TMP401 ±1°C Programmable, Remote and Local, Digital Out Temperature Sensor

1 Features

- ±1°C Remote Diode Sensor
- ±3°C Local Temperature Sensor
- Series Resistance Cancellation
- $\overline{\text{THERM}}$ Flag Output
- $\overline{\text{ALERT}}/\overline{\text{THERM2}}$ Flag Output
- Programmable Over- and Undertemperature Limits
- Programmable Resolution: 9- to 12-Bit
- Diode Fault Detection
- SMBus-Compatible

2 Applications

- Servers and Workstations
- Desktop and Notebook Computers
- Telecom and Network Infrastructure
- Set Top Boxes

3 Description

The TMP401 is a remote temperature sensor monitor with a built-in local temperature sensor. The remote sensor is capable of monitoring the temperature of any external PN junction. Typical sense elements include low-cost NPN- or PNP-type transistors and diodes, or accessible thermal diodes integrated within microcontrollers, microprocessors, or field-programmable gate arrays (FPGAs).

The accuracy of the remote sensor 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 alarm thresholds and to read temperature data.

Features included in the TMP401 are series resistance cancellation, wide remote temperature measurement range (up to +150°C), diode fault detection, and temperature alert functions.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TMP401	VSSOP (8)	3.00 mm × 3.00 mm

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

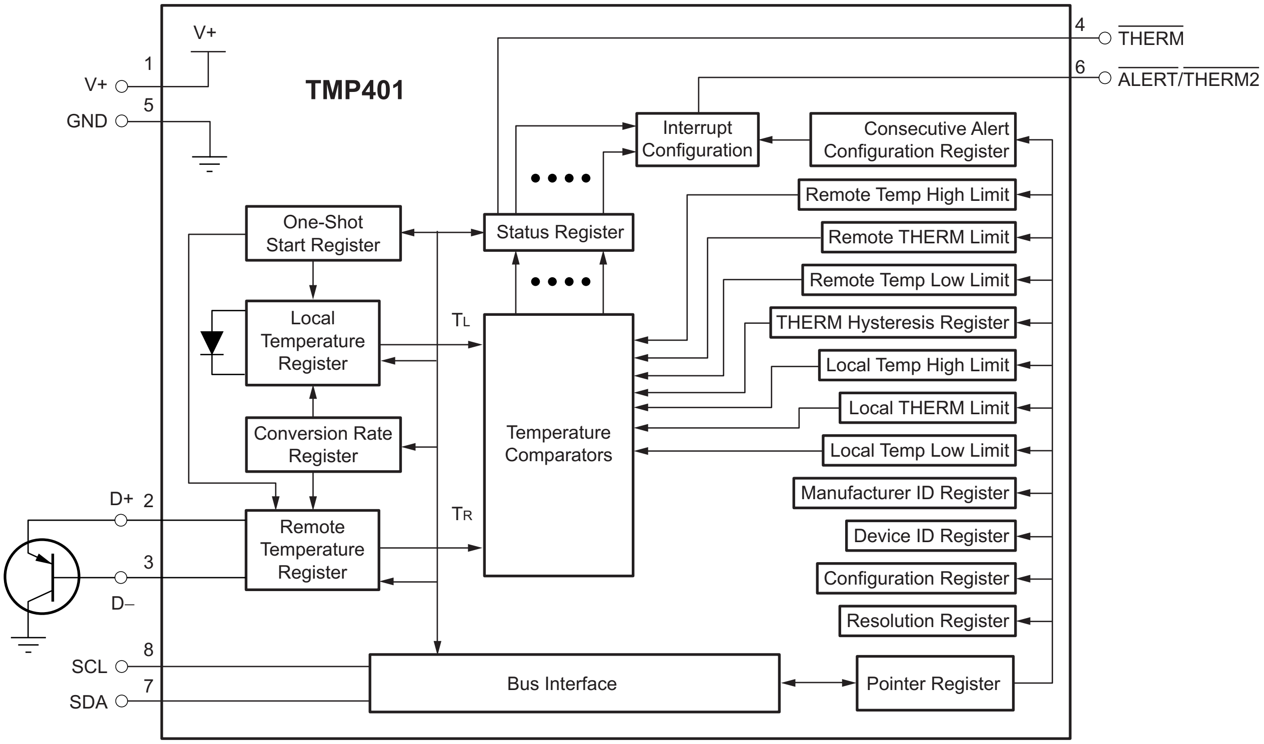


Table of Contents

4 Revision History

Changes from Revision A (October 2007) to Revision B — Page

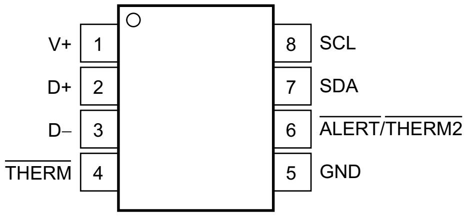
- Changed format to meet latest data sheet standards 1
- Added *Handling Rating*, *Recommended Operating Conditions*, and *Thermal Information* tables and *Feature Description*, *Device Functional Modes*, *Application and Implementation*, *Power Supply Recommendations*, *Layout*, *Device and Documentation Support*, and *Mechanical, Packaging, and Orderable Information* sections........ 1
- Changed V_S to V+ throughout document 1
- Changed last *Features* bullet 1
- Changed *Applications* section 1
- Changed first paragraph and first sentence of second paragraph in *Description* section 1
- Deleted Device Information Table title........ 4
- Changed Input and output voltage parameter name and footnote 2 in Absolute Maximum Ratings table........ 5
- Changed Operating temperature range maximum specification in Absolute Maximum Ratings table 5
- Changed HBM specifications in Handling Ratings table 5
- 5
- Changed test conditions for TE_{REMOTE} parameter in Electrical Characteristics table 6
- Changed Temperature Error, *TE_{LOCAL} and TE_{REMOTE} versus supply* parameter name 6
- Deleted SMBus Interface, *SMBus clock frequency* and *SCL falling edge to SDA valid time* parameters from Electrical Characteristics table 6
- Changed typical and maximum specifications in first two rows of Power Supply, I_Q parameter in Electrical Characteristics table 6
- Changed test conditions for third row of Power Supply, I_Q parameter in Electrical Characteristics table........ 6
- Added Power Supply, *UVLO* parameter to Electrical Characteristics table 6
- Changed Power Supply, *POR* parameter maximum specification in Electrical Characteristics table 6
- Changed Timing Requirements table 7
- Changed title of *Standard and Extended Temperature Measurement Range* section 12
- Changed second sentence of *High-Speed Mode* section 16
- Changed range for high-speed mode in *Serial Interface* section 17
- Changed POR value and D0 value in Consecutive alert register row of Table 3 20

Revision History (continued)

- Added Figure 19 to the *Configuration Register* section 24
- Added Figure 20 to the *Resolution Register* section 24
- Added Figure 21 to the *Conversion Rate Register* section 25
- Changed Table 6 for clarity of bit settings 25
- Added Figure 22 to the *Consecutive Alert Register* section 26
- Changed *Filtering* section 29
- Changed series line resistance value in second sentence of *Series Resistance Cancellation* section 29
- Changed supply voltage in second sentence of *Power-Supply Recommendations* section 30
- Changed last sentence of *Measurement Accuracy and Thermal Considerations* section 31
- Added Figure 30 33

5 Pin Configuration and Functions

DGK Package
VSSOP-8
(Top View)



Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
1	V+	Analog input	Positive supply (3 V to 5.5 V)
2	D+	Analog input	Positive connection to remote temperature sensor
3	D–	Analog input	Negative connection to remote temperature sensor
4	$\overline{\text{THERM}}$	Digital output	Thermal flag, active low, open-drain; requires pull-up resistor to V+
5	GND	—	Ground
6	$\overline{\text{ALERT}}/\overline{\text{THERM2}}$	Digital output	Alert (reconfigurable as second thermal flag), active low, open-drain; requires pull-up resistor to V+
7	SDA	Digital I/O	Serial data line for SMBus, open-drain; requires pull-up resistor to V+
8	SCL	Digital I/O	Serial clock line for SMBus, open-drain; requires pull-up resistor to V+

6 Specifications

6.1 Absolute Maximum Ratings[1]

	MIN	MAX	UNIT
Power supply, V+		7.0	V
Input and output voltage[2]	–0.5	(V+) + (0.5)	V
Input current		10	mA
Operating temperature range	–55	+125	°C
Junction Temperature (T_J max)		+150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Input voltage rating applies to all TMP401 input and output pins.

6.2 Handling Ratings

			MIN	MAX	UNIT
T_{stg}	Storage temperature range		–60	+130	°C
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins[1]	–3000	3000	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins[2]	–1000	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+	Positive supply (3 V to 5.5 V)		5		V
T_A	Ambient temperature		25		°C

6.4 Thermal Information

THERMAL METRIC[1]		TMP401 DGK (VSSOP) 8 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	78.8	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	71.6	
$R_{\theta JB}$	Junction-to-board thermal resistance	68.2	
Ψ_{JT}	Junction-to-top characterization parameter	22.0	
Ψ_{JB}	Junction-to-board characterization parameter	67.6	
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

6.5 Electrical Characteristics: V+ = 3 V to 5.5 V

At T_A = –40°C to +125°C, and V+ = 3 V to 5.5 V, unless otherwise noted.

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
TEMPERATURE ERROR							
TE_{LOCAL}	Local temperature sensor		T_A = –40°C to +125°C		±1	±3	°C
TE_{REMOTE}	Remote temperature sensor[1]		T_A = +15°C to +75°C, T_{REMOTE} = –40°C to +150°C, V+ = 3.3 V			±1	°C
			T_A = –40°C to +100°C, T_{REMOTE} = –40°C to +150°C, V+ = 3.3 V			±3	°C
			T_A = –40°C to +125°C, T_{REMOTE} = –40°C to +150°C			±5	°C
	TE_{LOCAL} and TE_{REMOTE} versus supply		V+ = 3 V to 5.5 V		±0.2	±0.5	°C/V
TEMPERATURE MEASUREMENT							
	Conversion time (per channel)		One-shot mode		115		ms
	Resolution	TE_{LOCAL} (programmable)		9		12	Bits
		TE_{REMOTE}			12		Bits
	Remote sensor source currents	High	Series resistance, 3 kΩ max		120		µA
		Medium high			60		µA
		Medium low			12		µA
		Low			6		µA
η	Remote transistor ideality factor		TMP401 optimized ideality factor		1.008		
SMBus INTERFACE							
V_{IH}	Logic input high voltage (SCL, SDA)			2.1			V
V_{IL}	Logic input low voltage (SCL, SDA)					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 timeout				30	35	ms
DIGITAL OUTPUTS							
V_{OL}	Output low voltage		I_{OUT} = 6 mA		0.15	0.4	V
I_{OH}	High-level output leakage current		V_{OUT} = V+		0.1	1	µA
	$\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ output low sink current		$\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ forced to 0.4 V	6			mA
	$\overline{\text{THERM}}$ output low sink current		$\overline{\text{THERM}}$ forced to 0.4 V	6			mA
POWER SUPPLY							
V+	Specified voltage range			3		5.5	V
I_Q	Quiescent current		0.0625 conversions per second		29	36	µA
			8 conversions per second		390	450	µA
			Serial bus inactive, shutdown mode		3	10	µA
			Serial bus active, f_S = 400 kHz, shutdown mode		90		µA
			Serial bus active, f_S = 2.5 MHz, shutdown mode		350		µA
UVLO	Undervoltage lock out			2.3	2.4	2.6	V
POR	Power-on reset threshold				1.6	2.3	V
TEMPERATURE RANGE							
	Specified range			–40		+125	°C
	Storage range			–60		+130	°C
θ_{JA}	Thermal resistance, VSSOP-8				150		°C/W

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

6.6 Timing Requirements

See the *Timing Diagrams* section for timing diagrams.

