

SBOS383A − FEBRUARY 2007

±1°C Remote and Local TEMPERATURE SENSOR with N-Factor and Series Resistance Correction

FEATURES

- ±1°C REMOTE DIODE SENSOR
- ±1°C LOCAL TEMPERATURE SENSOR
- PROGRAMMABLE NON-IDEALITY FACTOR
- SERIES RESISTANCE CANCELLATION
- ALERT FUNCTION
- PROGRAMMABLE RESOLUTION: 9 to 12 Bits
- PROGRAMMABLE THRESHOLD LIMITS
- TWO-WIRE/SMBus™ SERIAL INTERFACE
- MINIMUM AND MAXIMUM TEMPERATURE MONITORS
- MULTIPLE INTERFACE ADDRESSES
- $\overline{\text{ALERT}}/\overline{\text{THERM2}}$ PIN CONFIGURATION
- DIODE FAULT DETECTION

APPLICATIONS

- LCD/DLP™/LCOS PROJECTORS
- SERVERS
- INDUSTRIAL CONTROLLERS
- CENTRAL OFFICE TELECOM EQUIPMENT
- DESKTOP AND NOTEBOOK COMPUTERS
- STORAGE AREA NETWORKS (SAN)
- INDUSTRIAL AND MEDICAL EQUIPMENT
- PROCESSOR/FPGA TEMPERATURE MONITORING

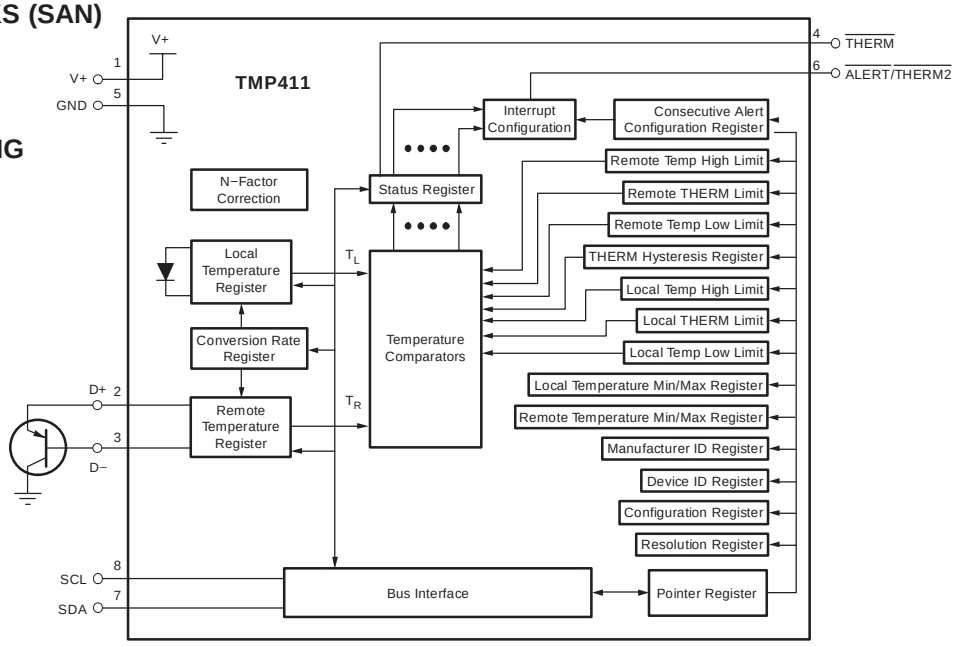
DESCRIPTION

The TMP411 is a remote temperature sensor monitor with a built-in local temperature sensor. The remote temperature sensor diode-connected transistors are typically low-cost, NPN- or PNP-type transistors or diodes that are an integral part of microcontrollers, microprocessors, or FPGAs.

Remote accuracy is ±1°C for multiple IC manufacturers, with no calibration needed. The Two-Wire serial interface accepts SMBus write byte, read byte, send byte, and receive byte commands to program the alarm thresholds and to read temperature data.

Features that are included in the TMP411 are: series resistance cancellation, programmable non-ideality factor, programmable resolution, programmable threshold limits, minimum and maximum temperature monitors, wide remote temperature measurement range (up to +150°C), diode fault detection, and temperature alert function.

The TMP411 is available in both MSOP-8 and SO-8 (available Q1 2007) packages.



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ABSOLUTE MAXIMUM RATINGS(1)

Power Supply, V_S	7.0V
Input Voltage, pins 2, 3, 4 only	−0.5V to V_S + 0.5V
Input Voltage, pins 6, 7, 8 only	−0.5V to 7V
Input Current	10mA
Operating Temperature Range	−55°C to +127°C
Storage Temperature Range	−60°C to +130°C
Junction Temperature (T_J max)	+150°C
ESD Rating:	
Human Body Model (HBM)	3000V
Charged Device Model (CDM)	1000V
Machine Model (MM)	200V

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not supported.

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

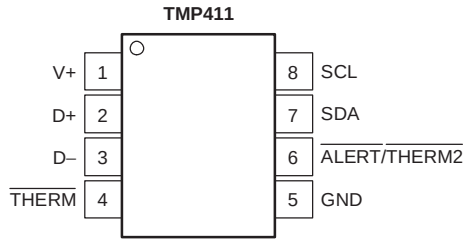
ORDERING INFORMATION(1)

PRODUCT	DESCRIPTION	I²C ADDRESS	PACKAGE-LEAD	PACKAGE DESIGNATOR	PACKAGE MARKING
TMP411A	Remote Junction Temperature Sensor	100 1100	MSOP-8	DGK	411A
			SO-8(2)	D	T411A
TMP411B	Remote Junction Temperature Sensor	100 1101	MSOP-8	DGK	411B
			SO-8(2)	D	T411B

(1) For the most current package and ordering information see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.
(2) Available Q1 2007.

PIN CONFIGURATION

Top View **MSOP, SO**



PIN ASSIGNMENTS

PIN	NAME	DESCRIPTION
1	V+	Positive supply (2.7V to 5.5V)
2	D+	Positive connection to remote temperature sensor
3	D−	Negative connection to remote temperature sensor
4	$\overline{\text{THERM}}$	Thermal flag, active low, open-drain; requires pull-up resistor to V+
5	GND	Ground
6	$\overline{\text{ALERT}}/\overline{\text{THERM2}}$	Alert (reconfigurable as second thermal flag), active low, open-drain; requires pull-up resistor to V+
7	SDA	Serial data line for SMBus, open-drain; requires pull-up resistor to V+
8	SCL	Serial clock line for SMBus, open-drain; requires pull-up resistor to V+

ELECTRICAL CHARACTERISTICS

At T_A = −40°C to +125°C and V_S = 2.7V to 5.5V, unless otherwise noted.

PARAMETERS		CONDITIONS	TMP411 MIN	TMP411 TYP	TMP411 MAX	UNITS
TEMPERATURE ERROR						
Local Temperature Sensor	TE_{LOCAL}	T_A = −40°C to +125°C		±1.25	±2.5	°C
		T_A = +15°C to +85°C, V_S = 3.3V		±0.0625	±1	°C
Remote Temperature Sensor(1)	TE_{REMOTE}	T_A = +15°C to +75°C, T_D = −40°C to +150°C, V_S = 3.3V		±0.0625	±1	°C
		T_A = −40°C to +100°C, T_D = −40°C to +150°C, V_S = 3.3V		±1	±3	°C
		T_A = −40°C to +125°C, T_D = −40°C to +150°C		±3	±5	°C
vs Supply						
Local/Remote		V_S = 2.7V to 5.5V		±0.2	±0.5	°C/V
TEMPERATURE MEASUREMENT						
Conversion Time (per channel)			105	115	125	ms
Resolution						
Local Temperature Sensor (programmable)			9		12	Bits
Remote Temperature Sensor				12		Bits
Remote Sensor Source Currents						
High		Series Resistance 3kΩ Max		120		µA
Medium High				60		µA
Medium Low				12		µA
Low				6		µA
Remote Transistor Ideality Factor	η	TMP411 Optimized Ideality Factor		1.008		
SMBus INTERFACE						
Logic Input High Voltage (SCL, SDA)	V_{IH}		2.1			V
Logic Input Low Voltage (SCL, SDA)	V_{IL}				0.8	V
Hysteresis				500		mV
SMBus Output Low Sink Current			6			mA
Logic Input Current			−1		+1	µA
SMBus Input Capacitance (SCL, SDA)				3		pF
SMBus Clock Frequency					3.4	MHz
SMBus Timeout			25	30	35	ms
SCL Falling Edge to SDA Valid Time					1	µs
DIGITAL OUTPUTS						
Output Low Voltage	V_{OL}	I_{OUT} = 6mA		0.15	0.4	V
High-Level Output Leakage Current	I_{OH}	V_{OUT} = V_S		0.1	1	µA
$\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ Output Low Sink Current		$\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ Forced to 0.4V	6			mA
$\overline{\text{THERM}}$ Output Low Sink Current		$\overline{\text{THERM}}$ Forced to 0.4V	6			mA
POWER SUPPLY						
Specified Voltage Range	V_S		2.7		5.5	V
Quiescent Current	I_Q	0.0625 Conversions per Second		28	30	µA
		Eight Conversions per Second		400	475	µA
		Serial Bus Inactive, Shutdown Mode		3	10	µA
		Serial Bus Active, f_S = 400kHz, Shutdown Mode		90		µA
		Serial Bus Active, f_S = 3.4MHz, Shutdown Mode		350		µA
Undervoltage Lock Out			2.3	2.4	2.6	V
Power-On Reset Threshold	POR			1.6	2.3	V
TEMPERATURE RANGE						
Specified Range			−40		+125	°C
Storage Range			−60		+130	°C
Thermal Resistance						
MSOP-8, SO-8				150		°C/W

(1) Tested with less than 5Ω effective series resistance and 100pF differential input capacitance.

TYPICAL CHARACTERISTICS

At T_A = +25°C and V_S = 5.0V, unless otherwise noted.

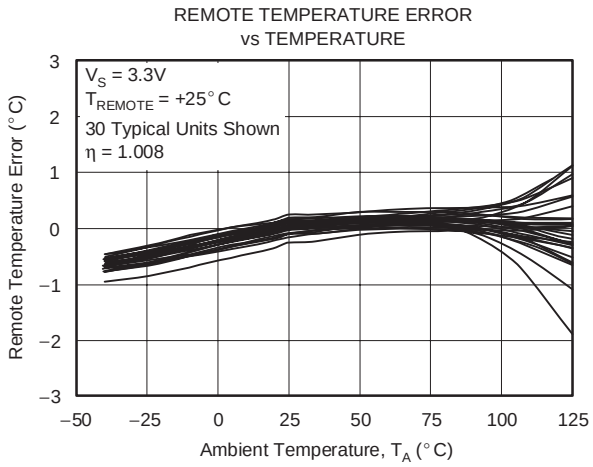


Figure 1.

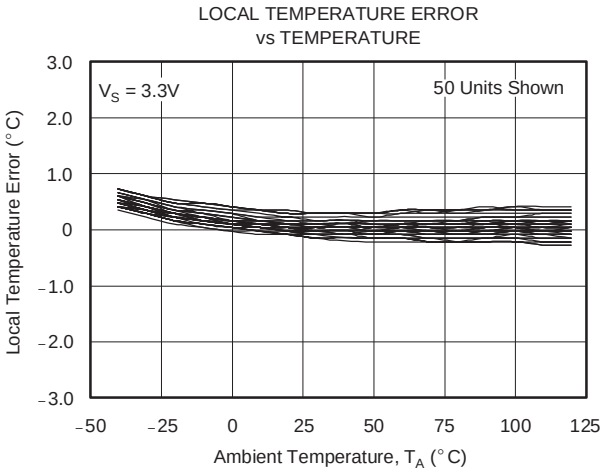


Figure 2.

