

### General Description

The MIC281 is a digital thermal sensor capable of measuring the temperature of a remote PN junction. It is optimized for applications favoring low cost and small size. 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® FPGAs.

The MIC281 is 100% software and hardware backward compatible with the MIC280 and features the same industry-leading noise performance and small size. The advanced integrating A/D converter and analog front-end reduce errors due to noise for maximum accuracy and minimum guardbanding.

A 2-wire SMBus 2.0-compatible serial interface is provided for host communication. The clock and data 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 performance, low power, and small size make the MIC281 an excellent choice for cost-sensitive thermal management applications.

Datasheets and support documentation are available on Micrel's website at: [www.micrel.com](http://www.micrel.com).

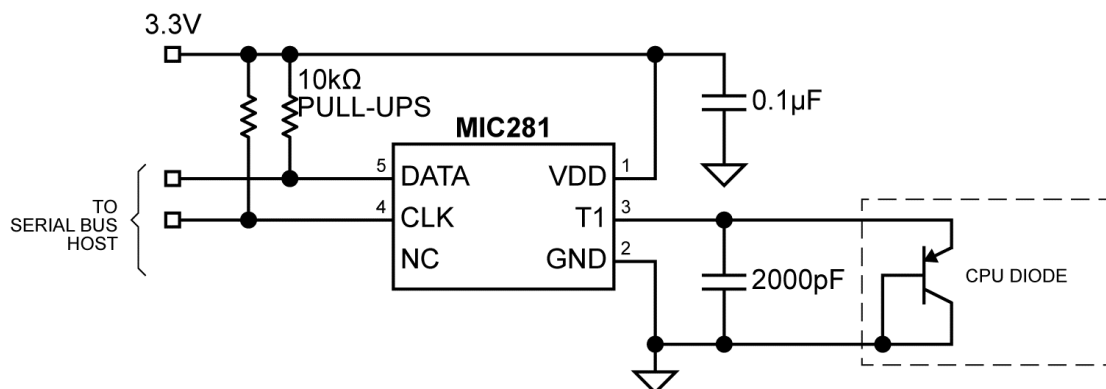
### Features

- Remote temperature measurement using embedded thermal diodes or commodity transistors
- Accurate remote sensing:  $\pm 3^{\circ}\text{C}$  max.,  $0^{\circ}\text{C}$  to  $100^{\circ}\text{C}$
- Excellent noise rejection
- I<sup>2</sup>C and SMBus 2.0-compatible serial interface
- SMBus timeout to prevent bus lockup
- Voltage tolerant I/Os
- Low power shutdown mode
- Failsafe response to diode faults
- 3.0V to 3.6V power supply range
- Available in IttyBitty SOT23-6 package

### Applications

- Desktop, server, and notebook computers
- Set-top boxes
- Game consoles
- Appliances

### Typical Application



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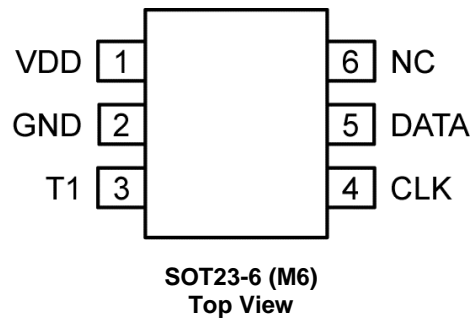
## Ordering Information

Part Number	Marking <sup>(1)</sup>	Slave Address	Ambient Temp. Range	Package
MIC281-0YM6	<u>T</u> B00	1001 000X <sub>b</sub>	-55° to +125°C	SOT23-6
MIC281-1YM6	<u>T</u> B01	1001 001X <sub>b</sub>	-55° to +125°C	SOT23-6
MIC281-2YM6	<u>T</u> B02	1001 010X <sub>b</sub>	-55° to +125°C	SOT23-6
MIC281-3YM6	<u>T</u> B03	1001 011X <sub>b</sub>	-55° to +125°C	SOT23-6
MIC281-4YM6	<u>T</u> B04	1001 100X <sub>b</sub>	-55° to +125°C	SOT23-6
MIC281-5YM6	<u>T</u> B05	1001 101X <sub>b</sub>	-55° to +125°C	SOT23-6
MIC281-6YM6	<u>T</u> B06	1001 110X <sub>b</sub>	-55° to +125°C	SOT23-6
MIC281-7YM6	<u>T</u> B07	1001 111X <sub>b</sub>	-55° to +125°C	SOT23-6

**Note:**

- Underbar ( ) may not be to scale.

