ON Semiconductor®

Intelligent Temperature Monitor and Dual PWM Fan Controller

ADM1031

FEATURES

- **Optimized for Pentium® III**
  - **Reduced guardbanding software**
  - **Automatic fan speed control, independent of CPU intervention after initial setup**
- **Control loop to minimal acoustic noise and battery consumption**
- **Remote temperature measurement accurate to 1°C using remote diode (two channels)**
- **0.125°C resolution on external temperature channels**
- **Local sensor with 0.25°C resolution**
- **Pulse width modulation (PWM) fan control for two fans**
- **Programmable PWM frequency and PWM duty cycle**
- **Tach fan speed measurement (two channels)**
- **Analog input to measure fan speed of 2-wire fans (using sense resistor)**
- **2-wire system management Bus (SMBus) with ARA support**
- **Overtemperature $\overline{\text{THERM}}$ output pin for CPU throttling**
- **Programmable $\overline{\text{INT}}$ output pin**
- **Configurable offsets for temperature channels 3 V to 5.5 V supply range**
- **Shutdown mode to minimize power consumption**
- **Limit comparison of all monitored values**

APPLICATIONS

- **Notebook PCs, network servers, and personal computers**
- **Telecommunications equipment**

GENERAL DESCRIPTION

The ADM1031 is an ACPI-compliant, three-channel digital thermometer and under/over temperature alarm for use in personal computers and thermal management systems. Optimized for the Pentium III, the part offers a 1°C higher accuracy, which allows system designers to safely reduce temperature guardbanding and increase system performance.

Two PWM fan control outputs control the speed of two cooling fans by varying output duty cycle. Duty cycle values between 33% and 100% allow smooth control of the fans. The speed of each fan can be monitored via TACH inputs, which can be reprogrammed as analog inputs to allow speeds for 2-wire fans to be measured via sense resistors. The device also detects a stalled fan. A dedicated fan speed control loop provides control without the intervention of CPU software. It also ensures that if the CPU or system locks up, each fan can still be controlled based on temperature measurements, and the fan speed is adjusted to correct any changes in system temperature. Fan speed can also be controlled using existing ACPI software.

Two inputs (four pins) are dedicated to remote temperature-sensing diodes with an accuracy of ±1°C, and an on-chip temperature sensor allows ambient temperature to be monitored. The device has a programmable $\overline{\text{INT}}$ output to indicate error conditions, and a dedicated $\overline{\text{FAN\_FAULT}}$ output to signal fan failure. The $\overline{\text{THERM}}$ pin is a fail-safe output for overtemperature conditions that can be used to throttle a CPU clock.

FUNCTIONAL BLOCK DIAGRAM

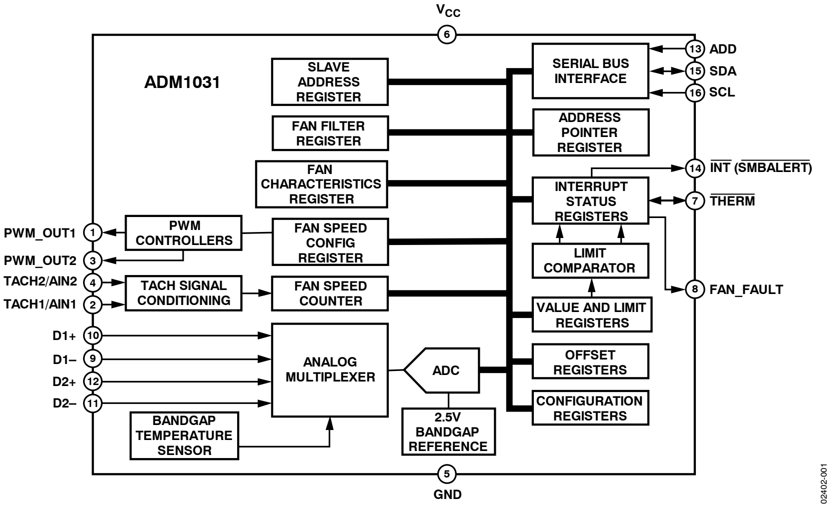

Figure 1.

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ADM1031/D

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REVISION HISTORY

01/08 - Rev 3: Conversion to ON Semiconductor

9/05—Rev. A to Rev. B

Updated Format .... Universal
Changes to Ordering Guide 33

4/03—Rev. 0 to Rev. A

Added ESD Caution 3
Updated Outline Dimensions 30

SPECIFICATIONS

$T_A = T_{MIN}$ to T_{MAX}, $V_{CC} = V_{MIN}$ to V_{MAX}, unless otherwise noted.[1]

Table 1.

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
POWER SUPPLY					
Supply Voltage, V_{CC}	3.0	3.30	5.5	V	
Supply Current, I_{CC}		1.4	3	mA	Interface inactive, ADC active
		32	50	μA	Standby mode
TEMPERATURE-TO-DIGITAL CONVERTER					
Local Sensor Accuracy		±1	±3	°C	
Resolution		0.25		°C	
Remote Diode1 Sensor Accuracy		±0.5	±1	°C	$60°C \leq T_D \leq 100°C$
Remote Diode2 Sensor Accuracy		±0.5	±1.75	°C	$60°C \leq T_D \leq 100°C$
Resolution		0.125		°C	
Remote Sensor Source Current		180		μA	High level
		11		μA	Low level
OPEN-DRAIN DIGITAL OUTPUTS ($\overline{\text{THERM}}$, $\overline{\text{INT}}$, $\overline{\text{FAN\_FAULT}}$, PWM_OUT)					
Output Low Voltage, V_{OL}			0.4	V	$I_{OUT} = -6.0$ mA; $V_{CC} = 3$ V
High-Level Output Leakage Current, I_{OH}		0.1	1	μA	$V_{OUT} = V_{CC}$; $V_{CC} = 3$ V
OPEN-DRAIN SERIAL DATA BUS OUTPUT (SDA)					
Output Low Voltage, V_{OL}			0.4	V	$I_{OUT} = -6.0$ mA; $V_{CC} = 3$ V
High-Level Output Leakage Current, I_{OH}		0.1	1	μA	$V_{OUT} = V_{CC}$
SERIAL BUS DIGITAL INPUTS (SCL, SDA)					
Input High Voltage, V_{IH}	2.1			V	
Input Low Voltage, V_{IL}			0.8	V	
Hysteresis		500		mV	
DIGITAL INPUT LOGIC LEVELS[2] (ADD, $\overline{\text{THERM}}$, TACH1/2)					
Input High Voltage, V_{IH}	2.1			V	
Input Low Voltage, V_{IL}			0.8	V	
DIGITAL INPUT LEAKAGE CURRENT					
Input High Current, I_{IH}	−1			μA	$V_{IN} = V_{CC}$
Input Low Current, I_{IL}			1	μA	$V_{IN} = 0$
Input Capacitance, C_{IN}		5		pF	
FAN RPM-TO-DIGITAL CONVERTER					
Accuracy			±6	%	$60°C \leq T_A \leq 100°C$
Full-Scale Count			255		
TACH Nominal Input RPM		4400		RPM	Divisor N = 1, Fan Count = 153
		2200		RPM	Divisor N = 2, Fan Count = 153
		1100		RPM	Divisor N = 4, Fan Count = 153
		550		RPM	Divisor N = 8, Fan Count = 153
Conversion Cycle Time		637		ms	