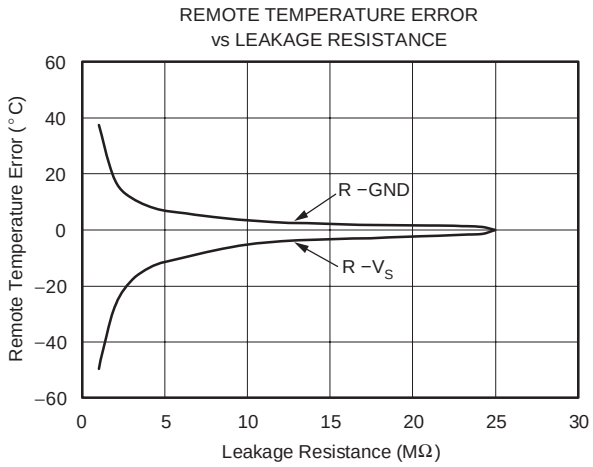


Figure 3.

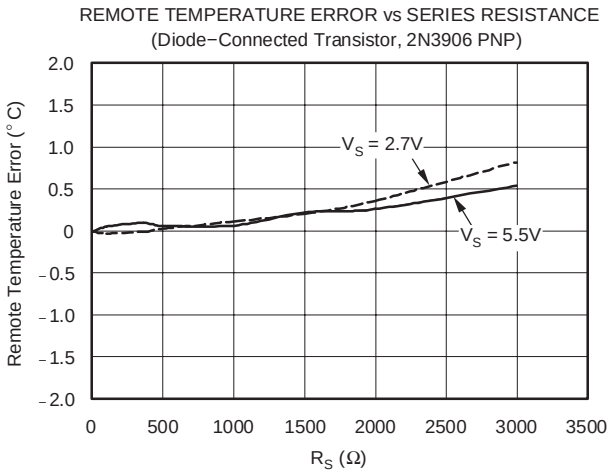


Figure 4.

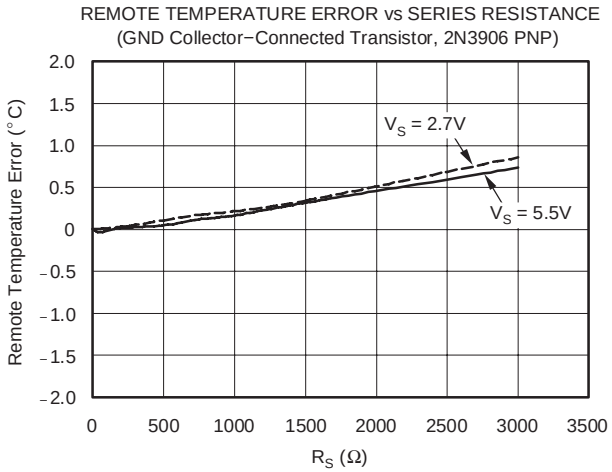


Figure 5.

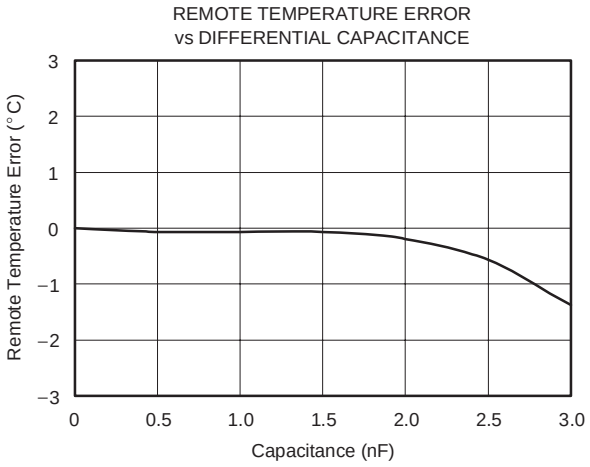


Figure 6.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C and V_S = 5.0V, unless otherwise noted.

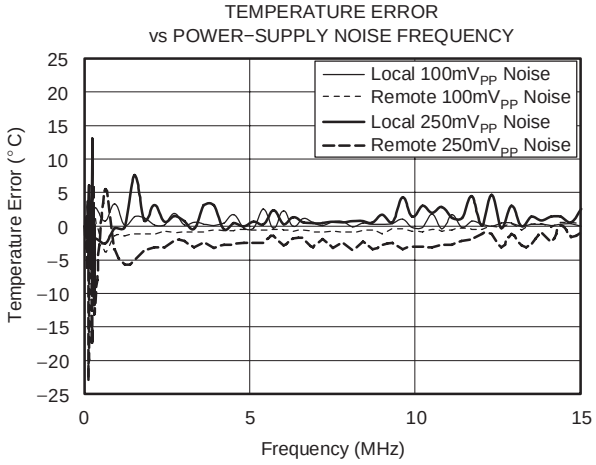


Figure 7.

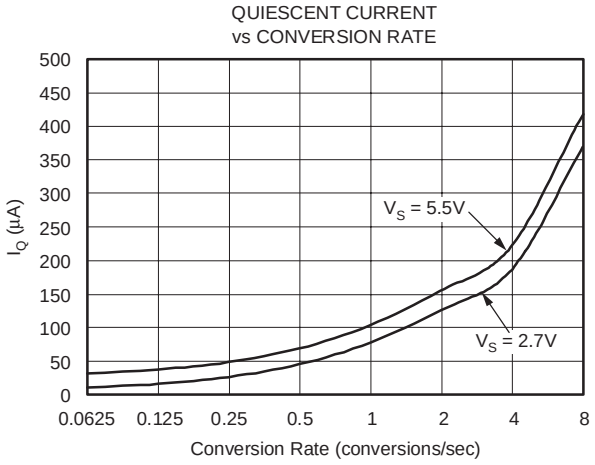


Figure 8.

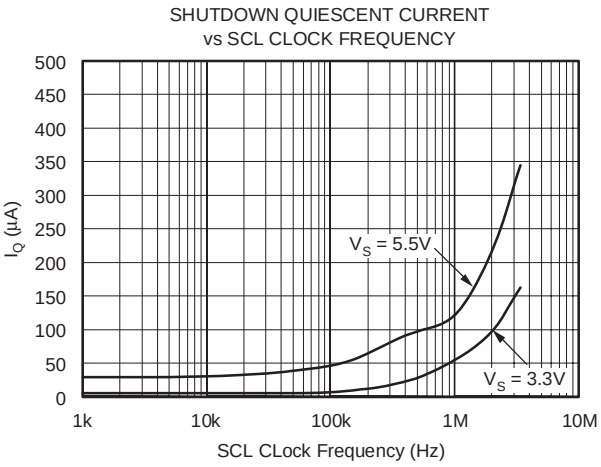


Figure 9.

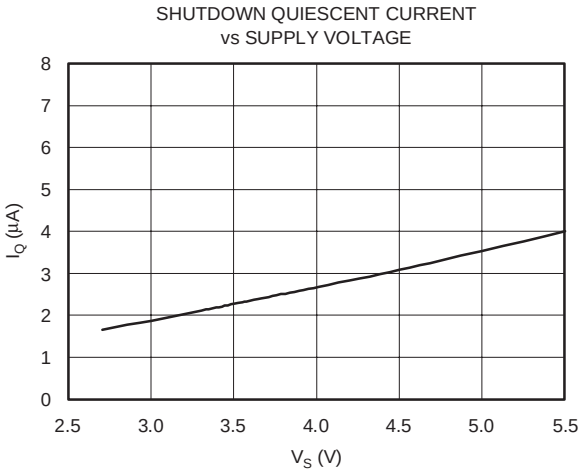


Figure 10.

APPLICATIONS INFORMATION

The TMP411 is a dual-channel digital temperature sensor that combines a local die temperature measurement channel and a remote junction temperature measurement channel in a single MSOP-8 or SO-8 package. The TMP411 is Two-Wire- and SMBus interface-compatible and is specified over a temperature range of −40°C to +125°C. The TMP411 contains multiple registers for holding configuration information, temperature measurement results, temperature comparator maximum/minimum limits, and status information.

User-programmed high and low temperature limits stored in the TMP401 can be used to monitor local and remote temperatures to trigger an over/under temperature alarm ($\overline{\text{ALERT}}$). Additional thermal limits can be programmed into the TMP411 and used to trigger another flag ($\overline{\text{THERM}}$) that can be used to initiate a system response to rising temperatures.

The TMP411 requires only a transistor connected between D+ and D− for proper remote temperature sensing operation. The SCL and SDA interface pins require pull-up resistors as part of the communication bus, while $\overline{\text{ALERT}}$ and $\overline{\text{THERM}}$ are open-drain outputs that also need pull−up resistors. $\overline{\text{ALERT}}$ and $\overline{\text{THERM}}$ may be shared with other devices if desired for a wired-OR implementation. A 0.1µF power-supply bypass capacitor is recommended for good local bypassing. Figure 11 shows a typical configuration for the TMP411.

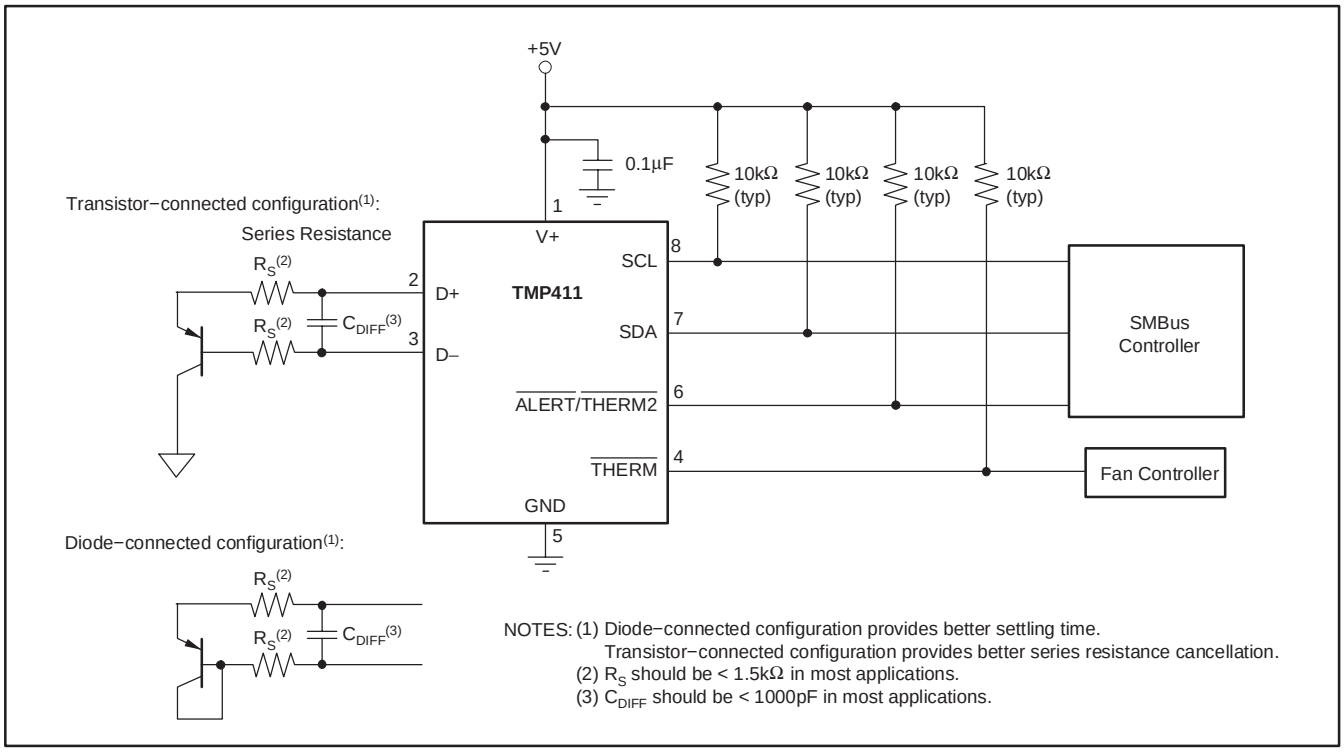


Figure 11. Basic Connections

SERIES RESISTANCE CANCELLATION

Series resistance in an application circuit that typically results from printed circuit board (PCB) trace resistance and remote line length (see Figure 11) is automatically cancelled by the TMP411, preventing what would otherwise result in a temperature offset.

