Temperature Monitor with Dual Serial Interface

MAX6638

General Description

The MAX6638 thermal-management sensor includes internal (local) and external (remote) digital temperature sensors and two independent SMBus™ serial ports. The remote temperature accuracy is ±1.0°C, and the local temperature accuracy is ±2°C. The MAX6638 also features extended temperature resolution data available in 0.125°C increments.

The MAX6638 provides three system alarms: channel 1 alert ($\overline{\text{ALERT1}}$), overtemperature ($\overline{\text{OVERT1}}$), and channel 2 alert ($\overline{\text{ALERT2}}$) that contain programmable thresholds set independently by each of the SMBus serial ports (SMBus1 and SMBus2). Each alert output asserts when any of four temperature conditions is violated: local overtemperature, remote overtemperature, local undertemperature, or remote undertemperature. The overtemperature signal asserts when the temperature rises above the value in the overtemperature limit register. Use the $\overline{\text{OVERT1}}$ output to activate a cooling fan or trigger a system shutdown.

Each of the 2-wire serial-interface ports accepts standard System Management Bus (SMBus) write byte, read byte, send byte, and receive byte commands independently of one another with total collision avoidance handled by the MAX6638. Each SMBus can operate its own unique serial-data rate to access any register in the MAX6638 for data reads or data writes. The MAX6638 manages all dual-port data register access functions providing a seamless, conflict-free integration into a multimaster architecture for thermal management.

The MAX6638 performs measurements autonomously, at the programmed conversion rate, or in a single-conversion mode. Each SMBus port can set the conversion rate with the higher conversion and update rate dominating the average power-supply current. Single-conversion requests have a maximum delay of two conversion cycles with channel-conversion management and cycling regulated by the dual-port controller.

The MAX6638 operating temperature range is -40°C to +125°C and measures temperatures between 0°C and +145°C. The MAX6638 is available in a 16-pin, 4mm x 4mm TQFN with exposed paddle package.

Applications

Graphics Cards

Notebook Computers

Computer Motherboard Systems

Desktop Computers

Workstations

Features

♦ **Two Independent SMBus/I²C*-Compatible Interfaces with Collision Avoidance**

♦ **High Accuracy ±1.0°C from +85°C to +100°C (Remote)**

♦ **Remote and Local Temperature Measurements**

♦ **Three Programmable Output Alarms: $\overline{\text{ALERT1}}$, $\overline{\text{OVERT1}}$, and $\overline{\text{ALERT2}}$**

♦ **Programmable Conversion Rates**

♦ **11-Bit Low-Noise Integrating ADC**
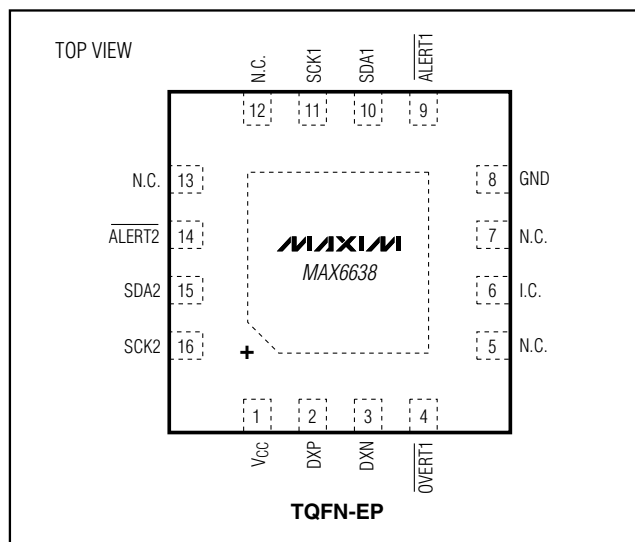
♦ **No Calibration Required**

♦ **Autoscan Conversions**

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	PKG CODE
MAX6638ATE+	-40°C to +125°C	16 TQFN-EP* (4mm x 4mm)	T1644-4

*EP = Exposed paddle.
+Denotes lead-free package.

Pin Configuration

TOP VIEW

```
              N.C.  SCK1  SDA1  ALERT1
              [12]  [11]  [10]  [9]

N.C.   [13]                          [8]  GND

ALERT2 [14]         MAXIM            [7]  N.C.
                    MAX6638
SDA2   [15]                          [6]  I.C.

SCK2   [16]    +                     [5]  N.C.

              [1]   [2]   [3]   [4]
              Vcc   DXP   DXN   OVERT1
```

TQFN-EP

Typical Operating Circuit appears at end of data sheet.

SMBus is a trademark of Intel Corporation.

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Temperature Monitor with
Dual Serial Interface

ABSOLUTE MAXIMUM RATINGS

(All voltages referenced to GND, unless otherwise noted.)

V_{CC} ....-0.3V to +6.0V
DXP...-0.3V to (V_{CC} + 0.3V)
DXN ....-0.3V to +0.8V
SCK1, SDA1, SCK2, SDA2, $\overline{ALERT1}$,
$\overline{OVERT1}$, $\overline{ALERT2}$...-0.3V to +6V
SDA1, SDA2, $\overline{ALERT1}$, $\overline{OVERT1}$, $\overline{ALERT2}$ ....-1mA to +50mA
DXN Current ....±1mA

Continuous Power Dissipation (T_A = +70°C)
   16-Pin TQFN (derate 16.9 mW/°C above +70°C) ....1349 mW
ESD Protection (all pins, Human Body Model)...............±2000V
Operating Temperature Range ....-40°C to +125°C
Junction Temperature ....+150°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 noted. Typical values are at V_{CC} = 3.3V and T_A = +85°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage	V_{CC}		3.0		5.5	V
Operating Current		During conversion		600	950	µA
		ADC not converting			80	
Standby Supply Current		SMBus1 and SMBus2 static		3	10	µA
TEMPERATURE MEASUREMENT						
Remote Diode-Source Current	I_{RJ}	High level	80	100	120	µA
		Low level	8	10	12	
Remote Temperature Error		V_{CC} = 3.3V, T_A = +85°C to +100°C, T_{RJ} = +85°C to +145°C	-1.0		+1.0	°C
		V_{CC} = 3.3V, T_A = +25°C to +100°C, T_{RJ} = +25°C to +145°C	-2.0		+2.0	
		V_{CC} = 3.3V, T_A = +0°C to +125°C, T_{RJ} = 0°C to +145°C	-3.0		+3.0	
Local Temperature Error		V_{CC} = 3.3V, T_A = +25°C to +85°C	-2.0		+2.0	°C
		V_{CC} = 3.3V, T_A = 0°C to +125°C	-3.5		+3.5	
Supply Sensitivity of Temperature Error				±0.2		°C/V
POWER-ON RESET						
Power-On-Reset Threshold		V_{CC} falling		1.9		V
POR Threshold Hysteresis				90		mV
Undervoltage-Lockout Threshold		V_{CC} falling	2.30	2.60	2.95	V
Undervoltage-Lockout Hysteresis				90		mV
ANALOG-TO-DIGITAL CONVERTER						
Conversion Time		Nonoverlapping single conversion from stop bit to conversion complete	23	32	39	ms
$\overline{ALERT1}$, $\overline{OVERT1}$, $\overline{ALERT2}$, SDA1, SDA2						
Output Low Voltage	V_{OL}	I_{OL} = 6mA			0.6	V
Leakage Current	I_{LEAK}	V_{OH} = 5.5V			±1	µA

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ELECTRICAL CHARACTERISTICS (continued)

(V_{CC} = 3.0V to 5.5V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at V_{CC} = 3.3V and T_A = +85°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SMBus INTERFACE (SCK1, SCK2, SDA1, SDA2)						
Logic Input Low Voltage	V_{IL}				0.8	V
Logic Input High Voltage	V_{IH}		2.1			V
Input Leakage Current	I_{LEAK}	V_{IN} = GND or V_{CC}			±1	µA
Input Capacitance	C_{IN}			5		pF
SMBus-COMPATIBLE TIMING (Figure 5) (Note 2)						
Serial-Clock Frequency	f_{SCK}	(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% of SCK_ to 90% of SDA_	50			ns
START Condition Hold Time	$t_{HD:STA}$	10% of SDA_ to 90% of SCK_	4			µs
STOP Condition Setup Time	$t_{SU:STO}$	90% of SCK_ 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%	4.0			µs
Data Setup Time	$t_{SU:DAT}$		250			ns
Data Hold Time	$t_{HD:DAT}$	(Note 4)	300			ns
SMBus Rise Time	t_R				1	µs
SMBus Fall Time	t_F				300	ns
SMBus Timeout	$t_{TIMEOUT}$	SDA_ low period for interface reset	30	45	60	ms

