

±1°C, SMBus-Compatible Remote/Local Temperature Sensor with Overtemperature Alarm

General Description

The MAX6642 precise, two-channel digital temperature sensor accurately measures the temperature of its own die and a remote PN junction and reports the temperature data over a 2-wire serial interface. The remote PN junction is typically a substrate PNP transistor on the die of a CPU, ASIC, GPU, or FPGA. The remote PN junction can also be a discrete diode-connected small-signal transistor.

The 2-wire serial interface accepts standard system management bus (SMBus™), Write Byte, Read Byte, Send Byte, and Receive Byte commands to read the temperature data and to program the alarm thresholds. To enhance system reliability, the MAX6642 includes an SMBus timeout. The temperature data format is 10 bit with the least significant bit (LSB) corresponding to +0.25°C. The ALERT output asserts when the local or remote overtemperature thresholds are violated. A fault queue may be used to prevent the ALERT output from setting until two consecutive faults have been detected.

Measurements can be done autonomously or in a single-shot mode.

Remote accuracy is ±1°C maximum error between +60°C and +100°C. The MAX6642 operates from -40°C to +125°C, and measures remote temperatures between 0°C and +150°C. The MAX6642 is available in a 6-pin TDFN package with an exposed pad.

Applications

Desktop Computers
Notebook Computers
Servers
Thin Clients
Test and Measurement
Workstations
Graphic Cards

Selector Guide

| PART | MEASURED TEMP RANGE | TOP MARK |
|----------------|---------------------|----------|
| MAX6642ATT90-T | 0°C to +150°C | AFC |
| MAX6642ATT92-T | 0°C to +150°C | AFD |
| MAX6642ATT94-T | 0°C to +150°C | AFE |
| MAX6642ATT96-T | 0°C to +150°C | AFF |
| MAX6642ATT98-T | 0°C to +150°C | AEW |
| MAX6642ATT9A-T | 0°C to +150°C | AFG |
| MAX6642ATT9C-T | 0°C to +150°C | AFH |
| MAX6642ATT9E-T | 0°C to +150°C | AFI |

SMBus is a trademark of Intel Corp.

Features

- ◆ **Dual Channel: Measures Remote and Local Temperature**
- ◆ **+0.25°C Resolution**
- ◆ **High Accuracy ±1°C (max) (Remote) and ±2°C (Local) from +60°C to +100°C**
- ◆ **Measures Remote Temperature Up to +150°C**
- ◆ **Programmable Overtemperature Alarm Temperature Thresholds**
- ◆ **SMBus/I²C-Compatible Interface**
- ◆ **Tiny TDFN Package with Exposed Pad**

Ordering Information

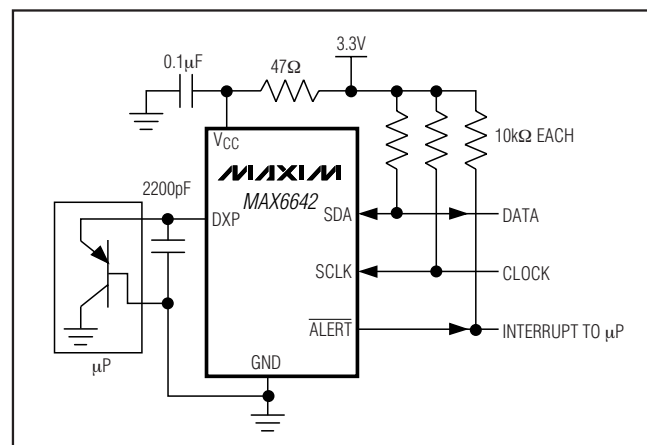
| PART | TEMP RANGE | PIN-PACKAGE |
|----------------|-----------------|-------------|
| MAX6642ATT90-T | -40°C to +125°C | 6 TDFN-EP* |
| MAX6642ATT92-T | -40°C to +125°C | 6 TDFN-EP* |
| MAX6642ATT94-T | -40°C to +125°C | 6 TDFN-EP* |
| MAX6642ATT96-T | -40°C to +125°C | 6 TDFN-EP* |
| MAX6642ATT98-T | -40°C to +125°C | 6 TDFN-EP* |
| MAX6642ATT9A-T | -40°C to +125°C | 6 TDFN-EP* |
| MAX6642ATT9C-T | -40°C to +125°C | 6 TDFN-EP* |
| MAX6642ATT9E-T | -40°C to +125°C | 6 TDFN-EP* |

T = Tape and reel.

*EP = Exposed pad.

Pin Configuration and Functional Diagram appear at end of data sheet.

Typical Operating Circuit



±1°C, SMBus-Compatible Remote/Local Temperature Sensor with Overtemperature Alarm

ABSOLUTE MAXIMUM RATINGS

All Voltages Referenced to GND

| | |
|---|-----------------------------------|
| V _{CC} | -0.3V to +6V |
| DXP | -0.3V to (V _{CC} + 0.3V) |
| SCLK, SDA, ALERT | -0.3V to +6V |
| SDA, ALERT Current | -1mA to +50mA |
| Continuous Power Dissipation (T _A = +70°C) | |
| 6-Pin TDFN (derate 24.4mW/°C above +70°C) | 1951mW |

| | |
|---|-----------------|
| ESD Protection (all pins, Human Body Model) | ±2000V |
| Junction Temperature | +150°C |
| Operating Temperature Range | -40°C to +125°C |
| Storage Temperature Range | -65°C to +150°C |
| Lead Temperature (soldering, 10s) | +300°C |

