MIC281

Low-Cost IttyBitty™ Thermal Sensor

Final Information

The Infinite Bandwidth Company™

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.

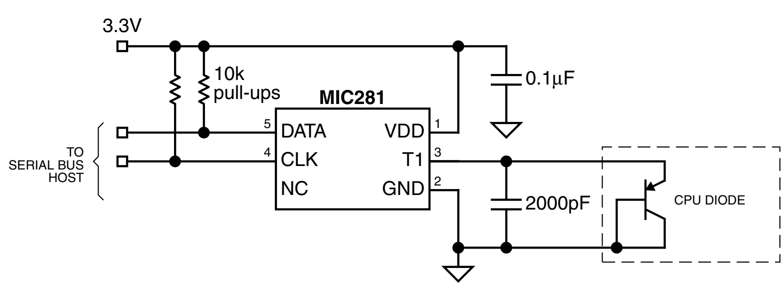
Features

- Remote temperature measurement using embedded thermal diodes or commodity transistors
- Accurate remote sensing
  ±3°C max., 0°C to 100°C
- Excellent noise rejection
- I^2C 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
- IttyBitty™ SOT23-6 Package

Applications

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

Typical Application



MIC281 Typical Application

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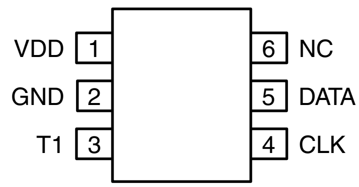
Ordering Information

Part Number	Marking	Slave Address	Ambient Temperature Range	Package
MIC281-0BM6*	TB00	1001 000x_b	–40°C to +85°C	SOT23-6
MIC281-1BM6*	TB01	1001 001x_b	–40°C to +85°C	SOT23-6
MIC281-2BM6*	TB02	1001 010x_b	–40°C to +85°C	SOT23-6
MIC281-3BM6*	TB03	1001 011x_b	–40°C to +85°C	SOT23-6
MIC281-4BM6	TB04	1001 100x_b	–40°C to +85°C	SOT23-6
MIC281-5BM6*	TB05	1001 101x_b	–40°C to +85°C	SOT23-6
MIC281-6BM6*	TB06	1001 110x_b	–40°C to +85°C	SOT23-6
MIC281-7BM6*	TB07	1001 111x_b	–40°C to +85°C	SOT23-6

* Contact Micrel regarding availability.

Pin Configuration



SOT23-6

Pin Description

Pin	Pin Name	Pin Description
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 I/O: Open-drain. Serial data input/output.
6	NC	No Connection: Must be left unconnected.

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 .... –0.3V to 6.0V
Current Into Any Pin .... ±10mA
Power Dissipation, T_A = 125°C 109mW
Junction Temperature .... 150°C
Storage Temperature .... –65°C to +150°C
ESD Ratings, **Note 7**
  Human Body Model 1.5kV
  Machine Model 200V
Soldering (SOT23-6 Package)
  Vapor Phase (60s) .... 220 $^{+5}/_{-0}$°C
  Infrared (15s) .... 235 $^{+5}/_{-0}$°C

Operating Ratings (Note 2)

Power Supply Voltage, V_{DD} .... +3.0V to +3.6V
Ambient Temperature Range (T_A) .... –40°C to +85°C
Package Thermal Resistance (θ_{JA})
  SOT-23-6 .... 230°C/W

Electrical Characteristics

For typical values, T_A=25°C, V_{DD}=3.3V unless otherwise noted. **Bold** values are for $T_{MIN} \le T_A \le T_{MAX}$ unless otherwise noted. **Note 2**

