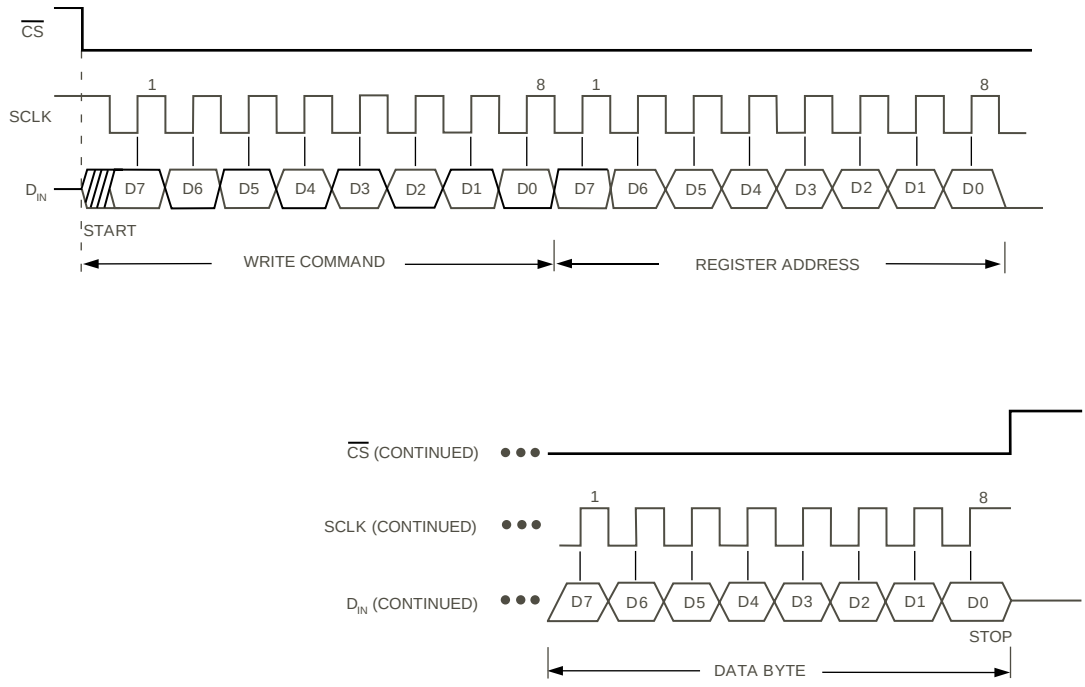


Figure 20. SPI - Writing to the Address Pointer Register followed by a single byte of data to the selected register

dressed register will be repeately loaded until the last data byte has been sent.

READING DATA FROM THE ADT7411

Reading data from the ADT7411 is done in a one byte operation. Reading back the contents of a register is shown in Figure 19. The register address previously having been set up by a single byte write operation to the Address Pointer Register. 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. Thus block reads are not possible i.e. no I^2C auto-increment.

SPI SERIAL INTERFACE

The SPI serial interface of the ADT7411 consists of four wires, $\overline{CS}$, SCLK, DIN and DOUT. The $\overline{CS}$ is used to select the device when more than one device is connected to the serial clock and data lines. The $\overline{CS}$ is also used to distinguish between any two seperate serial communications, reference Figure 24 for graphical explanation. The SCLK is used to clock data in and out of the part. The DIN line is used to write to the registers and the DOUT line is used to read data back from the registers.

The part operates in a slave mode and requires an externally applied serial clock to the SCLK input. The serial interface is designed to allow the part to be interfaced to systems that provide a serial clock that is synchronized to the serial data.

There are two types of serial operations, a read and a write. Command words are used to distinguish between a read and a write operation. These command words are given in Table 47. Address auto-increment is possible in SPI mode.

Table 47. SPI COMMAND WORDS

WRITE	READ
90h (1001 0000)	91h (1001 0001)

Write Operation

Figure 20 shows the timing diagram for a write operation to the ADT7411. Data is clocked into the registers on the rising edge of SCLK. When the $\overline{CS}$ line is high the DIN and DOUT lines are in three-state mode. Only when the $\overline{CS}$ goes from a high to a low does the part accept any data on the DIN line. In SPI mode the Address Pointer Register is capable of auto-incrementing to the next register in the register map without having to load the Address Pointer register each time. In Figure 20 the register address portion of the diagram gives the first register that will be written to. Subsequent data bytes will be written into sequential writable registers. Thus after each data byte has been written into a register, the Address Pointer Register auto increments it's value to the next available register. The Address Pointer Register will auto-increment

