system. The mechanical or thermal engineer who is tasked with the actual system evaluation should also be involved at the beginning of the process.

AUTOMATIC FAN CONTROL OVERVIEW

Figure 1 gives a top-level overview of the automatic fan control circuitry on the ADT7460/ADT7463. From a systems level perspective, up to three system temperatures can be monitored and used to control three PWM outputs. The three PWM outputs can be used to control up to four fans. The ADT7460/ADT7463 allow the speed of four fans to be monitored. Each temperature channel has a thermal calibration block. This allows the designer to individually configure the thermal characteristics of each temperature channel. For example, one may decide to run the CPU fan when CPU temperature increases above 60°C, and a chassis fan when the local temperature increases above 45°C. Note that at this stage, you have not assigned these thermal calibration settings to a particular fan drive (PWM) channel. The right side of the Block Diagram (Figure 1) shows controls that are fan-specific. The designer has individual control over parameters such as minimum PWM duty cycle, fan speed failure thresholds, and even ramp control of the PWM outputs. This ultimately allows graceful fan speed changes that are less perceptible to the system user.

STEP 1: DETERMINING THE HARDWARE CONFIGURATION

During system design, the motherboard sensing and control capabilities should not be an afterthought, but addressed early in the design stages. Decisions about how these capabilities are used should involve the system thermal/mechanical engineer. Ask the following questions:

1. What ADT7460/ADT7463 functionality will be used?
   - PWM2 or $\overline{\text{SMBALERT}}$?
   - 2.5 V voltage monitoring or $\overline{\text{SMBALERT}}$?
   - 2.5 V voltage monitoring or processor power monitoring?
   - TACH4 fan speed measurement or overtemperature $\overline{\text{THERM}}$ function?
   - 5 V voltage monitoring or overtemperature $\overline{\text{THERM}}$ function?
   - 12 V voltage monitoring or VID5 input?

   The ADT7460/ADT7463 offers multifunctional pins that can be reconfigured to suit different system requirements and physical layouts. These multifunction pins are software programmable. Various pinout options are discussed in a separate application note.

2. How many fans will be supported in system, three or four? This will influence the choice of whether to use the TACH4 pin or to reconfigure it for the $\overline{\text{THERM}}$ function.

3. Is the CPU fan to be controlled using the ADT7460/ADT7463 or will it run at full speed 100% of the time?

   If run at 100%, it will free up a PWM output, but the system will be louder.

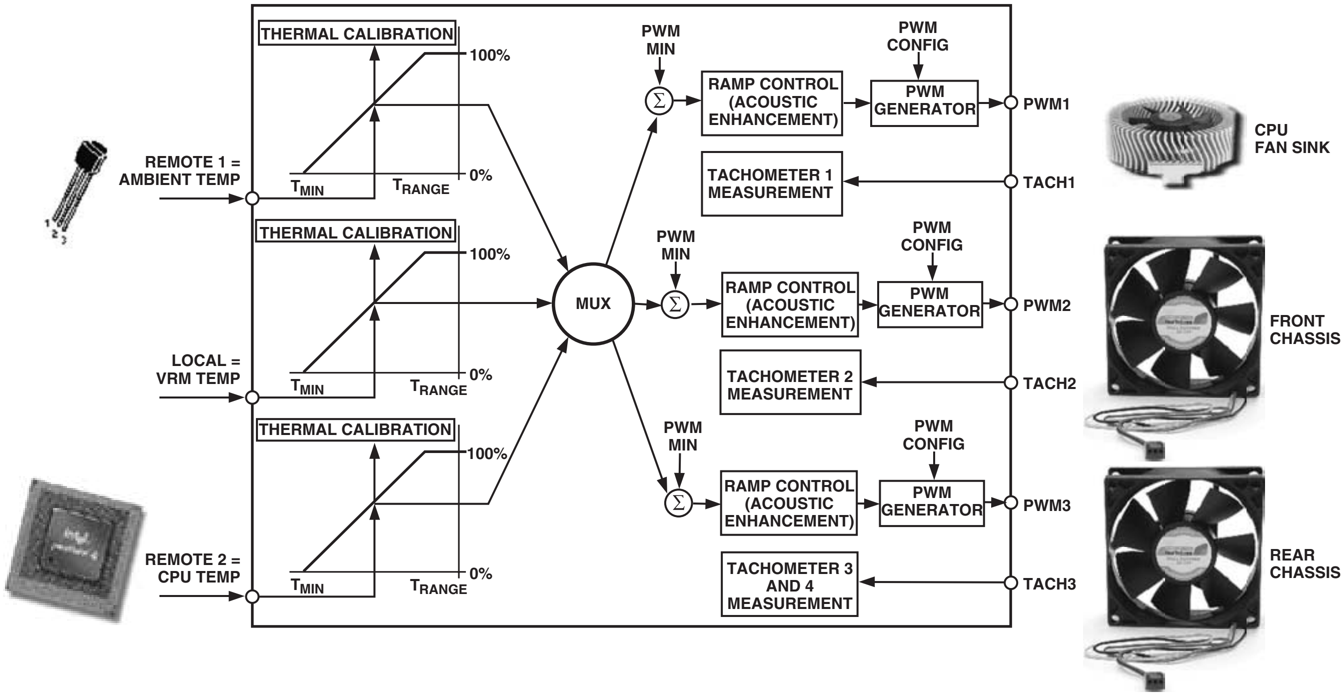


Figure 2. Hardware Configuration Example

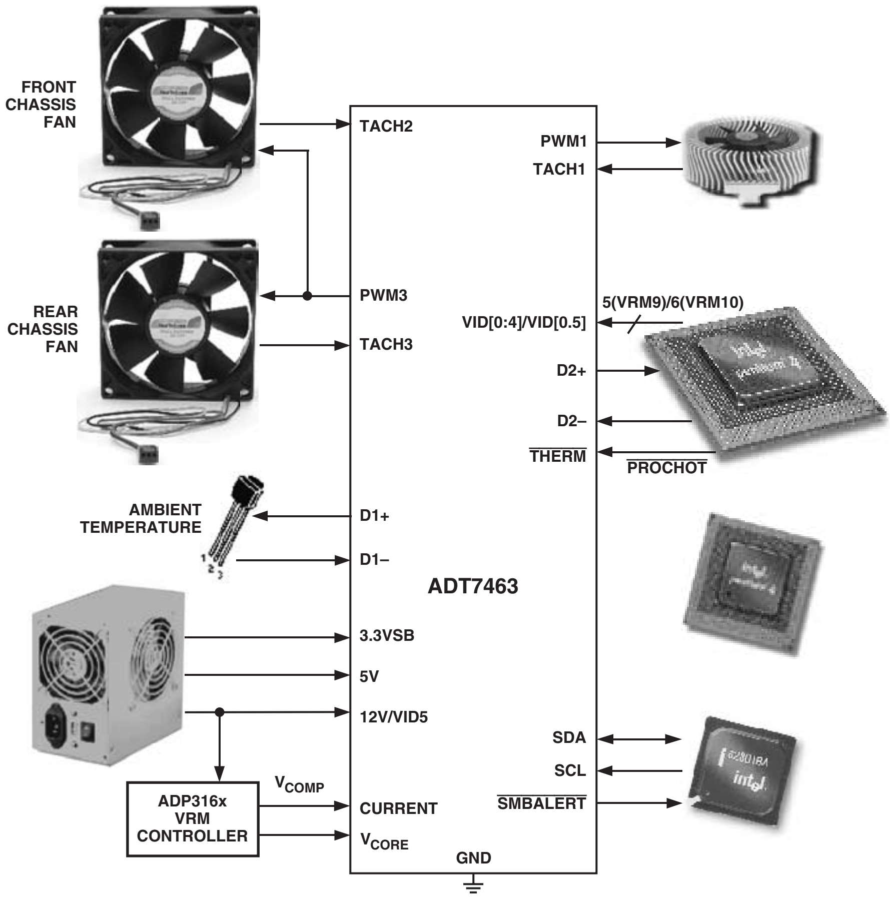


Figure 3. Recommended Implementation 1

4. Where will the ADT7460/ADT7463 be physically located in the system?

   This influences the assignment of the temperature measurement channels to particular system thermal zones. For example, locating the ADT7460/ADT7463 close to the VRM controller circuitry allows the VRM temperature to be monitored using the local temperature channel.

RECOMMENDED IMPLEMENTATION 1

Configuring the ADT7460/ADT7463 as in Figure 3 provides the systems designer with the following features:

1. Six VID Inputs (VID0 to VID5) for VRM10 Support.
2. Two PWM Outputs for Fan Control of up to Three Fans. (The front and rear chassis fans are connected in parallel.)
3. Three TACH Fan Speed Measurement Inputs.
4. V_{CC} Measured Internally through Pin 4.
5. CPU Core Voltage Measurement (V_{CORE}).
6. 2.5 V Measurement Input Used to Monitor CPU Current (connected to V_{COMP} output of ADP316x VRM controller). This is used to determine CPU power consumption.
7. 5 V Measurement Input.
8. VRM temperature uses local temperature sensor.
9. CPU Temperature Measured Using Remote 1 Temperature Channel.
10. Ambient Temperature Measured through Remote 2 Temperature Channel.
11. If not using VID5, this pin can be reconfigured as the 12 V monitoring input.
12. Bidirectional $\overline{\text{THERM}}$ Pin. Allows monitoring of $\overline{\text{PROCHOT}}$ output from Intel® P4 processor, for example, or can be used as an overtemperature $\overline{\text{THERM}}$ output.
13. $\overline{\text{SMBALERT}}$ System Interrupt Output.

