TMP116x High-Accuracy, Low-Power, Digital Temperature Sensor With SMBus- and I²C-Compatible Interface

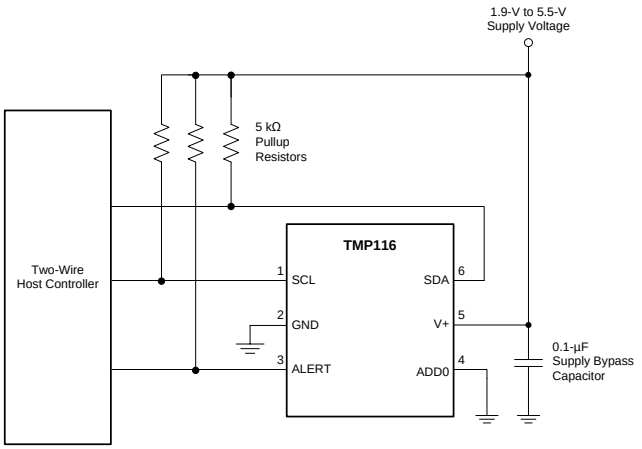
1 Features

- TMP116 Accuracy Without Calibration:
  - ±0.2°C (max) From –10°C to +85°C
  - ±0.25°C (max) From –40°C to +105°C
  - ±0.3°C (max) From +105°C to +125°C
- TMP116N Accuracy Without Calibration:
  - ±0.3°C (max) From –25°C to +85°C
  - ±0.4°C (max) From –40°C to +125°C
- Low Quiescent Current:
  - 3.5-µA, 1-Hz Conversion Cycle
  - 250-nA Shutdown Current
- Supply Range: 1.9 V to 5.5 V
- Resolution: 16 Bits at 0.0078°C (1 LSB)
- Programmable Temperature Alert Limits
- General-Purpose EEPROM: 64 Bits
- NIST Traceability
- SMBus™, I²C Interface Compatibility

2 Applications

- Environmental Monitoring and Thermostats
- Wearables
- Asset Tracking and Cold Chain
- Gas Meters and Heat Meters
- Test and Measurement
- RTDs Replacement: PT100, PT500, PT1000
- Cold-Junction Compensation of Thermocouples

Simplified Schematic



3 Description

The TMP116 (TMP116, TMP116N) is a family of low-power, high-precision temperature sensors with integrated EEPROM memory. The TMP116 provides a 16-bit temperature result with a resolution of 0.0078°C and an accuracy of up to ±0.2°C with no calibration. The TMP116 is I²C- and SMBus-interface compatible, has programmable alert functionality, and can support up to four devices on a single bus.

The TMP116 consumes minimal current that, in addition to providing power savings, minimizes self-heating and improves measurement accuracy. The TMP116 operates from 1.9 V to 5.5 V and typically consumes 3.5 µA.

Across the device operating temperature range of –55°C to +125°C, the TMP116 exceeds the accuracy of a class A RTD, while consuming less than one fifth of the typical excitation current for a PT100 RTD. The TMP116 is easier to use than RTDs, eliminating the need for calibration, external circuitry, matched traces, and Kelvin connections.

The TMP116 units are 100% tested on a production setup that is NIST traceable and verified with equipment that is calibrated to ISO/IEC 17025 accredited standards.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TMP116	WSON (6)	2.00 mm x 2.00 mm

(1) For all available packages, see the package option addendum at the end of the datasheet.

Temperature Accuracy

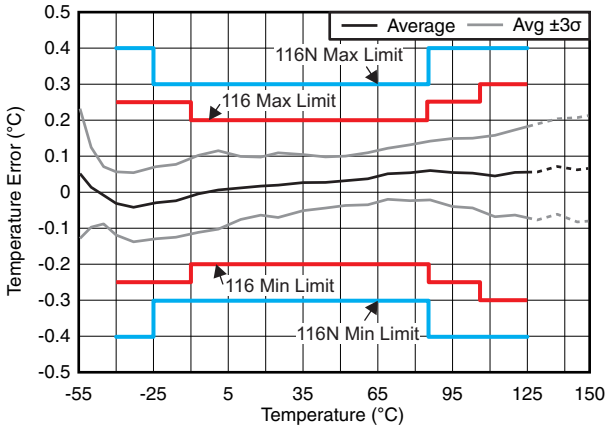


Table of Contents

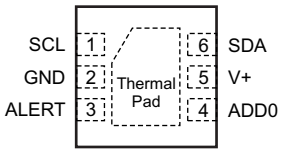
1 Features ... 1
2 Applications ... 1
3 Description ... 1
4 Revision History ... 2
5 Pin Configuration and Functions ... 3
6 Specifications ... 4
6.1 Absolute Maximum Ratings ... 4
6.2 ESD Ratings ... 4
6.3 Recommended Operating Conditions ... 4
6.4 Thermal Information ... 4
6.5 Electrical Characteristics ... 5
6.6 Two-Wire Interface Timing ... 6
6.7 Typical Characteristics ... 7
7 Detailed Description ... 10
7.1 Overview ... 10
7.2 Functional Block Diagrams ... 10
7.3 Feature Description ... 10
7.4 Device Functional Modes ... 12
7.5 Programming ... 16
7.6 Registers Map ... 23
8 Application and Implementation ... 31
8.1 Application Information ... 31
9 Power Supply Recommendations ... 36
10 Layout ... 36
10.1 Layout Guidelines to Achieve a High-Precision Temperature Reading ... 36
10.2 Layout Example ... 37
11 Device and Documentation Support ... 38
11.1 Documentation Support ... 38
11.2 Receiving Notification of Documentation Updates ... 38
11.3 Community Resources ... 38
11.4 Trademarks ... 38
11.5 Electrostatic Discharge Caution ... 38
11.6 Glossary ... 38
12 Mechanical, Packaging, and Orderable Information ... 38

4 Revision History

DATE	REVISION	NOTES
May 2017	*	Initial release.

5 Pin Configuration and Functions

DRV Package
6-Pin WSON
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
1	SCL	I	Serial clock
2	GND	—	Ground
3	ALERT	O	Overtemperature alert or data-ready signal. Open-drain output; requires a pullup resistor.
4	ADD0	I	Address select. Connect to GND, V+, SDA, or SCL.
5	V+	I	Supply voltage, 1.9 V to 5.5 V
6	SDA	I/O	Serial data. Open-drain output; requires a pullup resistor.

6 Specifications

6.1 Absolute Maximum Ratings

	MIN	MAX	UNIT
Supply voltage, V+	–0.3	6	V
Voltage at SCL, SDA, ALERT, and ADD0	–0.3	6	V
Operating junction temperature, T_J	–55	150	°C
Storage temperature, T_{stg}	–65	150	°C

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 (1)	±2000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101 (2)	±1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

		MIN	NOM	MAX	UNIT
V+	Supply voltage	1.9	3.3	5.5	V
T_A	Operating free-air temperature	–55		125	°C

6.4 Thermal Information

THERMAL METRIC (1)		TMP116 DRV (WSON) 6 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	68.7	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	70.3	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	9.5	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	38.3	°C/W
ψ_{JT}	Junction-to-top characterization parameter	1.7	°C/W
ψ_{JB}	Junction-to-board characterization parameter	38.6	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.

6.5 Electrical Characteristics

minimum and maximum specifications are over –55°C to +125°C and V+ = 1.9 V to 5.5 V (unless otherwise noted); typical specifications are at T_A = 25°C and V+ = 3.3 V

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
TEMPERATURE-TO-DIGITAL CONVERTER							
	Temperature accuracy(1)	TMP116	–10°C to +85°C, V+ = 3.3 V	–0.2	±0.1	0.2	°C
			–40°C to +105°C, V+ = 3.0 V to 3.6 V	–0.25	±0.2	0.25	
			+105°C to +125°C, V+ = 3.0 V to 3.6 V	–0.3	±0.25	0.3	
			–40°C to +125°C, V+ = 1.9 V to 5.5 V(2)	–0.4	±0.3	0.4	
		TMP116N	–25°C to +85°C, V+ = 3.3 V	–0.3	±0.2	0.3	
			–40°C to +125°C, V+ = 3.0 V to 3.6 V	–0.4	±0.3	0.4	
			–40°C to +125°C V+ = 1.9 V to 5.5 V(2)	–0.5	±0.4	0.5	
	DC power-supply sensitivity		One-shot mode, 8 averages, T_A = 25°C	0	20	55	m°C/V
	Temperature resolution (LSB)				7.8125		m°C
	Repeatability(3)		V+ = 3.3 V, 8 averages, 1-Hz sampling		±1		LSB
	Long-term stability and drift		300 hours at 150°C(4)		±0.05		°C
	Temperature cycling and hysteresis(5)		8 averages		±1		LSB
DIGITAL INPUT/OUTPUT							
	Input capacitance				3		pF
V_{IH}	Input logic high level			0.7 (V+)			V
V_{IL}	Input logic low level					0.3 (V+)	V
I_{IN}	Input current			–0.2		0.2	µA
$V_{OL}S$	SDA output logic low level		I_{OL} = –3 mA	0		0.4	V
$V_{OL}A$	$\overline{\text{ALERT}}$ output logic low level		I_{OL} = –3 mA	0		0.4	V
POWER SUPPLY							
I_Q	Quiescent current		Active conversion, serial bus inactive		135	220	µA
			1-Hz conversion cycle, averaging mode off, serial bus inactive, 25°C		3.5	4.5	
			1-Hz conversion cycle, 8 averages mode, serial bus inactive, 25°C		16	22	
			1-Hz conversion cycle, averaging mode off, serial bus active, SCL frequency = 400 kHz		21		
I_{SB}	Standby current(6)		Serial bus inactive, SCL and SDA = V+, 25°C		1.25	2.1	µA
I_{SD}	Shutdown current		Serial bus inactive, SCL and SDA = V+, 25°C		0.25	0.5	µA
			Serial bus inactive, SCL and SDA = V+, 125°C			8.5	
			Serial bus active, SCL frequency = 400 kHz		17		
I_{EE}	EEPROM write quiescent current		ADC conversion off; serial bus inactive		240		µA
V_{POR}	Power-on-reset threshold voltage		V+ rising		1.6		V
	Brownout detect		V+ falling		1.1		V
	Reset time		Time required by device to reset		1.5		ms
	Active conversion time		1 conversion	13.5	15.5	17	ms

(1) 8 averages, 1-Hz conversion cycle.
(2) ±0.75°C maximum error between –55°C to –40°C.
(3) Repeatability is the ability to reproduce a reading when the measured temperature is applied consecutively, under the same conditions.
(4) Long-term stability is determined using accelerated operational life testing at a junction temperature of 150°C.
(5) Hysteresis is defined as the ability to reproduce a temperature reading as the temperature varies from room → hot → room → cold → room. The temperatures used for this test are –40°C, 25°C, and 125°C.
(6) Quiescent current between conversions.

Electrical Characteristics (continued)

minimum and maximum specifications are over –55°C to +125°C and V+ = 1.9 V to 5.5 V (unless otherwise noted); typical specifications are at T_A = 25°C and V+ = 3.3 V

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
EEPROM					
Programming time			7		ms
Number of writes		1,000	50,000		Times
Data retention time		10	100		Years

6.6 Two-Wire Interface Timing

minimum and maximum specifications are over –55°C to 125°C and V+ = 1.9 V to 5.5 V (unless otherwise noted); typical specifications are at T_A = 25°C and V+ = 3.3 V; values are based on statistical analysis of samples tested during initial release

		MIN	MAX	UNIT
f_{SCL}	SCL operating frequency	1	400	kHz
t_{BUF}	Bus free time between STOP and START conditions	1300		ns
$t_{HD;STA}$	Hold time after repeated START condition. After this period, the first clock is generated.	600		ns
$t_{SU;STA}$	Repeated START condition setup time	600		ns
$t_{SU;STO}$	STOP condition setup time	600		ns
$t_{HD;DAT}$	Data hold time	0		ns
$t_{VD;DAT}$	Data valid time (1)		0.9	µs
$t_{SU;DAT}$	Data setup time	100		ns
t_{LOW}	SCL clock low period	1300		ns
t_{HIGH}	SCL clock high period	600		ns
t_F – SDA	Data fall time	20 × (V+ / 5.5)	300	ns
t_F, t_R – SCL	Clock fall and rise time		300	ns
t_R	Rise time for SCL ≤ 100 kHz		1000	ns
	Serial bus timeout (SDA bus released if there is no clock)	20	40	ms

(1) $t_{VD;DATA}$ = time for data signal from SCL low to SDA output (high to low, depending on which is worse).

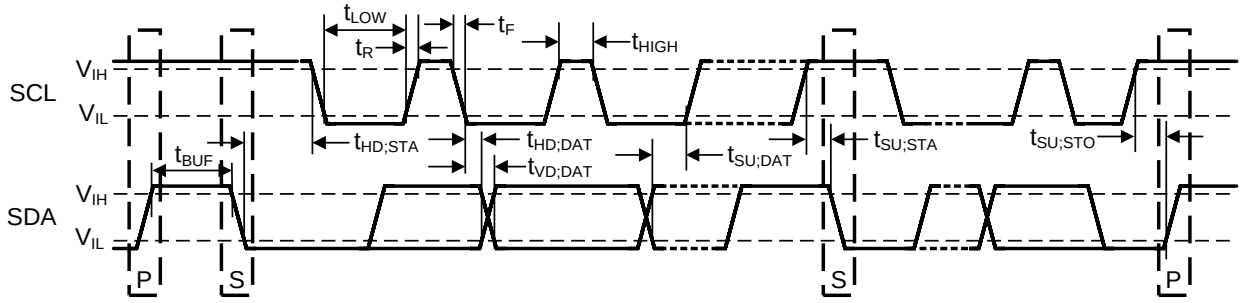
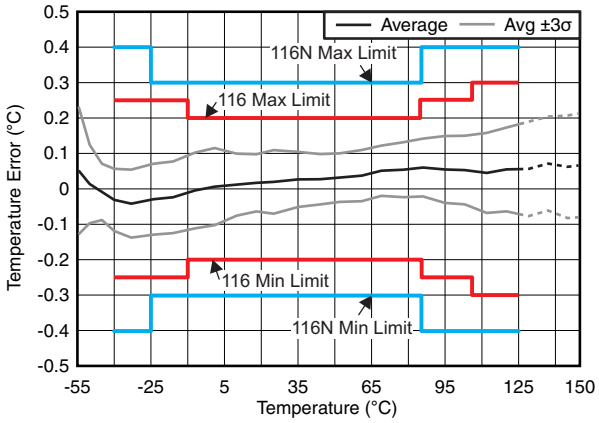


Figure 1. Two-Wire Timing Diagram

6.7 Typical Characteristics

at T_A = 25°C, V+ = 3.3 V, and measurement taken in oil bath (unless otherwise noted)