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{CC} = +3.0V to +5.5V, T_A = -40°C to +125°C, unless otherwise specified. Typical values are at V_{CC} = +3.3V and T_A = +25°C.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|-------------------|--|---|------|------|-------|
| Supply Voltage | V _{CC} | | 3.0 | | 5.5 | V |
| Temperature Resolution | | | 0.25 | | | °C |
| | | | 10 | | | Bits |
| Remote Temperature Error | | V _{CC} = 3.3V | T _{RJ} = +60°C to +100°C, T _A = +25°C to +85°C | -1.0 | +1.0 | °C |
| | | | T _{RJ} = 0°C to +125°C | -3.0 | +3.0 | |
| | | | T _{RJ} = +125°C to +150°C | -3.5 | +3.5 | |
| Local Temperature Error | | V _{CC} = 3.3V | T _A = +60°C to +100°C | -2.0 | +2.0 | °C |
| | | | T _A = 0°C to +125°C | -3.0 | +3.0 | |
| Supply Sensitivity of Temperature Error | | | ±0.2 | | | °C/V |
| Undervoltage Lockout Threshold | UVLO | Falling edge of V _{CC} disables ADC | 2.4 | 2.7 | 2.95 | V |
| Undervoltage Lockout Hysteresis | | | 90 | | | mV |
| Power-On-Reset (POR) Threshold | | V _{CC} falling edge | 1.5 | 2.0 | 2.4 | V |
| POR Threshold Hysteresis | | | 90 | | | mV |
| Standby Supply Current | | SMBus static | | 3 | 10 | μA |
| Operating Current | | During conversion | | 0.5 | 1.0 | mA |
| Average Operating Current | | | | 260 | | μA |
| Conversion Time | t _{CONV} | From stop bit to conversion completion | 106 | 125 | 143 | ms |
| Conversion Rate | f _{CONV} | | 8 | | | Hz |
| Remote-Diode Source Current | I _{RJ} | High level | 80 | 100 | 120 | μA |
| | | Low level | 8 | 10 | 12 | |
| ALERT | | | | | | |
| Output-Low Sink Current | | V _{OL} = 0.4V | 1 | | | mA |
| | | V _{OL} = 0.6V | 4 | | | |
| Output-High Leakage Current | | V _{OH} = V _{CC} | | | 1 | μA |

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ELECTRICAL CHARACTERISTICS (continued)

($V_{CC} = +3.0\text{V}$ to $+5.5\text{V}$, $T_A = -40^{\circ}\text{C}$ to $+125^{\circ}\text{C}$, unless otherwise specified. Typical values are at $V_{CC} = +3.3\text{V}$ and $T_A = +25^{\circ}\text{C}$.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|--|---------------|--|-----|-----|-----|---------------|
| SMBus-COMPATIBLE INTERFACE (SCLK and SDA) | | | | | | |
| Logic Input Low Voltage | V_{IL} | | | | 0.8 | V |
| Logic Input High Voltage | V_{IH} | $V_{CC} = 3.0\text{V}$ | 2.2 | | | V |
| Input Leakage Current | I_{LEAK} | $V_{IN} = \text{GND}$ or 5.5V | -1 | | +1 | μA |
| Output Low Sink Current | I_{OL} | $V_{OL} = 0.6\text{V}$ | 6 | | | mA |
| Input Capacitance | C_{IN} | | | 5 | | pF |
| SMBus TIMING (Note 2) | | | | | | |
| Serial Clock Frequency | f_{SCLK} | (Note 3) | | | 100 | kHz |
| Bus Free Time Between STOP and START Condition | t_{BUF} | | 4.7 | | | μs |
| START Condition Setup Time | | | 4.7 | | | μs |
| Repeat START Condition Setup Time | $t_{SU:STA}$ | 90% to 90% | 50 | | | ns |
| START Condition Hold Time | $t_{HD:STA}$ | 10% of SDA to 90% of SCLK | 4 | | | μs |
| STOP Condition Setup Time | $t_{SU:STO}$ | 90% of SCLK to 90% of SDA | 4 | | | μs |
| Clock Low Period | t_{LOW} | 10% to 10% | 4.7 | | | μs |
| Clock High Period | t_{HIGH} | 90% to 90% | 4 | | | μs |
| Data Setup Time | $t_{HD:DAT}$ | (Note 4) | 250 | | | μs |
| Receive SCLK/SDA Rise Time | t_R | | | | 1 | μs |
| Receive SCLK/SDA Fall Time | t_F | | | | 300 | ns |
| Pulse Width of Spike Suppressed | t_{SP} | | 0 | | 50 | ns |
| SMBus Timeout | $t_{TIMEOUT}$ | SDA low period for interface reset | 20 | 28 | 40 | ms |

Note 1: All parameters tested at $T_A = +25^{\circ}\text{C}$. Specifications over temperature are guaranteed by design.

Note 2: Timing specifications guaranteed by design.

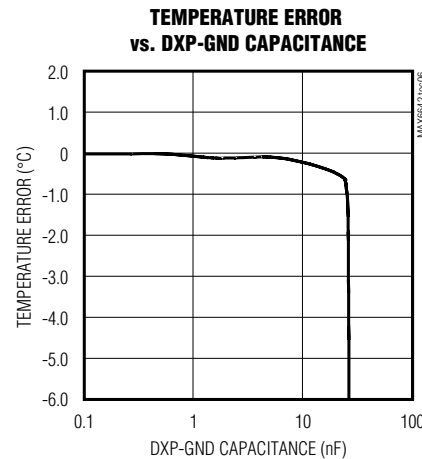
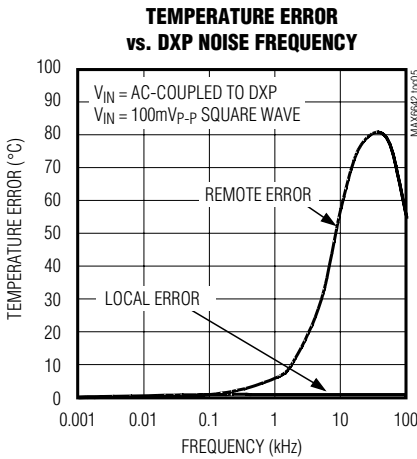
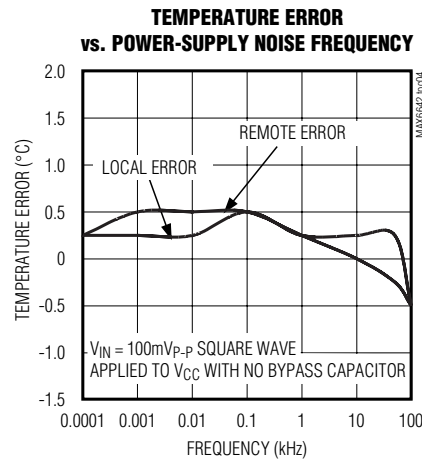
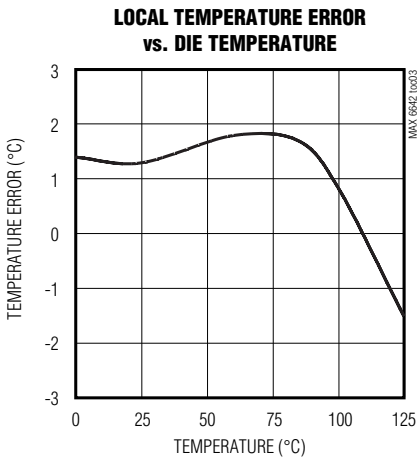
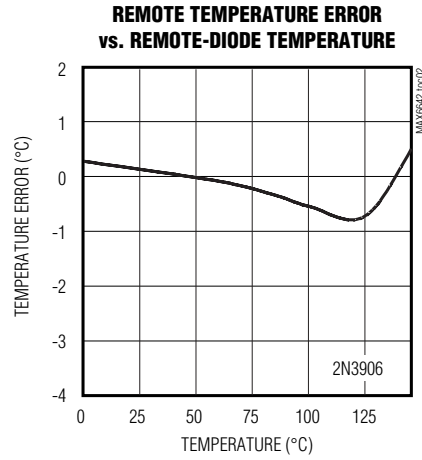
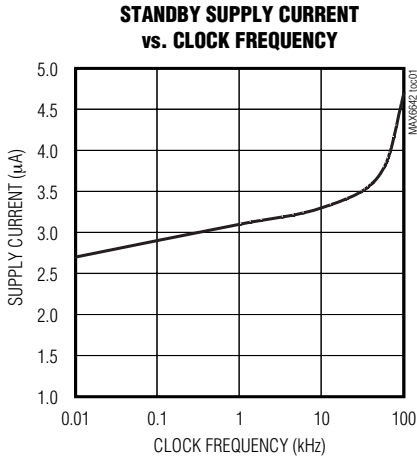
Note 3: The serial interface resets when SCLK is low for more than $t_{TIMEOUT}$.