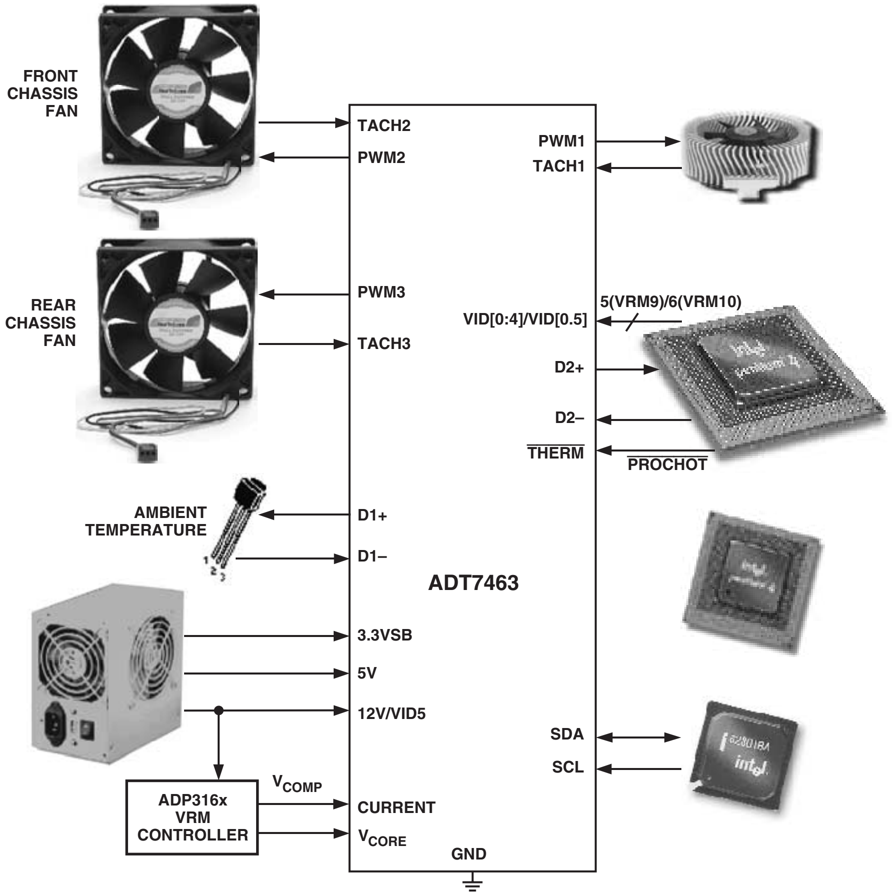


Figure 4. Recommended Implementation 2

RECOMMENDED IMPLEMENTATION 2

Configuring the ADT7460/ADT7463 as in Figure 4 provides the systems designer with the following features:

1. Six VID Inputs (VID0 to VID5) for VRM10 Support.
2. Three PWM Outputs for Fan Control of up to Three Fans. (All three fans can be individually controlled.)
3. Three TACH Fan Speed Measurement Inputs.
4. V_{CC} Measured Internally through Pin 4.
5. CPU Core Voltage Measurement (V_{CORE}).
6. 2.5 V Measurement Input Used to Monitor CPU Current (connected to V_{COMP} output of ADP316x VRM Controller). This is used to determine CPU power consumption.
7. 5 V Measurement Input.
8. VRM Temperature Uses Local Temperature Sensor.
9. CPU Temperature Measured Using Remote 1 Temperature Channel.
10. Ambient Temperature Measured through Remote 2 Temperature Channel.
11. If not using VID5, this pin can be reconfigured as the 12 V monitoring input.
12. BIDIRECTIONAL $\overline{\text{THERM}}$ Pin. Allows monitoring of $\overline{\text{PROCHOT}}$ output from Intel P4 processor, for example, or can be used as an overtemperature $\overline{\text{THERM}}$ output.

STEP 2: CONFIGURING THE MUX—WHICH TEMPERATURE CONTROLS WHICH FAN?

After the system hardware configuration is determined, the fans can be assigned to particular temperature channels. Not only can fans be assigned to individual channels, but the behavior of fans is also configurable. For example, fans can be run under automatic fan control, can run manually (under software control), or can run at the fastest speed calculated by multiple temperature channels. The MUX is the bridge between temperature measurement channels and the three PWM outputs.

Bits <7:5> (BHVR bits) of registers 0x5C, 0x5D, and 0x5E (PWM configuration registers) control the behavior of the fans connected to the PWM1, PWM2, and PWM3 outputs. The values selected for these bits determine how the MUX connects a temperature measurement channel to a PWM output.

AUTOMATIC FAN CONTROL MUX OPTIONS
<7:5> (BHVR) REGISTERS 05xC, 05xD, 05xE

000 = Remote 1 Temp controls PWMx
001 = Local Temp controls PWMx
010 = Remote 2 Temp controls PWMx
101 = Fastest Speed calculated by Local and Remote 2 Temp controls PWMx
110 = Fastest Speed calculated by all three temperature channels controls PWMx

The "Fastest Speed Calculated" options pertain to the ability to control one PWM output based on multiple temperature channels. The thermal characteristics of the three temperature zones can be set to drive a single fan. An example would be if the fan turns on when Remote 1 Temp exceeds 60°C or if the local Temperature exceeds 45°C.

OTHER MUX OPTIONS
<7:5> (BHVR) REGISTERS 05xC, 05xD, 05xE

011 = PWMx runs full speed (default)
100 = PWMx disabled
111 = Manual Mode. PWMx is run under software control. In this mode, PWM duty cycle registers (registers 0x30 to 0x32) are writeable and control the PWM outputs.