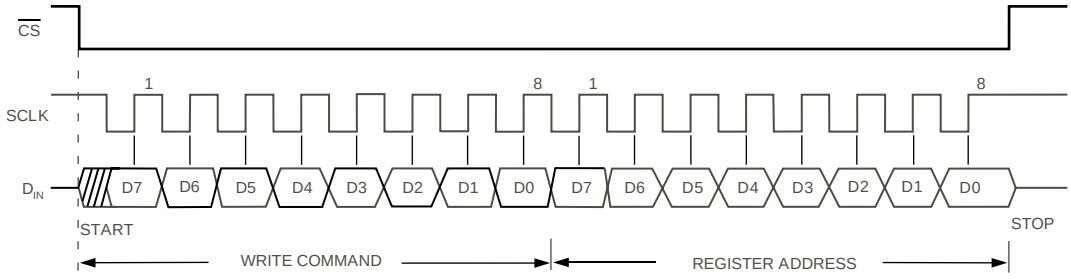


Figure 21. SPI - Writing to the Address Pointer Register to select a register for a subsequent read operation

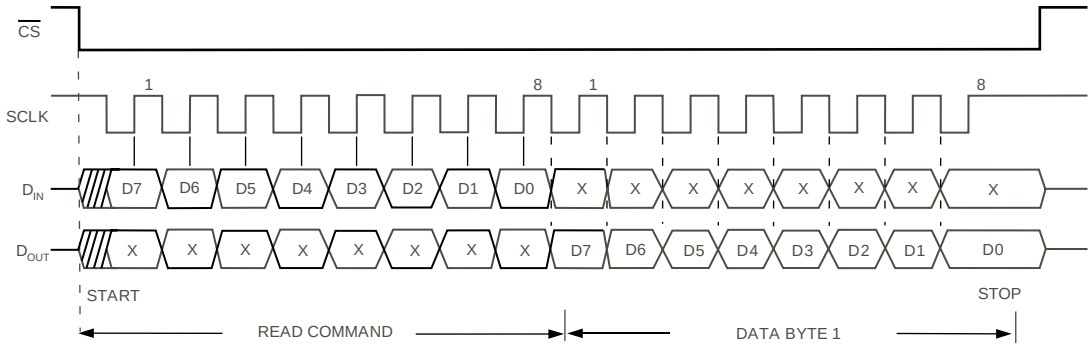


Figure 22. SPI - Reading a single byte of data from a selected register

from 00h to 3Fh and will loop back to start all over again at 00h when it reaches 3Fh.

Read Operation

Figures 21 to 23 show the timing diagrams necessary to accomplish correct read operations. To read back from a register you first have to write to the Address Pointer Register with the address of the register you wish to read from. This operation is shown in Figure 21. Figure 22 shows the procedure for reading back a single byte of data. The read command is first sent to the part during the first 8 clock cycles, during the following 8 clock cycles the data contained in the register selected by the Address Pointer register is outputted onto the DOUT line. Data is outputted onto the DOUT line on the falling edge of SCLK. Figure 23 shows the procedure when reading data from two sequential registers. Multiple data reads are possible in SPI interface mode as the Address Pointer Register is auto-incremental. The Address Pointer Register will auto-increment from 00h to 3Fh and will loop back to start all over again at 00h when it reaches 3Fh.

SMBUS/SPI INT/$\overline{\text{INT}}$

The ADT7411 INT/$\overline{\text{INT}}$ output is an interrupt line for devices that want to trade their ability to master for an extra pin. The ADT7411 is a slave only device and uses the SMBus/SPI INT/$\overline{\text{INT}}$ to signal the host device that it wants to talk. The SMBus/SPI INT/$\overline{\text{INT}}$ on the ADT7411 is used as an over/under limit indicator.

The INT/$\overline{\text{INT}}$ pin has an open-drain configuration which allows the outputs of several devices to be wired-AND together when the INT/$\overline{\text{INT}}$ pin is active low. Use C6 of the Control Configuration 1 Register to set the active polarity of the INT/$\overline{\text{INT}}$ output. The power-up default is active low. The INT/$\overline{\text{INT}}$ output can be disabled or enabled by setting C5 of Control Configuration 1 Register to a 1 or 0 respectively.