Note 4: A transition must internally provide at least a hold time to bridge the undefined region (300ns max) of SCLK's falling edge.

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Typical Operating Characteristics

(V_{CC} = 3.3V, T_A = +25°C, unless otherwise noted.)



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Pin Description

| PIN | NAME | FUNCTION |
|-----|---------------------------|---|
| 1 | V _{CC} | Supply Voltage Input, +3V to +5.5V. Bypass V _{CC} to GND with a 0.1 μ F capacitor. A 47 Ω series resistor is recommended but not required for additional noise filtering. |
| 2 | GND | Ground |
| 3 | DXP | Combined Remote-Diode Current Source and ADC Input for Remote-Diode Channel. Place a 2200pF capacitor between DXP and GND for noise filtering. |
| 4 | SCLK | SMBus Serial-Clock Input. May be pulled up to +5.5V regardless of V _{CC} . |
| 5 | SDA | SMBus Serial-Data Input/Output, Open Drain. May be pulled up to +5.5V regardless of V _{CC} . |
| 6 | $\overline{\text{ALERT}}$ | SMBus Alert (Interrupt) Output, Open Drain. $\overline{\text{ALERT}}$ asserts when temperature exceeds user-set limits. See the <i>ALERT Interrupts</i> section. |
| — | EP | Exposed Pad. Internally connected to GND. Connect to a PCB ground pad for optimal performance. Not intended as an electrical connection point. |

Detailed Description

The MAX6642 is a temperature sensor for local and remote temperature-monitoring applications. Communication with the MAX6642 occurs through the SMBus-compatible serial interface and dedicated alert pins. $\overline{\text{ALERT}}$ asserts if the measured local or remote temperature is greater than the software-programmed $\overline{\text{ALERT}}$ limit.

The MAX6642 converts temperatures to digital data either at a programmed rate of eight conversions per second or in single conversions. Temperature data is represented by 8 data bits (at addresses 00h and 01h), with the LSB equal to +1 $^{\circ}\text{C}$ and the MSB equal to +128 $^{\circ}\text{C}$. Two additional bits of remote temperature data are available in the “extended” register at address 10h and 11h (Table 2) providing resolution of +0.25 $^{\circ}\text{C}$.

ADC and Multiplexer

The averaging ADC integrates over a 60ms period (each channel, typ), with excellent noise rejection.

The multiplexer automatically steers bias currents through the remote and local diodes. The ADC and associated circuitry measure each diode’s forward voltage and compute the temperature based on this voltage. Both channels are automatically converted once the conversion process has started, either in free-running or single-shot mode. If one of the two channels is not used, the device still performs both measurements, and the user can ignore the results of the unused channel. If the remote-diode channel is unused, connect DXP to GND rather than leaving DXP open.

The conversion time per channel (remote and internal) is 125ms. If both channels are being used, then each channel is converted four times per second. If the external conversion-only option is selected, then the

remote temperature is measured eight times per second. The results of the previous conversion are always available, even if the ADC is busy.

Low-Power Standby Mode

Standby mode reduces the supply current to less than 10 μA by disabling the ADC and timing circuitry. Enter standby mode by setting the RUN bit to 1 in the configuration byte register (Table 4). All data is retained in memory, and the SMBus interface is active and listening for SMBus commands. Standby mode is not a shutdown mode. With activity on the SMBus, the device draws more supply current (see the *Typical Operating Characteristics*). In standby mode, the MAX6642 can be forced to perform ADC conversions through the one-shot command, regardless of the RUN bit status.

If a standby command is received while a conversion is in progress, the conversion cycle is truncated, and the data from that conversion is not latched into a temperature register. The previous data is not changed and remains available.

Supply-current drain during the 125ms conversion period is 500 μA (typ). In standby mode, supply current drops to 3 μA (typ).

SMBus Digital Interface

From a software perspective, the MAX6642 appears as a set of byte-wide registers that contain temperature data, alarm threshold values, and control bits. A standard SMBus-compatible 2-wire serial interface is used to read temperature data and write control bits and alarm threshold data.

