MIC281

Low-Cost IttyBitty™ Thermal Sensor

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.

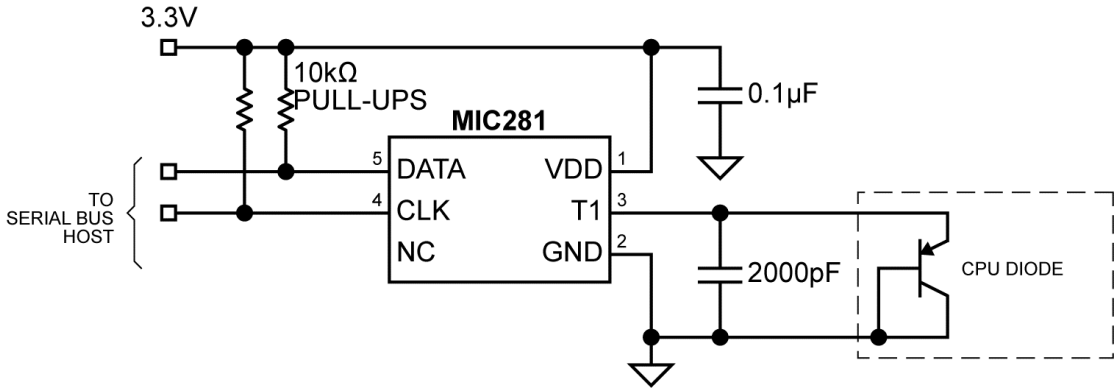
Features

- 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
- Available in IttyBitty SOT23-6 package

Applications

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

Typical Application



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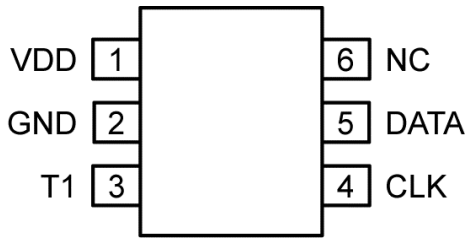
Ordering Information

Part Number	Marking[1]	Slave Address	Ambient Temp. Range	Package
MIC281-0YM6	TB00	1001 000x_b	–55° to +125°C	SOT23-6
MIC281-1YM6	TB01	1001 001x_b	–55° to +125°C	SOT23-6
MIC281-2YM6	TB02	1001 010x_b	–55° to +125°C	SOT23-6
MIC281-3YM6	TB03	1001 011x_b	–55° to +125°C	SOT23-6
MIC281-4YM6	TB04	1001 100x_b	–55° to +125°C	SOT23-6
MIC281-5YM6	TB05	1001 101x_b	–55° to +125°C	SOT23-6
MIC281-6YM6	TB06	1001 110x_b	–55° to +125°C	SOT23-6
MIC281-7YM6	TB07	1001 111x_b	–55° to +125°C	SOT23-6

Note:

1. Underbar (_) may not be to scale.

Pin Configuration



SOT23-6 (M6)
Top View

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[2]

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 ..... ±10mA
Power Dissipation, T_A = +125°C 109mW
Storage Temperature (Ts) ..... –65°C to +150°C
ESD Ratings[4]
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[3]

Power Supply Voltage (V_{DD}) ..... +3.0V to +3.6V
Ambient Temperature Range (T_A) ..... –55°C to +125°C
Package Thermal Resistance
SOT23-6 (θ_{JA}) ..... 230°C/W

Electrical Characteristics[5]

V_{DD} = 3.3V; T_A = 25°C, unless noted. **Bold** values indicate $T_{MIN} \le T_A \le T_{MAX}$, unless noted[3].