## Pin Configuration



## Pin Description

Pin Number	Pin Name	Pin Function
1	VDD	Analog input: Power supply input to the IC.
2	GND	Ground return for all IC functions.
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	NC	No connection: Must be left unconnected.

**Absolute Maximum Ratings<sup>(2)</sup>**

Power Supply Voltage ( $V_{DD}$ ).....	+3.8V
Voltage on T1 .....	-0.3V to $V_{DD} + 0.3V$
Voltage on CLK, DATA .....	-0.3V to 6V
Current into Any Pin .....	$\pm 10mA$
Power Dissipation, $T_A = +125^\circ C$ .....	109mW
Storage Temperature ( $T_S$ ).....	$-65^\circ C$ to $+150^\circ C$
<b>ESD Ratings<sup>(4)</sup></b>	
Human Body Model.....	1.5kV
Machine Model .....	200V
<b>Soldering (SOT23-6 package)</b>	
Vapor Phase (60s) .....	$220^\circ C^{+5}/_{-0}^\circ C$
Infrared (15s).....	$235^\circ C^{+5}/_{-0}^\circ C$

**Operating Ratings<sup>(3)</sup>**

Power Supply Voltage ( $V_{DD}$ ) .....	+3.0V to +3.6V
Ambient Temperature Range ( $T_A$ ) .....	$-55^\circ C$ to $+125^\circ C$
<b>Package Thermal Resistance</b>	
SOT23-6 ( $\theta_{JA}$ ) .....	$230^\circ C/W$

**Electrical Characteristics<sup>(5)</sup>**

$V_{DD} = 3.3V$ ;  $T_A = 25^\circ C$ , unless noted. **Bold** values indicate  $T_{MIN} \leq T_A \leq T_{MAX}$ , unless noted<sup>(3)</sup>.

Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
<b>Power Supply</b>						
$I_{DD}$	Supply Current	T1 open; CLK = DATA = High; Normal mode		0.23	<b>0.4</b>	mA
		Shutdown mode; T1 open; <a href="#">Note 7</a> CLK = 100kHz		9		$\mu A$
		Shutdown mode; T1 open; CLK = DATA = High		6		$\mu A$
$t_{POR}$	Power-on Reset Time, <a href="#">Note 7</a>	$V_{DD} > V_{POR}$		200		$\mu s$
$V_{POR}$	Power-on Reset Voltage	All registers reset to default values; A/D conversions initiated		2.65	<b>2.95</b>	V
$V_{HYST}$	Power-on Reset Hysteresis Voltage, <a href="#">Note 7</a>			300		mV
<b>Temperature-to-Digital Converter Characteristics</b>						
	Accuracy, <a href="#">Notes 7, 8, 9</a>	$0^\circ C \leq T_D \leq 100^\circ C$ , $0^\circ C < T_A < 85^\circ C$ ; $3.15V < V_{DD} < 3.45V$		<b><math>\pm 1</math></b>	<b><math>\pm 3</math></b>	$^\circ C$
		$-40^\circ C \leq T_D \leq 125^\circ C$ , $0^\circ C < T_A < 85^\circ C$ ; $3.15V < V_{DD} < 3.45V$		<b><math>\pm 2</math></b>	<b><math>\pm 5</math></b>	$^\circ C$
$t_{CONV}$	Conversion Time <a href="#">Note 7</a>			200	<b>240</b>	ms
<b>Remote Temperature Input, T1</b>						
$I_F$	Current into External Diode, <a href="#">Note 7</a>	T1 forced to 1.0V, high level		192	<b>400</b>	$\mu A$
		Low level	<b>7</b>	12		$\mu A$

