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SPI®-/I²C®-Compatible, 10-Bit Digital Temperature Sensor and 8-Channel ADC

ADT7411

FEATURES

10-bit temperature-to-digital converter
10-bit 8-channel ADC
  DC input bandwidth
  Input range: 0 V to 2.25 V and 0 V to V_{DD}
Temperature range: −40°C to +120°C
Temperature sensor accuracy of ±0.5°C
Supply range: 2.7 V to 5.5 V
Power-down current : <10 µA
Internal 2.25 V_{REF} option
Double-buffered input logic
I²C, SPI, QSPI™, MICROWIRE™, and DSP compatible
4-wire serial interface
SMBus packet error checking (PEC) compatible
16-lead QSOP

PIN CONFIGURATION

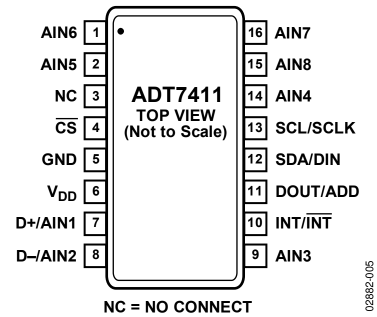

Figure 1.

APPLICATIONS

Portable battery-powered instruments
PCs
Smart battery chargers
Telecommunications systems electronic test equipment
Domestic appliances
Process controls

GENERAL DESCRIPTION

The ADT7411[1] combines a 10-bit temperature-to-digital converter and a 10-bit 8-channel ADC in a 16-lead QSOP. This includes a band gap 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 on the ADC channels has a range of 0 V to 2.25 V and the input bandwidth is dc. The reference for the ADC channels is derived internally. The ADT7411 provides two serial interface options: a 4-wire serial interface compatible with SPI, QSPI, MICROWIRE, and DSP interface standards, and a 2-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 PCs, office equipment, and domestic appliances.

[1] Protected by U.S. Patent Numbers: 6,169,442; 5,867,012; 5,764174.

Rev. B

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Last Content Update: 02/23/2017

COMPARABLE PARTS

View a parametric search of comparable parts.

EVALUATION KITS

- ADT7411 Evaluation Board

DOCUMENTATION

Data Sheet

- ADT7411: SPI-/I2C-Compatible, 10-Bit Digital Temperature Sensor and 8-Channel A/D Converter Data Sheet

DESIGN RESOURCES

- ADT7411 Material Declaration
- PCN-PDN Information
- Quality And Reliability
- Symbols and Footprints

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8/03–Revision 0: Initial Version

SPECIFICATIONS

V_{DD} = 2.7 V to 5.5 V, GND = 0 V, unless otherwise noted. Temperature ranges are −40°C to +120°C.

Table 1.

Parameter[1]	Min	Typ	Max	Unit	Conditions/Comments
ADC DC ACCURACY					Maximum V_{DD} = 5 V.
Resolution			10	Bits	
Total Unadjusted Error (TUE)		2	3	% of FSR	V_{DD} = 2.7 V to 5.5 V.
			2	% of FSR	V_{DD} = 3.3 V (±10%).
Offset Error			±0.5	% of FSR	
Gain Error			±2	% of FSR	
ADC BANDWIDTH			DC	Hz	
ANALOG INPUTS					
Input Voltage Range	0		2.25	V	AIN1 to AIN8. C4 = 0 in Control Configuration 3.
	0		V_{DD}	V	AIN1 to AIN8. C4 = 1 in Control Configuration 3.
DC Leakage Current			±1	μA	
Input Capacitance		5	20	pF	
Input Resistance		10		MΩ	
THERMAL CHARACTERISTICS					Internal reference used. Averaging on.
Internal Temperature Sensor					
Accuracy @ V_{DD} = 3.3 V ± 10%			±1.5	°C	T_A = 85°C.
		±0.5	±3	°C	T_A = 0°C to 85°C.
		±2	±5	°C	T_A = −40°C to +120°C.
Accuracy @ V_{DD} = 5 V ± 5%		±2	±3	°C	T_A = 0°C to 85°C.
		±3	±5	°C	T_A = −40°C to +120°C.
Resolution			10	Bits	Equivalent to 0.25°C.
Long-Term Drift		0.25		°C	Drift over 10 years if part is operated at 55°C.
External Temperature Sensor					External transistor = 2N3906.
Accuracy @ V_{DD} = 3.3 V ± 10%			±1.5	°C	T_A = 85°C.
			±3	°C	T_A = 0°C to 85°C.
			±5	°C	T_A = −40°C to +120°C.
Accuracy @ V_{DD} = 5 V ± 5%		±2	±3	°C	T_A = 0°C to 85°C.
		±3	±5	°C	T_A = −40°C to +120°C.
Resolution			10	Bits	Equivalent to 0.25°C.
Output Source Current		180		μA	High level.
		11		μA	Low level.
CONVERSION TIMES					Single-channel mode.
Slow ADC					
V_{DD}/AIN		11.4		ms	Averaging (16 samples) on.
		712		μs	Averaging off.
Internal Temperature		11.4		ms	Averaging (16 samples) on.
		712		μs	Averaging off.
External Temperature		24.22		ms	Averaging (16 samples) on.
		1.51		ms	Averaging off.
Fast ADC					
V_{DD}/AIN		712		μs	Averaging (16 samples) on.
		44.5		μs	Averaging off.
Internal Temperature		2.14		ms	Averaging (16 samples) on.
		134		μs	Averaging off.
External Temperature		14.25		ms	Averaging (16 samples) on.
		890		μs	Averaging off.

Parameter[1]	Min	Typ	Max	Unit	Conditions/Comments
ROUND ROBIN UPDATE RATE[2]					Time to complete one measurement cycle through all channels.
Slow ADC @ 25°C					
Averaging On		125.4		ms	AIN1 and AIN2 are selected on Pin 7 and Pin 8.
Averaging Off		17.1		ms	AIN1 and AIN2 are selected on Pin 7 and Pin 8.
Averaging On		140.36		ms	D+ and D– are selected on Pin 7 and Pin 8.
Averaging Off		12.11		ms	D+ and D– are selected on Pin 7 and Pin 8.
Fast ADC @ 25°C					
Averaging On		9.26		ms	AIN1 and AIN2 are selected on Pin 7 and Pin 8.
Averaging Off		578.96		µs	AIN1 and AIN2 are selected on Pin 7 and Pin 8.
Averaging On		24.62		ms	D+ and D– are selected on Pin 7 and Pin 8.
Averaging Off		3.25		ms	D+ and D– are selected on Pin 7 and Pin 8.
ON-CHIP REFERENCE[3]					
Reference Voltage	2.2662	2.28	2.2938	V	
Temperature Coefficient		80		ppm/°C	
DIGITAL INPUTS[1, 3]					
Input Current			±1	µA	V_{IN} = 0 V to V_{DD}.
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 OUTPUTS					
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/$\overline{\text{INT}}$ Output Saturation Voltage			0.8	V	I_{OUT} = 4 mA.
I^2C TIMING CHARACTERISTICS[4, 5]					
Serial Clock Period, t_1	2.5			µs	Fast-mode I^2C. See Figure 2.
Data In Setup Time to SCL High, t_2	50			ns	
Data Out Stable after SCL Low, t_3	0			ns	See Figure 2.
SDA Low Setup Time to SCL Low (Start Condition), t_4	50			ns	See Figure 2.
SDA High Hold Time after SCL High (Stop Condition), t_5	50			ns	See Figure 2.
SDA and SCL Fall Time, t_6			300	ns	See Figure 2.
SDA and SCL Rise Time, t_7			300[6]	ns	See Figure 2.
SPI TIMING CHARACTERISTICS[1, 3, 7]					
$\overline{\text{CS}}$ to SCLK Setup Time, t_1	0			ns	See Figure 3.
SCLK High Pulse Width, t_2	50			ns	See Figure 3.
SCLK Low Pulse Width, t_3	50			ns	See Figure 3.
Data Access Time after SCLK Falling Edge, t_4[7]			35	ns	See Figure 3.
Data Setup Time Prior to SCLK Rising Edge, t_5	20			ns	See Figure 3.
Data Hold Time after SCLK Rising Edge, t_6	0			ns	See Figure 3.
$\overline{\text{CS}}$ to SCLK Hold Time, t_7	0			ns	See Figure 3.
$\overline{\text{CS}}$ to DOUT High Impedance, t_8			40	ns	See Figure 3.

