General Description

The MAX31875 is a ±2°C-accurate local temperature sensor with I^{2}C/SMBus interface. The combination of tiny package and excellent temperature measurement accuracy makes this product ideal for a variety of equipment.

The I^{2}C/SMBus-compatible serial interface accepts standard write byte, read byte, send byte, and receive byte commands to read the temperature data and configure the behavior of the sensor. Bus timeout resets the interface if the clock is low for more than 30ms (nominal). PEC helps to avoid communication errors when used with a master that supports this feature.

The MAX31875 is available in a 4-bump WLP package and operates over the -55°C to +150°C temperature range.

Applications

- Battery-powered equipment
- Handheld electronics
- Data communications equipment
- Servers
- Industrial equipment

Benefits and Features

- Tiny, 0.87mm x 0.87mm x 0.35mm WLP
- Excellent temperature accuracy
  - ±1.5°C from +10°C to +45°C (±0.4°C typical)
  - ±2°C from -10°C to +100°C (±0.5°C typical)
  - ±3°C from -40°C to +125°C (±0.75°C typical)
- <10µA average power supply current
- Selectable Timeout Prevents Bus Lockup (Default Enabled)
- I2C and SMBus support
- Selectable PEC for reliable communications
- Up to 1MHz bus speed
- +1.4V to +3.6V power supply voltage

Ordering Information appears at end of datasheet.

Simplified Block Diagram

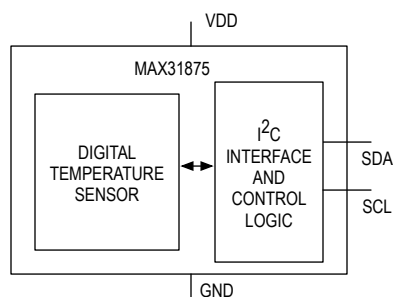Proprietary and Confidential. Preliminary Information - subject to change without notice.

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Absolute Maximum Ratings

VDD to GND ....-0.3V to +4V
SDA, SCL to GND ....-0.3V to +4V
Continuous Power Dissipation (Multilayer Board) (T$_A$ = +70°C, derate 9.7mW/°C above +70°C.)............ mW to 776mW

Package Junction-to-Ambient Thermal Resistance (θJA) 103°C/W
Operating Temperature Range .... -55°C to +150°C
Storage Temperature Range............................ -60°C to +150°C

Package Information

ULTRA THIN WLP

ULTRA THIN WLP Package Drawing Link

Package Code	Z40A0-1
Outline Number	21-0683
Land Pattern Number	
Thermal Resistance, Four-Layer Board:	
Junction to Ambient (θ$_{JA}$)	103
Junction to Case (θ$_{JC}$)	

For the latest package outline information and land patterns (footprints), go to www.maximintegrated.com/packages. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to www.maximintegrated.com/thermal-tutorial.

Electrical Characteristics

(T$_A$=-55°C to +125°C, V$_{DD}$=1.4V to 3.6V, resolution=10 bits, unless otherwise specified. Limits are guaranteed by production testing, design, and characterization.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Temperature Measurement Error		1.4V ≤ +V$_{DD}$ ≤3.6V, +10°C≤T$_A$≤ +45°C, resolution = 12 bits	-1.5	0.4	+1.5	°C
		1.4V ≤ +V$_{DD}$ ≤3.6V, -10°C ≤T$_A$≤ +100°C	-2	±0.5	+2	°C
		1.4V ≤ +V$_{DD}$ ≤3.6V, -40°C ≤T$_A$≤ +125°C	-3	0.75	+3	
		1.4V ≤ +V$_{DD}$ ≤3.6V, -55°C ≤T$_A$≤ +150°C		TBD		°C
Temperature Resolution		Selected by Resolution bits in Configuration register.		0.0625°C, 0.25°C, 0.5°C, 1.0°C		°C
Conversion Time		10-bit (0.25°C) resolution		35	50	ms