Note 1: All parameters are tested at a single temperature. Specifications over temperature are guaranteed by design.
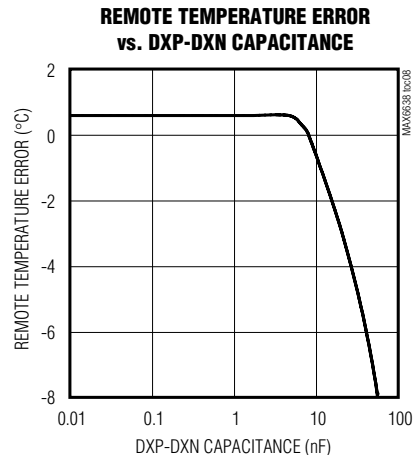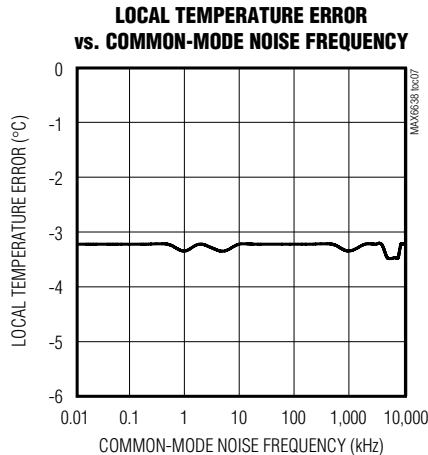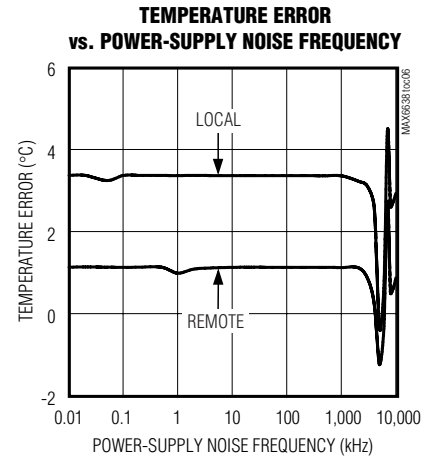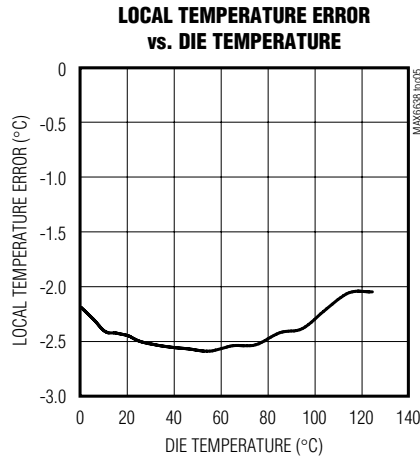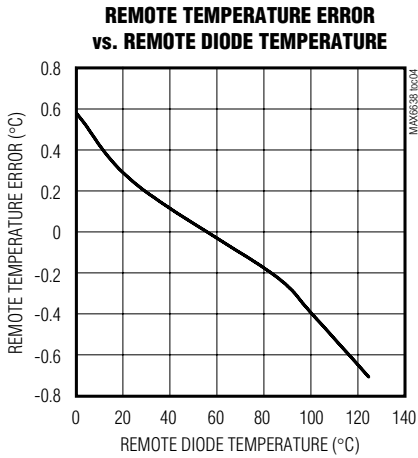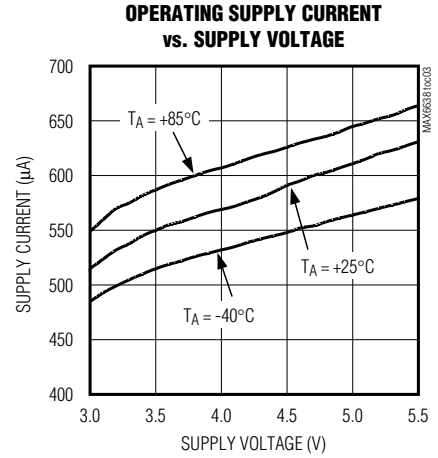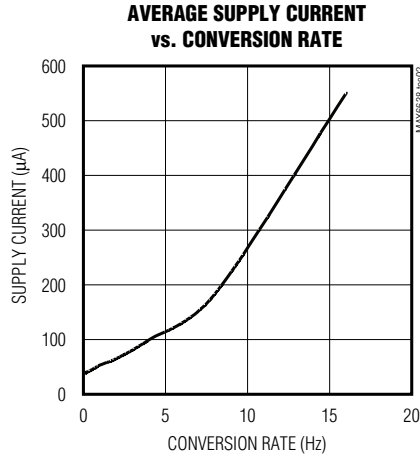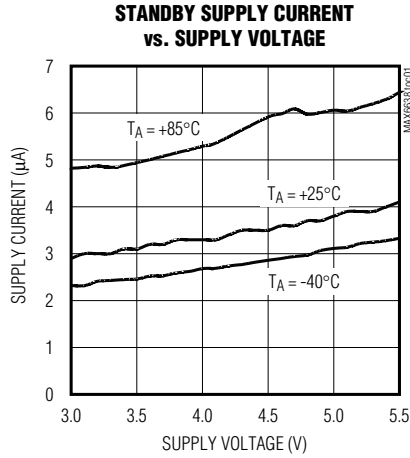**Note 2:** Timing specifications are guaranteed by design.
Note 3: Each serial interface resets when its SCK_ is low for more than $t_{TIMEOUT}$.
Note 4: A transition must internally provide at least a hold time to bridge the unidentified region (300ns max) of SCK_'s falling edge.

Temperature Monitor with Dual Serial Interface

_____**Typical Operating Characteristics**

(V$_{CC}$ = 3.3V, T$_A$ = +25°C, unless otherwise noted.)

STANDBY SUPPLY CURRENT vs. SUPPLY VOLTAGE

MAX6638 toc01

T$_A$ = +85°C

T$_A$ = +25°C

T$_A$ = -40°C

AVERAGE SUPPLY CURRENT vs. CONVERSION RATE

MAX6638 toc02

OPERATING SUPPLY CURRENT vs. SUPPLY VOLTAGE

MAX6638 toc03

T$_A$ = +85°C

T$_A$ = +25°C

T$_A$ = -40°C

REMOTE TEMPERATURE ERROR vs. REMOTE DIODE TEMPERATURE

MAX6638 toc04

LOCAL TEMPERATURE ERROR vs. DIE TEMPERATURE

MAX6638 toc05

TEMPERATURE ERROR vs. POWER-SUPPLY NOISE FREQUENCY

MAX6638 toc06

LOCAL

REMOTE

LOCAL TEMPERATURE ERROR vs. COMMON-MODE NOISE FREQUENCY

MAX6638 toc07

REMOTE TEMPERATURE ERROR vs. DXP-DXN CAPACITANCE

MAX6638 toc08

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Pin Description

PIN	NAME	FUNCTION
1	V_{CC}	Supply Voltage. Bypass V_{CC} to GND with a 0.1μF capacitor. A 47Ω series resistor is recommended for additional noise filtering, but not required.
2	DXP	Combined Current Source and ADC Positive Input for Remote Diode. If a remote-sensing junction is not used, connect DXP to DXN.
3	DXN	Combined Current Sink and ADC Negative Input for Remote Diode. DXN is internally biased to a diode voltage above ground.
4	$\overline{OVERT1}$	Digital Open-Drain Output. $\overline{OVERT1}$ indicates an overtemperature condition on channel 1.
5, 7, 12, 13	N.C.	No Connection. Not connected internally.
6	I.C.	Internally Connected. **I.C. must be connected to GND.**
8	GND	Power-Supply Ground
9	$\overline{ALERT1}$	Digital Open-Drain Output. $\overline{ALERT1}$ indicates alert condition on channel 1.
10	SDA1	SMBus Data Channel 1. Open-drain output.
11	SCK1	SMBus Clock Channel 1
14	$\overline{ALERT2}$	Digital Open-Drain Output. $\overline{ALERT2}$ indicates alert condition on channel 2.
15	SDA2	SMBus Data Channel 2. Open-drain output.
16	SCK2	SMBus Clock Channel 2
EP	GND	Ground. Connect to ground.

Detailed Description

The MAX6638 temperature monitor features dual-port SMBus access for use in thermal management of graphics processing unit (GPU) and CPU systems. Each of the two SMBus serial ports can be accessed independently by two thermal-monitoring systems with all dual-port collision-avoidance logic controlled by the MAX6638. Each SMBus thermal-monitoring channel (channels 1 and 2) has a corresponding over/under-temperature $\overline{ALERT\_}$ open-drain output with independently configurable limit registers. Channel 1 includes an overtemperature indicator ($\overline{OVERT1}$) with an initial set-point limit that is always activated after a power-on reset (POR). The initial $\overline{OVERT1}$ set point can be overwritten after POR by SMBus1 serial programming. The overtemperature alarm $\overline{OVERT1}$ asserts if the set-point limit is exceeded.