Parameter[1]	Min	Typ	Max	Unit	Conditions/Comments
POWER REQUIREMENTS					
V_{DD}	2.7		5.5	V	
V_{DD} Settling Time			50	ms	V_{DD} settles to within 10% of its final voltage level.
I_{DD} (Normal Mode)[8]			3	mA	V_{DD} = 3.3 V, V_{IH} = V_{DD} and V_{IL} = GND.
		2.2	3	mA	V_{DD} = 5 V, V_{IH} = V_{DD} and V_{IL} = GND.
I_{DD} (Power-Down Mode)			10	µA	V_{DD} = 3.3 V, V_{IH} = V_{DD} and V_{IL} = GND.
			10	µA	V_{DD} = 5 V, V_{IH} = V_{DD} and V_{IL} = GND.
Power Dissipation			10	mW	V_{DD} = 3.3 V. Using normal mode.
			33	µW	V_{DD} = 3.3 V. Using shutdown mode.

[1] See the Terminology section.
[2] 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.
[3] Guaranteed by design and characterization, not production tested.
[4] The SDA and SCL timing is measured with the input filters turned on so as to meet the fast-mode I²C specification. Switching off the input filters improves the transfer rate but has a negative effect on the EMC behavior of the part.
[5] Guaranteed by design. Not tested in production.
[6] The interface is also capable of handling the I²C standard mode rise time specification of 1000 ns.
[7] 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.
[8] I_{DD} specification is valid for full-scale analog input voltages. Interface inactive. ADC active. Load currents excluded.

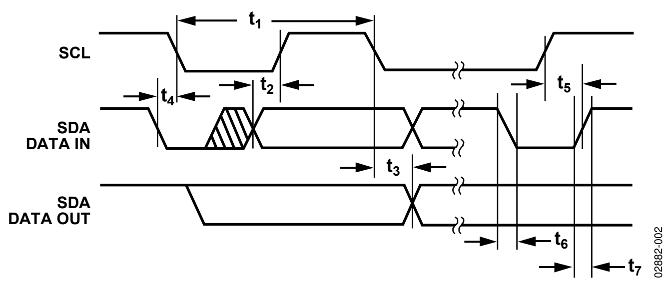


Figure 2. I²C Bus Timing Diagram

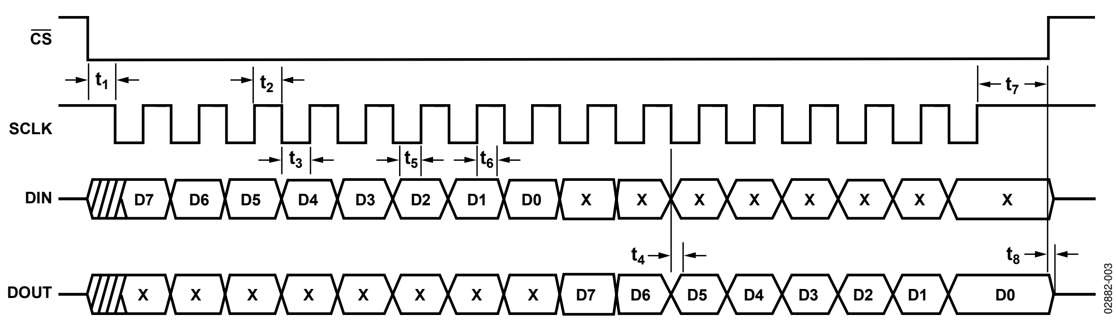


Figure 3. SPI Bus Timing Diagram

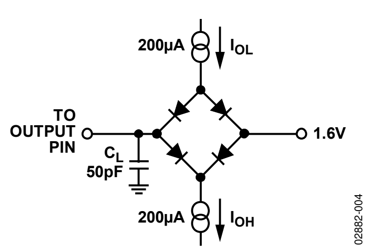


Figure 4. Load Circuit for Access Time and Bus Relinquish Time

FUNCTIONAL BLOCK DIAGRAM

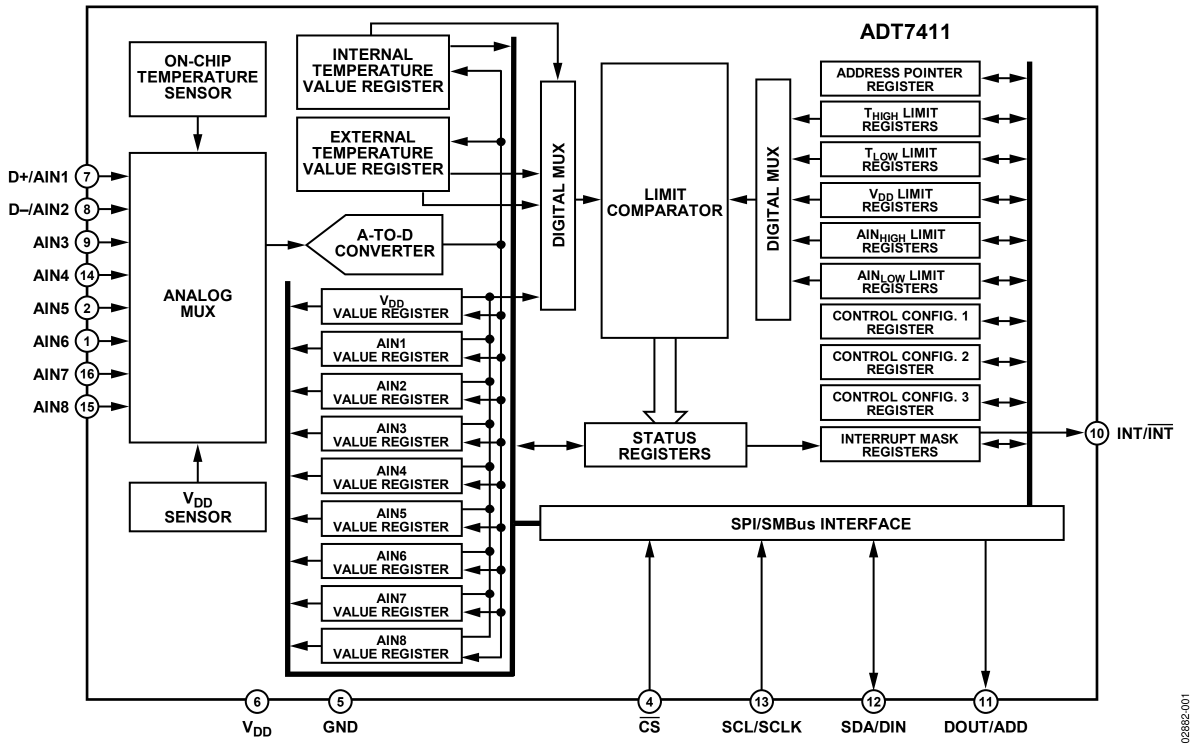


Figure 5.

