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
- 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).

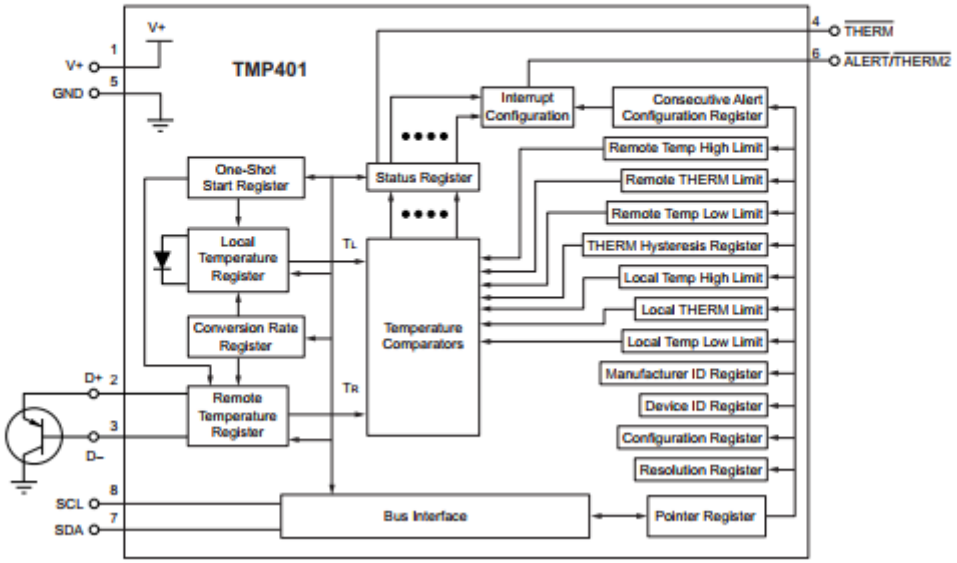
The accuracy of the remote sensor is ±1°C for multiple IC manufacturers, with no calibration needed. The two-wire serial interface accepts SMBus write byte, read byte, send byte, and receive byte commands to program alarm thresholds and to read temperature data.

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]

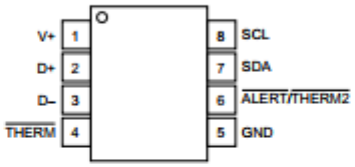
PART NUMBER	PACKAGE	BODY SIZE (NOM)
TMP401	VSSOP (8)	3.00 mm × 3.00 mm

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



5 Pin Configuration and Functions

DGK Package
VSSOP-8
(Top View)



Pin Functions

PIN NO.	PIN NAME	I/O	DESCRIPTION
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	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
	$\overline{ALERT}$/$\overline{THERM2}$ output low sink current		$\overline{ALERT}$/$\overline{THERM2}$ forced to 0.4 V	6			mA
	$\overline{THERM}$ output low sink current		$\overline{THERM}$ 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.