A total of up to 3kΩ of series line resistance is cancelled by the TMP411, eliminating the need for additional characterization and temperature offset correction.

See the two *Remote Temperature Error vs Series Resistance* typical characteristics curves for details on the effect of series resistance and power-supply voltage on sensed remote temperature error.

DIFFERENTIAL INPUT CAPACITANCE

The TMP411 tolerates differential input capacitance of up to 1000pF with minimal change in temperature error. The effect of capacitance on sensed remote temperature error is illustrated in typical characteristic *Remote Temperature Error vs Differential Capacitance*.

TEMPERATURE MEASUREMENT DATA

Temperature measurement data is taken over a default range of 0°C to +127°C for both local and remote locations. Measurements from −55°C to +150°C can be made both locally and remotely by reconfiguring the TMP411 for the extended temperature range. To change the TMP411 configuration from the standard to the extended temperature range, switch bit 2 (RANGE) of the Configuration Register from low to high.

Temperature data resulting from conversions within the default measurement range is represented in binary form, as shown in Table 1, Standard Binary column. Note that any temperature below 0°C results in a data value of zero (00h). Likewise, temperatures above +127°C result in a value of 127 (7Fh). The device can be set to measure over an extended temperature range by changing bit 2 of the Configuration Register from low to high. The change in measurement range and data format from standard binary to extended binary occurs at the next temperature conversion. For data captured in the extended temperature range configuration, an offset of 64 (40h) is added to the standard binary value, as shown in Table 1, Extended Binary column. This configuration allows measurement of temperatures below 0°C. Note that binary values corresponding to temperatures as low as −64°C, and as high as +191°C are possible; however, most temperature sensing diodes only measure with the range of −55°C to +150°C. Additionally, the TMP411 is rated only for ambient temperatures ranging from −40°C to +125°C. Parameters in the Absolute Maximum Ratings table must be observed.

Table 1. Temperature Data Format (Local and Remote Temperature High Bytes)

TEMP (°C)	LOCAL/REMOTE TEMPERATURE REGISTER HIGH BYTE VALUE (+1°C RESOLUTION)			
	STANDARD BINARY		EXTENDED BINARY	
	BINARY	HEX	BINARY	HEX
−64	0000 0000	00	0000 0000	00
−50	0000 0000	00	0000 1110	0E
−25	0000 0000	00	0010 0111	27
0	0000 0000	00	0100 0000	40
1	0000 0001	01	0100 0001	41
5	0000 0101	05	0100 0101	45
10	0000 1010	0A	0100 1010	4A
25	0001 1001	19	0101 1001	59
50	0011 0010	32	0111 0010	72
75	0100 1011	4B	1000 1011	8B
100	0110 0100	64	1010 0100	A4
125	0111 1101	7D	1011 1101	BD
127	0111 1111	7F	1011 1111	BF
150	0111 1111	7F	1101 0110	D6
175	0111 1111	7F	1110 1111	EF
191	0111 1111	7F	1111 1111	FF

NOTE: Whenever changing between standard and extended temperature ranges, be aware that the temperatures stored in the temperature limit registers are NOT automatically reformatted to correspond to the new temperature range format. These temperature limit values must be reprogrammed in the appropriate binary or extended binary format.

Both local and remote temperature data use two bytes for data storage. The high byte stores the temperature with 1°C resolution. The second or low byte stores the decimal fraction value of the temperature and allows a higher measurement resolution; see Table 2. The measurement resolution for the remote channel is 0.0625°C, and is not adjustable. The measurement resolution for the local channel is adjustable; it can be set for 0.5°C, 0.25°C, 0.125°C, or 0.0625°C by setting the RES1 and RES0 bits of the Resolution Register; see the *Resolution Register* section.

Table 2. Decimal Fraction Temperature Data Format (Local and Remote Temperature Low Bytes)

TEMP (°C)	REMOTE TEMPERATURE REGISTER LOW BYTE VALUE		LOCAL TEMPERATURE REGISTER LOW BYTE VALUE							
	0.0625°C RESOLUTION		0.5°C RESOLUTION		0.25°C RESOLUTION		0.125°C RESOLUTION		0.0625°C RESOLUTION	
	STANDARD AND EXTENDED BINARY	HEX	STANDARD AND EXTENDED BINARY	HEX	STANDARD AND EXTENDED BINARY	HEX	STANDARD AND EXTENDED BINARY	HEX	STANDARD AND EXTENDED BINARY	HEX
0.0000	0000 0000	00	0000 0000	00	0000 0000	00	0000 0000	00	0000 0000	00
0.0625	0001 0000	10	0000 0000	00	0000 0000	00	0000 0000	00	0001 0000	10
0.1250	0010 0000	20	0000 0000	00	0000 0000	00	0010 0000	20	0010 0000	20
0.1875	0011 0000	30	0000 0000	00	0000 0000	00	0010 0000	20	0011 0000	30
0.2500	0100 0000	40	0000 0000	00	0100 0000	40	0100 0000	40	0100 0000	40
0.3125	0101 0000	50	0000 0000	00	0100 0000	40	0100 0000	40	0101 0000	50
0.3750	0110 0000	60	0000 0000	00	0100 0000	40	0110 0000	60	0110 0000	60
0.4375	0111 0000	70	0000 0000	00	0100 0000	40	0110 0000	60	0111 0000	70
0.5000	1000 0000	80	1000 0000	80	1000 0000	80	1000 0000	80	1000 0000	80
0.5625	1001 0000	90	1000 0000	80	1000 0000	80	1000 0000	80	1001 0000	90
0.6250	1010 0000	A0	1000 0000	80	1000 0000	80	1010 0000	A0	1010 0000	A0
0.6875	1011 0000	B0	1000 0000	80	1000 0000	80	1010 0000	A0	1011 0000	B0
0.7500	1100 0000	C0	1000 0000	80	1100 0000	C0	1100 0000	C0	1100 0000	C0
0.8125	1101 0000	D0	1000 0000	80	1100 0000	C0	1100 0000	C0	1101 0000	D0
0.8750	1110 0000	E0	1000 0000	80	1100 0000	C0	1110 0000	E0	1110 0000	E0
0.9385	1111 0000	F0	1000 0000	80	1100 0000	C0	1110 0000	E0	1111 0000	F0

REGISTER INFORMATION

The TMP411 contains multiple registers for holding configuration information, temperature measurement results, temperature comparator maximum/minimum, limits, and status information. These registers are described in Figure 12 and Table 3.

POINTER REGISTER

Figure 12 shows the internal register structure of the TMP411. The 8-bit Pointer Register is used to address a given data register. The Pointer Register identifies which of the data registers should respond to a read or write command on the Two-Wire bus. This register is set with every write command. A write command must be issued to set the proper value in the Pointer Register before executing a read command. Table 3 describes the pointer address of the registers available in the TMP411. The power-on reset (POR) value of the Pointer Register is 00h (0000 0000b).

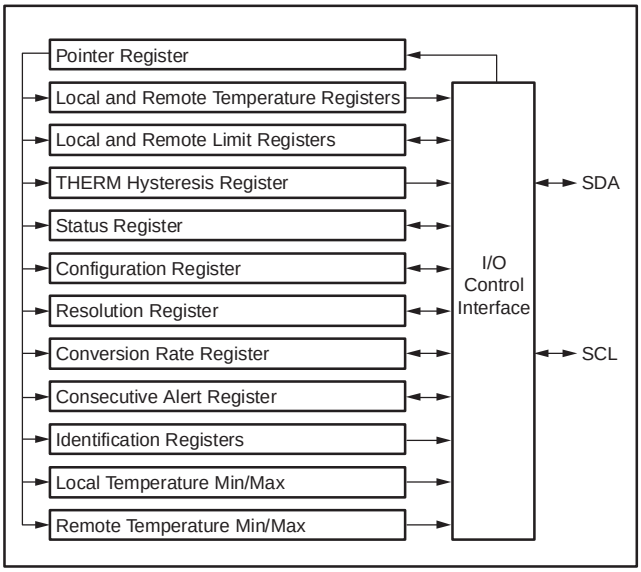


Figure 12. Internal Register Structure

Table 3. Register Map

POINTER ADDRESS (HEX)		POWER-ON RESET (HEX)	BIT DESCRIPTIONS								REGISTER DESCRIPTIONS
READ	WRITE		D7	D6	D5	D4	D3	D2	D1	D0	
00	NA(1)	00	LT11	LT10	LT9	LT8	LT7	LT6	LT5	LT4	Local Temperature (High Byte)
01	NA	00	RT11	RT10	RT9	RT8	RT7	RT6	RT5	RT4	Remote Temperature (High Byte)
02	NA	XX	BUSY	LHIGH	LLOW	RHIGH	RLOW	OPEN	RTHRM	LTHRM	Status Register
03	09	00	MASK1	SD	AL/TH	0	0	RANGE	0	0	Configuration Register
04	0A	08	0	0	0	0	R3	R2	R1	R0	Conversion Rate Register
05	0B	55	LTH11	LTH10	LTH9	LTH8	LTH7	LTH6	LTH5	LTH4	Local Temperature High Limit (High Byte)
06	0C	00	LTL11	LTL10	LTL9	LTL8	LTL7	LTL6	LTL5	LTL4	Local Temperature Low Limit (High Byte)
07	0D	55	RTH11	RTH10	RTH9	RTH8	RTH7	RTH6	RTH5	RTH4	Remote Temperature High Limit (High Byte)
08	0E	00	RTL11	RTL10	RTL9	RTL8	RTL7	RTL6	RTL5	RTL4	Remote Temperature Low Limit (High Byte)
10	NA	00	RT3	RT2	RT1	RT0	0	0	0	0	Remote Temperature (Low Byte)
13	13	00	RTH3	RTH2	RTH1	RTH0	0	0	0	0	Remote Temperature High Limit (Low Byte)
14	14	00	RTL3	RTL2	RTL1	RTL0	0	0	0	0	Remote Temperature Low Limit (Low Byte)
15	NA	00	LT3	LT2	LT1	LT0	0	0	0	0	Local Temperature (Low Byte)
16	16	00	LTH3	LTH2	LTH1	LTH0	0	0	0	0	Local Temperature High Limit (Low Byte)
17	17	00	LTL3	LTL2	LTL1	LTL0	0	0	0	0	Local Temperature Low Limit (Low Byte)
18	18	00	NC7	NC6	NC5	NC4	NC3	NC2	NC1	NC0	N-factor Correction
19	19	55	RTHL11	RTHL10	RTHL9	RTHL8	RTHL7	RTHL6	RTHL5	RTHL4	Remote THERM Limit
1A	1A	1C	0	0	0	1	1	1	RES1	RES0	Resolution Register
20	20	55	LTHL11	LTHL10	LTHL9	LTHL8	LTHL7	LTHL6	LTHL5	LTHL4	Local THERM Limit
21	21	0A	TH11	TH10	TH9	TH8	TH7	TH6	TH5	TH4	THERM Hysteresis
22	22	80	TO_EN	0	0	0	C2	C1	C0	0	Consecutive Alert Register
30	30	FF	LMT11	LMT10	LMT9	LMT8	LMT7	LMT6	LMT5	LMT4	Local Temperature Minimum (High Byte)
31	31	F0	LMT3	LMT2	LMT1	LMT0	0	0	0	0	Local Temperature Minimum (Low Byte)
32	32	00	LXT11	LXT10	LXT9	LXT8	LXT7	LXT6	LXT5	LXT4	Local Temperature Maximum (High Byte)
33	33	00	LXT3	LXT2	LXT1	LXT0	0	0	0	0	Local Temperature Maximum (Low Byte)
34	34	FF	RMT11	RMT10	RMT9	RMT8	RMT7	RMT6	RMT5	RMT4	Remote Temperature Minimum (High Byte)
35	35	F0	RMT3	RMT2	RMT1	RMT0	0	0	0	0	Remote Temperature Minimum (Low Byte)
36	36	00	RXT11	RXT10	RXT9	RXT8	RXT7	RXT6	RXT5	RXT4	Remote Temperature Maximum (High Byte)
37	37	00	RXT3	RXT2	RXT1	RXT0	0	0	0	0	Remote Temperature Maximum (Low Byte)
NA	FC	XX	X(2)	X	X	X	X	X	X	X	Software Reset
FE	NA	55	0	1	0	1	0	1	0	1	Manufacturer ID
FF	NA	11	0	0	0	1	0	0	0	1	Device ID

