MIC280

Precision IttyBitty™ Thermal Supervisor

REV. 11/04

General Description

The MIC280 is a digital thermal supervisor capable of measuring its own internal temperature and that of a remote PN junction. The remote junction may be an inexpensive commodity transistor, e.g., 2N3906, or an embedded thermal diode such as found in Intel Pentium* II/III/IV CPUs, AMD Athlon* CPUs, and Xilinx Virtex* FPGA's. A 2-wire SMBus* 2.0 compatible serial interface is provided for host communication. Remote temperature is measured with ±1°C accuracy and 9-bit to 12-bit resolution (programmable). Independent high, low, and over-temperature thresholds are provided for each zone.

The advanced integrating A/D converter and analog front-end reduce errors due to noise for maximum accuracy and minimum guardbanding. The interrupt output signals temperature events to the host, including data-ready and diode faults. Critical device settings can be locked to prevent changes and insure failsafe operation. The clock, data, and interrupt pins are 5V-tolerant regardless of the value of V_{DD}. They will not clamp the bus lines low even if the device is powered down. Superior accuracy, failsafe operation, and small size make the MIC280 an excellent choice for the most demanding thermal management applications.

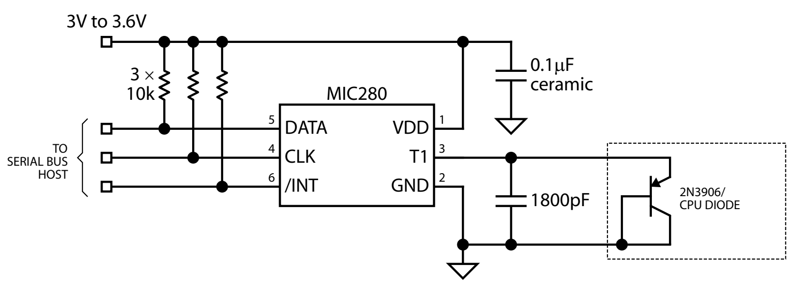
Features

- Measures local and remote temperature
- Highly accurate remote sensing
  ±1°C max., 60°C to 100°C
- Superior noise immunity for reduced temperature guardbands
- 9-bit to 12-bit temperature resolution for remote zone
- Fault queues to further reduce nuisance tripping
- Programmable high, low, and over-temperature thresholds for each zone
- SMBus 2 compatible serial interface including device timeout to prevent bus lockup
- Voltage tolerant I/O's
- Open-drain interrupt output pin - supports SMBus Alert Response Address protocol
- Low power shutdown mode
- Locking of critical functions to insure failsafe operation
- Failsafe response to diode faults
- Enables ACPI compliant thermal management
- 3.0V to 3.6V power supply range
- IttyBitty™ SOT23-6 package

Applications

- Desktop, server and notebook computers
- Printers and copiers
- Test and measurement equipment
- Thermal supervision of Xilinx Virtex FPGA's
- Wireless/RF systems
- Intelligent power supplies
- Datacom/telecom cards

Typical Application



MIC280 Typical Application

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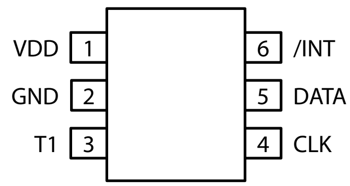
Ordering Information

Part Number				Slave Address	Ambient Temp. Range	Package
Standard	**Marking**	**Pb-FREE**	**Marking**			
MIC280-0BM6	TA00	MIC280-0YM6	TA00	$100\ 1000_b$	-55°C to +125°C	SOT23-6
MIC280-1BM6	TA01	MIC280-1YM6	TA01	$100\ 1001_b$	-55°C to +125°C	SOT23-6
MIC280-2BM6	TA02	MIC280-2YM6	TA02	$100\ 1010_b$	-55°C to +125°C	SOT23-6
MIC280-3BM6	TA03	MIC280-3YM6	TA03	$100\ 1011_b$	-55°C to +125°C	SOT23-6
MIC280-4BM6	TA04	MIC280-4YM6	TA05	$100\ 1100_b$	-55°C to +125°C	SOT23-6
MIC280-5BM6	TA05	MIC280-5YM6	TA05	$100\ 1101_b$	-55°C to +125°C	SOT23-6
MIC280-6BM6	TA06	MIC280-6YM6	TA06	$100\ 1110_b$	-55°C to +125°C	SOT23-6
MIC280-7BM6	TA07	MIC280-7YM6	TA07	$100\ 1111_b$	-55°C to +125°C	SOT23-6

Pin Configuration



SOT23-6

Pin Description

Pin Number	Pin Name	Pin Function
1	VDD	Power Supply Input.
2	GND	Ground.
3	T1	Analog Input. Connection to remote diode junction.
4	CLK	Digital Input. Serial bit clock input.
5	DATA	Digital Input/Output. Open-drain. Serial data input/output.
6	/INT	Digital Output. Open-drain. Interrupt output.

Absolute Maximum Ratings (Note 1)

Power Supply Voltage, V_{DD} 3.8V
Voltage on T1 .... –0.3V to V_{DD}+0.3V
Voltage on CLK, DATA, /INT .... –0.3V to 6V
Current Into Any Pin .... ±10mA
Power Dissipation, T_A = 125°C 109mW
Storage Temperature .... –65°C to +150°C
ESD Ratings, **Note 3**
  Human Body Model 1.5kV
  Machine Model 200V
Soldering (SOT23-6 Package)
  Vapor Phase (60s) .... 220°C $^{+5}$/-0°C
  Infrared (15s) .... 235°C $^{+5}$/-0°C

Operating Ratings (Note 2)

Power Supply Voltage, V_{DD} .... +3V to +3.6V
Ambient Temperature Range (T_A) .... –55°C to +125°C
Junction Temperature .... 150°C
Package Thermal Resistance (θ_{JA})
  SOT23-6 .... 230°C/W

Electrical Characteristics

For typical values T_A = 25°C, V_{DD} = 3.3V, unless otherwise noted.

Bold values indicate –55°C ≤ T_A ≤ 125°C, 3.0V ≤ V_{DD} ≤ 3.6V, unless otherwise noted. **Note 2**

Symbol	Parameter	Conditions	Min.	Typ	Max	Units
Power Supply						
I_{DD}	Supply Current	/INT, T1 open; CLK = DATA = High; Normal Mode		0.23	**0.4**	mA
		Shutdown Mode; /INT, T1 open; **Note 5** CLK = 100kHz, DATA = High		9		µA
		Shutdown Mode; /INT, T1 open; CLK = DATA = High		6	[TBD]	µA
t_{POR}	Power-on Reset Time, **Note 5**	V_{DD} > V_{POR}		200		µs
V_{POR}	Power-on Reset Voltage	All registers reset to default values; A/D conversions initiated		2.65	**2.95**	V
V_{HYST}	Power-on Reset Hysteresis Voltage **Note 5**			300		mV
Temperature-to-Digital Converter Characteristics						
	Accuracy, Remote Temperature **Notes 2, 7, 10, 11**	60°C ≤ T_D ≤ 100°C, 3.15V < V_{DD} < 3.45V, 25°C < T_A < 85°C		±0.25	**±1**	°C
		0°C ≤ T_D ≤ 100°C, 3.15V < V_{DD} < 3.45V, 25°C < T_A < 85°C		±1	**±2**	°C
		–55°C ≤ T_D ≤ 125°C, 3.15V < V_{DD} < 3.45V, 25°C < T_A < 85°C		±2	**±4**	°C
	Accuracy, Local Temperature **Note 2, 10**	0°C ≤ T_A ≤ 100°C, 3.15V < V_{DD} < 3.45V		±1	**±2**	°C
		–55°C ≤ T_A ≤ 125°C, 3.15V < V_{DD} < 3.45V		**±1.5**	**±2.5**	**°C**
t_{CONV}	**Conversion Time, Notes 2, 8**	RES[1:0]=00 (9 bits)		200	**240**	**ms**
		RES[1:0]=01 (10 bits)		**330**	**390**	ms
		RES[1:0]=10 (11 bits)		570	**670**	**ms**
		RES[1:0]=11 (12 bits)		**1000**	**1250**	ms
Remote Temperature Input, T1						
I_F	**Current into External Diode** **Note 5**	**T1 forced to 1.0V, High level**		**192**	**400**	µA
		Low level	**7**	12		µA