## Electrical Characteristics<sup>(5)</sup> (Continued)

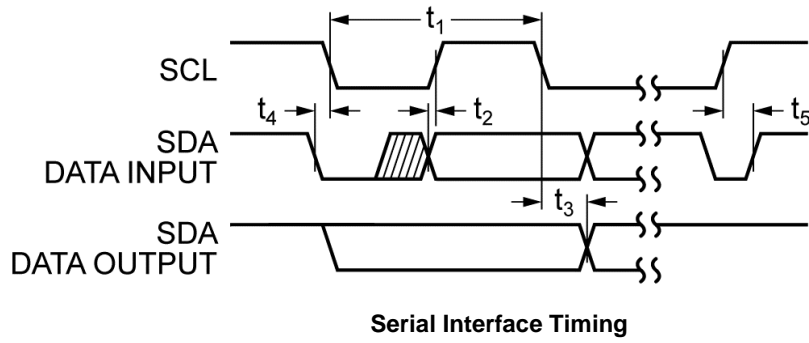
$V_{DD} = 3.3V$ ;  $T_A = 25^\circ C$ , unless noted. **Bold** values indicate  $T_{MIN} \leq T_A \leq T_{MAX}$ , unless noted<sup>(3)</sup>.

Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
<b>Serial Data I/O Pin, DATA</b>						
$V_{OL}$	Low Output Voltage, <a href="#">Note 6</a>	$I_{OL} = 3mA$			<b>0.3</b>	V
		$I_{OL} = 6mA$			<b>0.5</b>	V
$V_{IL}$	Low Input Voltage	$3V \leq V_{DD} \leq 3.6V$			<b>0.8</b>	V
$V_{IH}$	High Input Voltage	$3V \leq V_{DD} \leq 3.6V$	<b>2.1</b>		<b>5.5</b>	V
$C_{IN}$	Input Capacitance	<a href="#">Note 7</a>		10		pF
$I_{LEAK}$	Input Current				<b><math>\pm 1</math></b>	$\mu A$
<b>Serial Clock Input, CLK</b>						
$V_{IL}$	Low Input Voltage	$3V \leq V_{DD} \leq 3.6V$			<b>0.8</b>	V
$V_{IH}$	High Input Voltage	$3V \leq V_{DD} \leq 3.6V$	<b>2.1</b>		<b>5.5</b>	V
$C_{IN}$	Input Capacitance	<a href="#">Note 7</a>		10		pF
$I_{LEAK}$	Input Current				<b><math>\pm 1</math></b>	$\mu A$
<b>Serial Interface Timing</b>						
$t_1$	CLK (clock) Period		<b>2.5</b>			$\mu s$
$t_2$	Data In Setup Time to CLK High		<b>100</b>			ns
$t_3$	Data Out Stable after CLK Low		<b>300</b>			ns
$t_4$	Data Low Setup Time to CLK Low	Start Condition	<b>100</b>			ns
$t_5$	Data High Hold Time after CLK High	Stop Condition	<b>100</b>			ns
$t_{TO}$	Bus Timeout		<b>25</b>	30	<b>35</b>	ms