1-Hz conversion cycle, 8 averages mode

Figure 2. Temperature Error vs Temperature

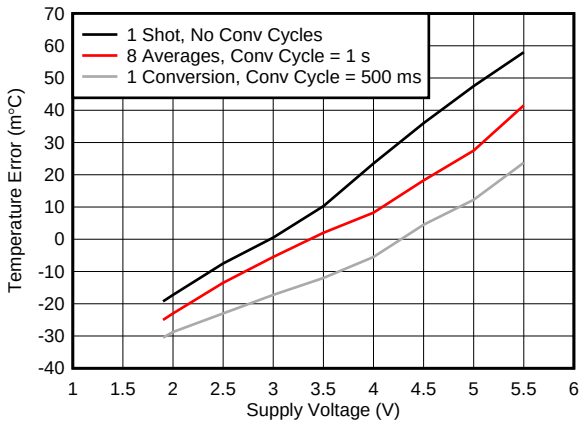
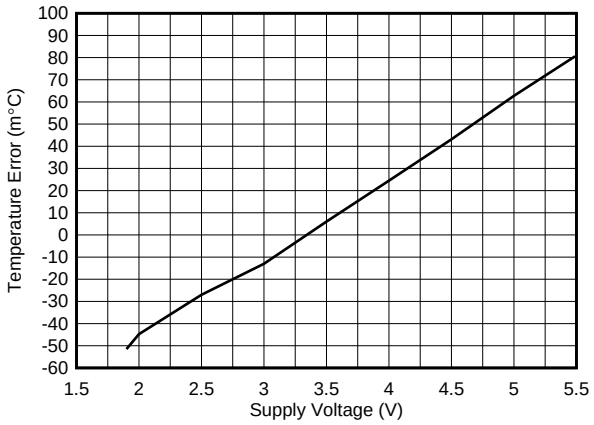


Figure 3. Temperature Error vs Supply Voltage



Continuous conversion, no conversion cycle in still air

Figure 4. Temperature Error vs Supply Voltage

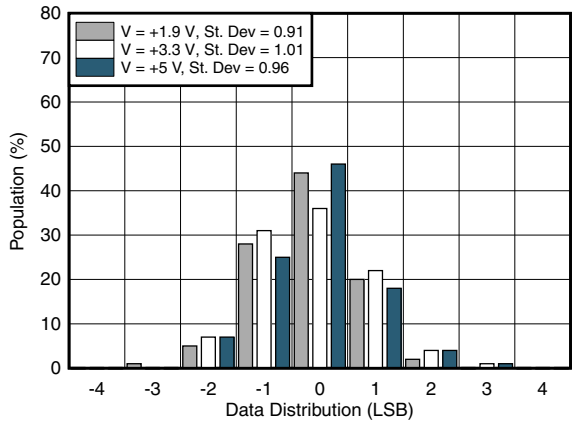


Figure 5. Data Reading Distribution Over Supply Voltage (No Averaging)

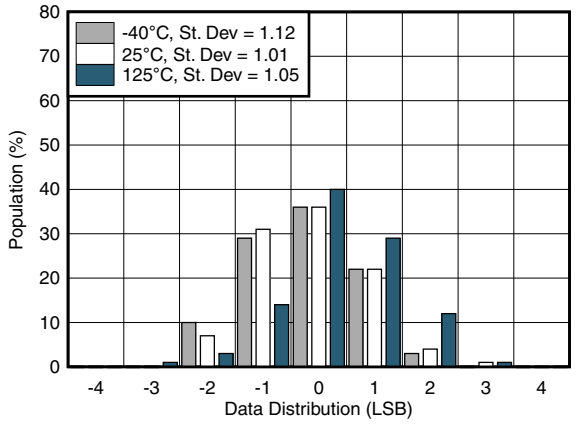


Figure 6. Data Reading Distribution Over Temperature (No Averaging)

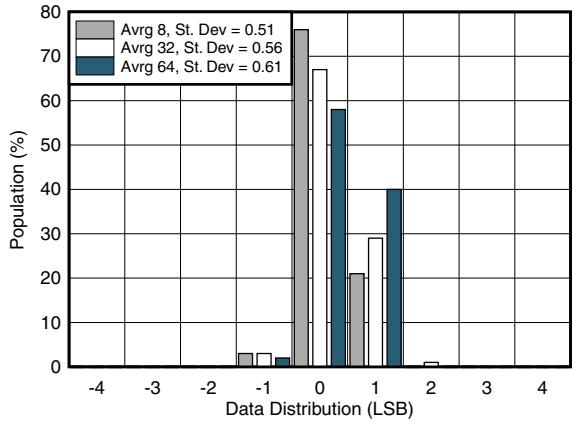


Figure 7. Data Reading Distribution Over Averaging Number

Typical Characteristics (continued)

at T_A = 25°C, V+ = 3.3 V, and measurement taken in oil bath (unless otherwise noted)

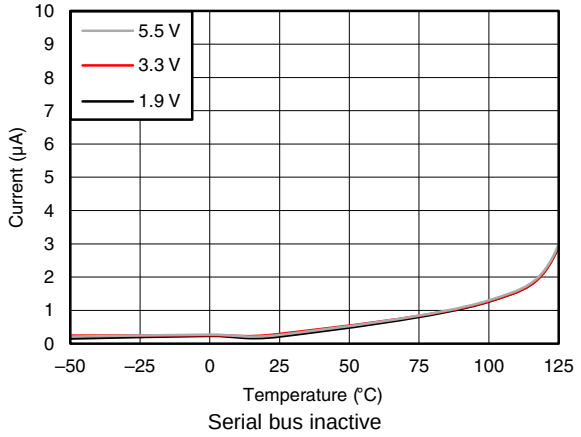


Figure 8. Quiescent Current in Shutdown Mode

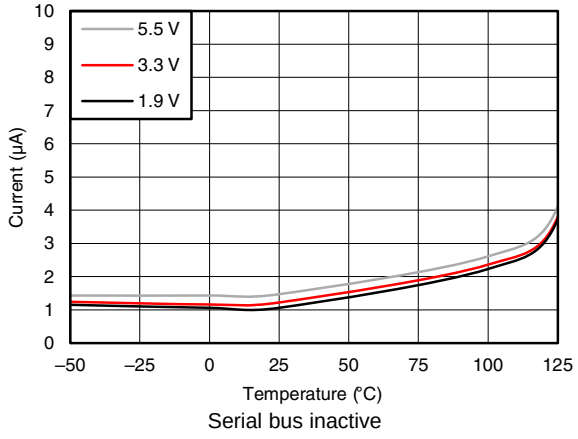


Figure 9. Quiescent Current in Standby Mode

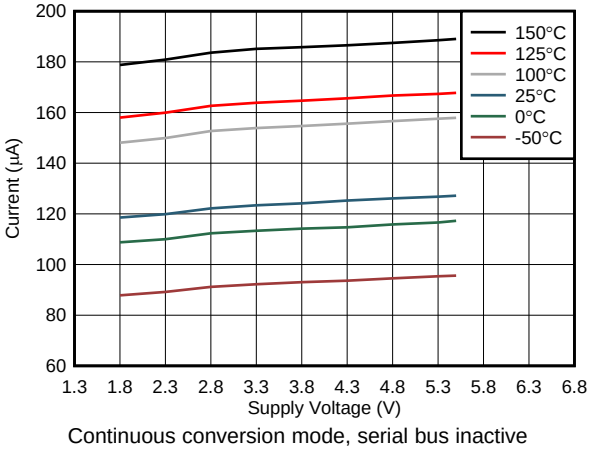


Figure 10. Quiescent Current During Active Conversion

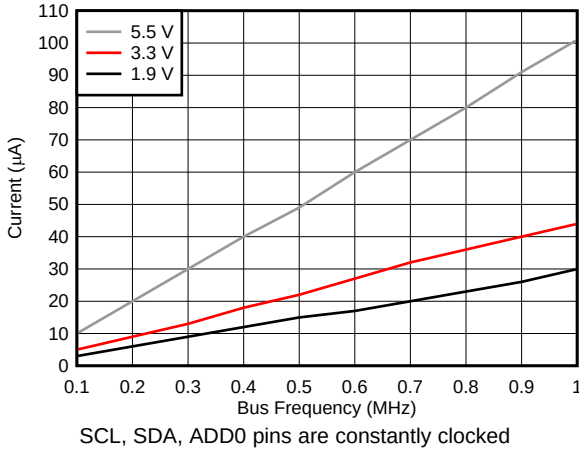


Figure 11. Quiescent Current in Shutdown Mode

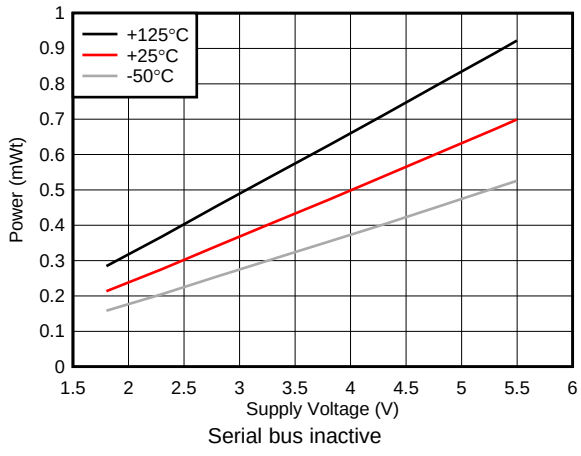


Figure 12. Power Consumption During Active Conversion

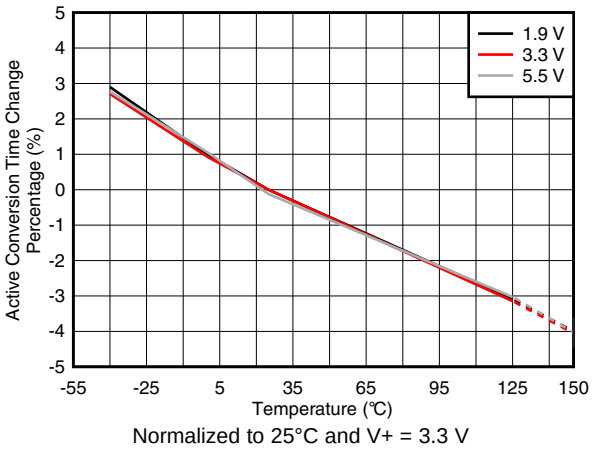
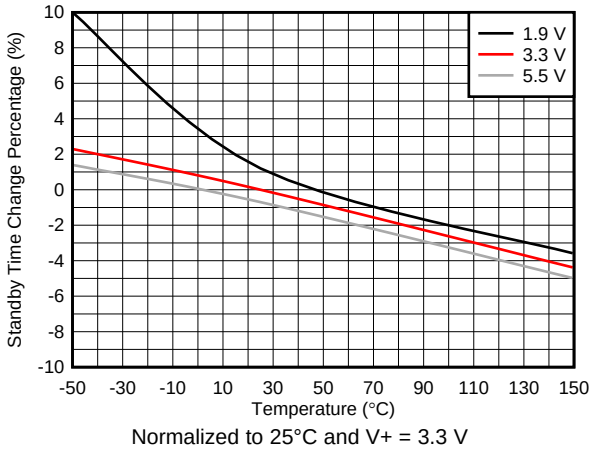


Figure 13. Active Conversion Time vs Temperature

Typical Characteristics (continued)

at T_A = 25°C, V+ = 3.3 V, and measurement taken in oil bath (unless otherwise noted)



Normalized to 25°C and V+ = 3.3 V

Figure 14. Standby Time vs Temperature

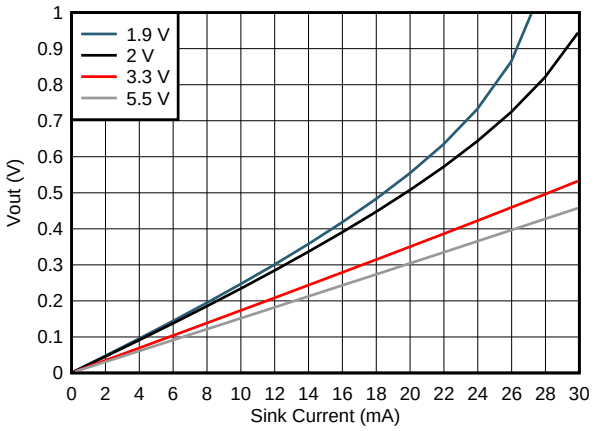
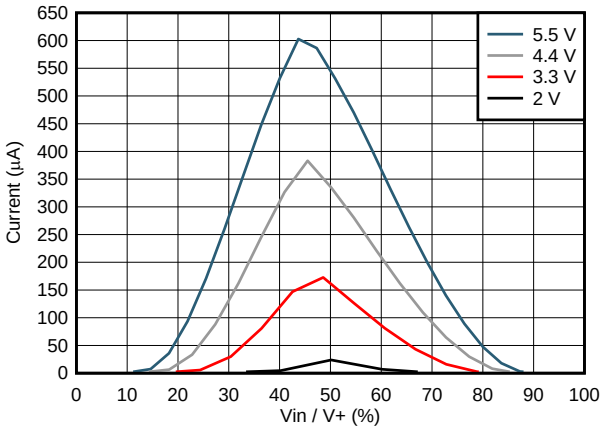


Figure 15. ALERT Pin Output Voltage vs Pin Sink Current



Input voltage of SCL, SDA, or ADD0 pin

Figure 16. Supply Current vs Input Cell Voltage

7 Detailed Description

7.1 Overview

The TMP116 is a digital output temperature sensor that is optimal for thermal-management and thermal-protection applications. The TMP116 is 2-wire, SMBus, and I^2C interface-compatible. The device is specified over an operating temperature range of –55°C to +125°C. Figure 17 shows a block diagram of the TMP116. Figure 18 shows the ESD protection circuitry contained in the TMP116.