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
SERIAL BUS TIMING[3]					
Clock Frequency, f_{SCLK}	10		100	kHz	See Figure 2
Glitch Immunity, t_{SW}		50		ns	See Figure 2
Bus Free Time, t_{BUF}	4.7			µs	See Figure 2
Start Setup Time, $t_{SU;STA}$	4.7			µs	See Figure 2
Start Hold Time, $t_{HD;STA}$	4			µs	See Figure 2
Stop Condition Setup Time, $t_{SU;STO}$	4			µs	See Figure 2
SCL Low Time, t_{LOW}	1.3			µs	See Figure 2
SCL High Time, t_{HIGH}	4		50	µs	See Figure 2
SCL, SDA Rise Time, t_R			1000	ns	See Figure 2
SCL, SDA Fall Time, t_F			300	ns	See Figure 2
Data Setup Time, $t_{SU;DAT}$	250			ns	See Figure 2
Data Hold Time, $t_{HD;DAT}$	300			ns	See Figure 2

[1] Typicals are at T_A = 25°C and represent most likely parametric norm. Shutdown current typ is measured with V_{CC} = 3.3 V.

[2] ADD is a three-state input that can be pulled high, low, or left open-circuit.

[3] Timing specifications are tested at logic levels of V_{IL} = 0.8 V for a falling edge and V_{IH} = 2.2 V for a rising edge.

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
Positive Supply Voltage (V_{CC})	6.5 V
Voltage on Any Input or Output Pin	−0.3 V to +6.5 V
Input Current at Any Pin	±5 mA
Package Input Current	±20 mA
Maximum Junction Temperature (T_{JMAX})	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature, Soldering	
Vapor Phase 60 sec	215°C
Infrared 15 sec	200°C
ESD Rating All Pins	2000 V

Stresses above those listed under Absolute Maximum Ratings can cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods can affect device reliability.

THERMAL RESISTANCE

θ_{JA} is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 3. Thermal Resistance

Package Type	θ_{JA}	θ_{JC}	Unit
16-Lead QSOP Package	105	39	°C/W

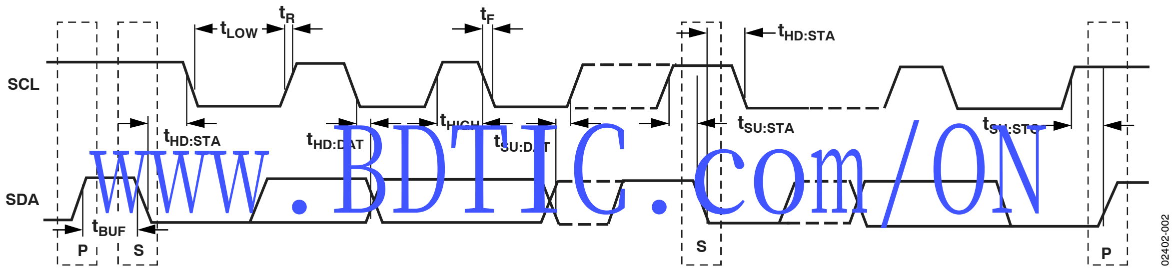

Figure 2. Diagram for Serial Bus Timing

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage can occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

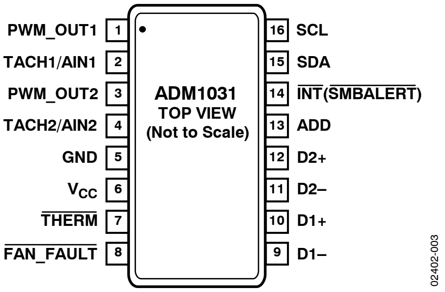

Figure 3. Pin Configuration

Table 4. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	PWM_OUT1	Digital Output, Open-Drain. Pulse width modulated output to control fan speed. Requires pull-up resistor (10 kΩ typical).
2	TACH1/AIN1	Digital/Analog Input. Fan tachometer input to measure FAN1 fan speed. Can be reprogrammed as an analog input to measure speed of a 2-wire fan via a sense resistor (2 Ω typical).
3	PWM_OUT2	Digital Output, Open-Drain. Pulse width modulated output to control FAN2 fan speed. Requires pull-up resistor (10 kΩ typical).
4	TACH2/AIN2	Digital/Analog Input. Fan tachometer input to measure FAN2 fan speed. Can be reprogrammed as an analog input to measure speed of a 2-wire fan via a sense resistor (2 Ω typical).
5	GND	System Ground.
6	V_{CC}	Power. Can be powered by 3.3 V standby power if monitoring in low power states is required.
7	$\overline{\text{THERM}}$	Digital I/O, Open-Drain. An active low thermal overload output that indicates a violation of a temperature set point (overtemperature). Also acts as an input to provide external fan control. When this pin is pulled low by an external signal, a status bit is set, and the fan speed is set to full-on. Requires pull-up resistor (10 kΩ).
8	$\overline{\text{FAN\_FAULT}}$	Digital Output, Open-Drain. Can be used to signal a fan fault. Drives second fan to full speed if one fan fails. Requires pull-up resistor (typically 10 kΩ).
9	D1–	Analog Input. Connected to cathode of first remote temperature-sensing diode. The temperature-sensing element is either a Pentium III substrate transistor or a general-purpose 2N3904.
10	D1+	Analog Input. Connected to anode of first remote temperature-sensing diode.
11	D2–	Analog Input. Connected to cathode of second remote temperature-sensing diode.
12	D2+	Analog Input. Connected to anode of second remote temperature-sensing diode.
13	ADD	Three-State Logic Input. Sets two lower bits of device SMBus address.
14	$\overline{\text{INT}}$ ($\overline{\text{SMBALERT}}$)	Digital Output, Open-Drain. Can be programmed as an interrupt (SMBus ALERT) output for temperature/fan speed interrupts. Requires pull-up resistor (10 kΩ typical).
15	SDA	Digital I/O, Serial Bus Bidirectional Data. Open-drain output. Requires pull-up resistor (2.2 kΩ typical).
16	SCL	Digital Input, Serial Bus Clock. Requires pull-up resistor (2.2 kΩ typical).