### Notes:

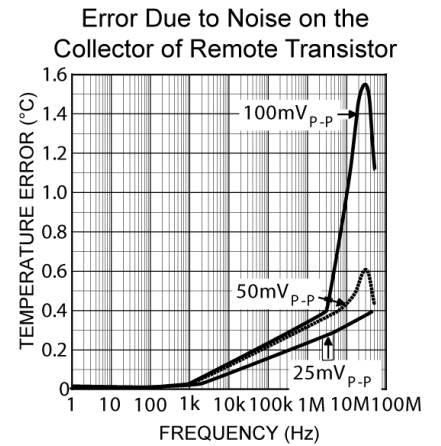
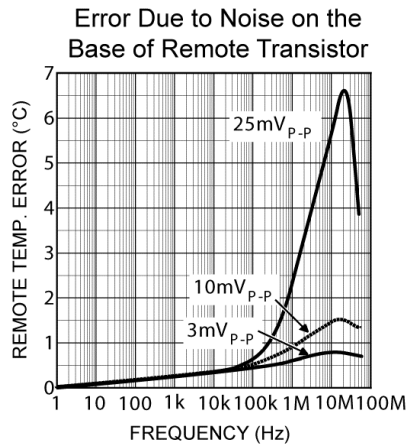
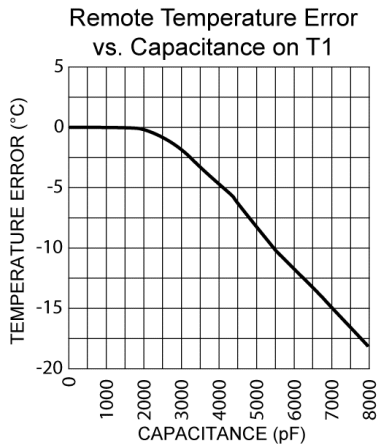
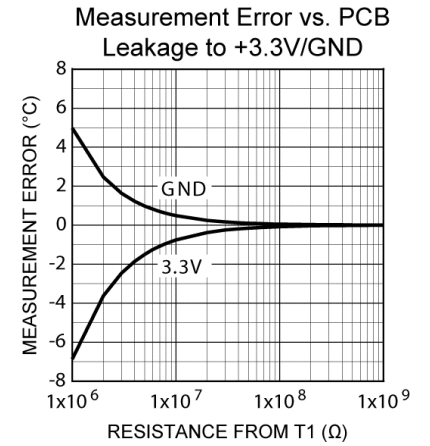
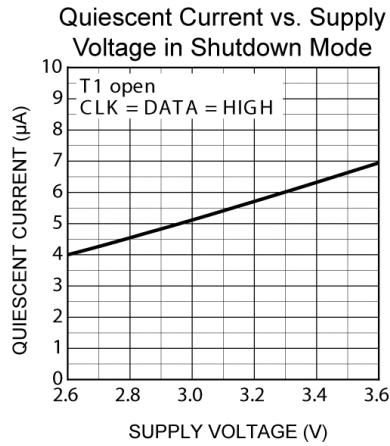
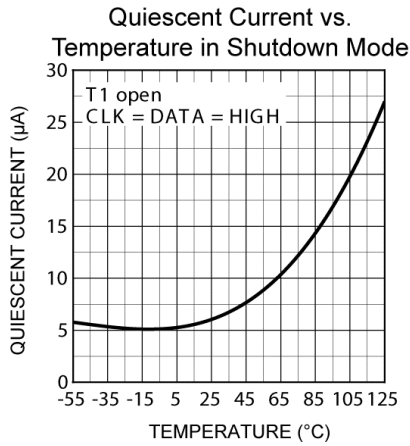
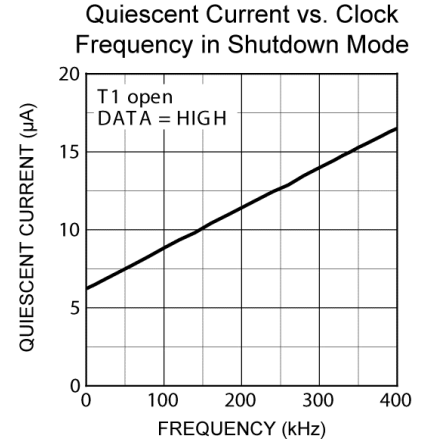
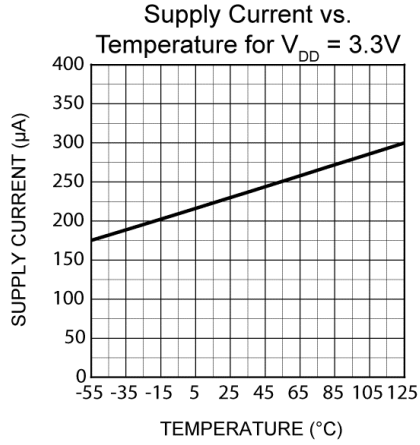
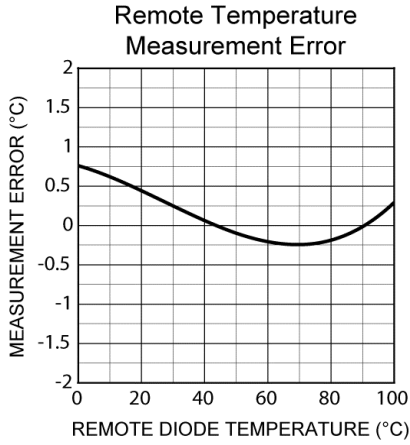
- Exceeding the absolute maximum ratings may damage the device.
- The device is not guaranteed to function outside its operating ratings. Final test on outgoing product is performed at  $T_A = 25^\circ C$ .
- Devices are ESD sensitive. Handling precautions are recommended. Human body model, 1.5k $\Omega$  in series with 100pF.
- Specification for packaged product only.
- Current into the DATA pin will result in self-heating of the device. Sink current should be minimized for best accuracy.
- Guaranteed by design over the operating temperature range. Not 100% production tested.
- Accuracy specification does not include quantization noise, which may be up to  $\pm 1/2$  LSB.
- $T_D$  is the temperature of the remote diode junction. Testing is performed using a single unit of one of the transistors listed in Table 4.