7.2 Functional Block Diagrams

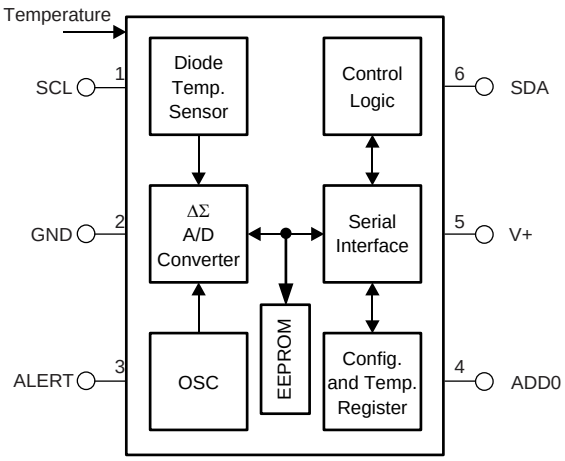


Figure 17. Internal Block Diagram

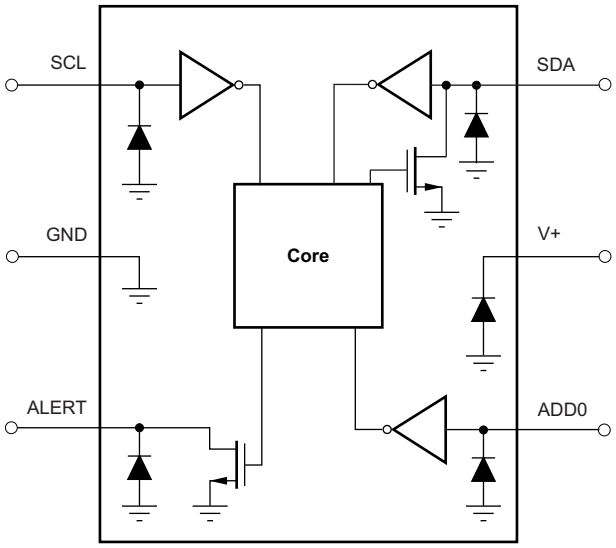


Figure 18. Equivalent Internal ESD Circuitry

7.3 Feature Description

7.3.1 Power Up

After the supply voltage reaches within the operating range, the device requires 1.5 ms to power up before conversions begin. The device can be programmed to startup in shutdown mode as well; see the *EEPROM Programming* section. The temperature register reads –256°C before the first conversion.

Feature Description (continued)

7.3.2 Temperature Result and Limits

At the end of every conversion, the device updates the temperature register with the conversion result. The data reading in the result register is in two's complement format, has a data width of 16 bits, and a resolution of 7.8125 m°C. Table 1 shows multiple examples of possible binary data that can be read from the temperature result register and the corresponding hexadecimal and decimal equivalents.

The TMP116 also has alert status flags and alert pin functionality that use the temperature limits stored in the low limit register and high limit register. The same data format used for the temperature result register can be used for data that are written to the high and low limit registers.

Table 1. 16-Bit Temperature Data Format

TEMPERATURE (°C)	TEMPERATURE REGISTER VALUE (0.0078125°C RESOLUTION)	
	BINARY	HEX
–256	1000 0000 0000 0000	8000
–25	1111 0011 1000 0000	F380
–0.1250	1111 1111 1111 0000	FFF0
–0.0078125	1111 1111 1111 1111	FFFF
0	0000 0000 0000 0000	0000
0.0078125	0000 0000 0000 0001	0001
0.1250	0000 0000 0001 0000	0010
1	0000 0000 1000 0000	0080
25	0000 1100 1000 0000	0C80
100	0011 0010 0000 0000	3200
255.9921	0111 1111 1111 1111	7FFF

7.4 Device Functional Modes

7.4.1 Temperature Conversions

The TMP116 can be configured to operate in various conversion modes by using the MOD[1:0] bits. These modes provide flexibility to operate the device in the most power efficient way required for the intended application.

7.4.1.1 Conversion Cycle

When the device is operating in continuous conversion mode (see the *Continuous Conversion Mode (CC)* section), every conversion cycle consists of an active conversion period followed by a standby period. During active conversion the device typically consumes 135 µA, and during the low-power standby period the device typically consumes 1.25 µA, as indicated in Table 1. Figure 19 shows a representative current consumption profile of a conversion cycle. The duration of the active conversion period and standby period can be configured using the CONV[2:0] and AVG[1:0] bits in the configuration register, thereby allowing the average current consumption of the device to be optimized based on the application requirements. Changing the conversion cycle period also affects the temperature result update rate because the temperature result register is updated at the end of every conversion.

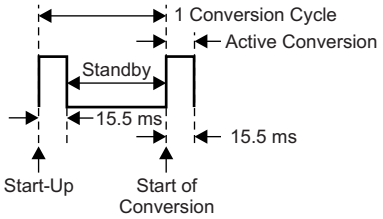


Figure 19. Conversion Cycle Timing Diagram

7.4.1.2 Averaging

Noise in the conversion result can be improved by configuring the device to report the average of multiple temperature conversions using the AVG[1:0] bits. When the TMP116 is configured to perform averaging, the device executes the configured number of conversions while accumulating the results and reports the average of all conversion results at the end of the process. As illustrated in the noise histograms of Figure 6 and Figure 7, the temperature result output has a repeatability of approximately ±3 LSBs when there is no averaging and ±1 LSB when the device is configured to perform eight averages. As illustrated in Figure 20, this improvement in noise performance is achieved with the tradeoff of an increase in the active conversion time in a conversion cycle, thereby increasing the average active current consumption. For example, a single active conversion typically takes 15.5 ms so if the device is configured to report an average of eight conversions then the active conversion time is 124 ms (15.5 ms × 8). Use Equation 1 to factor in this increase in active conversion time to accurately calculate the average current consumption of the device. The average current consumption of the device can be decreased by increasing the amount of time the device spends in standby period as compared to active conversion. On reset, the device is configured to report an average of eight conversions with a conversion cycle time of 1 second.

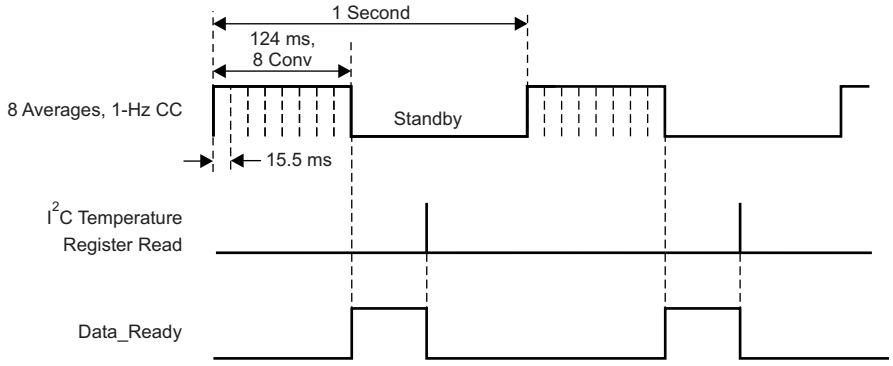


Figure 20. Averaging Timing Diagram

Device Functional Modes (continued)

Use Equation 1 to calculate the average current consumption of the device in continuous mode.

$$\frac{(\text{Active Current Consumption} \times \text{Active Conversion Time}) + (\text{Standby Current Consumption} \times \text{Standby Time})}{\text{Conversion Cycle Time}} \quad (1)$$

7.4.1.3 Continuous Conversion Mode (CC)

When the MOD[1:0] bits are set to 00, the TMP116 operates in continuous conversion mode. In this mode, the device continuously performs temperature conversions as illustrated in Figure 19 and updates the temperature result register at the end of every conversion. As described in the *Conversion Cycle* section, every conversion cycle consists of an active conversion period followed by a standby period whose duration can be configured using the CONV and AVG bits in the configuration register based on the temperature accuracy, power consumption, and temperature update rate tradeoffs of the application that the device is used in. At the end of a conversion, the Data_Ready flag in the configuration register is set. The Data_Ready flag is cleared by reading the configuration register or the temperature result register. Therefore, the Data_Ready flag can be used to determine when the conversion completes so that an external controller can synchronize reading the result register with conversion result updates. The state of the Data_Ready flag can also be monitored on the ALERT pin by setting the DR/nAlert_EN bit in the configuration register.

7.4.1.4 Shutdown Mode (SD)

When 01 is written to the MOD[1:0] bits in the configuration register, the device instantly aborts the currently running conversion and enters a low-power shutdown mode. In this mode, the device powers down all active circuitry and can be used in conjunction with the OS mode to perform temperature conversions. In SD mode, the device typically consumes only 250 nA, which makes the TMP116 suitable for low-power consumption applications, such as battery-operated systems.

7.4.1.5 One-Shot Mode (OS)

When in shutdown mode, a single conversion can be performed by writing 10 to MOD[1:0] bits in the configuration register, referred to as a one-shot conversion. After completing a one-shot conversion, the device returns to the low-power shutdown mode. A one-shot conversion cycle only consists of active conversion time and no standby period unlike CC mode. Thus, the duration of a one-shot conversion is only affected by the settings in the AVG bits. The CONV bits do not affect the duration of a one-shot conversion. Figure 21 shows a timing diagram for this mode with an AVG setting of 00. At the end of a one-shot conversion, the Data_Ready flag in the configuration register is set. Therefore, the Data_Ready flag can be used to determine when the conversion completes. The Data_Ready flag is cleared by performing an I^2C read on the configuration register or temperature result register. The state of the Data_Ready flag can also be monitored on the ALERT pin by setting the DR/nAlert_EN bit in the configuration register.

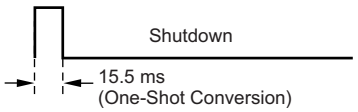


Figure 21. One-Shot Timing Diagram

7.4.2 Therm and Alert Functions

The TMP116 can be used to detect if the temperature has crossed a certain temperature limit or if the device is within a certain temperature range by using the therm or alert functions built into the device. At the end of every conversion, the TMP116 compares the converted temperature result to the values stored in the low limit register and high limit register and sets or clears the corresponding status flags in the configuration register, as described in this section.

Device Functional Modes (continued)

7.4.2.1 Alert Mode

When the T/nA bit in the configuration register is set to 0, the device is in alert mode. In this mode, the device compares the conversion result at the end of every conversion with the values in the low limit register and high limit register. If the temperature result exceeds the value in the high limit register, the HIGH_Alert status flag in the configuration register is set. On the other hand, if the temperature result is lower than the value in the low limit register, the LOW_Alert status flag in the configuration register is set. As shown in Figure 22, in alert mode the status flags can be cleared by performing an I^2C read transaction on the configuration register.

Configuring the device in alert mode also affects the behaviour of the ALERT pin. In this mode, the device asserts the ALERT pin when either the HIGH_Alert or the LOW_Alert status flag is set as shown in Figure 22. The ALERT pin can be deasserted by either performing an I^2C read of the configuration register (which also clears the status flags) or by performing an SMBus alert response command (see the *SMBus Alert Function* section). The polarity of the ALERT pin can be changed by using the POL bit setting in the configuration register.

This mode effectively makes the device behave like a window limit detector and can be used in applications where detecting if the temperature goes outside of the specified range is needed.

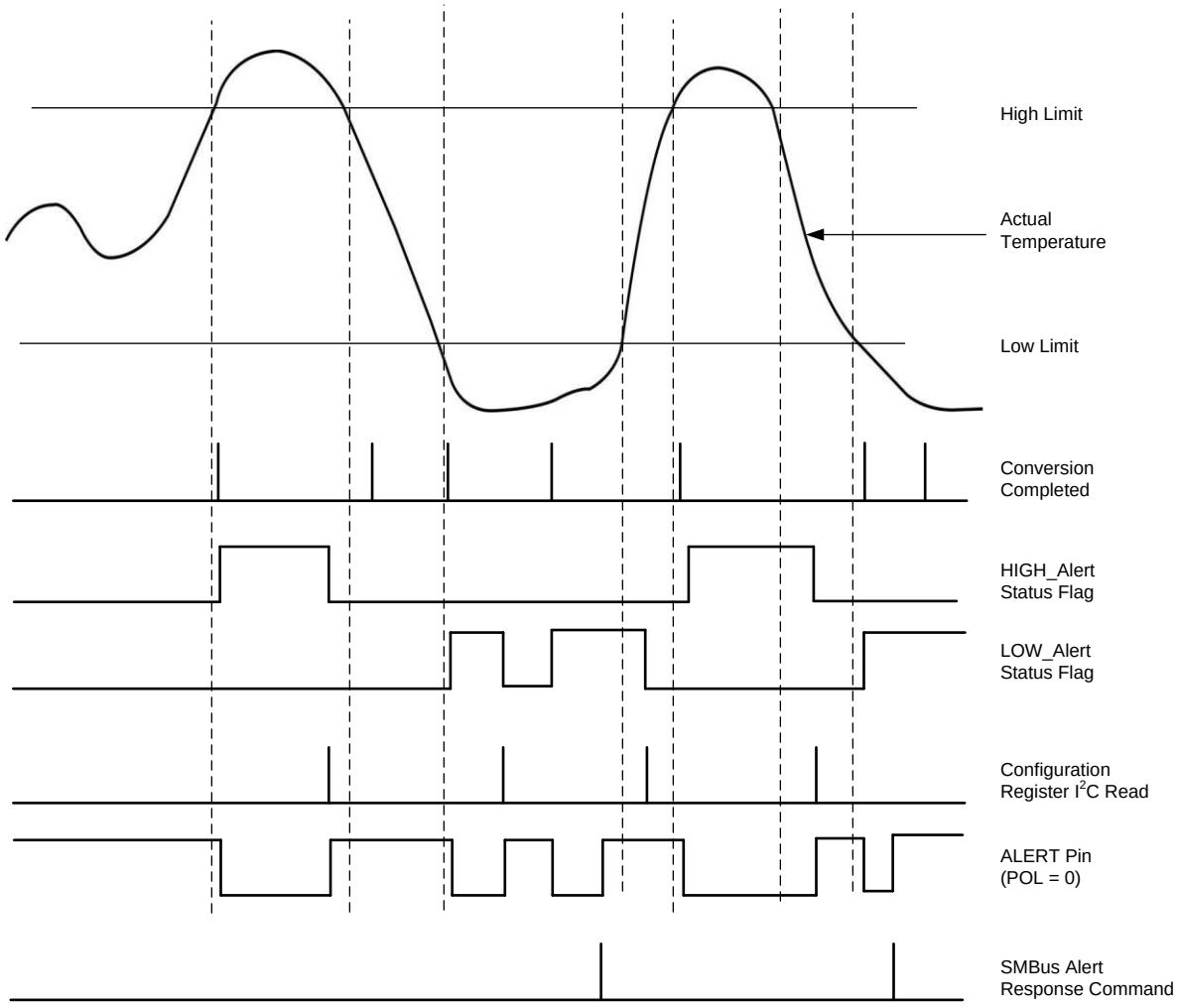


Figure 22. Alert Mode Timing Diagram

Device Functional Modes (continued)

7.4.2.2 Therm Mode

When the T/nA bit in the configuration register is set to 1 the device is in therm mode. In this mode, the device compares the conversion result at the end of every conversion with the values in the low limit register and high limit register and sets the HIGH_Alert status flag in the configuration register if the temperature exceeds the value in the high limit register. When set, the device clears the HIGH_Alert status flag if the conversion result goes below the value in the low limit register. Thus, the difference between the high and low limits effectively acts like a hysteresis. In this mode, the LOW_Alert status flag is disabled and always reads 0. Unlike the alert mode, I^2C reads of the configuration register do not affect the status bits. The HIGH_Alert status flag is only set or cleared at the end of conversions based on the value of the temperature result compared to the high and low limits.