TYPICAL PERFORMANCE CHARACTERISTICS

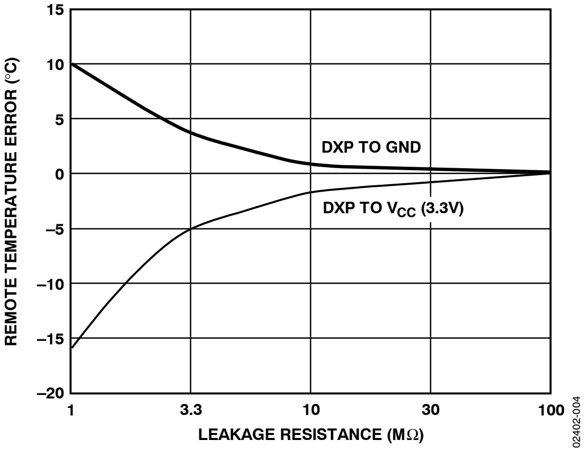

Figure 4. Temperature Error vs. PCB Track Resistance

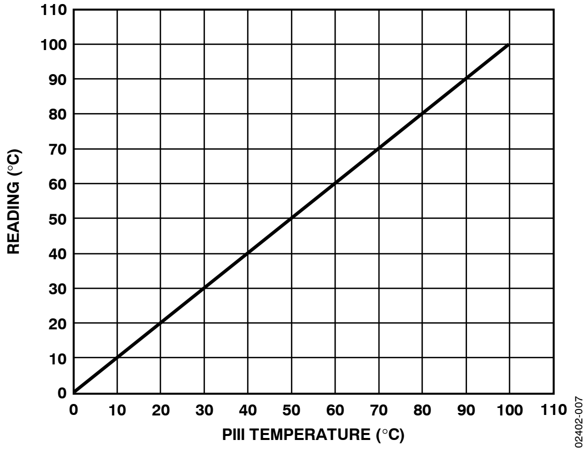

Figure 7. Pentium III Temperature Measurement vs. ADM1031 Reading

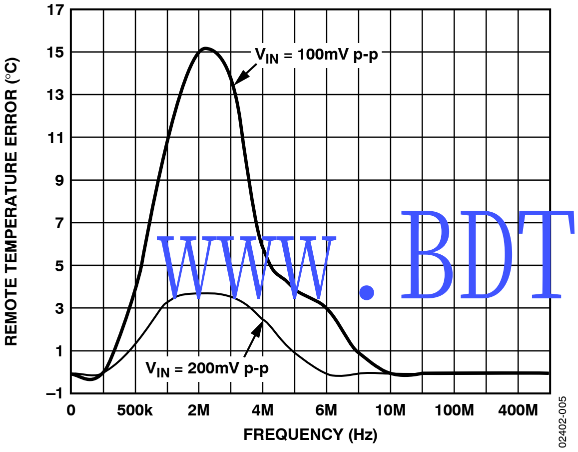

Figure 5. Temperature Error vs. Power Supply Noise Frequency

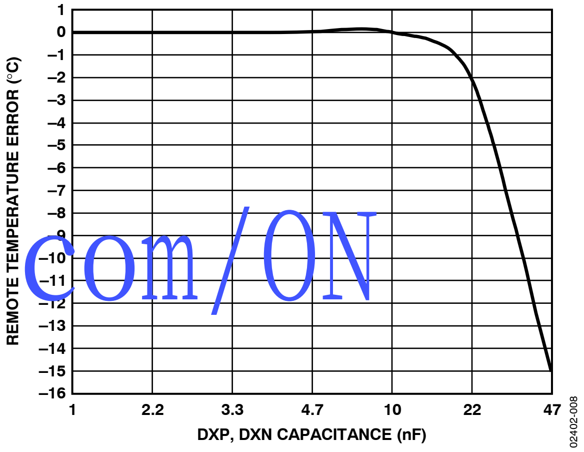

Figure 8. Temperature Error vs. Capacitance Between D+ and D–

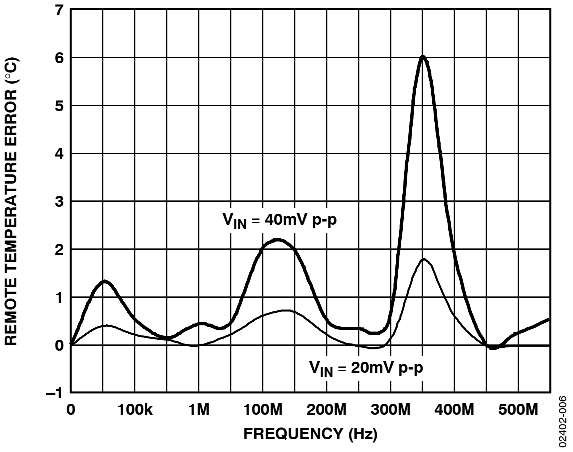

Figure 6. Temperature Error vs. Common-Mode Noise Frequency

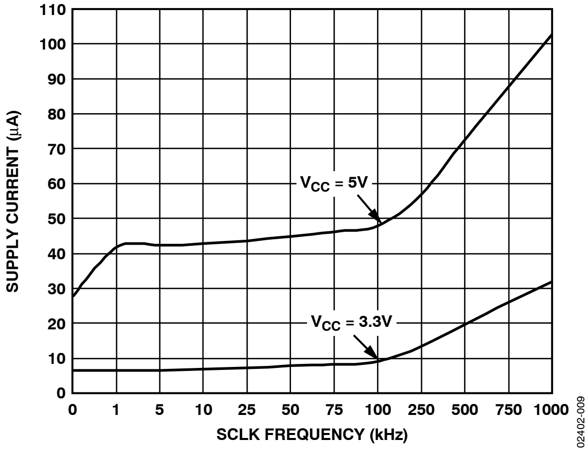

Figure 9. Standby Current vs. Clock Frequency

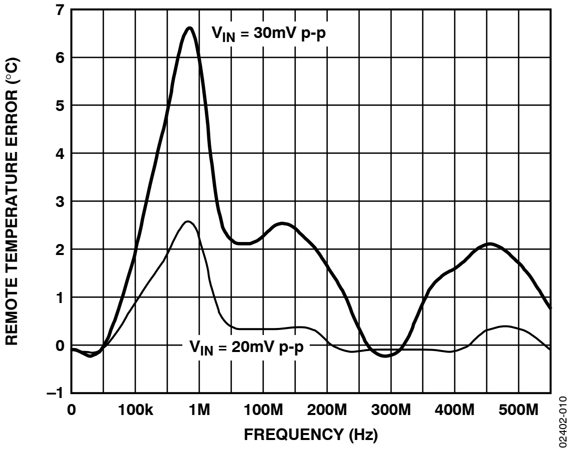

Figure 10. Temperature Error vs. Differential-Mode Noise Frequency

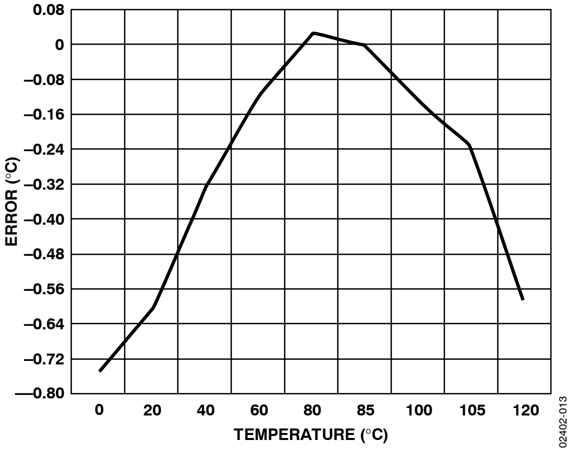

Figure 13. Remote Temperature Sensor Error

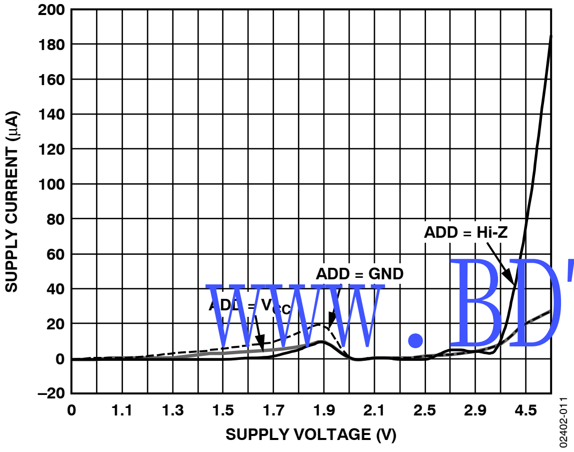

Figure 11. Standby Supply Current vs. Supply Voltage

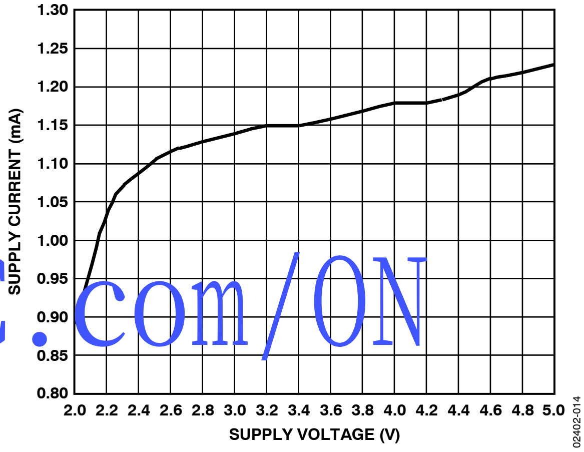

Figure 14. Supply Current vs. Supply Voltage

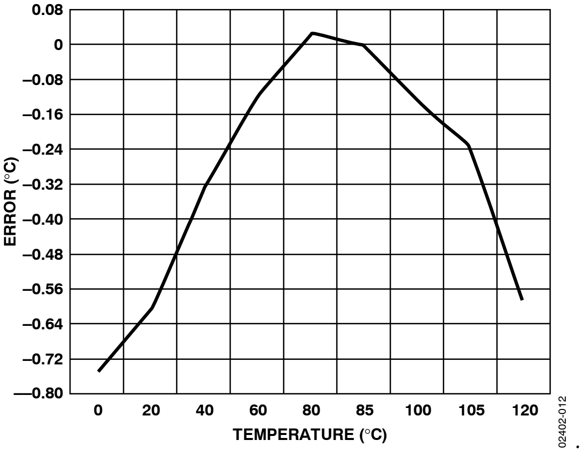

Figure 12. Local Sensor Temperature Error

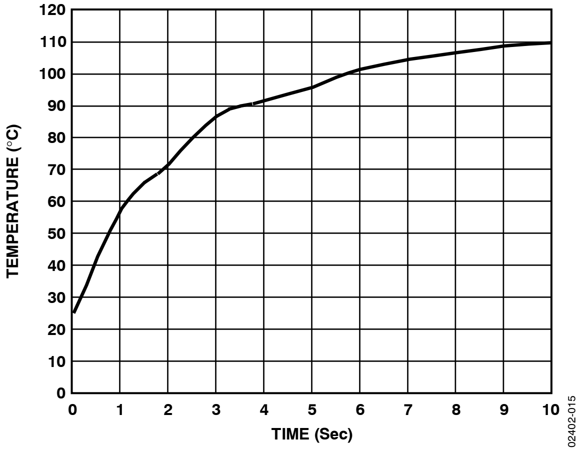

Figure 15. Response to Thermal Shock

FUNCTIONAL DESCRIPTION

The ADM1031 is a temperature monitor and dual PWM fan controller for microprocessor-based systems. The device communicates with the system via a serial System Management Bus (SMBus). The serial bus controller has a hardwired address pin for device selection (Pin 13), a serial data line for reading and writing addresses and data (Pin 15), and an input line for the serial clock (Pin 16). All control and programming functions of the ADM1031 are performed over the serial bus. The device also supports Alert Response Address (ARA).

INTERNAL REGISTERS

Brief descriptions of the ADM1031's principal internal registers are given below. For more detailed information on the function of each register, see

Table 18 through Table 33.

Configuration Register

This register controls and configures various functions on the device.

Address Pointer Register

This register contains the address that selects one of the other internal registers. When writing to the ADM1031, the first byte of data is always a register address, which is written to the address pointer register.

Status Registers

These registers provide status of each limit comparison.

Value and Limit Registers

Theses registers store the results of temperature and fan speed measurements, along with their limit values.

Fan Speed Configuration Register

This register is used to program the PWM duty cycle for each fan.

Offset Registers

These registers allow the temperature channel readings to be offset by a 5-bit twos complement value written to these registers. These values are automatically added to the temperature values (or subtracted from if negative). This allows the systems designer to optimize the system if required, by adding or subtracting up to 15°C from a temperature reading.

Fan Characteristics Registers