Symbol	Parameter	Condition	Min	Typ	Max	Units
Power Supply						
I_{DD}	Supply Current	T1 open; CLK=DATA=High; Normal Mode		0.23	**0.4**	mA
		Shutdown mode; T1 open; CLK = 100kHz; **Note 5**		9		µA
		Shutdown Mode; T1 open; CLK=DATA=High		6		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, **Notes 3, 5, 6**	0°C ≤ T_D ≤ 100°C; 0°C ≤ T_A ≤ 85°C; 3.15V ≤ V_{DD} ≤ 3.45V		±**1**	±**3**	°C
		–40°C ≤ T_D ≤ 125°C; 0°C ≤ T_A ≤ 85°C; 3.15V ≤ V_{DD} ≤ 3.45V		±**2**	±**5**	°C
t_{CONV}	Conversion time, **Note 5**			200	**240**	ms
Remote Temperature Input, T1						
I_F	Current into External Diode	T1 forced to 1.0V, high level		192	**400**	µA
	Note 5	Low level	**7**	12		µA
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	3.0V ≤ V_{DD} ≤ 5.5V			**0.8**	V
V_{IH}	High Input Voltage	3.0V ≤ V_{DD} ≤ 5.5V	**2.1**		**5.5**	V
C_{IN}	Input Capacitance, **Note 5**			10		pF
I_{LEAK}	Input Current				±**1**	µA

Symbol	Parameter	Condition	Min	Typ	Max	Units
Serial Clock Input, CLK						
V_{IL}	Low Input Voltage	$3.0V \le V_{DD} \le 3.6V$			**0.8**	V
V_{IH}	High Input Voltage	$3.0V \le V_{DD} \le 3.6V$	**2.1**		**5.5**	V
C_{IN}	Input Capacitance, **Note 5**			10		pF
I_{LEAK}	Input current				**±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. The device is not guaranteed to function outside its operating range.

Note 2. Final test on outgoing product is performed at $T_A = 25°C$.

Note 3. 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 5.

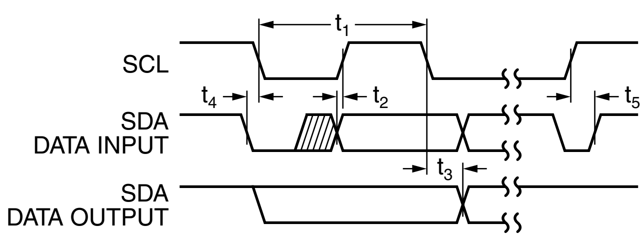
Note 4. Current into the DATA pin will result in self-heating of the device. Sink current should be minimized for best accuracy.

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

Note 6. Accuracy specifications do not include quantization noise which may be up to ± 0.5LSB.

Note 7. Devices are ESD sensitive. Observe appropriate handling precautions.

Timing Diagram

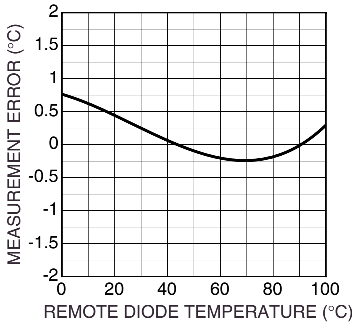


Serial Interface Timing

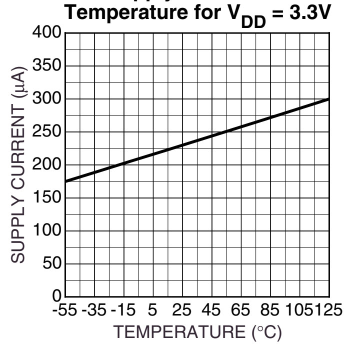
Typical Characteristics

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

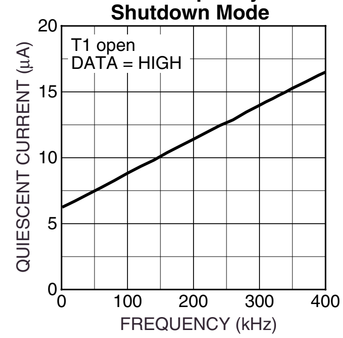
Remote Temperature Measurement Error



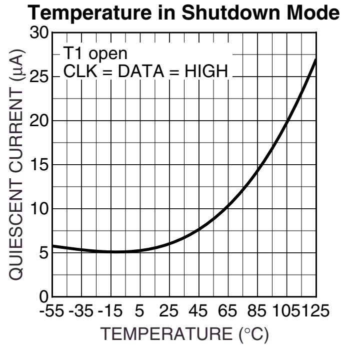
Supply Current vs. Temperature for V_{DD} = 3.3V



