# ADT7461A

# ±1°C Temperature Monitor with Series Resistance Cancellation

The ADT7461A is a dual-channel digital thermometer and undertemperature/overtemperature alarm, intended for use in PCs and thermal management systems. It is pin- and register-compatible with the ADM1032 and ADT7461. A feature of the ADT7461A is series resistance cancellation, where up to 1.5 kΩ (typical) of resistance in series with the temperature monitoring diode can be automatically cancelled from the temperature result, allowing noise filtering. The ADT7461A has a configurable $\overline{\text{ALERT}}$ output and an extended, switchable temperature measurement range.

The ADT7461A can measure the temperature of a remote thermal diode accurate to ±1°C and the ambient temperature accurate to ±3°C. The temperature measurement range defaults to 0°C to +127°C, compatible with the ADM1032, but it can be switched to a wider measurement range of −64°C to +191°C.

The ADT7461A communicates over a 2-wire serial interface, compatible with system management bus (SMBus) standards. The default SMBus address of the ADT7461A is 0x4C. An ADT7461A−2 is available with an SMBus address of 0x4D. This is useful if more than one ADT7461A is used on the same SMBus.

An $\overline{\text{ALERT}}$ output signals when the on-chip or remote temperature is out of range. The $\overline{\text{THERM}}$ output is a comparator output that allows on/off control of a cooling fan. The $\overline{\text{ALERT}}$



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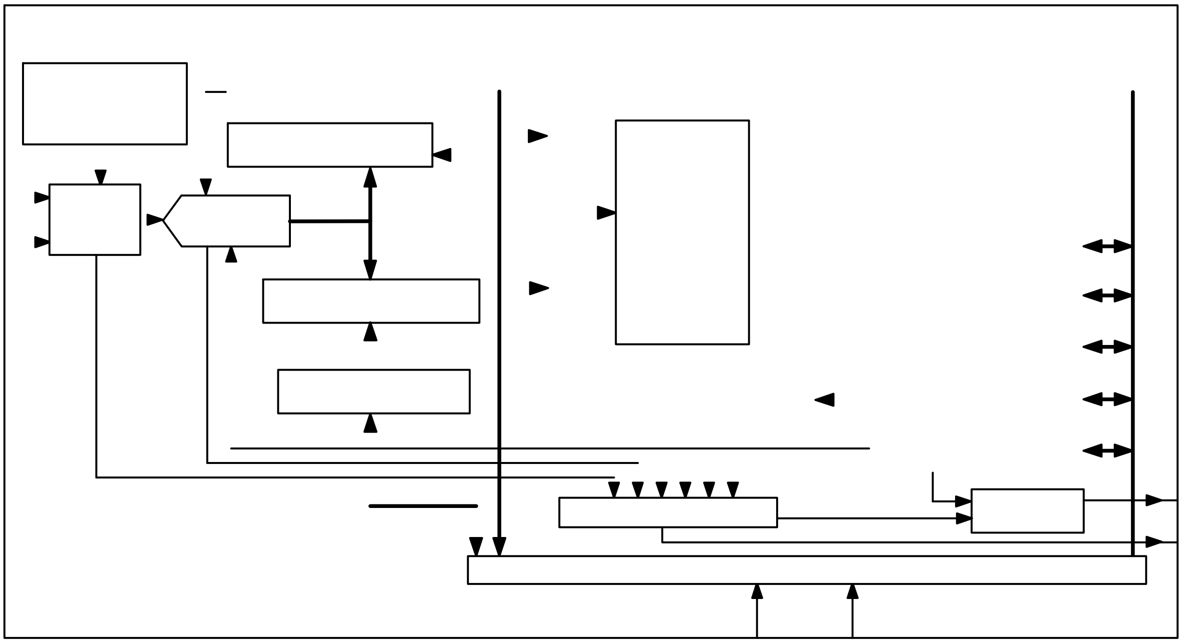