(1) NA = not applicable; register is write- or read-only.
(2) X = indeterminate state.

TEMPERATURE REGISTERS

The TMP411 has four 8-bit registers that hold temperature measurement results. Both the local channel and the remote channel have a high byte register that contains the most significant bits (MSBs) of the temperature ADC result and a low byte register that contains the least significant bits (LSBs) of the temperature ADC result. The local channel high byte address is 00h; the local channel low byte address is 15h. The remote channel high byte is at address 01h; the remote channel low byte address is 10h. These registers are read-only and are updated by the ADC each time a temperature measurement is completed.

The TMP411 contains circuitry to assure that a low byte register read command returns data from the same ADC conversion as the immediately preceding high byte read command. This assurance remains valid only until another register is read. For proper operation, the high byte of a temperature register should be read first. The low byte register should be read in the next read command. The low byte register may be left unread if the LSBs are not needed. Alternatively, the temperature registers may be read as a 16-bit register by using a single two-byte read command from address 00h for the local channel result or from address 01h for the remote channel result. The high byte will be output first, followed by the low byte. Both bytes of this read operation will be from the same ADC conversion. The power-on reset value of both temperature registers is 00h.

LIMIT REGISTERS

The TMP411 has 11 registers for setting comparator limits for both the local and remote measurement channels. These registers have read and write capability. The High and Low Limit Registers for both channels span two registers, as do the temperature registers. The local temperature high limit is set by writing the high byte to pointer address 0Bh and writing the low byte to pointer address 16h, or by using a single two-byte write command (high byte first) to pointer address 0Bh. The local temperature high limit is obtained by reading the high byte from pointer address 05h and the low byte from pointer address 16h. The power-on reset value of the local temperature high limit is 55h/00h (+85°C in standard temperature mode; +21°C in extended temperature mode).

Similarly, the local temperature low limit is set by writing the high byte to pointer address 0Ch and writing the low byte to pointer address 17h, or by using a single two-byte write command to pointer address 0Ch. The local temperature low limit is read by reading the high byte from pointer address 06h and the low byte from pointer address 17h, or by using a two-byte read from pointer address 06h. The power-on reset value of the local temperature low limit register is 00h/00h (0°C in standard temperature mode; −64°C in extended mode).

The remote temperature high limit is set by writing the high byte to pointer address 0Dh and writing the low byte to pointer address 13h, or by using a two-byte write command to pointer address 0Dh. The remote temperature high limit is obtained by reading the high byte from pointer address 07h and the low byte from pointer address 13h, or by using a two-byte read command from pointer address 07h. The power-on reset value of the Remote Temperature High Limit Register is 55h/00h (+85°C in standard temperature mode; +21°C in extended temperature mode).

The remote temperature low limit is set by writing the high byte to pointer address 0Eh and writing the low byte to pointer address 14h, or by using a two-byte write to pointer address 0Eh. The remote temperature low limit is read by reading the high byte from pointer address 08h and the low byte from pointer address 14h, or by using a two-byte read from pointer address 08h. The power-on reset value of the Remote Temperature Low Limit Register is 00h/00h (0°C in standard temperature mode; −64°C in extended mode).

The TMP411 also has a THERM limit register for both the local and the remote channels. These registers are eight bits and allow for THERM limits set to 1°C resolution. The local channel THERM limit is set by writing to pointer address 20h. The remote channel THERM limit is set by writing to pointer address 19h. The local channel THERM limit is obtained by reading from pointer address 20h; the remote channel THERM limit is read by reading from pointer address 19h. The power-on reset value of the THERM limit registers is 55h (+85°C in standard temperature mode; +21°C in extended temperature mode). The THERM limit comparators also have hysteresis. The hysteresis of both comparators is set by writing to pointer address 21h. The hysteresis value is obtained by reading from pointer address 21h. The value in the Hysteresis Register is an unsigned number (always positive). The power-on reset value of this register is 0Ah (+10°C).

Whenever changing between standard and extended temperature ranges, be aware that the temperatures stored in the temperature limit registers are NOT automatically reformatted to correspond to the new temperature range format. These values must be reprogrammed in the appropriate binary or extended binary format.

STATUS REGISTER

The TMP411 has a Status Register to report the state of the temperature comparators. Table 4 shows the Status Register bits. The Status Register is read-only and is read by reading from pointer address 02h.

The BUSY bit reads as ‘1’ if the ADC is making a conversion. It reads as ‘0’ if the ADC is not converting.

The OPEN bit reads as ‘1’ if the remote transistor was detected as open since the last read of the Status Register. The OPEN status is only detected when the ADC is attempting to convert a remote temperature.

The RTHRM bit reads as ‘1’ if the remote temperature has exceeded the remote THERM limit and remains greater than the remote THERM limit less the value in the shared Hysteresis Register; see Figure 17.

The LTHRM bit reads as ‘1’ if the local temperature has exceeded the local THERM limit and remains greater than the local THERM limit less the value in the shared Hysteresis Register; see Figure 17.

The LHIGH and RHIGH bit values depend on the state of the AL/TH bit in the Configuration Register. If the AL/TH bit is ‘0’, the LHIGH bit reads as ‘1’ if the local high limit was exceeded since the last clearing of the Status Register. The RHIGH bit reads as ‘1’ if the remote high limit was exceeded since the last clearing of the Status Register. If the AL/TH bit is ‘1’, the remote high limit and the local high limit are used to implement a $\overline{\text{THERM2}}$ function. LHIGH reads as ‘1’ if the local temperature has exceeded the local high limit and remains greater than the local high limit less the value in the Hysteresis Register.

The RHIGH bit reads as ‘1’ if the remote temperature has exceeded the remote high limit and remains greater than the remote high limit less the value in the Hysteresis Register.

The LLOW and RLOW bits are not affected by the AL/TH bit. The LLOW bit reads as ‘1’ if the local low limit was exceeded since the last clearing of the Status Register. The RLOW bit reads as ‘1’ if the remote low limit was exceeded since the last clearing of the Status Register.

The values of the LLOW, RLOW, and OPEN (as well as LHIGH and RHIGH when AL/TH is ‘0’) are latched and will read as ‘1’ until the Status Register is read or a device reset occurs. These bits are cleared by reading the Status Register, provided that the condition causing the flag to be set no longer exists. The values of BUSY, LTHRM, and RTHRM (as well as LHIGH and RHIGH when AL/TH is ‘1’) are not latched and are not cleared by reading the Status Register. They always indicate the current state, and are updated appropriately at the end of the corresponding ADC conversion. Clearing the Status Register bits does not clear the state of the $\overline{\text{ALERT}}$ pin; an SMBus alert response address command must be used to clear the $\overline{\text{ALERT}}$ pin.

The TMP411 NORs LHIGH, LLOW, RHIGH, RLOW, and OPEN, so a status change for any of these flags from ‘0’ to ‘1’ automatically causes the $\overline{\text{ALERT}}$ pin to go low (only applies when the $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ pin is configured for ALERT mode).

Table 4. Status Register Format

STATUS REGISTER (Read = 02h, Write = NA)								
BIT #	**D7**	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
BIT NAME	BUSY	LHIGH	LLOW	RHIGH	RLOW	OPEN	RTHRM	LTHRM
POR VALUE	0(1)	0	0	0	0	0	0	0

(1) The BUSY bit will change to ‘1’ almost immediately (<< 100µs) following power-up, as the TMP411 begins the first temperature conversion. It will be high whenever the TMP411 is converting a temperature reading.

CONFIGURATION REGISTER

The Configuration Register sets the temperature range, controls shutdown mode, and determines how the $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ pin functions. The Configuration Register is set by writing to pointer address 09h and read by reading from pointer address 03h.

The MASK bit (bit 7) enables or disables the $\overline{\text{ALERT}}$ pin output if AL/TH = 0. If AL/TH = 1 then the MASK bit has no effect. If MASK is set to '0', the $\overline{\text{ALERT}}$ pin goes low when one of the temperature measurement channels exceeds its high or low limits for the chosen number of consecutive conversions. If the MASK bit is set to '1', the TMP411 retains the $\overline{\text{ALERT}}$ pin status, but the $\overline{\text{ALERT}}$ pin will not go low.

The shutdown (SD) bit (bit 6) enables or disables the temperature measurement circuitry. If SD = 0, the TMP411 converts continuously at the rate set in the conversion rate register. When SD is set to '1', the TMP411 immediately stops converting and enters a shutdown mode. When SD is set to '0' again, the TMP411 resumes continuous conversions.

The AL/TH bit (bit 5) controls whether the $\overline{\text{ALERT}}$ pin functions in ALERT mode or THERM2 mode. If AL/TH = 0, the $\overline{\text{ALERT}}$ pin operates as an interrupt pin. In this mode, the $\overline{\text{ALERT}}$ pin goes low after the set number of consecutive out-of-limit temperature measurements occur.

If AL/TH = 1, the $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ pin implements a THERM function ($\overline{\text{THERM2}}$). In this mode, $\overline{\text{THERM2}}$ functions similar to the $\overline{\text{THERM}}$ pin except that the local high limit and remote high limit registers are used for the thresholds. $\overline{\text{THERM2}}$ goes low when either RHIGH or LHIGH is set.

The temperature range is set by configuring bit 2 of the Configuration Register. Setting this bit low configures the TMP411 for the standard measurement range (0°C to +127°C); temperature conversions will be stored in the standard binary format. Setting bit 2 high configures the TMP411 for the extended measurement range (−55°C to +150°C); temperature conversions will be stored in the extended binary format (see Table 1).