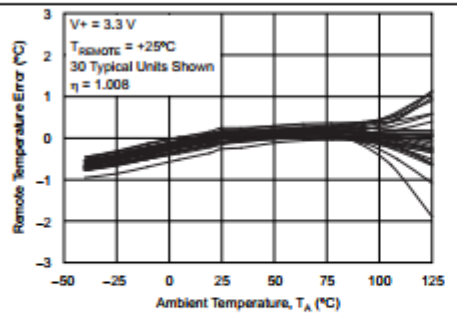


Figure 1. Remote Temperature Error vs Temperature

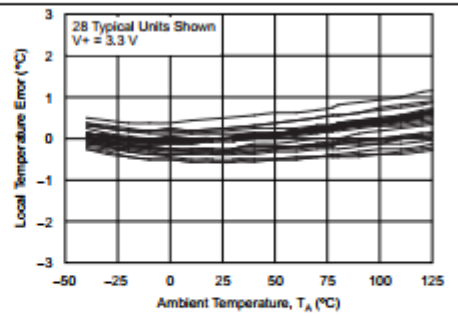


Figure 2. Local Temperature Error vs Temperature

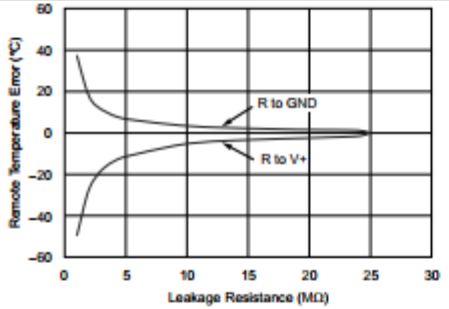


Figure 3. Remote Temperature Error vs Leakage Resistance

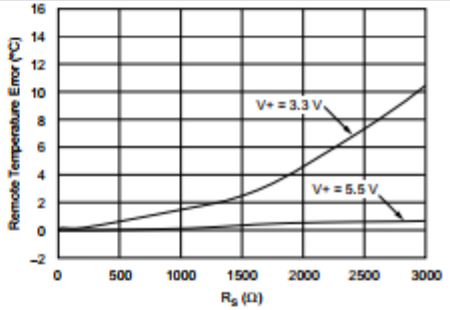


Figure 4. Remote Temperature Error vs Series Resistance (Diode-Connected Configuration; see Figure 11)

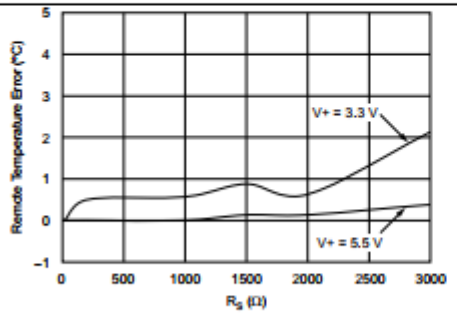


Figure 5. Remote Temperature Error vs Series Resistance (Transistor-Connected Configuration; see Figure 11)

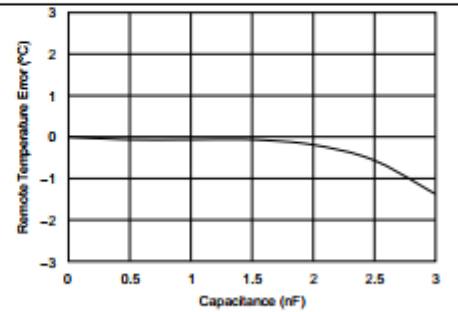
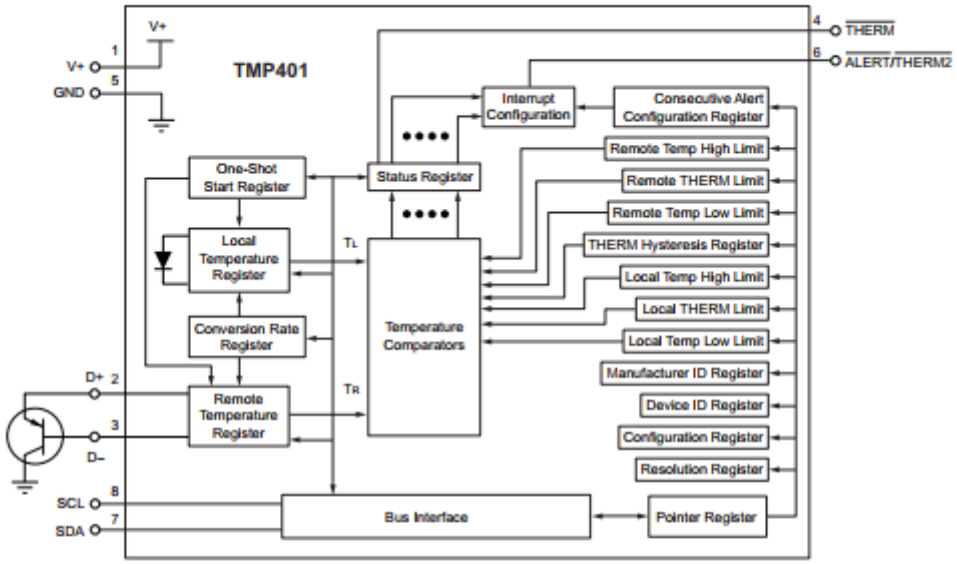