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
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 +120°C
Storage Temperature Range	−65°C to +150°C
Junction Temperature	
16-Lead QSOP	150°C
Power Dissipation[1]	$(T_{Jmax} - T_A)/\theta_{JA}$
Thermal Impedance[2]	
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°C/5°C)
Time at Peak Temperature	10 sec to 20 sec
Ramp-Up Rate	2°C/sec to 3°C/sec
Ramp-Down Rate	−6°C/sec
IR Reflow Soldering (Pb-Free Package)	
Peak Temperature	260°C (+0°C)
Time at Peak Temperature	20 sec to 40 sec
Ramp-Up Rate	3°C/sec maximum
Ramp-Down Rate	−6°C/sec maximum
Time 25°C to Peak Temperature	8 minutes maximum

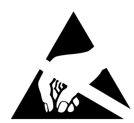
[1] Values relate to package being used on a 4-layer board.
[2] Junction-to-case resistance is applicable to components featuring a preferential flow direction, for example, components mounted on a heat sink. Junction-to-ambient resistance is more useful for air-cooled PCB-mounted components.

Table 3. I^2C Address Selection

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

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.

ESD CAUTION



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

PIN CONFIGURATION AND FUNCTIONAL DESCRIPTIONS

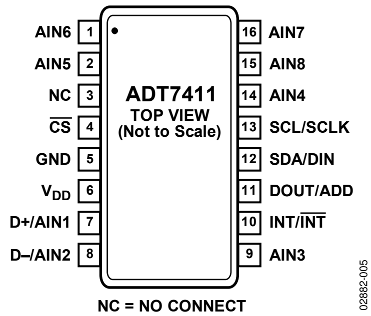


Figure 6. Pin Configuration

Table 4. Pin Function Descriptions

Pin No.	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.
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^{2}C 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	Positive Connection to External Temperature Sensor/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	Negative Connection to External Temperature Sensor/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/$\overline{INT}$	Overlimit 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. Open-drain output needs a pull-up resistor.
11	DOUT/ADD	DOUT—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 pull-up resistor. ADD—I^{2}C Serial Bus Address Selection Pin. Logic input. A low on this pin gives the Address 1001 000, while leaving it floating gives the Address 1001 010 and setting it high gives the Address 1001 011. The I^{2}C address set up by the ADD pin is not latched by the device until after this address has been sent twice. On the eighth SCL cycle of the second valid communication, the serial bus address is latched in. Any subsequent changes on this pin have no effect on the I^{2}C serial bus address.
12	SDA/DIN	SDA—I^{2}C Serial Data Input. I^{2}C serial data to be loaded into the part's registers is provided on this input. An open-drain configuration needs a pull-up resistor. DIN—SPI Serial Data Input. Serial data to be loaded into the part's registers is provided on this input. Data is clocked into a register on the rising edge of SCLK. An open-drain configuration needs a pull-up resistor.
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 to clock data into any register that can be written to. An open-drain configuration needs a pull-up resistor.
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. A typical INL vs. code plot can be seen in Figure 10.

Total Unadjusted Error (TUE)
Total unadjusted error is a comprehensive specification that includes the sum of the relative accuracy error, gain error, and offset error under a specified set of conditions.

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

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.

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 degrees Celsius. 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, ICs cannot be evaluated at room temperature (25°C) for 10 years or so to determine this shift. As a result, manufacturers typically perform accelerated lifetime testing of ICs by operating ICs at elevated temperatures (between 125°C and 150°C) over a shorter period (typically between 500 hours and 1,000 hours). Because of this operation, the lifetime of an IC is significantly accelerated due to the increase in rates of reaction within the semiconductor material.

DC Power Supply Rejection Ratio (PSRR)
The power supply rejection ratio (PSRR) is defined as the ratio of the power in the ADC output at full-scale frequency f to the power of a 100 mV sine wave applied to the V_{DD} supply of frequency fs.

$$PSRR\ (\text{dB}) = 10 \log(Pf/Pfs)$$

where:

Pf is the power at frequency f in ADC output.

Pfs is the power at frequency fs coupled into the V_{DD} supply.

Round Robin
This term describes the ADT7411 cycling through the available measurement channels in sequence, taking a measurement on each channel.

TYPICAL PERFORMANCE CHARACTERISTICS

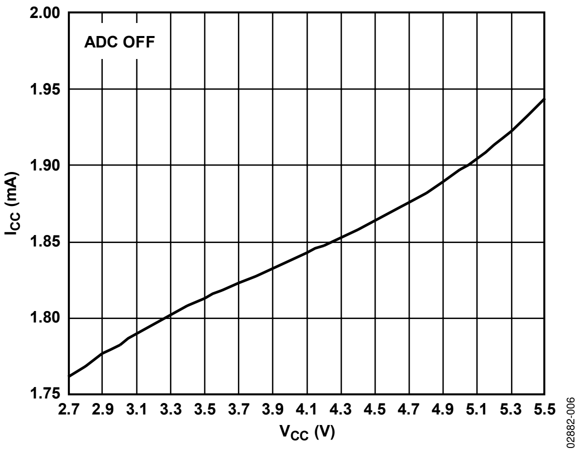


Figure 7. Supply Current vs. Supply Voltage at 25°C

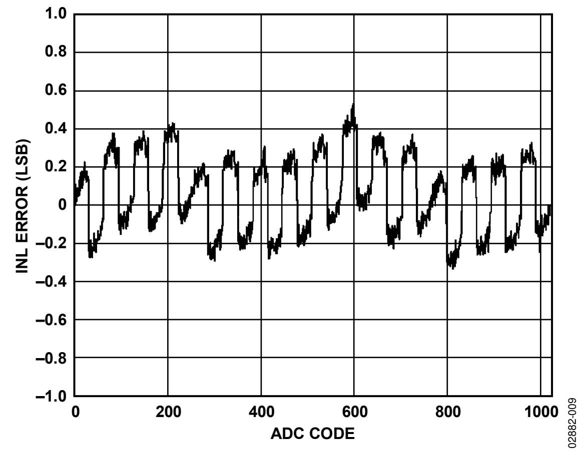


Figure 10. ADC INL with Ref = V_{DD} (3.3 V)