Electrical Characteristics

(T_A=-55°C to +125°C, V_{DD}=1.4V to 3.6V, resolution=10 bits, unless otherwise specified. Limits are guaranteed by production testing, design, and characterization.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
First Conversion Completed		After VDD exceeds 1.4V			60	ms
LOGIC (SDA, SCL) DC Characteristics						
Input High Voltage	V_{IH}		V_{DD} x 0.7		3.6	V
Input Low Voltage	V_{IL}		-0.5		V_{DD} x 0.3	V
Input High Leakage Current	I_{IH}	$V_{IN} = V_{DD}$	-1	±0.005	1	µA
Input Low Leakage Current	I_{IL}	$V_{IN} = 0V$	-1	±0.005	1	µA
Input Capacitance	C_{IN}			5		pF
Output High Leakage Current		$V_{OUT} = V_{DD}$		TBD	1	µA
AC Electrical Characteristics						
Serial Clock Frequency	f_{SCL}		DC		1	MHz
Bus Free Time Between Start and Stop Conditions	t_{BUF}		0.5			µs
START Condition Hold Time	$t_{HD:STA}$		0.26			µs
STOP Condition Setup Time	$t_{SU:STO}$	90% of SCL to 10% of SDA	.26			µs
Clock Low Period	t_{LOW}		0.5			µs
Clock High Period	t_{HIGH}		0.26			µs
START Condition Setup Time	$t_{SU:STA}$	90% of SCL to 90% of SDA	0.26			µs
Data Setup Time	tSU:DAT	10% of SDA to 10% of SCL	50			ns
Data In Hold Time	$t_{HD:DAT}$	10% of SCL to 10% of SDA (Note y)	0			µs
SCL/SDA Rise Time	t_R	Note 1			120	ns
SCL/SDA Fall Time	t_F	Note 1	20 + 0.1C_B		120	ns
Transmit SDA Fall Time	t_F	Note 1	20 x (VDD/5.5V)		TBD	ns
		V_{DD} ≥ 1.8V. Note 1.	20 x (V_{DD}/5.5)		120	
		Bus capacitance = 550pF. V_{DD} ≥ 2.4V	20 x (V_{DD}/5.5V)		120	
SCL Time Low for Reset of Serial Interface	$t_{TIMEOUT}$	Note 2	25		35	ms

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Electrical Characteristics

(T_A=-55°C to +125°C, V_{DD}=1.4V to 3.6V, resolution=10 bits, unless otherwise specified. Limits are guaranteed by production testing, design, and characterization.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Power Supply						
Operating Supply Voltage Range			1.4		3.6	V
Conversion Power Supply Current		Active Temperature Conversions, I2C Inactive		70	100	µA
Average Power Supply Current		I²C inactive, 0.25 conversions/s, 10-bit (0.25°C) resolution		TBD	3	µA
		I²C inactive, 4 conversions/s, 10-bit (0.25°C) resolution		TBD	10	
Standby Supply Current		In Standby and between conversions, I2C bus inactive, bus timeout disabled.		0.5	1	µA
		In Standby and between conversions, I2C bus inactive, bus timeout enabled.		0.7	1.5	µA

Note 1: C_B = total capacitance of one bus line in pF. Tested with C_B = 400pF.
Note 2: Holding the SCL line low for a time greater than $t_{TIMEOUT}$ causes the devices to reset SDA to the idle state of the serial bus communication (SDA released).

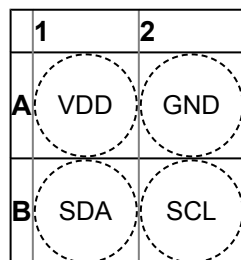## Typical Operating Characteristics

V_{DD} = +3.3V, T_A = 25°C unless otherwise noted,

Pin Configurations

DT18

TOP VIEW (BUMP SIDE DOWN)

	1	2
A	VDD	GND
B	SDA	SCL

Pin Description

PIN	NAME	FUNCTION
A1	VDD	Positive power supply voltage input. Bypass to GND with a 100nF capacitor.
A2	GND	Ground

PIN	NAME	FUNCTION
B1	SDA	Serial-Data Input/Output Line. Open drain. Connect SDA to a pull-up resistor. When VDD is less than the minimum operating voltage, SDA is high impedance for any pull-up voltage from 0 to 3.6V.
B2	SCL	Serial-Data Clock Input. Connect SCL to a pullup resistor. When VDD is less than the minimum operating voltage, SCL is high impedance for any pull-up voltage from 0 to 3.6V.