The remaining bits of the Configuration Register are reserved and must always be set to '0'. The power-on reset value for this register is 00h. Table 5 summarizes the bits of the Configuration Register.

Table 5. Configuration Register Bit Descriptions

CONFIGURATION REGISTER (Read = 02h, Write = NA, POR = 00h)			
BIT	**NAME**	**FUNCTION**	**POWER-ON RESET VALUE**
7	MASK	0 = ALERT Enabled 1 = ALERT Masked	0
6	SD	0 = Run 1 = Shut Down	0
5	AL/TH	0 = ALERT Mode 1 = THERM Mode	0
4, 3	Reserved	—	0
2	Temperature Range	0 = 0°C to +127°C 1 = −55°C to +150°C	0
1, 0	Reserved	—	0

RESOLUTION REGISTER

The RES1 and RES0 bits (resolution bits 1 and 0) of the Resolution Register set the resolution of the local temperature measurement channel. Remote temperature measurement channel resolution is not affected. Changing the local channel resolution also affects the conversion time and rate of the TMP411. The Resolution Register is set by writing to pointer address 1Ah and is read by reading from pointer address 1Ah. Table 6 shows the resolution bits for the Resolution Register.

Table 6. Resolution Register: Local Channel Programmable Resolution

RESOLUTION REGISTER (Read = 1Ah, Write = 1Ah, POR = 1Ch)			
RES1	**RES0**	**RESOLUTION**	**CONVERSION TIME (Typical)**
0	0	9 Bits (0.5°C)	12.5ms
0	1	10 Bits (0.25°C)	25ms
1	0	11 Bits (0.125°C)	50ms
1	1	12 Bits (0.0625°C)	100ms

Bits 2 through 4 of the Resolution Register must always be set to ‘1’. Bits 5 through 7 of the Resolution Register must always be set to ‘0’. The power-on reset value of this register is 1Ch.

CONVERSION RATE REGISTER

The Conversion Rate Register controls the rate at which temperature conversions are performed. This register adjusts the idle time between conversions but not the conversion timing itself, thereby allowing the TMP411 power dissipation to be balanced with the temperature register update rate. Table 7 shows the conversion rate options and corresponding current consumption.

N-FACTOR CORRECTION REGISTER

The TMP411 allows for a different *n*-factor value to be used for converting remote channel measurements to temperature. The remote channel uses sequential current excitation to extract a differential V_{BE} voltage measurement to determine the temperature of the remote transistor. Equation 1 relates this voltage and temperature.

$$V_{BE2} - V_{BE1} = \frac{nkT}{q} \ln\left(\frac{I_2}{I_1}\right) \quad (1)$$

The value *n* in Equation 1 is a characteristic of the particular transistor used for the remote channel. The default value for the TMP411 is *n* = 1.008. The value in the N-Factor Correction Register may be used to adjust the effective *n*-factor according to Equation 2 and Equation 3.

$$n_{eff} = \frac{1.008 \cdot 300}{(300 - N_{ADJUST})} \quad (2)$$

$$N_{ADJUST} = 300 - \left(\frac{300 \cdot 1.008}{n_{eff}}\right) \quad (3)$$

The *n*-correction value must be stored in two’s-complement format, yielding an effective data range from −128 to +127. The *n*-correction value may be written to and read from pointer address 18h. The register power-on reset value is 00h, thus having no effect unless written to.

Table 7. Conversion Rate Register

CONVERSION RATE REGISTER (Read = 04h, Write = 04h, POR = 08h)										
									AVERAGE I_Q (TYP) (μA)	
R7	**R6**	**R5**	**R4**	**R3**	**R2**	**R1**	**R0**	**CONVERSION/SEC**	**V_S = 2.7V**	**V_S = 5.5V**
0	0	0	0	0	0	0	0	0.0625	11	32
0	0	0	0	0	0	0	1	0.125	17	38
0	0	0	0	0	0	1	0	0.25	28	49
0	0	0	0	0	0	1	1	0.5	47	69
0	0	0	0	0	1	0	0	1	80	103
0	0	0	0	0	1	0	1	2	128	155
0	0	0	0	0	1	1	0	4	190	220
07h to 0Fh								8	373	413

Table 8. N-Factor Range

N_{ADJUST}			N
BINARY	HEX	DECIMAL	
01111111	7F	127	1.747977
00001010	0A	10	1.042759
00001000	08	8	1.035616
00000110	06	6	1.028571
00000100	04	4	1.021622
00000010	02	2	1.014765
00000001	01	1	1.011371
00000000	00	0	1.008
11111111	FF	−1	1.004651
11111110	FE	−2	1.001325
11111100	FC	−4	0.994737
11111010	FA	−6	0.988235
11111000	F8	−8	0.981818
11110110	F6	−10	0.975484
10000000	80	−128	0.706542

MINIMUM AND MAXIMUM REGISTERS

The TMP411 stores the minimum and maximum temperature measured since power-on, chip-reset, or minimum and maximum register reset for both the local and remote channels. The Local Temperature Minimum Register may be read by reading the high byte from pointer address 30h and the low byte from pointer address 31h. The Local Temperature Minimum Register may also be read by using a two-byte read command from pointer address 30h. The Local Temperature Minimum Register is reset at power-on, by executing the chip-reset command, or by writing any value to any of pointer addresses 30h through 37h. The reset value for these registers is FFh/F0h.

The Local Temperature Maximum Register may be read by reading the high byte from pointer address 32h and the low byte from pointer address 33h. The Local Temperature Maximum Register may also be read by using a two-byte read command from pointer address 32h. The Local Temperature Maximum Register is reset at power-on by executing the chip reset command, or by writing any value to any of pointer addresses 30h through 37h. The reset value for these registers is 00h/00h.

The Remote Temperature Minimum Register may be read by reading the high byte from pointer address 34h and the low byte from pointer address 35h. The Remote Temperature Minimum Register may also be read by using a two-byte read command from pointer address 34h. The Remote Temperature Minimum Register is reset at power-on by executing the chip reset command, or by writing any value to any of pointer addresses 30h through 37h. The reset value for these registers is FFh/F0h.

The Remote Temperature Maximum Register may be read by reading the high byte from pointer address 36h and the low byte from pointer address 37h. The Remote Temperature Maximum Register may also be read by using a two-byte read command from pointer address 36h. The Remote Temperature Maximum Register is reset at power-on by executing the chip reset command, or by writing any value to any of pointer addresses 30h through 37h. The reset value for these registers is 00h/00h.

SOFTWARE RESET

The TMP411 may be reset by writing any value to Pointer Register FCh. This restores the power-on reset state to all of the TMP411 registers as well as abort any conversion in process and clear the $\overline{\text{ALERT}}$ and $\overline{\text{THERM}}$ pins.

The TMP411 also supports reset via the two-wire general call address (00000000). The TMP411 acknowledges the general call address and responds to the second byte. If the second byte is 00000110, the TMP411 executes a software reset. The TMP411 takes no action in response to other values in the second byte.

CONSECUTIVE ALERT REGISTER

The value in the Consecutive Alert Register (address 22h) determines how many consecutive out-of-limit measurements must occur on a measurement channel before the $\overline{\text{ALERT}}$ signal is activated. The value in this register does not affect bits in the Status Register. Values of one, two, three, or four consecutive conversions can be selected; one conversion is the default. This function allows additional filtering for the $\overline{\text{ALERT}}$ pin. The consecutive alert bits are shown in Table 9.

Table 9. Consecutive Alert Register

CONSECUTIVE ALERT REGISTER (READ = 22h, WRITE = 22h, POR = 80h)			
C2	C1	C0	NUMBER OF CONSECUTIVE OUT-OF-LIMIT MEASUREMENTS
0	0	0	1
0	0	1	2
0	1	1	3
1	1	1	4

NOTE: Bit 7 of the Consecutive Alert Register controls the enable/disable of the timeout function. See the *Timeout Function* section for a description of this feature.

THERM HYSTERESIS REGISTER

The THERM Hysteresis Register stores the hysteresis value used for the $\overline{\text{THERM}}$ pin alarm function. This register must be programmed with a value that is less than the Local Temperature High Limit Register value, Remote Temperature High Limit Register value, Local THERM Limit Register value, or Remote THERM Limit Register value; otherwise, the respective temperature comparator will not trip on the measured temperature falling edges. Allowable hysteresis values are shown in Table 10. The default hysteresis value is 10°C, whether the device is operating in the standard or extended mode setting.

Table 10. Allowable THERM Hysteresis Values

TEMPERATURE (°C)	THERM HYSTERESIS VALUE	
	TH[11:4] (STANDARD BINARY)	(HEX)
0	0000 0000	00
1	0000 0001	01
5	0000 0101	05
10	0000 1010	0A
25	0001 1001	19
50	0011 0010	32
75	0100 1011	4B
100	0110 0100	64
125	0111 1101	7D
127	0111 1111	7F
150	1001 0110	96
175	1010 1111	AF
200	1100 1000	C8
225	1110 0001	E1
255	1111 1111	FF

BUS OVERVIEW

The TMP411 is SMBus interface-compatible. In SMBus protocol, the device that initiates the transfer is called a master, and the devices controlled by the master are slaves. The bus must be controlled by a master device that generates the serial clock (SCL), controls the bus access, and generates the START and STOP conditions.

To address a specific device, a START condition is initiated. START is indicated by pulling the data line (SDA) from a high to low logic level while SCL is high. All slaves on the bus shift in the slave address byte, with the last bit indicating whether a read or write operation is intended. During the ninth clock pulse, the slave being addressed responds to the master by generating an Acknowledge and pulling SDA low.

Data transfer is then initiated and sent over eight clock pulses followed by an Acknowledge bit. During data transfer SDA must remain stable while SCL is high, because any change in SDA while SCL is high is interpreted as a control signal.

Once all data has been transferred, the master generates a STOP condition. STOP is indicated by pulling SDA from low to high, while SCL is high.

SERIAL INTERFACE

The TMP411 operates only as a slave device on either the Two-Wire bus or the SMBus. Connections to either bus are made via the open-drain I/O lines, SDA and SCL. The SDA and SCL pins feature integrated spike suppression filters and Schmitt triggers to minimize the effects of input spikes and bus noise. The TMP411 supports the transmission protocol for fast (1kHz to 400kHz) and high-speed (1kHz to 3.4MHz) modes. All data bytes are transmitted MSB first.

SERIAL BUS ADDRESS

To communicate with the TMP411, the master must first address slave devices via a slave address byte. The slave address byte consists of seven address bits, and a direction bit indicating the intent of executing a read or write operation. The address of the TMP411 is 4Ch (1001100b).

READ/WRITE OPERATIONS

Accessing a particular register on the TMP411 is accomplished by writing the appropriate value to the Pointer Register. The value for the Pointer Register is the first byte transferred after the slave address byte with the R/$\overline{\text{W}}$ bit low. Every write operation to the TMP411 requires a value for the Pointer Register (see Figure 14).

Table 11. THERM Hysteresis Register Format

THERM HYSTERESIS REGISTER (Read = 21h, Write = 21h, POR = 0Ah)								
BIT #	**D7**	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
BIT NAME	TH11	TH10	TH9	TH8	TH7	TH6	TH5	TH4
POR VALUE	0	0	0	0	1	0	1	0

When reading from the TMP411, the last value stored in the Pointer Register by a write operation is used to determine which register is read by a read operation. To change the register pointer for a read operation, a new value must be written to the Pointer Register. This transaction is accomplished by issuing a slave address byte with the R/$\overline{W}$ bit low, followed by the Pointer Register byte. No additional data is required. The master can then generate a START condition and send the slave address byte with the R/$\overline{W}$ bit high to initiate the read command. See Figure 15 for details of this sequence. If repeated reads from the same register are desired, it is not necessary to continually send the Pointer Register bytes, because the TMP411 retains the Pointer Register value until it is changed by the next write operation. Note that register bytes are sent MSB first, followed by the LSB.