Symbol	Parameter	Condition	Min	Typ	Max	Units
Serial Data I/O Pin, DATA						
V_{OL}	**Low Output Voltage, Note 4**	I_{OL} = 3mA			**0.3**	V
		I_{OL} = 6mA			**0.5**	V
V_{IL}	Low Input Voltage	3V ≤ V_{DD} ≤ 3.6V			**0.8**	V
V_{IH}	High Input Voltage	3V ≤ V_{DD} ≤ 3.6V	**2.1**		**5.5**	V
C_{IN}	Input Capacitance	**Note 5**		10		pF
I_{LEAK}	Input Current				**±1**	µA
Serial Clock Input, CLK						
V_{IL}	Low Input Voltage	3V ≤ V_{DD} ≤ 3.6V			**0.8**	V
V_{IH}	High Input Voltage	3V ≤ V_{DD} ≤ 3.6V	**2.1**		**5.5**	V
C_{IN}	Input Capacitance	**Note 5**		10		pF
I_{LEAK}	Input Current				**±1**	µA
Interrupt Output, /INT						
V_{OL}	**Low Output Voltage, Note 4**	I_{OL} = 3mA			**0.3**	**V**
		I_{OL} = 6mA			**0.5**	V
t_{INT}	Interrupt Propagation Delay **Notes 5, 6**	from TEMPx < TLOWx or TEMPx > THIGHx or TEMPx > CRITx to /INT < V_{OL}; R_{PULLUP} = 10kΩ			**[t_{CONV}]**	ms
t_{nINT}	Interrupt Reset Propagation Delay **Note 5, 9**	from read of STATUS or A.R.A. to /INT > V_{OH}; R_{PULLUP} = 10kΩ			**1**	µs
I_{LEAK}					**±1**	µA
Serial Interface Timing						
t_1	CLK (Clock) Period		**2.5**			µs
t_2	Data In Setup Time to CLK High		**100**			ns
t_3	Data Out Stable after CLK Low		**300**			ns
t_4	Data Low Setup Time to CLK Low	Start Condition	**100**			ns
t_5	Data High Hold Time after CLK High	Stop Condition	**100**			ns
t_{TO}	Bus Timeout		**25**	30	**35**	ms

Note 1. Exceeding the absolute maximum rating may damage the device.

Note 2. The device is not guaranteed to function outside its operating range. Final test on outgoing product is performed at T_A = 25°C.

Note 3. Devices are ESD sensitive. Handling precautions recommended.

Note 4. Current into the /INT or DATA pins will result in self heating of the device. Sink current should be minimized for best accuracy.

Note 5. Guaranteed by design over the operating temperature range. Not 100% production tested.

Note 6. t_{INT} and t_{CRIT} are equal to t_{CONV}.

Note 7. T_D is the temperature of the remote diode junction. Testing is performed using a single unit of one of the transistors listed in Table 8.

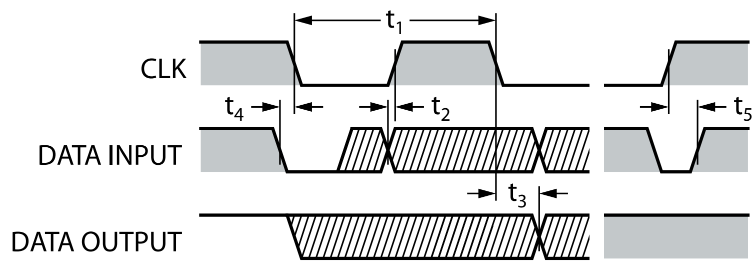
Note 8. t_{CONV} = t_{CONV}(local) + t_{CONV}(remote). Following the acquisition of either remote or local temperature data, the limit comparisons for that zone are performed and the device status updated; Status bits will be set and /INT driven active, if applicable.

Note 9. The interrupt reset propogation delay is dominated by the capacitance on the bus.

Note 10. Accuracy specification does not include quantization noise, which may be up to $\pm^1/_2$ LSB.

Note 11. Tested at 10-bit resolution.

Timing Diagrams

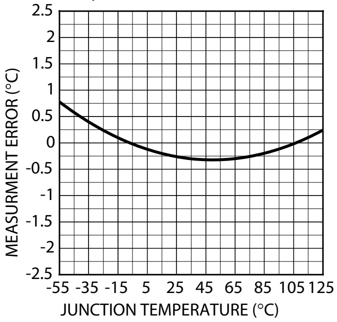


Serial Interface Timing

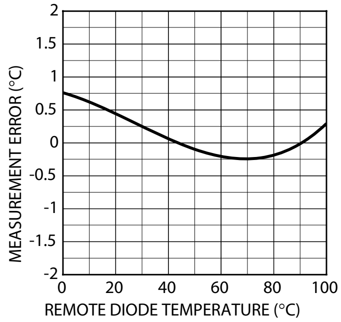
Typical Characteristics

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

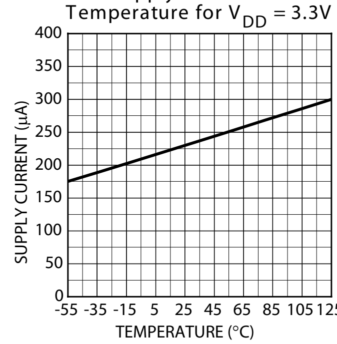
Accuracy vs. Temperature, Internal Sensor



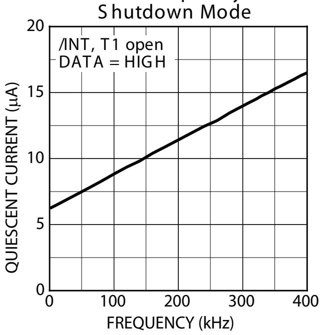
Remote Temperature Measurement Error



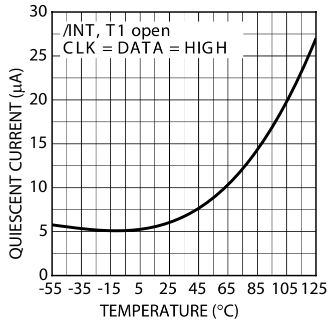
Supply Current vs. Temperature for V_{DD} = 3.3V



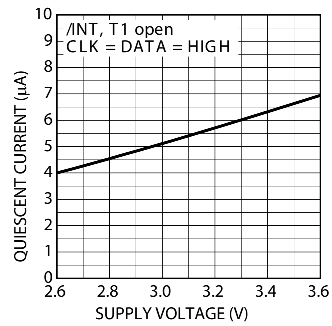
Quiescent Current vs. Clock Frequency in Shutdown Mode



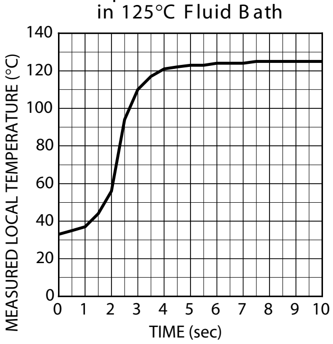
Quiescent Current vs. Temperature in Shutdown Mode



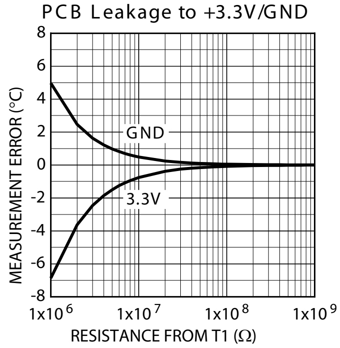
Quiescent Current vs. Supply Voltage in Shutdown Mode