ADC and Multiplexer

The MAX6638 converts temperatures to digital data either at a programmed rate or in single conversions. Either SMBus controller can set the programmed rate with the higher rate setting taking precedence. The MAX6638 begins conversions at the maximum rate after POR to provide the $\overline{OVERT1}$ output signal assertion for temperatures exceeding the set-point limit. The temperature conversion results of the two temperature channels are in integer format. The MSBs of the temperature data are in 8-bit registers (addresses 00h and 01h; see Table 1) that represent the data as 8 bits with the full-scale reading to indicate a diode fault. The remaining 3 bits of temperature data are available in the extended data-registers format with the LSB equal to +0.125°C (addresses 11h and 10h; see Table 2).

The converted readings are stored in SMBus reading registers along with the limit-value registers and other control functions.

Table 1. Temperature Data Format (RLTS1, RRTS1, RLTS2, RRTS2)

TEMPERATURE (°C)	DIGITAL OUTPUT (hex)	DIGITAL OUTPUT (bin)
+145	91	1001 0001
+130	82	1000 0010
+128	80	1000 0000
+25	19	0001 1001
0	00	0000 0000
< 0	00	0000 0000
Diode fault	FF	1111 1111

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Temperature Monitor with Dual Serial Interface

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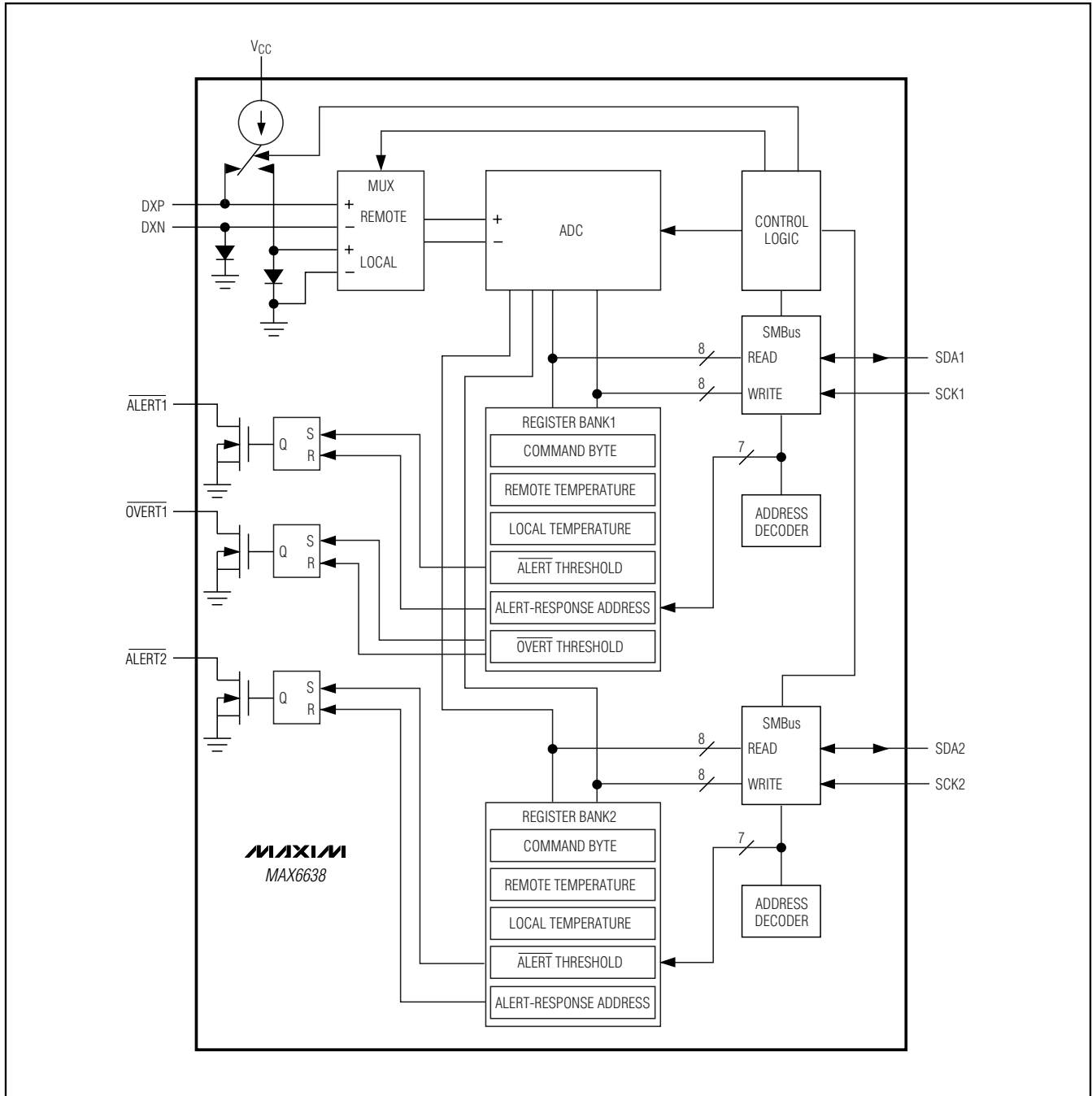
The averaging ADC integrates over a 16ms period (each channel, typical) with excellent noise rejection. The multiplexer automatically steers bias currents through the remote and local diodes. The ADC and associated circuitry measure each diode's forward voltage and compute the temperature based on this voltage. Both temperature sensors automatically convert

once the conversion process starts, either in free-running ($\overline{RUN}$ = 0) or single-shot mode. A BUSY status bit in the status byte indicates that the device is performing a new conversion. The results of the previous conversion are always available even when the ADC is busy. If one of the two temperature sensors is not used, the MAX6638 still performs both measurements and ignores the results of the unused channel. When not using the remote-diode temperature sensor, connect DXP to DXN. The DXP-DXN differential input voltage range is 0.25V to 0.95V. Excess resistance in series with the remote diode causes a +0.5°C (typ) error per ohm.

Table 2. Extended Temperature Data (RLET1, RRET1, RLET2, RRET2)

FRACTIONAL TEMPERATURE (°C)	DIGITAL OUTPUT (bin)
0.000	000X XXXX
0.125	001X XXXX
0.250	010X XXXX
0.375	011X XXXX
0.500	100X XXXX
0.675	101X XXXX
0.750	110X XXXX
0.875	111X XXXX

The MAX6638 initiates conversion cycling after POR, after exiting standby mode from either SMBus channel, and upon one-shot request from either SMBus channel. One conversion cycle consists of two ADC conversions (one for the local temperature, one for the remote temperature), a diagnostic check on the remote temperature sensor, loading of data into the read registers, setting diagnostic flags, and setting $\overline{ALERT1}$, $\overline{ALERT2}$, and $\overline{OVERT1}$, as required. Figure 1 shows the simplified timing sequence.