TIMING DIAGRAMS

The TMP411 is Two-Wire and SMBus-compatible. Figure 13 to Figure 16 describe the various operations on the TMP411. Bus definitions are given below. Parameters for Figure 13 are defined in Table 12.

Bus Idle: Both SDA and SCL lines remain high.

Start Data Transfer: A change in the state of the SDA line, from high to low, while the SCL line is high, defines a START condition. Each data transfer is initiated with a START condition.

Stop Data Transfer: A change in the state of the SDA line from low to high while the SCL line is high defines a STOP condition. Each data transfer terminates with a repeated START or STOP condition.

Data Transfer: The number of data bytes transferred between a START and a STOP condition is not limited and is determined by the master device. The receiver acknowledges the transfer of data.

Acknowledge: Each receiving device, when addressed, is obliged to generate an Acknowledge bit. A device that acknowledges must pull down the SDA line during the Acknowledge clock pulse in such a way that the SDA line is stable low during the high period of the Acknowledge clock pulse. Setup and hold times must be taken into account. On a master receive, data transfer termination can be signaled by the master generating a Not-Acknowledge on the last byte that has been transmitted by the slave.

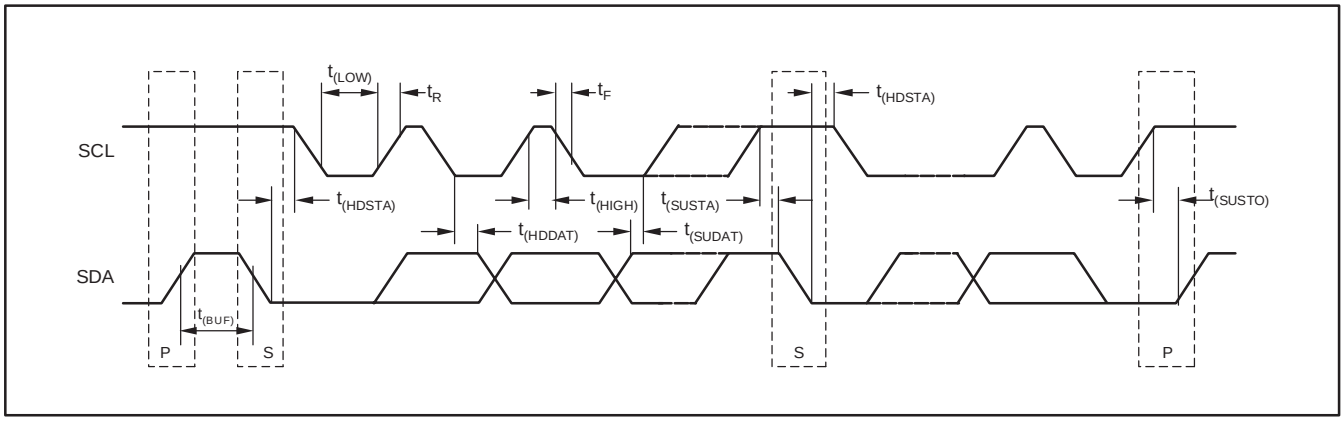
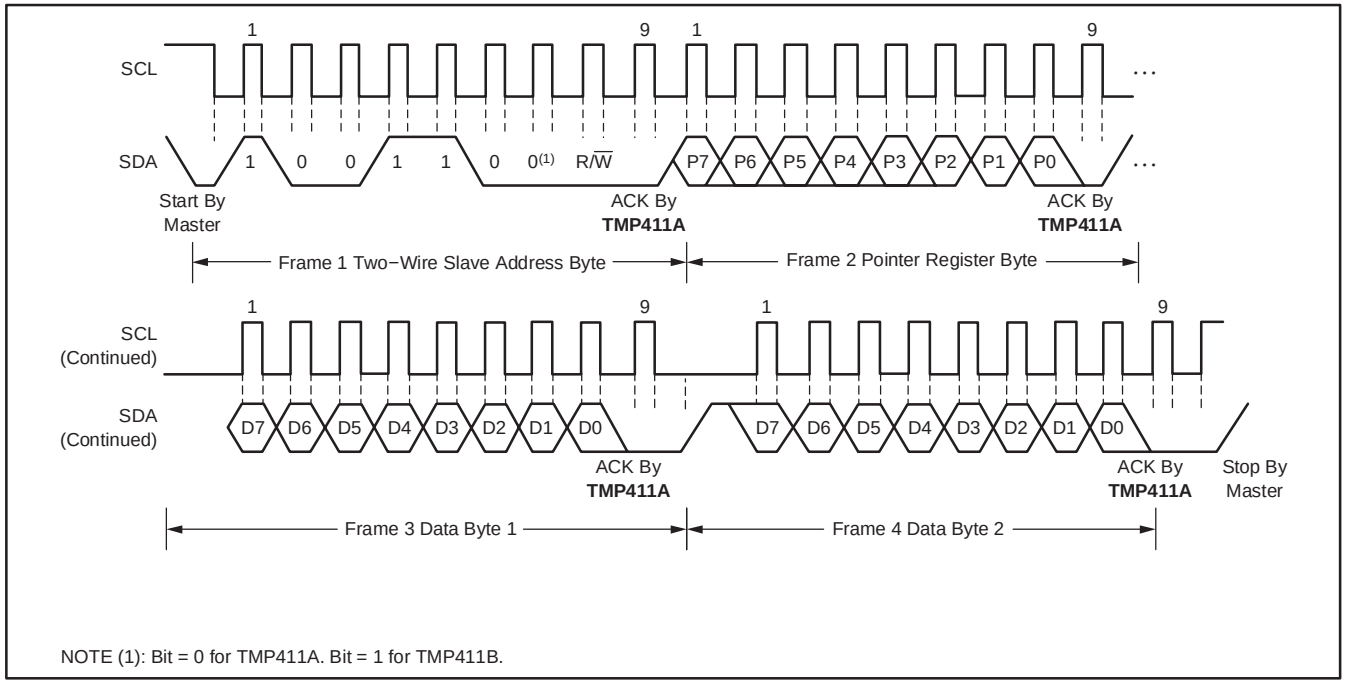


Figure 13. Two-Wire Timing Diagram

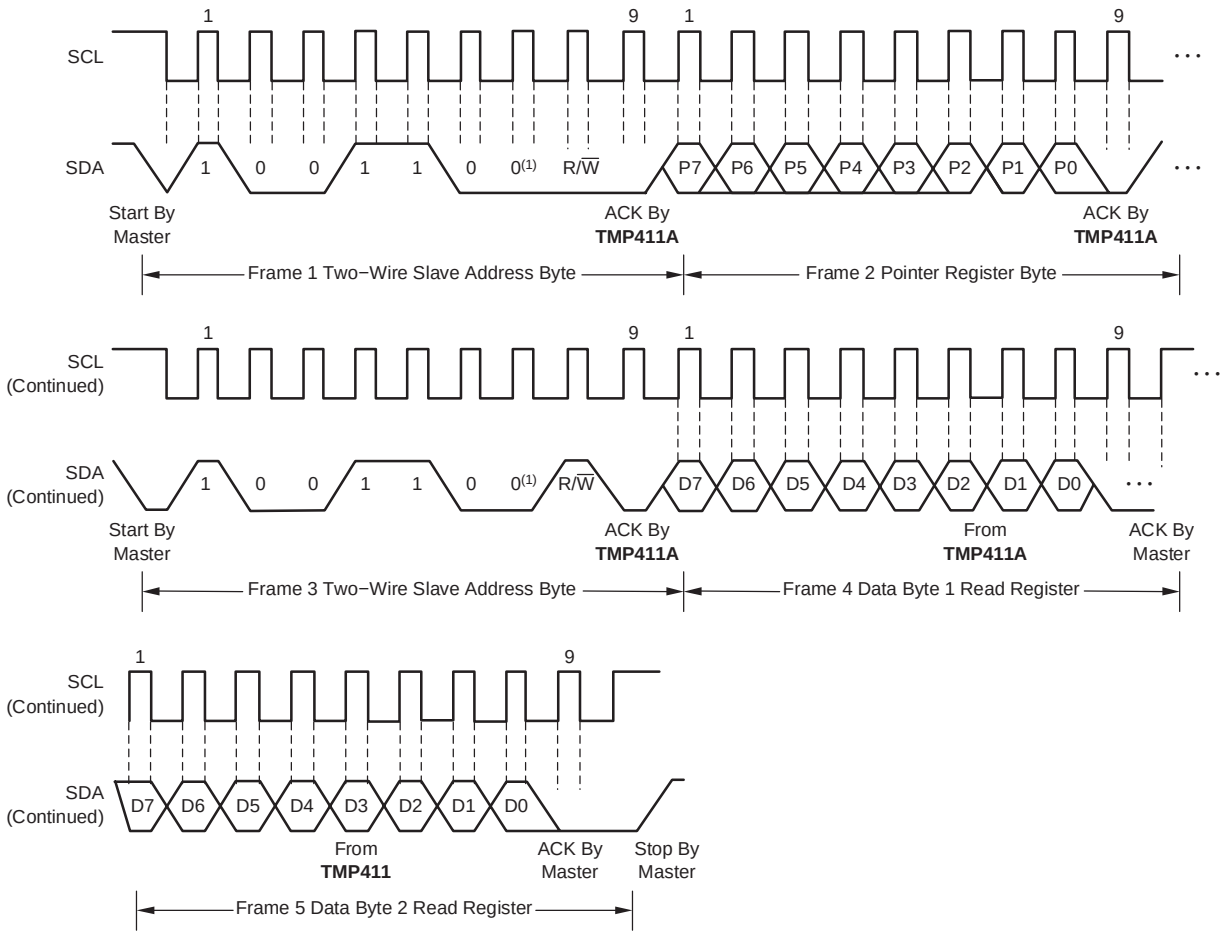
Table 12. Timing Diagram Definitions for Figure 13

PARAMETER		MIN	MAX	MIN	MAX	UNITS
SCL Operating Frequency	$f_{(SCL)}$	0.001	0.4	0.001	3.4	MHz
Bus Free Time Between STOP and START Condition	$t_{(BUF)}$	600		160		ns
Hold time after repeated START condition. After this period, the first clock is generated.	$t_{(HDSTA)}$	100		100		ns
Repeated START Condition Setup Time	$t_{(SUSTA)}$	100		100		ns
STOP Condition Setup Time	$t_{(SUSTO)}$	100		100		ns
Data Hold Time	$t_{(HDDAT)}$	0		0		ns
Data Setup Time	$t_{(SUDAT)}$	100		10		ns
SCL Clock LOW Period	$t_{(LOW)}$	1300		160		ns
SCL Clock HIGH Period	$t_{(HIGH)}$	600		60		ns
Clock/Data Fall Time	t_F		300		160	ns
Clock/Data Rise Time for SCL ≤ 100kHz	t_R t_R		300 1000		160	ns



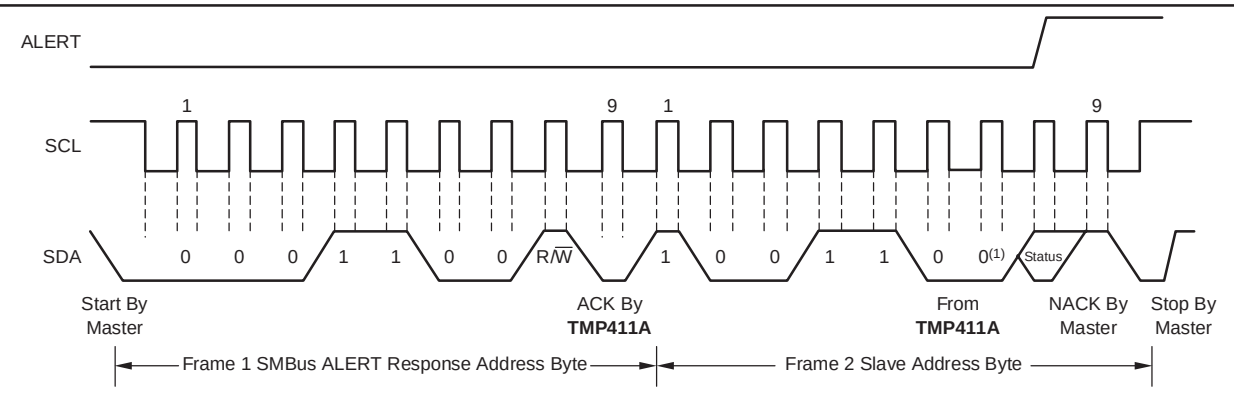
NOTE (1): Bit = 0 for TMP411A. Bit = 1 for TMP411B.