PARAMETER		FAST MODE		HIGH-SPEED MODE		UNIT
		MIN	MAX	MIN	MAX	
$f_{(SCL)}$	SCL operating frequency	0.001	0.4	0.001	2.5	MHz
$t_{(BUF)}$	Bus free time between stop and start condition	600		160		ns
$t_{(HDSTA)}$	Hold time after repeated start condition. After this period, the first clock is generated.	600		160		ns
$t_{(SUSTA)}$	Repeated start condition setup time	600		160		ns
$t_{(SUSTO)}$	Stop condition setup time	600		160		ns
$t_{(HDDAT)}$	Data hold time	100		80		ns
$t_{(SUDAT)}$	Data setup time	100		60		ns
$t_{(LOW)}$	SCL clock low period	1300		260		ns
$t_{(HIGH)}$	SCL clock high period	600		60		ns
	Clock rise and fall time		300		40	ns
t_F	Data fall time		300		120	ns
t_R	Data rise time for SCL ≤ 100 kHz		300			ns
			1000			ns

6.7 Typical Characteristics

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

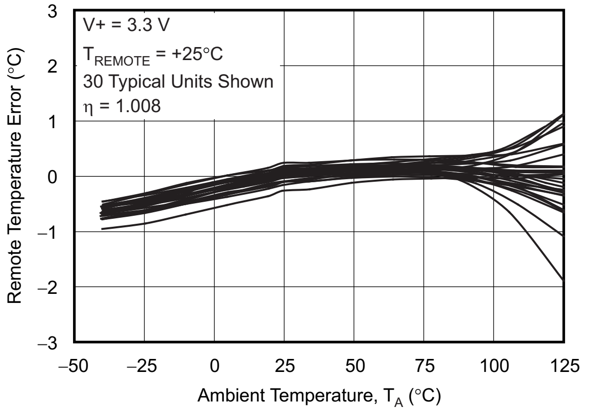


Figure 1. Remote Temperature Error vs Temperature

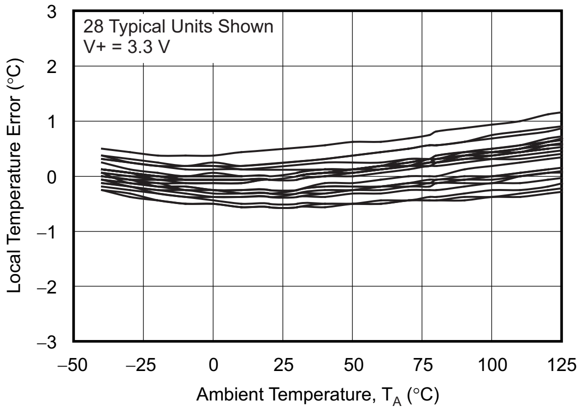


Figure 2. Local Temperature Error vs Temperature

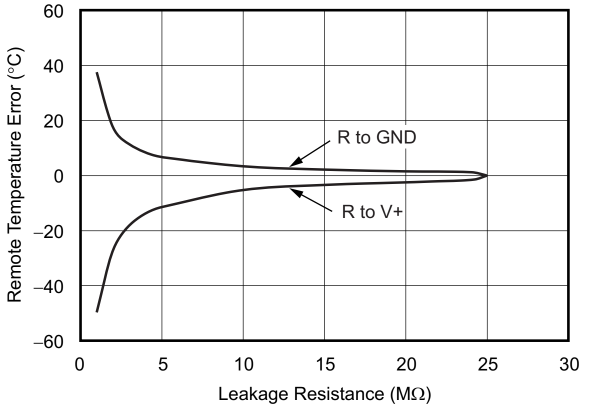


Figure 3. Remote Temperature Error vs Leakage Resistance

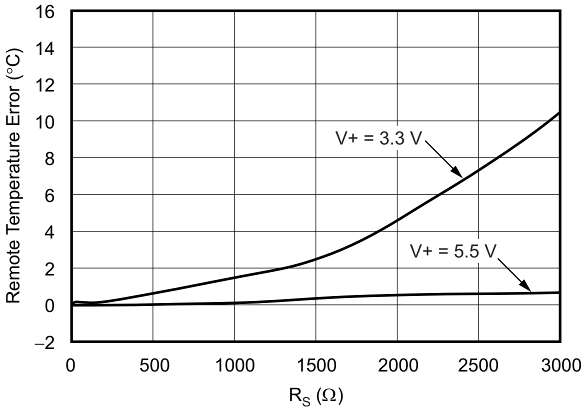


Figure 4. Remote Temperature Error vs Series Resistance (Diode-Connected Configuration; see Figure 11)

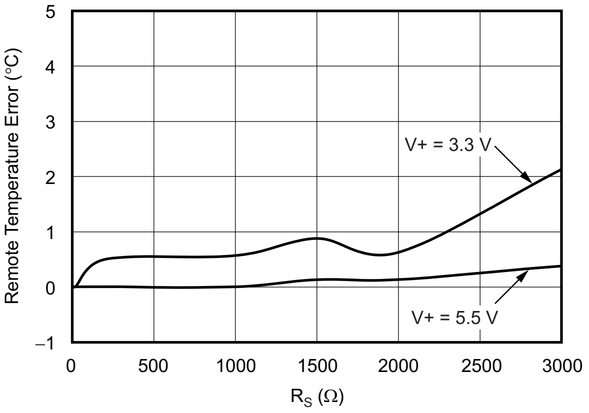


Figure 5. Remote Temperature Error vs Series Resistance (Transistor-Connected Configuration; see Figure 11)

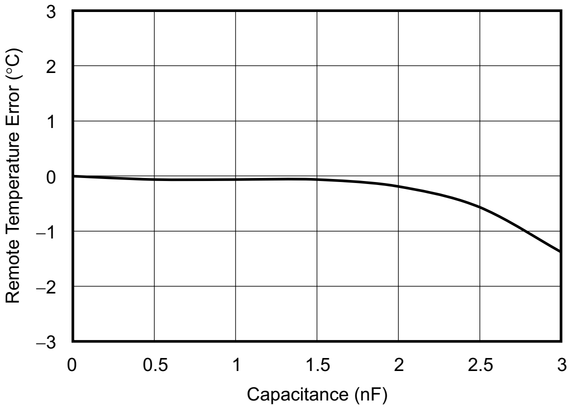


Figure 6. Remote Temperature Error vs Differential Capacitance

Typical Characteristics (continued)