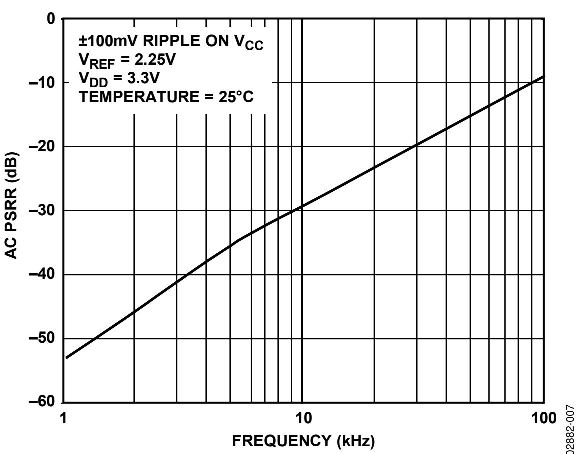


Figure 8. PSRR vs. Supply Ripple Frequency

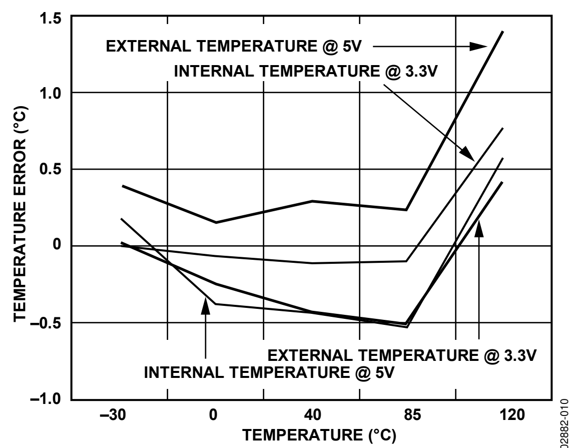


Figure 11. Temperature Error at 3.3 V and 5 V

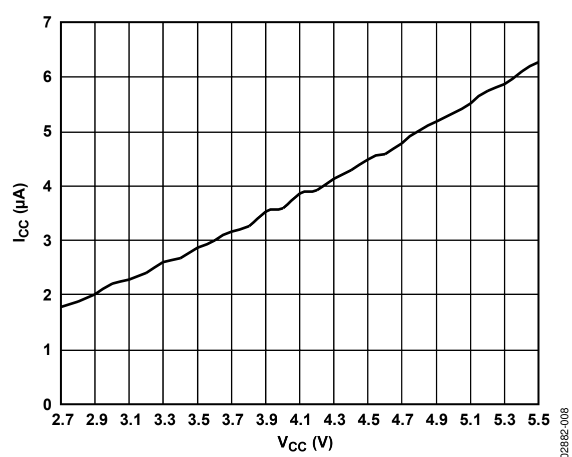


Figure 9. Power-Down Current vs. Supply Voltage at 25°C

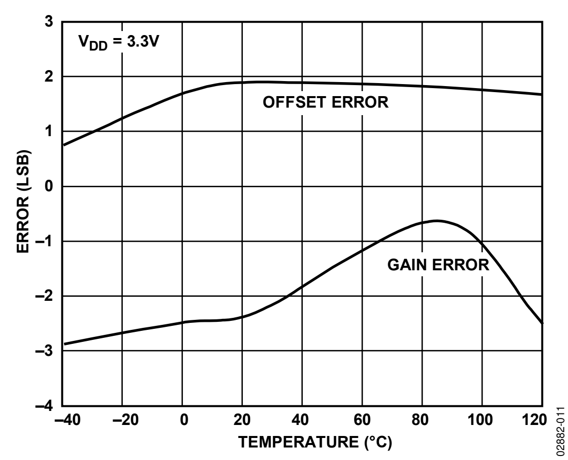


Figure 12. ADC Offset Error and Gain Error vs. Temperature

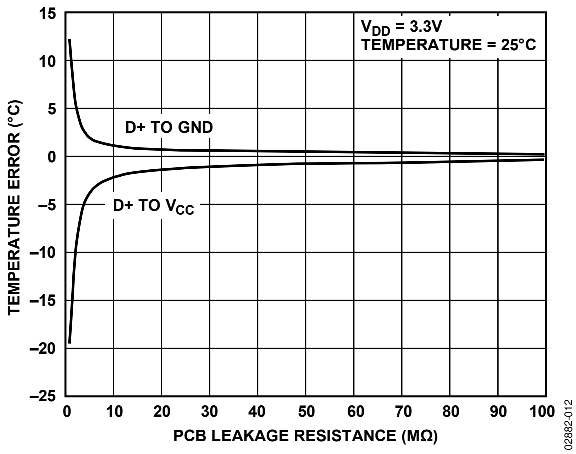


Figure 13. External Temperature Error vs. PCB Leakage Resistance

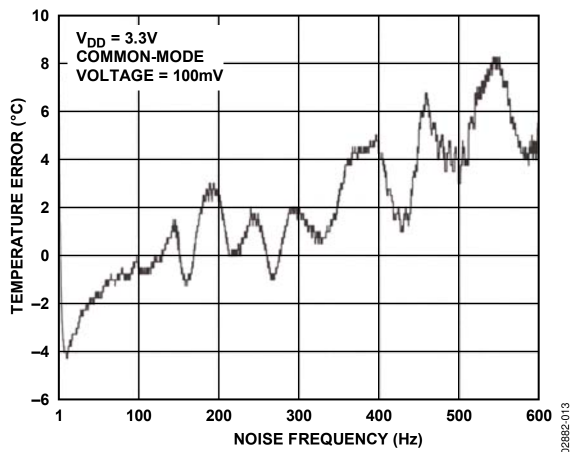


Figure 14. External Temperature Error vs. Common-Mode Noise Frequency

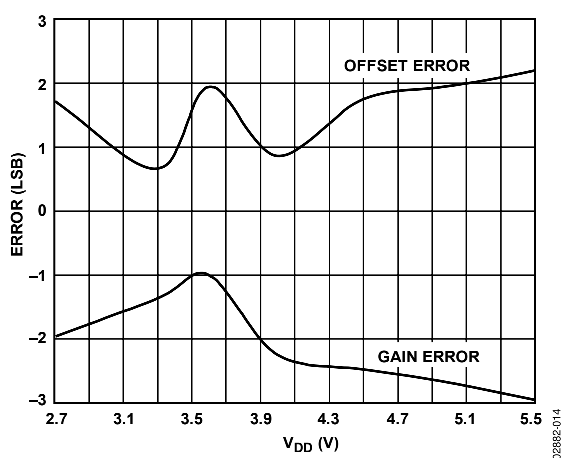


Figure 15. ADC Offset Error and Gain Error vs. V_{DD}

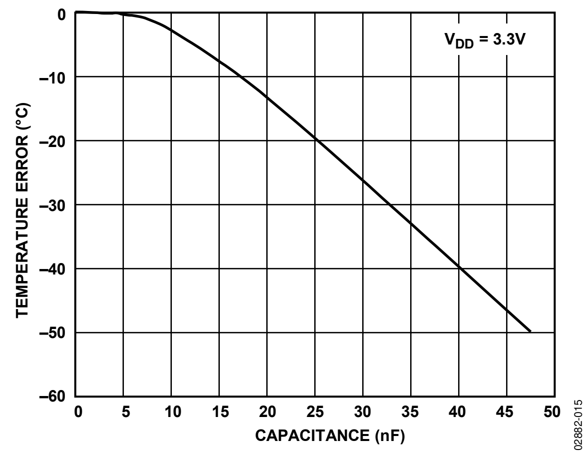


Figure 16. External Temperature Error vs. Capacitance Between D+ and D–

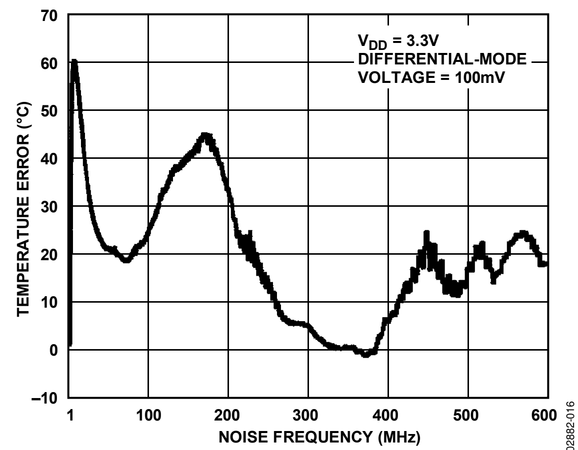


Figure 17. External Temperature Error vs. Differential Mode Noise Frequency

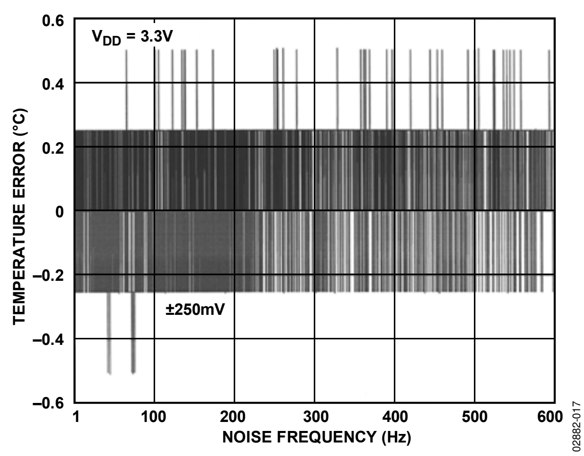


Figure 18. Internal Temperature Error vs. Power Supply Noise Frequency

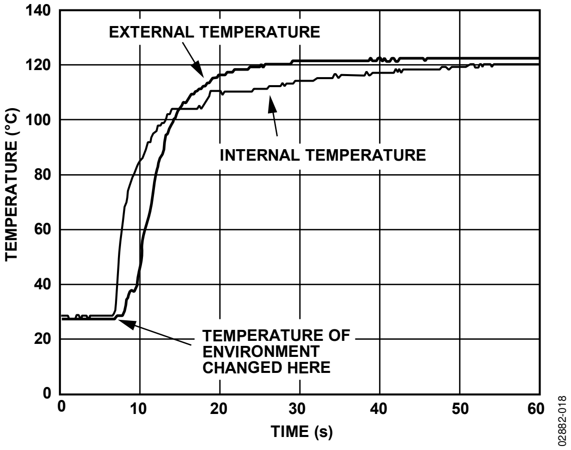


Figure 19. Temperature Sensor Response to Thermal Shock

THEORY OF OPERATION

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 the Control Configuration 1 register (Address 18h) and set Bit C0 = 1. The ADT7411 goes into its power-up default measurement mode, which is round robin. The device performs measurements in the following channel sequence:

1. V_{DD} channel
2. Internal temperature sensor channel
3. External temperature sensor channel (or AIN1 and AIN2 if external diode is not set up)
4. AIN3
5. AIN4
6. AIN5
7. AIN6
8. AIN7
9. 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 the Control Configuration 1 register to 0. It is also possible to continue monitoring as well as switching to single-channel mode by writing to the Control Configuration 2 register (Address 19h) and setting Bit C4 = 1. Further explanations of the single-channel and round robin measurement modes are given in the Single-Channel Measurement and Round Robin Measurement sections. All measurement channels have averaging enabled on them at 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 the 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 the Control Configuration 1 register (Address 18h) are used to select between AIN1/2 and the 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 the Control Configuration 3 register is used to select between the internal reference and 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, 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 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 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 5 ms after V_{DD} has settled to within 10% of its final value. It is generally accepted that most systems take a maximum of 50 ms to power up. Power-up time is directly related to the amount of decoupling on the voltage supply line.

During the 5 ms after V_{DD} has settled, the part is performing a calibration routine; any communication to the device interrupts this routine and can cause erroneous temperature measurements. If it is not possible to have V_{DD} at its nominal value by the time 50 ms elapses or that communication to the device starts 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.

CONVERSION SPEED

The internal oscillator circuit used by the ADC has the capability to output two different clock frequencies. This means that the ADC is capable of running at two different speeds when doing a conversion on a measurement channel. Therefore, the time taken to perform a conversion on a channel can be reduced by setting C0 of the Control Configuration 3 register (Address 1Ah). This increases the ADC clock speed from 1.4 Hz to 22 kHz. At the higher clock speed, the analog filters on the D+ and D− input pins (external temperature sensor) are switched off. This is why the power-up default setting is to have the ADC working at the slow speed. The typical times for fast and slow ADC speeds are given in Table 1.

The ADT7411 powers up with averaging on. This means every channel is measured 16 times and internally averaged to reduce noise. The conversion time can also be reduced by turning the averaging off. This is done by setting Bit C5 of the Control Configuration 2 register (Address 19h) to a 1.

FUNCTIONAL DESCRIPTION

ANALOG INPUTS

Single-Ended Inputs

The ADT7411 offers eight single-ended analog input channels. The analog input range is from 0 V to 2.25 V or 0 V to V_{DD}. To maintain the linearity specification, it is recommended that the maximum V_{DD} value be set at 5 V. Selection between the two input ranges is done by Bit C4 of the Control Configuration 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 slowly varying ac signals. Bit C1 and Bit C2 of the Control Configuration 1 register (Address 18h) are used to set up Pin 7 and Pin 8 as AIN1 and AIN2. Figure 20 shows the overall view of the 8-channel analog input path.

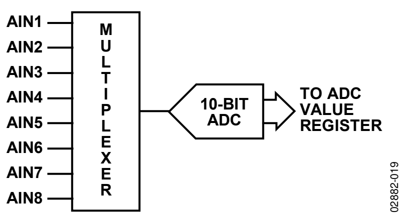


Figure 20. Octal Analog Input Path

Converter Operation

The analog input channels use a successive approximation ADC based around a capacitor DAC. Figure 21 and Figure 22 show simplified schematics of the ADC. Figure 21 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.

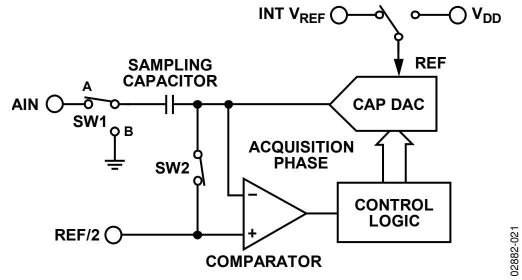


Figure 21. ADC Acquisition Phase

When the ADC eventually goes into conversion phase (see Figure 22) 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 24 shows the ADC transfer function for single-ended analog inputs.

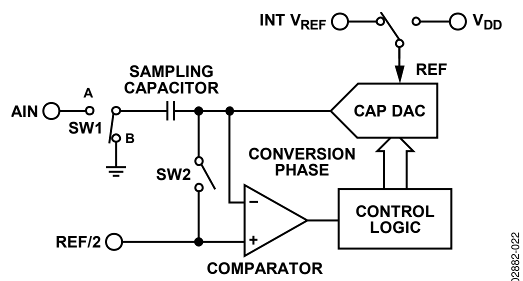


Figure 22. ADC Conversion Phase

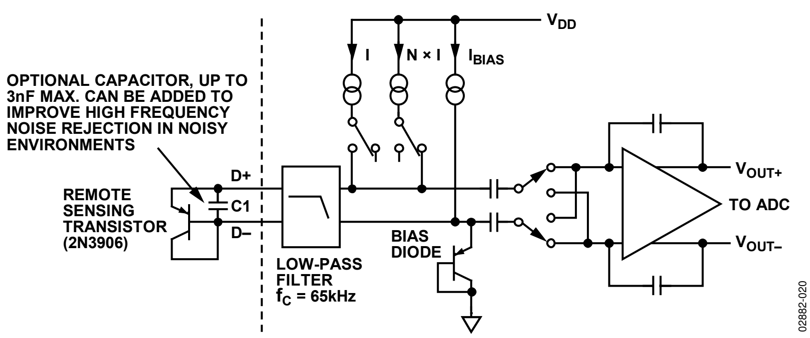


Figure 23. Signal Conditioning for External Diode Temperature Sensor

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 (that is, 1/2 LSB, 3/2 LSB). 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 24.

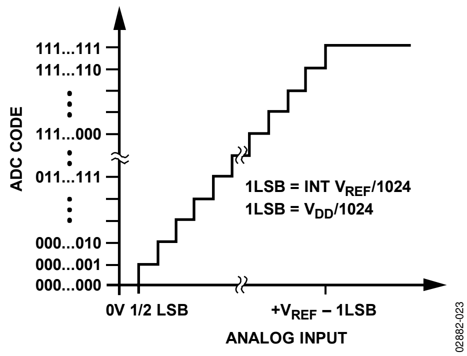


Figure 24. Transfer Function

To work out the voltage on any analog input channel, the following method is used.

1 LSB = *Reference* (V)/1024

Convert the value read back from the AIN value register into decimal.

AIN Voltage = *AIN Value* (d) × *LSB Size*

where *d* is the decimal.

Example:

Internal reference used. Therefore, V_{REF} = 2.25 V.

AIN Value = 512d

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

AIN Voltage = $512 \times 2.197 \times 10^{-3}$

= 1.125 V

Analog Input ESD Protection

Figure 26 shows the input structure that provides ESD protection on any of the analog input pins. 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 200 mV. If this happens, the diode becomes forward biased and starts conducting current into the substrate. The 4 pF capacitor is the typical pin capacitance and the resistor is a lumped component made up of the on resistance of the multiplexer switch.