**Figure 1. Functional Block Diagram**

**Table 3. PIN ASSIGNMENT**

| Pin No. | Mnemonic | Description |
|---|---|---|
| 1 | $V_{DD}$ | Positive Supply, 3.0 V to 3.6 V. |
| 2 | D+ | Positive Connection to Remote Temperature Sensor. |
| 3 | D− | Negative Connection to Remote Temperature Sensor. |
| 4 | $\overline{\text{THERM}}$ | Open-Drain Output. Can be used to turn a fan on/off or throttle a CPU clock in the event of an overtemperature condition. Requires pullup resistor. |
| 5 | GND | Supply Ground Connection. |
| 6 | $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$ | Open-Drain Logic Output Used as Interrupt or SMBus $\overline{\text{ALERT}}$. This can also be configured as a second $\overline{\text{THERM}}$ output. Requires pullup resistor. |
| 7 | SDATA | Logic Input/Output, SMBus Serial Data. Open-Drain Output. Requires pullup resistor. |
| 8 | SCLK | Logic Input, SMBus Serial Clock. Requires pullup resistor. |

**Table 4. SMBus TIMING SPECIFICATIONS** (Note 1)

| Parameter | Limit at $T_{MIN}$ and $T_{MAX}$ | Unit | Description |
|---|---|---|---|
| $f_{SCLK}$ | 400 | kHz max | – |
| $t_{LOW}$ | 1.3 | μs min | Clock Low Period, between 10% Points |
| $t_{HIGH}$ | 0.6 | μs min | Clock High Period, between 90% Points |
| $t_R$ | 300 | ns max | Clock/Data Rise Time |
| $t_F$ | 300 | ns max | Clock/Data Fall Time |
| $t_{SU; STA}$ | 600 | ns min | Start Condition Setup Time |
| $t_{HD; STA}$ (Note 2) | 600 | ns min | Start Condition Hold Time |
| $t_{SU; DAT}$ (Note 3) | 100 | ns min | Data Setup Time |
| $t_{SU; STO}$ (Note 4) | 600 | ns min | Stop Condition Setup Time |
| $t_{BUF}$ | 1.3 | μs min | Bus Free Time between Stop and Start Conditions |

1. Guaranteed by design, but not production tested.
2. Time from 10% of SDATA to 90% of SCLK.
3. Time for 10% or 90% of SDATA to 10% of SCLK.
4. Time for 90% of SCLK to 10% of SDATA.

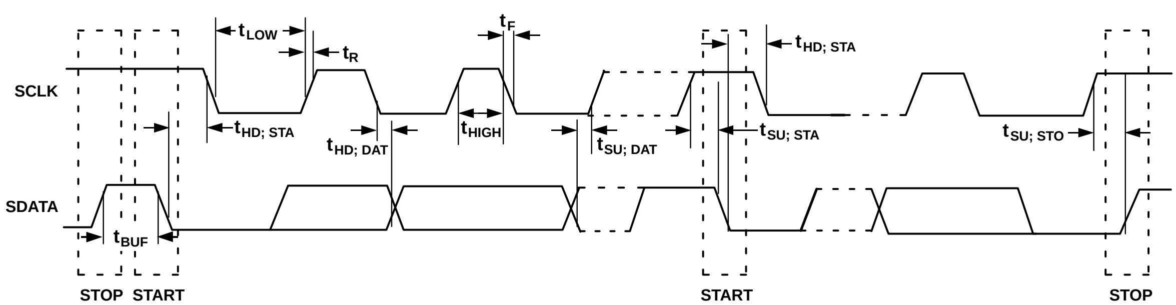



**Figure 2. Serial Bus Timing**

**Table 5. ELECTRICAL CHARACTERISTICS** ($T_A$ = −40°C to +125°C, $V_{DD}$ = 3.0 V to 3.6 V, unless otherwise noted.)

| Parameter | Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| **Power Supply** | | | | | |
| Supply Voltage, $V_{DD}$ | | 3.0 | 3.30 | 3.6 | V |
| Average Operating Supply Current, $I_{DD}$ | 0.0625 Conversions/Sec Rate (Note 1)<br>Standby Mode | –<br>– | 240<br>5.0 | 350<br>30 | µA |
| Undervoltage Lockout Threshold | $V_{DD}$ Input, Disables ADC, Rising Edge | – | 2.55 | – | V |
| Power-On-Reset Threshold | | 1.0 | – | 2.5 | V |
| **Temperature-To-Digital Converter** | | | | | |
| Local Sensor Accuracy | 0°C ≤ $T_A$ ≤ +70°C<br>0°C ≤ $T_A$ ≤ +85°C<br>−40°C ≤ $T_A$ ≤ +100°C | –<br>–<br>– | –<br>–<br>– | ±1.0<br>±1.5<br>±2.5 | °C |
| Resolution | | – | | | |