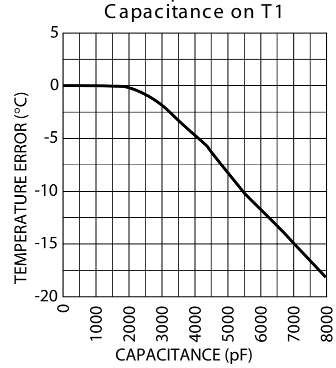
Response to Immersion in 125°C Fluid Bath



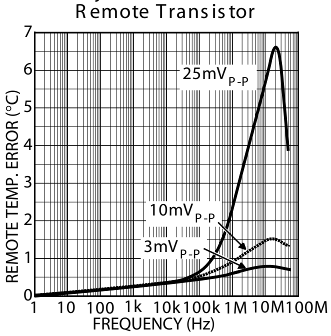
Measurement Error vs. PCB Leakage to +3.3V/GND



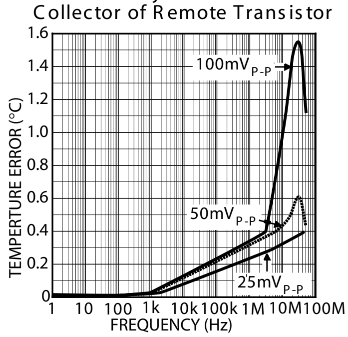
Remote Temperature Error vs. Capacitance on T1



Noise Injected into the Base of Remote Transistor



Noise Injected into the Collector of Remote Transistor



Functional Description

Serial Port Operation

The MIC280 uses standard SMBus Write_Byte, Read_Byte, and Read_Word operations for communication with its host. The SMBus Write_Byte operation involves sending the device's slave address (with the R/W bit low to signal a write operation), followed by a command byte and the data byte. The SMBus Read_Byte operation is a composite write and read operation: the host first sends the device's slave address followed by the command byte, as in a write operation. A new start bit must then be sent to the MIC280, followed by a repeat of the slave address with the R/W bit (LSB) set to the high (read) state. The data to be read from the part may then be clocked out. A Read_Word is similar, but two successive data bytes are clocked out rather than one. These protocols are shown in Figure 1, Figure 2, and Figure 3.

The Command byte is eight bits (one byte) wide. This byte carries the address of the MIC280 register to be operated upon. The command byte values corresponding to the various MIC280 registers are shown in Table 1. Other command byte values are reserved, and should not be used.

Slave Address

The MIC280 will only respond to its own unique slave address. A match between the MIC280's address and the address specified in the serial bit stream must be made to initiate communication. The MIC280's slave address is fixed at the time of manufacture. Eight different slave addresses are available as determined by the part number. See Table 2 below and the Ordering Information table above.

Part Number	Slave Address
MIC280-0BM6	100 1000_b = 48_h
MIC280-1BM6	100 1001_b = 49_h
MIC280-2BM6	100 1010_b = $4A_h$
MIC280-3BM6	100 1011_b = $4B_h$
MIC280-4BM6	100 1100_b = $4C_h$
MIC280-5BM6	100 1101_b = $4D_h$
MIC280-6BM6	100 1110_b = $4E_h$
MIC280-7BM6	100 1111_b = $4F_h$

Table 2: MIC280 Slave Addresses

Alert Response Address

In addition to the Read_Byte, Write_Byte, and Read_Word protocols, the MIC280 adheres to the SMBus protocol for response to the Alert Response Address (ARA). The MIC280 expects to be interrogated using the ARA when it has asserted its /INT output.

Temperature Data Format

The least-significant bit of each temperature register (high bytes) represents one degree Centigrade. The values are in a two's complement format, wherein the most significant bit

Target Register		Command Byte Value		Power-on Default
Label	**Description**	**Read**	**Write**	
TEMP0	Local temperature result	00_h	n/a	00_h (0°C)
TEMP1h	Remote temperature result, high byte	01_h	n/a	00_h (0°C)
STATUS	Status	02_h	n/a	00_h
CONFIG	Configuration	03_h	03_h	80_h
IMASK	Interrupt mask register	04_h	04_h	07_h
THIGH0	Local temperature high limit	05_h	05_h	$3C_h$ (60°C)
TLOW0	Local temperature low limit	06_h	06_h	00_h (0°C)
THIGH1h	Remote temperature high limit, high byte	07_h	07_h	50_h (80°C)
TLOW1h	Remote temperature low limit, high byte	08_h	08_h	00_h (0°C)
LOCK	Security register	09_h	09_h	00_h
TEMP1l	Remote temperature result, low byte	10_h	n/a	00_h
THIGH1l	Remote temperature high limit, low byte	13_h	13_h	00_h
TLOW1l	Remote temperature low limit, low byte	14_h	14_h	00_h
CRIT1	Remote over-temperature limit	19_h	19_h	64_h (100°C)
CRIT0	Local over-temperature limit	20_h	20_h	46_h (70°C)
MFG_ID	Manufacturer Identification	FE_h	n/a	$2A_h$
DEV_ID	Device and revision identification	FF_h	n/a	$0x_h$*

* The lower nibble contains the die revision level, e.g., Rev 0 = 00h.

Table 1: MIC280 Register Addresses

(D7) represents the sign: zero for positive temperatures and one for negative temperatures. Table 3 shows examples of the data format used by the MIC280 for temperatures:

Temperature	Binary	Hex
+127°C	0111 1111	7F
+125°C	0111 1101	7D
+25°C	0001 1001	19
+1°C	0000 0001	01
0°C	0000 0000	00
–1°C	1111 1111	FF
–25°C	1110 0111	E7
–125°C	1000 0011	83
–128°C	1000 0000	80

Table 3: Digital Temperature Format, High Bytes

Extended temperature resolution is provided for the external zone. The high and low temperature limits and the measured temperature for zone one are reported as 12-bit values stored in a pair of 8-bit registers. The measured temperature, for example, is reported in registers TEMP1h, the high-order byte, and TEMP1l, the low-order byte. The values in the low-order bytes are left-justified four-bit binary values representing one-sixteenth degree increments. The A-D converter resolution for zone 1 is selectable from nine to twelve bits via the configuration register. Low-order bits beyond the resolution selected will be reported as zeroes. Examples of this format are shown below in Table 4.

FAULT QUEUE

A set of fault queues (programmable digital filters) are provided in the MIC280 to prevent false tripping due to thermal or electrical noise. Two bits, CONFIG[5:4], set the depth of the fault queues. The fault queue setting then determines the number of consecutive temperature events (TEMPx > THIGHx or TEMPx < TLOWx) which must occur in order for the condition to be considered valid. As an example, assume CONFIG[5:4] is programmed with 10b. The measured temperature for a given zone would have to exceed THIGHx for four consecutive A/D conversions before /INT would be asserted or the status bit set.

Like any filter, the fault queue function also has the effect of delaying the detection of temperature events. In this example, it would take 4 x t_{CONV} to detect a temperature event. The fault queue depth vs. CONFIG[5:4] of the configuration register is shown in Table 5. Note: there is no fault queue for over-temperature events (CRIT0 and CRIT1) or diode faults. The fault queue applies only to high-temperature and low-temperature events as determined by the THIGHx and TLOWx registers. Any write to CONFIG will result in the fault queues being purged and reset. Writes to any of the limit registers, TLOWx or THIGHx, will result in the fault queue for the corresponding zone being purged and reset.

CONFIG[5:4]	FAULT QUEUE DEPTH
00	1 (Default)
01	2
10	4
11	6

Table 5: Fault Queue Depth Settings

Interrupt Generation

There are eight different conditions that will cause the MIC280 to set one of the bits in STATUS and assert its /INT output, if so enabled. These conditions are listed in Table 6. Unlike previous generations of thermal supervisor IC's, there are no interdependencies between any of these conditions. That is, if CONDITION is true, the MIC280 will respond accordingly, regardless of any previous or currently pending events.