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

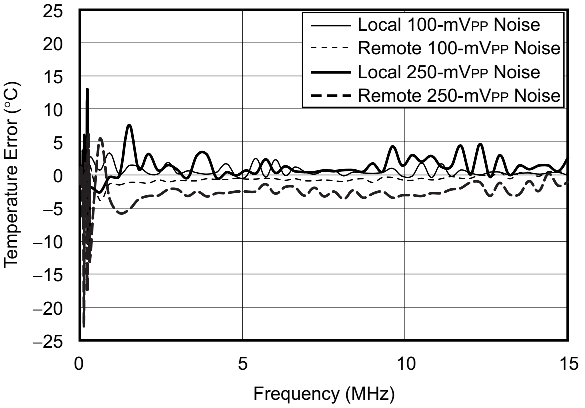


Figure 7. Temperature Error vs Power-Supply Noise Frequency

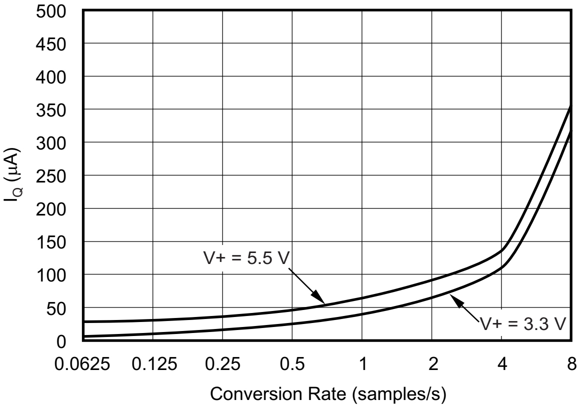


Figure 8. Quiescent Current vs Conversion Rate

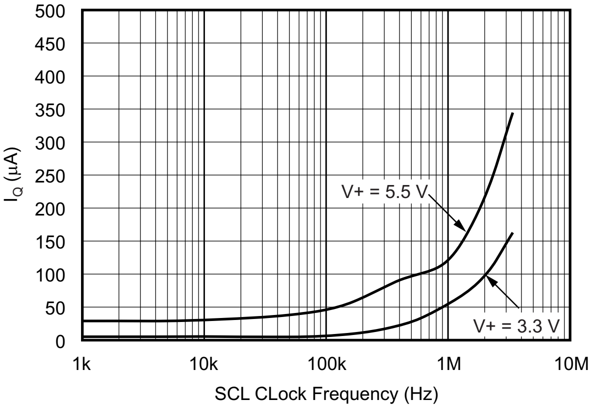


Figure 9. Shutdown Quiescent Current vs SCL Clock Frequency

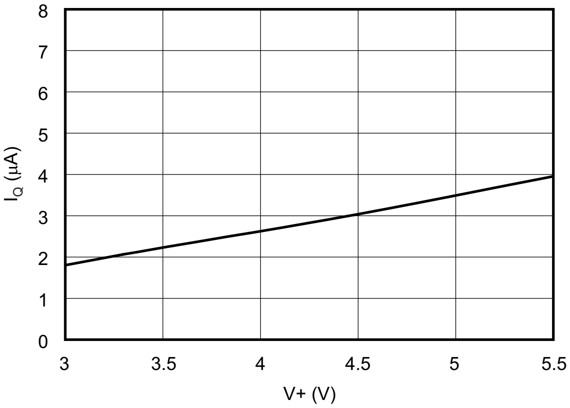


Figure 10. Shutdown Quiescent Current vs Supply Voltage

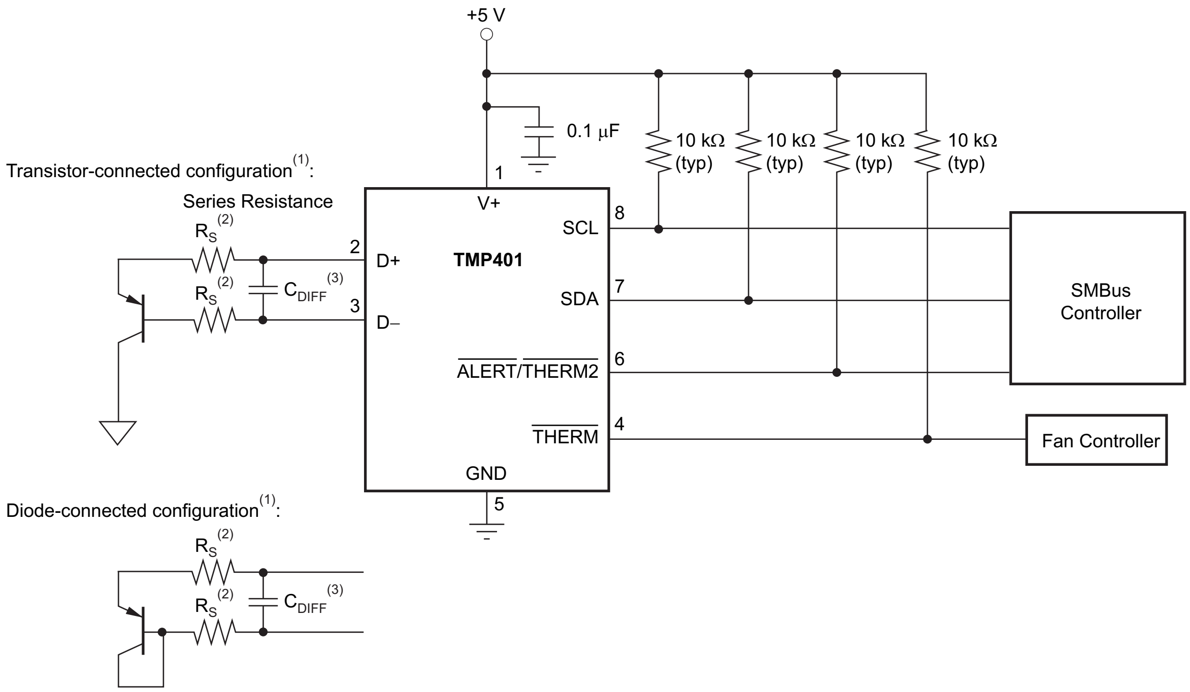
7 Detailed Description

7.1 Overview

The TMP401 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 VSSOP-8 package. The TMP401 is two-wire- and SMBus interface-compatible and is specified over a temperature range of –40°C to +125°C. The TMP401 contains multiple registers for holding configuration information, temperature measurement results, temperature comparator 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- and undertemperature alarm ($\overline{\text{ALERT}}$). Additional thermal limits can be programmed into the TMP401 and used to trigger another flag ($\overline{\text{THERM}}$) that can be used to initiate a system response to rising temperatures.

The TMP401 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 0.1-µF power-supply bypass capacitor is recommended for good local bypassing. Figure 11 shows a typical configuration for the TMP401.



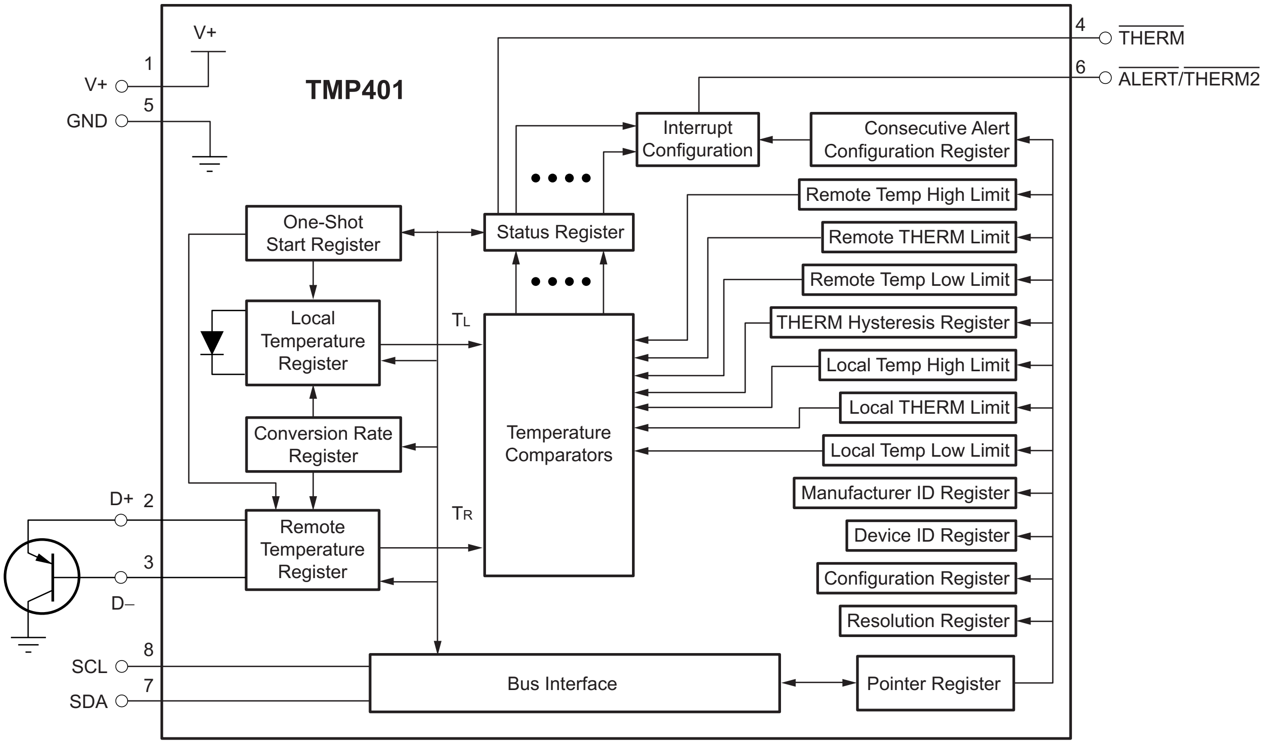
(1) The diode-connected configuration provides better settling time. The transistor-connected configuration provides better series resistance cancellation. A 2N3906 PNP is used in this configuration.

(2) In most applications, R_S is < 1.5 kΩ.

(3) In most applications, C_{DIFF} is < 1000 pF.

Figure 11. Basic Connections

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Standard and Extended Temperature Measurement Range

Temperature measurement data are 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 TMP401 for the extended temperature range. To change the TMP401 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 are represented in binary form, as shown in Table 1 (see the 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 (see the 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 TMP401 is rated only for ambient temperatures ranging from –40°C to +125°C. Parameters in the *Absolute Maximum Ratings* table must be followed.

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

TEMPERATURE (°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 and 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)

TEMPERATURE (°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
0.9375	1111 0000	F0	1000 0000	80	1100 0000	C0	1110 0000	E0	1111 0000	F0

7.3.2 Remote Sensing

The TMP401 is designed to be used with either discrete transistors or substrate transistors built into processor chips and application-specific integrated circuits (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 are the consequence of the ideality factor and current excitation used by the TMP401 versus the manufacturer's specified operating current for a given transistor. Some manufacturers specify a high-level and low-level current for the temperature-sensing substrate transistors. The TMP401 uses 6 µA for I_{LOW} and 120 µA for I_{HIGH}.

The ideality factor (η) is a measured characteristic of a remote temperature sensor diode as compared to an ideal diode. The ideality factor for the TMP401 is trimmed to be 1.008. For transistors whose ideality factor does not match the TMP401, Equation 1 can be used to calculate the temperature error. Note that for Equation 1 to be used correctly, actual temperature (°C) must be converted to Kelvin (°K).

$$T_{ERR} = \left[\frac{(\eta - 1.008)}{1.008}\right] \text{ x } \left[2.73.15 + T\left(^{\circ}C\right)\right]$$

where

- η = Ideality factor of the remote temperature sensor,
- T(°C) = actual temperature, and
- T_{ERR} = Error in the TMP401 reading resulting from η ≠ 1.008. Degree delta is the same for °C and °K. (1)

For η = 1.004 and T(°C) = 100°C, use Equation 2:

$$T_{ERR} = \left[\frac{(1.004 - 1.008)}{1.008}\right] \text{ x } \left[2.73.15 + 100^{\circ}C\right]$$

$$T_{ERR} = -1.48^{\circ}C \qquad (2)$$

If a discrete transistor is used as the remote temperature sensor with the TMP401, the best accuracy can be achieved by selecting the transistor according to the following criteria:

1. Base-emitter voltage > 0.25 V at 6 µA, at the highest sensed temperature.
2. Base-emitter voltage < 0.95 V at 120 µA, at the lowest sensed temperature.
3. Base resistance < 100 Ω.
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).

7.4 Device Functional Modes

7.4.1 SMBus Alert Function

The TMP401 supports the SMBus alert function. When pin 6 is configured as an alert output, the $\overline{\text{ALERT}}$ pin of the TMP401 can 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 (0001 1001b) on the bus. If the $\overline{\text{ALERT}}$ pin of the TMP401 is active, the devices 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 is high if the temperature is greater than or equal to one of the temperature high limit settings; this bit is low if the temperature is less than one of the temperature low limit settings. See Figure 15 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 its alert status. If the TMP401 wins the arbitration, its $\overline{\text{ALERT}}$ pin becomes inactive at the completion of the SMBus alert command. If the TMP401 loses the arbitration, the $\overline{\text{ALERT}}$ pin remains active.

7.4.2 $\overline{\text{THERM}}$ (Pin 4) and $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ (Pin 6)

The TMP401 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 $\overline{\text{ALERT/THERM2}}$ 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 and remote THERM limit register. The $\overline{\text{THERM}}$ 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 listed in Table 8. The default hysteresis is 10°C. When the $\overline{\text{ALERT/THERM2}}$ pin is configured as a second thermal alarm (configuration register, bit 7 = 0, bit 5 = 1), the pin functions the same as $\overline{\text{THERM}}$, but uses the temperatures stored in the local and remote temperature high and 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 and remote temperature high and 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 is reset.

7.4.3 Sensor Fault

The TMP401 senses 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+) – 0.6 V (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 TMP401, the D+ and D– inputs must be connected together to prevent meaningless fault warnings.