### Timing Diagram



## Typical Characteristics

$V_{DD} = 3.3V$ ;  $T_A = 25^\circ C$ , unless otherwise noted.



## Functional Description

### Serial Port Operation

The MIC281 uses standard SMBus Write\_Byte and Read\_Byte 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 MIC281, 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. These protocols are shown in Figures 1 and 2.

The Command byte is eight bits (one byte) wide. This byte carries the address of the MIC281 register to be operated upon. The command byte values corresponding to the various MIC281 registers are shown in Table 1. Other command byte values are reserved, and should not be used.

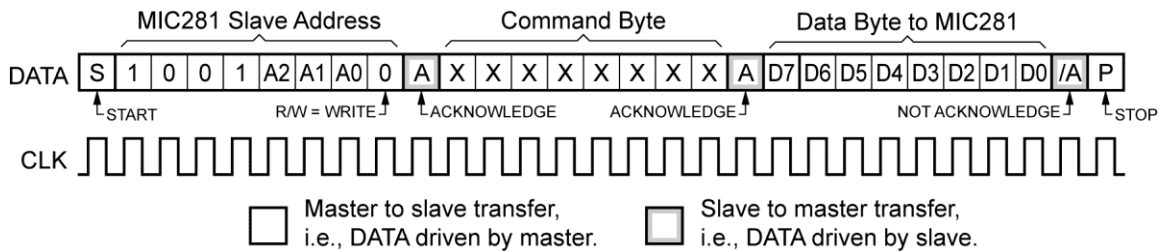


Figure 1. Write\_Byte Protocol

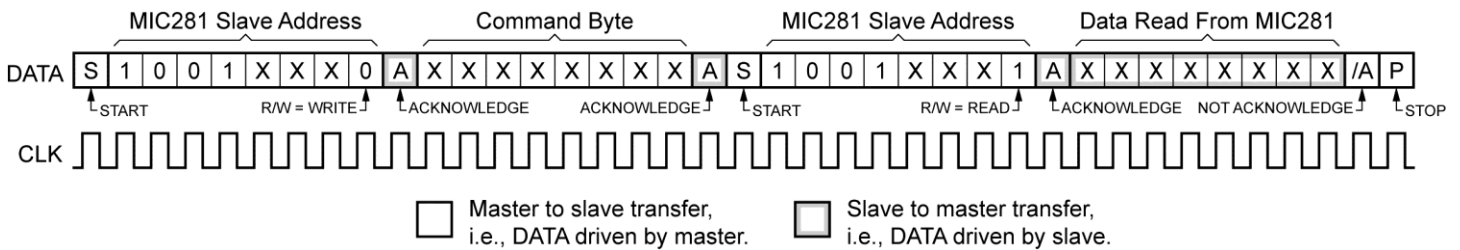


Figure 2. Read\_Byte Protocol

Table 1. MIC281 Register Addresses

Target Register		Command Byte Value		Power-on Default
Label	Description	Read	Write	
TEMP	Remote temperature result	01 <sub>h</sub>	N/A	00 <sub>h</sub> (0°C)
CONFIG	Configuration	03 <sub>h</sub>	03 <sub>h</sub>	80 <sub>h</sub>
MFG_ID	Manufacturer identification	FE <sub>h</sub>	N/A	2A <sub>h</sub>
DEV_ID	Device and revision identification	FF <sub>h</sub>	N/A	0X <sub>h</sub> <sup>(10)</sup>

**Note:**

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

## Slave Address

The MIC281 will only respond to its own unique slave address. A match between the MIC281's address and the address specified in the serial bit stream must be made to initiate communication. The MIC281'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 and the Ordering Information table.