Normally when a temperature event occurs, the corresponding status bit will be set in STATUS, the corresponding interrupt mask bit will be cleared, and /INT will be asserted. Clearing the interrupt mask bit(s) prohibits continuous interrupt generation while the device is being serviced. (It is possible to prevent events from clearing interrupt mask bits by setting bits in the lock register. See Table 7 for Lockbit functionality.) A temperature event will only set bits in the status register if it is specifically enabled by the corresponding bit in the interrupt mask register. An interrupt signal will only be generated on /INT if interrupts are also globally enabled (IE =1 in CONFIG).

The MIC280 expects to be interrogated using the Alert Response Address once it has asserted its interrupt output. Following an interrupt, a successful response to the A.R.A. or a read operation on STATUS will cause /INT to be de-asserted. STATUS will also be cleared by the read operation. Reading STATUS following an interrupt is an acceptable substitute for

Extended Temperature, Low Byte	Resolution							
	9 BITS		10 BITS		11 BITS		12 BITS	
	Binary	Hex	Binary	Hex	Binary	Hex	Binary	Hex
0.0000	0000 0000	00	0000 0000	00	0000 0000	00	0000 0000	00
0.0625	0000 0000	00	0000 0000	00	0000 0000	00	0001 0000	10
0.1250	0000 0000	00	0000 0000	00	0010 0000	20	0010 0000	20
0.2500	0000 0000	00	0100 0000	40	0100 0000	40	0100 0000	40
0.5625	1000 0000	80	1000 0000	80	1000 0000	80	1001 0000	90
0.9375	1000 0000	80	1100 0000	C0	1110 0000	E0	1111 0000	F0

Table 4: Digital Temperature Format, Low Bytes

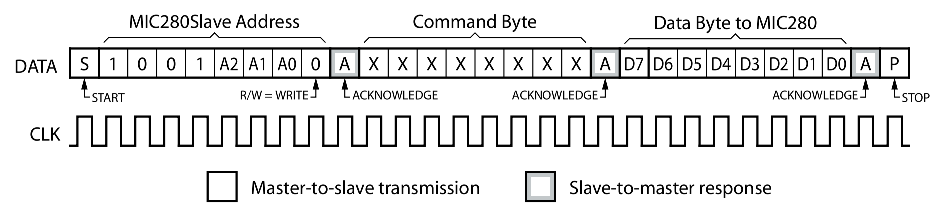


Figure 1. WRITE_BYTE Protocol

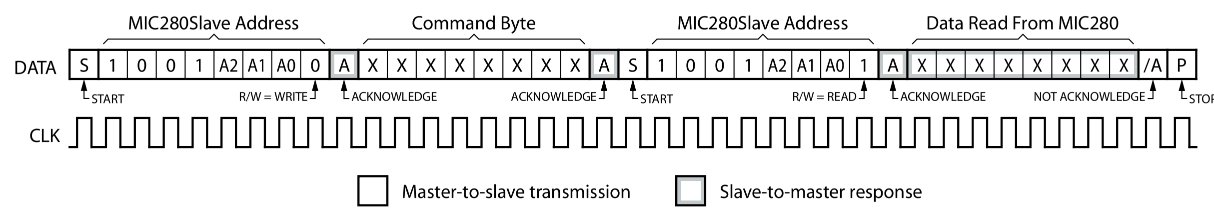


Figure 2. READ_BYTE Protocol

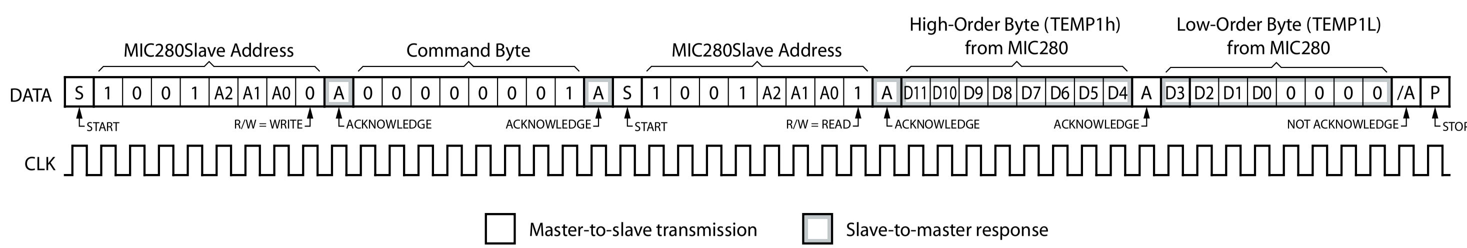


Figure 3. READ_WORD Protocol for Accessing TEMP1h : TEMP1l

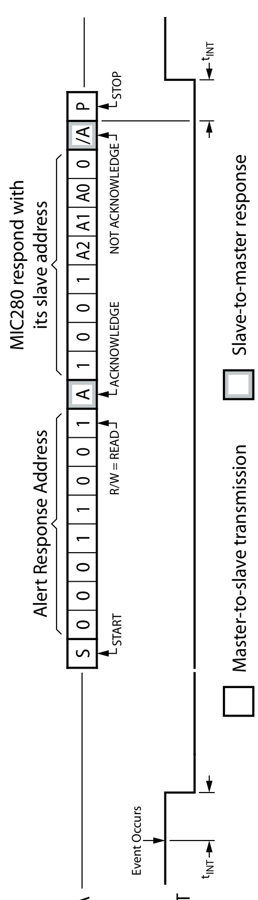


Figure 4. MIC280 Alert Response Address Protocol

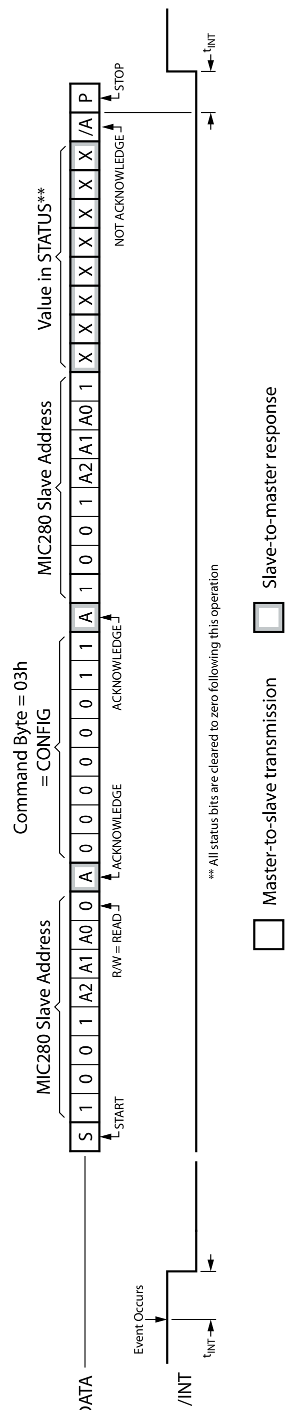


Figure 5. Reading Status in response to an interrupt

using the A.R.A. if the host system does not implement the A.R.A protocol. Figure 4 and Figure 5 illustrate these two methods of responding to MIC280 interrupts.

Since temperature-to-digital conversions continue while /INT is asserted, the measured temperature could change between the MIC280's assertion of /INT and the host's response. It is good practice for the interrupt service routine to read the value in TEMPx, to verify that the over-temperature or under-temperature condition still exists. In addition, more than one temperature event may have occurred simultaneously or in rapid succession between the assertion of /INT and servicing of the MIC280 by the host. The interrupt service routine should allow for this eventuality. At the end of the interrupt service routine, the interrupt enable bits should be reset to permit future interrupts.

Reading the Result Registers

All MIC280 registers are eight bits wide and may be accessed using the standard Read_Byte protocol. The temperature result for the local zone, zone 0, is a single 8-bit value in register TEMP0. A single Read_Byte operation by the host is sufficient for retrieving this value. The temperature result for the remote zone is a twelve-bit value split across two eight-bit registers, TEMP1h and TEMP1l. A series of two Read_Byte operations are needed to obtain the entire twelve-bit temperature result for zone 1. It is possible under certain conditions that the temperature result for zone 1 could be updated between the time TEMP1l or TEMP1h is read and the companion register is read. In order to insure coherency, TEMP1h supports the use of the Read_Word protocol for accessing both TEMP1h and TEMP1l with a single operation. This insures that the values in both result registers are from the same ADC cycle. This is illustrated in Figure 3 above. Read_Word operations are only supported for TEMP1h: TEMP1l, i.e., only for command byte values of 01h.