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; Note 7 CLK = 100kHz		9		µA
		Shutdown mode; T1 open; CLK = DATA = High		6		µA
t_{POR}	Power-on Reset Time, Note 7	$V_{DD} > V_{POR}$		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 7			300		mV
Temperature-to-Digital Converter Characteristics						
	Accuracy, Notes 7, 8, 9	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 7			200	**240**	ms
Remote Temperature Input, T1						
I_F	Current into External Diode, Note 7	T1 forced to 1.0V, high level		192	**400**	µA
		Low level	**7**	12		µA

Electrical Characteristics[5] (Continued)

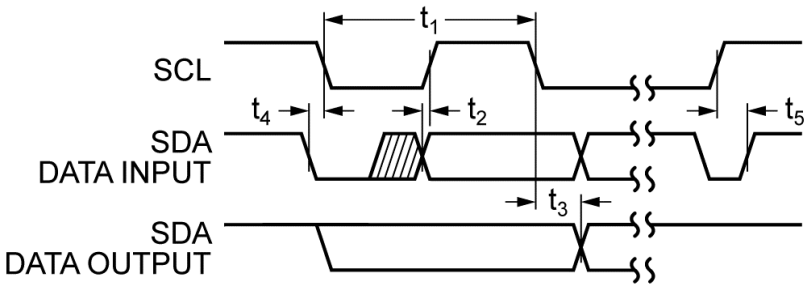
V_{DD} = 3.3V; T_A = 25°C, unless noted. **Bold** values indicate $T_{MIN} \le T_A \le T_{MAX}$, unless noted[3].

Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
Serial Data I/O Pin, DATA						
V_{OL}	Low Output Voltage, Note 6	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 7		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 7		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

Notes:

2. Exceeding the absolute maximum ratings may damage the device.
3. The device is not guaranteed to function outside its operating ratings. Final test on outgoing product is performed at T_A = 25°C.
4. Devices are ESD sensitive. Handling precautions are recommended. Human body model, 1.5kΩ in series with 100pF.
5. Specification for packaged product only.
6. Current into the DATA pin will result in self-heating of the device. Sink current should be minimized for best accuracy.
7. Guaranteed by design over the operating temperature range. Not 100% production tested.
8. Accuracy specification does not include quantization noise, which may be up to ±1/2 LSB.
9. 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

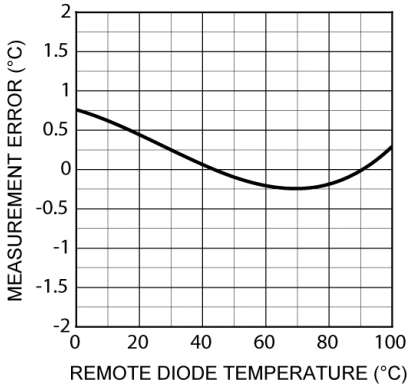


Serial Interface Timing

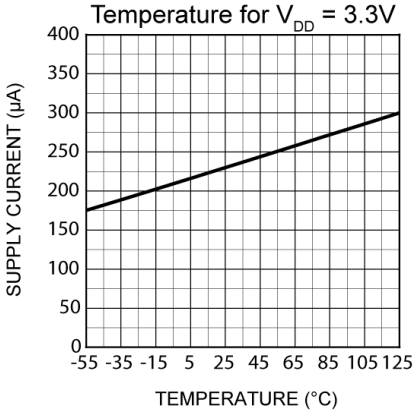
Typical Characteristics

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

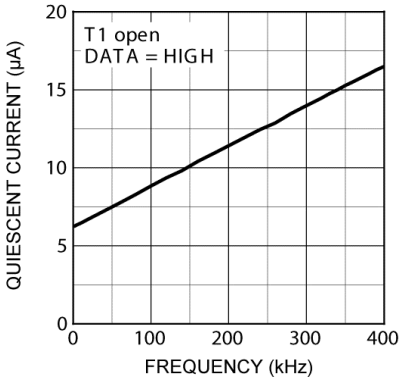
Remote Temperature Measurement Error



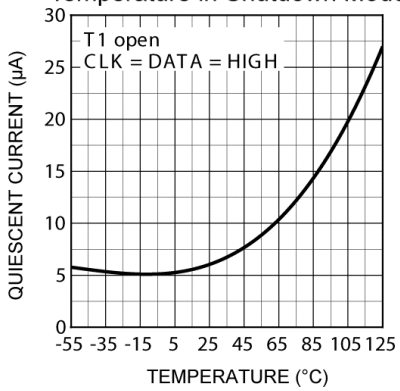
Supply Current vs. Temperature for V_{DD} = 3.3V