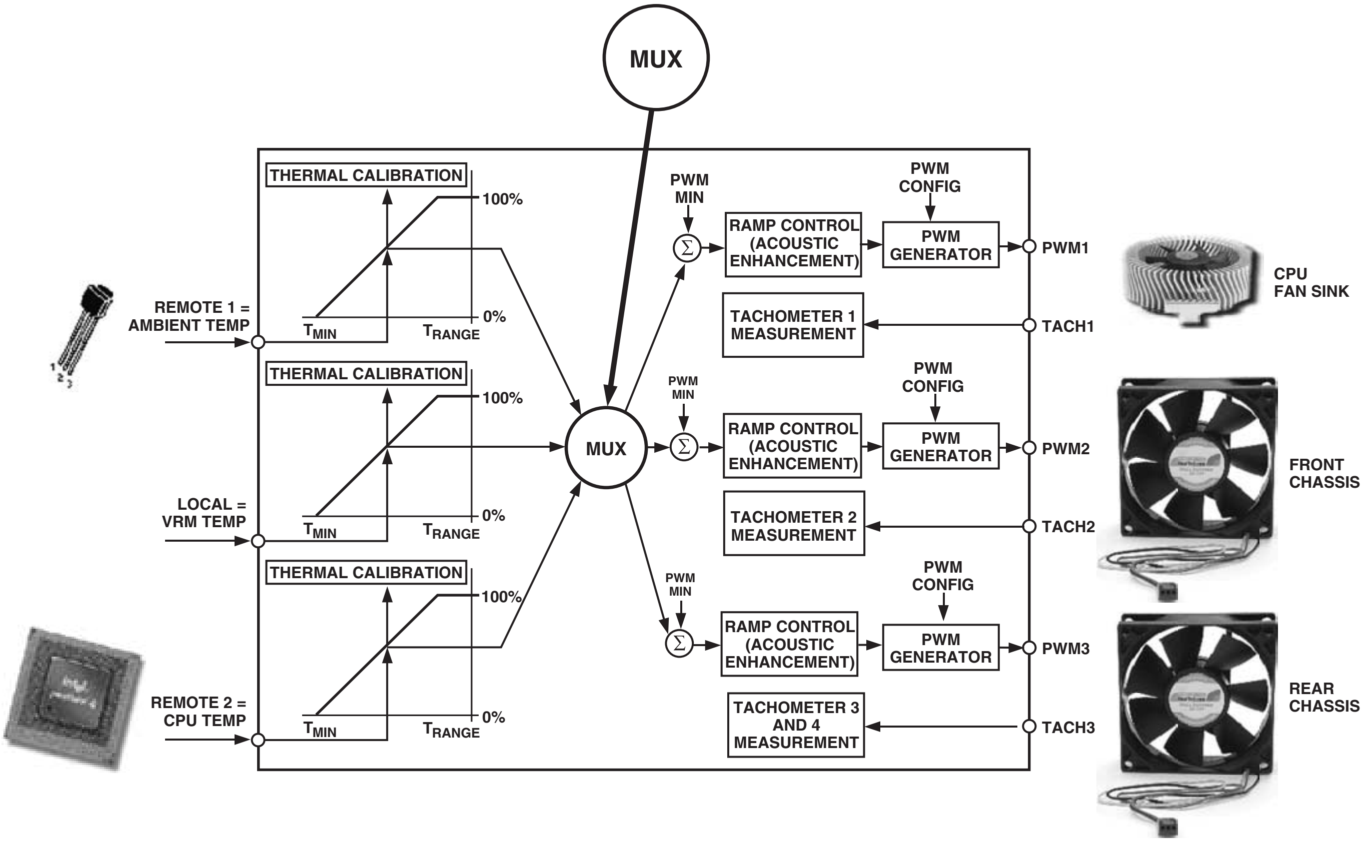


Figure 5. Assigning Temperature Channels to Fan Channels

MUX CONFIGURATION EXAMPLE

This is an example of how to configure the MUX in a system using the ADT7460/ADT7463 to control three fans. The CPU fan sink is controlled by PWM1, the front chassis fan is controlled by PWM 2, and the rear chassis fan is controlled by PWM3. The MUX is configured for the following fan control behavior:

PWM1 (CPU fan sink) is controlled by the fastest speed calculated by the Local (VRM Temp) and Remote 2 (Processor) Temp. In this case, the CPU fan sink is also being used to cool the VRM.

PWM2 (front chassis fan) is controlled by the Remote 1 Temp (Ambient).

PWM3 (rear chassis fan) is controlled by the Remote 1 Temp (Ambient).

EXAMPLE MUX SETTINGS

<7:5> (BHVR) PWM1 CONFIGURATION REG 5CH

101 = Fastest speed calculated by Local and Remote 2 Temp controls PWM1.

<7:5> (BHVR) PWM2 CONFIGURATION REG 5DH

000 = Remote 1 Temp controls PWM2.

<7:5> (BHVR) PWM3 CONFIGURATION REG 5EH

000 = Remote 1 Temp controls PWM3.

These settings configure the MUX, as shown in Figure 6.

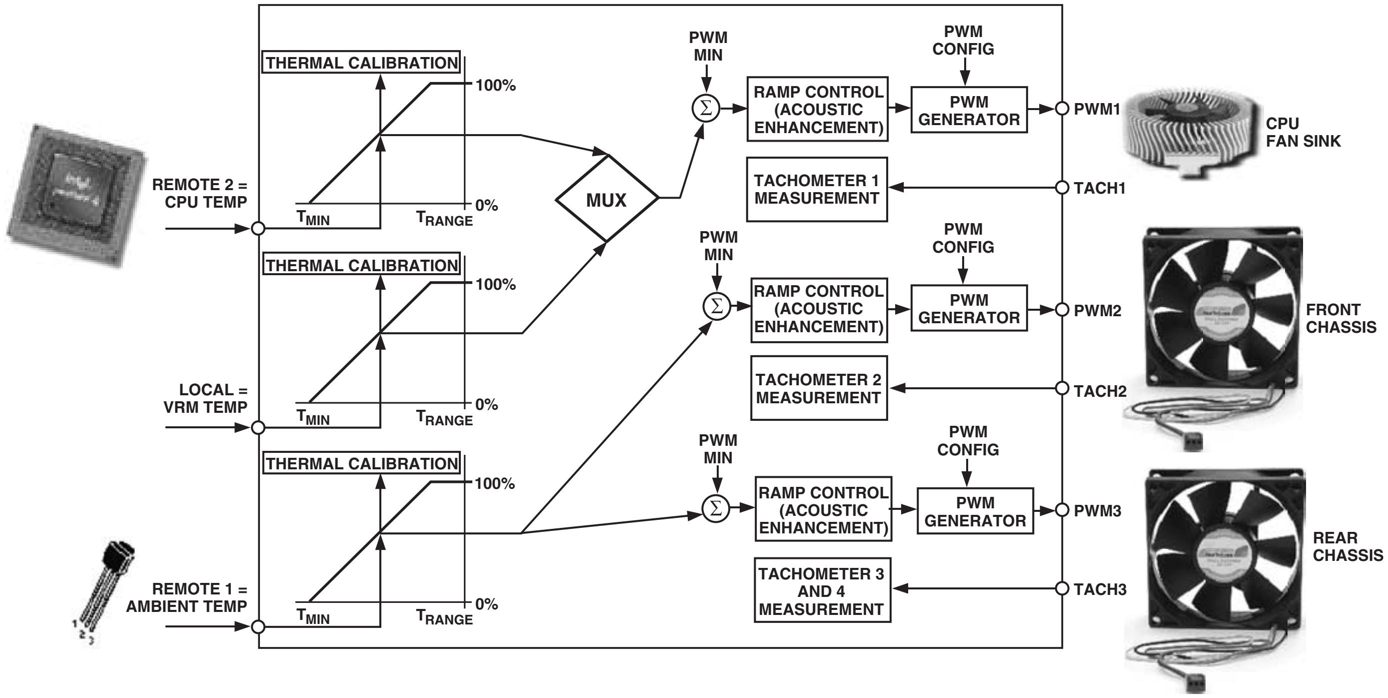


Figure 6. MUX Configuration Example

STEP 3: DETERMINING T_{MIN} SETTING FOR EACH THERMAL CALIBRATION CHANNEL

T_{MIN} is the temperature at which the fans will start to turn on under automatic fan control. The speed at which the fan runs at T_{MIN} is programmed later. The T_{MIN} values chosen will be temperature channel specific, e.g., 25°C for ambient channel, 30°C for VRM temperature, and 40°C for processor temperature.

T_{MIN} is an 8-bit twos complement value that can be programmed in 1°C increments. There is a T_{MIN} register associated with each temperature measurement channel: Remote 1, Local, and Remote 2 Temp. Once the T_{MIN} value is exceeded, the fan turns on and runs at minimum PWM duty cycle. The fan will turn off once temperature has dropped below $T_{MIN} – T_{HYST}$ (detailed later).

To overcome fan inertia, the fan is spun up until two valid tach rising edges are counted. See the Fan Startup Timeout section of the ADT7460/ADT7463 data sheet for more details. In some cases, primarily for psychoacoustic reasons, it is desirable that the fan never switches off below T_{MIN}. Bits <7:5> of Enhance Acoustics Register 1 (Reg. 0x62), when set, keeps the fans running at PWM minimum duty cycle if the temperature should fall below T_{MIN}.

T_{MIN} REGISTERS

Reg. 0x67 Remote 1 Temp T_{MIN} = 0x5A (90°C default)
Reg. 0x68 Local Temp T_{MIN} = 0x5A (90°C default)
Reg. 0x69 Remote 2 Temp T_{MIN} = 0x5A (90°C default)

ENHANCE ACOUSTICS REG 1 (REG. 62H)

Bit 7 (MIN3) = 0, PWM3 is OFF (0% PWM duty cycle) when Temp is below $T_{MIN} – T_{HYST}$.
Bit 7 (MIN3) = 1, PWM3 runs at PWM3 minimum duty cycle below $T_{MIN} – T_{HYST}$.

Bit 6 (MIN2) = 0, PWM2 is OFF (0% PWM duty cycle) when Temp is below $T_{MIN} – T_{HYST}$.
Bit 6 (MIN2) = 1, PWM2 runs at PWM2 minimum duty cycle below $T_{MIN} – T_{HYST}$.

Bit 5 (MIN1) = 0, PWM1 is OFF (0% PWM duty cycle) when Temp is below $T_{MIN} – T_{HYST}$.
Bit 5 (MIN1) = 1, PWM1 runs at PWM1 minimum duty cycle below $T_{MIN} – T_{HYST}$.