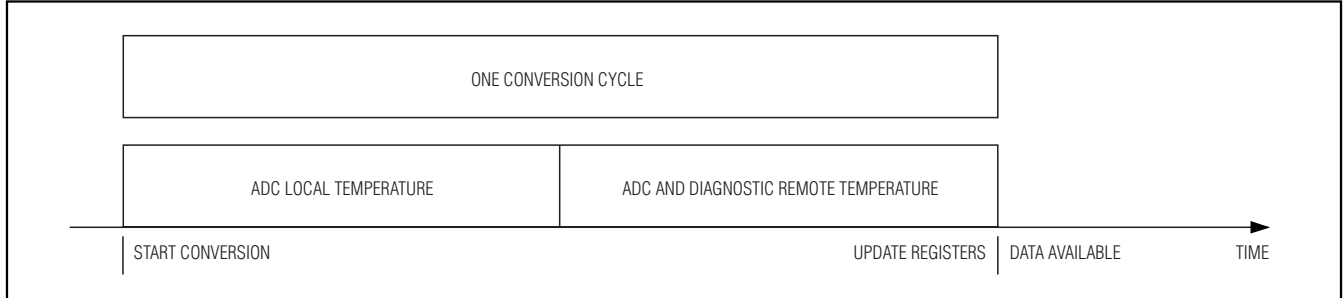

Figure 1. One Complete ADC Conversion Cycle

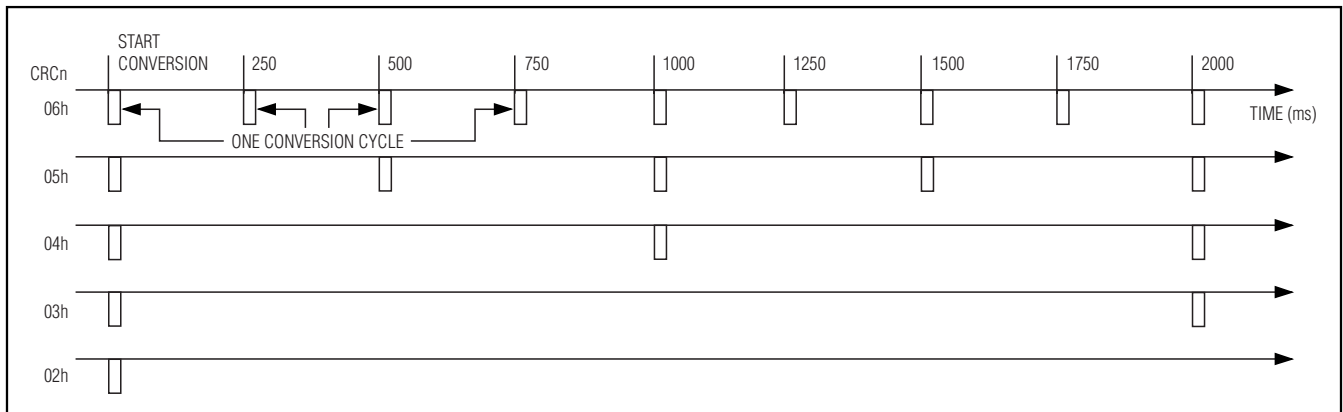Figure 2. Repeating ADC Conversion Cycles for Various Conversion Rate Settings
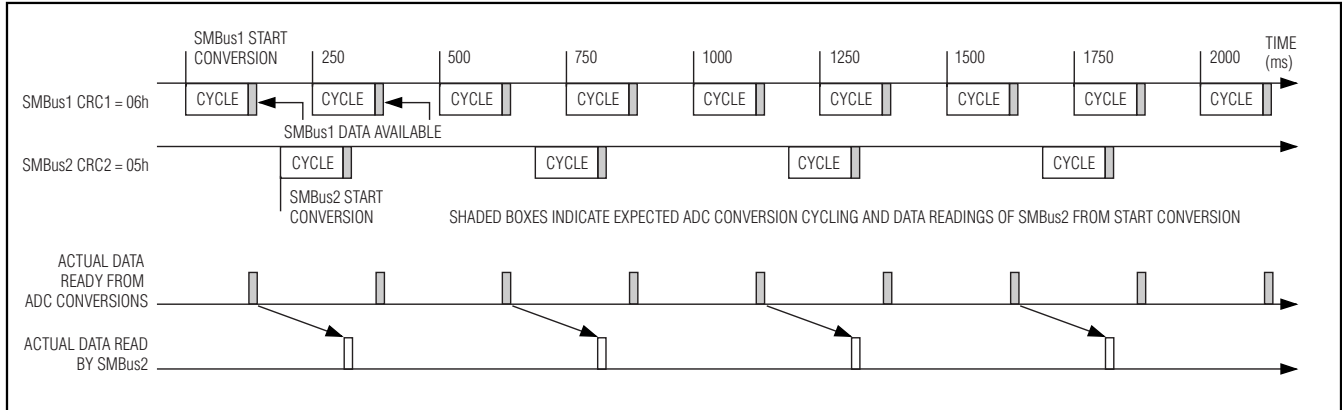
Figure 3. An Example of ADC Cycling for Two Conversion Rates Set by Each Controllers on SMBus1 and SMBus2

The MAX6638 allows conversion rates that are 2x multiples of the minimum rate of 0.0625Hz. Figure 2 shows several different conversion rate settings.

The ADC converts at the higher rate of the two conversions set by SMBus1 and SMBus2 controllers. The controller that sets the higher rate receives a new conversion at the higher conversion-rate time. The controller that sets the lower rate receives the most recent conversion result at the lower conversion-rate timing. Figure 3 shows an example of this. SMBus1 initiates the ADC converter by selecting conversion rate 06h (4Hz) prior to SMBus2 initiating a conversion. Then SMBus2 initiates conversions of 05h (2Hz) independent of the process initiated by SMBus1. The controller accesses data at its programmed time set by the initiated conversion time. The data presented to SMBus2 is always ready at the anticipated time, but the data is actually the result of a previous conversion sequence driven by the higher conversion rate set by SMBus1.

The first SMBus channel that activates a conversion sequence always establishes the MAX6638 conversion cycling. The ADC conversion rates increase and decrease as set by each of the SMBus controllers with the higher conversion rate always dominating. Increasing the conversion rate with the ADC cycling increases the rate the MAX6638 performs cycles without losing sync of the previously established cycle timing. A decrease in conversion rate reduces the ADC cycling to the lower rate without losing sync with the previously set cycle pattern. The ADC cycling pattern is only reset following a POR event or upon exiting the standby mode through one of the SMBus controllers' initiation of cycling or single-shot conversion.

Low-Power Standby Mode

Standby mode reduces the supply current to 3µA (typ) by disabling the ADC and timing circuitry when both SMBus controller channels enable standby mode. Standby mode is enabled only when both SMBus controllers request standby mode. Set each of the $\overline{RUN}$ bits to 1 in each corresponding configuration register (see Tables 3 and 5) to enter standby mode. When one SMBus controller channel is set to standby mode, the other conversion rate is automatically set to the active channel's conversion rate and mode. The MAX6638 retains all data in the registers and each SMBus interface is active and listening for SMBus commands. Standby mode is not a shutdown mode. With activity on either SMBus, the device draws more supply current (see the *Typical Operating Characteristics*). In standby mode, the MAX6638 performs an ADC conversion sequence through the one-shot command, regardless of either of the $\overline{RUN}$ bit statuses, upon receipt of a one-shot command from either SMBus controller.

If the device receives standby commands from both SMBus controllers during a conversion, the conversion cycle truncates, and the data from that conversion is not latched into a temperature register. The previous data does not change and remains available.

Supply current drawn during the 32ms conversion period is 800µA (typ). Slowing down the conversion rate reduces the average supply current (see the *Typical Operating Characteristics*). Between conversions, the conversion rate timer consumes 40µA (typ) of supply current.

SMBus Interface

From a software perspective, the MAX6638 appears as a set of byte-wide registers that contain temperature data,

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threshold limit values, and control. A standard SMBus 2-wire serial interface is used to read temperature data, write control bits, and set threshold data. The MAX6638 employs four standard SMBus protocols: write byte, read byte, send byte, and receive byte (Figure 4).

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

The external extended-temperature register (10h) provides additional 3 bits, extending the data to 11 bits and the resolution to 0.125°C per LSB (Table 2).

The main temperature register and the extended temperature registers update simultaneously upon completion of a conversion. To ensure the registers contain the results of the same conversion of the main temperature data (MSBs) and the extended temperature data (LSBs), read the data before a new conversion completes.

Alarm-Threshold Registers

Four registers store $\overline{ALERT}$ threshold values: one high temperature (THIGH_) and one low temperature (TLOW_) limit register each for the local and remote temperature sensors. If either measured temperature equals or exceeds the corresponding $\overline{ALERT\_}$ threshold value, the $\overline{ALERT\_}$ output asserts.

The MAX6638 local $\overline{ALERT\_}$ THIGH_ register POR state is 0101 0101, which corresponds to +85°C, while the remote $\overline{ALERT\_}$ THIGH_ register POR state is 0101 1111, which corresponds to +95°C. The POR state of the local and remote TLOW_ registers for all devices is 0000 0000, corresponding to 0°C.

Two additional registers store remote and local alarm threshold data corresponding to the $\overline{OVERT1}$ output accessible only through SMBus1. The MAX6638 stores high-temperature thresholds in these registers. If either of the measured temperatures equals or exceeds the corresponding alarm threshold value, the $\overline{OVERT1}$ output asserts. The MAX6638 local $\overline{OVERT1}$ register POR state is 0101 0101, corresponding to +85°C, while the remote $\overline{OVERT1}$ register POR state is 0111 1101, corresponding to +125°C.