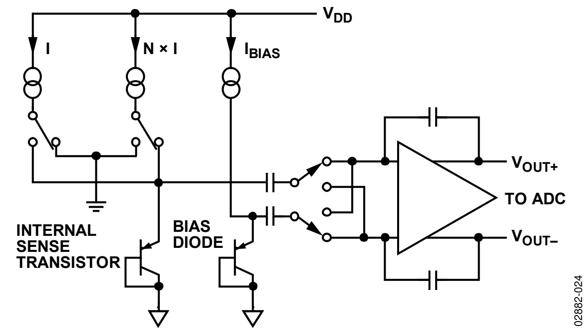


Figure 25. Top Level Structure of Internal Temperature Sensor

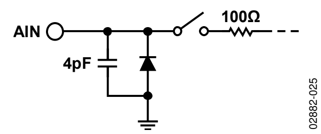


Figure 26. Equivalent Analog Input ESD Circuit

AIN Interrupts

The measured results from the AIN inputs are compared with the AIN V_{HIGH} (greater than comparison) and V_{LOW} (less than or equal to comparison) limits. An interrupt occurs if the AIN inputs exceed or equal the limit registers. These voltage limits are stored in on-chip registers. Note that the limit registers are eight bits long while the AIN conversion result is 10 bits long. If the voltage limits are not masked out, any out-of-limit comparisons generate flags that are stored in the 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 27 shows the interrupt structure for the ADT7411. It shows 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 ADC 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 ADC continually processes the measurement taken on one channel only. This channel is preselected by Bit C0 to Bit C3 in the Control Configuration 2 register (Address 19h). When in round robin mode, the analog input multiplexer sequentially 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.

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

Theoretically, the temperature measuring circuit 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. In single-channel mode, the part is continuously monitoring the selected channel, that is, as soon as one measurement is taken, another one is started on the same channel. The total time to measure a temperature channel with the ADC operating at slow speed is typically 11.4 ms (712 μs × 16) for the internal temperature sensor and 24.22 ms (1.51 ms × 16) for the external temperature sensor. The new temperature value is stored in two 8-bit registers and ready for reading by the I²C or SPI interface. The user has the option of disabling the averaging by setting Bit 5 in the Control Configuration 2 register (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 is reset. Conversion starts again immediately after the serial communication has finished. The temperature measurement proceeds normally as previously described.

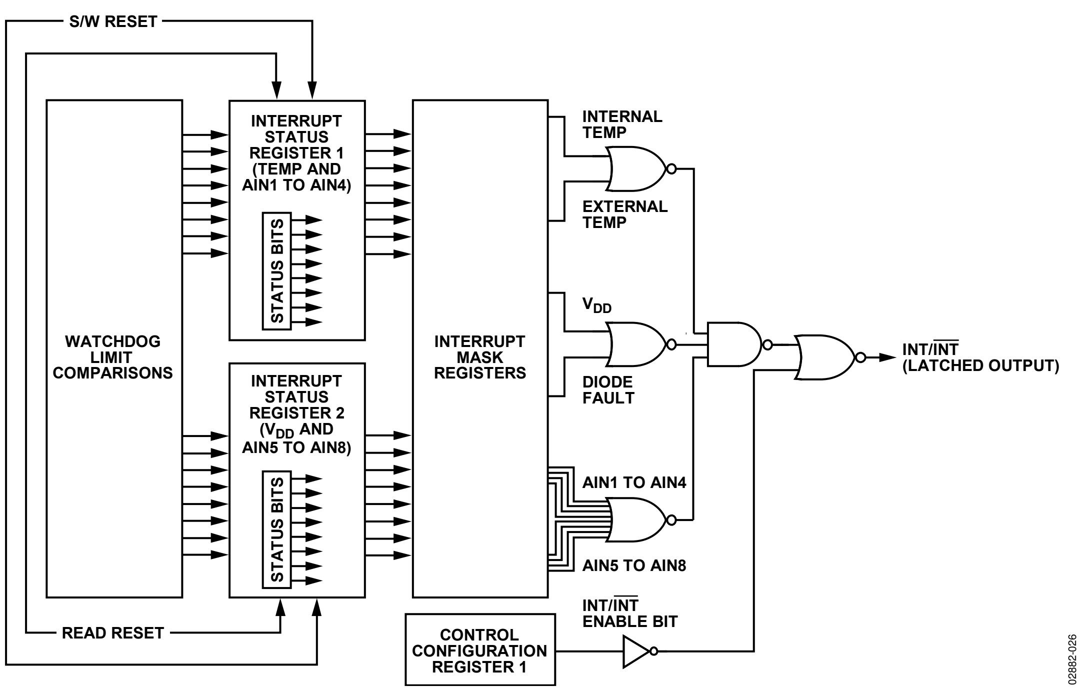


Figure 27. ADT7411 Interrupt Structure

V_{DD} Monitoring

The ADT7411 also has the capability of monitoring its own power supply. The part measures the voltage on its V_{DD} pin to a resolution of 10 bits. The resulting value is stored in two 8-bit registers, with the 2 LSBs stored in register Address 03h and the 8 MSBs stored in register Address 06h. This allows the user to have the option of just doing a 1-byte read if 10-bit resolution is not important. The measured result is compared with the 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 the Interrupt Status 2 register, and one or more out-of-limit results causes the INT/$\overline{\text{INT}}$ 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. The user can select the V_{DD} channel for single-channel measurement by setting Bit C4 = 1 and by setting Bit C0 to Bit C2 to all 0s in the Control Configuration 2 register.

When measuring the V_{DD} value, the reference for the ADC is sourced from the internal reference. Table 5 shows the data format. As the maximum V_{DD} voltage measurable is 7 V, internal scaling is performed on the V_{DD} voltage to match the 2.25 V internal reference value. The following is an example of how the transfer function works.

ADC Reference = 2.25 V

1 LSB = *ADC Reference*/210 = 2.25/1024 = 2.197 mV

Scale Factor = *Full Scale VCC*/*ADC Reference* = 7/2.25 = 3.11

Conversion Result = *VDD*/(*Scale Factor* × *LSB Size*)

= 5/(3.11 × 2.197 mV)

= 2DBh

Table 5. V_{DD} Data Format, V_{REF} = 2.25 V

	Digital Output	
V_{DD} Value (V)	Binary	Hex
2.5	01 0110 1110	16E
2.7	01 1000 1011	18B
3.0	01 1011 0111	1B7
3.5	10 0000 0000	200
4.0	10 0100 1001	249
4.5	10 1001 0010	292
5.0	10 1101 1011	2DB
5.5	11 0010 0100	324
6.0	11 0110 1101	36D
6.5	11 1011 0110	3B6
7.0	11 1111 1111	3FF

On-Chip Reference

The ADT7411 has an on-chip 1.125 V band gap reference that 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. The internal reference is used as the reference for the ADC.

Round Robin Measurement

Upon power-up, the ADT7411 goes into round robin mode but monitoring is disabled. Setting Bit C0 of the Configuration 1 register to 1 enables conversions. It sequences through all available channels, taking a measurement from each in the following order: 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 as either external temperature sensor pins or standalone 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 the Control Configuration 2 register (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, for example, the 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, typical times at 25°C are given in Table 1.

Single-Channel Measurement

Setting Bit C4 of the 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 Bit C0 to Bit C3 in the 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 0s to Bit C0 to Bit C3. All subsequent conversions are 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.

Temperature Measurement Method

Internal Temperature Measurement

The ADT7411 contains an on-chip, band gap temperature sensor whose output is digitized by the on-chip ADC. The temperature data is stored in the internal temperature value register. As both positive and negative temperatures can be measured, the temperature data is stored in twos complement format, as shown in Table 6. 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 −2 mV/°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 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

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

where:

K is Boltzmann's constant.

q is the charge on the carrier.

T is the absolute temperature in Kelvin.

N is the ratio of the two currents.

Figure 23 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 is not 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. A 2N3906 is recommended as the external transistor.

To prevent ground noise from 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 Layout Considerations section for more information on C1.