Figure 14. Two-Wire Timing Diagram for Write Word Format



NOTE (1): Bit = 0 for TMP411A. Bit = 1 for TMP411B.

Figure 15. Two-Wire Timing Diagram for Read Word Format



NOTE (1): Bit = 0 for TMP411A. Bit = 1 for TMP411B.

Figure 16. Timing Diagram for SMBus ALERT

HIGH-SPEED MODE

In order for the Two-Wire bus to operate at frequencies above 400kHz, the master device must issue a High-speed mode (Hs-mode) master code (00001XXX) as the first byte after a START condition to switch the bus to high-speed operation. The TMP411 will not acknowledge this byte, but will switch the input filters on SDA and SCL and the output filter on SDA to operate in Hs-mode, allowing transfers at up to 3.4MHz. After the Hs-mode master code has been issued, the master transmits a Two-Wire slave address to initiate a data transfer operation. The bus continues to operate in Hs-mode until a STOP condition occurs on the bus. Upon receiving the STOP condition, the TMP411 switches the input and output filter back to fast-mode operation.

TIMEOUT FUNCTION

When bit 7 of the Consecutive Alert Register is set high, the TMP411 timeout function is enabled. The TMP411 resets the serial interface if either SCL or SDA are held low for 30ms (typical) between a START and STOP condition. If the TMP411 is holding the bus low, it releases the bus and waits for a START condition. To avoid activating the timeout function, it is necessary to maintain a communication speed of at least 1kHz for the SCL operating frequency. The default state of the timeout function is enabled (bit 7 = high).

$\overline{\text{THERM}}$ (PIN 4) AND $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ (PIN 6)

The TMP411 has two pins dedicated to alarm functions, the $\overline{\text{THERM}}$ and $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ pins. Both pins are open-drain outputs that each require a pull-up resistor to V+. These pins can be wire-ORed together with other alarm pins for system monitoring of multiple sensors. The $\overline{\text{THERM}}$ pin provides a thermal interrupt that cannot be software disabled. The $\overline{\text{ALERT}}$ pin is intended for use as an earlier warning interrupt, and can be software disabled, or masked. The $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ pin can also be configured for use as $\overline{\text{THERM2}}$, a second $\overline{\text{THERM}}$ pin (Configuration Register: AL/TH bit = 1). The default setting configures pin 6 to function as $\overline{\text{ALERT}}$ (AL/TH = 0).

The $\overline{\text{THERM}}$ pin asserts low when either the measured local or remote temperature is outside of the temperature range programmed in the corresponding Local/Remote THERM Limit Register. The THERM temperature limit range can be programmed with a wider range than that of the limit registers, which allows $\overline{\text{ALERT}}$ to provide an earlier warning than $\overline{\text{THERM}}$. The $\overline{\text{THERM}}$ alarm resets automatically when the measured temperature returns to within the THERM temperature limit range minus the hysteresis value stored in the THERM Hysteresis Register. The allowable values of hysteresis are shown in Table 10. The default hysteresis is 10°C. When the $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ pin is configured as a second thermal alarm (Configuration Register: bit 7 = 0, bit 5 = 1), it functions the same as $\overline{\text{THERM}}$, but uses the temperatures stored in the Local/Remote Temperature High/Low Limit Registers to set its comparison range.

When $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ (pin 6) is configured as $\overline{\text{ALERT}}$ (Configuration Register: bit 7 = 0, bit 5 = 0), the pin asserts low when either the measured local or remote temperature violates the range limit set by the corresponding Local/Remote Temperature High/Low Limit Registers. This alert function can be configured to assert only if the range is violated a specified number of consecutive times (1, 2, 3, or 4). The consecutive violation limit is set in the Consecutive Alert Register. False alerts that occur as a result of environmental noise can be prevented by requiring consecutive faults. $\overline{\text{ALERT}}$ also asserts low if the remote temperature sensor is open-circuit. When the MASK function is enabled (Configuration Register: bit 7 = 1), $\overline{\text{ALERT}}$ is disabled (that is, masked). $\overline{\text{ALERT}}$ resets when the master reads the device address, as long as the condition that caused the alert no longer persists, and the Status Register has been reset.

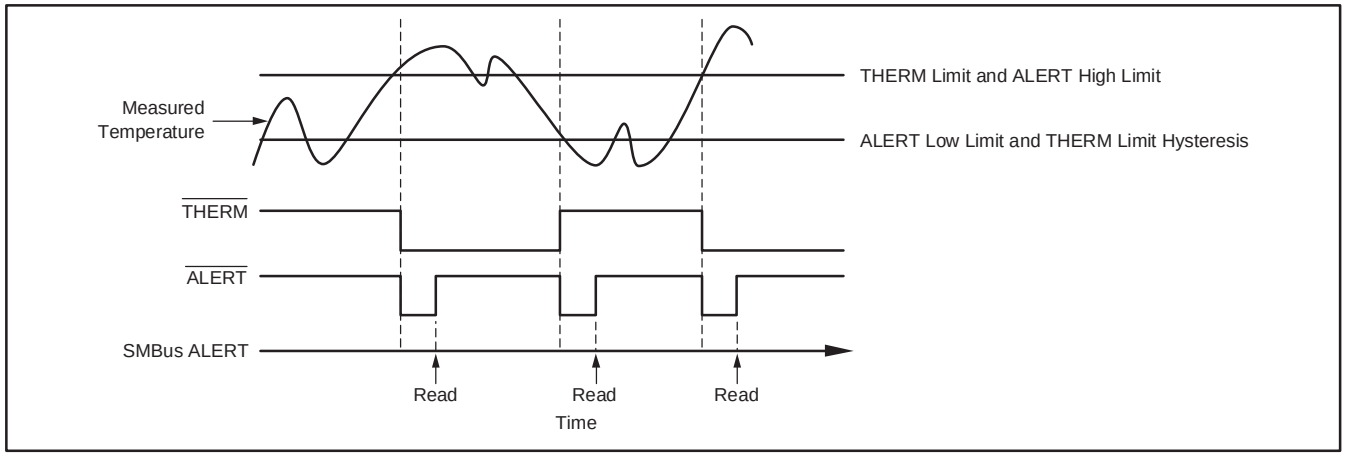


Figure 17. SMBus Alert Timing Diagram

SMBUS ALERT FUNCTION

The TMP411 supports the SMBus Alert function. When pin 6 is configured as an alert output, the $\overline{\text{ALERT}}$ pin of the TMP411 may be connected as an SMBus Alert signal. When a master detects an alert condition on the $\overline{\text{ALERT}}$ line, the master sends an SMBus Alert command (00011001) on the bus. If the $\overline{\text{ALERT}}$ pin of the TMP411 is active, the devices will acknowledge the SMBus Alert command and respond by returning its slave address on the SDA line. The eighth bit (LSB) of the slave address byte indicates whether the temperature exceeding one of the temperature high limit settings or falling below one of the temperature low limit settings caused the alert condition. This bit will be high if the temperature is greater than or equal to one of the temperature high limit settings; this bit will be low if the temperature is less than one of the temperature low limit settings. See Figure 16 for details of this sequence.

If multiple devices on the bus respond to the SMBus Alert command, arbitration during the slave address portion of the SMBus Alert command determines which device will clear its alert status. If the TMP411 wins the arbitration, its $\overline{\text{ALERT}}$ pin becomes inactive at the completion of the SMBus Alert command. If the TMP411 loses the arbitration, the $\overline{\text{ALERT}}$ pin remains active.

SHUTDOWN MODE (SD)

The TMP411 Shutdown Mode allows the user to save maximum power by shutting down all device circuitry other than the serial interface, reducing current consumption to typically less than 3μA; see typical characteristic curve *Shutdown Quiescent Current vs Supply Voltage*. Shutdown Mode is enabled when the SD bit of the Configuration Register is high; the device shuts down once the current conversion is completed. When SD is low, the device maintains a continuous conversion state.

SENSOR FAULT

The TMP411 will sense a fault at the D+ input resulting from incorrect diode connection or an open circuit. The detection circuitry consists of a voltage comparator that trips when the voltage at D+ exceeds (V+) − 0.6V (typical). The comparator output is continuously checked during a conversion. If a fault is detected, the last valid measured temperature is used for the temperature measurement result, the OPEN bit (Status Register, bit 2) is set high, and, if the alert function is enabled, $\overline{\text{ALERT}}$ asserts low.

When not using the remote sensor with the TMP411, the D+ and D− inputs must be connected together to prevent meaningless fault warnings.

UNDER-VOLTAGE LOCKOUT

The TMP411 senses when the power-supply voltage has reached a minimum voltage level for the ADC converter to function. The detection circuitry consists of a voltage comparator that enables the ADC converter after the power supply (V+) exceeds 2.45V (typical). The comparator output is continuously checked during a conversion. The TMP411 will not perform a temperature conversion if the power supply is not valid. The last valid measured temperature is used for the temperature measurement result.

GENERAL CALL RESET

The TMP411 supports reset via the Two-Wire General Call address 00h (0000 0000b). The TMP411 acknowledges the General Call address and responds to the second byte. If the second byte is 06h (0000 0110b), the TMP411 executes a software reset. This software reset restores the power-on reset state to all TMP411 registers, aborts any conversion in progress, and clears the $\overline{\text{ALERT}}$ and $\overline{\text{THERM}}$ pins. The TMP411 takes no action in response to other values in the second byte.

IDENTIFICATION REGISTERS

The TMP411 allows for the Two-Wire bus controller to query the device for manufacturer and device IDs to allow for software identification of the device at the particular Two-Wire bus address. The manufacturer ID is obtained by reading from pointer address FEh. The device ID is obtained by reading from pointer address FFh. The TMP411 returns 55h for the manufacturer code and 11h for the device ID. These registers are read-only.

FILTERING

Remote junction temperature sensors are usually implemented in a noisy environment. Noise is most often created by fast digital signals, and it can corrupt measurements. The TMP411 has a built-in 65kHz filter on the inputs of D+ and D− to minimize the effects of noise. However, a bypass capacitor placed differentially across the inputs of the remote temperature sensor is recommended to make the application more robust against unwanted coupled signals. The value of the capacitor should be between 100pF and 1nF. Some applications attain better overall accuracy with additional series resistance; however, this increased accuracy is setup-specific. When series resistance is added, the value should not be greater than 3kΩ.