The MAX6642 employs four standard SMBus protocols: Write Byte, Read Byte, Send Byte, and Receive Byte. (Figures 1, 2, and 3). The shorter Receive Byte protocol allows quicker transfers, provided that the correct data

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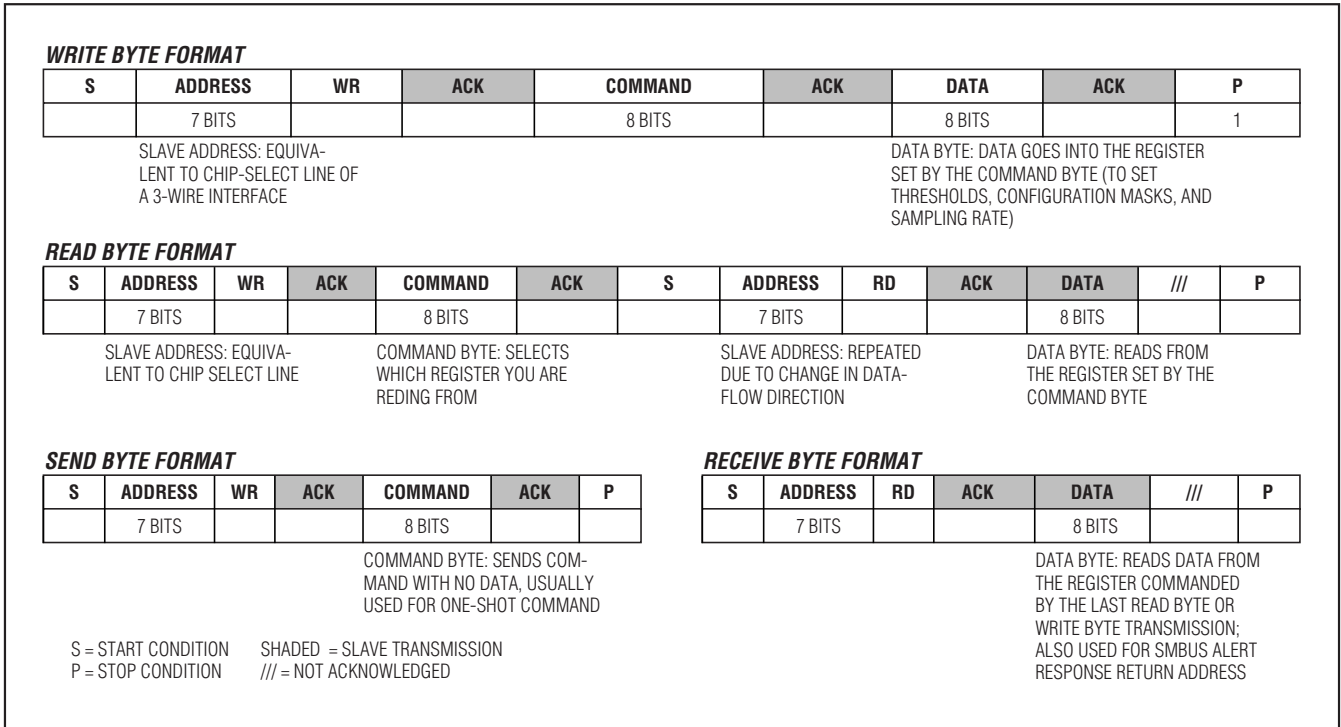


Figure 1. SMBus Protocols

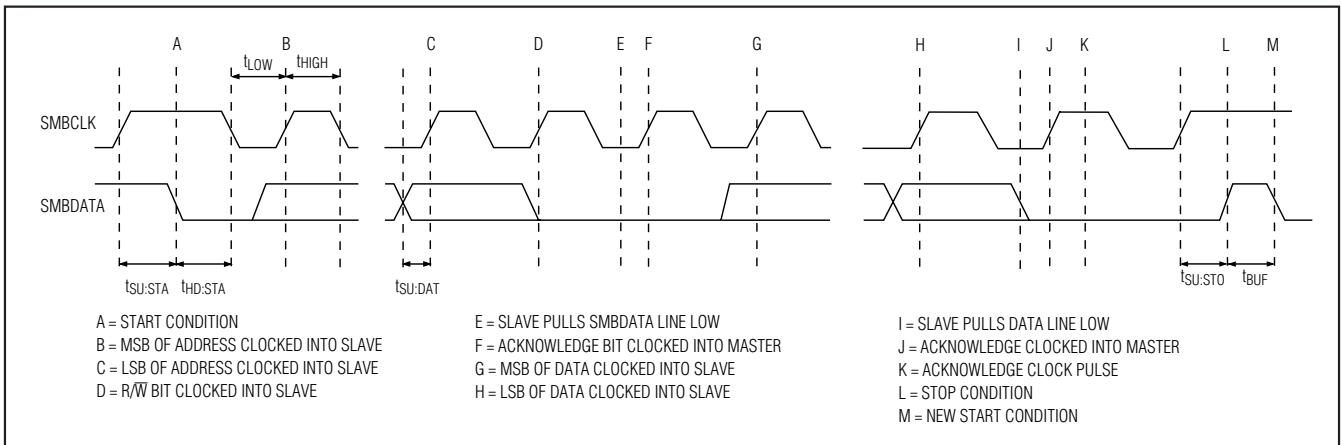


Figure 2. SMBus Write Timing Diagram

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register was previously selected by a Write Byte instruction. Use caution when using the shorter protocols in multimaster systems, as a second master could overwrite the command byte without informing the first master.

Read temperature data from the read internal temperature (00h) and read external temperature (01h) registers. The temperature data format for these registers is 8 bits for each channel, with the LSB representing +1°C (Table 1).

Read the additional bits from the read extended temperature byte register (10h, 11h), which extends the data to 10 bits and the resolution to +0.25°C per LSB (Table 2).

When a conversion is complete, the main temperature register and the extended temperature register are updated.

Alarm Threshold Registers

Two registers store $\overline{\text{ALERT}}$ threshold values—one each for the local and remote channels. If either measured temperature equals or exceeds the corresponding $\overline{\text{ALERT}}$ threshold value, the $\overline{\text{ALERT}}$ interrupt asserts unless the $\overline{\text{ALERT}}$ bit is masked.

The power-on-reset (POR) state of the local $\overline{\text{ALERT}}$ THIGH register is +70°C (0100 0110). The POR state of the remote $\overline{\text{ALERT}}$ THIGH register is +120°C (0111 1000).

Diode Fault Detection

A continuity fault detector at DXP detects an open circuit on DXP, or a DXP short to VCC or GND. If an open or short circuit exists, the external temperature register is loaded with 1111 1111 and status bit 2 (OPEN) of the status byte is set to 1. Immediately after POR, the status register indicates that no fault is present. If a fault is

Table 1. Main Temperature Register (High Byte) Data Format

| TEMP (°C) | DIGITAL OUTPUT |
|-----------------------------|----------------|
| 130.00 | 1 000 0010 |
| 127.00 | 0 111 1111 |
| 126.00 | 0 111 1110 |
| 25 | 0 001 1001 |
| 0.00 | 0 000 0000 |
| <0.00 | 0 000 0000 |
| Diode fault (short or open) | 1 111 1111 |

Table 2. Extended Resolution Temperature Register (Low Byte) Data Format

| FRACTIONAL TEMP (°C) | DIGITAL OUTPUT |
|----------------------|----------------|
| 0.000 | 00XX XXXX |
| 0.250 | 01XX XXXX |
| 0.500 | 10XX XXXX |
| 0.750 | 11XX XXXX |

present upon power-up, the fault is not indicated until the end of the first conversion. Diode faults do not set the $\overline{\text{ALERT}}$ output.