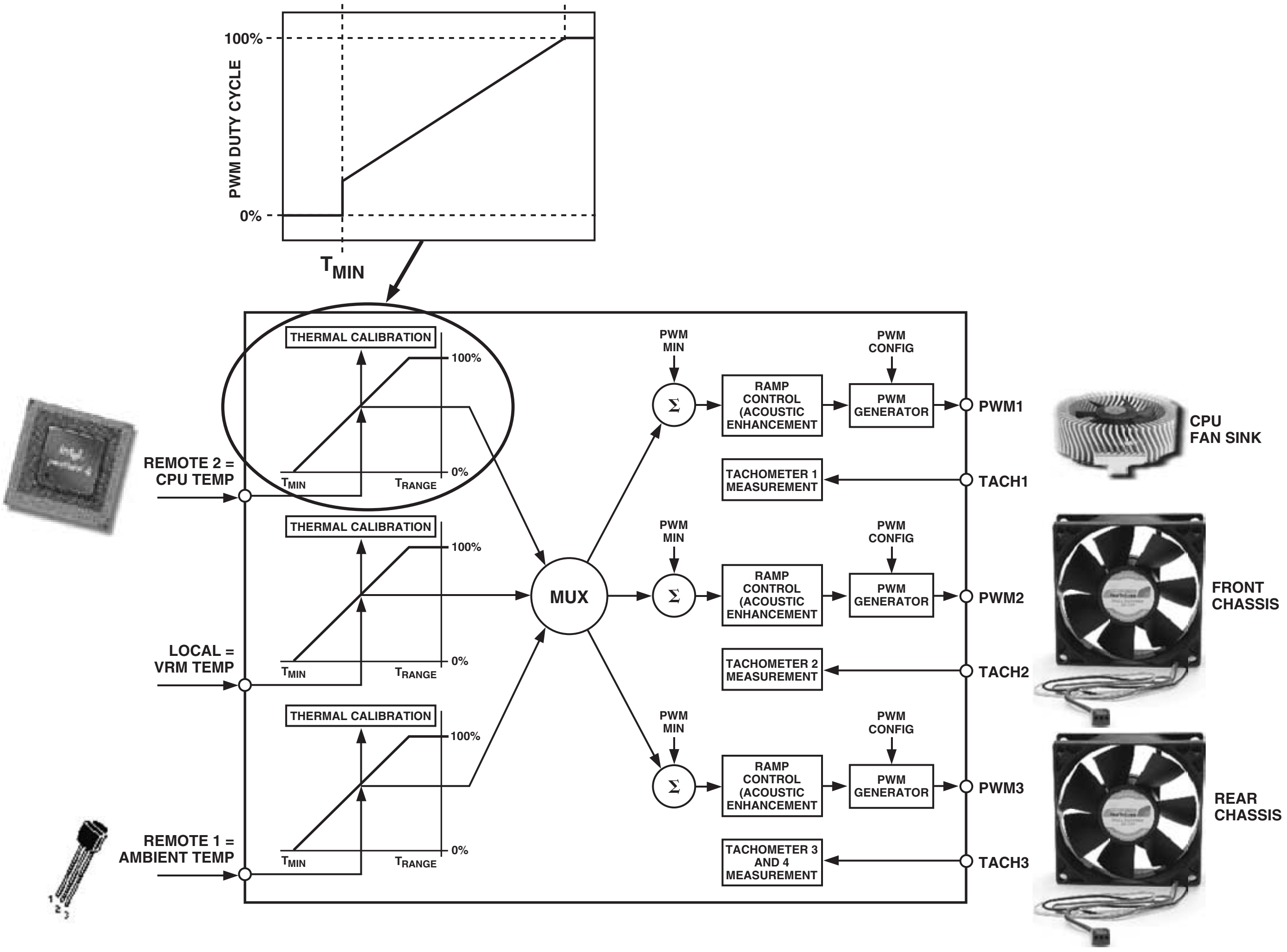


Figure 7. Understanding the T_{MIN} Parameter

STEP 4: DETERMINING PWM$_{MIN}$ FOR EACH PWM (FAN) OUTPUT

PWM$_{MIN}$ is the minimum PWM duty cycle at which each fan in the system will run. It is also the "start" speed for each fan under automatic fan control once the temperature rises above T$_{MIN}$. For maximum system acoustic benefit, PWM$_{MIN}$ should be as low as possible. Starting the fans at higher speeds than necessary will merely make the system louder than necessary. Depending on the fan used, the PWM$_{MIN}$ setting should be in the 20% to 33% duty cycle range. This value can be found through fan validation.

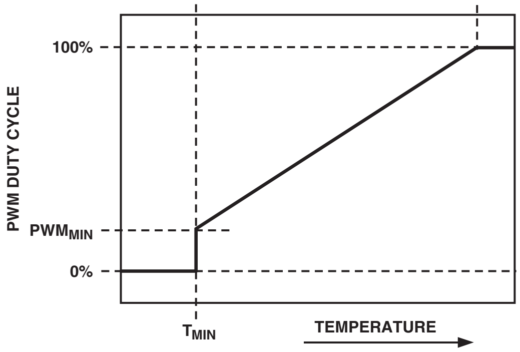


Figure 8. PWM$_{MIN}$ Determines Minimum PWM Duty Cycle

It is important to note that more than one PWM output can be controlled from a single temperature measurement channel. For example, Remote 1 Temp can control PWM1 and PWM2 outputs. If two different fans are used on PWM and PWM2, then the fan characteristics can be set up differently. As a result, Fan 1 driven by PWM1 can have a different PWM$_{MIN}$ value than that of Fan 2 connected to PWM2. Figure 9 illustrates this as PWM1$_{MIN}$ (front fan) is turned on at a minimum duty cycle of 20%, whereas PWM2$_{MIN}$ (rear fan) turns on at a minimum of 40% duty cycle. Note, however, that both fans turn on at exactly the same temperature, defined by T$_{MIN}$.

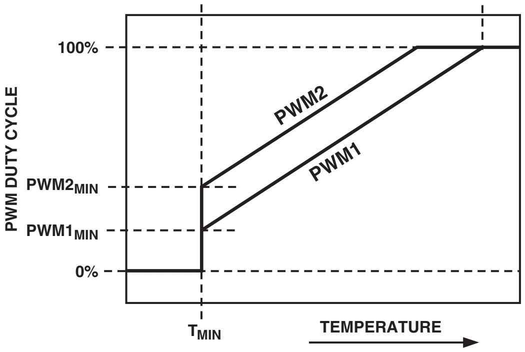


Figure 9. Operating Two Different Fans from a Single Temperature Channel

PROGRAMMING THE PWM$_{MIN}$ REGISTERS

The PWM$_{MIN}$ registers are 8-bit registers that allow the minimum PWM duty cycle for each output to be configured anywhere from 0% to 100%. This allows minimum PWM duty cycle to be set in steps of 0.39%.

The value to be programmed into the PWM$_{MIN}$ register is given by:

Value (decimal) = PWM$_{MIN}$/0.39

Example 1: For a minimum PWM duty cycle of 50%,

Value (decimal) = 50/0.39 = 128 decimal
Value = 128 decimal or 80 hex

Example 2: For a minimum PWM duty cycle of 33%,

Value (decimal) = 33/0.39 = 85 decimal
Value = 85 decimal or 54 hex

PWM$_{MIN}$ REGISTERS

Reg. 0x64 PWM1 Min Duty Cycle = 0x80 (50% default)
Reg. 0x65 PWM2 Min Duty Cycle = 0x80 (50% default)
Reg. 0x66 PWM3 Min Duty Cycle = 0x80 (50% default)

FAN SPEED AND PWM DUTY CYCLE

It should be noted that PWM duty cycle does not directly correlate to fan speed in RPM. Running a fan at 33% PWM duty cycle does not equate to running the fan at 33% speed. Driving a fan at 33% PWM duty cycle actually runs the fan at closer to 50% of its full speed. This is because fan speed in %RPM relates to the square root of PWM duty cycle. Given a PWM square wave as the drive signal, fan speed in RPM equates to:

$$\%\text{ fan speed} = \sqrt{\text{PWM duty cycle}} \times 10$$

STEP 5: DETERMINING T_{RANGE} FOR EACH TEMPERATURE CHANNEL

T_{RANGE} is the range of temperature over which automatic fan control occurs once the programmed T_{MIN} temperature has been exceeded. T_{RANGE} is actually a temperature slope and not an arbitrary value, i.e., a T_{RANGE} of 40°C only holds true for PWM_{MIN} = 33%. If PWM_{MIN} is increased or decreased, the effective T_{RANGE} is changed, as described later.

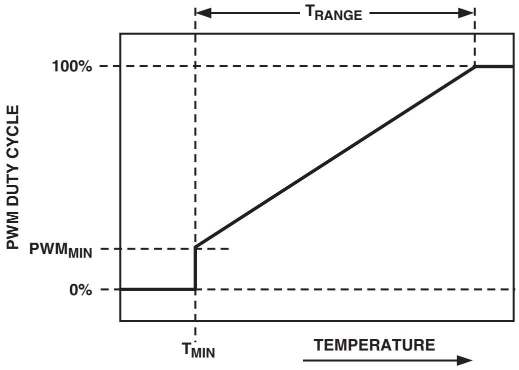


Figure 10. T_{RANGE} Parameter Affects Cooling Slope

The T_{RANGE} or fan control slope is determined by the following procedure:

1. Determine the maximum operating temperature for that channel, e.g., 70°C.
2. Determine experimentally the fan speed (PWM duty cycle value) that will not exceed the temperature at the worst-case operating points, e.g., 70°C is reached when the fans are running at 50% PWM duty cycle.
3. Determine the slope of the required control loop to meet these requirements.
4. Use best fit approximation to determine the most suitable T_{RANGE} value. ADT7460/ADT7463 evaluation software is available to calculate the best fit value. Ask your local Analog Devices representative for more details.