Figure 6. Remote Temperature Error vs Differential Capacitance

7.2 Functional Block Diagram



Typical Characteristics (continued)

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

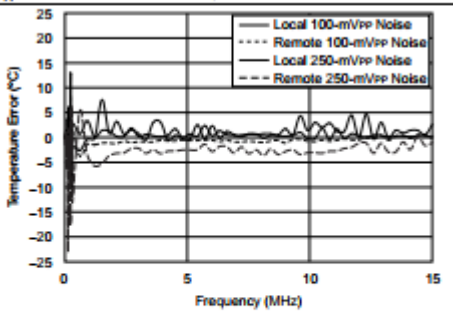


Figure 7. Temperature Error vs Power-Supply Noise Frequency

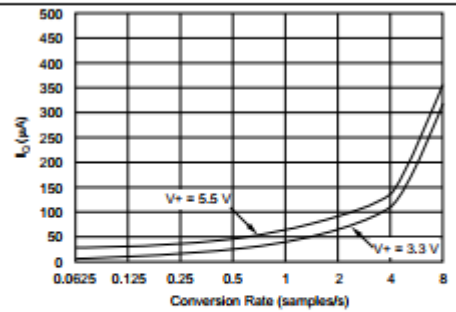


Figure 8. Quiescent Current vs Conversion Rate

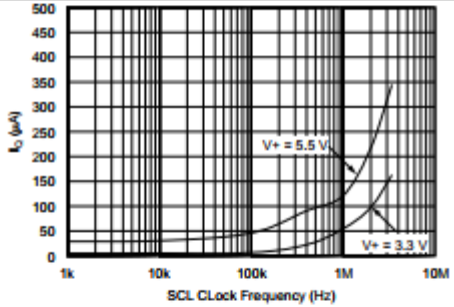


Figure 9. Shutdown Quiescent Current vs SCL Clock Frequency

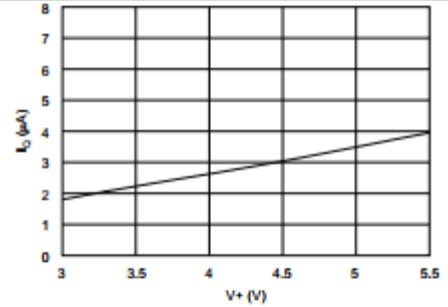


Figure 10. Shutdown Quiescent Current vs Supply Voltage

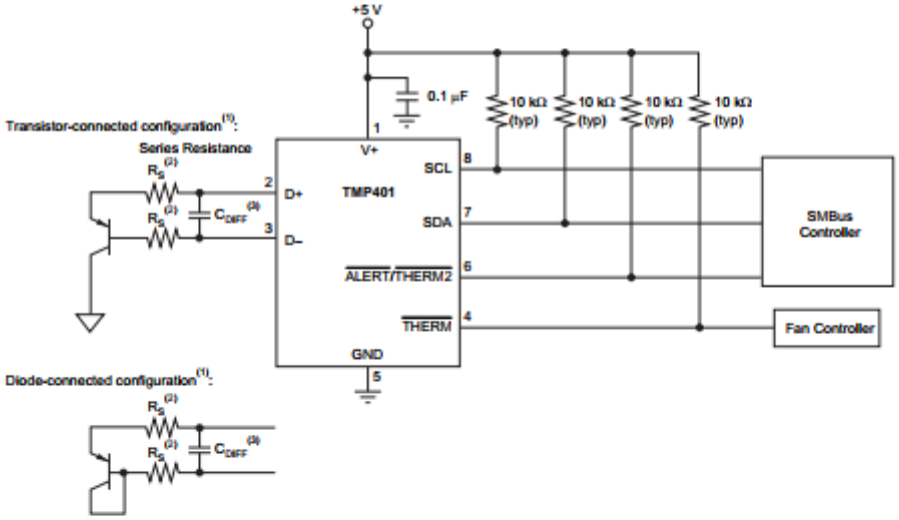
7 Detailed Description

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

7.3 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.