Diode Fault

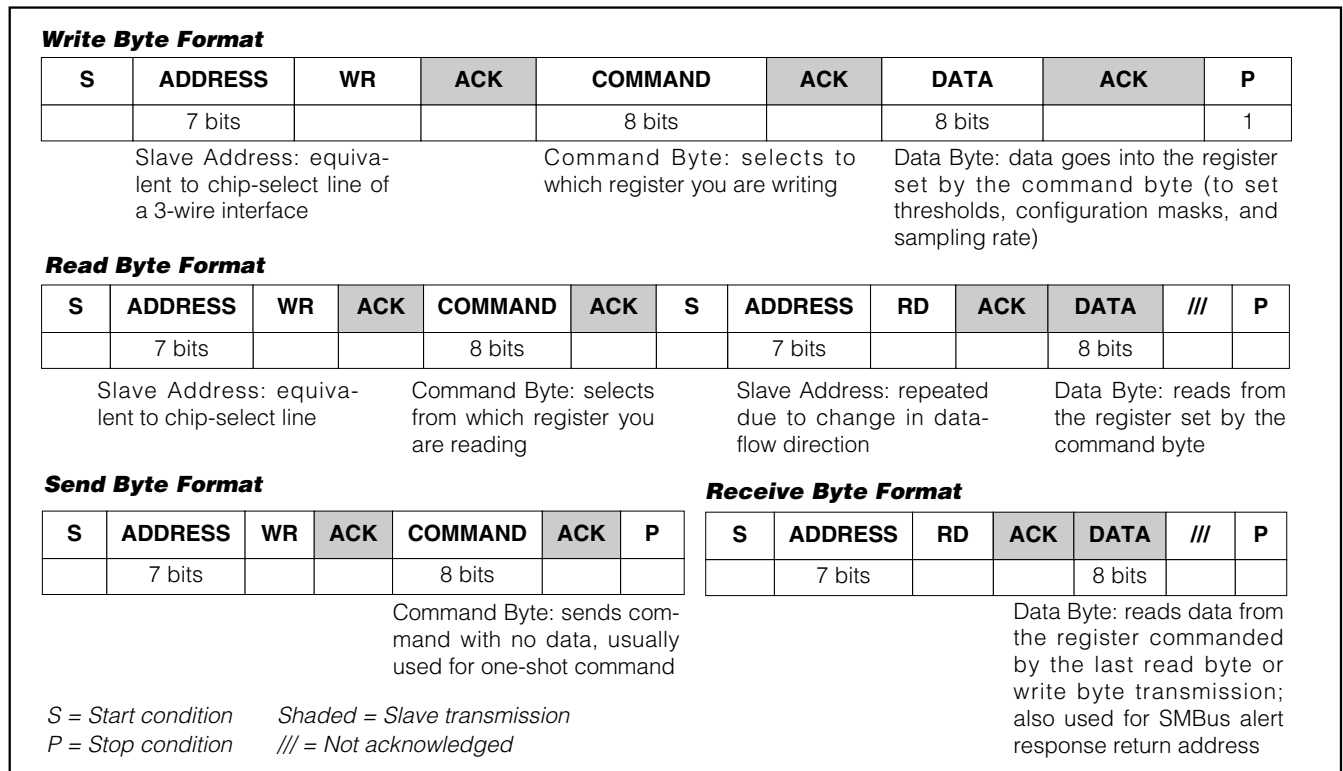A continuity fault detector at DXP detects an open circuit between DXP and DXN, or a DXP short to V_{CC},

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Write Byte Format

S	ADDRESS	WR	ACK	COMMAND	ACK	DATA	ACK	P
	7 bits			8 bits		8 bits		1

Slave Address: equivalent to chip-select line of a 3-wire interface · Command Byte: selects to which register you are writing · Data Byte: data goes into the register set by the command byte (to set thresholds, configuration masks, and sampling rate)

Read Byte Format

S	ADDRESS	WR	ACK	COMMAND	ACK	S	ADDRESS	RD	ACK	DATA	///	P
	7 bits			8 bits			7 bits			8 bits		

Slave Address: equivalent to chip-select line · Command Byte: selects from which register you are reading · Slave Address: repeated due to change in data-flow direction · Data Byte: reads from the register set by the command byte

Send Byte Format

S	ADDRESS	WR	ACK	COMMAND	ACK	P
	7 bits			8 bits		

Command Byte: sends command with no data, usually used for one-shot command

Receive Byte Format

S	ADDRESS	RD	ACK	DATA	///	P
	7 bits			8 bits		

Data Byte: reads data from the register commanded by the last read byte or write byte transmission; also used for SMBus alert response return address

S = Start condition   *Shaded = Slave transmission*
P = Stop condition   */// = Not acknowledged*

Figure 4. SMBus Protocols
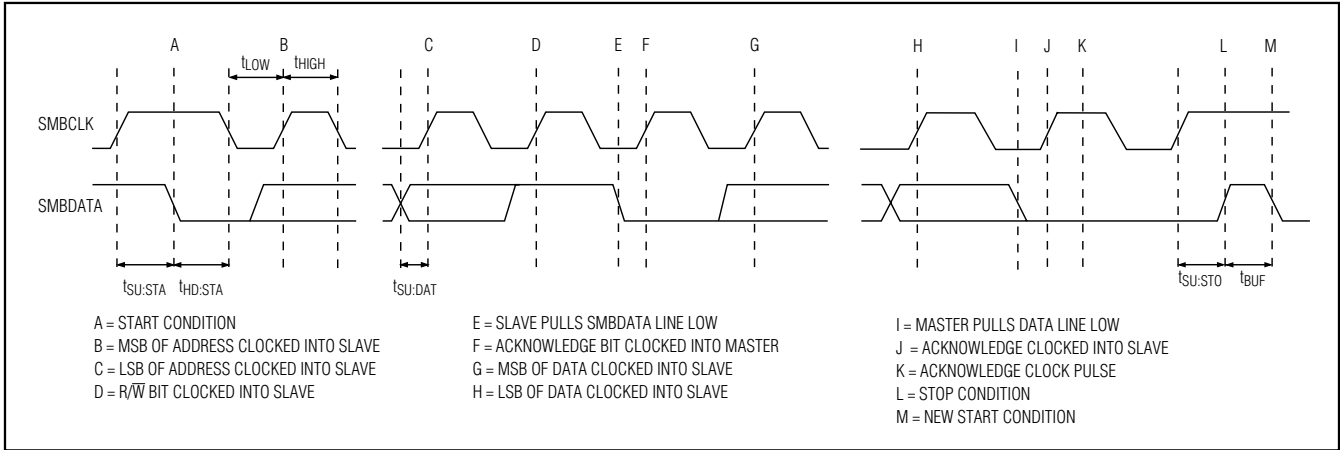
MAX6638

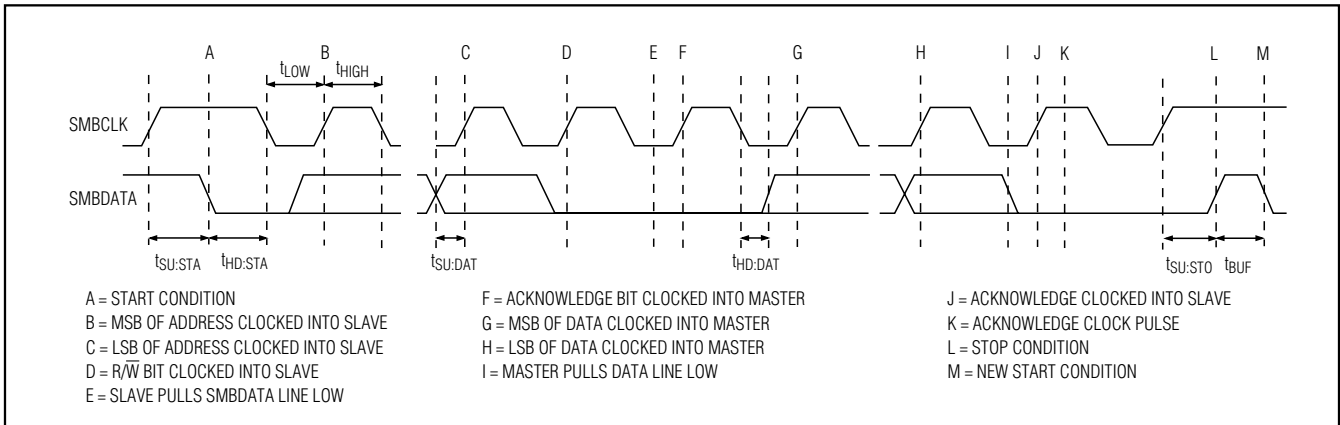Figure 5. SMBus Write Timing Diagram

Figure 6. SMBus Read Timing Diagram

GND, or DXN. If an open or short exists, each of the external temperature registers contains 1111 1111. When an open-circuit fault occurs, bit 2 (OPEN) in the status byte sets to 1. If a fault is present upon power-up, the fault is not indicated until the end of the first conversion cycle.

$\overline{ALERT}$_ Interrupts

The $\overline{ALERT}$_ interrupt occurs when the internal or external temperature reading exceeds a high- or low-temperature limit (programmed). The $\overline{ALERT}$_ output signal latches and can only clear by either reading the status register or by successfully responding to an alert-response address. In both cases, the alert clears if the temperature fault condition no longer exists. Asserting $\overline{ALERT}$_ does not halt automatic conversion. The open-drain $\overline{ALERT}$_ outputs allow multiple devices to share a common interrupt line.

The MAX6638 responds to the SMBus alert-response address, an interrupt pointer return-address feature. Prior to taking corrective action, always check to ensure that an interrupt is valid by reading the current temperature.

Alert Fault-Queue Register

In some systems, it is desirable to ignore a single temperature measurement that falls outside the $\overline{ALERT}$_ limits. Bits 1 and 2 of the fault queue register (address 22h) determine the number of consecutive temperature faults necessary to set $\overline{ALERT}$_.

Alert-Response Address

The SMBus alert-response interrupt pointer provides quick fault identification for simple slave devices that

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lack the complex logic needed to be a bus master. 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 generating an interrupt attempts to identify itself by putting its own address on the bus.