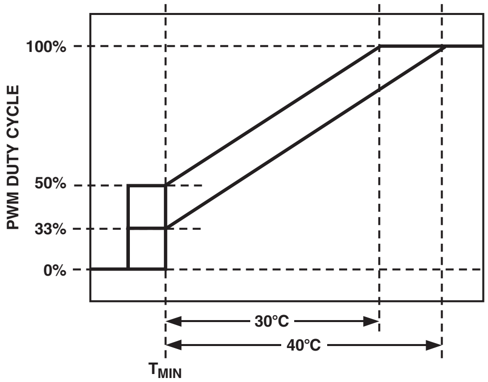


Figure 11. Adjusting PWM_{MIN} Affects T_{RANGE}

T_{RANGE} is implemented as a slope, which means as PWM_{MIN} is changed, T_{RANGE} changes but the actual slope remains the same. The higher the PWM_{MIN} value, the smaller the effective T_{RANGE} will be, i.e., the fan will reach full speed (100%) at a lower temperature.

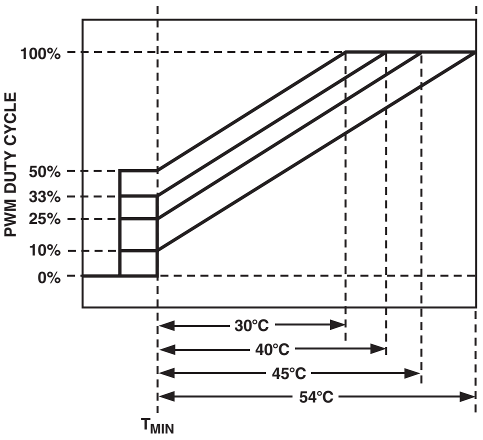


Figure 12. Increasing PWM_{MIN} Changes Effective T_{RANGE}

For a given T_{RANGE} value, the temperature at which the fan will run at full speed for different PWM_{MIN} values can easily be calculated:

$T_{MAX} = T_{MIN} + ((Max\ D.\ C. - Min\ D.\ C.) \times T_{RANGE}/170$

where

T_{MAX} = Temperature at which the fan runs full speed
T_{MIN} = Temperature at which the fan will turn on
$Max\ D.\ C.$ = Maximum duty cycle (100%) = 255 decimal
$Min\ D.\ C.$ = PWM_{MIN}
T_{RANGE} = PWM duty cycle versus temperature slope

Example: Calculate T_{MAX}, given T_{MIN} = 30°C, T_{RANGE} = 40°C, and PWM_{MIN} = 10% duty cycle = 26 decimal

$T_{MAX} = T_{MIN} + (Max\ D.\ C. - Min\ D.\ C.) \times T_{RANGE}/170$
$T_{MAX} = 30°C + (100\% - 10\%) \times 40°C/170$
$T_{MAX} = 30°C + (255 - 26) \times 40°C/170$
$T_{MAX} = 84°C$ (*effective* $T_{RANGE} = 54°C$)

Example: Calculate T_{MAX}, given T_{MIN} = 30°C, T_{RANGE} = 40°C, and PWM_{MIN} = 25% duty cycle = 64 decimal

$T_{MAX} = T_{MIN} + (Max\ D.\ C. - Min\ D.\ C.) \times T_{RANGE}/170$
$T_{MAX} = 30°C + (100\% - 25\%) \times 40°C/170$
$T_{MAX} = 30°C + (255 - 64) \times 40°C/170$
$T_{MAX} = 75°C$ (*effective* $T_{RANGE} = 45°C$)

Example: Calculate T_{MAX}, given T_{MIN} = 30°C, T_{RANGE} = 40°C, and PWM_{MIN} = 33% duty cycle = 85 decimal

$T_{MAX} = T_{MIN} + (Max\ D.\ C. - Min\ D.\ C.) \times T_{RANGE}/170$
$T_{MAX} = 30°C + (100\% - 33\%) \times 40°C/170$
$T_{MAX} = 30°C + (255 - 85) \times 40°C/170$
$T_{MAX} = 70°C$ (*effective* $T_{RANGE} = 40°C$)

Example: Calculate T_{MAX}, given T_{MIN} = 30°C, T_{RANGE} = 40°C, and PWM_{MIN} = 50% duty cycle = 128 decimal

$$T_{MAX} = T_{MIN} + (Max\ D.\ C. - Min\ D.\ C.) \times T_{RANGE}/170$$
$$T_{MAX} = 30°C + (100\% - 50\%) \times 40°C/170$$
$$T_{MAX} = 30°C + (255 - 128) \times 40°C/170$$
$$T_{MAX} = 60°C\ (effective\ T_{RANGE} = 30°C)$$

SELECTING A T_{RANGE} SLOPE

The T_{RANGE} value can be selected for each temperature channel: Remote 1, Local, and Remote 2 Temp. Bits <7:4> (T_{RANGE}) of registers 0x5F to 0x61 define the T_{RANGE} value for each temperature channel.

Table I. Selecting a T_{RANGE} Value

Bits <7:4>*	T_{RANGE}
0000	2°C
0001	2.5°C
0010	3.33°C
0011	4°C
0100	5°C
0101	6.67°C
0110	8°C
0111	10°C
1000	13.33°C
1001	16°C
1010	20°C
1011	26.67°C
1100	32°C (default)
1101	40°C
1110	53.33°C
1111	80°C

*Register 0x5F configures Remote 1 T_{RANGE}
Register 0x60 configures Local T_{RANGE}
Register 0x61 configures Remote 2 T_{RANGE}

SUMMARY OF T_{RANGE} FUNCTION

When using the automatic fan control function, the temperature at which the fan reaches full speed can be calculated by

$$T_{MAX} = T_{MIN} + T_{RANGE} \quad (1)$$

Equation 1 only holds true when PWM_{MIN} = 33% PWM duty cycle.

Increasing or decreasing PWM_{MIN} will change the effective T_{RANGE}, although the fan control will still follow the same PWM duty cycle to temperature slope. The effective T_{RANGE} for different PWM_{MIN} values can be calculated using Equation 2.

$$T_{MAX} = T_{MIN} + (Max\ D.\ C. - Min\ D.\ C.) \times T_{RANGE}/170 \quad (2)$$

where:

$(Max\ D.\ C. - Min\ D.\ C.) \times T_{RANGE}/170$ = *effective* T_{RANGE} *value.*

Remember that %PWM duty cycle does not correspond to %RPM. %RPM relates to the square root of the PWM duty cycle.

$$\%\ \text{fan speed} = \sqrt{\text{PWM duty cycle}} \times 10$$

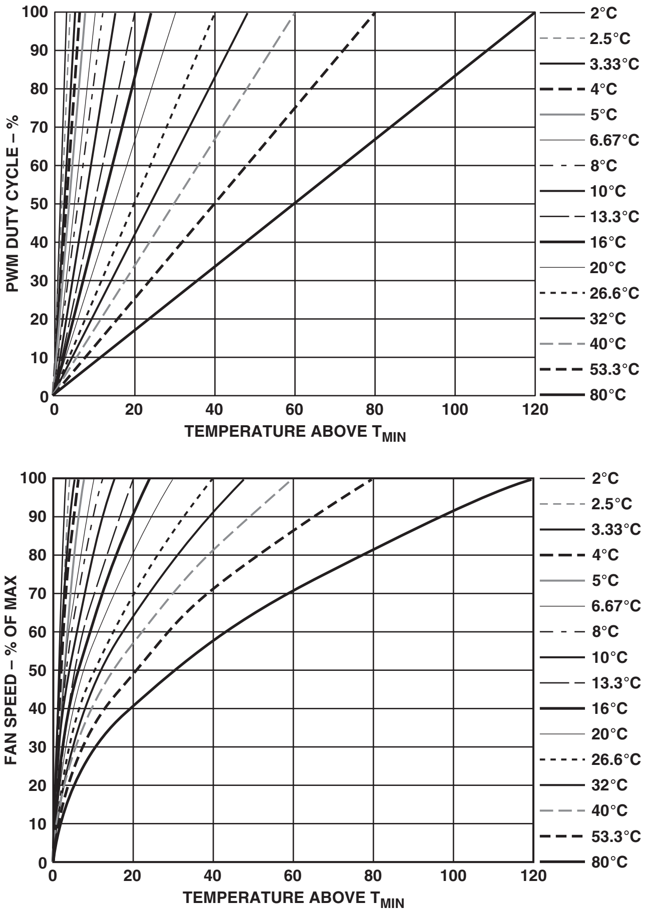


Figure 13. T_{RANGE} vs. Actual Fan Speed Profile

Figure 13 shows PWM duty cycle versus temperature for each T_{RANGE} setting. The lower graph shows how each T_{RANGE} setting affects fan speed versus temperature. As can be seen from the graph, the effect on fan speed is nonlinear. The graphs in Figure 13 assume that the fan starts from 0% PWM duty cycle. Clearly, the minimum PWM duty cycle, PWM_{MIN}, needs to be factored in to see how the loop actually performs in the system. Figure 14 shows how T_{RANGE} is affected when the PWM_{MIN} value is set to 20%. It can be seen that the fan will actually run at about 45% fan speed when the temperature exceeds T_{MIN}.