Polling

The MIC280 may either be polled by the host, or request the host's attention via the /INT pin. In the case of polled operation, the host periodically reads the contents of STATUS to check the state of the status bits. The act of reading STATUS clears it. If more than one event that sets a given status bit occurs before the host polls STATUS, only the fact that at least one such event has occurred will be apparent to the host. For polled systems, the global interrupt enable bit should be clear (IE = 0). This will disable interrupts from the MIC280 (prevents the /INT pin from sinking current). For interrupt-driven systems, IE must be set to enable the /INT output.

Shutdown Mode

Putting the device into shutdown mode by setting the shutdown bit in the configuration register will unconditionally deassert /INT, clear STATUS, and purge the fault queues. Therefore, this should not be done before completing the appropriate interrupt service routine(s). No other registers will be affected by entering shutdown mode. The last temperature readings will persist in the TEMPx registers.

The MIC280 can be prevented from entering shutdown mode using the shutdown lockout bit in the lock register. If L3 in LOCK is set while the MIC280 is in shutdown mode, it will immediately exit shutdown mode and resume normal operation. It will not be possible to subsequently re-enter shutdown mode. If the reset bit is set while the MIC280 is shut down, normal operation resumes from the reset state. (see below)

Warm Resets

The MIC280 can be reset to its power-on default state during operation by setting the RST bit in the configuration register. When this bit is set, /INT will be deasserted, the fault queues will be purged, the limit registers will be restored to their normal power-on default values, and any A/D conversion in progress will be halted and the results discarded. This includes resetting bits L3 - L0 in the security register, LOCK. The state of the MIC280 following this operation is indistinguishable from a power-on reset. If the reset bit is set while the MIC280 is shut down, the shutdown bit is cleared and normal operation resumes from the reset state.

If bit 4 of LOCK, the Warm Reset Lockout Bit, is set, warm resets cannot be initiated, and writes to the RST bit will be completely ignored. Setting L4 while the MIC280 is shut down will result in the device exiting shutdown mode and resuming normal operation, just as if the shutdown bit had been cleared.

EVENT	CONDITION	MIC280 RESPONSE*
Data ready	A/D conversions complete for both zones; result registers updated; state of /INT updated	Set S7, clear IM7, assert /INT
Over-temperature, remote	([TEMP1h:TEMP1l]) > CRIT1	Set S1, assert /INT
Over-temperature, local	TEMP0 > CRIT0	Set S0, assert /INT
High temperature, remote	([TEMP1h:TEMP1l]) > THIGH1h:THIGH1l]**	Set S4, clear IM4, assert /INT
High temperature, local	TEMP0 > THIGH0**	Set S6, clear IM6, assert /INT
Low temperature, remote	([TEMP1h:TEMP1l]) < TLOW1h:TLOW1l]**	Set S3, clear IM3, assert /INT
Low temperature, local	TEMP0 < TLOW0**	Set S5, clear IM5, assert /INT
Diode fault	T1 open or T1 shorted to VDD or GND	Set S2, clear IM2, assert /INT

* Assumes interrupts enabled. **CONDITION must be true for Fault_Queue conversions to be recognized.

Table 6: MIC280 Temperature Events

Configuration Locking

The security register, LOCK, provides the ability to disable configuration changes as they apply to the MIC280's most critical functions: shutdown mode, and reporting diode faults and over-temperature events. LOCK provides a way to prevent malicious or accidental changes to the MIC280 registers that might prevent a system from responding properly to critical events. Once L0, L1, or L2 has been set, the global interrupt enable bit, IE, will be set and fixed. It cannot subsequently be cleared. Its state will be reflected in the configuration register. The bits in LOCK can only be set once. That is, once a bit is set, it cannot be reset until the MIC280 is power-cycled or a warm reset is performed by setting RST in the configuration register. The warm reset function can be disabled by setting L4 in LOCK. If L4 is set, locked settings cannot be changed during operation and warm resets cannot be performed; only a power-cycle will reset the locked state(s).

If L0 is set, the values of IM0 and CRIT0 become fixed and unchangeable. That is, writes to CRIT0 and the corresponding interrupt enable bit are locked out. A local over-temperature event will generate an interrupt regardless of the setting of IE or its interrupt mask bit.

If L1 is set, the values of IM1 and CRIT1 become fixed and unchangeable. A remote over-temperature event will generate an interrupt regardless of the setting of IE or its interrupt mask bit. Similarly, setting L2 will fix the state of IM2, allowing the system to permanently enable or disable diode fault interrupts. A diode fault will generate an interrupt regardless of the setting of IE or its interrupt mask bit.

L3 can be used to lock out shutdown mode. If L3 is set, the MIC280 will not shut down under any circumstances. Attempts to set the SHDN bit will be ignored and all chip functions will remain operational. If L3 is set while the MIC280 is in shutdown mode, it will immediately exit shutdown mode and resume normal operation. It will not be possible to subsequently re-enter shutdown mode.

Setting L4 disables the RST bit in the configuration register, preventing the host from initiating a warm reset. Writes to RST will be completely ignored if L4 is set.

LOCK BIT	FUNCTION LOCKED	RESPONSE WHEN SET
L0	Local over-temperature detection	IM0 fixed at 1, writes to CRIT0 locked-out; IE permanently set
L1	Remote over-temperature detection	IM1 fixed at 1; writes to CRIT1 locked-out; IE permanently set
L2	Diode fault interrupts locked on or off	IM2 fixed at current state; IE permanently set if IM2=1
L3	Shutdown mode	SHDN fixed at 0; exit shutdown if SHDN=1 when L3 is set
L4	Warm resets	RST bit disabled; cannot initiate Warm resets

Table 7: Lock bit functionality

Detailed Register Descriptions

Local Temperature Result Register (TEMP0)
8-bits, read-only

Local Temperature Result Register							
D[7] read-only	D[6] read-only	D[5] read-only	D[4] read-only	D[3] read-only	D[2] read-only	D[1] read-only	D[0] read-only
Temperature Data from ADC							

Bit	Function	Operation
D[7:0]	Measured temperature data for the local zone.	Read only

Power-up default value: $0000\ 0000_b = 00_h$ (0°C)**

Read command byte: $0000\ 0000_b = 00_h$

Each LSB represents one degree centigrade. The values are in a two's complement binary format such that 0°C is reported as $0000\ 0000_b$. See Temperature Data Format (above) for more details.

**TEMP0 will contain measured temperature data after the completion of one conversion.

Remote Temperature Result High-Byte Register (TEMP1h)
8-bits, read only

Remote Temperature Result High-Byte Register							
D[7] read-only	D[6] read-only	D[5] read-only	D[4] read-only	D[3] read-only	D[2] read-only	D[1] read-only	D[0] read-only
Temperature Data from ADC							

Bit	Function	Operation
D[7:0]	Measured temperature data for the remote zone, most significant byte.	Read only

Power-up default value: $0000\ 0000_b = 00_h$ (0°C)**

Read command byte: $0000\ 0001_b = 01_h$

Each LSB represents one degree centigrade. The values are in a two's complement binary format such that 0°C is reported as 0000 0000b. See Temperature Data Format (above) for more details.

TEMP1h can be read using either a Read_Byte operation or a Read_Word operation. Using Read_Byte will yield the 8-bit value in TEMP1h. The complete remote temperature result in both TEMP1h and TEMP1l may be obtained by performing a Read_Word operation on TEMP1h. The MIC280 will respond to a Read_Word with a command byte of 01h (TEMP1h) by returning the value in TEMP1h followed by the value in TEMP1l. This guarantees that the data in both registers is from the same temperature-to-digital conversion cycle. The Read_Word operation is diagramed in Figure 3. This is the only MIC280 register that supports Read_Word.