To measure ΔV_{BE}, the sensor is switched between operating currents of I, and N × I. The resulting waveform is passed through a low-pass filter to remove noise, then 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 twos 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 inches 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. A 10 mil track minimum width and spacing is recommended (see Figure 28).

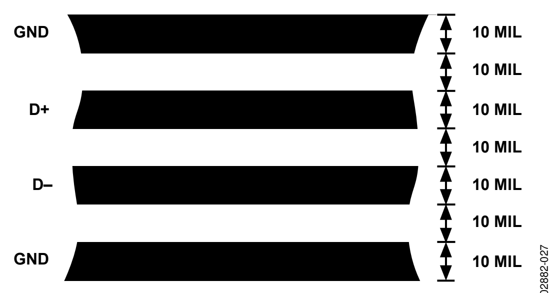


Figure 28. Arrangement of Signal Tracks

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 240 μV, and thermocouple voltages are about 3 μV/°C of temperature difference. Unless there are two thermocouples with a big temperature differential between them, thermocouple voltages should be much less than 200 mV.

5. Place 0.1 µF bypass and 2200 pF 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 works up to about 6 feet to 12 feet.
7. For long distances (up to 100 feet) use shielded twisted-pair cable, 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 can be reduced or removed.

Cable resistance can also introduce errors. A series resistance of 1 Ω 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 6.

The result of the internal or external temperature measurements is stored as twos complement format in the temperature value registers and is compared with limits programmed into the internal or external high and low registers.

Table 6. Temperature Data Format (Internal and External Temperature)

Temperature (°C)	Digital Output
−40	11 0110 0000
−25	11 1001 1100
−10	11 1101 1000
−0.25	11 1111 1111
0	00 0000 0000
+0.25	00 0000 0001
+10	00 0010 1000
+25	00 0110 0100
+50	00 1100 1000
+75	01 0010 1100
+100	01 1001 0000
+105	01 1010 0100
+125	01 1111 0100

Temperature Conversion Formula:

Positive Temperature = ADC Code/4

Negative Temperature = (ADC Code[1] *– 512)/4*

[1] DB9 is removed from the ADC Code.

Interrupts

The measured results from the internal temperature sensor, external temperature sensor, V_{DD} pin, and AIN inputs are compared with their T_{HIGH}/V_{HIGH} (greater than comparison) and T_{LOW}/V_{LOW} (less 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. Note that the limit registers are eight 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 the Interrupt Status 1 register (Address 00h) and the Interrupt Status 2 register (Address 01h). One or more out-of limit results causes 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 27 shows 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.

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. See Table 7 for a detailed description of these registers.

The register map is divided into registers of 8 bits. Each register has its own individual 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 MSBs of the V_{DD} measurement are stored in Register Address 06h while the two LSBs are stored in Register Address 03h. The link involved between these types of registers is that when the LSB register is read first, the MSB registers associated with that LSB register are locked out to prevent any updates. To unlock these MSB registers the user has only to read any one of them, which has the effect of unlocking all previously locked out MSB registers. Therefore, for the example given above, if Register 03h is read first, MSB Register 06h and Register 07h would be locked out to prevent any updates to them. If Register 06h is read this register, then Register 07h would be subsequently unlocked.

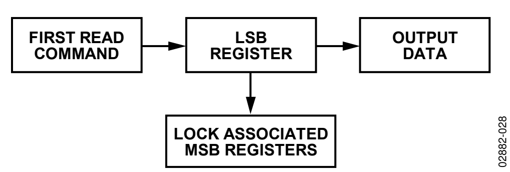


Figure 29. Phase 1 of 10-Bit Read

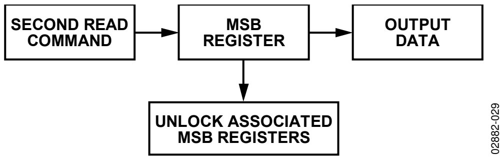


Figure 30. Phase 2 of 10-Bit Read

If an MSB register is read first, its corresponding LSB register is not locked out, 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 out other MSB registers, and likewise reading an LSB register first does not lock out other LSB registers.

Table 7. ADT7411 Registers

RD/WR Address	Name	Power-on Default
00h	Interrupt Status 1	00h
01h	Interrupt Status 2	00h
02h	Reserved	
03h	Internal Temperature and V_{DD} LSBs	00h
04h	External Temperature and AIN1 to AIN 4 LSBs	00h
05h	AIN5 to AIN8 LSBs	00h
06h	V_{DD} MSBs	xxh
07h	Internal Temperature MSBs	00h
08h	External Temperature MSBs/AIN1 MSBs	00h
09h	AIN2 MSBs	00h
0Ah	AIN3 MSBs	00h
0Bh	AIN4 MSBs	00h
0Ch	AIN5 MSBs	00h
0Dh	AIN6 MSBs	00h
0Eh	AIN7 MSBs	00h
0Fh	AIN8 MSBs	00h
10h-17h	Reserved	
18h	Control Configuration 1	08h
19h	Control Configuration 2	00h
1Ah	Control Configuration 3	00h
1Bh-1Ch	Reserved	
1Dh	Interrupt Mask 1	00h
1Eh	Interrupt Mask 2	00h
1Fh	Internal Temperature Offset	00h
20h	External Temperature 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	AIN2 V_{HIGH} Limit	FFh
2Ch	AIN2 V_{LOW} Limit	00h
2Dh	AIN3 V_{HIGH} Limit	FFh
2Eh	AIN3 V_{LOW} Limit	00h
2Fh	AIN4 V_{HIGH} Limit	FFh
30h	AIN4 V_{LOW} Limit	00h
31h	AIN5 V_{HIGH} Limit	FFh
32h	AIN5 V_{LOW} Limit	00h
33h	AIN6 V_{HIGH} Limit	FFh
34h	AIN6 V_{LOW} Limit	00h
35h	AIN7 V_{HIGH} Limit	FFh
36h	AIN7 V_{LOW} Limit	00h
37h	AIN8 V_{HIGH} Limit	FFh
38h	AIN8 V_{LOW} Limit	00h
39h-4Ch	Reserved	
4Dh	Device ID	02h
4Eh	Manufacturer's ID	41h
4Fh	Silicon Revision	xxh
50h-7Eh	Reserved	00h
7F	SPI Lock Status	00h
80hn-FFh	Reserved	00h

Interrupt Status 1 Register (Read-Only) [Address = 00h]

This 8-bit read-only register reflects the status of some of the interrupts that can cause the INT/$\overline{\text{INT}}$ pin to go active. This register is reset by a read operation provided that any out-of-limit event is corrected. It is also reset by a software reset.

Table 8. Interrupt Status 1 Register

D7	D6	D5	D4	D3	D2	D1	D0
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

Table 9.

Bit	Function
D0	1 when internal temperature value exceeds T_{HIGH} limit. Any internal temperature reading greater than the set limit causes an out-of-limit event.
D1	1 when internal temperature value exceeds T_{LOW} limit. Any internal temperature reading less than or equal to the set limit causes an out-of-limit event.
D2	This status bit is linked to the configuration of Pin 7 and Pin 8. If configured for external temperature sensor, this bit is 1 when external temperature 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 causes an out-of-limit event. If configured for AIN1 and AIN2, this bit is 1 when the AIN1 input voltage exceeds V_{HIGH} or V_{LOW} limits.
D3	1 when external temperature 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 causes an out-of-limit event.
D4	1 indicates a fault (open or short) for the external temp 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) [Address = 01h]

This 8-bit read-only register reflects the status of the V_{DD} and AIN5 to 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 is corrected. It is also reset by a software reset.

Table 10. Interrupt Status 2 Register

D7	D6	D5	D4	D3	D2	D1	D0
N/A	N/A	N/A	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

Table 11.