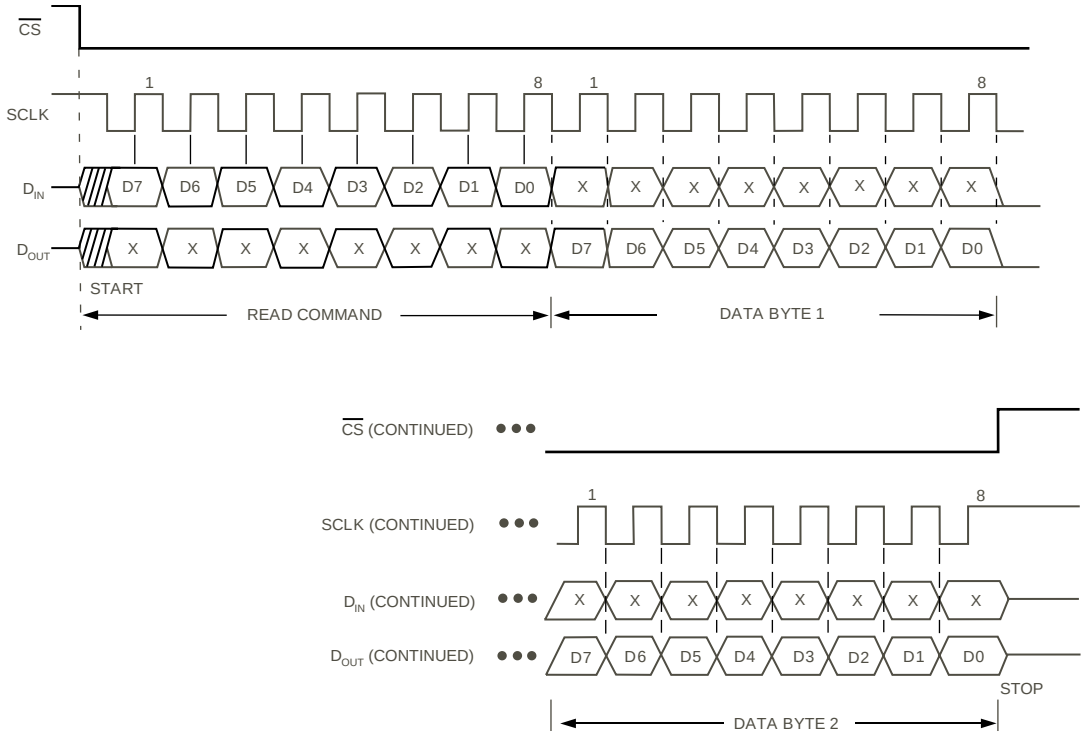


Figure 23. SPI - Reading a two bytes of data from two sequential registers

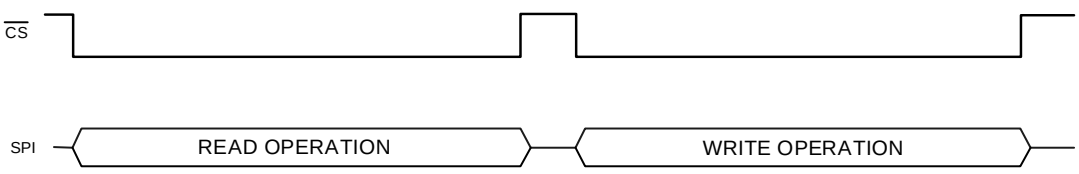


Figure 24. SPI - Correct use of $\overline{CS}$ during SPI communication

The INT/$\overline{\text{INT}}$ output becomes active when either the Internal Temperature Value, the External Temperature Value, V_{DD} Value or any of the AIN input values exceed the values in their corresponding T_{HIGH}/V_{HIGH} or T_{LOW}/V_{LOW} Registers. The INT/$\overline{\text{INT}}$ output goes inactive again when a conversion result has the measured value back within the trip limits. The two Interrupt Status registers show which event caused the INT/$\overline{\text{INT}}$ pin to go active.

The INT/$\overline{\text{INT}}$ output requires an external pull-up resistor. This can be connected to a voltage different from V_{DD} provided the maximum voltage rating of the INT/$\overline{\text{INT}}$ output pin is not exceeded. The value of the pull-up resistor depends on the application, but should be as large enough to avoid excessive sink currents at the INT/$\overline{\text{INT}}$ output, which can heat the chip and affect the temperature reading.

Outline Dimensions
(Dimensions shown in inches and mm)
16-Lead QSOP Package
(RQ-16)