**Table 2. MIC281 Slave Addresses**

Part Number	Slave Address
MIC281-0YM6	1001 000 <sub>b</sub> = 90 <sub>h</sub>
MIC281-1YM6	1001 001 <sub>b</sub> = 92 <sub>h</sub>
MIC281-2YM6	1001 010 <sub>b</sub> = 94 <sub>h</sub>
MIC281-3YM6	1001 011 <sub>b</sub> = 96 <sub>h</sub>
MIC281-4YM6	1001 100 <sub>b</sub> = 98 <sub>h</sub>
MIC281-5YM6	1001 101 <sub>b</sub> = 9A <sub>h</sub>
MIC281-6YM6	1001 110 <sub>b</sub> = 9C <sub>h</sub>
MIC281-7YM6	1001 111 <sub>b</sub> = 9E <sub>h</sub>

## Temperature Data Format

The least-significant bit of the temperature register represents one degree Centigrade. The values are in a two's complement format, wherein the most significant bit (D7) represents the sign: zero for positive temperatures and one for negative temperatures. Table 3 shows examples of the data format used by the MIC281 for temperatures.

**Table 3. Digital Temperature Format**

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

## Diode Faults

The MIC281 is designed to respond in a failsafe manner to diode faults. If an internal or external fault occurs in the temperature sensing circuitry, such as T1 being open or shorted to VDD or GND, the temperature result will be reported as the maximum full-scale value of +127°C. Note that diode faults will not be detected until the first A/D conversion cycle is completed following power-up or exiting shutdown mode.

## Shutdown Mode

Setting the shutdown bit in the configuration register will cause the MIC281 to cease operation. The A/D converter will stop and power consumption will drop to the I<sub>SHDN</sub> level. No registers will be affected by entering shutdown mode. The last temperature reading will persist in the TEMP register.

## Detailed Register Descriptions

### Remote Temperature Result (TEMP) 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 remote zone.	Read only

Power-up default value:  $0000\ 0000_b = 00_h = (0^\circ\text{C})^{(11)}$

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

Each LSB represents one degree centigrade. The values are in a twos complement binary format such that  $0^\circ\text{C}$  is reported as  $0000\ 0000_b$ . See the Temperature Data Format section for more details.

**Note:**

11. TEMP will contain measured temperature data after the completion of one conversion.

### Configuration Register (CONFIG) 8-bits, Read/Write

Configuration Register							
D[7] reserved	D[6] reserved	D[5] reserved	D[4] reserved	D[3] reserved	D[2] reserved	D[1] reserved	D[0] write-only
Reserved	Shutdown (SHDN)	Reserved					

Bit	Function	Operation <sup>(12)</sup>
D7	Reserved	Always writes as zero; reads undefined
D6	Shutdown bit	0 = normal operation; 1 = shutdown
D[5:0]	Reserved	Always writes as zero; reads undefined

**Note:**

12. Any write to CONFIG will result in 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.

Power-up default value:  $x0xx\ xxxx_b$  (not in shutdown mode)

Command byte:  $0000\ 0011_b = 03_h$

**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	Function	Operation
D[7:0]	Identifies Micrel, Inc. as the manufacturer of the device	Read only. Always returns 2A <sub>h</sub>

Power-up default value: 0010 1010<sub>b</sub> = 2A<sub>h</sub>

Read command byte: 1111 1110<sub>b</sub> = FE<sub>h</sub>

**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] read-only	D[2] read-only	D[1] read-only	D[0] read-only
MIC281 die revision number							

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

Power-up default value: [device revision number]<sub>h</sub>

Read command byte: 1111 1111<sub>b</sub> = FF<sub>h</sub>

## Application Information

### Remote Diode Section

Most small-signal PNP transistors with characteristics similar to the JEDEC 2N3906 will perform well as remote temperature sensors. Table 4 lists several examples of such parts that Micrel has tested for use with the MIC281. Other transistors equivalent to these should also work well.