As in alert mode, configuring the device in therm mode also affects the behaviour of the ALERT pin. In this mode, the device asserts the ALERT pin if the HIGH_Alert status flag is set and deasserts the ALERT pin when the HIGH_Alert status flag is cleared. In therm mode the ALERT pin cannot be cleared by performing an I^2C read of the configuration register or by performing an SMBus alert response command. As in alert mode, the polarity of the active state of the ALERT pin can be changed by using the POL bit setting in the configuration register.

Thus, this mode effectively makes the device behave like a high-limit threshold detector and can be used in applications where detecting if the temperature has gone above a desired threshold is needed. Figure 23 shows a timing diagram of this mode.

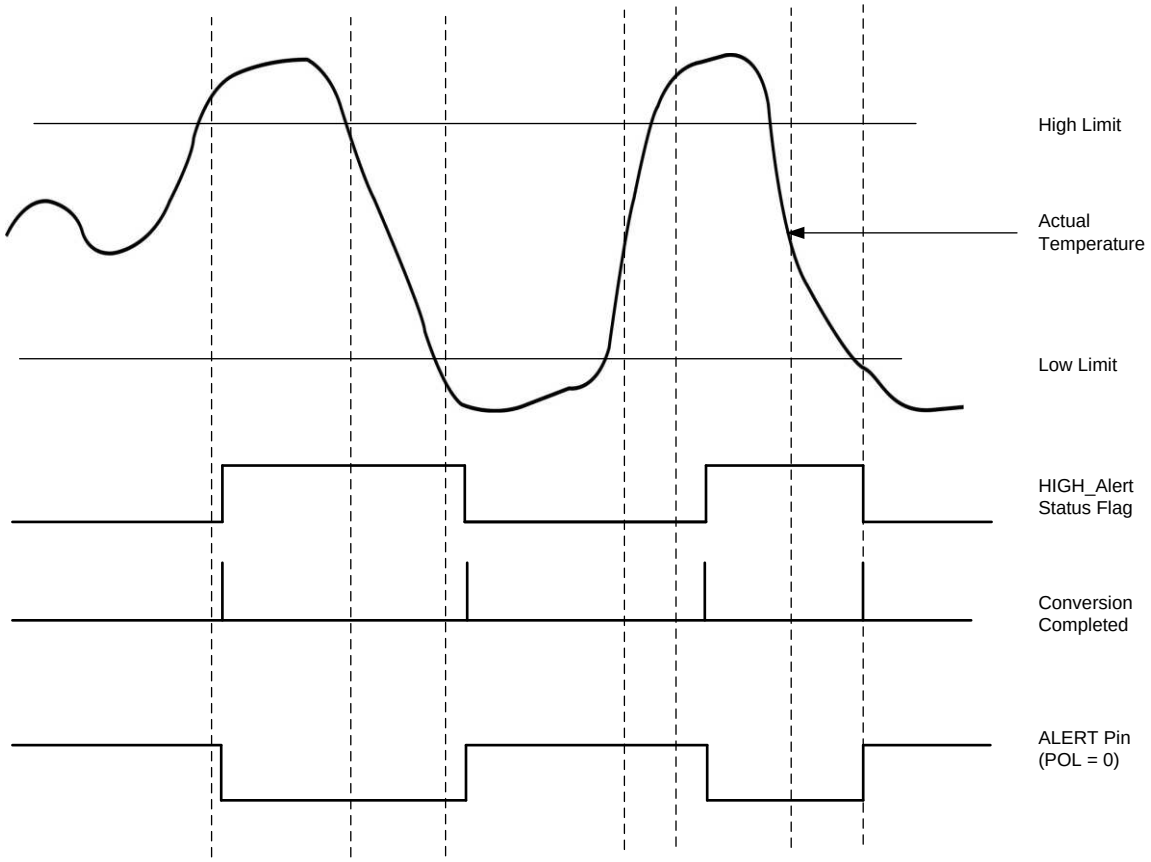


Figure 23. Therm Mode Timing Diagram

7.5 Programming

7.5.1 EEPROM Programming

7.5.1.1 EEPROM Overview

The device consists of a user-programmable EEPROM that can be used for two purposes:

- Storing power-on-reset (POR) values of the high limit register, low limit register, conversion cycle time, averaging mode, conversion mode (continuous or shutdown mode), alert function mode (alert or therm mode), and alert polarity
- Four 16-bit locations for general-purpose use; see the EEPROM[4:1] registers

On reset, the device goes through a POR sequence that loads the values programmed in the EEPROM into the respective register map locations. This process takes approximately 1.5 ms. When the power-up sequence is completed the device starts operating in accordance to the configuration parameters that are loaded from the EEPROM. Any I^2C writes performed during this initial POR period to the limit registers or the configuration register are ignored. I^2C read transactions can still be performed with the device during the power-up period. While the POR sequence is being executed, the EEPROM_Busy status flag in the EEPROM unlock register is set.

During production, the EEPROM in the TMP116 is programmed with reset values as shown in Table 3. The *Programming the EEPROM* section describes how to change these values. Additionally, during production a unique ID is programmed in the general-purpose EEPROM locations. This unique ID is used to support NIST traceability. The TMP116 units are 100% tested on a production setup that is NIST traceable and verified with equipment that is calibrated to ISO/IEC 17025 accredited standards. Only reprogram the general-purpose EEPROM[4:1] locations if NIST traceability is not desired.

7.5.1.2 Programming the EEPROM

In order to prevent accidental programming, the EEPROM is locked by default. When locked, any I^2C writes to the register map locations are performed only on the volatile registers and not on the EEPROM.

Figure 24 illustrates a flow chart describing the EEPROM programming sequence. To program the EEPROM, first unlock the EEPROM by setting the EUN bit in the EEPROM unlock register. After the EEPROM is unlocked, any subsequent I^2C writes to the register map locations program a corresponding non-volatile memory location in the EEPROM. Programming a single location typically takes 7 ms to complete and consumes 230 µA. Do not perform any I^2C writes until programming is completed. During programming, the EEPROM_busy flag is set. Read this flag to monitor if the programming is complete. After programming the desired data, issue a general-call reset command to trigger a software reset. The programmed data from the EEPROM are then loaded to the corresponding register map locations as part of the reset sequence. This command also clears the EUN bit and automatically locks the EEPROM to prevent any further accidental programming. Avoid using the device to perform temperature conversions when the EEPROM is unlocked.

Programming (continued)

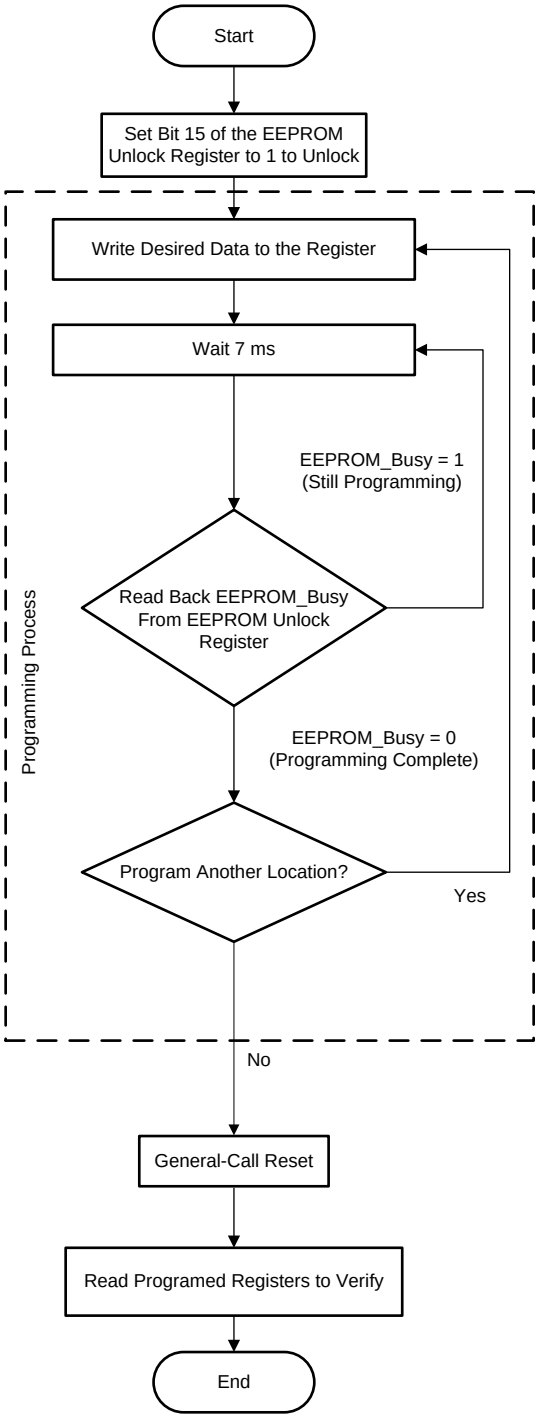


Figure 24. EEPROM Programming Sequence

Programming (continued)

7.5.2 Pointer Register

Figure 25 shows the internal register structure of the TMP116. The 8-bit pointer register of the device is used to address a given data register. The power-up reset value is 00. By default, the TMP116 reads the temperature on power-up.

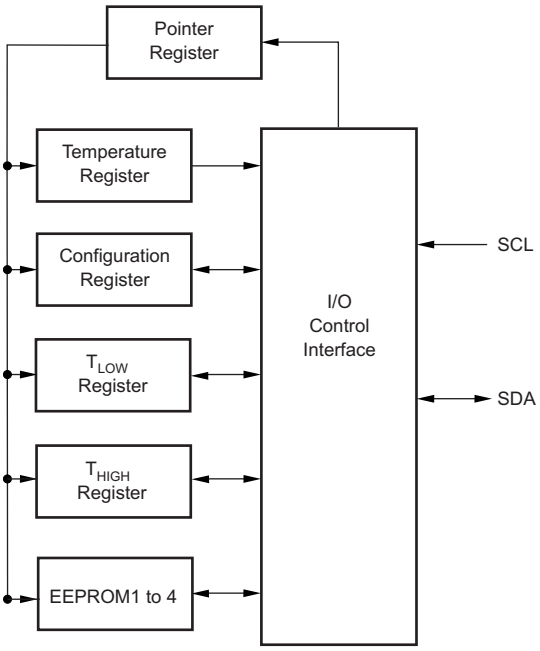


Figure 25. Internal Register Structures

7.5.3 I²C and SMBus Interface

7.5.3.1 Serial Interface

The TMP116 operates as a slave device only on the 2-wire, SMBus and I²C interface-compatible bus. Connections to the bus are made through the open-drain I/O lines and the SDA and SCL pins. The SDA and SCL pins feature integrated spike-suppression filters and Schmitt triggers to minimize the effects of input spikes and bus noise. The device supports the transmission protocol for fast (1 kHz to 400 kHz) mode. Register bytes are sent with the most significant byte first, followed by the least significant byte.

7.5.3.1.1 Bus Overview

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, indicated by pulling the data line (SDA) from a high- to low-logic level when the SCL pin is high. All slaves on the bus shift in the slave address byte on the rising edge of the clock, 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 the SDA pin low.

A data transfer is then initiated and sent over eight clock pulses followed by an acknowledge bit. During the data transfer, the SDA pin must remain stable when the SCL pin is high because any change in the SDA pin when the SCL pin is high is interpreted as a START or STOP signal.

When all data are transferred, the master generates a repeated START or STOP condition indicated by pulling the SDA pin from low to high when the SCL pin is high.

Programming (continued)

7.5.3.1.2 Serial Bus Address

To communicate with the TMP116, the master must first address slave devices through an address byte. The address byte consists of seven address bits and a read-write (R/W) bit indicating the intent of executing a read or write operation.

The TMP116 features an address pin to allow up to four devices to be addressed on a single bus. Table 2 describes the pin logic levels used to properly connect up to four devices. *x* represents the read-write (R/$\overline{W}$) bit.

Table 2. Address Pin and Slave Addresses

DEVICE TWO-WIRE ADDRESS	ADD0 PIN CONNECTION
1001000x	Ground
1001001x	V+
1001010x	SDA
1001011x	SCL

7.5.3.1.3 Writing and Reading Operation

Accessing a particular register on the TMP116 is accomplished by writing the register address to the pointer register. The value for the pointer register is the first byte transferred after the slave address byte with the R/$\overline{W}$ bit low. Every write operation to the TMP116 requires a value for the pointer register.

When reading from the TMP116, 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 action is accomplished by issuing an address byte with the R/$\overline{W}$ bit low, followed by the pointer register byte. No additional data are 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 28 for details of this sequence. If repeated reads from the same register are desired, continuously sending the pointer register bytes is not necessary because the TMP116 retains the pointer register value until the value is changed by the next write operation.

Register bytes are sent with the most significant byte first, followed by the least significant byte.

7.5.3.1.4 Slave Mode Operations

The TMP116 can operate as a slave receiver or slave transmitter. As a slave device, the TMP116 never drives the SCL line.

7.5.3.1.4.1 Slave Receiver Mode

The first byte transmitted by the master is the slave address with the R/$\overline{W}$ bit low. The TMP116 then acknowledges reception of a valid address. The next byte transmitted by the master is the pointer register. The TMP116 then acknowledges reception of the pointer register byte. The next byte or bytes are written to the register addressed by the pointer register. The TMP116 acknowledges reception of each data byte. The master can terminate data transfer by generating a START or STOP condition.

7.5.3.1.4.2 Slave Transmitter Mode

The first byte transmitted by the master is the slave address with the R/$\overline{W}$ bit high. The slave acknowledges reception of a valid slave address. The next byte is transmitted by the slave and is the most significant byte of the register indicated by the pointer register. The master acknowledges reception of the data byte. The next byte transmitted by the slave is the least significant byte. The master acknowledges reception of the data byte. The master can terminate data transfer by generating a *not-acknowledge* on reception of any data byte or by generating a START or STOP condition.

7.5.3.1.5 SMBus Alert Function

The TMP116 supports the SMBus alert function. When the ALERT pin is connected to an SMBus alert signal and a master senses that an alert condition is present, the master can send out an SMBus ALERT command (0001 1001) to the bus. If the ALERT pin is active, the device acknowledges the SMBus ALERT command and responds by returning the slave address on the SDA line. The eighth bit (LSB) of the slave address byte indicates if the alert condition is caused by the temperature exceeding $T_{(HIGH)}$ or falling below $T_{(LOW)}$. The LSB is high if the temperature is greater than $T_{(HIGH)}$, or low if the temperature is less than $T_{(LOW)}$; see Figure 29 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 clears the alert status of that device. The device with the lowest 2-wire address wins the arbitration. If the TMP116 wins the arbitration, the TMP116 ALERT pin becomes inactive at the completion of the SMBus ALERT command. If the TMP116 loses the arbitration, the TMP116 ALERT pin remains active.