$\overline{\text{ALERT}}$ Interrupts

The $\overline{\text{ALERT}}$ interrupt occurs when the internal or external temperature reading exceeds a high temperature limit (user programmed). The $\overline{\text{ALERT}}$ interrupt output signal is latched and can be cleared only by reading the status register after the fault condition no longer exists or by successfully responding to the alert response address. If

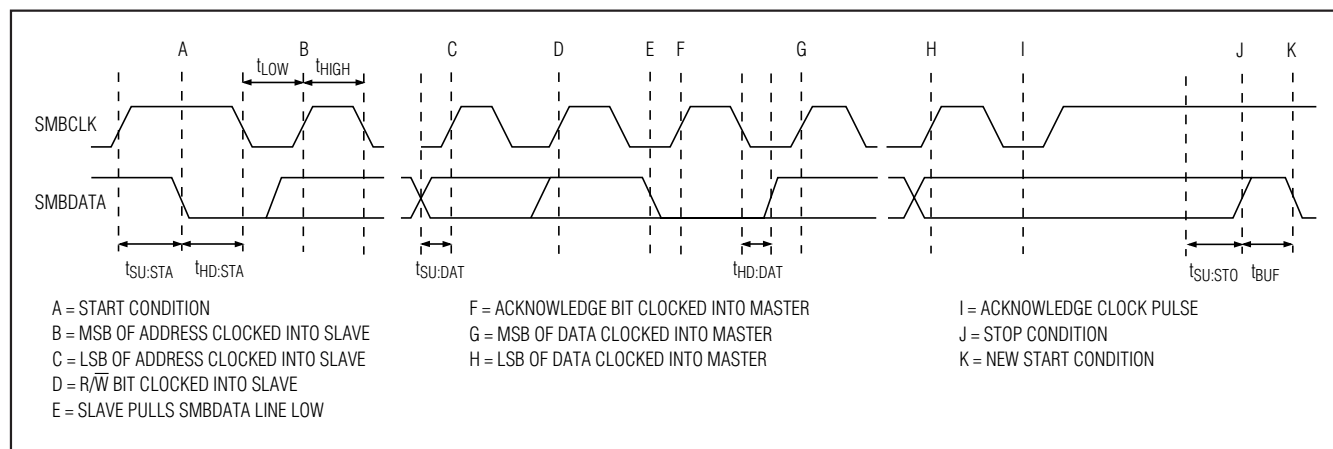


Figure 3. SMBus Read Timing Diagram

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Table 3. Command-Byte Assignments

| ADDRESS | POR STATE | FUNCTION |
|---------|------------------------|------------------------------------|
| 00h | 00h (0000 0000) | Read local temperature |
| 01h | 00h (0000 0000) | Read remote temperature |
| 02h | N/A | Read status byte |
| 03h | 10h (0001 0000) | Read configuration byte |
| 05h | 46h (0100 0110) +70°C | Read local high limit |
| 07h | 78h (0111 1000) +120°C | Read remote high limit |
| 09h | N/A | Write configuration byte |
| 0Bh | N/A | Write local high limit |
| 0Dh | N/A | Write remote high limit |
| 0Fh | N/A | Single shot |
| 10h | 0000 0000 | Read remote extended temperature |
| 11h | 0000 0000 | Read internal extended temperature |
| FEh | 4Dh (0100 1101) | Read manufacturer ID |

the $\overline{\text{ALERT}}$ is cleared by responding to the alert response address and the temperature fault condition still exists, $\overline{\text{ALERT}}$ is reasserted after the next temperature-monitoring cycle. To clear $\overline{\text{ALERT}}$ while the temperature is above the trip threshold, write a new high limit that is higher than the current temperature. The $\overline{\text{ALERT}}$ output is open drain, allowing multiple devices to share a common interrupt line.

Alert Response Address

The SMBus alert response interrupt pointer provides quick fault identification for simple slave devices like temperature sensors. Upon receiving an $\overline{\text{ALERT}}$ interrupt signal, the host master can broadcast a Receive Byte transmission to the alert response slave address (0001 100). Following such a broadcast, any slave device that generated an interrupt attempts to identify itself by putting its own address on the bus.

The alert response can activate several different slave devices simultaneously, similar to the I²C General Call. If more than one slave attempts to respond, bus arbitra-

Table 4. Configuration-Byte Bit Assignments

| BIT | NAME | POR STATE | FUNCTION |
|---------|---------------|-----------|--|
| 7 (MSB) | MASK1 | 0 | A 1 masks off (disables) the $\overline{\text{ALERT}}$ interrupts. |
| 6 | STOP/RUN | 0 | A 1 puts the MAX6642 into standby mode. |
| 5 | External only | 0 | A 1 disables local temperature measurements so that only remote temperature is measured. The measurement rate becomes 8Hz. |
| 4 | Fault queue | 1 | 0: $\overline{\text{ALERT}}$ is set by a single fault. 1: Two consecutive faults are required to set $\overline{\text{ALERT}}$. |
| 3 to 0 | — | 0000 | Reserved. |

Table 5. Status-Byte Bit Assignments

| BIT | NAME | POR STATE | FUNCTION |
|---------|-------|-----------|--|
| 7 (MSB) | BUSY | 0 | A 1 indicates the MAX6642 is busy converting. |
| 6 | LHIGH | 0 | A 1 indicates an internal high-temperature fault. Clear LHIGH with a POR or by reading the status byte. |
| 5 | — | 0 | Reserved. |
| 4 | RHIGH | 0 | A 1 indicates an external high-temperature fault. Clear RHIGH with a POR or by reading the status byte. |
| 3 | — | 0 | Reserved. |
| 2 | OPEN | 0 | A 1 indicates a diode open condition. Clear OPEN with a POR or by reading the status byte when the condition no longer exists. |
| 1 to 0 | — | 0 | Reserved. |

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tion rules apply, and the device with the lower address code wins. The losing device does not generate an acknowledge and continues to hold the $\overline{\text{ALERT}}$ line low until cleared. (The conditions for clearing an $\overline{\text{ALERT}}$ vary depending on the type of slave device.) Successful completion of the alert response protocol clears the interrupt latch. If the condition still exists, the device reasserts the $\overline{\text{ALERT}}$ interrupt at the end of the next conversion.