Device Functional Modes (continued)

7.4.4 High-Speed Mode

In order for the two-wire bus to operate at frequencies above 400 kHz, the master device must issue a high-speed mode (Hs-mode) master code (0000 1xxxb) as the first byte after a start condition to switch the bus to high-speed operation. The TMP401 does not acknowledge this byte, but switches the input filters on SDA and SCL and the output filter on SDA to operate in Hs-mode, allowing transfers at up to 2.5 MHz. After the Hs-mode master code is 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 TMP401 switches the input and output filter back to fast-mode operation.

7.4.5 Shutdown Mode (SD)

The TMP401 shutdown mode (SD) allows the user to save maximum power by shutting down all device circuitry other than the serial interface, thus reducing current consumption to typically less than 3 μA; see Figure 10 (*Shutdown Quiescent Current vs Supply Voltage*). Shutdown mode is enabled when the SD bit of the configuration register is high; the device shuts down when the current conversion is completed. When SD is low, the device maintains a continuous conversion state.

7.4.6 One-Shot Conversion

When the TMP401 is in shutdown mode (SD = 1 in the configuration register), a single conversion on both channels is started by writing any value to the one-shot start register, pointer address 0Fh. This write operation starts one conversion; the TMP401 returns to shutdown mode when that conversion completes. The value of the data sent in the write command is irrelevant and is not stored by the TMP401. When the TMP401 is set to shutdown mode, an initial 200 μs is required before a one-shot command can be given. This wait time only applies to the 200 μs immediately following shutdown. One-shot commands can be issued without delay thereafter.

7.4.7 General-Call Reset

The TMP401 supports reset via the two-wire general-call address 00h (0000 0000b). The TMP401 acknowledges the general-call address and responds to the second byte. If the second byte is 06h (0000 0110b), the TMP401 executes a software reset. This software reset restores the power-on reset state to all TMP401 registers, aborts any conversion in progress, and clears the $\overline{\text{ALERT}}$ and $\overline{\text{THERM}}$ pins. The TMP401 takes no action in response to other values in the second byte.

7.5 Programming

7.5.1 Bus Overview

The TMP401 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. A start condition 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.

When all data are transferred, the master generates a stop condition. A stop condition is indicated by pulling SDA from low to high while SCL is high.

7.5.2 Serial Interface

The TMP401 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 TMP401 supports the transmission protocol for fast (1 kHz to 400 kHz) and high-speed (1 kHz to 2.5 MHz) modes. All data bytes are transmitted MSB first.

7.5.3 Serial Bus Address

To communicate with the TMP401, 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 TMP401 is 4Ch (1001100b).

7.5.4 Read and Write Operations

Accessing a particular register on the TMP401 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/W bit low. Every write operation to the TMP401 requires a value for the pointer register (see Figure 13).

When reading from the TMP401, 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/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/W bit high to initiate the read command. See Figure 14 for details of this sequence. If repeated reads from the same register are desired, continually sending the pointer register bytes is not necessary, because the TMP401 retains the pointer register value until changed by the next write operation. Note that register bytes are sent MSB first, followed by the LSB.

7.5.5 Timeout Function

When bit 7 of the consecutive alert register is set high, the TMP401 timeout function is enabled. The TMP401 resets the serial interface if either SCL or SDA are held low for 30 ms (typ) between a start and stop condition. If the TMP401 is holding the bus low, the device releases the bus and waits for a start condition. To avoid activating the timeout function, a communication speed of at least 1 kHz must be maintained for the SCL operating frequency. The default state of the timeout function is enabled (bit 7 = high).

Programming (continued)

7.5.6 Timing Diagrams

The TMP401 is two-wire and SMBus compatible. Figure 12 to Figure 15 describe the various operations on the TMP401. Parameters for Figure 12 are defined in *Timing Requirements* table. Bus definitions are as follows:

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 transmitted by the slave.

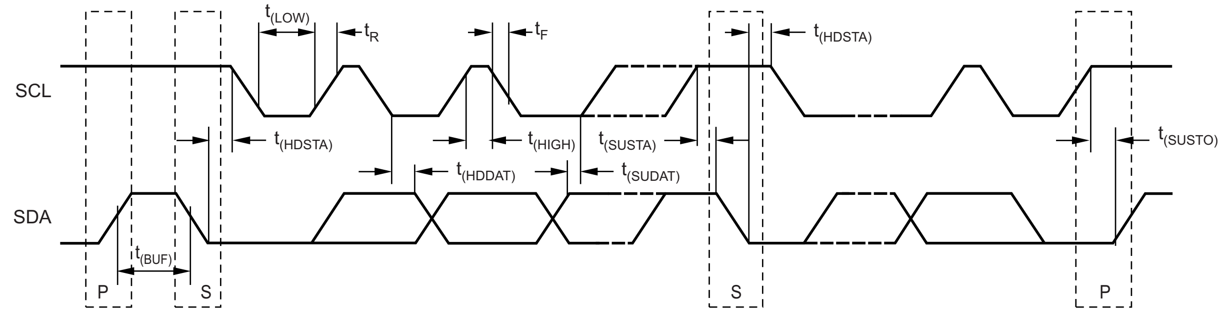


Figure 12. Two-Wire Timing Diagram

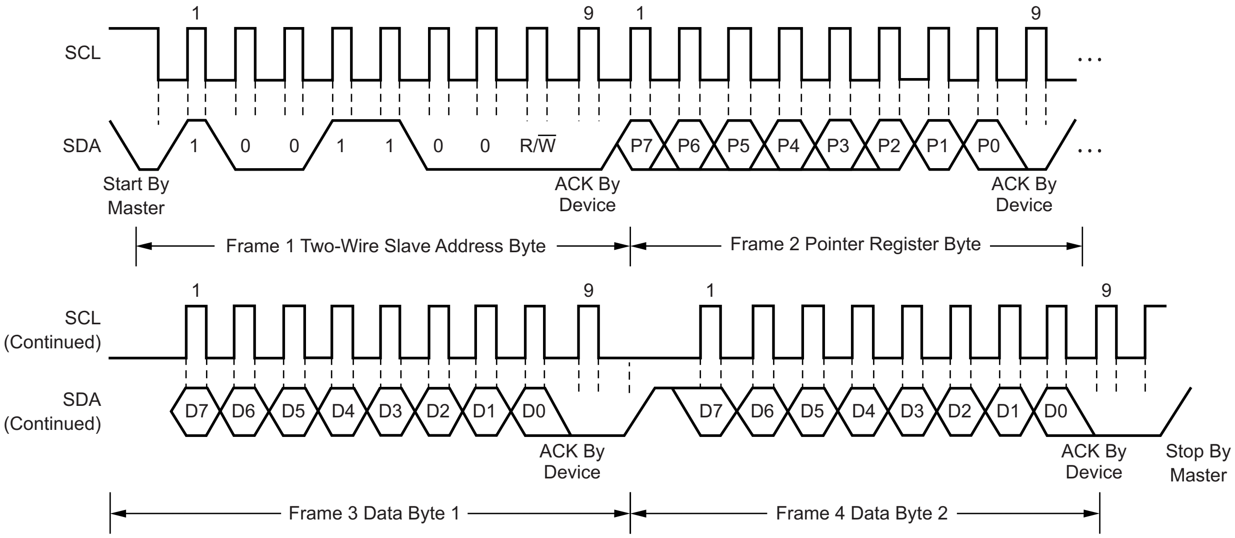


Figure 13. Two-Wire Timing Diagram for Write Word Format

Programming (continued)