REMOTE SENSING

The TMP411 is designed to be used with either discrete transistors or substrate transistors built into processor chips and ASICs. Either NPN or PNP transistors can be used, as long as the base-emitter junction is used as the remote temperature sense. Either a transistor or diode connection can also be used; see Figure 11.

Errors in remote temperature sensor readings will be the consequence of the ideality factor and current excitation used by the TMP411 versus the manufacturer-specified operating current for a given transistor. Some manufacturers specify a high-level and low-level current for the temperature-sensing substrate transistors. The TMP411 uses 6μA for I_{LOW} and 120μA for I_{HIGH}. The TMP411 allows for different *n*-factor values; see the *N-Factor Correction Register* section.

The ideality factor (*n*) is a measured characteristic of a remote temperature sensor diode as compared to an ideal diode. The ideality factor for the TMP411 is trimmed to be 1.008. For transistors whose ideality factor does not match the TMP411, Equation 4 can be used to calculate the temperature error. Note that for the equation to be used correctly, actual temperature (°C) must be converted to Kelvin (°K).

$$T_{ERR} = \left(\frac{n - 1.008}{1.008}\right) \times \left(273.15 + T(^{\circ}C)\right) \quad (4)$$

Where:

n = Ideality factor of remote temperature sensor
T(°C) = actual temperature
T_{ERR} = Error in TMP411 reading due to $n \neq 1.008$
Degree delta is the same for °C and °K

For *n* = 1.004 and T(°C) = 100°C:

$$T_{ERR} = \left(\frac{1.004 - 1.008}{1.008}\right) \times \left(273.15 + 100^{\circ}C\right)$$
$$T_{ERR} = -1.48^{\circ}C \quad (5)$$

If a discrete transistor is used as the remote temperature sensor with the TMP411, the best accuracy can be achieved by selecting the transistor according to the following criteria:

1. Base-emitter voltage > 0.25V at 6μA, at the highest sensed temperature.
2. Base-emitter voltage < 0.95V at 120μA, at the lowest sensed temperature.
3. Base resistance < 100Ω.
4. Tight control of V_{BE} characteristics indicated by small variations in h_{FE} (that is, 50 to 150).

Based on these criteria, two recommended small-signal transistors are the 2N3904 (NPN) or 2N3906 (PNP).

MEASUREMENT ACCURACY AND THERMAL CONSIDERATIONS

The temperature measurement accuracy of the TMP411 depends on the remote and/or local temperature sensor being at the same temperature as the system point being monitored. Clearly, if the temperature sensor is not in good thermal contact with the part of the system being monitored, then there will be a delay in the response of the sensor to a temperature change in the system. For remote temperature sensing applications using a substrate transistor (or a small, SOT23 transistor) placed close to the device being monitored, this delay is usually not a concern.

The local temperature sensor inside the TMP411 monitors the ambient air around the device. The thermal time constant for the TMP411 is approximately two seconds. This constant implies that if the ambient air changes quickly by 100°C, it would take the TMP411 about 10 seconds (that is, five thermal time constants) to settle to within 1°C of the final value. In most applications, the TMP411 package is in electrical and therefore thermal contact with the printed circuit board (PCB), as well as subjected to forced airflow. The accuracy of the measured temperature directly depends on how accurately the PCB and forced airflow temperatures represent the temperature that the TMP411 is measuring. Additionally, the internal power dissipation of the TMP411 can cause the temperature to rise above the ambient or PCB temperature. The internal power dissipated as a result of exciting the remote temperature sensor is negligible because of the small currents used. For a 5.5V supply and maximum conversion rate of eight conversions per second, the TMP411 dissipates 1.82mW (PD_{IQ} = 5.5V × 330μA). If both the $\overline{\text{ALERT}}/\overline{\text{THERM2}}$ and $\overline{\text{THERM}}$ pins are each sinking 1mA, an additional power of 0.8mW is dissipated (PD_{OUT} = 1mA × 0.4V + 1mA × 0.4V = 0.8mW). Total power dissipation is then 2.62mW (PD_{IQ} + PD_{OUT}) and, with an θ_{JA} of 150°C/W, causes the junction temperature to rise approximately 0.393°C above the ambient.

LAYOUT CONSIDERATIONS

Remote temperature sensing on the TMP411 measures very small voltages using very low currents; therefore, noise at the IC inputs must be minimized. Most applications using the TMP411 will have high digital content, with several clocks and logic level transitions creating a noisy environment. Layout should adhere to the following guidelines:

1. Place the TMP411 as close to the remote junction sensor as possible.
2. Route the D+ and D− traces next to each other and shield them from adjacent signals through the use of ground guard traces, as shown in Figure 18. If a multilayer PCB is used, bury these traces between ground or V_{DD} planes to shield them from extrinsic noise sources. 5 mil PCB traces are recommended.
3. Minimize additional thermocouple junctions caused by copper-to-solder connections. If these junctions are used, make the same number and approximate locations of copper-to-solder connections in both the D+ and D− connections to cancel any thermocouple effects.
4. Use a 0.1µF local bypass capacitor directly between the V+ and GND of the TMP411, as shown in Figure 19. Minimize filter capacitance between D+ and D− to 1000pF or less for optimum measurement performance. This capacitance includes any cable capacitance between the remote temperature sensor and TMP411.
5. If the connection between the remote temperature sensor and the TMP411 is between 8 inches and 12 feet long, use a twisted-wire pair connection. Beyond this distance (up to 100 feet), use a twisted, shielded pair with the shield grounded as close to the TMP411 as possible. Leave the remote sensor connection end of the shield wire open to avoid ground loops and 60Hz pickup.

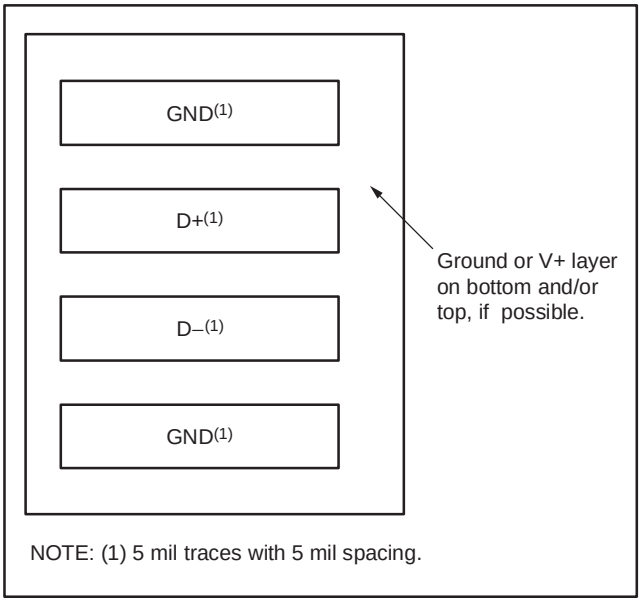


Figure 18. Example Signal Traces

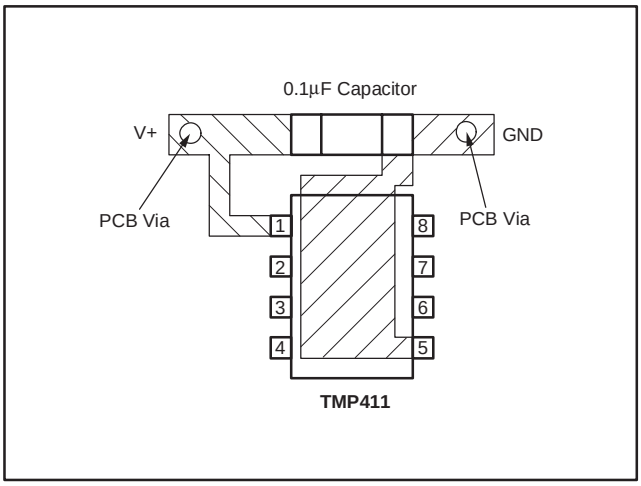


Figure 19. Suggested Bypass Capacitor Placement

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
TMP411ADGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TMP411ADGKRG4	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TMP411ADGKT	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TMP411ADGKTG4	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TMP411BDGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TMP411BDGKRG4	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TMP411BDGKT	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TMP411BDGKTG4	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

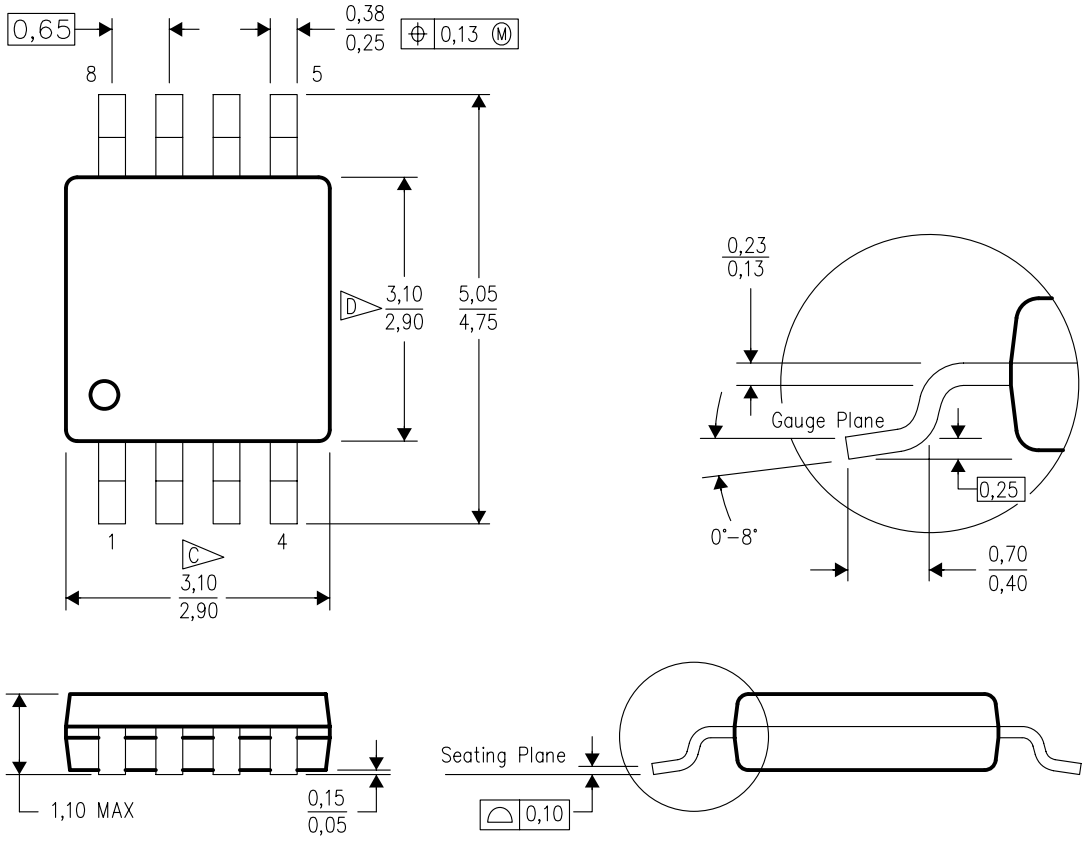
(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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DGK (S–PDSO–G8) PLASTIC SMALL–OUTLINE PACKAGE



4073329/E 05/06

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.
E. Falls within JEDEC MO–187 variation AA, except interlead flash.

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