These registers are used to select the spin-up time, PWM frequency, and speed range for the fans used.

THERM Limit Registers

These registers contain the temperature values at which $\overline{\text{THERM}}$ is asserted.

T_{MIN}/T_{RANGE} Registers

These registers are read/write registers that hold the minimum temperature value below which the fan does not run when the device is in automatic fan speed control mode. These registers also hold the temperature range value that defines the range over which auto fan control is provided, and hence determines the temperature at which the fan is run at full speed.

SERIAL BUS INTERFACE

Control of the ADM1031 is carried out via the SMBus. The ADM1031 is connected to this bus as a slave device, under the control of a master device, for example, the 810 chipset.

The ADM1031 has a 7-bit serial bus address. When the device is powered up, it does so with a default serial bus address. The five MSBs of the address are set to 01011; the two LSBs are determined by the logical state of Pin 13 (ADD). This is a three-state input that can be grounded, connected to V_{CC}, or left open-circuit to give three different addresses. The state of the ADD pin is only sampled at power-up, so changing ADD with power on has no effect until the device is powered off, then on again.

Table 5. ADD Pin Truth Table

ADD Pin	A1	A0
GND	0	0
No Connect	1	0
V_{CC}	0	1

If ADD is left open-circuit, then the default address is 0101110. The facility to make hardwired changes at the ADD pin allows the user to avoid conflicts with other devices sharing the same serial bus; for example, if more than one ADM1031 is used in a system.

Serial Bus Protocol

1. The master initiates data transfer by establishing a START condition, defined as a high-to-low transition on the serial data line SDA while the serial clock line SCL 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 $R/\overline{W}$ bit that 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 now remain idle while the selected device waits for data to be read from or written to it. If the $R/\overline{W}$ bit is a 0, then the master writes to the slave device. If the $R/\overline{W}$ bit is a 1, then the master reads from the slave device.

2. Data is sent over the serial bus in sequences of nine clock pulses, eight bits of data, followed by an acknowledge bit from the slave device. Transitions on the data line must occur during the low period of the clock signal and remain stable during the high period, as a low-to-high transition when the clock is high can be interpreted as a stop signal. The number of data bytes that can be transmitted over the serial bus in a single read or 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 then 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 can be transferred 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.

In the case of the ADM1031, write operations contain either one byte or two bytes, and read operations contain one byte, and perform the functions described next.