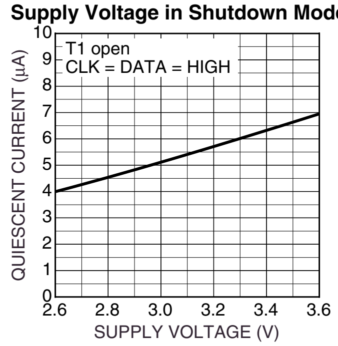
Quiescent Current vs. Clock Frequency in Shutdown Mode



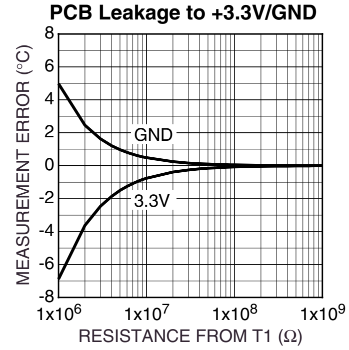
Quiescent Current vs. Temperature in Shutdown Mode



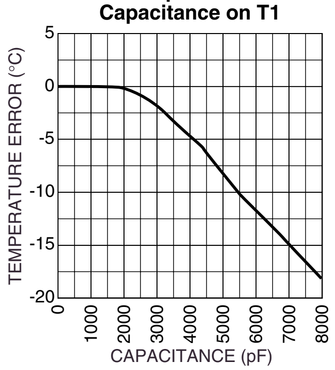
Quiescent Current vs. Supply Voltage in Shutdown Mode



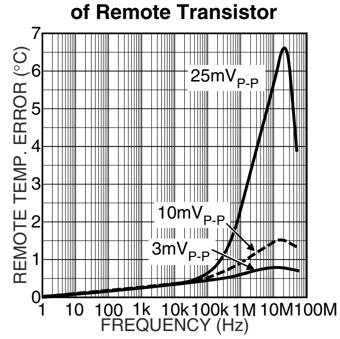
Measurement Error vs. PCB Leakage to +3.3V/GND



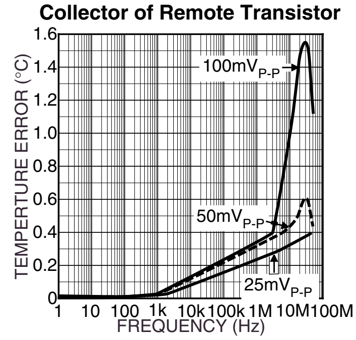
Remote Temperature Error vs. Capacitance on T1



Error Due to Noise on the Base of Remote Transistor



Error Due to Noise on the Collector of Remote Transistor



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.

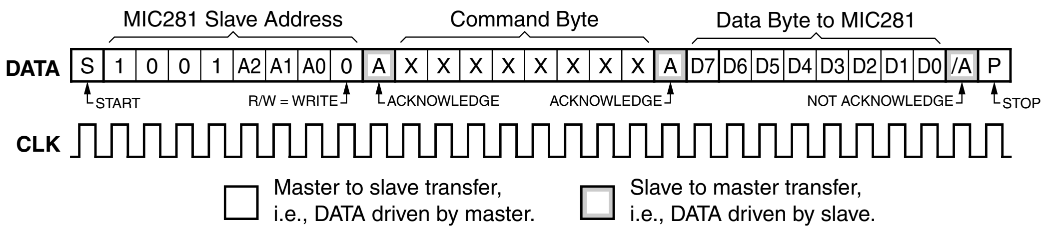


Figure 1. Write_Byte Protocol

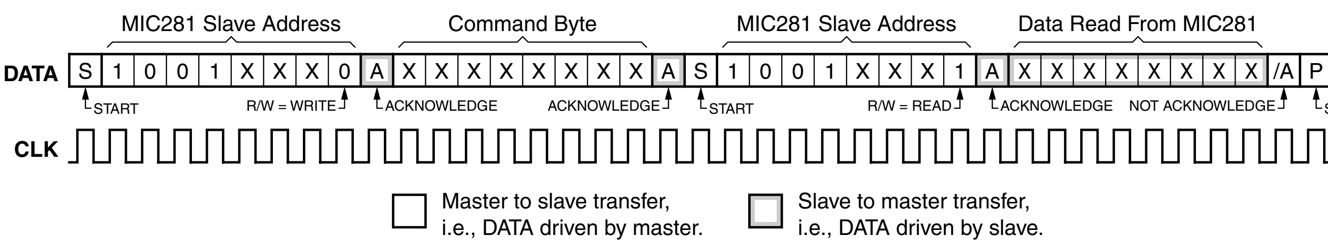


Figure 2. Read_Byte Protocol

Target Register		Command Byte Value		Power-on Default
Label	**Description**	**Read**	**Write**	
TEMP	Remote temperature result	01_h	n/a	00_h (0°C)
CONFIG	Configuration	03_h	03_h	80_h
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. MIC281 Register Addresses

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 below and the Ordering Information table.