7.5.3.1.6 General-Call Reset Function

The TMP116 responds to a two-wire, general-call address (0000 000) if the eighth bit is 0. The device acknowledges the general-call address and responds to commands in the second byte. If the second byte is 0000 0110, the TMP116 internal registers are reset to power-up values.

7.5.3.1.7 Timeout Function

The TMP116 resets the serial interface if the SCL line is held low by the master or the SDA line is held low by the TMP116 for 35 ms (typical) between a START and STOP condition. The TMP116 releases the SDA line if the SCL pin is pulled low and waits for a START condition from the host controller. To avoid activating the timeout function, maintain a communication speed of at least 1 kHz for the SCL operating frequency.

7.5.3.1.8 Timing Diagrams

The TMP116 is 2-wire, SMBus, and I^2C interface-compatible. Figure 26 to Figure 30 describe the various operations on the TMP116. Parameters for Figure 26 are defined in *Two-Wire Interface Timing*. Bus definitions are:

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 when 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 when the SCL line is high defines a STOP condition. Each data transfer is terminated 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 TMP116 can also be used for single byte updates. To update only the MS byte, terminate the communication by issuing a START or STOP communication on the bus.

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, the termination of the data transfer can be signaled by the master generating a *not-acknowledge* (1) on the last byte transmitted by the slave.

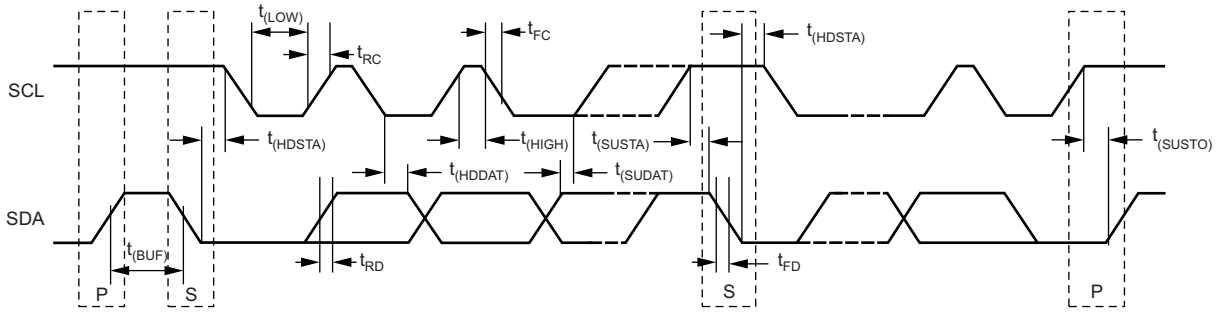


Figure 26. Two-Wire Timing Diagram

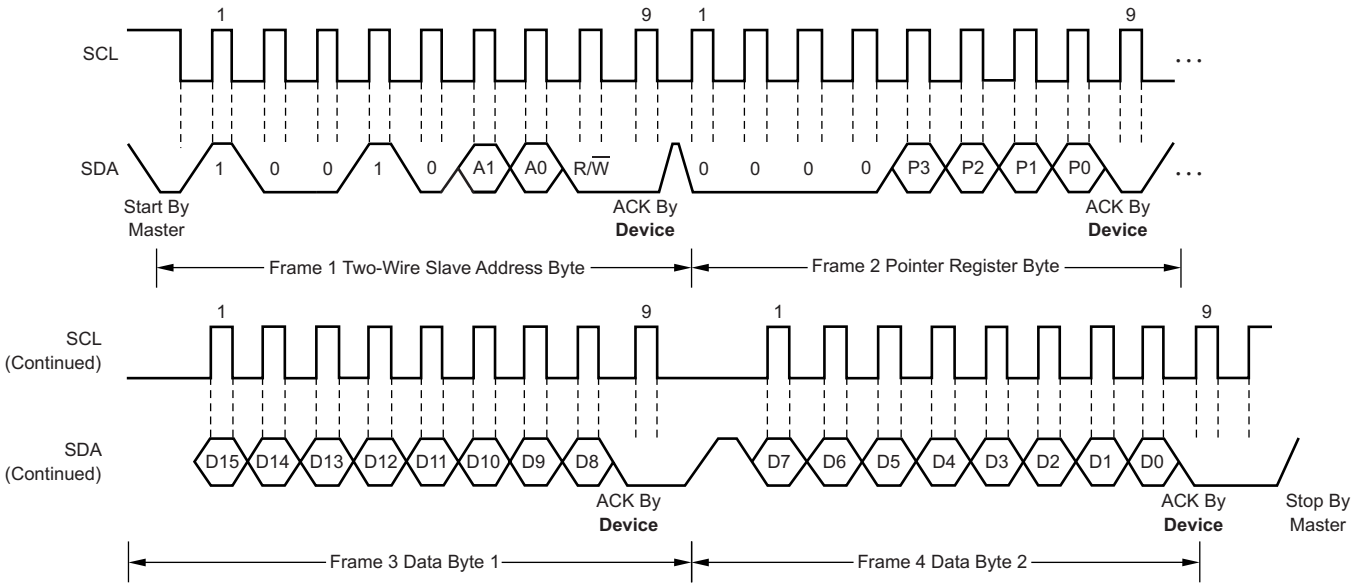


Figure 27. Write Word Command Timing Diagram

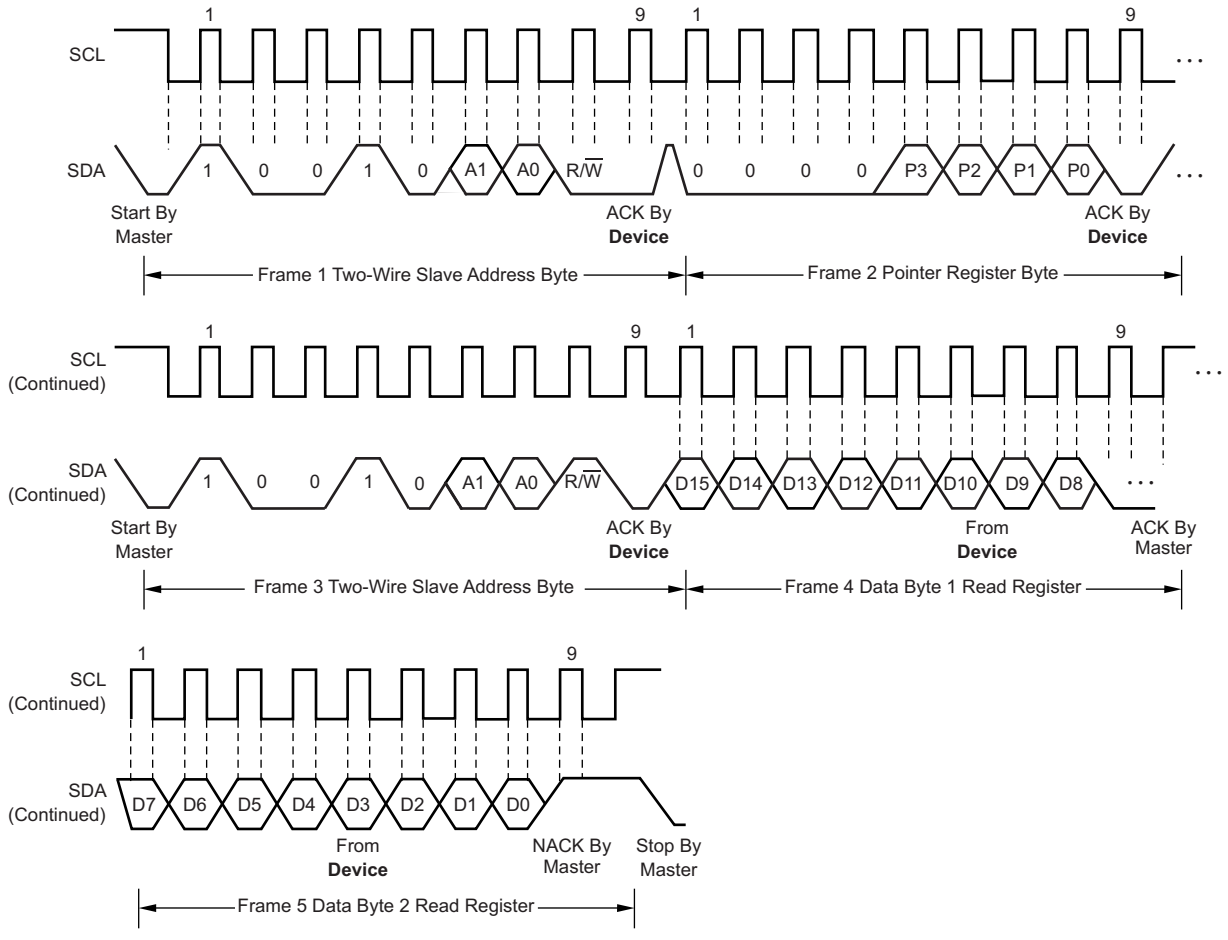


Figure 28. Read Word Command Timing Diagram

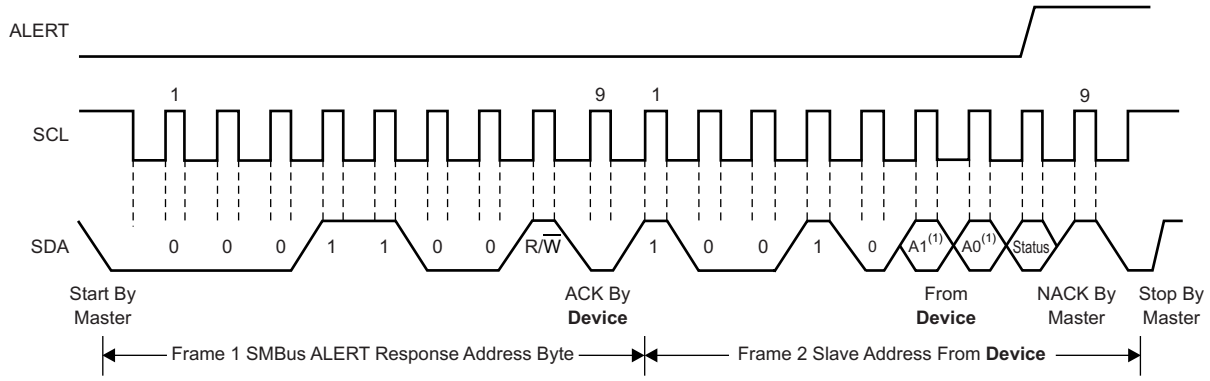


Figure 29. SMBus ALERT Timing Diagram

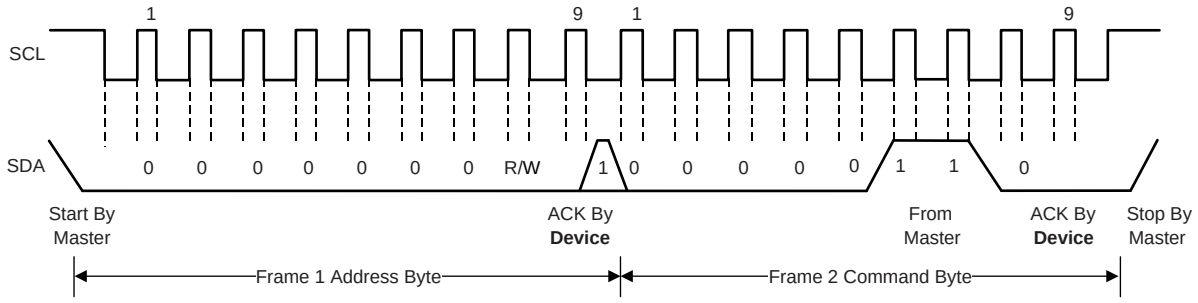


Figure 30. General-Call Reset Command Timing Diagram

7.6 Registers Map

Table 3. Register Map

ADDRESS (Hex)	DEFAULT VALUE (Hex)	REGISTER DATA																REGISTER NAME
		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
00h	8000	T15	T14	T13	T12	T11	T10	T9	T8	T7	T6	T5	T4	T3	T2	T1	T0	Temperature
01h	0220(1)	HIGH_ Alert	LOW_ Alert	Data_ Ready	EEPROM _Busy	MOD1	MOD0	CONV2	CONV1	CONV0	AVG1	AVG0	T/nA	POL	DR/nAlert _EN	—	—	Configuration
02h	6000(1)	H15	H14	H13	H12	H11	H10	H9	H8	H7	H6	H5	H4	H3	H2	H1	H0	High Limit
03h	8000(1)	L15	L14	L13	L12	L11	L10	L9	L8	L7	L6	L5	L4	L3	L2	L1	L0	Low Limit
04h	0000	EUN	EEPROM _ Busy	—	—	—	—	—	—	—	—	—	—	—	—	—	—	EEPROM Unlock
05h	xxxx(1)	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	EEPROM1
06h	xxxx(1)	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	EEPROM2
07h	0000(1)	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	EEPROM3
08h	xxxx(1)	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	EEPROM4
0Fh	x116	—	—	—	—	DID11	DID10	DID9	DID8	DID7	DID6	DID5	DID4	DID3	DID2	DID1	DID0	Device ID

(1) This value is stored in electrically-erasable, programmable read-only memory (EEPROM) during device manufacturing. The device reset value can be changed by writing the relevant code in the EEPROM cells (see the *EEPROM Overview* section).

7.6.1 Register Descriptions

Table 4. TMP116 Access Type Codes

Access Type	Code	Description
R	R	Read
Read-write	R/W	Read, write, or both
W	W	Write
-n		Value after reset or the default value

7.6.1.1 Temperature Register (address = 00h) [default reset = 8000h]

This register is a 16-bit, read-only register that stores the output of the most recent conversion. One LSB equals 7.8125 m°C. Data are represented in binary two's complement format. Following power-up or a general-call reset, the temperature register reads –256°C until the first conversion is complete (see the *Power Up* section).

Figure 31. Temperature Register

15	14	13	12	11	10	9	8
T15	T14	T13	T12	T11	T10	T9	T8
R-1	R-0	R-0	R-0	R-0	R-0	R-0	R-0
7	6	5	4	3	2	1	0
T7	T6	T5	T4	T3	T2	T1	T0
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

Table 5. Temperature Register Field Descriptions

Bit	Field	Type	Reset	Description
15:0	T[15:0]	R	8000h	16-bit, read-only register that stores the most recent temperature conversion results.

7.6.1.2 Configuration Register (address = 01h) [default reset = 0220h]

Figure 32. Configuration Register

15	14	13	12	11	10	9	8
HIGH_Alert	LOW_Alert	Data_Ready	EEPROM_Busy	MOD1(1)	MOD0(2)	CONV2(2)	CONV1(2)
R-0	R-0	R-0	R-0	R/W-0	R/W-0	R/W-1	R/W-0
7	6	5	4	3	2	1	0
CONV0(2)	AVG1(2)	AVG0(2)	T/nA(2)	POL(2)	DR/Alert(2)	—	—
R/W-0	R/W-0	R/W-1	R/W-0	R/W-0	R/W-0	R-0	R-0

(1) The MOD1 bit cannot be stored in EEPROM. The device can only be programmed to start up in shutdown mode or continuous conversion mode.
(2) These bits can be stored in EEPROM. The factory setting for this register is 0220.