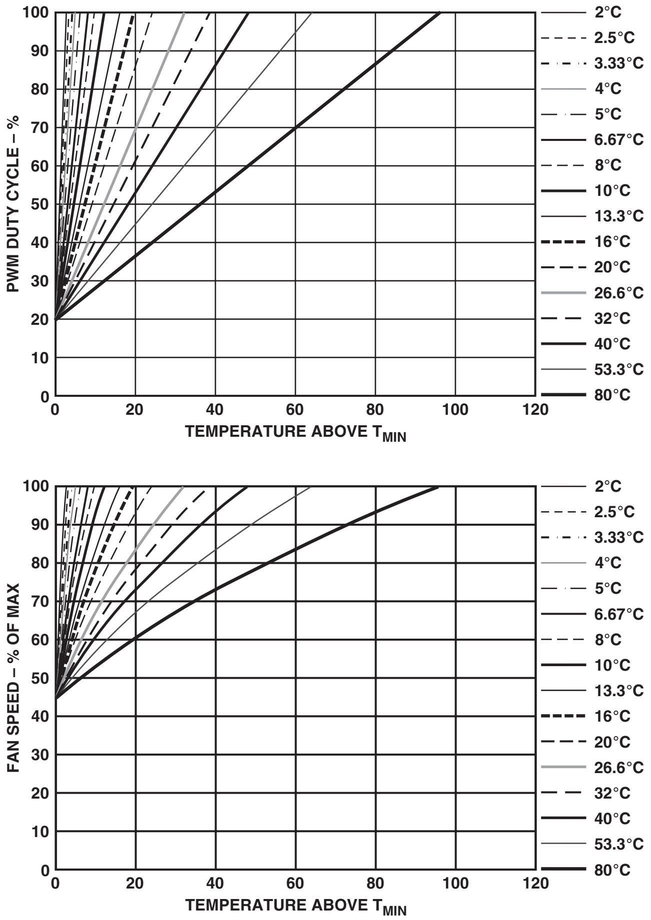


Figure 14. T_{RANGE}, % Fan Speed Slopes with PWM_{MIN} = 20%

EXAMPLE: DETERMINING T_{RANGE} FOR EACH TEMPERATURE CHANNEL

The following example is used to show how T_{MIN}, T_{RANGE} settings might be applied to three different thermal zones. In this example, the following T_{RANGE} values apply:

T_{RANGE} = 80°C for Ambient Temperature
T_{RANGE} = 53.3°C for CPU Temperature
T_{RANGE} = 40°C for VRM Temperature

This example uses the MUX configuration described in Step 2, with the ADT7460/ADT7463 connected as shown in Figure 6. Both CPU temperature and VRM temperature drive the CPU fan connected to PWM1. Ambient temperature drives the front chassis fan and rear chassis fan connected to PWM2 and PWM3.

The front chassis fan is configured to run at PWM_{MIN} = 20%. The rear chassis fan is configured to run at PWM_{MIN} = 30%.

The CPU fan is configured to run at PWM_{MIN} = 10%.

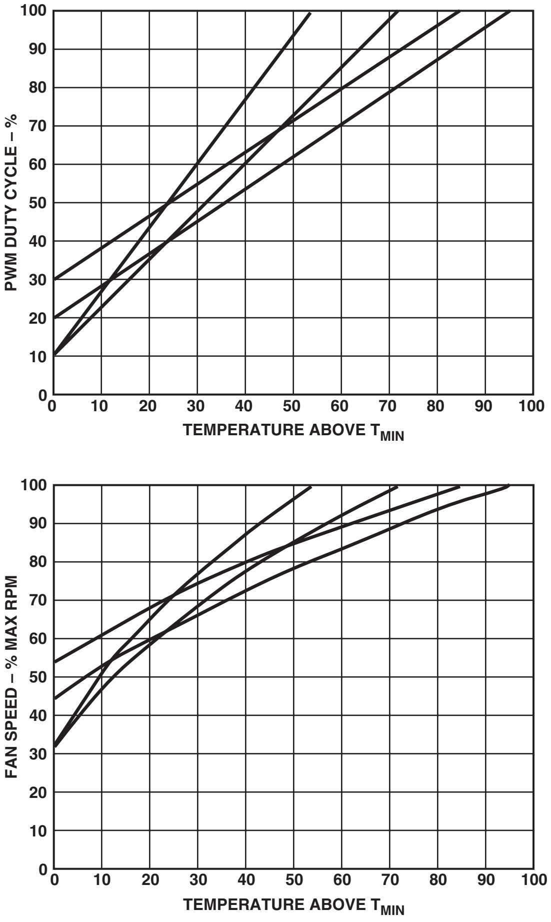


Figure 15. T_{RANGE}, % Fan Speed Slopes for VRM, Ambient, and CPU Temperature Channels

STEP 6: DETERMINING T_{THERM} FOR EACH TEMPERATURE CHANNEL

T_{THERM} is the absolute maximum temperature allowed on a temperature channel. Above this temperature, a component such as the CPU or VRM may be operating beyond its safe operating limit. When the temperature measured exceeds T_{THERM}, all fans are driven at 100% PWM duty cycle (full speed) to provide critical system cooling. The fans remain running 100% until the temperature drops below T_{THERM} – hysteresis. The hysteresis value is the number programmed into hysteresis registers 0x6D and 0x6E. The default hysteresis value is 4°C.

The T_{THERM} limit should be considered the maximum worst-case operating temperature of the system. Since exceeding any T_{THERM} limit runs all fans at 100%, it has very negative acoustic effects. Ultimately, this limit should be set up as a failsafe, and one should ensure that it is not exceeded under normal system operating conditions.

Note that the T_{THERM} limits are nonmaskable and affect the fan speed no matter what Automatic Fan Control settings are configured. This allows some flexibility since a T_{RANGE} value can be selected based on its slope, while a "hard limit," e.g., 70°C, can be programmed as T_{MAX} (the temperature at which the fan reaches full speed) by setting T_{THERM} to 70°C.

$\overline{\text{THERM}}$ REGISTERS

Reg. 0x6A Remote 1 $\overline{\text{THERM}}$ limit = 0x64 (100°C default)
Reg. 0x6B Local Temp $\overline{\text{THERM}}$ limit = 0x64 (100°C default)
Reg. 0x6C Remote 2 $\overline{\text{THERM}}$ limit = 0x64 (100°C default)

HYSTERESIS REGISTERS

Reg. 0x6D Remote 1, Local Hysteresis Register
<7:4> = Remote 1 Temp Hysteresis (4°C default)
<3:0> = Local Temp Hysteresis (4°C default)

Reg. 0x6E Remote 2 Temp Hysteresis Register
<7:4> = Remote 2 Temp Hysteresis (4°C default)

Since each hysteresis setting is four bits, hysteresis values are programmable from 1°C to 15°C. It is not recommended that hysteresis values ever be programmed to 0°C, as this actually disables hysteresis. In effect, this would cause the fans to cycle between normal speed and 100% speed, creating unsettling acoustic noise.