**Table 4. Transistors suitable for use as remote diodes**

Vendor	Part Number	Package
Fairchild Semiconductor	MMBT3906	SOT-23
On Semiconductor	MMBT3906L	SOT-23
Philips Semiconductor	SMBT3906	SOT-23
Samsung Semiconductor	KST3906-TF	SOT-23

### Minimizing Errors

#### Self-Heating

One concern when using a part with the temperature accuracy and resolution of the MIC281 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 MIC281 must be calculated and its effects reduced to a temperature offset. The worst-case operating condition for the MIC281 is when  $V_{DD} = 3.6V$ . The maximum power dissipated in the part is given in the following equation:

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

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

$$P_D = 4.44mW$$

$R_{\theta(J-A)}$  of SOT23-6 package is 230°C/W, therefore the theoretical maximum self-heating is:

$$4.44mW \times 230^\circ C/W = 1.02^\circ C$$

In most applications, the DATA pin will 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. This is illustrated by the next equation. In any application, the best approach is to verify performance against calculation in the final application environment. This is especially true when dealing with systems for which some temperature data may be poorly defined or unobtainable except by empirical means.

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

$$P_D = [(0.23mA \times 3.3V) + (25\% \times 1.5mA \times 0.15V)] \quad P_D = 0.815mW$$

$R_{\theta(J-A)}$  of SOT23-6 package is 230°C/W, therefore the typical self-heating is:

$$0.815mW \times 230^\circ C/W = 0.188^\circ C$$

#### Series Resistance

The operation of the MIC281 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. Because 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 MIC281. A good rule of thumb is that for each ohm in series with the external transistor, there will be a 0.9°C error in the MIC281's temperature measurement. It is not difficult to keep the series resistance well below an ohm (typically <0.1Ω), 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 MIC281. The use of this capacitor is recommended in environments with a lot of high frequency noise (such as digital switching noise), or if long traces or wires are used to connect to the remote diode. The recommended total capacitance from the T1 pin to GND is 2200pF. If the remote diode is to be at a distance of more than six-to-twelve inches from the MIC281, 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 total capacitance.

### Layout Considerations

The following guidelines should be kept in mind when designing and laying out circuits using the MIC281.

1. Place the MIC281 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. Because 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 MIC281'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 MIC281, thereby providing a Kelvin connection for the base of the diode. See Figure 3.
3. When using the MIC281 to sense the temperature of a processor or other device which has an integral thermal diode, e.g., Intel's Pentium III, connect the emitter and base of the remote sensor to the MIC281 using the guard traces and Kelvin return shown in Figure 3. The collector of the remote diode is typically inaccessible to the user on these devices.
4. Due to the small currents involved in the measurement of the remote diode's  $\Delta V_{BE}$ , 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 10mm wherever possible and provide a ground plane under the MIC281 and under the connections from the MIC281 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 MIC281. This should be a 0.1 $\mu$ F ceramic capacitor. Surface-mount parts provide the best bypassing because of their low inductance.