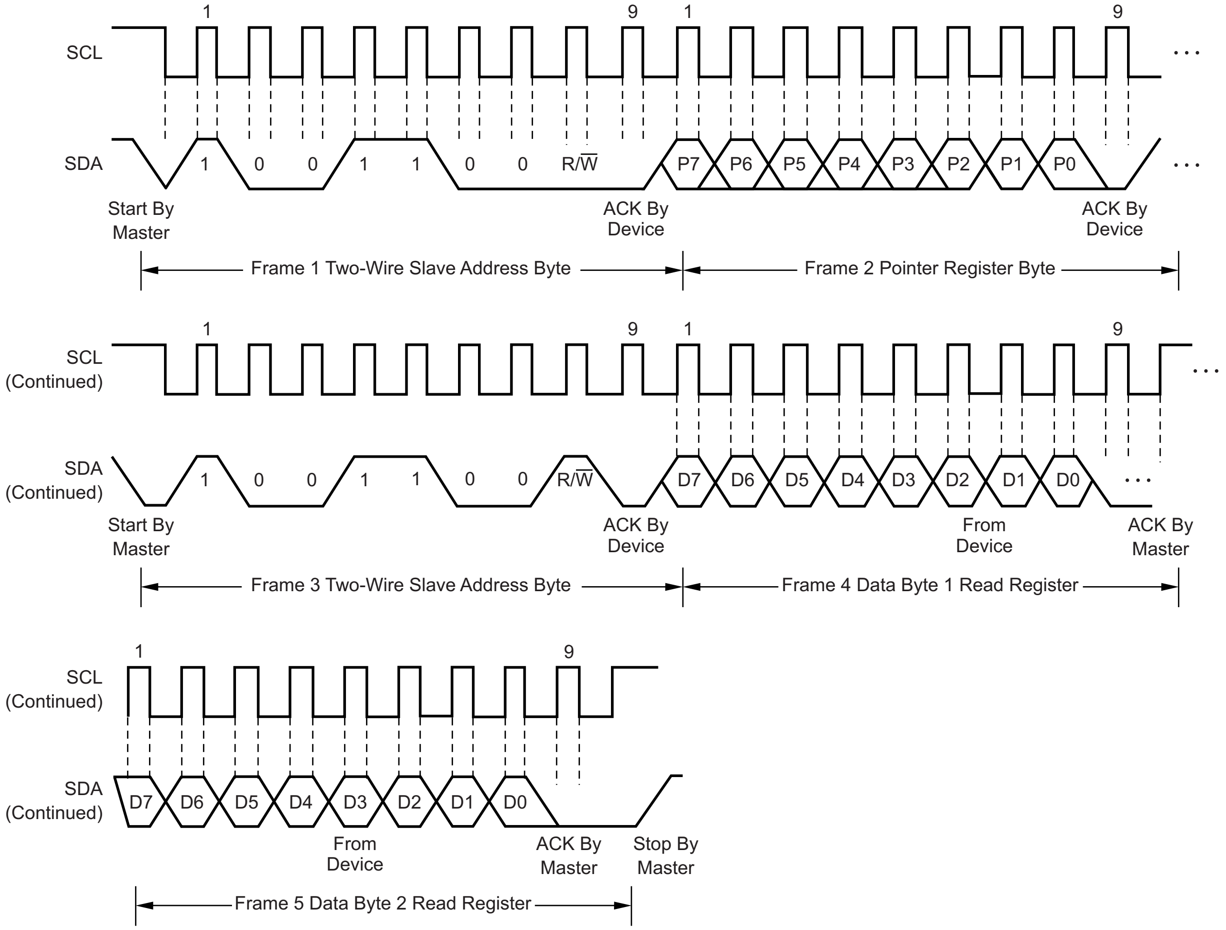


Figure 14. Two-Wire Timing Diagram for Read Word Format

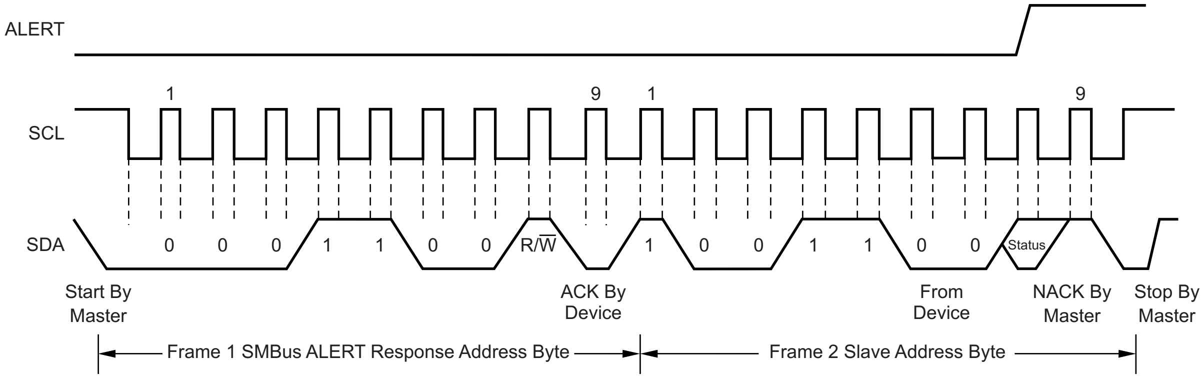


Figure 15. Timing Diagram for SMBus Alert

7.6 Register Maps

The TMP401 contains multiple registers for holding configuration information, temperature measurement results, temperature comparator limits, and status information. These registers are described in Figure 16 and Table 3.

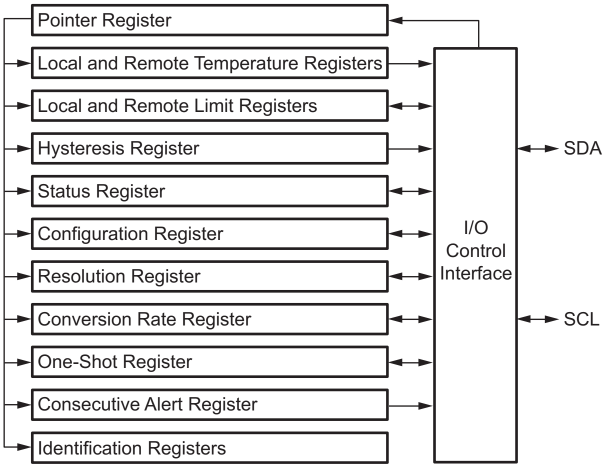


Figure 16. Internal Register Structure

Table 3. Register Map

POINTER ADDRESS (HEX)		POWER-ON RESET (HEX)	BIT DESCRIPTION								
READ	WRITE		D7	D6	D5	D4	D3	D2	D1	D0	REGISTER DESCRIPTION
00	NA	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)
NA	0F	XX	X	X	X	X	X	X	X	X	One-shot start
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)
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	81	TO_EN	0	0	0	C2	C1	C0	1	Consecutive alert register
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

7.6.1 Pointer Register

Figure 16 illustrates the internal register structure of the TMP401. The 8-bit pointer register is used to address a given data register. The pointer register identifies which of the data registers 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 TMP401. The power-on reset (POR) value of the pointer register is 00h (0000 0000b).

7.6.2 Temperature Registers

The TMP401 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 TMP401 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 must be read first. Read the low byte register in the next read command. The low byte register may be left unread if the LSBs are not needed. Alternatively, the temperature registers can 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 is output first, followed by the low byte. Both bytes of this read operation are from the same ADC conversion. The power-on reset value of both temperature registers is 00h.

7.6.3 Limit Registers

The TMP401 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, or by using a two-byte read command from pointer address 05h. The power-on reset value of the local temperature high limit is 55h, standard, and 00h, extended (+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, standard and extended (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, standard, and 00h, extended (+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, standard and extended (0°C in standard temperature mode; –64°C in extended mode).

The TMP401 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.

7.6.4 Status Register

The TMP401 has a status register to report the state of the temperature comparators. Figure 17 shows the status register bits. The status register is read-only and is read by reading from pointer address 02h.

Figure 17. Status Register (Read = 02h, Write = NA, POR = XXh)

D7	D6	D5	D4	D3	D2	D1	D0
BUSY[1]	LHIGH	LLOW	RHIGH	RLOW	OPEN	RTHRM	LTHRM
R-0b	R-0b	R-0b	R-0b	R-0b	R-0b	R-0b	R-0b

LEGEND: R = Read only; -n = value after reset

(1) The BUSY bit will change to ‘1’ almost immediately (<< 100μs) following power-up, as the TMP401 begins the first temperature conversion. It will be high whenever the TMP401 is converting a temperature reading.

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 is detected as open from 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 exceeds the remote THERM limit and remains greater than the remote THERM limit less the value in the shared hysteresis register, as shown in Figure 18.

The LTHRM bit reads as ‘1’ if the local temperature exceeds the local THERM limit and remains greater than the local THERM limit less the value in the shared hysteresis register, as shown in Figure 18.

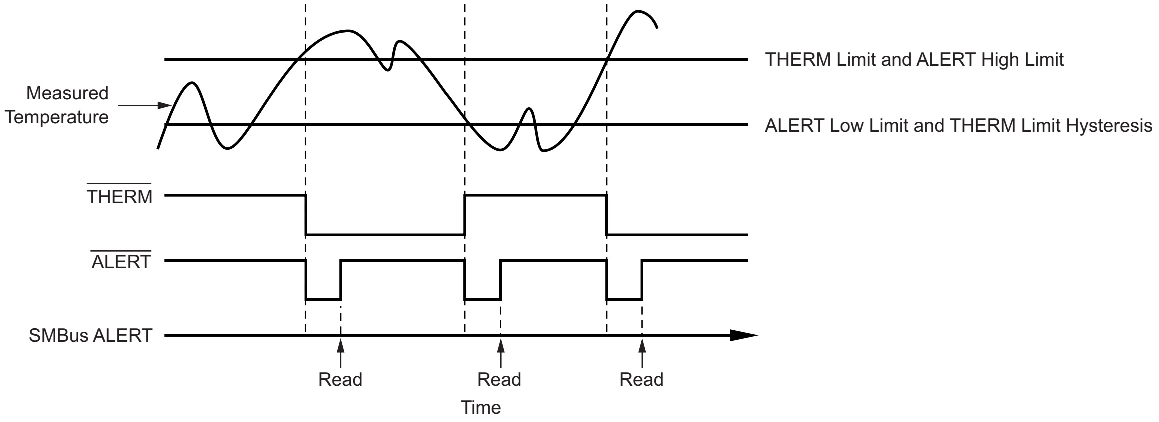


Figure 18. SMBus Alert Timing Diagram

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 is exceeded from the last clearing of the status register. The RHIGH bit reads as ‘1’ if the remote high limit is exceeded from 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 THERM2 function. LHIGH reads as ‘1’ if the local temperature exceeds 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 exceeds 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 is exceeded from the last clearing of the status register. The RLOW bit reads as ‘1’ if the remote low limit is exceeded from 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 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. These bits 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 ALERT pin; an SMBus alert response address command must be used to clear the ALERT pin.

The TMP401 NORs LHIGH, LLOW, RHIGH, RLOW, and OPEN, so a status change for any of these flags from ‘0’ to ‘1’ automatically causes the ALERT pin to go low (only applies when the ALERT/THERM2 pin is configured for ALERT mode).

7.6.5 Configuration Register

The configuration register sets the temperature range, controls shutdown mode, and determines how the ALERT/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 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 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 TMP401 retains the ALERT pin status, but the ALERT pin does not go low.

The shutdown (SD) bit (bit 6) enables or disables the temperature measurement circuitry. If SD = 0, the TMP401 converts continuously at the rate set in the conversion rate register. When SD is set to ‘1’, the TMP401 immediately stops converting and enters a shutdown mode. When SD is set to ‘0’ again, the TMP401 resumes continuous conversions. A single conversion can be started when SD = 1 by writing to the one-shot register.

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

If AL/TH = 1, the ALERT/THERM2 pin implements a THERM function (THERM2). In this mode, THERM2 functions similar to the THERM pin except that the local high limit and remote high limit registers are used for the thresholds. 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 TMP401 for the standard measurement range (0°C to +127°C); temperature conversions are stored in standard binary format. Setting bit 2 high configures the TMP401 for the extended measurement range (–55°C to +150°C); temperature conversions are stored in 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. Figure 19 and Table 4 summarize the bits of the configuration register.

Figure 19. Configuration Register (Read = 02h, Write = NA, POR = 00h)

D7	D6	D5	D4	D3	D2	D1	D0
MASK	SD	AL/TH	Reserved	Reserved	Temperature Range	Reserved	Reserved
R/W-0	R/W-0	R/W-0	—	—	R/W-0	—	—

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 4. Configuration Register Field Descriptions

Bit	Field	Type	Reset	Description
D7	MASK	R/W	0	0 = ALERT Enabled 1 = ALERT Masked
D6	SD	R/W	0	0 = Run 1 = Shut Down
D5	AL/TH	R/W	0	0 = ALERT Mode 1 = THERM Mode
D[4:3]	Reserved	—	—	—
D2	Temperature Range	R/W	0	0 = 0°C to +127°C 1 = –55°C to +150°C
D[1:0]	Reserved	—	—	—

7.6.6 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 TMP401. The resolution register is set by writing to pointer address 1Ah and is read by reading from pointer address 1Ah. Figure 20 and Table 5 show the resolution bits for the resolution register.

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.

Figure 20. Resolution Register (Read/Write = 1Ah, POR = 1Ch)

D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	1	1	1	RES1	RES0
R-0b	R-0b	R-0b	R-1b	R-1b	R-1b	R/W-0b	R/W-0b

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 5. Resolution Register: Local Channel Programmable Resolution

RES1	RES0	RESOLUTION	CONVERSION TIME (Typical)
0	0	9 Bits (0.5°C)	12.5 ms
0	1	10 Bits (0.25°C)	25 ms
1	0	11 Bits (0.125°C)	50 ms
1	1	12 Bits (0.0625°C)	100 ms

7.6.7 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 TMP401 power dissipation to be balanced with the temperature register update rate. Figure 21 shows the conversion rate register bits and Table 6 shows the conversion rate options and corresponding current consumption.