Table 6. Configuration Register Field Descriptions

Bit	Field	Type	Reset	Description
15	HIGH_Alert	R	0	Alert mode: 1: Set when the conversion result is higher than the high limit 0: Cleared on read of configuration register Therm mode: 1: Set when the conversion result is higher than the therm limit 0: Cleared when the conversion result is lower than the hysteresis
14	LOW_Alert	R	0	Alert mode: 1: Set when the conversion result is lower than the low limit 0: Cleared when the configuration register is read Therm mode: Always set to 0
13	Data_Ready	R	0	Data ready flag. This flag indicates that the conversion is complete and the temperature register can be read. Every time the temperature register or configuration register is read, this bit is cleared. This bit is set at the end of the next conversion when the temperature register is updated. Data ready can be monitored on the ALERT pin by using bit 2 of the configuration register.
12	EEPROM_Busy	R	0	EEPROM busy flag. The value of the flag indicates that the EEPROM is busy during programming or power-up.
11:10	MOD[1:0]	R/W	0	Set conversion mode. 00: Continuous conversion (CC) 01: Shutdown (SD) 10: Continuous conversion (read back = 00) 11: One-shot conversion (OS)
9:7	CONV[2:0]	R/W	100	Conversion cycle bit. See Table 7 for the standby time between conversions.
6:5	AVG[1:0]	R/W	01	Conversion averaging modes. These bits determine the number of conversion results that are collected and averaged before updating the temperature register. The average is an accumulated average and not a running average. Table 8 lists the bit settings for AVG.
4	T/nA	R/W	0	Therm/alert mode select. 1: Therm mode 0: Alert mode
3	POL	R/W	0	ALERT pin polarity bit. 1: Active high 0: Active low
2	DR/Alert	R/W	0	Data ready, ALERT flag select bit. 1: ALERT pin reflects the status of the data ready flag 0: ALERT pin reflects the status of the alert flags
1:0	—	R	0	Not used

Table 7. Conversion Cycle Time in CC Mode

CONV[2:0]	AVG[1:0] = 00	AVG[1:0] = 01	AVG[1:0] = 10	AVG[1:0] = 11
000	15.5 ms	125 ms	500 ms	1 s
001	125 ms	125 ms	500 ms	1 s
010	250 ms	250 ms	500 ms	1 s
011	500 ms	500 ms	500 ms	1 s
100	1 s	1 s	1 s	1 s
101	4 s	4 s	4 s	4 s
110	8 s	8 s	8 s	8 s
111	16 s	16 s	16 s	16 s

Table 8. AVG Bit Settings

AVG1	AVG0	DESCRIPTION
0	0	No averaging,15.5-ms active conversion time
0	1	8 averages, 125-ms active conversion time
1	0	32 averages, 500-ms active conversion time
1	1	64 averages, 1-s active conversion time

7.6.1.3 High Limit Register (address = 02h) [reset = 6000h]

This register is a 16-bit, read/write register that stores the high limit for comparison with the temperature result. One LSB equals 7.8125 m°C. The range of the register is ±256°C. Negative numbers are represented in binary two's complement format. Following power-up or a general-call reset, the high-limit register is loaded with the stored value from the EEPROM that is set as factory default to 6000h.

Figure 33. High Limit Register

15	14	13	12	11	10	9	8
H15	H14	H13	H12	H11	H10	H9	H8
R/W-0	R/W-1	R/W-1	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
H7	H6	H5	H4	H3	H2	H1	H0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

Table 9. High Limit Register Field Descriptions

Bit	Field	Type	Reset	Description
15:0	H[15:0]	R/W	6000h	16-bit, read/write register that stores the high limit for comparison with the temperature result.

7.6.1.4 Low Limit Register (address = 03h) [reset = 8000h]

This register is configured as a 16-bit, read/write register that stores the low limit for comparison with the temperature result. One LSB equals 7.8125 m°C. The range of the register is ±256°C. Negative numbers are represented in binary two's complement format. Following power-up or reset, the low-limit register is loaded with the stored value from the EEPROM that is set in the factory to 8000h.

Figure 34. Low Limit Register

15	14	13	12	11	10	9	8
L15	L14	L13	L12	L11	L10	L9	L8
R/W-1	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
L7	L6	L5	L4	L3	L2	L1	L0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

Table 10. Low Limit Register Field Descriptions

Bit	Field	Type	Reset	Description
15:0	L[15:0]	R/W	8000h	16-bit, read/write register that stores the low limit for comparison with the temperature result.

7.6.1.5 EEPROM Unlock Register (address = 04h) [reset = 0000h]

Figure 35. EEPROM Unlock Register

15	14	13	12	11	10	9	8
EUN	EEPROM_Busy	—	—	—	—	—	—
R/W-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
7	6	5	4	3	2	1	0
—	—	—	—	—	—	—	—
R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0

Table 11. EEPROM Unlock Register Field Descriptions

Bit	Field	Type	Reset	Description
15	EUN	R/W	0	EEPROM unlock. 0: EEPROM is locked for programming: writes to all EEPROM addresses (such as configuration, limits, and EEPROM locations 1-4) are written to registers in digital logic and are not programmed in the EEPROM 1: EEPROM unlocked for programming: any writes to writable registers program the respective location in the EEPROM
14	EEPROM_Busy	R	0	EEPROM busy. This flag is the mirror of the EEPROM busy flag (bit 12) in the configuration register. 0: Indicates that the EEPROM is ready, which means that the EEPROM has finished the last transaction and is ready to accept new commands 1: Indicates that the EEPROM is busy, which means that the EEPROM is currently completing a program or power-up on reset load
13:0	—	R	0	Not used

7.6.1.6 EEPROM1 Register (address = 05h) [reset = 0000h]

The EEPROM1 register is a 16-bit register that be used as a scratch pad by the customer to store general-purpose data. This register has a corresponding EEPROM location. Writes to this address when the EEPROM is locked write data into the register and not to the EEPROM. Writes to this register when the EEPROM is unlocked causes the corresponding EEPROM location to be programmed; see the *Programming the EEPROM* section. EEPROM[4:1] are preprogrammed during manufacturing with the unique ID that can be overwritten. In order to support NIST traceability, do not delete or reprogram EEPROM[4:1].

Figure 36. EEPROM1 Register

15	14	13	12	11	10	9	8
D15	D14	D13	D12	D11	D10	D9	D8
R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x
7	6	5	4	3	2	1	0
D7	D6	D5	D4	D3	D2	D1	D0
R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x

Table 12. EEPROM1 Register Field Descriptions

Bit	Field	Type	Reset	Description
15:0	D[15:0]	R/W	xxxxh	This 16-bit register is to be used as a scratch pad by the customer.

7.6.1.7 EEPROM2 Register (address = 06h) [reset = 0000h]

This register function the same as the EEPROM1 register.

Figure 37. EEPROM2 Register

15	14	13	12	11	10	9	8
D15	D14	D13	D12	D11	D10	D9	D8
R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x
7	6	5	4	3	2	1	0
D7	D6	D5	D4	D3	D2	D1	D0
R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x

Table 13. EEPROM2 Register Field Descriptions

Bit	Field	Type	Reset	Description
15:0	D[15:0]	R/W	xxxxh	This 16-bit register is to be used as a scratch pad by the customer.

7.6.1.8 EEPROM3 Register (address = 07h) [reset = 0000h]

This register function is the same as the EEPROM1 register.

Figure 38. EEPROM3 Register

15	14	13	12	11	10	9	8
D15	D14	D13	D12	D11	D10	D9	D8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
7	6	5	4	3	2	1	0
D7	D6	D5	D4	D3	D2	D1	D0
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0

Table 14. EEPROM3 Register Field Descriptions

Bit	Field	Type	Reset	Description
15:0	D[15:0]	R/W	0	This 16-bit register is to be used as a scratch pad by the customer.

7.6.1.9 EEPROM4 Register (address = 08h) [reset = xxxxh]

This register function is the same as the EEPROM1 register.

Figure 39. EEPROM4 Register

15	14	13	12	11	10	9	8
D15	D14	D13	D12	D11	D10	D9	D8
R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x
7	6	5	4	3	2	1	0
D7	D6	D5	D4	D3	D2	D1	D0
R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x

Table 15. EEPROM4 Register Field Descriptions

Bit	Field	Type	Reset	Description
15:0	D[15:0]	R/W	xxxxh	This 16-bit register is to be used as a scratch pad by the customer.

7.6.1.10 Device ID Register (address = 0Fh) [reset = x116h]

This read-only register indicates the device ID.

Figure 40. Device ID Register

15	14	13	12	11	10	9	8
—	—	—	—	DID11	DID10	DID9	DID8
R-x	R-x	R-x	R-x	R-0	R-0	R-0	R-1
7	6	5	4	3	2	1	0
DID7	DID6	DID5	DID4	DID3	DID2	DID1	DID0
R-0	R-0	R-0	R-1	R-0	R-1	R-1	R-0

Table 16. Device ID Register Field Descriptions

Bit	Field	Type	Reset	Description
15:12	—	R	x	Not used.
11:0	DID[11:0]	R	116h	These bits indicate the device ID.

8 Application and Implementation

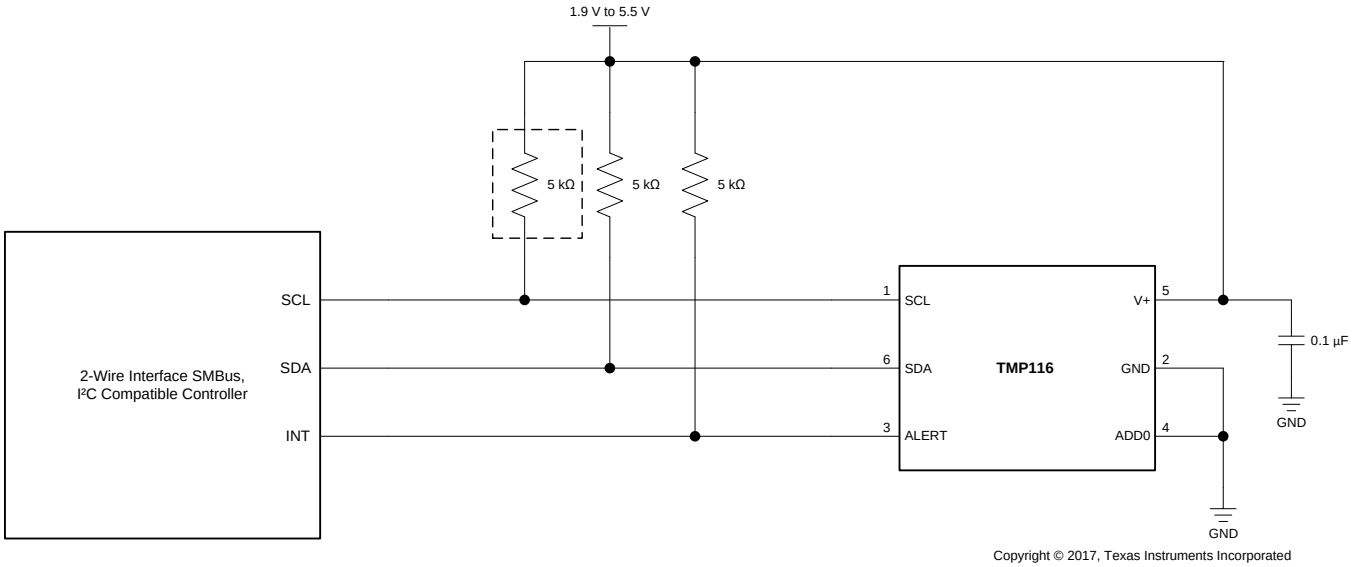
NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The TMP116 is used to measure the temperature of the board location where the device is mounted. The programmable address options allow up to four locations on the board to be monitored on a single serial bus.

8.1.1 Typical Application



NOTE: The SDA and ALERT pins require pullup resistors.

Figure 41. Typical Connections

8.1.1.1 Design Requirements

The TMP116 operates only as a slave device and communicates with the host via the I^2C-compatible serial interface. SCL is the input pin, SDA is a bidirectional pin, and ALERT is the output. The TMP116 requires a pullup resistor on the SCL, SDA, and ALERT pins. The recommended value for the pullup resistors is 5 kΩ. In some applications the pullup resistor can be lower or higher than 5 kΩ. A 0.1-µF bypass capacitor is recommended to be connected between V+ and GND. An SCL pullup resistor is required if the system microprocessor SCL pin is open-drain. Use a ceramic capacitor type with a temperature rating from –40°C to +125°C, placed as close as possible to the V+ pin of the TMP116. The decoupling capacitor reduces any noise induced by the system. When connected directly to GND, V+, SDA, and SCL, use the ADD0 pin for address selection for configuring four possible unique slave ID addresses; Table 1 explains the addressing scheme. The ALERT output pin can be connected to a microcontroller interrupt that triggers an event that occurred when the temperature limit exceeds the programmable value in registers 02h and 03h. The ALERT pin can be left floating if not in use or connected to ground.

Application Information (continued)

8.1.1.2 Detailed Design Procedure

8.1.1.2.1 TMP116 Design Procedure

The TMP116 is a local temperature sensor. Measuring a temperature point with a surface-mount device is very challenging because of the external influence of surrounding air and other components. The TMP116 mainly monitors the PCB temperature at the desired hotspot. To maintain accuracy in applications that requires surface temperature measurement, follow good layout techniques (such as understanding the dominant thermal path, isolating the island surround by the package, and keeping the distance as far as possible from the heat source).

For sensors in plastic packages (such as the TMP116 DFN device), Figure 42 shows that the die attach pad (DAP) provides the most dominant thermal path. With the DAP, a board-mounted sensor usually does an excellent job of measuring board temperature. The die sits on top of the metal plate leadframe with a non-conductive die adhesive in between, allowing for a fast thermal response.