The alert response can activate several different slave devices simultaneously. If more than one slave attempts to respond, bus arbitration rules apply, and the device with the lower address code wins. The losing device does not generate an acknowledge response and continues to hold the $\overline{\text{ALERT}\_}$ line low until cleared. Successful completion of the read alert-response protocol clears the interrupt latch, provided the condition that caused the alert no longer exists.

Overtemperature Limit Output
$\overline{\text{OVERT1}}$ asserts when the temperature rises to a value stored in one of the $\overline{\text{OVERT1}}$ limit registers (19h and 20h). It deasserts when the temperature drops below the stored limit, minus hysteresis. $\overline{\text{OVERT1}}$ can be used to activate a cooling fan, send a warning, invoke clock throttling, or trigger a system shutdown to prevent component damage.

Command-Byte Functions
The 8-bit command-byte register (Table 3) is the master index that points to the various other registers within the MAX6638. 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.

One-Shot Conversion Cycle
The one-shot command immediately forces a new conversion cycle to begin. If the MAX6638 receives a one-shot command while the MAX6638 is in standby mode ($\overline{\text{RUN}}$ = 1), a new conversion begins, after which the device returns to standby mode. If during a conversion the MAX6638 receives a one-shot command, the MAX6638 ignores the command; however, the results of the conversion in progress update the data registers accordingly.

Configuration-Byte Functions
The configuration-byte register (Tables 3 and 5) is a read-write register with several functions. Bit 7 masks interrupts. Bit 6 puts the MAX6638 into a standby (STOP) mode or autonomous ($\overline{\text{RUN}}$) mode. The MAX6638 enters standby mode when both SMBus controllers set the corresponding configuration bits.

Status-Byte Functions
The status-byte register (Tables 3 and 4) indicates when any temperature threshold is exceeded. This byte also indicates whether the ADC is converting and if there is a fault detected in the external sense diode. After POR, the state of the flag bits are zero, assuming no alarm conditions are present. The status byte clears with any successful read of the status byte, after completion of a conversion and if the fault condition no longer exists. Note that the $\overline{\text{ALERT}\_}$ interrupt latch does not automatically clear when the status-flag bit indicating the $\overline{\text{ALERT}\_}$ clears.

Registers
The internal registers of the MAX6638 are all 8-bit data word width and are all accessible through SMBus by read and write operations.

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Table 3. SMBus1 Registers and Command-Byte Bit Assignments

REG. ADDRESS	REGISTER NAME	ABBR.	BIT								POR VALUE
			7	6	5	4	3	2	1	0	
00h	Read Local Temp Sensor	RLTS1	7	6	5	4	3	2	1	0	00h
01h	Read Remote Temp Sensor	RRTS1	7	6	5	4	3	2	1	0	00h
02h	Read Status Byte	RS1	BUSY	LHIGH	LLOW	RHIGH	RLOW	FAULT	EOT	IOT	00h
03h	Read Configuration Byte	RC1	MASK	$\overline{RUN}$	RFU	RFU	RFU	RFU	RFU	RFU	00h
04h	Read Conversion-Rate Byte	RCR1	7	6	5	4	3	2	1	0	00h
05h	Read Local $\overline{ALERT1}$ High Limit	RLAH1	7	6	5	4	3	2	1	0	55h
06h	Read Local $\overline{ALERT1}$ Low Limit	RLAL1	7	6	5	4	3	2	1	0	00h
07h	Read Remote $\overline{ALERT1}$ High Limit	RRAH1	7	6	5	4	3	2	1	0	55h
08h	Read Remote $\overline{ALERT1}$ Low Limit	RRAL1	7	6	5	4	3	2	1	0	00h
09h	Write Configuration Byte	WC1	7	6	5	4	3	2	1	0	00h
0Ah	Write Conversion-Rate Byte	WCR1	7	6	5	4	3	2	1	0	08h
0Bh	Write Local Alert-High Limit	WLAH1	7	6	5	4	3	2	1	0	55h
0Ch	Write Local Alert-Low Limit	WLAL1	7	6	5	4	3	2	1	0	00h
0Dh	Write Remote Alert-High Limit	WRAH1	7	6	5	4	3	2	1	0	5Fh
0Eh	Write Remote Alert-Low Limit	WRAL1	7	6	5	4	3	2	1	0	00
0Fh	One-Shot Conversion	OSC1	7	6	5	4	3	2	1	0	—
10h	Read Local-Extended Temp	RLET1	7	6	5	4	3	2	1	0	00h
11h	Read Remote-Extended Temp	RRET1	7	6	5	4	3	2	1	0	00h
19h	Read/Write Remote $\overline{OVERT1}$ Limit	RWRO1	7	6	5	4	3	2	1	0	7Dh
20h	Read/Write Local $\overline{OVERT1}$ Limit	RWLO1	7	6	5	4	3	2	1	0	55h
21h	Overtemperature Hysteresis	HYS1	7	6	5	4	3	2	1	0	0Ah
22h	Write Fault Queue	WFQ1	7	6	5	4	3	2	1	0	80h
FEh	Read Manufacturer ID	RMID	7	6	5	4	3	2	1	0	4Dh
FFh	Read Device ID	RDID	7	6	5	4	3	2	1	0	78h

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Table 4. Read Status-Byte (RS1) Bit Assignments (02h)

BIT	NAME	POR STATE	FUNCTION
7	BUSY	0	ADC is busy converting when 1.
6	LHIGH	0	Local High-Temperature Alarm. A 1 indicates a local high-temperature fault. Clears with a POR or readout of the status byte if the fault condition no longer exists.
5	LLOW	0	Local Low-Temperature Alarm. A 1 indicates a local low-temperature fault. Clears with a POR or readout of the status byte if the fault condition no longer exists.
4	RHIGH	0	Remote High-Temperature Alarm. A 1 indicates a remote high-temperature fault. Clears with a POR or readout of the status byte if the fault condition no longer exists.
3	RLOW	0	Remote Low-Temperature Alarm. A 1 indicates a remote low-temperature fault. Clears with a POR or readout of the status byte if the fault condition no longer exists.
2	OPEN	0	A 1 indicates DXN and DXP are open. Clears with a POR or readout of the status byte if the open condition no longer exists.
1	EOT	0	A 1 indicates the remote temperature exceeds the external $\overline{OVERT1}$ threshold.
0	IOT	0	A 1 indicates the local temperature exceeds the external $\overline{OVERT1}$ threshold.

Table 5. Read Configuration-Byte (RC1) Bit Assignments (03h)

BIT	NAME	POR STATE	FUNCTION
7	MASK	0	Masks $\overline{ALERT1}$ interrupts when set to 1.
6	$\overline{RUN}$	0	Standby-Mode Control Bit. If set to 1, standby mode enables and enters if the standby-mode control bit ($\overline{RUN}$) for channel 2 is also set.
5–0	RFU	0	Reserved for future use.

Table 6. Conversion-Rate Control-Byte (RCR1 and WCR1) Bit Assignments (04h and 0Ah)

BIT	DATA	CONVERSION RATE (Hz)
7–0	00h	0.0625
7–0	01h	0.125
7–0	02h	0.25
7–0	03h	0.5
7–0	04h	1
7–0	05h	2
7–0	06h	4
7–0	07h	8
7–0	08h	16
7–0	09–FFh	Reserved

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Table 7. SMBus2 Registers and Command-Byte Bit Assignments

REG. ADDRESS	REGISTER NAME	ABBR.	BIT								POR VALUE
			7	6	5	4	3	2	1	0	
00h	Read Local Temp Sensor	RLTS2	7	6	5	4	3	2	1	0	00h
01h	Read Remote Temp Sensor	RRTS2	7	6	5	4	3	2	1	0	00h
02h	Read Status Byte	RS2	BUSY	LHIGH	LLOW	RHIGH	RLOW	FAULT	RFU	RFU	00h
03h	Read Configuration Byte	RC2	MASK	$\overline{RUN}$	RFU	RFU	RFU	RFU	RFU	RFU	00h
04h	Read Conversion-Rate Byte	RCR2	7	6	5	4	3	2	1	0	00h
05h	Read Local $\overline{ALERT1}$ High Limit	RLAH2	7	6	5	4	3	2	1	0	55h
06h	Read Local $\overline{ALERT1}$ Low Limit	RLAL2	7	6	5	4	3	2	1	0	00h
07h	Read Remote $\overline{ALERT1}$ High Limit	RRAH2	7	6	5	4	3	2	1	0	5Fh
08h	Read Remote $\overline{ALERT1}$ Low Limit	RRAL2	7	6	5	4	3	2	1	0	00h
09h	Write Configuration Byte	WC2	7	6	5	4	3	2	1	0	00h
0Ah	Write Conversion Rate Byte	WCR2	7	6	5	4	3	2	1	0	08h
0Bh	Write Local Alert-High Limit	WLAH2	7	6	5	4	3	2	1	0	55h
0Ch	Write Local Alert-Low Limit	WLAL2	7	6	5	4	3	2	1	0	00h
0Dh	Write Remote Alert-High Limit	WRAH2	7	6	5	4	3	2	1	0	5Fh
0Eh	Write Remote Alert-Low Limit	WRAL2	7	6	5	4	3	2	1	0	00h
0Fh	One-Shot Conversion	OSC2	7	6	5	4	3	2	1	0	—
10h	Read Local-Extended Temp	RLET2	7	6	5	4	3	2	1	0	00h
11h	Read Remote-Extended Temp	RRET2	7	6	5	4	3	2	1	0	00h
19h	Read/Write Remote $\overline{OVERT1}$ Limit	RWRO2	7	6	5	4	3	2	1	0	7Dh
20h	Read/Write Local $\overline{OVERT1}$ Limit	RWLO2	7	6	5	4	3	2	1	0	55h
21h	Overtemperature Hysteresis	HYS2	7	6	5	4	3	2	1	0	0Ah
22h	Write Fault Queue	WFQ2	7	6	5	4	3	2	1	0	80h
FEh	Read Manufacturer ID	RMID	7	6	5	4	3	2	1	0	4Dh
FFh	Read Device ID	RDID	7	6	5	4	3	2	1	0	78h