**TEMP1h will contain measured temperature data after the completion of one conversion.

Status Register (STATUS)
8-bits, read-only

Status Register							
D[7] read-only	D[6] read-only	D[5] read-only	D[4] read-only	D[3] read-only	D[2] read-only	D[1] read-only	D[0] read-only
S7	S6	S5	S4	S3	S2	S1	S**0**

Bit(s)	Function	Operation*
S7	Data ready	1 = data available 0 = ADC busy
S6	Local high temperature event	1 = event occurred, 0 = none
S5	Local low temperature event	1 = event occurred, 0 = none
S4	Remote high temperature event	1 = event occurred, 0 = none
S3	Remote low temperature event	1 = event occurred, 0 = none
S2	Diode fault	1 = fault, 0 = none
S1	Remote over-temperature event	1 = event occurred, 0 = none
S0	Local over-temperature event	1 = event occurred, 0 = none

* All status bits are cleared after any read operation is performed on STATUS.

Power-up default value: $0000\ 0000_b = 00_h$ (no events pending)

Read command byte: $0000\ 0010_b = 02_h$

The power-up default value is 00h. Following the first conversion, however, any of the status bits may be set depending on the measured temperature results or the existence of a diode fault.

Configuration Register (CONFIG)
8-bits, read/write

Configuration Register							
D[7] read/write	D[6] read/write	D[5] reserved	D[4] reserved	D[3] reserved	D[2] reserved	D[1] reserved	D[0] reserved
Interrupt Enable (IE)	Shut-down (SHDN)	Fault Queue (FQ[1:0])		Resolution (RES[1:0])		Reserved	Reset (RST)

Bits(s)	Function	Operation*
IE	Interrupt enable	1 = interrupts enabled, 0 = disabled
SHDN	Selects operating mode: normal/shutdown	1 = shutdown, 0 = normal
FQ[1:0]	Depth of fault queue*	[00]=1, [01]=2, [10]=4, [11]=6
RES[1:0]	A/D converter resolution for external zone - affects conversion rate	[00]=9-bits, [01]=10-bits, [10]=11-bits, [11]=12-bits
D[1]	Reserved	always write as zero!
RST	Resets all MIC280 functions and restores the power-up default state	write only; 1 = reset, 0 = normal operation; disabled by setting L4

Power-up default value: $1000\ 0000_b = 80_h$ (Not in shutdown mode; Interrupts enabled; Fault queue depth=1; Resolution = 9 bits)

Read/Write command byte: $0000\ 0011_b = 03_h$

* Any write to CONFIG will result in the fault queues being purged and reset and any A/D conversion in progress being aborted and the result discarded. The A/D will begin a new conversion sequence once the write operation is complete.

Interrupt Mask Register (IMASK)
8-bits, read/write

Interrupt Mask Register							
D[7] read/write	D[6] read/write	D[5] read/write	D[4] read/write	D[3] read/write	D[2] read/write	D[1] read/write	D[0] read/write
IM7	IM6	IM 5	IM 4	IM 3	IM 2	IM 1	IM0

Bit(s)	Function	Operation*
IM7	Data ready event mask	1 = enabled, 0 = disabled
IM6	Local high temperature event mask	1 = enabled, 0 = disabled
IM5	Local low temperature event mask	1 = enabled, 0 = disabled
IM4	Remote high temperature event mask	1 = enabled, 0 = disabled
IM3	Remote low temperature event mask	1 = enabled, 0 = disabled
IM2	Diode fault mask	1 = enabled, 0 = disabled
IM1	Remote over-temperature event mask	1 = enabled, 0 = disabled
IM0	Local over-temperature event mask	1 = enabled, 0 = disabled

Power-up default value: $0000\ 0111_b = 07_h$ (Over-temp. and diode faults enabled)

Read/Write command byte: $0000\ 0100_b = 04_h$

Local Temperature High Limit Register (THIGH0)
8-bits, read/write

Local Temperature High Limit Register							
D[7] read/write	D[6] read/write	D[5] read/write	D[4] read/write	D[3] read/write	D[2] read/write	D[1] read/write	D[0] read/write
High temperature limit for local zone.							

Bit	Function	Operation
D[7:0]	High temperature limit for the local zone.	Read/write

Power-up default value: $0011\ 1100_b = 3C_h$ (60°C)

Read/Write command byte: $0000\ 0101_b = 05_h$

Each LSB represents one degree centigrade. The values are in a two's complement binary format such that 0°C is reported as $0000\ 0000_b$. See Temperature Data Format (above) for more details.

Any writes to a temperature limit register will result in the corresponding fault queue being purged and reset.

Local Temperature Low Limit Register (TLOW0)
8-bits, read/write

Local Temperature Low Limit Register							
D[7] read/write	D[6] read/write	D[5] read/write	D[4] read/write	D[3] read/write	D[2] read/write	D[1] read/write	D[0] read/write
Low temperature limit for local zone							

Bit	Function	Operation
D[7:0]	Low temperature limit for the local zone	Read/write

Power-up default value: 0000 0000_b = 00_h (0°C)

Read/Write command byte: 0000 0110_b = 06_h

Each LSB represents one degree centigrade. The values are in a two's complement binary format such that 0°C is reported as 0000 0000_b. See TEMPERATURE DATA FORMAT (above) for more details.

Any writes to a temperature limit register will result in the corresponding fault queue being purged and reset.

Remote Temperature High Limit High-Byte Register (THIGH1h)
8-bits, read/write

Remote Temperature High Limit High-Byte Register							
D[7] read/write	D[6] read/write	D[5] read/write	D[4] read/write	D[3] read/write	D[2] read/write	D[1] read/write	D[0] read/write
High temperature limit for remote zone, most significant byte.							

Bit	Function	Operation
D[7:0]	High temperature limit for the remote zone, most significant byte.	Read/write

Power-up default value: 0101 0000_b = 50_h (80°C)

Read/Write command byte: 0000 0111_b = 07_h

Each LSB represents one degree centigrade. The values are in a two's complement binary format such that 0°C is reported as 0000 0000_b. See TEMPERATURE DATA FORMAT (above) for more details.

Any writes to a temperature limit register will result in the corresponding fault queue being purged and reset.

Remote Temperature Low Limit High-Byte Register (TLOW1h)
8-bits, read/write

Remote Temperature Low Limit High-Byte Register							
D[7] read/write	D[6] read/write	D[5] read/write	D[4] read/write	D[3] read/write	D[2] read/write	D[1] read/write	D[0] read/write
Low temperature limit for remote zone, most significant byte.							

Bit	Function	Operation
D[7:0]	Low temperature limit for the remote zone, most significant byte.	Read/write

Power-up default value: $0000\ 0000_b = 00_h$ (0°C)

Read/Write command byte: $0000\ 1000_b = 08_h$

Each LSB represents one degree centigrade. The values are in a two's complement binary format such that 0°C is reported as 0000 0000b. See Temperature Data Format (above) for more details.

Any writes to a temperature limit register will result in the corresponding fault queue being purged and reset.

Security Register (LOCK)
8-bits, write once

Security Register							
D[7] reserved	D[6] reserved	D[5] reserved	D[4] read/ write-once	D[3] read/ write-once	D[2] read/ write-once	D[1] read/ write-once	D[0] read/ write-once
Reserved			L4	L3	L2	L1	L0

Bit	Function	Operation*
D[7:5]	Reserved	Always write as zero
L4	Warm reset lockout bit	1 = RST bit disabled; 0 = unlocked
L3	Shutdown mode lockout bit*	1= shutdown disabled; 0 = unlocked
L2	Diode fault event lock bit	1 = locked, 0 = unlocked
L1	Remote over-temperature event lock bit	1 = locked, 0 = unlocked
L0	Local over-temperature event lock bit	1 = locked, 0 = unlocked

Power-up default value: $0000\ 0000_b = 00_h$ (All events unlocked)

Read/Write command byte: $0000\ 1001_b = 09_h$

* If the chip is shutdown when L3 is set, the chip will exit shutdown mode and resume normal operation. It will not be possible to subsequently re-enter shutdown mode.