Writing Data to a Register

To write data to one of the device data registers or read data from it, the address pointer register must be set so that the correct data register is addressed; data can then be written to that register or read from it. The first byte of a write operation always contains an 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 is illustrated in Figure 16. 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.

Reading Data from a Register

When reading data from a register there are two possibilities:

1. If the ADM1031's address pointer register value 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 performing a write to the ADM1031 as before, but only the data byte containing the register address is sent, as data is not to be written to the register. This is shown in Figure 17.

   A read operation is then performed consisting of the serial bus address, R/$\overline{W}$ bit set to 1, followed by the data byte read from the data register. This is shown in Figure 18.
2. If the address pointer register is known to be already at the desired address, data can be read from the corresponding data register without first writing to the address pointer register, so Figure 17 can be omitted.

Notes

- Although it is possible to read a data byte from a data register without first writing to the address pointer register, 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. This is because the first data byte of a write is always written to the address pointer register.
- In Figure 16, Figure 17, and Figure 18, the serial bus address is shown as the default value 01011(A1)(A0), where A1 and A0 are set by the three-state ADD pin.
- The ADM1031 also supports the Read Byte protocol, as described in the system management bus specification.

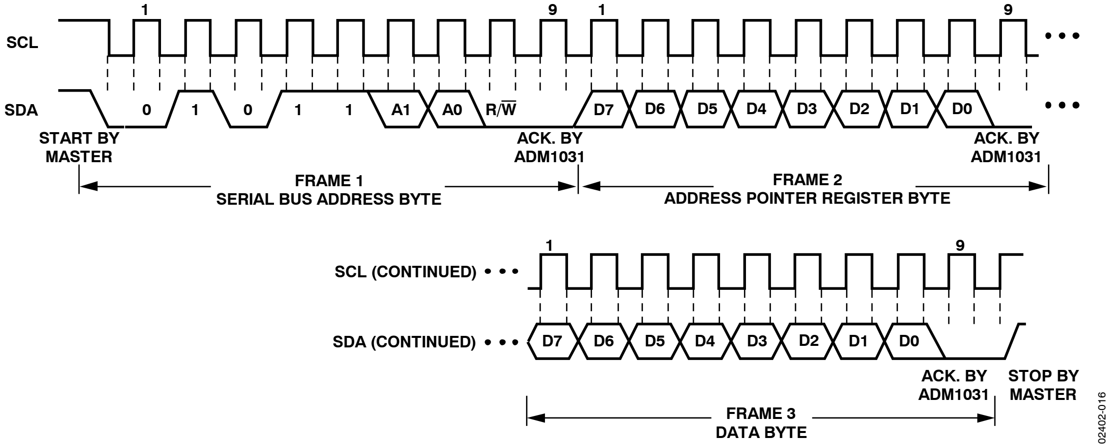

Figure 16. Writing a Register Address to the Address Pointer Register, then Writing Data to the Selected Register

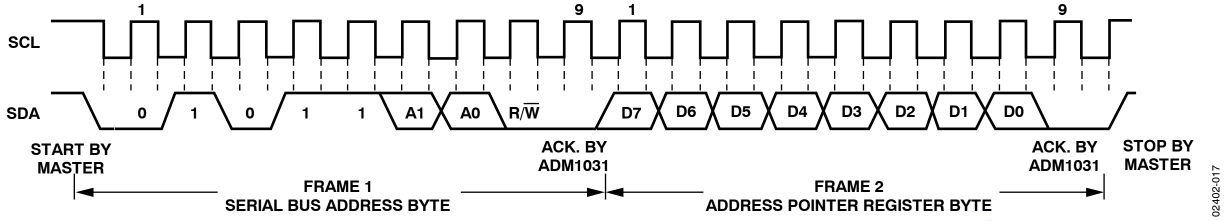

Figure 17. Writing to the Address Pointer Register Only

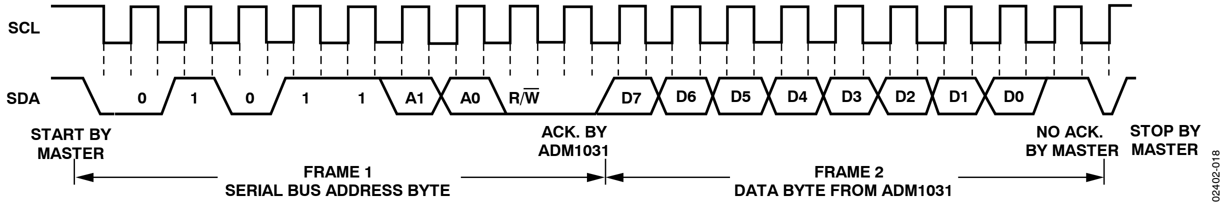

Figure 18. Reading Data from a Previously Selected Register

ALERT RESPONSE ADDRESS

Alert Response Address (ARA) is a feature of SMBus devices that allows an interrupting device to identify itself to the host when multiple devices exist on the same bus.

The $\overline{\text{INT}}$ output can be used as an interrupt output or can be used as an $\overline{\text{SMBALERT}}$. One or more $\overline{\text{INT}}$ outputs can be connected to a common $\overline{\text{SMBALERT}}$ line connected to the master. If a device's $\overline{\text{INT}}$ line goes low, the following procedure occurs:

1. $\overline{\text{SMBALERT}}$ is pulled low.
2. Master initiates a read operation and sends the Alert Response Address (ARA = 0001 100). This is a general call address that must not be used as a specific device address.
3. The device whose $\overline{\text{INT}}$ output is low responds to the alert response address, and the master reads its device address. The address of the device is now known and can be interrogated in the usual way.
4. If more than one device's $\overline{\text{INT}}$ output is low, the one with the lowest device address has priority, in accordance with normal SMBus arbitration.
5. Once the ADM1031 has responded to the alert response address, it resets its $\overline{\text{INT}}$ output. However, if the error condition that caused the interrupt persists, then $\overline{\text{INT}}$ is reasserted on the next monitoring cycle.

TEMPERATURE MEASUREMENT SYSTEM

INTERNAL MEASUREMENT

The ADM1031 contains an on-chip bandgap temperature sensor. The on-chip ADC performs conversions on the output of this sensor and outputs the temperature data in 10-bit twos complement format. The resolution of the local temperature sensor is 0.25°C. The format of the temperature data is shown in Table 6.

EXTERNAL MEASUREMENT

The ADM1031 can measure the temperatures of two external diode sensors or diode-connected transistors, connected to Pins 9 and 10, and Pins 11 and 12.

These pins are dedicated temperature input channels. The function of Pin 7 is as a $\overline{\text{THERM}}$ input/output and is used to flag overtemperature conditions.

The forward voltage of a diode or diode-connected transistor, operated at a constant current, exhibits a negative temperature coefficient of about –2 mV/°C. Unfortunately, the absolute value of V_{BE}, varies from device to device, and individual calibration is required to null this out. As a result, the technique is unsuitable for mass production.

The technique used in the ADM1031 is to measure the change in V_{BE} when the device is operated at two different currents.

This is given by

$$\Delta VBE = KT/q \times \ln (N)$$

where:
K is Boltzmann's constant.
q is charge on the carrier.
T is absolute temperature in Kelvins.
N is ratio of the two currents.