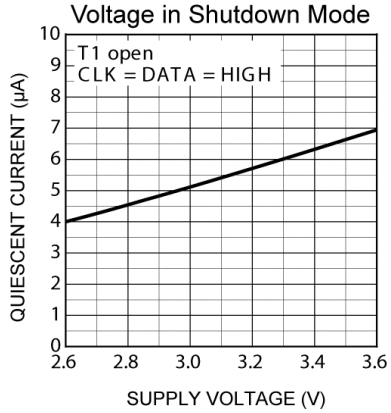
Quiescent Current vs. Clock Frequency in Shutdown Mode



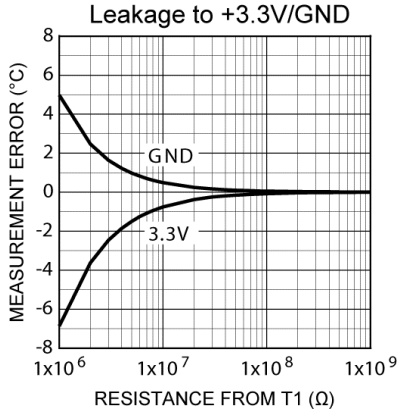
Quiescent Current vs. Temperature in Shutdown Mode



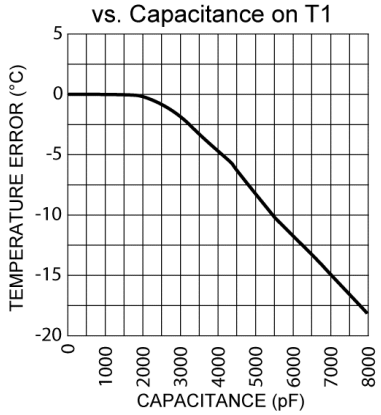
Quiescent Current vs. Supply Voltage in Shutdown Mode



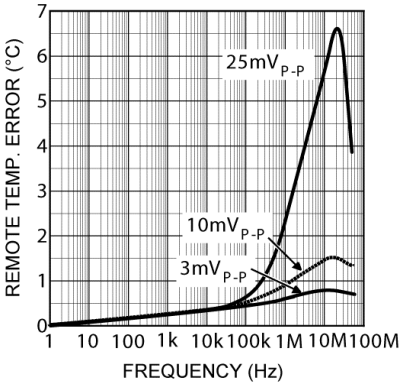
Measurement Error vs. PCB Leakage to +3.3V/GND



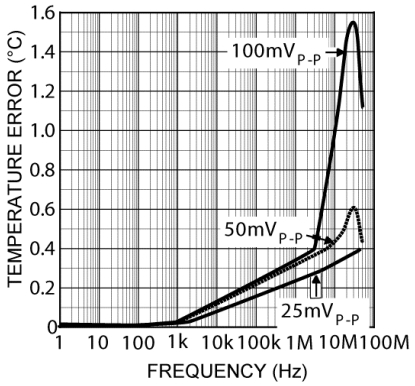
Remote Temperature Error vs. Capacitance on T1



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.