Detailed Description

The MAX31875 temperature sensor measures temperature and converts the data into digital form. An I^{2}C-compatible two-wire serial interface allows access to conversion results. Standard I^{2}C commands allow reading the data and configuring other operating characteristics. While reading the temperature register, any changes in measured temperature are ignored until the read is completed. The temperature register is updated for the new temperature measurement upon completion of the read operation.

I2C-Compatible Bus Interface

A standard I^{2}C-compatible 2-wire serial interface reads temperature data from the temperature registers and reads and writes control bits to and from the configuration registers. In addition, the interface supports useful SMBus functions, including selectable bus timeout and selectable Packet Error Checking (PEC).
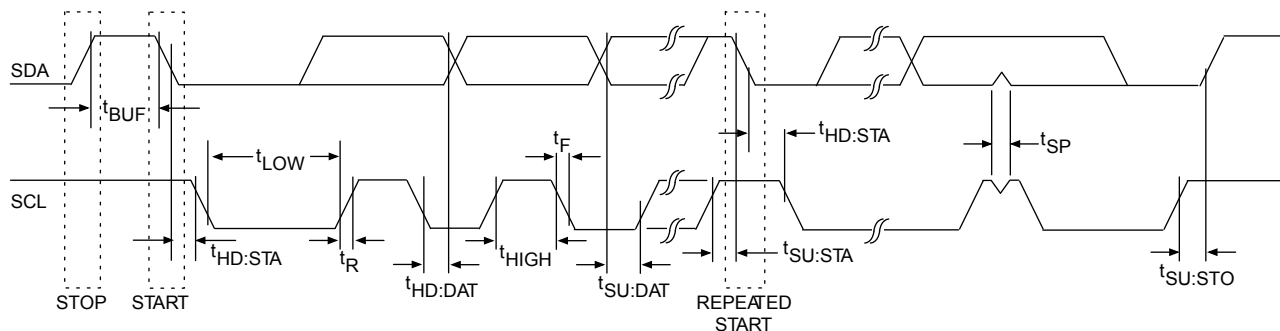

Figure 1. I^{2}C/SMBus Timing Diagram

Normal transactions consist of 2-byte writes and reads. An additional byte will be appended when PEC is enabled. Attempting longer transactions is not recommended. A transaction always begins with a START (S) condition followed by the slave address and the Write/Read bit.

A 2-byte write transaction begins with the master generating a START condition and then transmitting the MAX31875's slave address followed by the Write bit. The MAX31875 acknowledges with an ACK (A) bit, and the master transmits the target register, followed by another ACK from the MAX31875. The master then writes the two data bytes, and the MAX31875 ACKs each. The master ends the transaction by generating a STOP (P) condition. Writing more bytes (not recommended) will simply overwrite the register (e.g. DATA HIGH - DATA LOW - DATA HIGH - DATA LOW for a 4-byte write).

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DIRECTION	M→S	M→S	M→S	S→M	M→S	S→M	M→S	S→M	M→S	S→M	M→S
BITS	1	7	1	1	8	1	8	1	8	1	1
CONTENT	S	SLAVE ADDRESS	WR	A	REGISTER SELECT	A	DATA HIGH	A	DATA LOW	A	P

Figure 2. 2-Byte Write to MAX31875.

When Packet Error Checking (PEC) is enabled, the write transaction is similar except that the PEC byte (calculated using SLAVE ADDRESS, REGISTER ADDRESS, DATA HIGH and DATA LOW) is appended by the master after the ACK bit that follows the second data byte. Any attempted write that is not a multiple of three bytes will be ignored. If more than one set of three bytes is written, the PEC byte is calculated using the bytes listed above, plus the first PEC byte and the second DATA HIGH and DATA LOW bytes. Again, writing more than three bytes with PEC enabled is not recommended.

DIRECTION	M→S	M→S	M→S	S→M	M→S	S→M	M→S	S→M	M→S	S→M	M→S	S→M	M→S
BITS	1	7	1	1	8	1	8	1	8	1	8	1	1
CONTENT	S	SLAVE ADDRESS	WR	A	REGISTER SELECT	A	DATA HIGH	A	DATA LOW	A	PEC BYTE	A	P

Figure 3. 2-Byte Write to MAX31875 with PEC Byte

A 2-byte read is slightly more complex than a write. After transmitting the register byte and receiving an ACK from the MAX31875, the master generates a REPEAT START (Sr) and writes the address and a Read bit. The MAX31875 then ACKs the address/read byte and transmits the two data bytes. The master ACKs the first and NACKs the second, signaling that the transaction is complete, and then generates the STOP condition.