Figure 19 shows the input signal conditioning used to measure the output of an external temperature sensor. This figure shows the external sensor as a substrate transistor, provided for temperature monitoring on some microprocessors, but it could equally well be a discrete transistor.

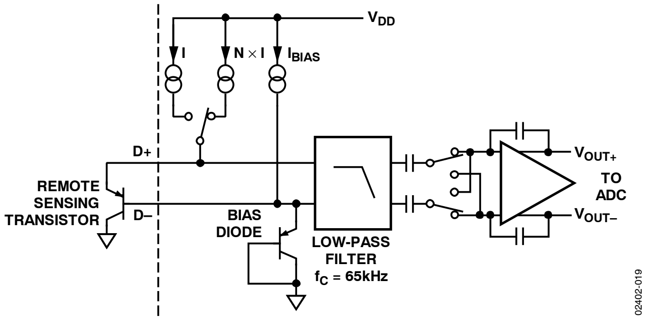

Figure 19. Signal Conditioning

If a discrete transistor is used, then the collector is not grounded, and is linked to the base. If a PNP transistor is used, the base is connected to the D– input and the emitter to the D+ input. If an NPN transistor is used, the emitter is connected to the D– input and the base to the D+ input.

One LSB of the ADC corresponds to 0.125°C, so the ADM1031 can theoretically measure temperatures from –127°C to +127.75°C, although –127°C is outside the operating range for the device. The extended temperature resolution data format is shown in Table 7 and

Table 8.

Table 6. Temperature Data Format (Local Temperature and Remote Temperature High Bytes)

Temperature (°C)	Digital Output
−128°C	1000 0000
−125°C	1000 0011
−100°C	1001 1100
−75°C	1011 0101
−50°C	1100 1110
−25°C	1110 0111
−1°C	1111 1111
0°C	0000 0000
+1°C	0000 0001
+10°C	0000 1010
+25°C	0001 1001
+50°C	0011 0010
+75°C	0100 1011
+100°C	0110 0100
+125°C	0111 1101
+127°C	0111 1111

Table 7. Remote Sensor Extended Temperature Resolution

Extended Resolution (°C)	Remote Temperature Low Bits
0.000	000
0.125	001
0.250	010
0.375	011
0.500	100
0.625	101
0.750	110
0.875	111

The extended temperature resolution for the local and remote channels is stored in the extended temperature resolution register (Register 0×06), and is outlined in Table 31.

Table 8. Local Sensor Extended Temperature Resolution

Extended Resolution (°C)	Local Temperature Low Bits
0.00	00
0. 25	01
0.50	10
0.75	11

To prevent ground noise interfering with the measurement, the more negative terminal of the sensor is not referenced to ground, but biased above ground by an internal diode at the D– input. If the sensor is used in a very noisy environment, a capacitor of value up to 1000 pF can be placed between the D+ and D– inputs to filter the noise.

To measure ΔV_{BE}, the sensor is switched between operating currents of I and N × I. The resulting waveform is passed through a 65 kHz low-pass filter to remove noise, then to a chopper-stabilized amplifier that performs the functions of amplification and rectification of the waveform to produce a dc voltage proportional to ΔV_{BE}. This voltage is measured by the ADC to give a temperature output in 11-bit twos complement format. To further reduce the effects of noise, digital filtering is performed by averaging the results of 16 measurement cycles. An external temperature measurement nominally takes 9.6 ms.

LAYOUT CONSIDERATIONS

Digital boards can be electrically noisy environments and care must be taken to protect the analog inputs from noise, particularly when measuring the very small voltages from a remote diode sensor. The following precautions should be taken:

1. Place the ADM1031 as close as possible to the remote sensing diode. Provided that the worst noise sources such as clock generators, data/address buses, and CRTs are avoided, this distance can be 4 to 8 inches.
2. Route the D+ and D– tracks close together, in parallel, with grounded guard tracks on each side. Provide a ground plane under the tracks if possible.
3. Use wide tracks to minimize inductance and reduce noise pickup. Ten mil track minimum width and spacing is recommended.

Figure 20. Arrangement of Signal Tracks

4. Try to minimize the number of copper/solder joints, which can cause thermocouple effects. Where copper/solder joints are used, make sure that they are in both the D+ and D– path and at the same temperature.

Thermocouple effects should not be a major problem as 1°C corresponds to about 200 μV, and thermocouple voltages are about 3 μV/°C of temperature difference. Unless there are two thermocouples with a big temperature differential between them, thermocouple voltages should be much less than 200 μV.

5. Place a 0.1 μF bypass capacitor close to the ADM1031.
6. If the distance to the remote sensor is more than 8 inches, the use of twisted pair cable is recommended. This works up to about 6 to 12 feet.
7. For extra long distances (up to 100 feet), use a shielded twisted pair cable, such as the Belden #8451 microphone cable. Connect the twisted pair to D+ and D– and the shield to GND close to the ADM1031. Leave the remote end of the shield unconnected to avoid ground loops.

Because the measurement technique uses switched current sources, excessive cable and/or filter capacitance can affect the measurement. When using long cables, the filter capacitor C1 can be reduced or removed. In any case the total shunt capacitance should not exceed 1000 pF.

Cable resistance can also introduce errors. One ohm series resistance introduces about 0.5°C error.

ADDRESSING THE DEVICE

ADD (Pin 13) is a three-state input. It is sampled, on power-up to set the lowest two bits of the serial bus address. Up to three addresses are available to the systems designer via this address pin. This reduces the likelihood of conflicts with other devices attached to the system management bus.

THE INTERRUPT SYSTEM

The ADM1031 has two interrupt outputs, $\overline{\text{INT}}$ and $\overline{\text{THERM}}$. These have different functions. $\overline{\text{INT}}$ responds to violations of software programmed temperature limits and is maskable.

$\overline{\text{THERM}}$ is intended as a “fail-safe” interrupt output that cannot be masked. If the temperature is below the low temperature limit, the $\overline{\text{INT}}$ pin is asserted low to indicate an out-of-limit condition. If the temperature exceeds the high temperature limit, the $\overline{\text{INT}}$ pin is also asserted low. A third limit, $\overline{\text{THERM}}$ limit, can be programmed into the device to set the temperature limit above which the overtemperature $\overline{\text{THERM}}$ pin is asserted low. The behavior of the high limit and $\overline{\text{THERM}}$ limit is as follows:

1. Whenever the temperature measured exceeds the high temperature limit, the $\overline{\text{INT}}$ pin is asserted low.
2. If the temperature exceeds the $\overline{\text{THERM}}$ limit, the $\overline{\text{THERM}}$ output asserts low. This can be used to throttle the CPU clock. If the $\overline{\text{THERM}}$-to-Fan Enable bit (Bit 7 of $\overline{\text{THERM}}$

behavior/revision register) is cleared to 0, then the fans do not run full-speed. The THERM limit can be programmed at a lower temperature than the high temperature limit. This allows the system to run in silent mode, where the CPU can be throttled while the cooling fan is off. If the temperature continues to increase, and exceeds the high temperature limit, an INT is generated. Software can then decide whether the fan should run to cool the CPU. This allows the system to run in silent mode.