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Table 8. Read Status-Byte (RS2) Bit Assignments (02h)

BIT	NAME	POR STATE	FUNCTION
7	BUSY	0	ADC is busy converting when 1.
6	LHIGH	0	Local High-Temperature Alarm. A 1 indicates a local high-temperature fault. Clears with a POR or readout of the status byte if the fault condition no longer exists.
5	LLOW	0	Local Low-Temperature Alarm. A 1 indicates a local low-temperature fault. Clears with a POR or readout of the status byte if the fault condition no longer exists.
4	RHIGH	0	Remote High-Temperature Alarm. A 1 indicates a remote high-temperature fault. Clears with a POR or readout of the status byte if the fault condition no longer exists.
3	RLOW	0	Remote Low-Temperature Alarm. A 1 indicates a remote low-temperature fault. Clears with a POR or readout of the status byte if the fault condition no longer exists.
2	OPEN	0	A 1 indicates DXN and DXP are open. Clears with a POR or a read of the status byte if the open condition no longer exists.
1	RFU	0	Reserved for future use.
0	RFU	0	Reserved for future use.

Table 9. Read Configuration-Byte (RC2) Bit Assignments (03h)

BIT	NAME	POR STATE	FUNCTION
7	MASK	0	Masks $\overline{ALERT2}$ interrupts when set to 1.
6	$\overline{RUN}$	0	Standby-Mode Control Bit. If set to 1, standby mode is enabled and is entered if or when the standby-mode control bit ($\overline{RUN}$) for channel 1 is also set.
5–0	RFU	0	Reserved for future use.

Table 10. Conversion-Rate Control-Byte (RCR2 and WCR2) Bit Assignments (04h and 0Ah)

BIT	DATA	CONVERSION RATE (Hz)
7–0	00h	0.0625
7–0	01h	0.125
7–0	02h	0.25
7–0	03h	0.5
7–0	04h	1
7–0	05h	2
7–0	06h	4
7–0	07h	8
7–0	08h	16
7–0	09–FFh	Reserved

Table 11. Slave Addresses

PART	SMBus CHANNEL	SLAVE ADDRESS
MAX6638ATC	1	1001 101
	2	1001 101

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Applications Information

Remote-Diode Selection
The MAX6638 can directly measure the die temperature of CPUs and other ICs that have on-board temperature-sensing diodes (see the *Typical Operating Circuit*), or it 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 (which is actually a transistor). The MAX6638 is optimized for n = 1.008. If a sense transistor with a different ideality factor is used, the output data is different. 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:

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

where temperature is measured in Kelvin.

The following example uses the MAX6638 with a CPU that has an ideality factor of 1.002. If the diode has negligible series resistance, the measured data is related to the real temperature as follows:

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

For a real temperature of +85°C (358.15K), the converted and quantized temperature data is +82.875°C (356.03K), which is an error of -2.12°C. Using the correction formula above, the corrected temperature data is +85.0°C (358.16K).

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

$$\Delta V_M = R_S (100\mu A - 10\mu A) = 90\mu A \times R_S.$$

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

$$\frac{90 \frac{\mu V}{\Omega}}{198.6 \frac{\mu V}{\Omega}} = 0.453 \frac{°C}{\Omega}$$

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

$$3\Omega \times 0.453 \frac{°C}{\Omega} = 1.36°C$$

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

$$1.36°C - 2.12°C = -0.77°C$$

for a diode temperature of +85°C.

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

Discrete Remote Diodes
When the remote-sensing diode is a discrete transistor, short the collector to the base. Table 12 lists examples of discrete transistors that are appropriate for use with the MAX6638. Avoid violating the A/D input voltage range by using a small-signal transistor with a relatively high forward voltage. The forward voltage at the highest expected temperature must be greater than 0.25V at 10µA, and the forward voltage at the lowest expected temperature must be less than 0.95V at 100µA. Do not use large power transistors. Ensure that the base resistance is less than 100Ω. Tight specifications for forward current gain (50 < ß < 150, for example) indicate that the manufacturer has good process controls and that the device has consistent VBE characteristics.

Table 12. Remote-Sensor Transistor Manufacturers

MANUFACTURER	MODEL
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).*

ADC Noise Filtering
The ADC is an integrating type with inherently good noise rejection, especially of low-frequency signals, such as 60Hz/120Hz power-supply hum. Micropower operation places constraints on high-frequency noise rejection;

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therefore, careful PC board layout and proper external noise filtering are required for high-accuracy remote measurements in electrically noisy environments.

Filter high-frequency EMI at DXP and DXN with an external 2200pF capacitor. This value can be increased to approximately 3300pF (max), including cable capacitance. Capacitance > 3300pF introduces errors due to the rise time of the switched current source. Typically noise sources cause the ADC measurements to be higher than the actual temperature, approximately by +1°C to +10°C, depending on the frequency and amplitude.

PC Board Layout

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

1) Place the MAX6638 as close as is practical to the remote 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.

2) Do not route the DXP-DXN 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.

3) Route the DXP and DXN traces in parallel and in close proximity to each other, away from any higher voltage traces, such as 12V DC. Leakage currents from PC board contamination must be dealt with carefully since a 20MΩ leakage path from DXP to ground causes approximately a 1°C error. If high-voltage traces are unavoidable, connect guard traces to GND on either side of the DXP-DXN traces (Figure 4).

4) Route through as few vias and crossunders as possible to minimize copper/solder thermocouple effects.

5) When introducing a thermocouple, make sure that both the DXP and the DXN paths have matching thermocouples. A copper-solder thermocouple exhibits 3µV/°C, and takes approximately 200µV of voltage error at DXP-DXN to cause a 1°C measurement error. Adding a few thermocouples causes a negligible error.

6) Use wide traces. Narrow traces are more inductive and tend to pick up radiated noise. The 10-mil withstand spacing recommended in Figure 4 is not absolutely necessary, as it offers only a minor improvement in leakage and noise over narrow traces. Use wider traces when practical.

7) Add a 200Ω resistor in series with V_CC for best noise filtering (see the *Typical Operating Circuit*).

8) 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.

PC Board Layout Checklist

• Place the MAX6638 close to the remote-sense junction.

• Keep traces away from high voltages (+12V bus).

• Keep traces away from fast data buses and CRTs.

• Use recommended trace widths and spacings.

• Place a ground plane under the traces.

• Use guard traces flanking DXP and DXN and connecting to GND.

• Add a 47Ω resistor in series with V_CC for best noise filtering (see the *Typical Operating Circuit*).

• Place the noise filter and a 0.1µF V_CC bypass capacitor close to the MAX6638.

Twisted-Pair and Shielded Cables

Use a twisted-pair cable to connect the remote sensor for remote-sensor distance 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 DXN and the shield to GND. Leave the shield unconnected at the remote sensor.

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. Cable resistance also affects remote-sensor accuracy. For every 1Ω of series resistance, the error is approximately 0.5°C.

Thermal Mass and Self-Heating

When sensing local temperature, these devices are intended to measure the temperature of the PC board to which the devices are soldered. The leads provide a good thermal path between the PC board 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 PC board is far greater than that of the

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MAX6638, the device follows temperature changes on the PC board with little or no perceivable delay.