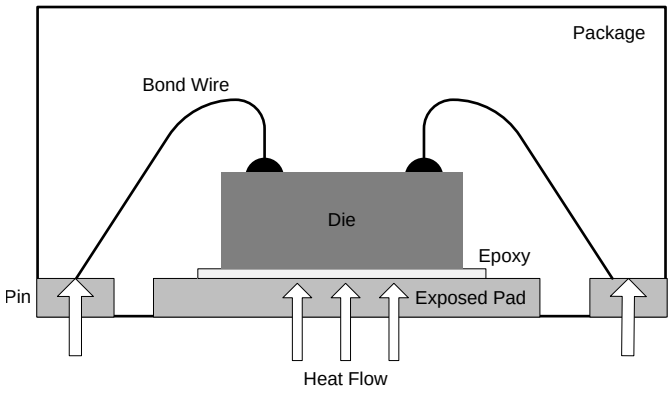


Figure 42. WSON Package Cross Section

Most power-hungry electronic components such as processor chips, field programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), and voltage regulators heat up during operation. In order to accurately measure the ambient temperature of a sensor in a plastic package, isolate the sensor from the heat source using isolation island techniques and distance. TI recommends two vias per TMP116 dimension of the thermal pad. The DAP and two vias help improve thermal characteristics. Thus, in order to take advantage of this feature, mount the TMP116 on the board with the two copper planes on the top and bottom of the via of equal length as the exposed die attach dimension. The bottom plane contains the temperature sensing elements. In order to achieve the fast temperature response, the mini board dimension must be enough to accommodate the TMP116 and the bypass capacitor with the isolation air gap to prevent the heat source dissipated to the mini sub-board.

8.1.1.2.2 Noise and Averaging

The device temperature sampling distribution (without internal averaging) covers an area of approximately six neighboring codes. The noise area of the six codes remains the same at full supply and full temperature range with a standard deviation of approximately 1 LSB. The device provides an averaging tool for 8, 32, and 64 samples. As illustrated in Figure 7, even the 8-sample averaging reduces the internal noise distribution to a theoretical minimum of 2 LSB. This averaging means that if the system temperature slowly changes and the supply voltage is stable, then the 8-sample averaging can be enough to neutralize the device noise and provide stable temperature readings. However, if the system temperature is noisy (such as when measuring air flow temperatures), than higher averaging numbers are recommended to be used.

Application Information (continued)

8.1.1.2.3 Self-Heating Effect (SHE)

During ADC conversion some power is dissipated that heats the device despite the small power consumption of the TMP116. Consider the self-heating effect (SHE) for certain precise measurements. Figure 43 shows the device SHE in still air at 25°C after the supply is switched on. The device package, including the thermo pad, is soldered to the 11-mm × 20-mm × 1.1-mm size coupon board. The board is located horizontally, with the device on top. The TMP116 is in continuous conversion mode with 64 sampling averaging and zero conversion cycle time. There is no digital bus activity aside from reading temperature data one time each second. As shown in Figure 43, the SHE stabilization time in still air is greater when the device dissipates more power.

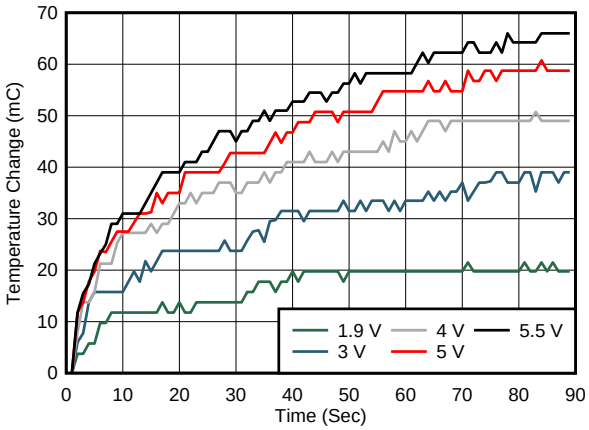


Figure 43. Self-Heating in Still Air versus Temperature and Dissipated Power

The SHE drift is strongly proportional to the device dissipated power. The SHE drift is also proportional to the device temperature because the consumption current with the same supply voltage increases with temperature. Figure 44 shows the SHE drifts versus temperature and dissipated power at 25°C for the same coupon board and the same conditions described previously.

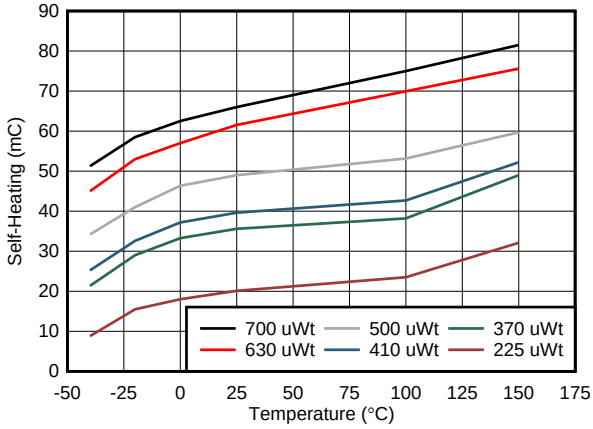


Figure 44. Self-Heating in Still Air vs Temperature and Dissipated Power at 25°C

To estimate the SHE for similar size boards, calculate the device consumption power for 25°C and use the corresponding power line shown in Figure 44. For example, in CC mode without dc at a 3.3-V supply at 25°C, the device dissipates 410 µWt. So self-heating in still air is approximately 40 m°C for the described condition.

Application Information (continued)

The following methods can reduce the SHE:

- System calibration removes not only the self-heating error and power-supply rejection ratio (PSRR) effect but also compensates the temperature shift caused by the thermal resistance between the device and the measured object.
- If practical, use the device one-shot mode. If continuous conversion is needed, use the conversion cycle mode with significant standby time. For example, in most cases an 8-sample averaging (125 ms) with a 1-second conversion cycle provides enough time for the device to cool down to the environment temperature and removes the SHE.
- Use the minimal acceptable power supply voltage.
- Use a printed-circuit board (PCB) layout that provides minimal thermal resistance to the device.
- Avoid using small-value pullup resistors on the SDA and ALERT pins. Instead, use pullup resistors larger than 2 kΩ.
- Ensure that the SCL and SDA signal levels remain below 10% or above 90% of the device supply voltage.
- Avoid heavy bypass traffic on the data line. Communication to other devices on the same data line increases the supply current even if the device is in SD mode.
- Use the highest available communication speed.

8.1.1.2.4 Synchronized Temperature Measurements

When four temperature measurements are needed in four different places simultaneously, triggering a reset is recommended. In this method, four devices are programed with control registers set to CC mode with a conversion cycle time of 16 s. All four devices are connected to same 2-wire bus with four different bus addresses. The bus general-call reset command is issued by the master. This command triggers all devices to reset (which takes approximately 1.5 ms) and triggers a simultaneous temperature sampling according to configuration registers setting. The master has 16 seconds to read data from the devices.

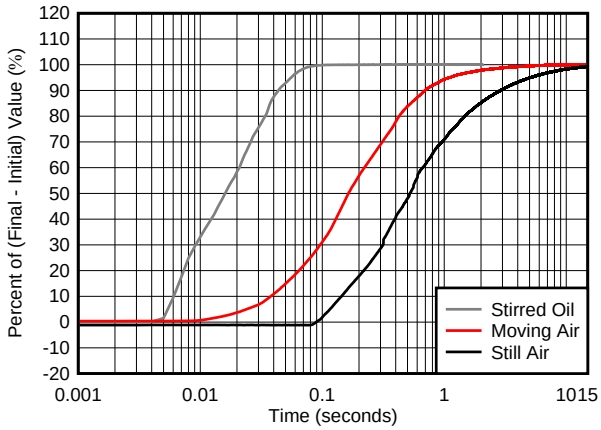
Application Information (continued)

8.1.1.3 Application Curve

Figure 45 shows how fast the TMP116 reacts to changes in temperature. Two elements must be considered when conducting the thermal responses experiment: the thermal conductivity and thermal mass. Thermal conductivity is the measure of the capacity of a material (such as still air or stirred oil) to conduct heat. Thermal conductivity is mainly used to describe how heat is conducted through a material. Higher values reflect greater efficiency of transferring heat. A good layout technique is to keep the thermal mass as small as possible. Smaller thermal masses result in better thermal responses.

The purpose of these experiments is to investigate how much time is required for the TMP116 temperature to reach the set point temperature and stabilize. There are three types of tests for the thermal response: still air, moving air, and stirred oil, as shown in Figure 45. This figure shows the step response of the TMP116 enclosed in a chamber of still air, in a wind tunnel of moving air, and submerged in an oil bath (for the respective traces) in a temperature environment of 70°C from room temperature (23°C). The time-constant, or the time for the output to reach 63% of the input step is dependent on the type of test. The time-constant result depends on the PCB and the thickness of the board that the TMP116 is mounted to. For this test, the TMP116EVM is used to perform the thermal response. The TMP116EVM dimension is 7.6 mm × 17.8 mm with a 1-mm thickness.

Among all methods, still air has the slowest thermal response because of the enclosed box placed inside the oven chamber without any helping elements, whereas the stirred oil experiment yields the fastest thermal response time.



V+ = 3.3 V, $t_{INITIAL}$ = 23°C, t_{FINAL} = 70°C

Figure 45. Thermal Response

9 Power Supply Recommendations

The TMP116 operates on a power-supply range from 1.9 V to 5.5 V. The device is trimmed for operation at a 3.3-V supply, but can measure temperature accurately in the full supply range. A power-supply bypass capacitor is required, which much be placed as close as possible to the supply and ground pins of the device. A typical value for this supply bypass capacitor is 100 nF. Applications with noisy or high-impedance power supplies may require additional decoupling capacitors to reject power-supply noise.

The TMP116 is a very low-power device and generates low noise on the supply bus. Applying an RC filter to the V+ pin of the device can further reduce any noise that the TMP116 might propagate to other components. R_F in Figure 46 must be less than 0.5 kΩ and C_F must be at least 100 nF. The package thermal pad is not connected to the device ground and can be left floating for convenience or grounded for better thermal resistance.

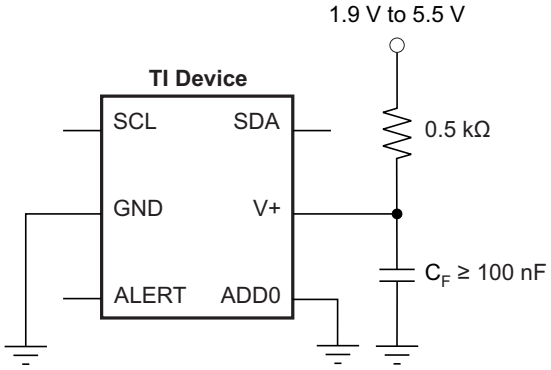


Figure 46. Noise-Reduction Techniques

10 Layout

10.1 Layout Guidelines to Achieve a High-Precision Temperature Reading

Place the power-supply bypass capacitor as close as possible to the supply and ground pins. The recommended value of this bypass capacitor is 0.1 μF. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies. In some cases the pullup resistor can be the heat source, therefore, maintain some distance between the resistor and the device.

Mount the TMP116 on the PCB pad to provide the minimum thermal resistance to the measured object surface or to the surrounding air. The recommended PCB layout minimizes the device self-heating effect, reduces the time delay as temperature changes, and minimizes the temperature offset between the device and the object.

1. The device thermal pad has a direct thermal contact to the die; therefore, soldering is essential to minimize thermal resistance from the sensor to the PCB. The recommendations are:
   - Solder the package thermal pad to the corresponding PCB pad.
   - Extend the PCB pad outside the package, if possible.
   - Place thermal pads on the top and bottom of the PCB and connect pads through vias. (Vias typically have four times less thermal resistance than the same area of the PCB board.)
   - Fill vias with metal, if possible.
   - The thermal pad can be left floating.
2. Minimize thermal resistance from the PCB to the environment:
   - Design the pin-soldering pads to be as large as possible, especially if these pads are corner pads.
   - Use a PCB with thicker copper layers, when possible.
   - If the PCB has unused internal layers, extend these layers under the TMP116.
   - Cover the top and bottom unused board space with the copper layer.

Layout Guidelines to Achieve a High-Precision Temperature Reading (continued)

3. If the device is used to measure air temperature:
   - Miniaturize the board to reduce thermal mass. Smaller thermal mass results in better thermal response.
   - Place two copper planes of equal size to the top and bottom of the exposed pad.
   - Remove the top solder mask.
   - To prevent oxidation, cover any exposed copper with solder paste.
   - Thermal isolation is required to avoid thermal coupling from heat source components through the PCB.
   - Avoid running the copper plane underneath the temperature sensor.
   - Maximize the air gap between the sensor and the surrounding copper areas (anti-etch), especially when close to the heat source.
   - Create a PCB cutout between sensor and other circuits. Leave a narrow channel away from heat source components as a routing bridge into the island.
   - If the heat source is top side, avoid running traces on top; instead, route all signals on the bottom side.
   - Place the board vertically to improve air flow and to reduce dust collection.

10.2 Layout Example

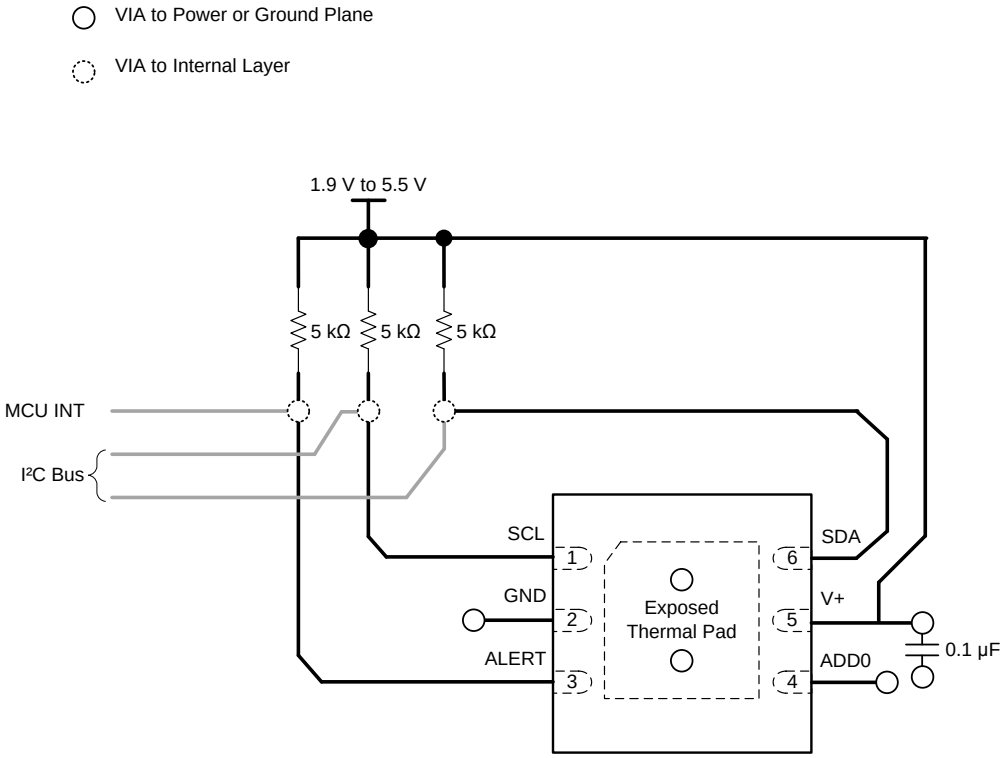


Figure 47. Layout Recommendation

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation see the following:

- *TMPx75 Temperature Sensor With I²C and SMBus Interface in Industry Standard LM75 Form Factor and Pinout*
- *TMP275 ±0.5°C Temperature Sensor With I2C and SMBus Interface in Industry Standard LM75 Form Factor and Pinout*

11.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.3 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.4 Trademarks

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SMBus is a trademark of Intel Corporation.
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11.5 Electrostatic Discharge Caution

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.