## TYPICAL PERFORMANCE CHARACTERISTICS

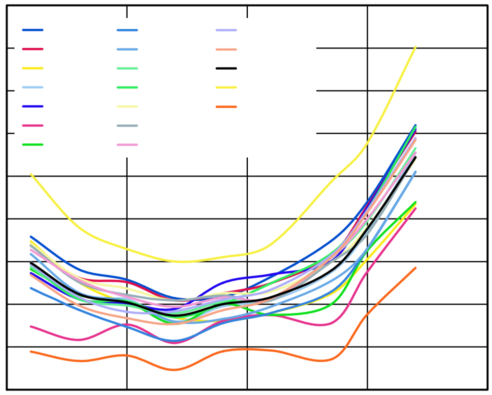


**Figure 3. Local Temperature Error vs. Temperature**

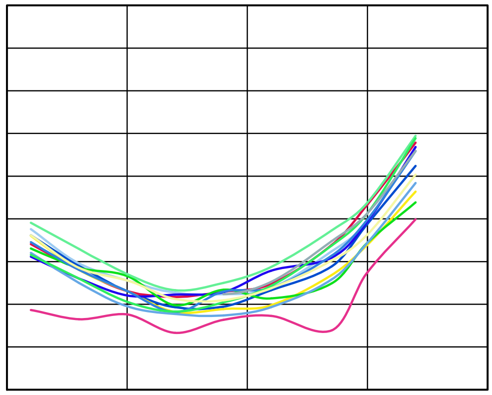


**Figure 4. Remote Temperature Error vs. Actual Temperature**

**Figure 5. Temperature Error vs. D+/D− Leakage Resistance**

**Figure 6. Temperature Error vs. D+/D− Capacitance**

**Figure 7. Operating Supply Current vs. Conversion Rate**

**Figure 8. Operating Supply Current vs. Voltage**

### Differences between the ADT7461A and the ADT7461

Although the ADT7461A is pin- and register-compatible with the ADT7461, there are some specification differences between the two devices. A summary of these differences is shown below in Table 6.

**Table 6. DIFFERENCES BETWEEN THE ADT7461A AND THE ADT7461**

| Specification | ADT7461A | ADT7461 | Unit |
|---|---|---|---|
| Supply Voltage | 3.0 to 3.6 | 3.0 to 5.5 | V |
| Maximum Local Sensor Accuracy | 1.0 | 3.0 | °C |
| Maximum Series Resistance Cancellation | 1.5 | 3.0 | kΩ |
| Average Operating Supply Current | | | μA |
| 16 Conversions/Sec | 240 | 170 | |
| Standby Mode | 5.0 | 5.5 | |
| Max Conversion Time | | | ms |
| One Shot, Averaging On | 52 | 114.6 | |
| One Shot, Averaging Off | 8.0 | 12.56 | |
| Remote Sensor Current Levels | | | μA |
| High | 220 | 96 | |
| Mid | 82 | 36 | |
| Low | 13.5 | 6.0 | |