DIRECTION	M→S	M→S	M→S	S→M	M→S	S→M
BITS	1	7	1	1	8	1
CONTENT	S	SLAVE ADDRESS	WR	A	REGISTER SELECT	A

•••

M→S	M→S	M→S	S→M	S→M	M→S	S→M	M→S	M→S
1	7	1	1	8	1	8	1	1
Sr	SLAVE ADDRESS	RD	A	DATA HIGH	A	DATA LOW	N	P

Figure 4. 2-Byte Read from MAX31875

When Packet Error Checking (PEC) is enabled, the read transaction is similar except that the PEC byte is appended by the MAX31875 after the ACK bit that follows the second data byte.

DIRECTION	M→S	M→S	M→S	S→M	M→S	S→M
BITS	1	7	1	1	8	1
CONTENT	S	SLAVE ADDRESS	WR	A	REGISTER SELECT	A

•••

M→S	M→S	M→S	S→M	S→M	M→S	S→M	M→S	S→M	M→S	M→S
1	7	1	1	8	1	8	1	8	1	1
Sr	SLAVE ADDRESS	RD	A	DATA HIGH	A	DATA LOW	A	PEC BYTE	N	P

Figure 5. 2-Byte Read from MAX31875 with PEC Byte

I2C Slave Address

The MAX31875 responds to its own I^{2}C slave address, which is factory-programmed to one of the values shown in the table below.

Table 1. I^{2}C Slave Addresses

Part Number	Slave Address
MAX31875R0	1001000
MAX31875R1	1001001
MAX31875R2	1001010
MAX31875R3	1001011
MAX31875R4	1001100
MAX31875R5	1001101
MAX31875R6	1001110
MAX31875R7	1001111

Internal Registers

Two two-byte registers contain conversion data, configuration settings, and temperature threshold (T_{OS}) and hysteresis (T_{HYST}) values. The pointer register selects between the registers as shown in the table below. The pointer register must be written for each I2C transaction. All registers are read and write, except for the read-only temperature data register. Register addresses are not auto-incremented during reads and writes.

Write to the configuration register by writing the slave address byte, the pointer register byte to value 01h, and the data bytes. The TOS and THYST registers require the slave address byte, pointer register byte (02h or 03h), and 2 data bytes. If only 1 data byte is written, it is saved in bits D[15:8] of the respective register. If more than 2 data bytes are written, the additional data writes to the same register.

Perform a read operation by issuing the slave address byte (write), pointer byte, repeat START, another slave address byte (read), and then reading the data byte. If more than 2 data bytes are read, the additional reads are from the same register. See Figure 4.

Table 2. Register Functions and POR States

REGISTER NAME	ADDRESS (HEX)	NUMBER OF BYTES	POR STATE (HEX)	POR STATE (°C)	READ/WRITE
Temperature	00h	2	0000h	0	RO
Configuration	01h	2	0000h	n/a	R/W
T_{HYST}	02h	2	4B00h	75	R/W
T_{OS}	03h	2	5000h	80	R/W

Temperature Register

The temperature data format is 16 bits, two's complement, and the register is read out in 2 bytes: an upper byte and a

lower byte. Bits D[15:3] contain the temperature data, but depending on the resolution and data format selected, some of the lower-value bits may be set to 0. For 8-bit resolution, the LSB has a value of 1°C, and for 12-bit resolution, the LSB has a value of 0.0625°C. The MSB is the sign bit; see Table 3. The MSB is transmitted first.

Table 3. Temperature Register Definition

Upper Byte								Lower Byte								Comment
D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	
Sign	128°C	64°C	32°C	16°C	8°C	4°C	2°C	1°C	0.5°C	0.25°C	0.125°C	0.0625°C	0	0	0	Extended Format
Sign	64°C	32°C	16°C	8°C	4°C	2°C	1°C	0.5°C	0.25°C	0.125°C	0.0625°C	0	0	0	0	Normal Format

In addition to the normal temperature data format, an optional extended data format allows temperatures equal to or greater than +128°C to be read. In the extended format, selected by bit 5 of the configuration register, the MSB is increased from 64°C to 128°C.