Figure 21. Conversion Rate (Read = 04h, Write = 0Ah, POR = 08h)

D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	0	R3	R2	R1	R0
R-0b	R-0b	R-0b	R-0b	R/W-1b	R/W-0b	R/W-0b	R/W-0b

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 6. Conversion Rate Register

D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**		**AVERAGE I_Q (typ) (μA)**	
0	**0**	**0**	**0**	**R3**	**R2**	**R1**	**R0**	**CONVERSION/SEC**	**V+ = 3 V**	**V+ = 5 V**
0	0	0	0	0	0	0	0	0.0625	8	29
0	0	0	0	0	0	0	1	0.125	11	31
0	0	0	0	0	0	1	0	0.25	15	36
0	0	0	0	0	0	1	1	0.5	24	45
0	0	0	0	0	1	0	0	1	41	63
0	0	0	0	0	1	0	1	2	69	92
0	0	0	0	0	1	1	0	4	111	136
07h to 0Fh								8	320	355

7.6.8 Identification Registers

The TMP401 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 TMP401 returns 55h for the manufacturer code and 11h for the device ID. These registers are read-only.

7.6.9 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. Figure 22 lists the consecutive alert register bits. The consecutive alert bits are shown in Table 7.

Figure 22. Consecutive Alert Register (Read/Write = 22h, POR = 81h)

D7	D6	D5	D4	D3	D2	D1	D0
TO_EN	0	0	0	C2	C1	C0	1
R/W-1b	R-0b	R-0b	R-0b	R/W-0b	R/W-0b	R/W-0b	R-1b

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 7. Consecutive Alert Register

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 and disable of the timeout function. See the *Timeout Function* section for a description of this feature.

7.6.10 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 does not trip on the measured temperature falling edges. Figure 23 lists the THERM hysteresis register bits. Allowable hysteresis values are shown in Table 8. The default hysteresis value is 10°C, whether the device is operating in the standard or extended mode setting.

Figure 23. Therm Hysteresis (Read/Write = 21h, POR = 0Ah)

D7	D6	D5	D4	D3	D2	D1	D0
TH11	TH10	TH9	TH8	TH7	TH6	TH5	TH4
R/W-0h	R/W-0h	R/W-0h	R/W-0h	R/W-1h	R/W-0h	R/W-1h	R/W-0h

LEGEND: R/W = Read/Write; -n = value after reset

Table 8. Allowable THERM Hysteresis Values

TEMPERATURE (°C)	THERM HYSTERESIS VALUE	
	TH[11:4] (Standard Binary)	HEXADECIMAL
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

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.

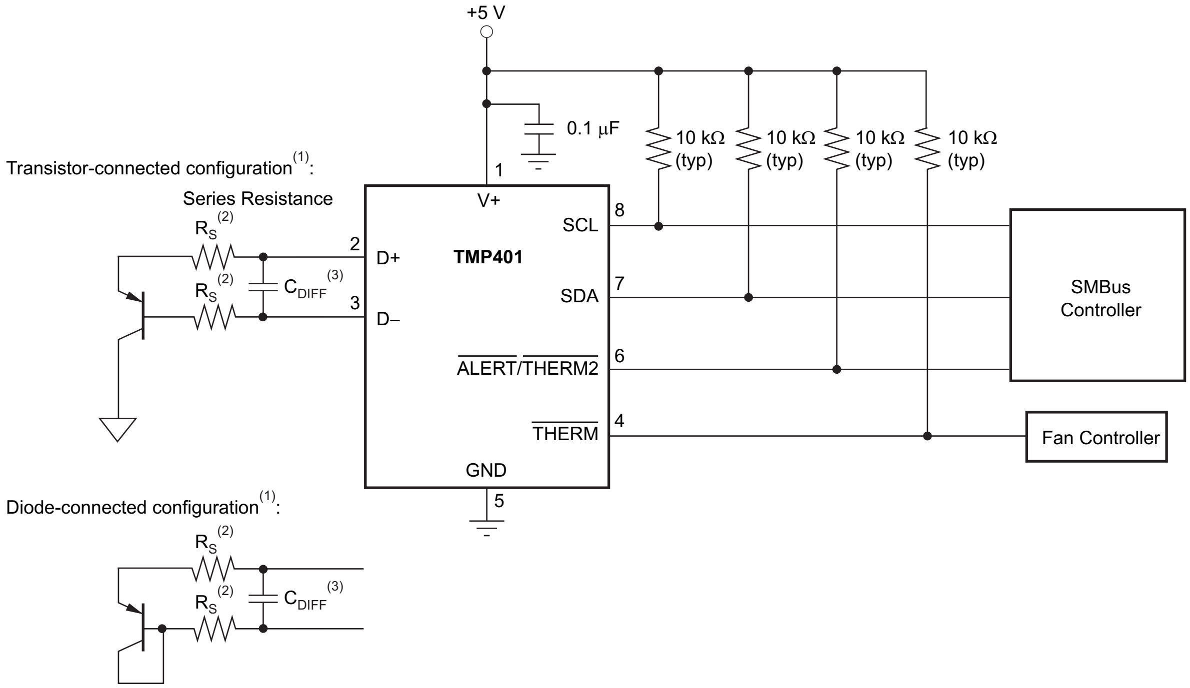
8.1 Application Information

The TMP401 is a remote temperature sensor monitor that includes 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 device manufacturers, with no calibration required. The two-wire serial interface accepts SMBus write, read, send, and receive byte commands to program alarm thresholds and to read temperature data.

Features included in the TMP401 are series resistance cancellation, wide remote temperature measurement range (–40°C to +150°C), diode fault detection, and temperature alert functions.

8.2 Typical Application



(1) The diode-connected configuration provides better settling time. The transistor-connected configuration provides better series resistance cancellation. A 2N3906 PNP is used in this configuration.

(2) In most applications, R_S is < 1.5 kΩ.

(3) In most applications, C_{DIFF} is < 1000 pF.

Figure 24. Remote Noise Filtering

8.2.1 Design Requirements

The TMP401 device requires pull-up resistors on the SCL, SDA, ALERT/$\overline{\text{THERM2}}$, and $\overline{\text{THERM}}$ pins. The recommended value for the pull-up resistors is 10-kΩ. A 0.1-µF bypass capacitor on the supply is recommended, as shown in Figure 24. The SCL and SDA lines can be pulled up to a supply that is equal to or higher than V+ through the pull-up resistors, but not to exceed (V+) + 0.5 V.

Typical Application (continued)

8.2.2 Detailed Design Procedure

Place the TMP401 device in close proximity to the heat source to be monitored, with proper layout for good thermal coupling. This placement ensures that temperature changes are captured within the shortest possible time interval. To maintain accuracy in applications that require air or surface temperature measurement, care must be taken to isolate the package and leads from ambient air temperature. A thermally-conductive adhesive is helpful in achieving accurate surface temperature measurement.

8.2.2.1 Filtering

Remote junction temperature sensors are usually implemented in a noisy environment. Noise is most often created by fast digital signals, and can corrupt measurements. The TMP401 has a built-in, 65-kHz 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 must be between 100 pF and 1 nF. Some applications attain better overall accuracy with additional series resistance. When series resistance is added, the value must not be greater than R_S = 3 kΩ. If filtering is needed, the suggested component values are 100 pF and 50 Ω on each input. Exact values are application-specific.

8.2.3 Application Curves

8.2.3.1 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 TMP401, preventing what otherwise results in a temperature offset. When using a 5-V supply voltage, a total of up to R_S = 3 kΩ of series line resistance is cancelled by the TMP401, eliminating the need for additional characterization and temperature offset correction. Limit series line resistance to 500 Ω total when using a 3.3-V supply voltage. See Figure 25 and Figure 26 for details on the effect of series resistance and power-supply voltage on sensed remote temperature error.

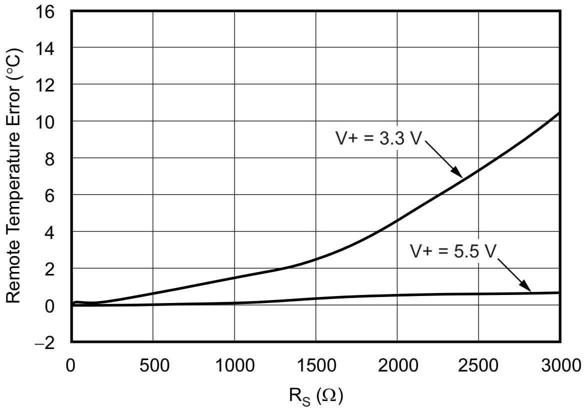


Figure 25. Remote Temperature Error vs Series Resistance (Diode-Connected Configuration; see Figure 24)

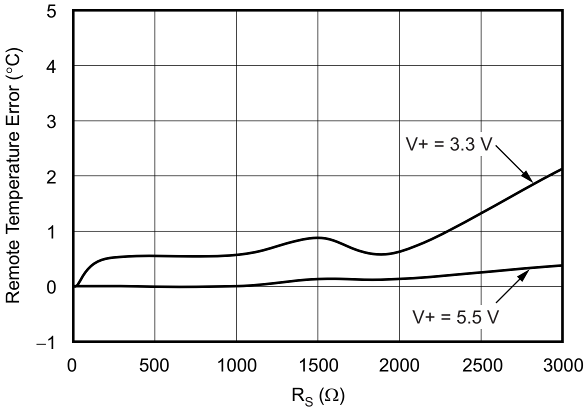


Figure 26. Remote Temperature Error vs Series Resistance (Transistor-Connected Configuration; see Figure 24)

Typical Application (continued)

8.2.3.2 Differential Input Capacitance

The TMP401 tolerates differential input capacitance of up to 1000 pF with minimal change in temperature error. The effect of capacitance on sensed remote temperature error is illustrated in Figure 27.

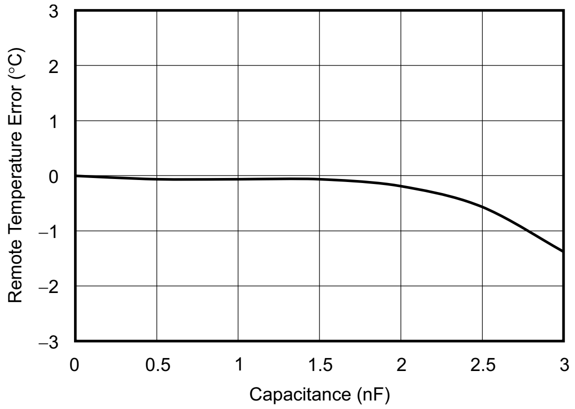


Figure 27. Remote Temperature Error vs Differential Capacitance

9 Power-Supply Recommendations

The TMP401 device operates with power supply in the range of 3.0 V to 5.5 V. The device is optimized for operation at a 5-V supply but can measure temperature accurately in the full supply range. Refer to the TE_{LOCAL} and TE_{REMOTE} versus supply parameter in the *Electrical Characteristics* table for more information about the power supply affect on the accuracy of the device.