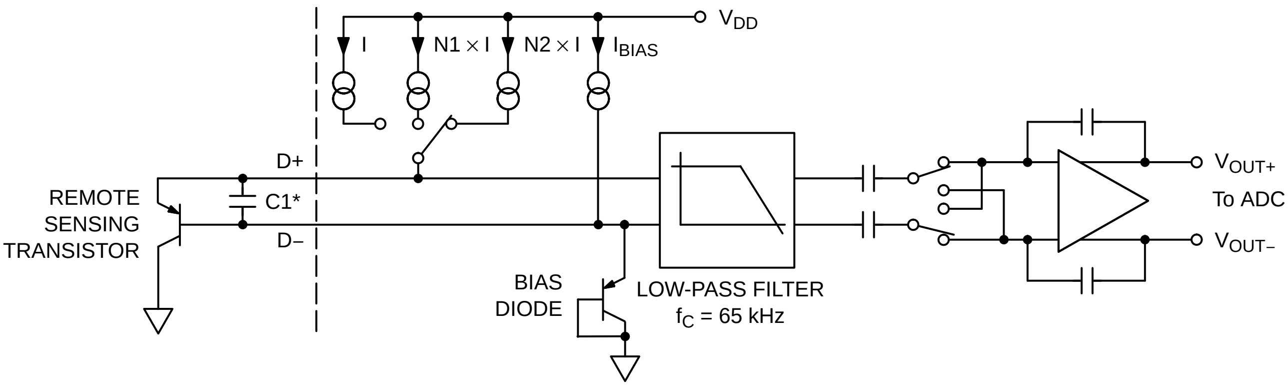
### Theory of Operation

The ADT7461A is a local and remote temperature sensor and over/under temperature alarm, with the added ability to automatically cancel the effect of 1.5 kΩ (typical) of resistance in series with the temperature monitoring diode. When the ADT7461A is operating normally, the on-board ADC operates in a free running mode. The analog input multiplexer alternately selects either the on-chip temperature sensor to measure its local temperature or the remote temperature sensor. The ADC digitizes these signals and the results are stored in the local and remote temperature value registers.

The local and remote measurement results are compared with the corresponding high, low, and $\overline{\text{THERM}}$ temperature limits, stored in eight on-chip registers. Out-of-limit comparisons generate flags that are stored in the status register. A result that exceeds the high temperature limit or the low temperature limit causes the $\overline{\text{ALERT}}$ output to assert. The $\overline{\text{ALERT}}$ output also asserts if an external diode fault is detected. Exceeding the $\overline{\text{THERM}}$ temperature limits causes the $\overline{\text{THERM}}$

The resulting $\Delta V_{BE}$ waveforms are passed through a 65 kHz low-pass filter to remove noise and then to a chopper-stabilized amplifier. This amplifies and rectifies the waveform to produce a dc voltage proportional to $\Delta V_{BE}$. The ADC digitizes this voltage producing a temperature measurement. To reduce the effects of noise, digital filtering is performed by averaging the results of 16 measurement cycles for low conversion rates. At rates of 16-, 32-, and 64-conversions/second, no digital averaging occurs.

Signal conditioning and measurement of the internal temperature sensor are performed in the same manner.




*CAPACITOR C1 IS OPTIONAL. IT IS ONLY NECESSARY IN NOISY ENVIRONMENTS. C1 = 1000 pF MAX.

**Figure 14. Input Signal Conditioning**

### Temperature Measurement Results

The results of the local and remote temperature measurements are stored in the local and remote temperature value registers and compared with limits programmed into the local and remote high and low limit registers.

The local temperature value is in Register 0x00 and has a resolution of 1°C. The external temperature value is stored in two registers, with the upper byte in Register 0x01 and the lower byte in Register 0x10. Only the two MSBs in the external temperature low byte are used giving the external temperature measurement a resolution of 0.25°C. Table 7 lists the data format for the external temperature low byte.

**Table 7. EXTENDED TEMPERATURE RESOLUTION (REMOTE TEMPERATURE LOW BYTE)**

| Extended Resolution | Remote Temperature Low Byte |
|---|---|
| 0.00°C | 0 000 0000 |
| 0.25°C | 0 100 0000 |
| 0.50°C | 1 000 0000 |
| 0.75°C | 1 100 0000 |

When reading the full external temperature value, read the LSB first. This causes the MSB to be locked (that is, the ADC does not write to it) until it is read. This feature ensures that the results read back from the two registers come from the same measurement.

### Temperature Measurement Range

The temperature measurement range for both internal and external measurements is, by default, 0°C to +127°C. However, the ADT7461A can be operated using an extended temperature range. The extended measurement range is −64°C to +191°C. Therefore, the ADT7461A can be used to measure the full temperature range of an external diode, from −55°C to +150°C.

The extended temperature range is selected by setting Bit 2 of the configuration register to 1. The temperature range is 0°C to 127°C when Bit 2 equals 0. A valid result is available in the next measurement cycle after changing the for both internal and external results. Temperature values are offset by 64°C in the offset binary data format. Examples of temperatures in both data formats are shown in Table 8.

**Table 8. TEMPERATURE DATA FORMAT (TEMPERATURE HIGH BYTE)**

| Temperature | Binary | Offset Binary (Note 1) |
|---|---|---|
| –55°C | 0 000 0000 (Note 2) | 0 000 1001 |
| 0°C | 0 000 0000 | 0 100 0000 |
| +1°C | 0 000 0001 | 0 100 0001 |
| +10°C | 0 000 1010 | 0 100 1010 |
| +25°C | 0 001 1001 | 0 101 1001 |
| +50°C | 0 011 0010 | 0 111 0010 |
| +75°C | 0 100 1011 | 1 000 1011 |
| +100°C | 0 110 0100 | 1 010 0100 |
| +125°C | 0 111 1101 | 1 011 1101 |
| +127°C | 0 111 1111 | 1 011 1111 |
| +150°C | .3968 0 TD(C)Tj | ET59.123ET59.8o43ote 2) |