Remote Temperature Result Low-Byte Register (TEMP1l)
8-bits, read only

Remote Temperature Result Low-Byte Register							
D[7] read-only	D[6] read-only	D[5] read-only	D[4] read-only	D[3] reserved	D[2] reserved	D[1] reserved	D[0] reserved
Temperature data from ADC, least significant bits				Reserved - always reads zero			

Bit	Function	Operation
D[7:4]	Measured temperature data for the remote zone, least significant bits.	Read only
D[3:0]	Reserved	Always reads as zeroes

Power-up default value: $0000\ 0000_b = 00_h$ (0°C)**

Read command byte: $0001\ 0000_b = 10_h$

Each LSB represents one-sixteenth degree centigrade. The values are in a binary format such that 1/16th°C (0.0625°C) is reported as $0001\ 0000_b$. See Temperature Data Format (above) for more details.

TEMP1l can be accessed using a Read_Byte operation. However, the complete remote temperature result in both TEMP1h and TEMP1l may be obtained by performing a Read_Word operation on TEMP1h. The MIC280 will respond to a Read_Word with a command byte of 01h (TEMP1h) by returning the value in TEMP1h followed by the value in TEMP1l. This guarantees that the data in both registers is from the same temperature-to-digital conversion cycle. The Read_Word operation is diagramed in Figure 3. TEMP1h is the only MIC280 register that supports Read_Word.

**TEMP1l will contain measured temperature data after the completion of one conversion.

Remote Temperature High Limit Low-Byte Register (THIGH1l)
8-bits, read/write

Remote Temperature High Limit Low-Byte Register							
D[7] read/write	D[6] read/write	D[5] read/write	D[4] read/write	D[3] reserved	D[2] reserved	D[1] reserved	D[0] reserved
High temperature limit for remote zone, least significant bits.				Reserved - always reads zero			

Bit	Function	Operation
D[7:4]	High temperature limit for the remote zone, least significant bits.	Read/write
D[3:0]	Reserved.	Always reads as zeros

Power-up default value: $0000\ 0000_b = 00_h$ (0°C)

Read/Write command byte: $0001\ 0011_b = 13_h$

Each LSB represents one-sixteenth degree centigrade. The values are in a binary format such that 1/16th°C (0.0625°C) is reported as $0001\ 0000_b$. See Temperature Data Format (above) for more details.

Any writes to a temperature limit register will result in the corresponding fault queue being purged and reset.

Remote Temperature Low Limit Low-Byte Register (TLOW1l)
8-bits, read/write

Remote Temperature Low Limit Low-Byte Register							
D[7] read/write	D[6] read/write	D[5] read/write	D[4] read/write	D[3] reserved	D[2] reserved	D[1] reserved	D[0] reserved
Low temperature limit for remote zone, least significant bits.				Reserved - always reads zero.			

Bit	Function	Operation
D[7:4]	Low temperature limit for the remote zone, least significant bits.	Read/write
D[3:0]	Reserved	Always reads as zeros.

Power-up default value: $0000\ 0000_b = 00_h$ (0°C)

Read/Write command byte: $0001\ 0100_b = 14_h$

Each LSB represents one-sixteenth degree centigrade. The values are in a binary format such that 1/16th°C (0.0625°C) is reported as $0001\ 0000_b$. See Temperature Data Format (above) for more details.

Any writes to a temperature limit register will result in the corresponding fault queue being purged and reset.

Remote Over-Temperature Limit Register (CRIT1)
8-bit, read/write

Remote Over-Temperature Limit Register							
D[7] read/write	D[6] read/write	D[5] read/write	D[4] read/write	D[3] read/write	D[2] read/write	D[1] read/write	D[0] read/write
Over-temperature limit for remote zone.							

Bit	Function	Operation
D[7:0]	Over-temperature limit for the remote zone.	Read/write

Power-up default value: $0110\ 0100_b = 64_h$ (100°C)

Read/Write command byte: $0001\ 1001_b = 19_h$

Each LSB represents one degree centigrade. The values are in a two's complement binary format such that 0°C is reported as $0000\ 0000_b$. SeeTemperature Data Format (above) for more details.

Any writes to a temperature limit register will result in the corresponding fault queue being purged and reset.

Local Over-Temperature Limit Register (CRIT0)
8-bits, read/write

Local Over-Temperature Limit Register							
D[7] read/write	D[6] read/write	D[5] read/write	D[4] read/write	D[3] read/write	D[2] read/write	D[1] read/write	D[0] read/write
Over-temperature limit for local zone.							

Bit	Function	Operation
D[7:0]	Over-temperature limit for the local zone.	Read/write

Power-up default value: $0100\ 0110_b = 46_h$ (70°C)

Read/Write command byte: $0010\ 0000_b = 20_h$

Each LSB represents one degree centigrade. The values are in a two's complement binary format such that 0°C is reported as $0000\ 0000_b$. SeeTemperature Data Format (above) for more details.

Any writes to a temperature limit register will result in the corresponding fault queue being purged and reset.

Manufacturer ID Register (MFG_ID)
8-bits, read only

Manufacturer ID Register							
D[7] read only	D[6] read only	D[5] read only	D[4] read only	D[3] read only	D[2] read only	D[1] read only	D[0] read only
0	0	1	0	1	0	1	0

BIT(S)	FUNCTION	Operation*
D[7:0]	Identifies Micrel as the manufacturer of the device. Always returns $2A_h$.	Read only. Always returns $2A_h$

Power-up default value: $0010\ 1010_b = 2A_h$

Read command byte: $1111\ 1110_b = FE_h$

Die Revision Register (DIE_REV)
8-bits, read only

Die Revision Register							
D[7] read-only	D[6] read-only	D[5] read-only	D[4] read-only	D[3] reserved	D[2] reserved	D[1] reserved	D[0] reserved
MIC280 DIE REVISION NUMBER							

Bit(s)	Function	Operation*
D[7:0]	Identifies the device revision number	Read only.

Power-up default value: $[\text{Device revision number}]_h$

Read command byte: $1111\ 1111_b = FF_h$

Application Information

Remote Diode Selection

Most small-signal PNP transistors with characteristics similar to the JEDEC 2N3906 will perform well as remote temperature sensors. Table 8 lists several examples of such parts that Micrel has tested for use with the MIC280. Other transistors equivalent to these should also work well.

Vendor	Part Number	Package
Fairchild Semiconductor	MMBT3906	SOT-23
On Semiconductor	MMBT3906L	SOT-23
Philips Semiconductor	PMBT3906	SOT-23
Samsung Semiconductor	KST3906-TF	SOT-23

Table 8: Transistors suitable for use as remote diodes

Minimizing Errors

Self-Heating

One concern when using a part with the temperature accuracy and resolution of the MIC280 is to avoid errors induced by self-heating ($V_{DD} \times I_{DD}$) + ($V_{OL} \times I_{OL}$). In order to understand what level of error this might represent, and how to reduce that error, the dissipation in the MIC280 must be calculated and its effects reduced to a temperature offset. The worst-case operating condition for the MIC280 is when V_{DD} = 3.6V. The maximum power dissipated in the part is given in the following equation:

$$P_D = [(I_{DD} \times V_{DD}) + (I_{OL(DATA)} \times V_{OL(DATA)}) + (I_{OL(/INT)} \times V_{OL(/INT)}]$$

$$P_D = [(0.4mA \times 3.6V) + (6mA \times 0.5V) + (6mA \times 0.5V)]$$

$$P_D = 7.44mW$$

$R_{\theta(J-A)}$ of SOT23-6 package is 230°C/W

Theoretical Maximum ΔT_J due to self-heating is:

$$7.44mW \times 230°C/W = 1.7112°C$$

Worst-case self-heating

In most applications, the /INT output will be low for at most a few milliseconds before the host resets it back to the high state, making its duty cycle low enough that its contribution to self-heating of the MIC280 is negligible. Similarly, the DATA pin will in all likelihood have a duty cycle of substantially below 25% in the low state. These considerations, combined with more typical device and application parameters, give a better system-level view of device self-heating in interrupt-mode usage given in the following equation:

$$(0.23mA\ I_{DD(typ)} \times 3.3V) + (25\% \times 1.5mA\ I_{OL(DATA)} \times 0.15V) + (1\% \times 1.5mA\ I_{OL(/INT)} \times 0.15V) = 0.817mW$$

$$\Delta T_J = (0.8175mW \times 230°C/W) = 0.188°C$$

Real-world self-heating example

In any application, the best test is to verify performance against calculation in the final application environment. This is especially true when dealing with systems for which temperature data may be poorly defined or unobtainable except by empirical means.