A power-supply bypass capacitor is required for proper operation. Place this capacitor as close as possible to the supply and ground pins of the device. A typical value for this supply bypass capacitor is 0.1 µF. Applications with noisy or high-impedance power supplies may require additional decoupling capacitors to reject power-supply noise.

10 Layout

10.1 Layout Guidelines

10.1.1 Measurement Accuracy and Thermal Considerations

The temperature measurement accuracy of the TMP401 depends on the remote and 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 is 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 TMP401 monitors the ambient air around the device. The thermal time constant for the TMP401 is approximately two seconds. This constant implies that if the ambient air changes quickly by 100°C, the TMP401 takes approximately 10 seconds (that is, five thermal time constants) to settle to within 1°C of the final value. In most applications, the TMP401 package is in electrical and therefore thermal contact with the 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 TMP401 is measuring. Additionally, the internal power dissipation of the TMP401 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 5.5-V supply and maximum conversion rate of eight conversions per second, the TMP401 dissipates 1.82 mW (PD_{IQ} = 5.5 V × 330 μA). If both the $\overline{\text{ALERT}}/\overline{\text{THERM2}}$ and $\overline{\text{THERM}}$ pins are each sinking 1 mA, an additional power of 0.8 mW is dissipated (PD_{OUT} = 1 mA × 0.4 V + 1 mA × 0.4 V = 0.8 mW). Total power dissipation is then 2.62 mW ($PD_{IQ} + PD_{OUT}$) and, with a θ_{JA} of 78.8°C/W, causes the junction temperature to rise approximately 0.206°C above the ambient.

10.1.2 Layout Considerations

Remote temperature sensing on the TMP401 measures very small voltages using very small currents; therefore, noise at the IC inputs must be minimized. Most applications using the TMP401 have high digital content, with several clocks and logic level transitions creating a noisy environment. Layout must adhere to the following guidelines:

1. Place the TMP401 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; see Figure 28. 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; see Figure 30.
4. Use a 0.1-μF local bypass capacitor directly between the V+ and GND of the TMP401; see Figure 29. Minimize filter capacitance between D+ and D– to 1000 pF or less for optimum measurement performance. This capacitance includes any cable capacitance between the remote temperature sensor and the TMP401.
5. If the connection between the remote temperature sensor and the TMP401 is between 8 inches and 12 feet, use a twisted-wire pair connection. Beyond this distance (up to 100 ft), use a twisted, shielded pair with the shield grounded as close to the TMP401 as possible. Leave the remote sensor connection end of the shield wire open to avoid ground loops and 60-Hz pickup.

Layout Guidelines (continued)

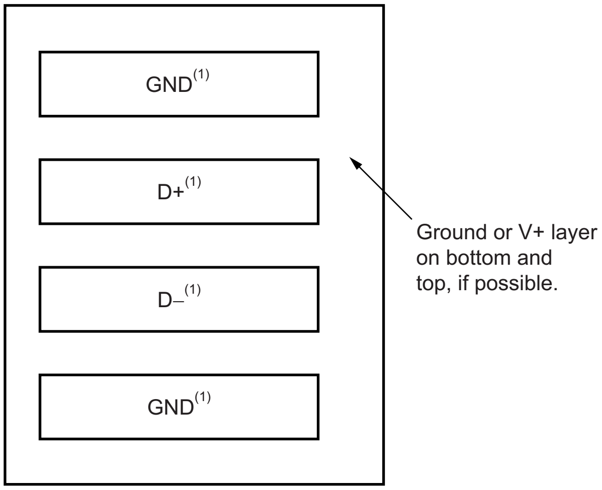


Figure 28. Example Signal Traces

10.2 Layout Examples

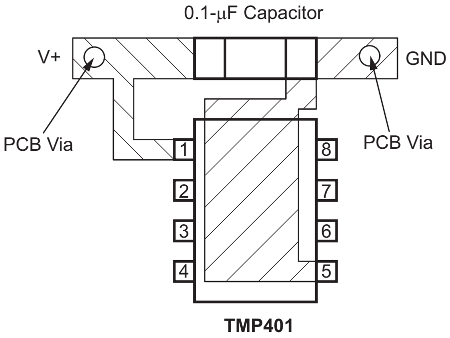
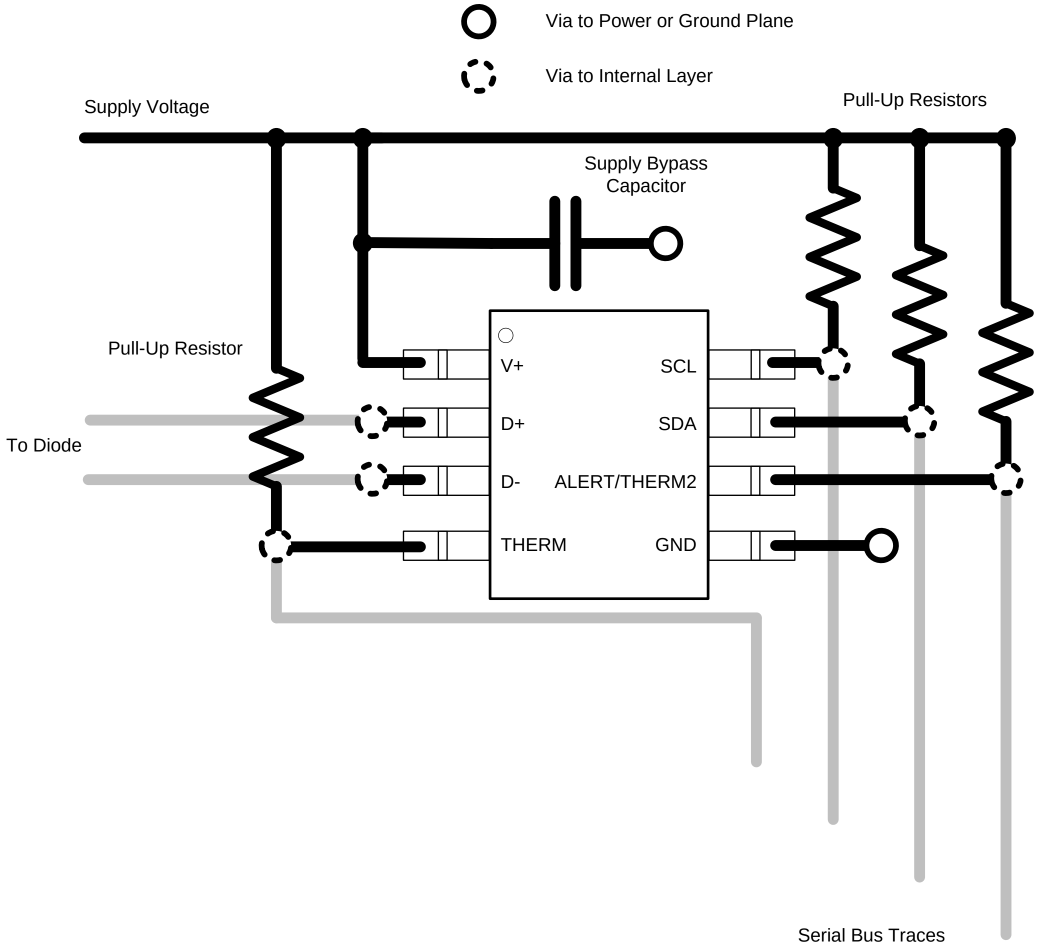


Figure 29. Suggested Bypass Capacitor Placement

Layout Examples (continued)



NOTE: The copper to solder connections must be symmetrical between D+ and D–.

Figure 30. Example Layout

11 Device and Documentation Support

11.1 Trademarks

All trademarks are the property of their respective owners.

11.2 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.

11.3 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 part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
TMP401AIDGKR	Active	Production	VSSOP (DGK) | 8	2500 | LARGE T&R	Yes	NIPDAU | NIPDAUAG	Level-2-260C-1 YEAR	-40 to 125	BRB
TMP401AIDGKR.A	Active	Production	VSSOP (DGK) | 8	2500 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BRB
TMP401AIDGKT	Obsolete	Production	VSSOP (DGK) | 8	-	-	Call TI	Call TI	-40 to 125	BRB

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

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

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

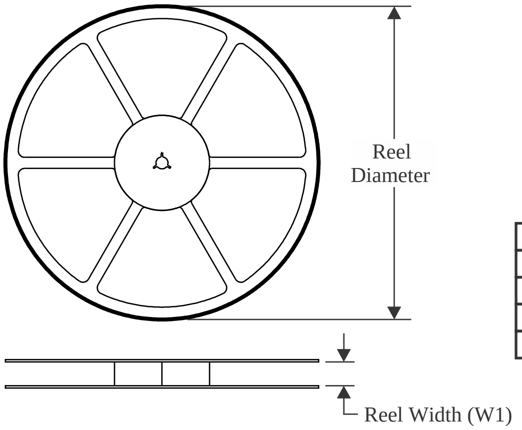
Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

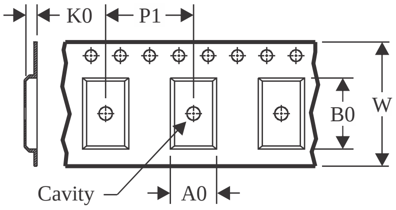
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