**Table 9. CONFIGURATION REGISTER BIT ASSIGNMENTS**

**Table 14. LIST OF REGISTERS**

| Read Address (Hex) | Write Address (Hex) | Name | Power-On Default |
|---|---|---|---|
| Not Applicable | Not Applicable | Address Pointer | Undefined |
| 00 | Not Applicable | Local Temperature Value | 0000 0000 (0x00) |
| 01 | Not Applicable | External Temperature Value High Byte | 0000 0000 (0x00) |
| 02 | Not Applicable | Status | Undefined |
| 03 | 09 | Configuration | 0000 0000 (0x00) |
| 04 | 0A | Conversion Rate | 0000 1000 (0x08) |
| 05 | 0B | Local Temperature High Limit | 0101 0101 (0x55) (85°C) |
| 06 | 0C | Local Temperature Low Limit | 0000 0000 (0x00) (0°C) |
| 07 | 0D | External Temperature High Limit High Byte | 0101 0101 (0x55) (85°C) |
| 08 | 0E | External Temperature Low Limit High Byte | 0000 0000 (0x00) (0°C) |
| Not Applicable | 0F (Note 1) | One-Shot | |
| 10 | Not Applicable | External Temperature Value Low Byte | 0000 0000 |
| 11 | 11 | External Temperature Offset High Byte | 0000 0000 |
| 12 | 12 | External Temperature Offset Low Byte | 0000 0000 |
| 13 | 13 | External Temperature High Limit Low Byte | 0000 0000 |
| 14 | 14 | External Temperature Low Limit Low Byte | 0000 0000 |
| 19 | 19 | External $\overline{\text{THERM}}$ Limit | 0101 0101 (0x55) (85°C) |
| 20 | 20 | Local $\overline{\text{THERM}}$ Limit | 0101 0101 (0x55) (85°C) |
| 21 | 21 | $\overline{\text{THERM}}$ Hysteresis | 0000 1010 (0x0A) (10°C) |
| 22 | 22 | Consecutive $\overline{\text{ALERT}}$ | 0000 0001 (0x01) |
| FE | Not Applicable | Manufacturer ID | 0100 0001 (0x41) |
| FF | Not Applicable | Die Revision Code | 0101 0111 (0x57) |

1. Writing to Address 0x0F causes the ADT7461A to perform a single measurement. It is not a data register, and it does not matter what data is written to it.

### Serial Bus Interface

Control of the ADT7461A is carried out via the serial bus. The ADT7461A is connected to this bus as a slave device, under the control of a master device.

The ADT7461A has an SMBus timeout feature. When this is enabled, the SMBus times out after typically 25 ms of no activity. However, this feature is not enabled by default. Bit 7 of the consecutive alert register (Address = 0x22) should be set to enable it.

### Addressing the Device

In general, every SMBus device has a 7-bit device address, except for some devices that have extended 10-bit addresses. When the master device sends a device address over the bus, the slave device with that address responds. The ADT7461Ais available with one device address, 0x4C (1001 100b). An ADT7461A−2 is also available.

The ADT7461A−2 has an SMBus address of 0x4D (1001 101b). This is to allow two ADT7461A devices on the same bus, or if the default address conflicts with an existing device on the SMBus. The serial bus protocol operates as follows:

1. The master initiates a data transfer by establishing a start condition, defined as a high-to-low transition on SDATA, the serial data line, while SCLK, the serial clock line, remains high. This indicates that an address/data stream follows. All slave peripherals connected to the serial bus respond to the start condition and shift in the next eight bits, consisting of a 7-bit address (MSB first) plus an R/$\overline{\text{W}}$ bit, which determines the direction of the data transfer, that is, whether data is written to, or read from, the slave device. The peripheral whose address corresponds to the transmitted address responds by pulling the data line low during the low period before the ninth clock pulse, known as the acknowledge bit. All other devices on the bus remain idle while the selected device waits for data to be read from or written to it. If the R/$\overline{\text{W}}$

write operation is limited only by what the master and slave devices can handle.