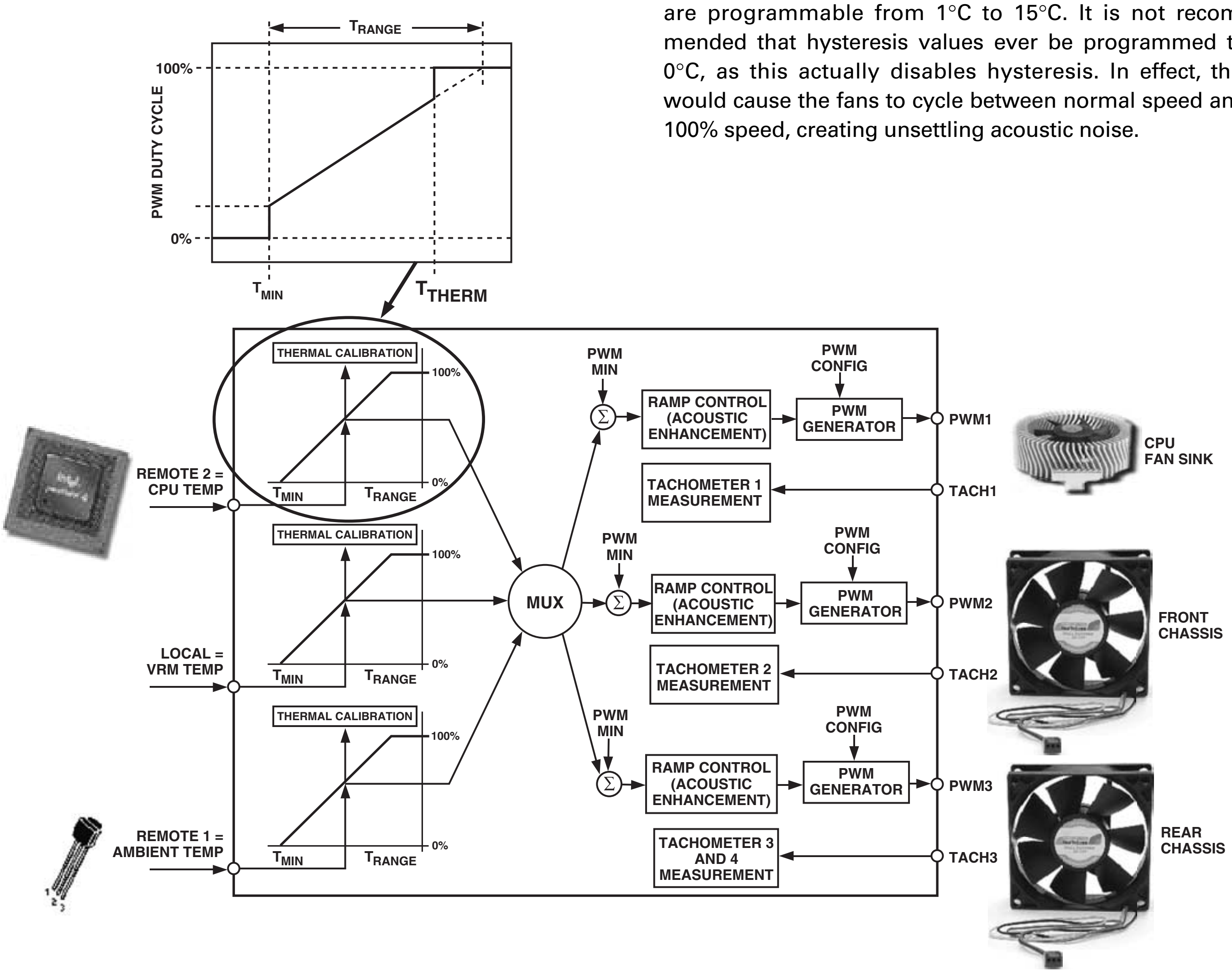


Figure 16. Understanding How T_{THERM} Relates to Automatic Fan Control

STEP 7: DETERMINING T_{HYST} FOR EACH TEMPERATURE CHANNEL

T_{HYST} is the amount of extra cooling a fan provides after the temperature measured has dropped back below T_{MIN} before the fan turns off. The premise for temperature hysteresis (T_{HYST}) is that without it, the fan would merely "chatter," or cycle on and off regularly, whenever temperature is hovering at about the T_{MIN} setting.

The T_{HYST} value chosen will determine the amount of time needed for the system to cool down or heat up as the fan is turning on and off. Values of hysteresis are programmable in the range 1°C to 15°C. Larger values of T_{HYST} prevent the fans from chattering on and off as previously described. The T_{HYST} default value is set at 4°C.

Note that the T_{HYST} setting applies not only to the temperature hysteresis for fan turn on/off, but the same setting is used for the T_{THERM} hysteresis value described in Step 6. So programming registers 0x6D and 0x6E sets the hysteresis for both fan on/off and the $\overline{\text{THERM}}$ function.

HYSTERESIS REGISTERS

Reg. 0x6D Remote 1, Local Hysteresis Register
<7:4> = Remote 1 Temp Hysteresis (4°C default)
<3:0> = Local Temp Hysteresis (4°C default)

Reg. 0x6E Remote 2 Temp Hysteresis Register
<7:4> = Remote 2 Temp Hysteresis (4°C default)

Note that in some applications, it is required that the fans not turn off below T_{MIN} but remain running at PWM_{MIN}. Bits <7:5> of Enhance Acoustics Register 1 (Reg. 0x62) allow the fans to be turned off, or to be kept spinning below T_{MIN}. If the fans are always on, the T_{HYST} value has no effect on the fan when the temperature drops below T_{MIN}.

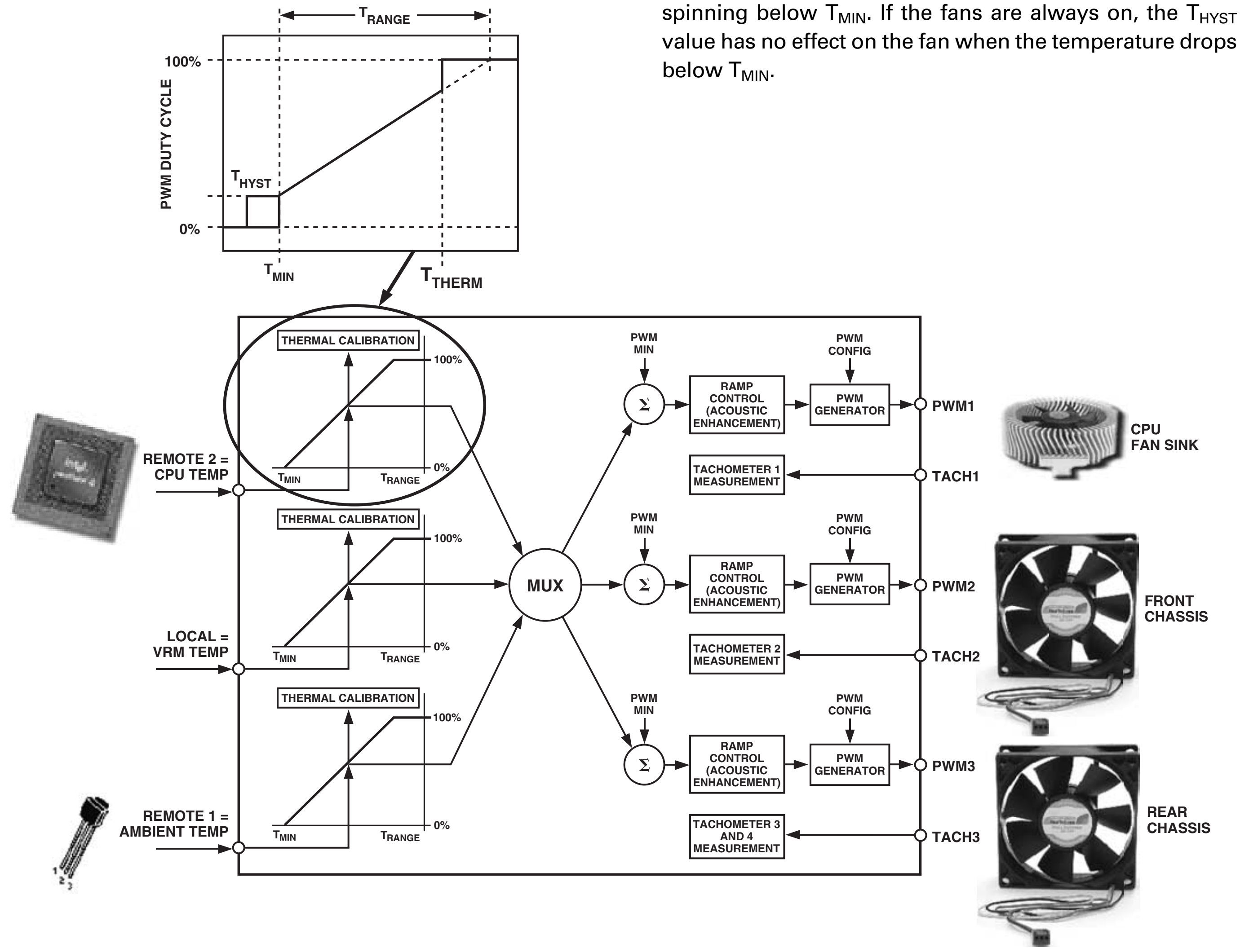


Figure 17. The T_{HYST} Value Applies to Fan On/Off Hysteresis and THERM Hysteresis

ENHANCE ACOUSTICS REG 1 (REG. 62H)

Bit 7 (MIN3) = 0, PWM3 is OFF (0% PWM duty cycle) when Temp is below $T_{MIN} – T_{HYST}$.
Bit 7 (MIN3) = 1, PWM3 runs at PWM3 minimum duty cycle below $T_{MIN} – T_{HYST}$.

Bit 6 (MIN2) = 0, PWM2 is OFF (0% PWM duty cycle) when Temp is below $T_{MIN} – T_{HYST}$.
Bit 6 (MIN2) = 1, PWM2 runs at PWM2 minimum duty cycle below $T_{MIN} – T_{HYST}$.

Bit 5 (MIN1) = 0, PWM1 is OFF (0% PWM duty cycle) when Temp is below $T_{MIN} – T_{HYST}$.
Bit 5 (MIN1) = 1, PWM1 runs at PWM1 minimum duty cycle below $T_{MIN} – T_{HYST}$.

DYNAMIC T_{MIN} CONTROL MODE

In addition to the automatic fan speed control mode described in the previous section, the ADT7460/ADT7463 have a mode that extends the basic automatic fan speed control loop. Dynamic T_{MIN} control allows the ADT7460/ADT7463 to intelligently adapt the system's cooling solution for best system performance or lowest possible system acoustics, depending on user or design requirements.

AIM OF THIS SECTION

This section has two primary goals:

1. To show how dynamic T_{MIN} control alleviates the need for designing for worst-case conditions.
2. To illustrate how the dynamic T_{MIN} control function significantly reduces system design and validation time.