When measuring the temperature of a CPU or another 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 SC70s or 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 $\overline{ALERT1}$ output. For example, with V_{CC} 5.5V, at a 16Hz conversion rate and with $\overline{ALERT1}$ sinking 1mA, the typical power dissipation is:
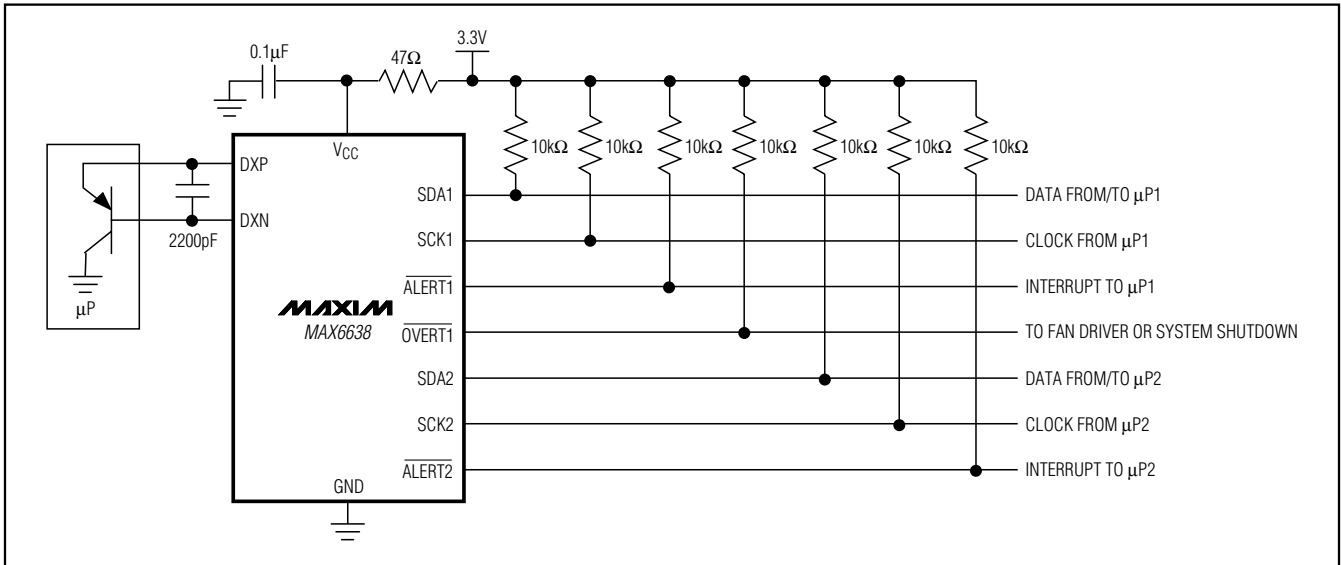
$$5.5V \times 800\mu A + 0.4V \times 1.0mA = 4.8mW$$

θ_{J-A} for the 16-pin, 4mm x 4mm TQFN package is 59.3°C/W, so assuming no copper PC board heat sinking, the resulting temperature rise is:

$$\Delta T = 4.8mW \times 59.3°C/W = +0.283°C.$$

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

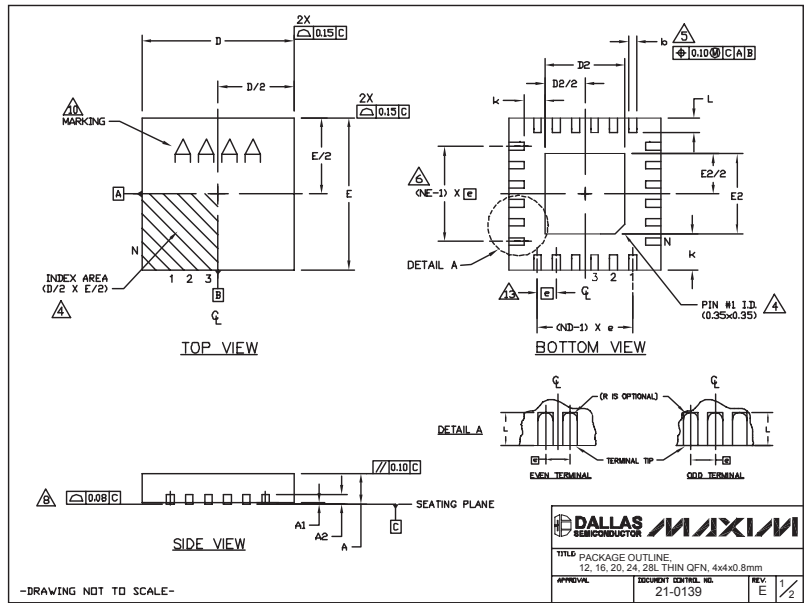## Typical Operating Circuit

Chip Information

PROCESS: BiCMOS

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Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

TOP VIEW

BOTTOM VIEW

DETAIL A

SIDE VIEW

24L QFN THIN.EPS

DALLAS SEMICONDUCTOR / MAXIM

TITLE: PACKAGE OUTLINE,
12, 16, 20, 24, 28L THIN QFN, 4x4x0.8mm

APPROVAL | DOCUMENT CONTROL NO. 21-0139 | REV. E | 1/2

-DRAWING NOT TO SCALE-

COMMON DIMENSIONS

PKG REF.	12L 4x4 MIN.	NOM.	MAX.	16L 4x4 MIN.	NOM.	MAX.	20L 4x4 MIN.	NOM.	MAX.	24L 4x4 MIN.	NOM.	MAX.	28L 4x4 MIN.	NOM.	MAX.
A	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80
A1	0.0	0.02	0.05	0.0	0.02	0.05	0.0	0.02	0.05	0.0	0.02	0.05	0.0	0.02	0.05
A2	0.20 REF			0.20 REF			0.20 REF			0.20 REF			0.20 REF		
b	0.25	0.30	0.35	0.25	0.30	0.35	0.20	0.25	0.30	0.18	0.23	0.30	0.15	0.20	0.25
D	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10
E	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10
e	0.80 BSC.			0.65 BSC.			0.50 BSC.			0.50 BSC.			0.40 BSC.		
k	0.25	–	–	0.25	–	–	0.25	–	–	0.25	–	–	0.25	–	–
L	0.45	0.55	0.65	0.45	0.55	0.65	0.45	0.55	0.65	0.30	0.40	0.50	0.30	0.40	0.50
N	12			16			20			24			28		
ND	3			4			5			6			7		
NE	3			4			5			6			7		
Jedec Var.	WGGB			WGGC			WGGD-1			WGGD-2			WGGE		

EXPOSED PAD VARIATIONS

PKG CODES	D2 MIN.	NOM.	MAX.	E2 MIN.	NOM.	MAX.	DOWN BONDS ALLOWED
T1244-3	1.95	2.10	2.25	1.95	2.10	2.25	YES
T1244-4	1.95	2.10	2.25	1.95	2.10	2.25	NO
T1644-3	1.95	2.10	2.25	1.95	2.10	2.25	YES
T1644-4	1.95	2.10	2.25	1.95	2.10	2.25	NO
T2044-2	1.95	2.10	2.25	1.95	2.10	2.25	YES
T2044-3	1.95	2.10	2.25	1.95	2.10	2.25	NO
T2444-2	1.95	2.10	2.25	1.95	2.10	2.25	YES
T2444-3	2.45	2.60	2.63	2.45	2.60	2.63	YES
T2444-4	2.45	2.60	2.63	2.45	2.60	2.63	NO
T2844-1	2.50	2.60	2.70	2.50	2.60	2.70	NO

NOTES:
1. DIMENSIONING & TOLERANCING CONFORM TO ASME Y14.5M-1994.
2. ALL DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.
3. N IS THE TOTAL NUMBER OF TERMINALS.
4. THE TERMINAL #1 IDENTIFIER AND TERMINAL NUMBERING CONVENTION SHALL CONFORM TO JESD 95-1 SPP-012. DETAILS OF TERMINAL #1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE TERMINAL #1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FEATURE.
5. DIMENSION b APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.25 mm AND 0.30 mm FROM TERMINAL TIP.
6. ND AND NE REFER TO THE NUMBER OF TERMINALS ON EACH D AND E SIDE RESPECTIVELY.
7. DEPOPULATION IS POSSIBLE IN A SYMMETRICAL FASHION.
8. COPLANARITY APPLIES TO THE EXPOSED HEAT SINK SLUG AS WELL AS THE TERMINALS.
9. DRAWING CONFORMS TO JEDEC MO220, EXCEPT FOR T2444-3, T2444-4 AND T2844-1.
10. MARKING IS FOR PACKAGE ORIENTATION REFERENCE ONLY.
11. COPLANARITY SHALL NOT EXCEED 0.08mm
12. WARPAGE SHALL NOT EXCEED 0.10mm
13. LEAD CENTERLINES TO BE AT TRUE POSITION AS DEFINED BY BASIC DIMENSION "e", ±0.05.
14. NUMBER OF LEADS SHOWN ARE FOR REFERENCE ONLY

DALLAS SEMICONDUCTOR / MAXIM

TITLE: PACKAGE OUTLINE,
12, 16, 20, 24, 28L THIN QFN, 4x4x0.8mm

APPROVAL | DOCUMENT CONTROL NO. 21-0139 | REV. E | 2/2

-DRAWING NOT TO SCALE-