3. When all data bytes have been read or written, stop conditions are established. In write mode, the master pulls the data line high during the tenth clock pulse to assert a stop condition. In read mode, the master device overrides the acknowledge bit by pulling the data line high during the low period before the ninth clock pulse. This is known as no acknowledge. The master takes the data line low during the low period before the tenth clock pulse, then high during the tenth clock pulse to assert a stop condition.

   Any number of bytes of data are transferable over the serial bus in one operation, but it is not possible to mix read and write in one operation because the type of operation is determined at the beginning and cannot subsequently be changed without starting a new operation. For the ADT7461A, write operations contain either one or two bytes, while read operations contain one byte.

To write data to one of the device data registers, or to read data from it, the address pointer register must be set so that the correct data register is addressed. The first byte of a write operation always contains a valid address that is stored in the address pointer register. If data is to be written to the device, the write operation contains a second data byte that is written to the register selected by the address pointer register.

This procedure is illustrated in Figure 15. The device address is sent over the bus followed by $R/\overline{W}$ set to 0. This is followed by two data bytes. The first data byte is the address of the internal data register to be written to, which is stored in the address pointer register. The second data byte is the data to be written to the internal data register.

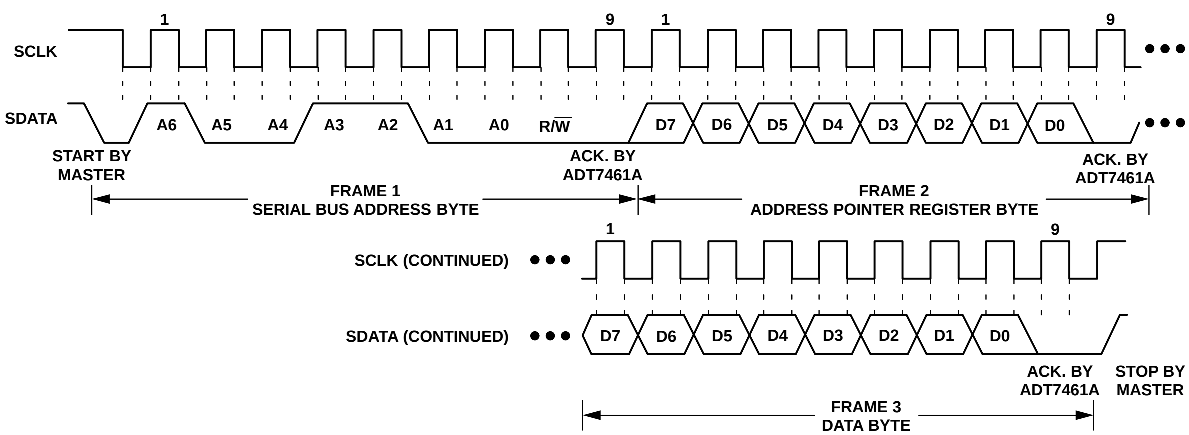



**Figure 15. Writing a Register Address to the Address Pointer Register, then Writing Data to the Selected Register**

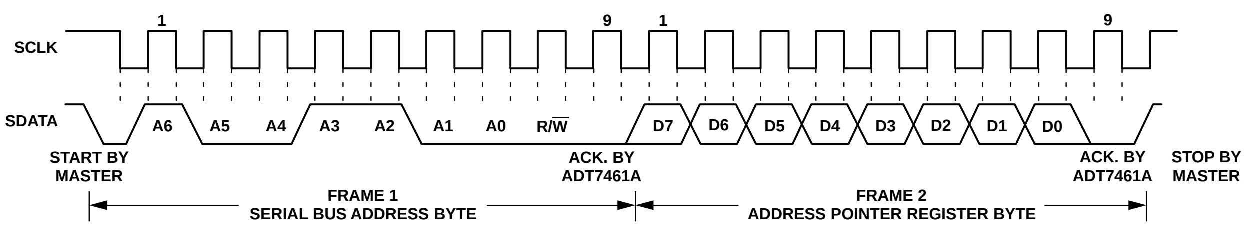



**Figure 16. Writing to the Address Pointer Register Only**

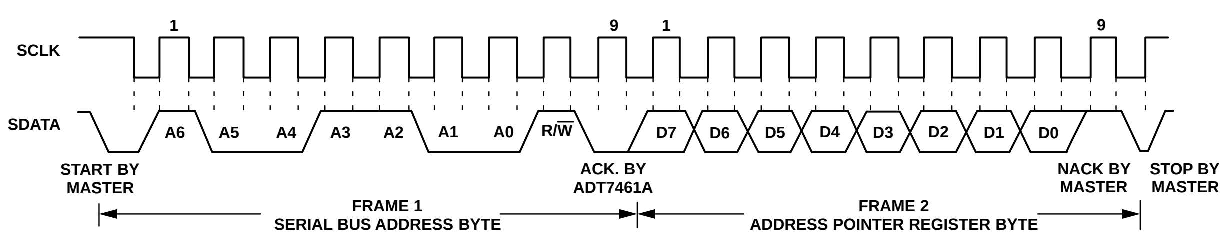



**Figure 17. Reading Data from a Previously Selected Register**

When reading data from a register there are two possibilities.

1. If the address pointer register value of the ADT7461A is unknown or not the desired value, it is first necessary to set it to the correct value before data can be read from the desired data register. This is done by writing to the ADT7461A as before, but only the data byte containing the register read address is sent, because data is not to be written to the register see Figure 16.
   A read operation is then performed consisting of the serial bus address, R/$\overline{\text{W}}$ bit set to 1, followed by the data byte read from the data register see Figure 17.
2. If the address pointer register is known to be at the desired address, data can be read from the corresponding data register without first writing to the address pointer register and the bus transaction shown in Figure 16 can be omitted.

NOTES:

1. It is possible to read a data byte from a data register without first writing to the address pointer register. However, if the address pointer register is already at the correct value, it is not possible to write data to a register without writing to the address pointer register because the first data byte of a write is always written to the address pointer register.