11.6 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TMP116AIDRVR	ACTIVE	WSON	DRV	6	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-55 to 150	T116	Samples
TMP116AIDRVT	ACTIVE	WSON	DRV	6	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-55 to 150	T116	Samples
TMP116NAIDRVR	ACTIVE	WSON	DRV	6	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-55 to 150	116N	Samples
TMP116NAIDRVT	ACTIVE	WSON	DRV	6	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-55 to 150	116N	Samples

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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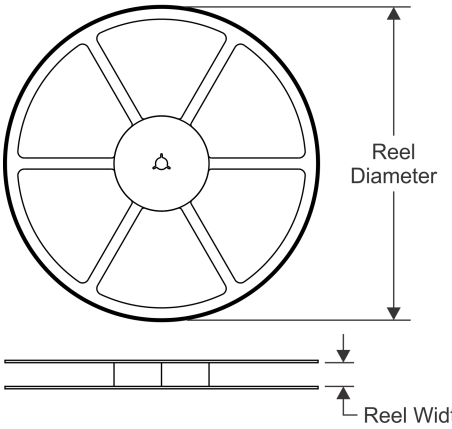
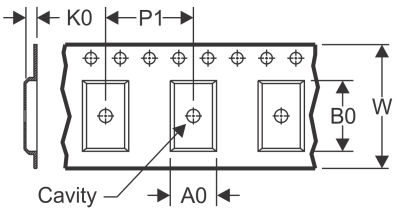
TAPE AND REEL INFORMATION

REEL DIMENSIONS

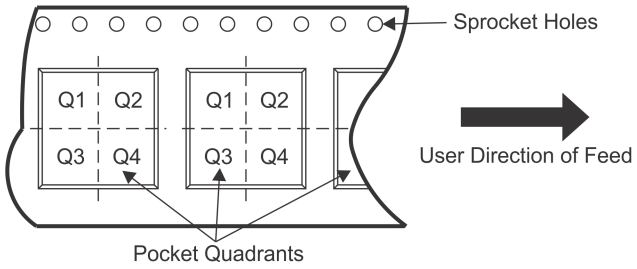


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

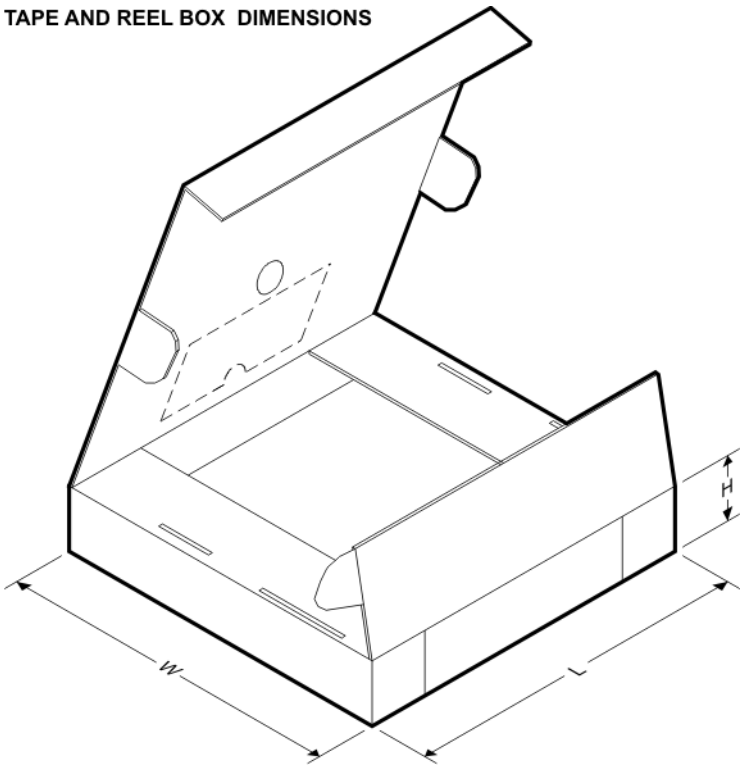
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TMP116AIDRVR	WSON	DRV	6	3000	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2
TMP116AIDRVT	WSON	DRV	6	250	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2
TMP116NAIDRVR	WSON	DRV	6	3000	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2
TMP116NAIDRVT	WSON	DRV	6	250	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2

TAPE AND REEL BOX DIMENSIONS

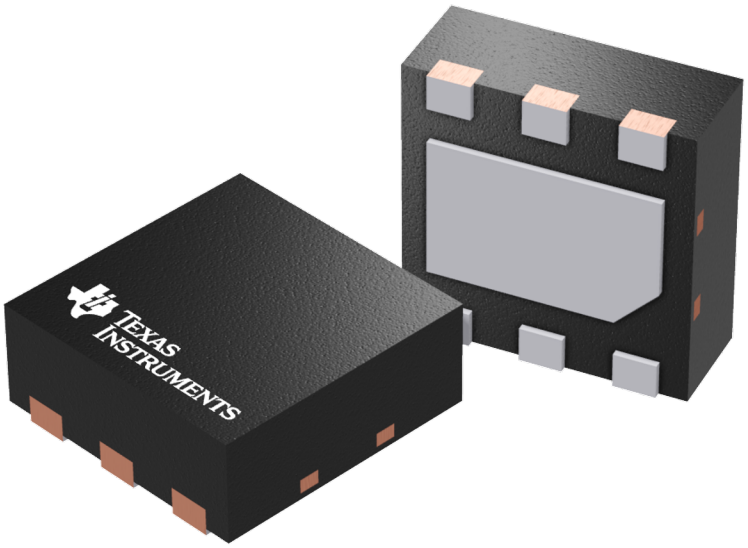


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TMP116AIDRVR	WSON	DRV	6	3000	210.0	185.0	35.0
TMP116AIDRVT	WSON	DRV	6	250	210.0	185.0	35.0
TMP116NAIDRVR	WSON	DRV	6	3000	210.0	185.0	35.0
TMP116NAIDRVT	WSON	DRV	6	250	210.0	185.0	35.0

DRV 6 WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



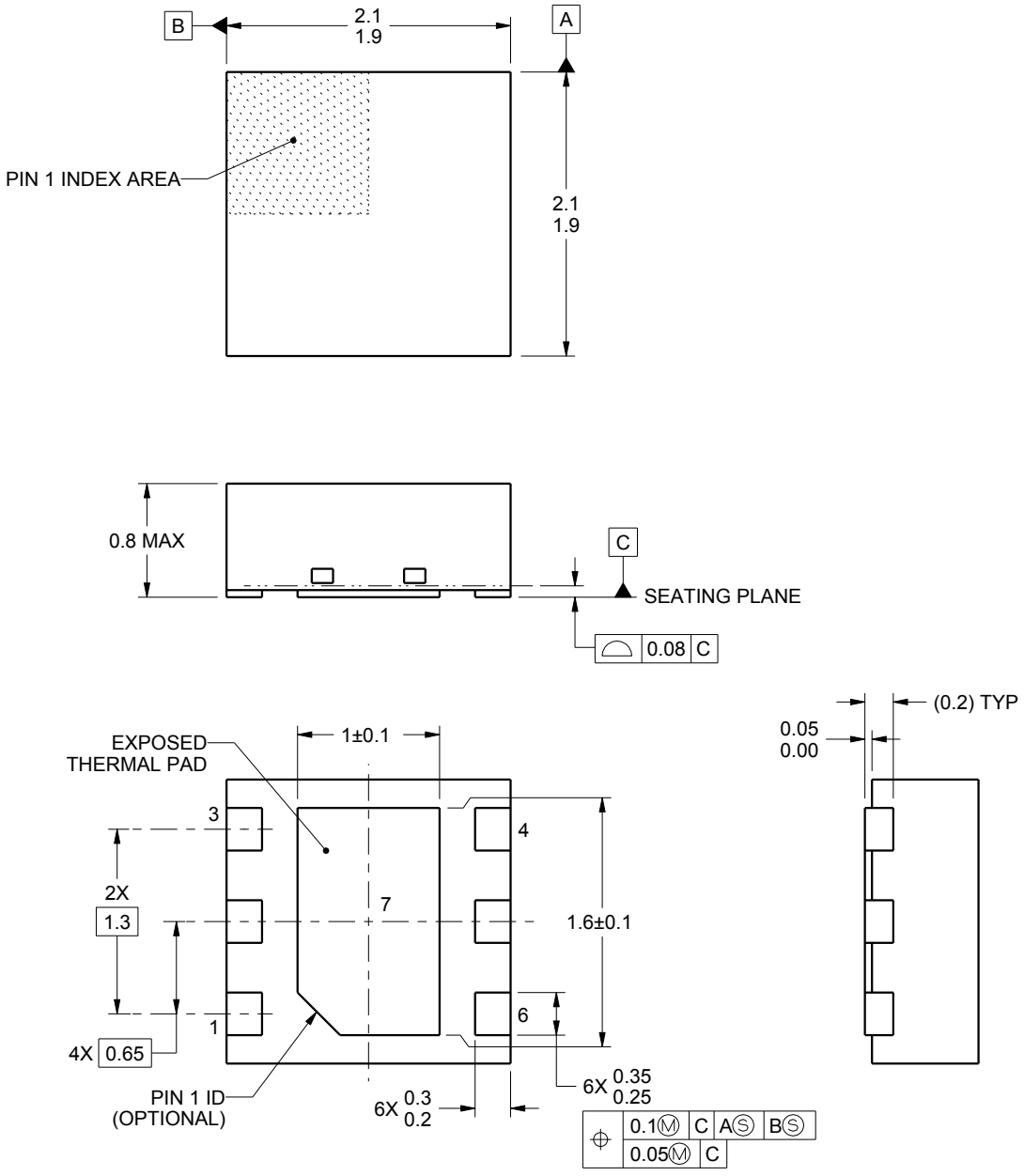
Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

PACKAGE OUTLINE

DRV0006A

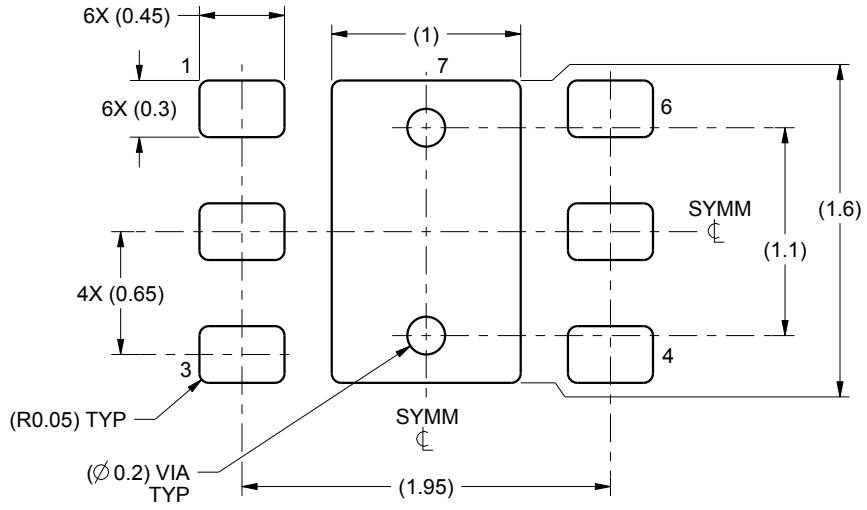
WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD

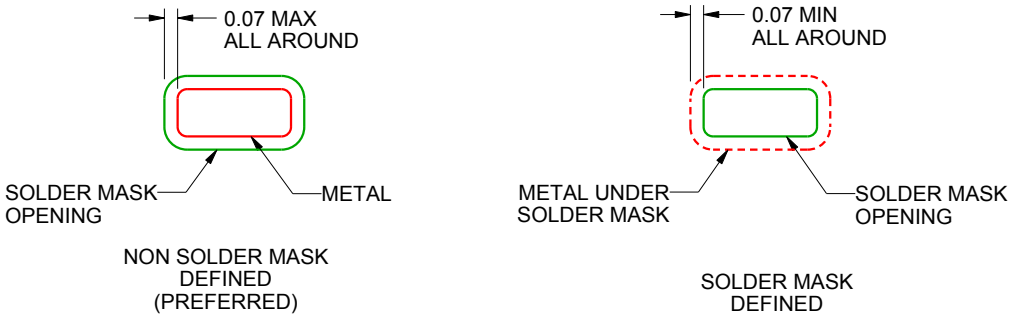


NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.



LAND PATTERN EXAMPLE
SCALE:25X

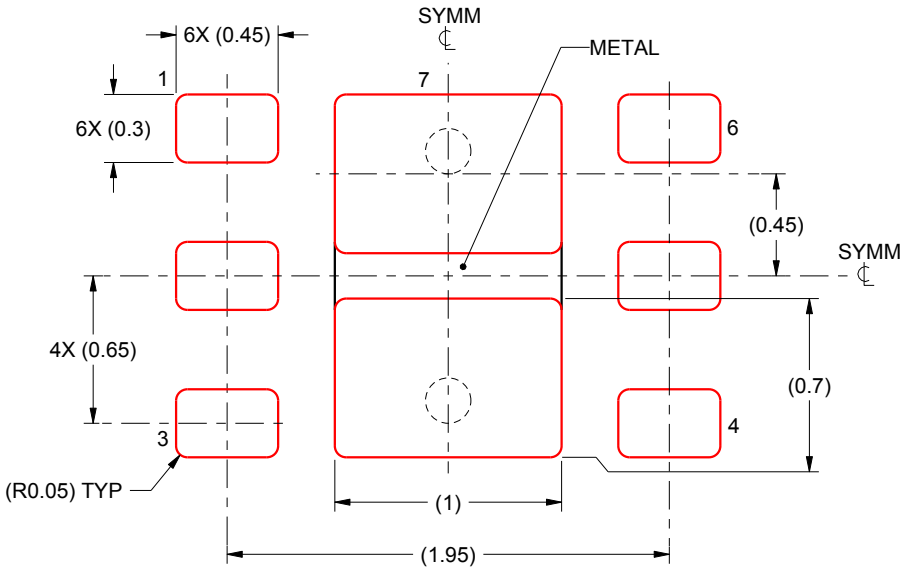


SOLDER MASK DETAILS

4222173/A 12/2015

NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If some or all are implemented, recommended via locations are shown.



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD #7
88% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:30X

4222173/A 12/2015

NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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