3. If the THERM-to-Fan Enable bit is set to 1, then the fan runs full-speed whenever THERM is asserted low. In this case, both throttling and active cooling take place. If the high temperature limit is programmed to a lower value than the THERM limit, exceeding the high temperature limit asserts INT low. Software could change the speed of the fan depending on temperature readings. If the temperature continues to increase and exceeds the THERM limit, THERM asserts low to throttle the CPU and the fan runs full-speed. This allows the system to run in performance mode, where active cooling takes place and the CPU is only throttled at high temperature.

Using the high temperature limit and the THERM limit in this way allows the user to gain maximum performance from the system by only slowing it down, should it be at a critical temperature.

Although the ADM1031 does not have a dedicated interrupt mask register, clearing the appropriate enable bits in Configuration Register 2 clears the appropriate interrupts and masks out future interrupts on that channel. Disabling interrupt bits prevents out-of-limit conditions from generating an interrupt or setting a bit in the status registers.

USING THERM AS AN INPUT

The THERM pin is an open-drain input/output pin. When used as an output, it signals overtemperature conditions. When asserted low as an output, the fan is driven full-speed if the THERM-to-Fan Enable bit is set to 1 (Bit 7 of Register 0×3F). When THERM is pulled low as an input, the THERM bit (Bit 7) of Status Register 2 is set to 1, and the fans are driven full-speed. Note that the THERM-to-Fan Enable bit has no effect whenever THERM is used as an input. If THERM is pulled low as an input, and the THERM-to-Fan Enable bit = 0, then the fans are still driven full-speed. The THERM-to-Fan Enable bit only affects the behavior of THERM when used as an output.

STATUS REGISTERS

All out-of-limit conditions are flagged by status bits in Status Register 1 (0×02) and Status Register 2 (0×03). Bit 0 (Alarm Speed) and Bit 1 (Fan Fault) of Status Register 1, once set, can be cleared by reading Status Register 1. Once the alarm speed bit is cleared, this bit is not reasserted on the next monitoring cycle even if the condition still persists. This bit can be reasserted only if the fan is no longer at alarm speed. Bit 1 (Fan Fault) is set whenever a fan tach failure is detected. Once cleared, it reasserts on subsequent fan tach failures.

Bit 2 and Bit 3 of Status Register 1 and Status Register 2 are the Remote 1 and Remote 2 Temperature High and Low status bits. Exceeding the high or low temperature limits for the external channel sets these status bits. Reading the status register clears these bits. However, these bits are reasserted if the out-of-limit condition still exists on the next monitoring cycle. Bit 6 and Bit 7 are the Local Temperature High and Low status bits. These behave exactly the same as the Remote Temperature High and Low status bits. Bit 4 of Status Register 1 indicates that the Remote Temperature THERM limit has been exceeded. This bit gets cleared on a read of Status Register 1 (see Figure 21). Bit 5 indicates a remote diode error. This bit is a 1 if a short or open is detected on the remote temperature channel on power-up. If this bit is set to 1 on power-up, it cannot be cleared. Bit 6 of Status Register 2 (0×03) indicates that the Local THERM limit has been exceeded. This bit is cleared on a read of Status Register 2. Bit 7 indicates that THERM has been pulled low as an input. This bit can also be cleared on a read of Status Register 2.

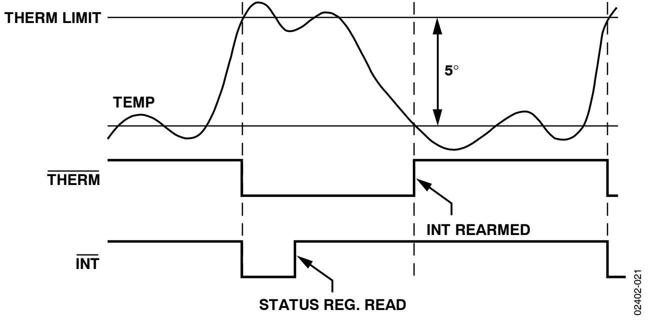

Figure 21. Operation of THERM and INT Signals

Figure 21 shows the interaction between INT and THERM. Once a critical temperature THERM limit is exceeded, both INT and THERM assert low. Reading the status registers clears the interrupt and the INT pin goes high. However, the THERM pin remains asserted until the measured temperature falls 5°C below the exceeded THERM limit. This feature can be used to CPU throttle or drive a fan full speed for maximum cooling. Note that the INT pin for that interrupt source is not rearmed until the temperature has fallen below the THERM limit −5°C. This prevents unnecessary interrupts from tying up valuable CPU resources.

FAN CONTROL MODES OF OPERATION

The ADM1031 has four different modes of operation. These modes determine the behavior of the system.

1. Automatic Fan Speed Control Mode.
2. Filtered Automatic Fan Speed Control Mode.
3. PWM Duty Cycle Select Mode (directly sets fan speed under software control).
4. RPM Feedback Mode.

AUTOMATIC FAN SPEED CONTROL

The ADM1031 has a local temperature channel and two remote temperature channels, which can be connected to an on-chip diode-connected transistor on a CPU. These three temperature channels can be used as the basis for an automatic fan speed control loop to drive fans using pulse width modulation (PWM).

How Does the Control Loop Work?

The automatic fan speed control loop is shown in Figure 22.

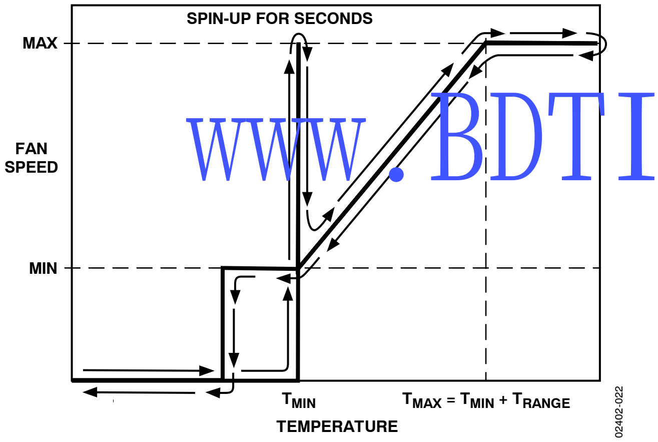

Figure 22. Automatic Fan Speed Control Loop

T_{MIN} is the temperature at which the fan should switch on and run at minimum speed. The fan only turns on once the temperature being measured rises above the TMIN value programmed. The fan spins up for a predetermined time (default = 2 seconds). See the Fan Spin-Up section for more details.

T_{RANGE} is the temperature range over which the ADM1031 automatically adjusts the fan speed. As the temperature increases beyond T_{MIN}, the PWM_OUT duty cycle increases accordingly. The T_{RANGE} parameter actually defines the fan speed vs. temperature slope of the control loop.

T_{MAX} is the temperature at which the fan is at its maximum speed. At this temperature, the PWM duty cycle driving the fan is 100%. T_{MAX} is given by $T_{MIN} + T_{RANGE}$. Since this parameter is the sum of the T_{MIN} and T_{RANGE} parameters, it does *not* need to be programmed into a register on-chip.

A hysteresis value of 5°C is included in the control loop to prevent the fan continuously switching on and off if the temperature is close to T_{MIN}. The fan continues to run until the temperature drops 5°C below T_{MIN}.