2. Some of the registers have different addresses for read and write operations. The write address of a register must be written to the address pointer if data is to be written to that register, but it may not be possible to read data from that address. The read address of a register must be written to the address pointer before data can be read from that register.

### $\overline{\text{ALERT}}$ Output

This is applicable when Pin 6 is configured as an $\overline{\text{ALERT}}$ output. The $\overline{\text{ALERT}}$ output goes low whenever an out-of-limit measurement is detected, or if the remote temperature sensor is open circuit. It is an open-drain output and requires a pullup resistor. Several $\overline{\text{ALERT}}$ outputs can be wire-OR'ed together, so that the common line goes low if one or more of the $\overline{\text{ALERT}}$ outputs goes low.

The $\overline{\text{ALERT}}$

### The ADT7461A Interrupt System

The ADT7461A has two interrupt outputs, ALERT and THERM. Both have different functions and behavior. ALERT is maskable and responds to violations of software programmed temperature limits or an open-circuit fault on the external diode. THERM is intended as a fail-safe interrupt output that cannot be masked.

If the external or local temperature exceeds the programmed high temperature limits, or equals or exceeds the low temperature limits, the ALERT output is asserted low. An open-circuit fault on the external diode also causes ALERT to assert. ALERT is reset when serviced by a master reading its device address, provided the error condition has gone away and the status register has been reset.

The THERM output asserts low if the external or local temperature exceeds the programmed THERM limits. THERM temperature limits should normally be equal to or greater than the high temperature limits. THERM is reset automatically when the temperature falls back within the THERM limit. The external and local limits are set by default to 85°C. A hysteresis value can be programmed; in which case, THERM resets when the temperature falls to the limit value minus the hysteresis value. This applies to both local and remote measurement channels. The power-on hysteresis default value is 10°C, but this can be reprogrammed to any value after powerup.

The hysteresis loop on the THERM outputs is useful when THERM is used, for example, as an on/off controller for a fan. The user's system can be set up so that when THERM asserts, a fan is switched on to cool the system. When THERM goes high again, the fan can be switched off. Programming a hysteresis value protects from fan jitter, where the temperature hovers around the THERM limit, and the fan is constantly switched.

**Table 15. THERM HYSTERESIS**

| THERM Hysteresis | Binary Representation |
|---|---|
| 0°C | 0 000 0000 |
| 1°C | 0 000 0001 |
| 10°C | 0 000 1010 |

Figure 19 shows how the THERM and ALERT outputs operate. The ALERT output can be used as a SMBALERT to signal to the host via the SMBus that the temperature has risen. The user can use the THERM output to turn on a fan to cool the system, if the temperature continues to increase. This method ensures that there is a fail-safe mechanism to cool the system, without the need for host intervention.