Command Byte Functions

The 8-bit command byte register (Table 3) is the master index that points to the various other registers within the MAX6642. The register's POR state is 0000 0000, so a Receive Byte transmission (a protocol that lacks the command byte) that occurs immediately after POR returns the current local temperature data.

Single-Shot

The single-shot command immediately forces a new conversion cycle to begin. If the single-shot command is received while the MAX6642 is in standby mode ($\overline{\text{RUN}}$ bit = 1), a new conversion begins, after which the device returns to standby mode. If a single-shot conversion is in progress when a single-shot command is received, the command is ignored. If a single-shot command is received in autonomous mode ($\overline{\text{RUN}}$ bit = 0), the command is ignored.

Configuration Byte Functions

The configuration byte register (Table 4) is a read-write register with several functions. Bit 7 is used to mask (disable) interrupts. Bit 6 puts the MAX6642 into standby mode (STOP) or autonomous (RUN) mode. Bit 5 disables local temperature conversions for faster (8Hz) remote temperature monitoring. Bit 4 prevents setting the $\overline{\text{ALERT}}$ output until two consecutive measurements result in fault conditions.

Table 6. Slave Address

| PART NO. SUFFIX | ADDRESS |
|-----------------|----------|
| MAX6642ATT90 | 1001 000 |
| MAX6642ATT92 | 1001 001 |
| MAX6642ATT94 | 1001 010 |
| MAX6642ATT96 | 1001 011 |
| MAX6642ATT98 | 1001 100 |
| MAX6642ATT9A | 1001 101 |
| MAX6642ATT9C | 1001 110 |
| MAX6642ATT9E | 1001 111 |

Status Byte Functions

The status byte register (Table 5) indicates which (if any) temperature thresholds have been exceeded. This byte also indicates whether the ADC is converting and whether there is an open-circuit fault detected on the external sense junction. After POR, the normal state of all flag bits is zero, assuming no alarm conditions are present. The status byte is cleared by any successful read of the status byte after the overtemperature fault condition no longer exists.

Slave Addresses

The MAX6642 has eight fixed addresses available. These are shown in Table 6.

The MAX6642 also responds to the SMBus alert response slave address (see the *Alert Response Address* section).

POR and UVLO

To prevent ambiguous power-supply conditions from corrupting the data in memory and causing erratic behavior, a POR voltage detector monitors V_{CC} and clears the memory if V_{CC} falls below 2.1 (typ). When power is first applied and V_{CC} rises above 2.1 (typ), the logic blocks begin operating, although reads and writes at V_{CC} levels below 3V are not recommended. A second V_{CC} comparator, the ADC undervoltage lockout (UVLO) comparator prevents the ADC from converting until there is sufficient headroom ($V_{CC} = +2.7\text{V}$ typ).

Power-Up Defaults

Power-up defaults include:

- $\overline{\text{ALERT}}$ output is cleared.
- ADC begins autoconverting at a 4Hz rate.
- Command byte is set to 00h to facilitate quick local Receive Byte queries.
- Local (internal) T_{HIGH} limit set to $+70^{\circ}\text{C}$.
- Remote (external) T_{HIGH} limit set to $+120^{\circ}\text{C}$.

Applications Information

Remote-Diode Selection

The MAX6642 can directly measure the die temperature of CPUs and other ICs that have on-board temperature-sensing diodes (see the *Typical Operating Circuit*) or they can measure the temperature of a discrete diode-connected transistor.

Effect of Ideality Factor

The accuracy of the remote temperature measurements depends on the ideality factor (n) of the remote "diode" (actually a transistor). The MAX6642 is optimized for $n = 1.008$, which is the typical value for the Intel Pentium

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III. A thermal diode on the substrate of an IC is normally a PNP with its collector grounded. Connect the anode (emitter) to DXP and the cathode to GND of the MAX6642.

If a sense transistor with an ideality factor other than 1.008 is used, the output data is different from the data obtained with the optimum ideality factor. Fortunately, the difference is predictable.

Assume a remote-diode sensor designed for a nominal ideality factor n_{NOMINAL} is used to measure the temperature of a diode with a different ideality factor n_1 . The measured temperature T_M can be corrected using:

$$T_M = T_{\text{ACTUAL}} \left(\frac{n_1}{n_{\text{NOMINAL}}} \right)$$

where temperature is measured in Kelvin and n_{NOMINAL} for the MAX6642 is 1.008.

As an example, assume you want to use the MAX6642 with a CPU that has an ideality factor of 1.002. If the diode has no series resistance, the measured data is related to the real temperature as follows:

$$T_{\text{ACTUAL}} = T_M \left(\frac{n_{\text{NOMINAL}}}{n_1} \right) = T_M \left(\frac{1.008}{1.002} \right) = T_M(1.00599)$$

For a real temperature of +85°C (358.15K), the measured temperature is +82.91°C (356.02K), an error of -2.13°C.

Effect of Series Resistance

Series resistance in a sense diode contributes additional errors. For nominal diode currents of 10μA and 100μA, the change in the measured voltage due to series resistance is:

$$\Delta V_M = R_S (100\mu\text{A} - 10\mu\text{A}) = 90\mu\text{A} \times R_S$$

Since +1°C corresponds to 198.6μV, series resistance contributes a temperature offset of:

$$\frac{90 \frac{\mu\text{V}}{\Omega}}{198.6 \frac{\mu\text{V}}{^\circ\text{C}}} = 0.453 \frac{^\circ\text{C}}{\Omega}$$

Assume that the diode being measured has a series resistance of 3Ω. The series resistance contributes an offset of:

Table 7. Remote-Sensor Transistor Manufacturers

| MANUFACTURER | MODEL NO. |
|-----------------------------|---------------|
| Central Semiconductor (USA) | CMPT3906 |
| Rohm Semiconductor (USA) | SST3906 |
| Samsung (Korea) | KST3906-TF |
| Siemens (Germany) | SMBT3906 |
| Zetex (England) | FMMT3906CT-ND |

Note: Discrete transistors must be diode connected (base shorted to collector).

$$3\Omega \times 0.453 \frac{^\circ\text{C}}{\Omega} = +1.36^\circ\text{C}$$

The effects of the ideality factor and series resistance are additive. If the diode has an ideality factor of 1.002 and series resistance of 3Ω, the total offset can be calculated by adding error due to series resistance with error due to ideality factor:

$$1.36^\circ\text{C} - 2.13^\circ\text{C} = -0.77^\circ\text{C}$$

for a diode temperature of +85°C.