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

Internal Temperature Value/V_{DD} Value Register LSBs (Read-Only) [Address = 03h]

This internal temperature value and V_{DD} value register is an 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 12. Internal Temperature/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[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

Table 13.

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 AIN1 to AIN4 Register LSBs (Read-Only) [Address = 04h]

This is an 8-bit read-only register. Bit D2 to Bit D7 store the two LSBs of the analog inputs AIN2 to AIN4. Bit D0 and Bit 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 Bit 1 and Bit 2 of the Control Configuration 1 register.

Table 14. External Temperature and AIN1to AIN4 LSBs

D7	D6	D5	D4	D3	D2	D1	D0
A4	$A4_{LSB}$	A3	$A3_{LSB}$	A2	$A2_{LSB}$	T/A	T/A_{LSB}
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

Table 15.

Bit	Function
D0	LSB of External Temperature Value or AIN1 Value
D1	Bit 1 of External Temperature Value or AIN1 Value
D2	LSB of AIN2 Value
D3	Bit 1 of AIN2 Value
D4	LSB of AIN3 Value
D5	Bit 1 of AIN3 Value
D6	LSB of AIN4 Value
D7	Bit 1 of AIN4 Value

AIN5 to AIN8 Registers LSBs (Read-Only) [Address = 05h]

This is an 8-bit read-only register. Bit D0 to Bit D7 store the two LSBs of the analog inputs AIN5 to AIN8. The MSBs are stored in Register 0Ch to Register 0Fh.

Table 16. AIN5 to AIN8 LSBs

D7	D6	D5	D4	D3	D2	D1	D0
A8	$A8_{LSB}$	A7	$A7_{LSB}$	A6	$A6_{LSB}$	A5	$A5_{LSB}$
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

Table 17.

Bit	Function
D0	LSB of AIN5 Value
D1	Bit 1 of AIN5 Value
D2	LSB of AIN6 Value
D3	Bit 1 of AIN6 Value
D4	LSB of AIN7 Value
D5	Bit 1 of AIN7 Value
D6	LSB of AIN8 Value
D7	Bit 1 of AIN8 Value

V_{DD} Value Register MSBs (Read-Only) [Address = 06h]

This 8-bit read-only register stores the supply voltage value. The eight MSBs of the 10-bit value are stored in this register.

Table 18. V_{DD} Value MSBs

D7	D6	D5	D4	D3	D2	D1	D0
V9	V8	V7	V6	V5	V4	V3	V2
x[1]	x[1]	x[1]	x[1]	x[1]	x[1]	x[1]	x[1]

[1] Loaded with V_{DD} value after power-up.

Internal Temperature Value Register MSBs (Read-Only) [Address = 07h]

This 8-bit read-only register stores the internal temperature value from the internal temperature sensor in twos complement format. This register stores the eight MSBs of the 10-bit value.

Table 19. Internal Temperature Value MSBs

D7	D6	D5	D4	D3	D2	D1	D0
T9	T8	T7	T6	T5	T4	T3	T2
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

External Temperature Value or AIN1 Register MSBs (Read-Only) [Address = 08h]

This 8-bit read-only register stores, if selected, the external temperature value or the analog input AIN1 value. Selection is done in Control Configuration 1 register. The external temperature value is stored in twos complement format. The eight MSBs of the 10-bit value are stored in this register.

Table 20. 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[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

AIN2 Register MSBs (Read) [Address = 09h]

This 8-bit read register contains the eight MSBs of the AIN2 analog input voltage word. The value in this register is combined with Bit D2 and Bit D3 of the external temperature value and AIN1 to AIN4 register LSBs, Address 04h, to give the full 10-bit conversion result of the analog value on the AIN2 pin.

Table 21. AIN2 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

AIN3 Register MSBs (Read) [Address = 0Ah]

This 8-bit read register contains the eight MSBs of the AIN3 analog input voltage word. The value in this register is combined with Bit D4 and Bit D5 of the external temperature value and AIN1 to AIN4 register LSBs, Address 04h, to give the full 10-bit conversion result of the analog value on the AIN3 pin.

Table 22. AIN3 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

AIN4 Register MSBs (Read) [Address = 0Bh]

This 8-bit read register contains the eight MSBs of the AIN4 analog input voltage word. The value in this register is combined with Bit D6 and Bit D7 of the external temperature value and AIN1 to AIN4 register LSBs, Address 04h, to give the full 10-bit conversion result of the analog value on the AIN4 pin.

Table 23. AIN4 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

AIN5 Register MSBs (Read) [Address = 0Ch]

This 8-bit read register contains the eight MSBs of the AIN5 analog input voltage word. The value in this register is combined with Bit D0 and Bit D1 of the AIN5 to AIN8 register LSBs, Address 05h, to give the full 10-bit conversion result of the analog value on the AIN5 pin.

Table 24. AIN5 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

AIN6 Register MSBs (Read) [Address = 0Dh]

This 8-bit read register contains the eight MSBs of the AIN6 analog input voltage word. The value in this register is combined with Bit D2 and Bit D3 of the AIN5 to AIN8 register LSBs, Address 05h, to give the full 10-bit conversion result of the analog value on the AIN6 pin.

Table 25. AIN6 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

AIN7 Register MSBs (Read) [Address = 0Eh]

This 8-bit read register contains the eight MSBs of the AIN7 analog input voltage word. The value in this register is combined with Bit D4 and Bit D5 of the AIN5 to AIN8 register LSBs, Address 05h, to give the full 10-bit conversion result of the analog value on the AIN7 pin.

Table 26. AIN7 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

AIN8 Register MSBs (Read) [Address = 0Fh]

This 8-bit read register contains the eight MSBs of the AIN8 analog input voltage word. The value in this register is combined with Bit D6 and Bit D7 of the AIN5 to AIN8 register LSBs, Address 05h, to give the full 10-bit conversion result of the analog value on the AIN8 pin.

Table 27. AIN8 MSBs

D7	D6	D5	D4	D3	D2	D1	D0
MSB	A8	A7	A6	A5	A4	A3	A2
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

Control Configuration 1 Register (Read/Write) [Address = 18h]

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

Table 28. Control Configuration 1

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

[1] Default settings at power-up.

Table 29.

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 Pin 7 and Pin 8. The 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/$\overline{INT}$ output. 1: Disable INT/$\overline{INT}$ output.
C6	Configures INT/$\overline{INT}$ output polarity. 0: Active low. 1: 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 the serial interface is still operational. To power up the part again, write 0 to this bit.

Control Configuration 2 Register (Read/Write) [Address = 19h]

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

Table 30. Control Configuration 2

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

[1] Default settings at power-up.

Table 31.

Bit	Function
C3:C0	In single-channel mode, these bits select between V_{DD}, the internal temperature sensor, external temperature sensor/AIN1, AIN2 to AIN8 for conversion. The default is V_{DD}. 0000 = V_{DD}. 0001 = Internal Temperature Sensor. 0010 = External Temperature Sensor/AIN1. (Bit C1 and Bit C2 of Control Configuration 1 affect this selection.) 0011 = AIN2. 0100 = AIN3. 0101 = AIN4. 0110 = AIN5. 0111 = AIN6. 1000 = AIN7. 1001 = AIN8. 1010 to 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 25 ms limit on the pulse width of the clock, ensuring 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 reset to their default settings.

Control Configuration 3 Register (Read/Write) [Address = 1Ah]

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

Table 32. Control Configuration 3

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

[1] Default settings at power-up.

Table 33.

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. D+ and D− analog filters are disabled.
C1:C2	Reserved. Only write 0s.
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 0s.

Interrupt Mask 1 Register (Read/Write) [Address = 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/$\overline{\text{INT}}$ pin to go active.

Table 34. Interrupt Mask 1

D7	D6	D5	D4	D3	D2	D1	D0
D7	D6	D5	D4	D3	D2	D1	D0
0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	0[1]

[1] Default settings at power-up.

Table 35.

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