Temperature Threshold Registers

The TOS and THYST registers use the same data format as the temperature data register. Note that THYST is intended to have values less than or equal to TOS. Therefore, a THYST value greater than TOS will be interpreted as being equal to TOS.

Configuration Register

The configuration register contains 16 bits of data and initiates single conversions (1-Shot), enables bus timeout, controls shutdown, sets the data format, and selects the automatic conversion rate. The upper byte is compatible with popular temperature sensors such as the DS75, and the lower byte includes additional features. See Table 4.

Table 4. Configuration Register Definition

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Over Temp Status	X	X	Fault Queue		X	Comp/Int	Shut Down	Data Format	Resolution		Time-out	PEC	Conversion Rate		One-Shot

One-Shot

The ONE-SHOT function helps to reduce average supply current when continuous conversions are not necessary. Writing a 1 to D0 while in shutdown mode immediately begins a new temperature conversion. After the conversion has completed, the device returns to shutdown mode. D0 returns to 0 when the conversion completes. Writing 1 to D0 has no effect when not in shutdown.

Timeout Enable

Write 1 to D4 to disable bus timeout.

Write 0 to D4 to enable bus timeout. Bus timeout resets the I2C-compatible interface when SCL is low for more than 30ms (nominal).

Data Format

Bit D7 selects the temperature data format. When D7 is 0 (normal format), the data format is two's complement with a range of -128°C to (128°C - 1LSB), where the value of an LSB depends on the resolution selection.

Write a 1 to D7 for extended temperature format. In extended format, the MSB is given a value of 128°C, which allows temperatures as high as 150°C to be measured. See Table 4. After changing the value of bit D7 the data format does not update until the completion of the following temperature conversion. After setting D7 to 1, new extended temperature data is guaranteed ready after a time equal to twice the maximum conversion time. Note that changing the data format bit does not change the format of the values in the TOS and THYST registers; these values must be written to the registers in the current format.

Conversion Rate

The conversion rate bits, D2:D1, select the rate for automatic continuous conversions. Rates of 0.25sps, 1sps, 4sps, and 8sps are available. The nominal conversion time is TBDms. In automatic conversion mode, a conversion is started every 4, 1, 0.25, or 0.125 seconds, and shutdown mode is entered between conversions to reduce average power supply current.

Conversion Rate Selection

D2	D1	Conversions/sec
0	0	0.25 (POR)
0	1	1
1	0	4
1	1	8

Shutdown

Set bit D8 to 1 to enter shutdown mode and reduce supply current to 1µA or less. If bit D8 is set to 1 when a temperature conversion is taking place, the conversion completes and then shutdown occurs. While in shutdown, the I2C interface remains active and all registers remain accessible to the master.

Writing 0 to D8 begins continuous conversion mode at the rate defined by D2:D1 and starts a new conversion.

Resolution

The resolution bits, D6:D5, select the conversion resolution. Because the conversion time doubles with every bit of increased resolution, the resolution bits allow resolution, conversion time, and supply current to be optimized for the application's requirements.

Resolution Selection

D6	D5	Resolution
0	0	8 bit
0	1	9 bit
1	0	10 bit (POR)
1	1	12 bit

Fault Queue

The fault queue bits, D12:D11, select how many consecutive over-temperature faults must occur before an over-temperature fault is indicated in the Over-Temperature Status bit. The fault queue selection applies to both Comparator and Interrupt modes. The Fault Queue does not apply to de-asserting the over-temperature status when the measured temperature drops below THYST.

Fault Queue
Selection

D12	D11	# Faults
0	0	1 (POR)
0	1	2
1	0	4
1	1	6

Over-Temperature Status

D15 is a read-only bit that indicates that the over-temperature value in the T_{OS} register has been exceeded. Its behavior is controlled by the Comparator/Interrupt bit.

Comparator/Interrupt

Set bit D9, the COMPARATOR/INTERRUPT bit to 0 to make the Over-Temperature Status (OT Status) bit operate in comparator mode. In comparator mode, the OT Status bit has a value of 1 when the temperature rises above the TOS value (subject to the Fault Queue selection). OT Status returns to 0 when the temperature drops below the THYST value or when shutdown mode is entered.