In this example, the effect of the series resistance and the ideality factor partially cancel each other.

Discrete Remote Diodes

When the remote-sensing diode is a discrete transistor, connect its collector and base together. Table 7 lists examples of discrete transistors that are appropriate for use with the MAX6642.

The transistor must be a small-signal type with a relatively high forward voltage; otherwise, the A/D input voltage range can be violated. The forward voltage at the highest expected temperature must be greater than 0.25V at 10μA, and at the lowest expected temperature, the forward voltage must be less than 0.95V at 100μA. Large power transistors must not be used. Also, ensure that the base resistance is less than 100Ω. Tight specifications for forward current gain ($50 < \beta < 150$, for example) indicate that the manufacturer has good process controls and that the devices have consistent V_{BE} characteristics.

Manufacturers of discrete transistors do not normally specify or guarantee ideality factor. This is normally not a problem since good-quality discrete transistors tend to have ideality factors that fall within a relatively narrow

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range. We have observed variations in remote temperature readings of less than $\pm 2^{\circ}\text{C}$ with a variety of discrete transistors. Still, it is good design practice to verify good consistency of temperature readings with several discrete transistors from any manufacturer under consideration.

ADC Noise Filtering

The integrating ADC used has good noise rejection for low-frequency signals such as 60Hz/120Hz power-supply hum. In noisy environments, high-frequency noise reduction is needed for high-accuracy remote measurements. The noise can be reduced with careful PCB layout and proper external noise filtering.

High-frequency EMI is best filtered at DXP with an external 2200pF capacitor. Larger capacitor values can be used for added filtering, but do not exceed 3300pF because excessive capacitance can introduce errors due to the rise time of the switched current source. Nearly all noise sources tested cause the temperature conversion results to be higher than the actual temperature, typically by $+1^{\circ}\text{C}$ to $+10^{\circ}\text{C}$, depending on the frequency and amplitude (see the *Typical Operating Characteristics*).

PCB Layout

Follow these guidelines to reduce the measurement error of the temperature sensors:

- 1) Connect the thermal-sense diode to the MAX6642 using two traces—one between DXP and the anode, the other between the MAX6642's GND and the cathode. Do not connect the cathode to GND at the sense diode.
- 2) Place the MAX6642 as close as is practical to the remote thermal diode. In noisy environments, such as a computer motherboard, this distance can be 4in to 8in (typ). This length can be increased if the worst noise sources are avoided. Noise sources include CRTs, clock generators, memory buses, and ISA/PCI buses.
- 3) Do not route the thermal diode lines next to the deflection coils of a CRT. Also, do not route the traces across fast digital signals, which can easily introduce a 30°C error, even with good filtering.
- 4) Route the thermal diode traces in parallel and in close proximity to each other, away from any higher voltage traces, such as +12VDC. Leakage currents from PCB contamination must be dealt with carefully since a $20\text{M}\Omega$ leakage path from DXP to ground causes about $+1^{\circ}\text{C}$ error. If high-voltage traces are unavoidable, connect guard traces to GND on either side of the DXP trace (Figure 4).

- 5) Route through as few vias and crossunders as possible to minimize copper/solder thermocouple effects.
- 6) When introducing a thermocouple, make sure that both the thermal diode paths have matching thermocouples. A copper-solder thermocouple exhibits $3\mu\text{V}/^{\circ}\text{C}$, and it takes about $200\mu\text{V}$ of voltage error at DXP to cause a $+1^{\circ}\text{C}$ measurement error. Adding a few thermocouples causes a negligible error.
- 7) Use wide traces. Narrow traces are more inductive and tend to pick up radiated noise. The 10-mil widths and spacing recommended in Figure 4 are not absolutely necessary, as they offer only a minor improvement in leakage and noise over narrow traces. Use wider traces when practical.
- 8) Add a 47Ω resistor in series with V_{CC} for best noise filtering (see the *Typical Operating Circuit*).
- 9) Copper cannot be used as an EMI shield; only ferrous materials such as steel work well. Placing a copper ground plane between the DXP-DXN traces and traces carrying high-frequency noise signals does not help reduce EMI.

Twisted-Pair and Shielded Cables

Use a twisted-pair cable to connect the remote sensor for remote-sensor distances longer than 8in or in very noisy environments. Twisted-pair cable lengths can be between 6ft and 12ft before noise introduces excessive errors. For longer distances, the best solution is a shielded twisted pair like that used for audio microphones. For example, Belden #8451 works well for distances up to 100ft in a noisy environment. At the device, connect the twisted pair to DXP and GND and the shield to GND. Leave the shield unconnected at the remote diode.

For very long cable runs, the cable's parasitic capacitance often provides noise filtering, so the 2200pF capacitor can often be removed or reduced in value.

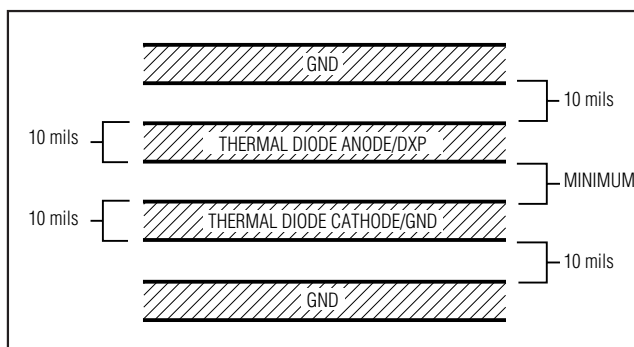


Figure 4. Recommended DXP PC Traces

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Cable resistance also affects remote-sensor accuracy. For every 1Ω of series resistance, the error is approximately $1/2^{\circ}\text{C}$.

Thermal Mass and Self-Heating

When sensing local temperature, this device is intended to measure the temperature of the PCB to which it is soldered. The leads provide a good thermal path between the PCB traces and the die. Thermal conductivity between the die and the ambient air is poor by comparison, making air temperature measurements impractical. Because the thermal mass of the PCB is far greater than that of the MAX6642, the device follows temperature changes on the PCB with little or no perceivable delay.