Series Resistance

The operation of the MIC280 depends upon sensing the V_{CB-E} of a diode-connected PNP transistor ("diode ") at two different current levels. For remote temperature measurements, this is done using an external diode connected between T1 and ground. Since this technique relies upon measuring the relatively small voltage difference resulting from two levels of current through the external diode, any resistance in series with the external diode will cause an error in the temperature reading from the MIC280. A good rule of thumb is this: for each ohm in series with the external transistor, there will be a 0.8°C error in the MIC280's temperature measurement. It is not difficult to keep the series resistance well below an ohm (typically < 0.1), so this will rarely be an issue.

Filter Capacitor Selection

It is usually desirable to employ a filter capacitor between the T1 and GND pins of the MIC280. The use of this capacitor is recommended in environments with a lot of high frequency noise (such as digital switching noise), or if long wires are used to conect to the remote diode. The maximum recommended total capacitance from the T1 pin to GND is 2200pF. This typically suggests the use of a 1800pF NP0 or C0G ceramic capacitor with a 10% tolerance. If the remote diode is to be at a distance of more than 6"-12" from the MIC280, using twisted pair wiring or shielded microphone cable for the connections to the diode can significantly reduce noise pickup. If using a long run of shielded cable, remember to subtract the cable's conductor-to-shield capacitance from the 2200pF maximum total capacitance.

Layout Considerations

The following guidelines should be kept in mind when designing and laying out circuits using the MIC280:

1. Place the MIC280 as close to the remote diode as possible, while taking care to avoid severe noise sources such as high frequency power transformers, CRTs, memory and data busses, and the like.
2. Since any conductance from the various voltages on the PC Board and the T1 line can induce serious errors, it is good practice to guard the remote diode's emitter trace with a pair of ground traces. These ground traces should be returned to the MIC280's own ground pin. They should not be grounded at any other part of their run. However, it is highly desirable to use these guard traces to carry the diode's own ground return back to the ground pin of the MIC280, thereby providing a Kelvin connection for the base of the diode. See Figure 6.
3. When using the MIC280 to sense the temperature of a processor or other device which has an integral thermal diode, e.g., Intel's Pentium II, III, IV, AMD Athlon CPU, Xilinx Virtex FPGAs, connect the emitter and base of the remote sensor to the MIC280 using the guard traces and Kelvin return shown in Figure 6. The collector of the remote diode is typically inaccessible to the user

on these devices. To allow for this, the MIC280 has superb rejection of noise appearing from collector to GND.

4. Due to the small currents involved in the measurement of the remote diode's ΔV_{BE}, it is important to adequately clean the PC board after soldering to prevent current leakage. This is most likely to show up as an issue in situations where water-soluble soldering fluxes are used.

5. In general, wider traces for the ground and T1 lines will help reduce susceptibility to radiated noise (wider traces are less inductive). Use trace widths and spacing of 10 mils wherever possible and provide a ground plane under the MIC280 and under the connections from the MIC280 to the remote diode. This will help guard against stray noise pickup.

6. Always place a good quality power supply bypass capacitor directly adjacent to, or underneath, the MIC280. This should be a 0.1 µF ceramic capacitor. Surface-mount parts provide the best bypassing because of their low inductance.

7. When the MIC280 is being powered from particularly noisy power supplies, or from supplies which may have sudden high-amplitude spikes appearing on them, it can be helpful to add additional power supply filtering. This should be implemented as a 100Ω resistor in series with the part's V_{DD} pin, and a 4.7 µF, 6.3V electrolytic capacitor from V_{DD} to GND. See Figure 7.

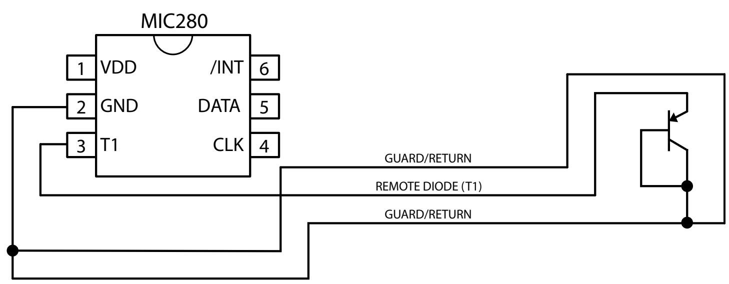


Figure 6. Guard Traces/Kelvin Ground Returns

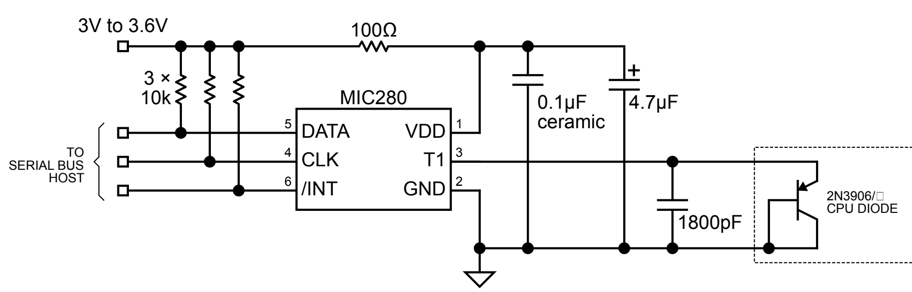
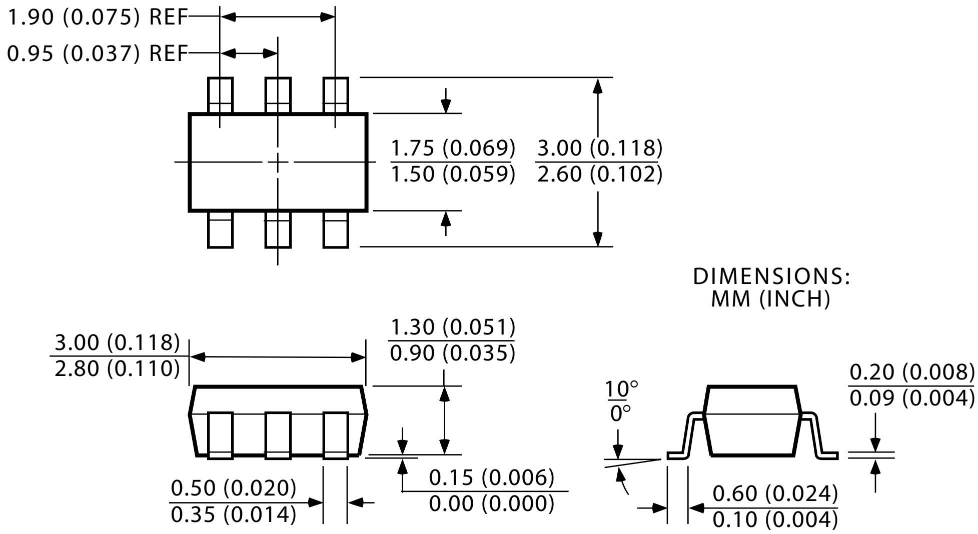


Figure 7. V_{DD} Decoupling for Very Noisy Supplies

Package Information



6-Lead SOT23 (M6)

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