Set bit D9 to 1 to operate OT Status in interrupt mode. In interrupt mode, exceeding TOS also sets OT Status to 1. OT Status remains set to 1 until a read operation is performed on any of the registers, at which point it returns to 0. Once OT Status has been set to 1 due to crossing above TOS and is then reset, it is set to 1 again only when the temperature drops below THYST. The output then remains asserted until it is reset by a read. It is then set again if the temperature rises above TOS, and so on. Putting the MAX31875 into shutdown mode also resets OT Status. Note that if the mode is changed while OT Status is set to 1, an OT Status reset may be required before it begins to behave normally.
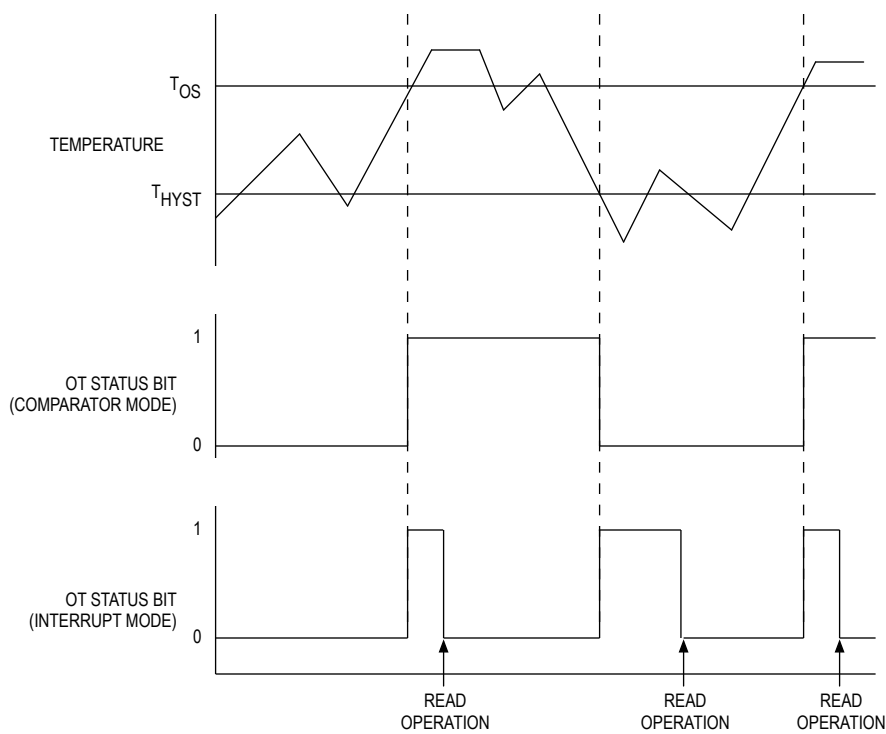
Figure 6. OT status bit temperature response for comparator and interrupt modes.

Power-On Reset Value

The configuration register always powers up to a known state, as indicated in Table 2. These default POR values correspond to the following modes of operation:

- Normal data format
- 0.25 conversions per second
- Timeout enabled
- 10-bit (0.25°C) resolution

PEC

Set bit 3 to enable Packet Error Checking (PEC). When enabled, a PEC byte is appended to the end of each message transfer. This is a CRC-8 byte that is calculated on all of the message bytes (including the address/read/write byte). The last device to transmit a data byte also transmits the PEC byte, so the master transmits the PEC byte after a Write transaction and the MAX31875 transmits the PEC byte after a Read transaction.

Applications Information

Power Supply Current, Resolution, and Conversion Rate

The MAX31875 is a low-power temperature sensor whose average power supply current is affected by the conversion resolution and the conversion rate. Understanding the relationships between these values can help to optimize performance tradeoffs.

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In Standby mode, and between conversions, the power supply current is typically 500nA. During a conversion, the typical supply current increases to 70µA. The duration of a conversion depends on the conversion resolution selected in the Configuration register. A 10-bit conversion requires 35ms (typical). Each 1-bit increase in resolution doubles the conversion time, and each 1-bit decrease halves the conversion time. Therefore, if 12-bit resolution is selected, the conversion time will typically be 140ms.