Part Number	Slave Address
MIC281-0BM6	1001 000x_b = 90_h
MIC281-1BM6	1001 001x_b = 92_h
MIC281-2BM6	1001 010x_b = 94_h
MIC281-3BM6	1001 011x_b = 96_h
MIC281-4BM6	1001 100x_b = 98_h
MIC281-5BM6	1001 101x_b = $9A_h$
MIC281-6BM6	1001 110x_b = $9C_h$
MIC281-7BM6	1001 111x_b = $9E_h$

Table 2. MIC281 Slave Addresses

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.

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

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 V_{DD} or GND, the temperature result will be reported as the maximum full-scale value, +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_{SHDN} 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

Remote 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°C)**

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.

**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					

Bits(s)	Function	Operation*
D7	Reserved	Always write as zero; reads undefined
SHDN	Shutdown bit	0 = normal operation, 1 = shutdown
D[5:0]	Reserved	Always write as zero; reads undefined

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

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

* 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.

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] read-only	D[2] read-only	D[1] read-only	D[0] read-only
MIC281 DIE REVISION NUMBER							

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

Power-up default value: [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 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.

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

Table 4. 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 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 Equation 1 below.

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 Equation 2. 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.

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

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

$P_D = 4.44mW$

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

the theoretical maximum self-heating is:

$4.44mW \times 230°C/W = 1.02°C$

Equation 1. Worst-Case Self-Heating

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

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

$P_D = 0.815mW$

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

the typical self-heating is:

$0.815mW \times 230°C/W = 0.188°C$

Equation 2. Real-World Self-Heating Example

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. 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 MIC281. A good rule of thumb is this: 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 6”-12” 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, etc.
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 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 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 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 0.1µF ceramic capacitor. Surface mount parts provide the best bypassing because of their low inductance.

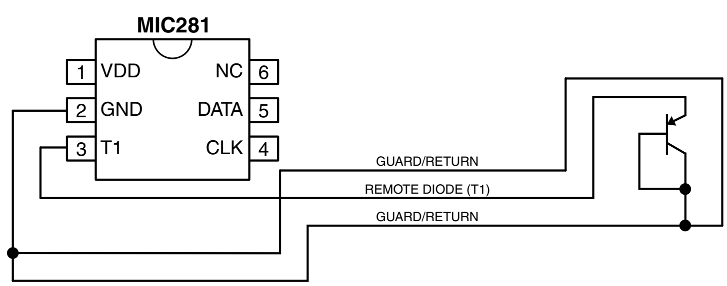
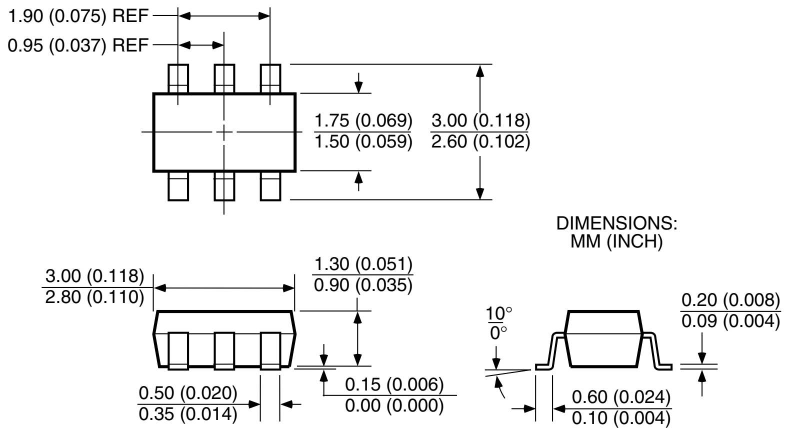


Figure 3. Guard Traces/Kelvin Ground Returns

Package Information



6-Lead SOT23 (M6)

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