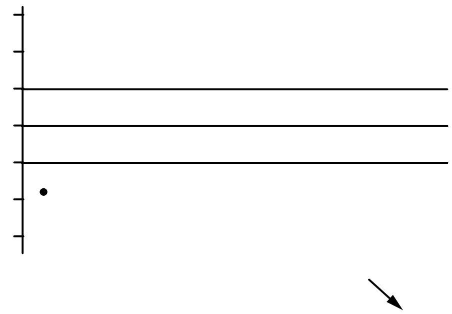


**Figure 19. Operation of the ALERT and THERM Interrupts**

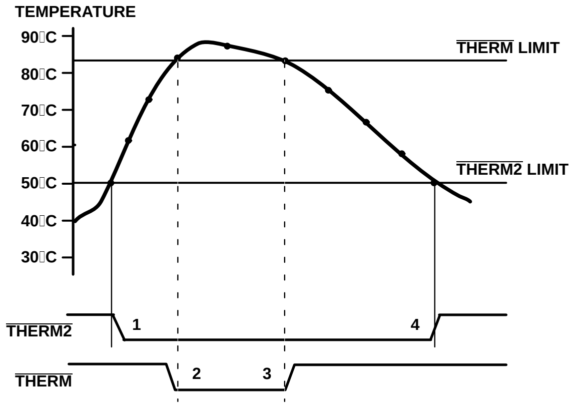



**Figure 20. Operation of the THERM and THERM2 Interrupts**

- When the THERM2 limit is exceeded, the THERM2 signal asserts low.
- If the temperature continues to increase and exceeds the THERM limit, the THERM output asserts low.
- The THERM output deasserts (goes high) when the temperature falls to THERM limit minus hysteresis. In Figure 20, there is no hysteresis value shown.
- As the system cools further, and the temperature falls below the THERM2 limit, the THERM2 signal resets. Again, no hysteresis value is shown for THERM2.

Both the external and internal temperature measurements cause THERM and THERM2 to operate as described.

## Application Information

### Noise Filtering

For temperature sensors operating in noisy environments, the industry standard practice was to place a capacitor across the D+ and D− pins to help combat the effects of noise. However, large capacitances affect the accuracy of the temperature measurement, leading to a recommended maximum capacitor value of 1000 pF. Although this capacitor reduces the noise, it does not eliminate it, making it difficult to use the sensor in a very noisy environment.

The ADT7461A has a major advantage over other devices when it comes to eliminating the effects of noise on the external sensor. The series resistance cancellation feature allows a filter to be constructed between the external temperature sensor and the part. The effect of any filter resistance seen in series with the remote sensor is automatically cancelled from the temperature result.

The construction of a filter allows the ADT7461A and the remote maxim-.4( )-9(remote )-d from the temperature result.

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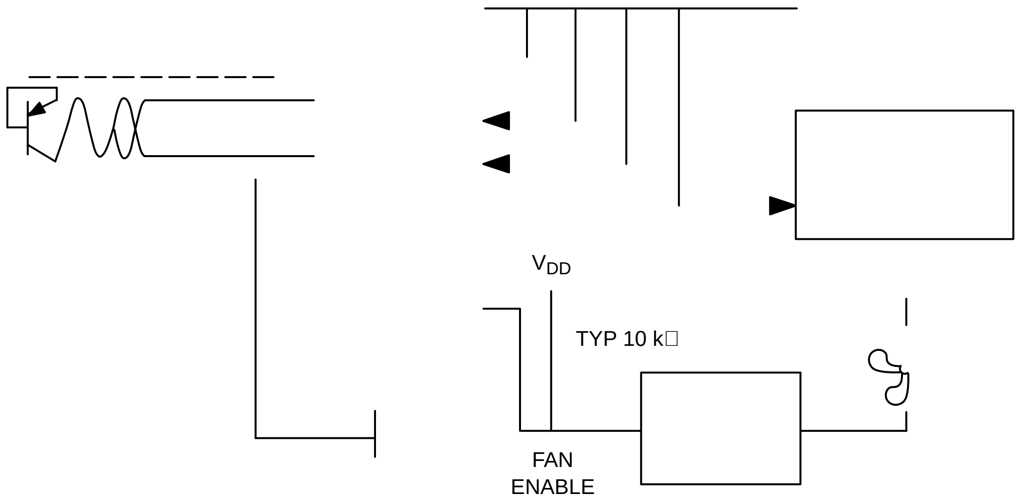


**Figure 23. Typical Application Circuit**

## PACKAGE DIMENSIONS