Figure 23 shows the different control slopes determined by the T_{RANGE} value chosen, and programmed into the ADM1031. T_{MIN} is set to 0°C to start all slopes from the same point. The figure shows how changing the T_{RANGE} value affects the PWM duty cycle vs. temperature slope.

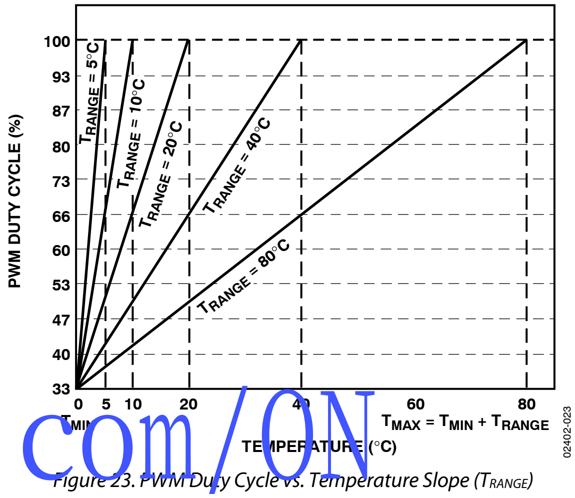

Figure 23. PWM Duty Cycle vs. Temperature Slope (T_{RANGE})

Figure 24 shows how, for a given T_{RANGE}, changing the T_{MIN} value affects the loop. Increasing the T_{MIN} value increases the T_{MAX} (temperature at which the fan runs full speed) value, since $T_{MAX} = T_{MIN} + T_{RANGE}$. Note, however, that the PWM duty cycle vs. temperature slope remains exactly the same. Changing the T_{MIN} value merely shifts the control slope. The T_{MIN} can be changed in increments of 4°C.

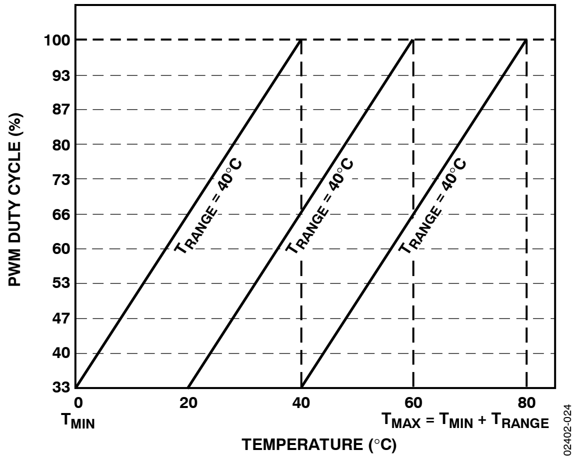

Figure 24. Effect of Increasing T_{MIN} Value on Control Loop

Fan Spin-Up

As mentioned in the How Does the Control Loop Work? section, once the temperature being measured exceeds the T_{MIN} value programmed, the fan turns on at minimum speed (default = 33% duty cycle). However, the problem with fans being driven by PWM is that 33% duty cycle is not enough to reliably start the fan spinning. The solution is to spin the fan up for a predetermined time, and once the fan has spun up, its running speed can be reduced in line with the temperature being measured.

The ADM1031 allows fan spin-up times between 200 ms and 8 seconds. Bits <2:0> of Fan Characteristics Register 1 (Register 0×20) and Fan Characteristic Register 2 (Register 0×21) program the fan spin-up times.

Table 9. Fan Spin-Up Times

Bits 2:0	Spin-Up Time (Fan Characteristics Registers 1, 2)
000	200 ms
001	400 ms
010	600 ms
011	800 ms
100	1 sec
101	2 sec (Default)
110	4 sec
111	8 sec

Once the automatic fan speed control loop parameters have been chosen, the ADM1031 device can be programmed. The ADM1031 is placed into automatic fan speed control mode by setting Bit 7 of Configuration Register 1 (Register 0×00). The device powers up in automatic fan speed control mode by default. The control mode offers further flexibility in that the user can decide which temperature channel/channels control each fan.

Table 10. Auto Mode Fan Behavior

Bits 6, 5	Control Operation (Configuration Register 1)
00	Remote Temperature 1 Controls Fan 1 Remote Temperature 2 Controls Fan 2
01	Remote Temperature 1 Controls Fan 1 and 2
10	Remote Temperature 2 Controls Fan 1 and 2
11	Maximum Speed Calculated by Local and Remote Temperature Channels Controls Fans 1 and 2

When Bit 5 and Bit 6 of Configuration Register 1 are both set to 1, increased flexibility is offered. The local and remote temperature channels can have independently programmed control loops with different control parameters. Whichever control loop calculates the fastest fan speed based on the temperature being measured, drives the fans.

Figure 25 and Figure 26 show how the fan's PWM duty cycle is determined by two independent control loops. This is the type of auto mode fan behavior seen when Bit 5 and Bit 6 of Configuration Register 1 are set to 11. Figure 25 shows the control loop for the local temperature channel. Its T_{MIN} value has been programmed to 20°C, and its T_{RANGE} value is 40°C. The local temperature's T_{MAX} is thus 60°C. Figure 26 shows the control loop for the remote temperature channel. Its T_{MIN} value has been set to 0°C, while its T_{RANGE} = 80°C. Therefore, the remote temperature's T_{MAX} value is 80°C.

Consider if both temperature channels measure 40°C. Both control loops calculate a PWM duty cycle of 66%. Therefore, the fan is driven at 66% duty cycle. If both temperature channels measure 20°C, the local channel calculates 33% PWM duty cycle, while the Remote 1 channel calculates 50% PWM duty cycle. Thus, the fans are driven at 50% PWM duty cycle. Consider the local temperature measuring 60°C while the Remote 1 temperature is measuring 70°C. The PWM duty cycle calculated by the local temperature control loop is 100% (because the temperature = T_{MAX}). The PWM duty cycle calculated by the Remote 1 temperature control loop at 70°C is approximately 90%. Therefore, the fan runs full-speed (100% duty cycle). Remember, that the fan speed is based on the fastest speed calculated, and is not necessarily based on the highest temperature measured. Depending on the control loop parameters programmed, a lower temperature on one channel, can actually calculate a faster speed than a higher temperature on the other channel.

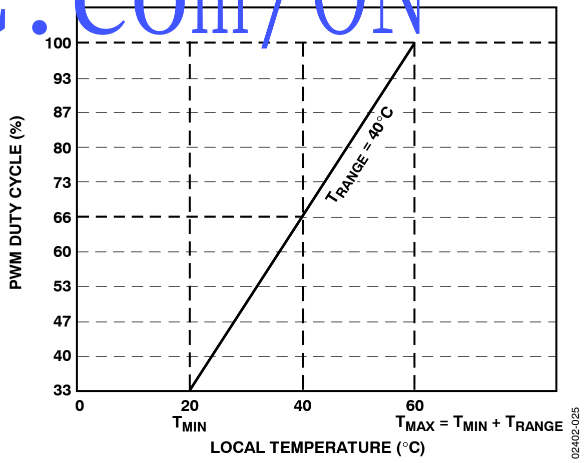

Figure 25. Maximum Speed Calculated by Local Temperature Control Loop Drives Fan