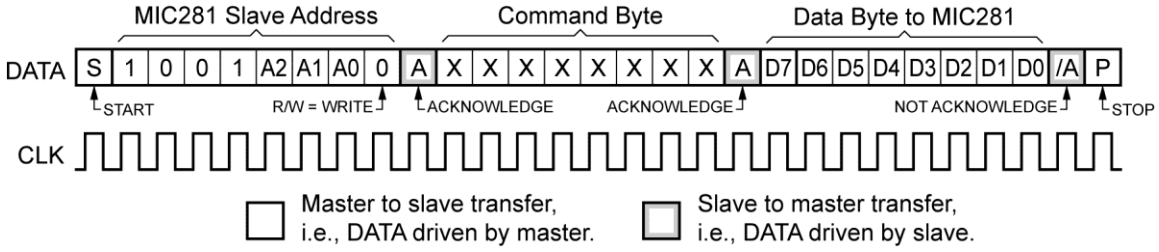


Figure 1. Write_Byte Protocol

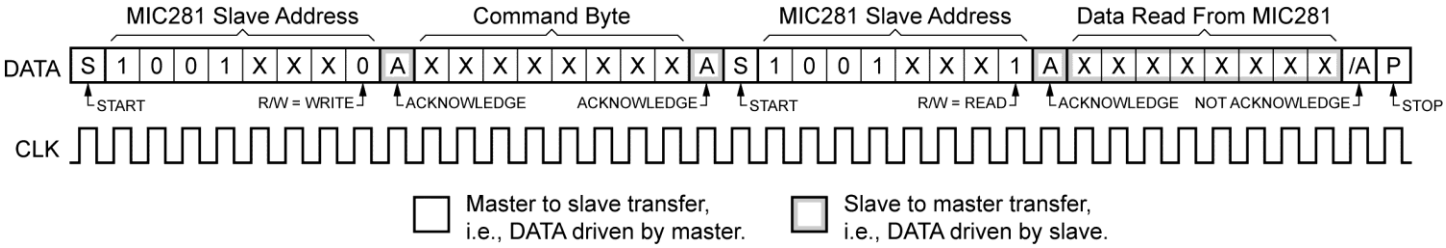


Figure 2. Read_Byte Protocol

Table 1. MIC281 Register Addresses

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	$0x_h$[10]

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	$1001\ 000_b = 90_h$
MIC281-1YM6	$1001\ 001_b = 92_h$
MIC281-2YM6	$1001\ 010_b = 94_h$
MIC281-3YM6	$1001\ 011_b = 96_h$
MIC281-4YM6	$1001\ 100_b = 98_h$
MIC281-5YM6	$1001\ 101_b = 9A_h$
MIC281-6YM6	$1001\ 110_b = 9C_h$
MIC281-7YM6	$1001\ 111_b = 9E_h$

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_{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

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°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°C is reported as 0000 0000b. 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[12]
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 $2A_h$

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	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 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 × 230°C/W = 1.02°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.

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

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

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

0.815mW × 230°C/W = 0.188°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 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.