The conversion rate is also selectable, and, along with resolution, helps to set the conversion duty cycle and average power supply current. As an example, 10-bit conversions occurring at a rate of one conversion per second will result in an average power supply current of

$$I_{AVE} = 70µA \times 0.035 + 0.5µA \times 0.965 = 2.45µA.$$

Tradeoffs may be made depending on the design priorities. For example, when supply current is much more important than resolution, reducing the resolution in the example above to 8 bits will reduce the duty cycle by 75%, yielding
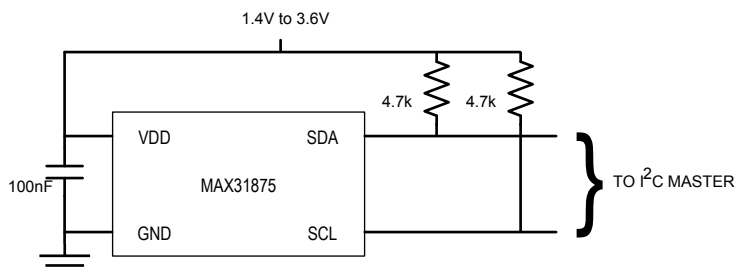
$$I_{AVE} = 70µA \times 0.00875 + 0.5µA \times 0.99125 = 1.11µA.$$

Temperature Sensing Considerations

The MAX31875 measures the temperature of its own die. The thermal path between the die and the outside world determines the accuracy of temperature measurements. External temperature is conducted to the die primarily through the leads . Because of this, PCB temperature can be measured accurately. For ambient temperature measurements, the sensor should be mounted on a PCB (or a section of the PCB) that is at ambient temperature, separated from heat-dissipating components. Temperature errors due to self-heating of the sensor die are minimal due to the low supply current.

Typical Application Circuits
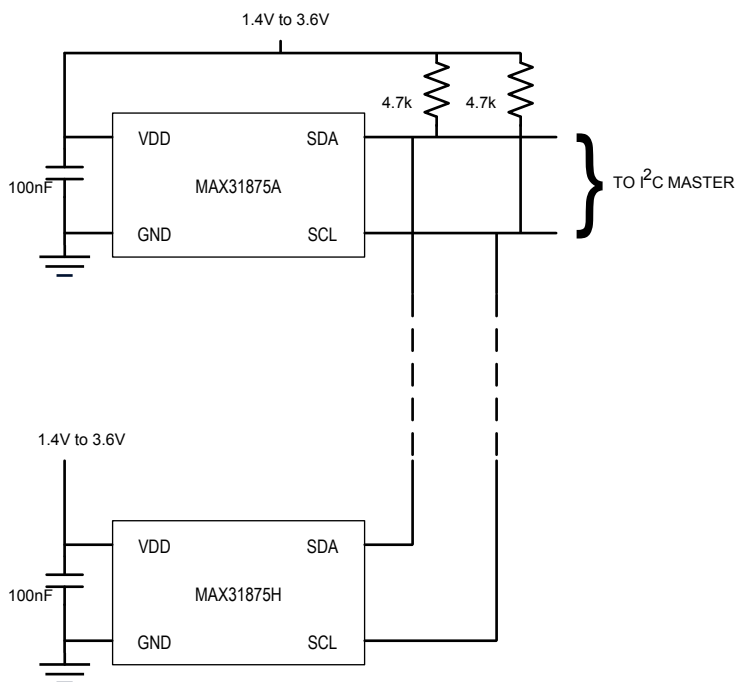
Single-Sensor Application

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Multi-Sensor Application

Each sensor has a different factory-selected slave address. Eight different addresses are available.

Ordering Information

Part Number	Temperature Range	Pins-Package	Slave Address
MAX31875R0TZS+1	-40°C to +150°C	4 WLP	1001000
MAX31875R1TZS+1	-40°C to +150°C	4 WLP	1001001
MAX31875R2TZS+1	-40°C to +150°C	4 WLP	1001010
MAX31875R3TZS+1	-40°C to +150°C	4 WLP	1001011
MAX31875R4TZS+1	-40°C to +150°C	4 WLP	1001100
MAX31875R5TZS+1	-40°C to +150°C	4 WLP	1001101
MAX31875R6TZS+1	-40°C to +150°C	4 WLP	1001110
MAX31875R7TZS+1	-40°C to +150°C	4 WLP	1001111

+ Denotes a lead(Pb)-free/RoHS-compliant package.

T Denotes tape-and-reel.