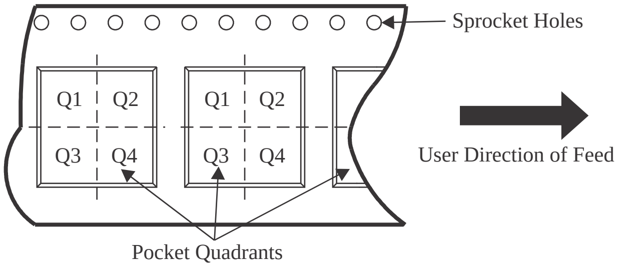


TAPE DIMENSIONS



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

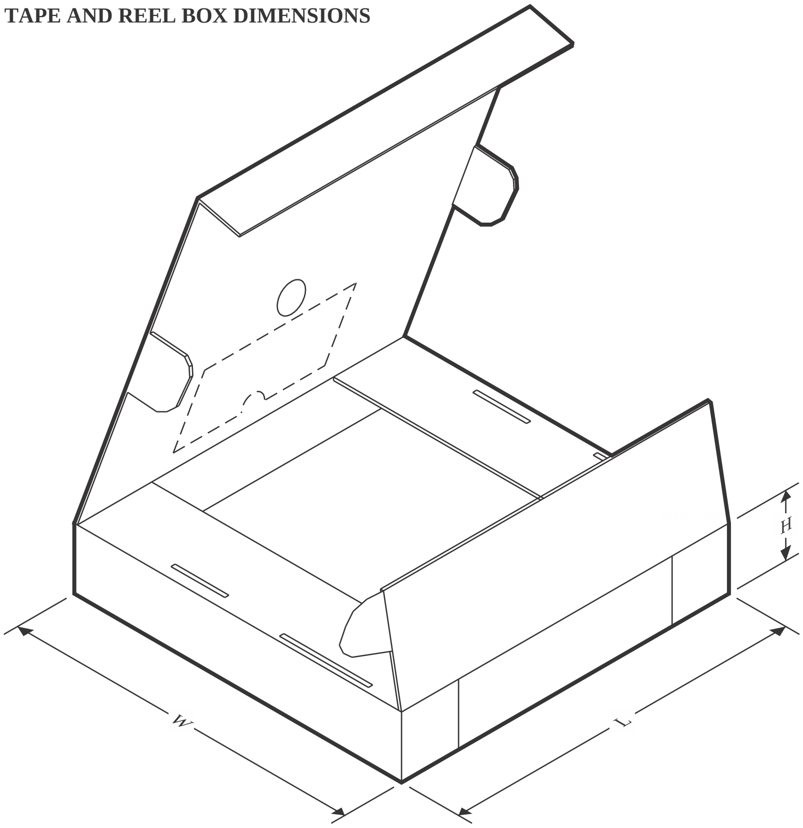
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
TMP401AIDGKR	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1

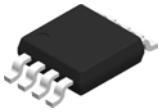
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TMP401AIDGKR	VSSOP	DGK	8	2500	366.0	364.0	50.0

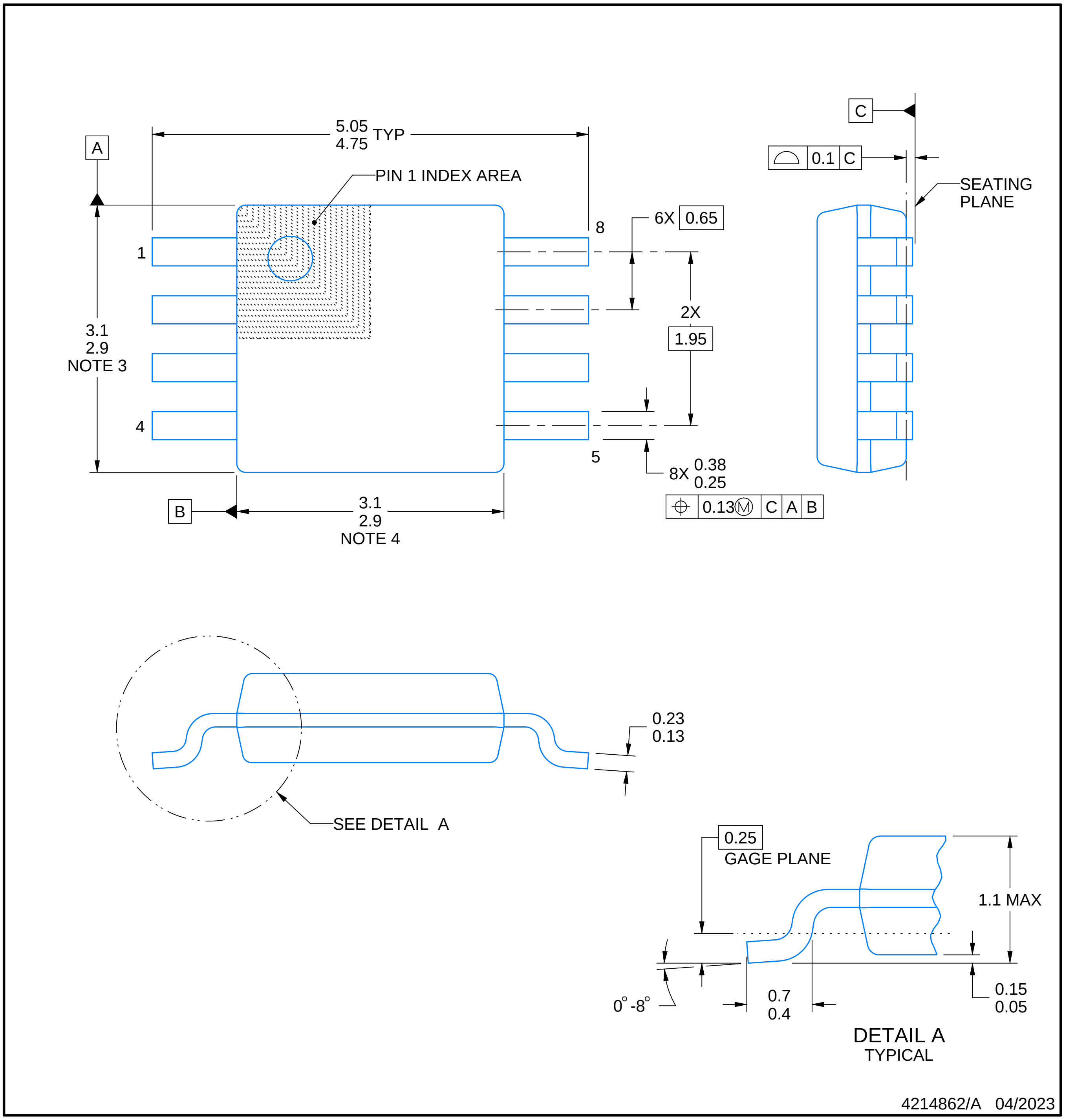
DGK0008A



PACKAGE OUTLINE

VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE

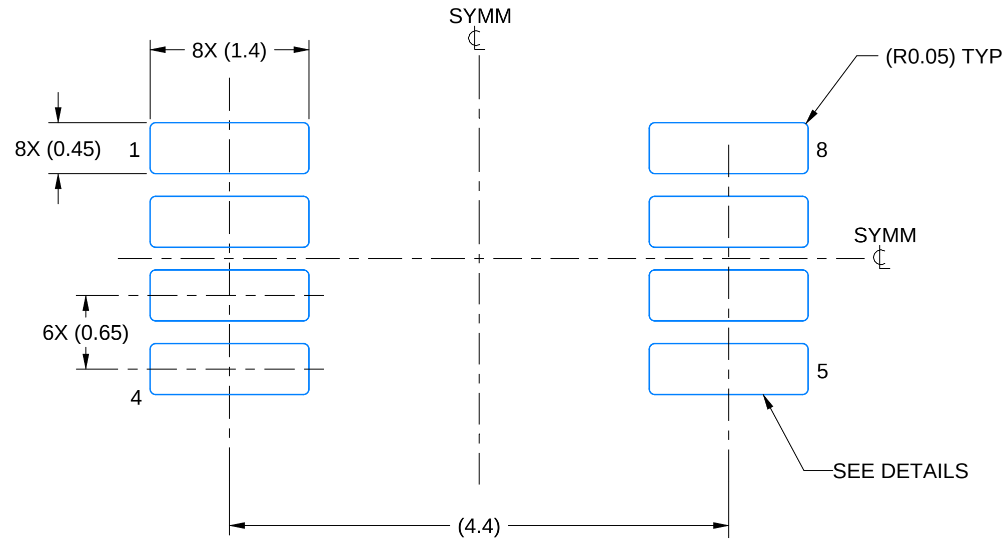


4214862/A 04/2023

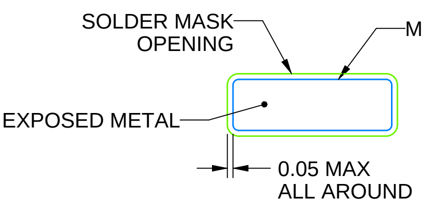
PowerPAD is a trademark of Texas Instruments.

NOTES:

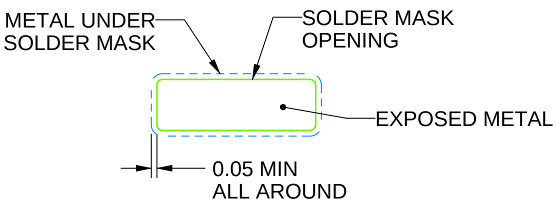
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-187.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 15X



NON-SOLDER MASK
DEFINED
(PREFERRED)



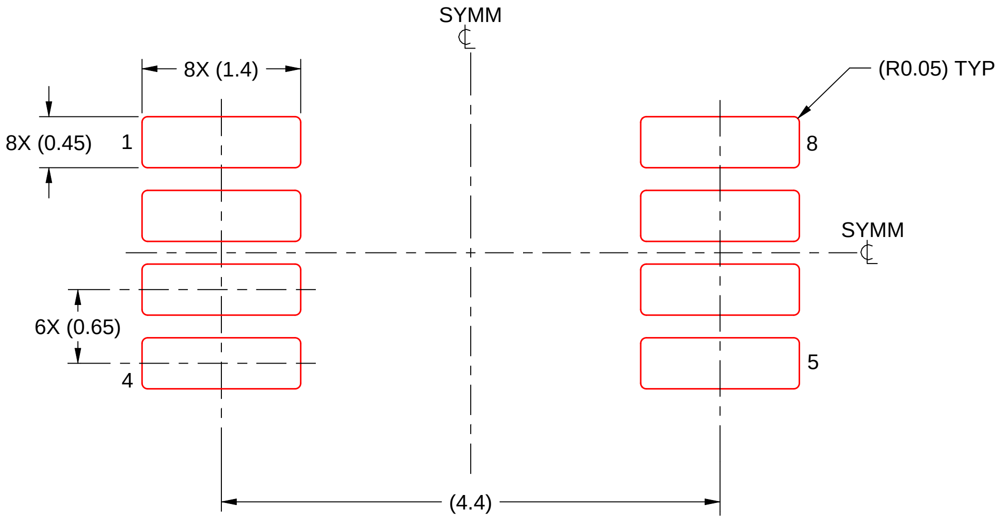
SOLDER MASK
DEFINED

SOLDER MASK DETAILS

4214862/A 04/2023

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
8. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.
9. Size of metal pad may vary due to creepage requirement.



SOLDER PASTE EXAMPLE
SCALE: 15X

NOTES: (continued)

11. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
12. Board assembly site may have different recommendations for stencil design.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you fully indemnify TI and its representatives against any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale, TI’s General Quality Guidelines, or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products. Unless TI explicitly designates a product as custom or customer-specified, TI products are standard, catalog, general purpose devices.

TI objects to and rejects any additional or different terms you may propose.

Copyright © 2025, Texas Instruments Incorporated

Last updated 10/2025