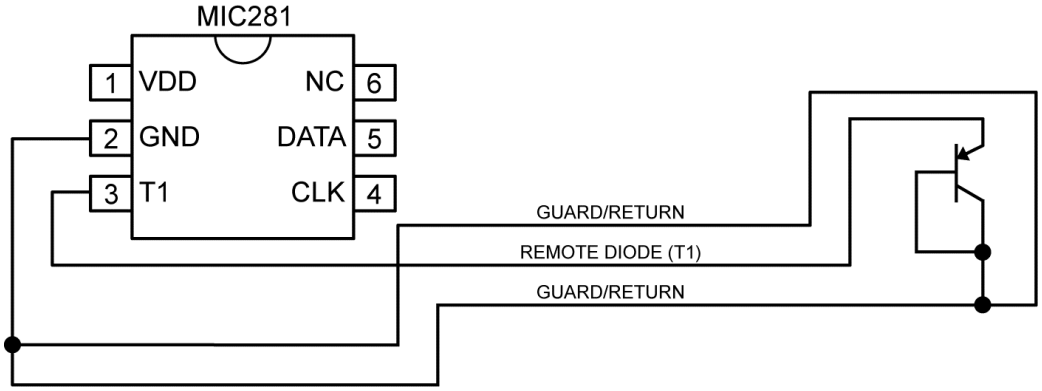
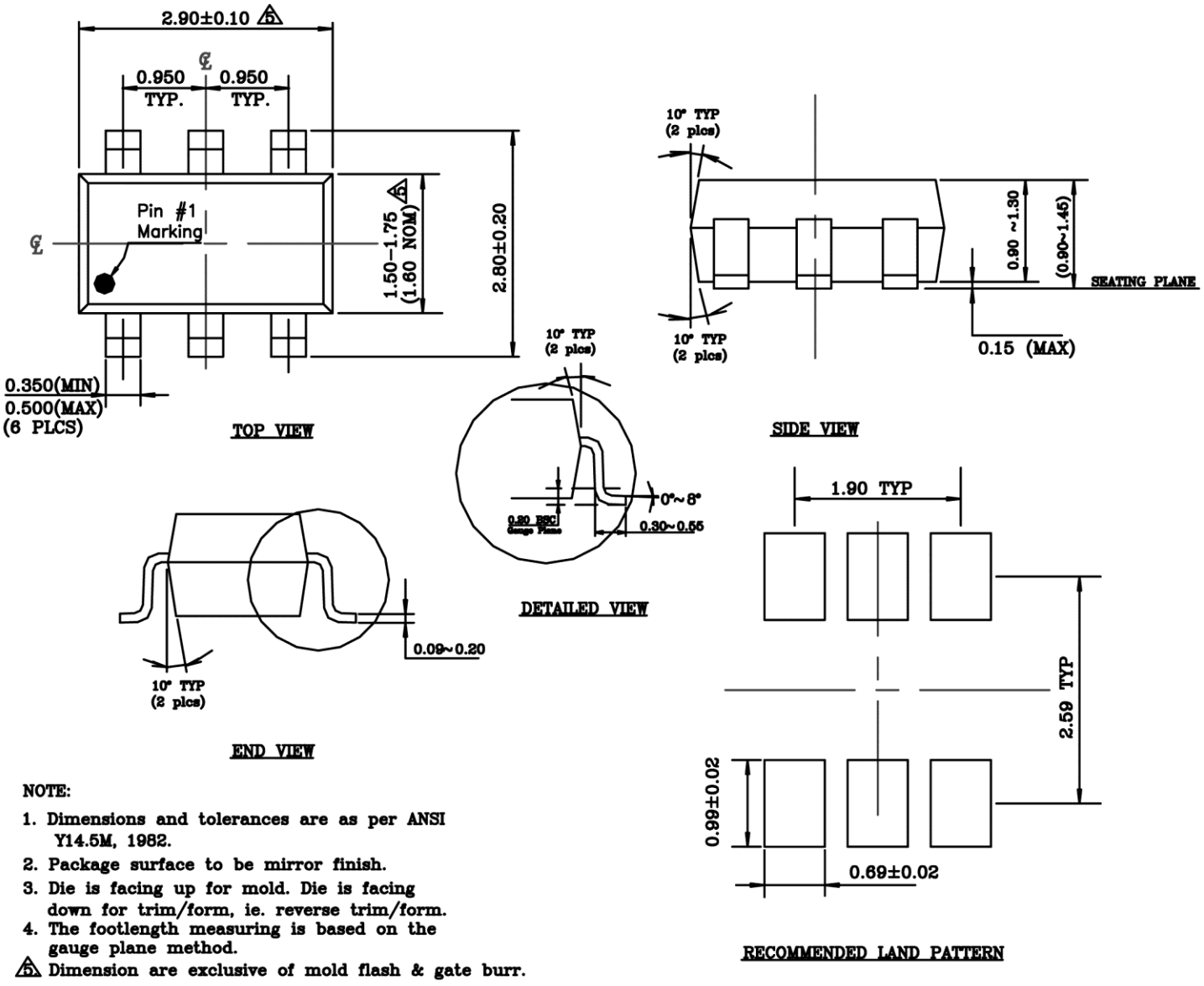


Figure 3. Guard Traces/Kelvin Ground Returns

Package Information[13]



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.

(5) 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.

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