When measuring temperature of a CPU or other IC with an on-chip sense junction, thermal mass has virtually no effect; the measured temperature of the junction tracks the actual temperature within a conversion cycle. When measuring temperature with discrete remote sensors, smaller packages, such as SOT23s, yield the best thermal response times. Take care to account for thermal gradients between the heat source and the sensor, and ensure that stray air currents across the sensor package do not interfere with measurement accuracy.

Self-heating does not significantly affect measurement accuracy. Remote-sensor self-heating due to the diode current source is negligible. For the local diode, the worst-case error occurs when autoconverting at the fastest rate and simultaneously sinking maximum current at the $\overline{\text{ALERT}}$ output. For example, with $V_{\text{CC}} = +5.0\text{V}$, at an 8Hz conversion rate and with $\overline{\text{ALERT}}$ sinking 1mA, the typical power dissipation is:

$$5.0\text{V} \times 450\mu\text{A} + 0.4\text{V} \times 1\text{mA} = 2.65\text{mW}$$

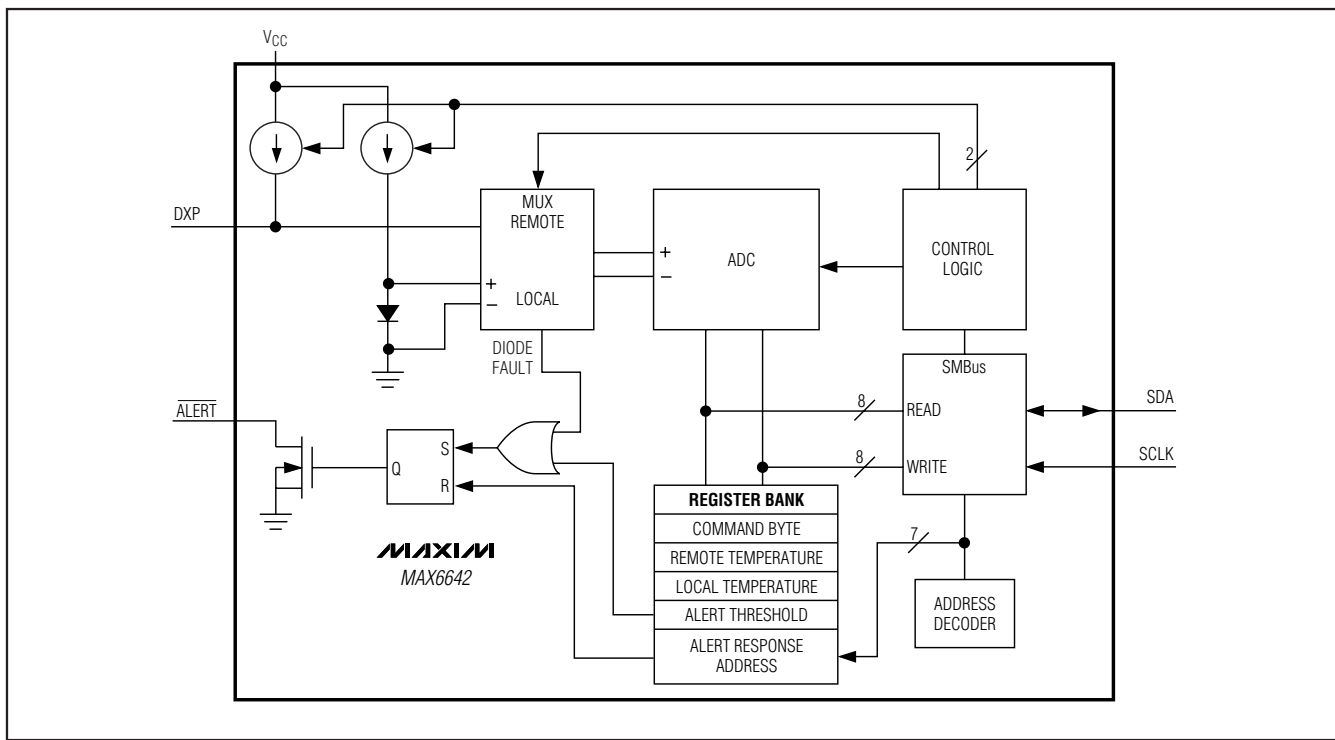
$\theta_{\text{J-A}}$ for the 6-pin TDFN package is about $+41^{\circ}\text{C/W}$, so assuming no copper PCB heat sinking, the resulting temperature rise is:

$$\Delta T = 2.65\text{mW} \times 41^{\circ}\text{C/W} = +0.11^{\circ}\text{C}$$

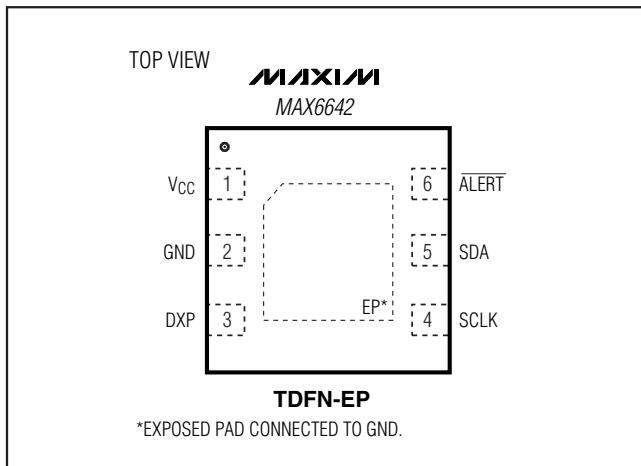
Even under nearly worst-case conditions, it is difficult to introduce a significant self-heating error.

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Functional Diagram



Pin Configuration



Chip Information

PROCESS: BiCMOS

Package Information

For the latest package outline information and land patterns, go to www.maxim-ic.com/packages.

| PACKAGE TYPE | PACKAGE CODE | DOCUMENT NO. |
|--------------|--------------|-------------------------|
| 6 TDFN-EP | T633-2 | 21-0137 |

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Revision History

| REVISION NUMBER | REVISION DATE | DESCRIPTION | PAGES CHANGED |
|-----------------|---------------|---|-----------------|
| 0 | 8/03 | Initial release | — |
| 1 | 10/08 | Added missing EP description to <i>Ordering Information</i> and <i>Pin Description</i> , removed the transistor count on page 12, and corrected some minor style issues | 1, 5, 9, 10, 12 |
| 2 | 7/09 | Corrected errors in Figures 2 and 3 | 6, 7 |
| 3 | 10/09 | Corrected error in <i>Package Information</i> table | 13 |

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