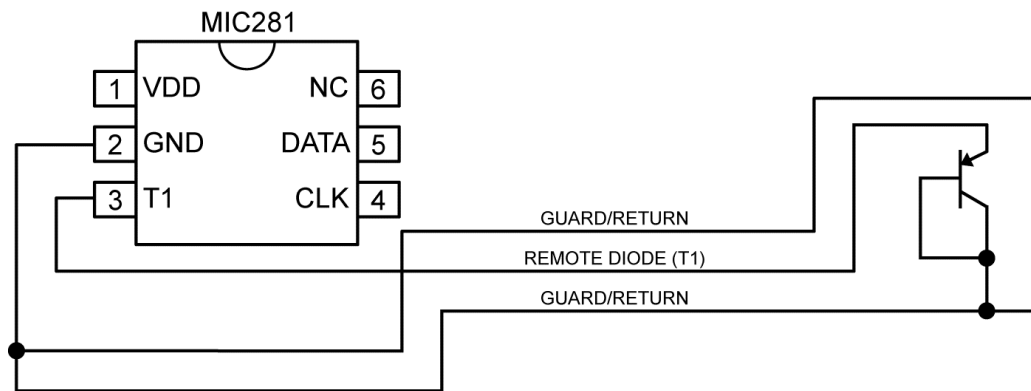
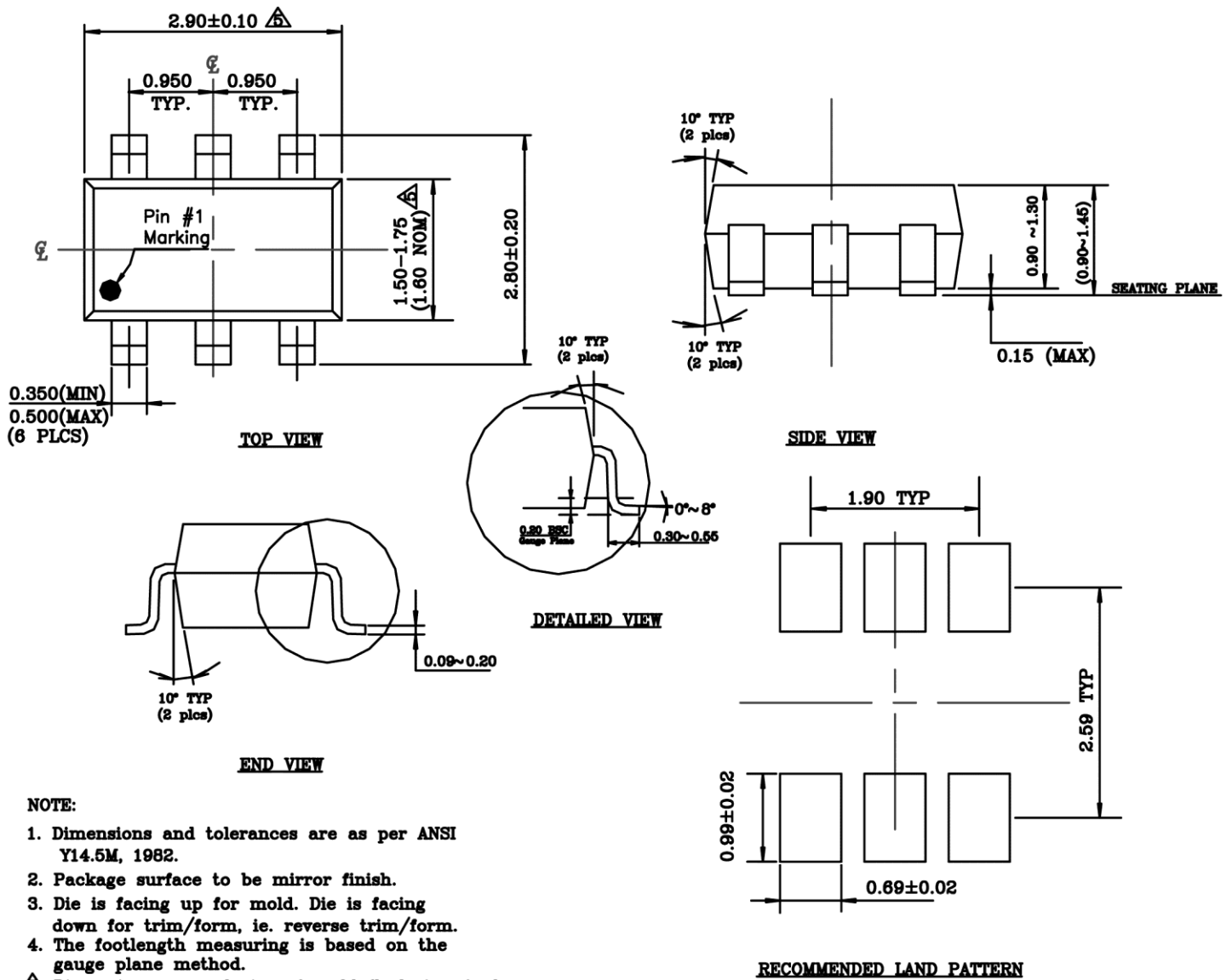


Figure 3. Guard Traces/Kelvin Ground Returns

Package Information<sup>(13)</sup>



NOTE:

1. Dimensions and tolerances are as per ANSI Y14.5M, 1982.
  2. Package surface to be mirror finish.
  3. Die is facing up for mold. Die is facing down for trim/form, ie. reverse trim/form.
  4. The footlength measuring is based on the gauge plane method.
- $\Delta$  Dimension are exclusive of mold flash & gate burr.

6-Pin SOT23 (M6)

Note:

13. Package information is correct as of the publication date. For updates and most current information, go to [www.micrel.com](http://www.micrel.com).

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**MICREL, INC. 2180 FORTUNE DRIVE SAN JOSE, CA 95131 USA**  
TEL +1 (408) 944-0800 FAX +1 (408) 474-1000 WEB <http://www.micrel.com>

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