DESIGNING FOR WORST-CASE CONDITIONS

When designing a system, you always design for worst-case conditions. In PC design, the worst-case conditions include, but are not limited to:

1. Worst-Case Altitude. A computer can be operated at different altitudes. The altitude affects the relative air density, which will alter the effectiveness of the fan cooling solution. For example, comparing 40°C air temperature at 10,000 ft to 20°C air temperature at sea level, relative air density is increased by 40%. This means that the fan can spin 40% slower, and make less noise, at sea level than at 10,000 ft while keeping the system at the same temperature at both locations.
2. Worst-Case Fan. Due to manufacturing tolerances, fan speeds in RPM are normally quoted with a tolerance of ±20%. The designer needs to assume that the fan RPM can be 20% below tolerance. This translates to reduced system airflow and elevated system temperature. Note that fans 20% out of tolerance will negatively impact system acoustics since they run faster and generate more noise.
3. Worst-Case Chassis Airflow. The same motherboard can be used in a number of different chassis configurations. The design of the chassis and physical location of fans and components determine the system thermal characteristics. Moreover, for a given chassis, the addition of add-in cards, cables, or other system configuration options can alter the system airflow and reduce the effectiveness of the system cooling solution. The cooling solution can also be inadvertently altered by the end user, e.g., placing a computer against a wall can block the air ducts and reduce system airflow.

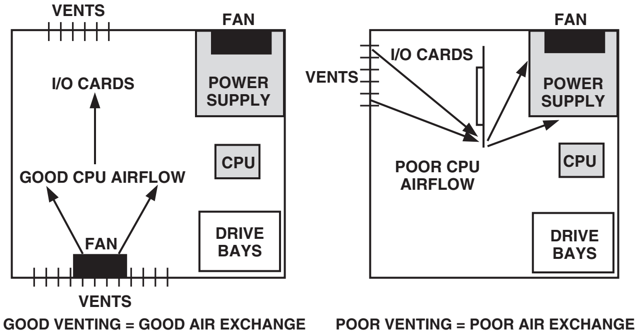


Figure 18. Chassis Airflow Issues

4. Worst-Case Processor Power Consumption. This is a data sheet maximum that does not necessarily reflect the true processor power consumption. Designing for worst-case CPU power consumption results in that the processor getting overcooled (generating excess system noise).
5. Worst-Case Peripheral Power Consumptions. The tendency is to design to data sheet maximums for these components (again overcooling the system).
6. Worst-Case Assembly. Every system manufactured is unique because of manufacturing variations. Heat sinks may be loose fitting or slightly misaligned. Too much or too little thermal grease may be used, or variations in application pressure for thermal interface material can affect the efficiency of the thermal solution. How can this be accounted for in every system? Again, the system is designed for the worst case.

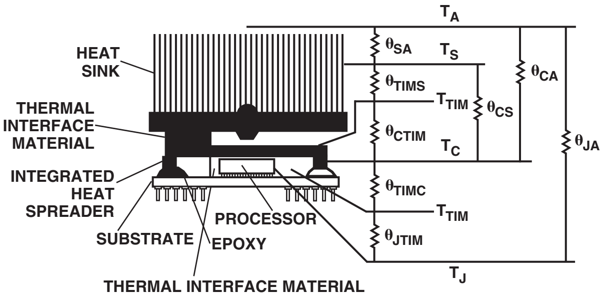


Figure 19. Thermal Model

The design usually accounts for worst-case conditions in all of these cases.

Note, however, that the actual system is almost never operated at worst-case conditions.

The alternative to designing for the worst case is to use the dynamic T_{MIN} control function.

DYNAMIC T_{MIN} CONTROL—OVERVIEW

Dynamic T_{MIN} Control mode builds upon the basic automatic fan control loop by adjusting the T_{MIN} value based on system performance and measured temperature. Why is this important?

Instead of designing for the worst case, the system thermals can be defined as "operating zones." The ADT7460/ADT7463 will self-adjust its fan control loop to maintain an operating zone temperature or system target temperature. For example, you can specify that the ambient temperature in a system should be maintained at 50°C. If the temperature is below 50°C, the fans may not need to run or may run very slowly. If the temperature is higher than 50°C, the fans need to throttle up. How is this different from the automatic fan control mode?

The challenge presented by any thermal design is finding the right settings to suit the system's fan control solution. This can involve designing for the worst case (as previously outlined), followed by weeks of system thermal characterization, and finally fan acoustic optimization (for psycho-acoustic reasons). Getting the most benefit from the automatic fan control mode involves characterizing the system to find the best T_{MIN} and T_{RANGE} settings for the control loop, and the best PWM_{MIN} value for the quietest fan speed setting. Using the ADT7460/ADT7463's dynamic T_{MIN} control mode shortens the characterization time and alleviates tweaking the control loop settings because the device can self-adjust during system operation.

DYNAMIC T_{MIN} CONTROL—THE SPECIFICS

The dynamic T_{MIN} control mode is operated by specifying the "operating zone temperatures" required for the system. Associated with this control mode are three operating point registers, one for each temperature channel. This allows the system thermal solution to be broken down into distinct thermal zones, e.g., CPU operating temperature = 70°C, VRM operating temperature = 80°C, ambient operating temperature = 50°C. The ADT7460/ADT7463 will dynamically alter the control solution to maintain each zone temperature as closely as possible to their target operating points.

OPERATING POINT REGISTERS

Reg. 0x33 Remote 1 Operating Point = 0x64 (100°C)
Reg. 0x34 Local Temp Operating Point = 0x64 (100°C)
Reg. 0x35 Remote 2 Operating Point = 0x64 (100°C)

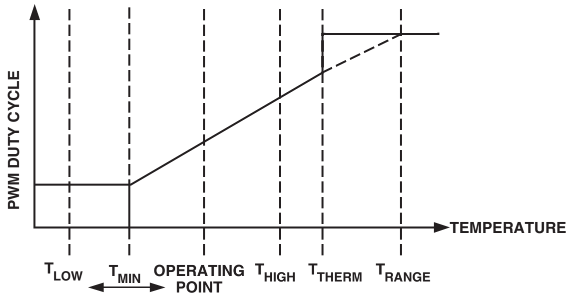


Figure 20. Dynamic T_{MIN} Control Loop

Figure 20 shows an overview of the parameters that affect the operation of the dynamic T_{MIN} control loop. A brief description of each parameter follows:

1. T_{LOW}. If temperature drops below the T_{LOW} limit, an error flag is set in a status register and an $\overline{\text{SMBALERT}}$ interrupt can be generated.
2. T_{HIGH}. If temperature exceeds the T_{HIGH} limit, an error flag gets set in a status register and an $\overline{\text{SMBALERT}}$ interrupt can be generated.
3. T_{MIN}. This is the temperature at which the fan turns on under automatic fan speed control.
4. Operating Point. This temperature defines the target temperature or optimal operating point for a particular temperature zone. The ADT7460/ADT7463 attempt to maintain system temperature at about the operating point by adjusting the T_{MIN} parameter of the control loop.
5. T_{THERM}. If temperature exceeds this critical limit, the fans can be run at 100% for maximum cooling.
6. T_{RANGE}. This programs the PWM duty cycle versus temperature control slope.

DYNAMIC T_{MIN} CONTROL PROGRAMMING

Since the dynamic T_{MIN} control mode is a basic extension of the automatic fan control mode, the automatic fan control mode parameters should be programmed first. Follow the seven steps in the Automatic Fan Control section of the ADT7460/ADT7463 data sheet before proceeding with dynamic T_{MIN} control mode programming.

STEP 8: DETERMINING THE OPERATING POINT FOR EACH TEMPERATURE CHANNEL

The operating point for each temperature channel is the optimal temperature for that thermal zone. The hotter each zone is allowed to be, the quieter the system since the fans are not required to run at 100% all of the time. The ADT7460/ADT7463 will increase/decrease fan speeds as necessary to maintain operating point temperature. This allows for system-to-system variation and removes the need for worst-case design. As long as a sensible operating point value is chosen, any T_{MIN} value can be selected in the system characterization. If the T_{MIN} value is too low, the fans will run sooner than required, and the temperature will be below the operating point. In response, the ADT7460/ADT7463 will increase T_{MIN} to keep the fans off for longer and allow the temperature zone to get closer to the operating point. Likewise, too high a T_{MIN} value will cause the operating point to be exceeded, and in turn, the ADT7460/ADT7463 will reduce T_{MIN} to turn the fans on earlier to cool the system.

PROGRAMMING OPERATING POINT REGISTERS

There are three operating point registers, one associated with each temperature channel. These 8-bit registers allow the operating point temperatures to be programmed with 1°C resolution.

OPERATING POINT REGISTERS

Reg. 0x33 Remote 1 Operating Point = 0x64 (100°C)
Reg. 0x34 Local Temp Operating Point = 0x64 (100°C)
Reg. 0x35 Remote 2 Operating Point = 0x64 (100°C)

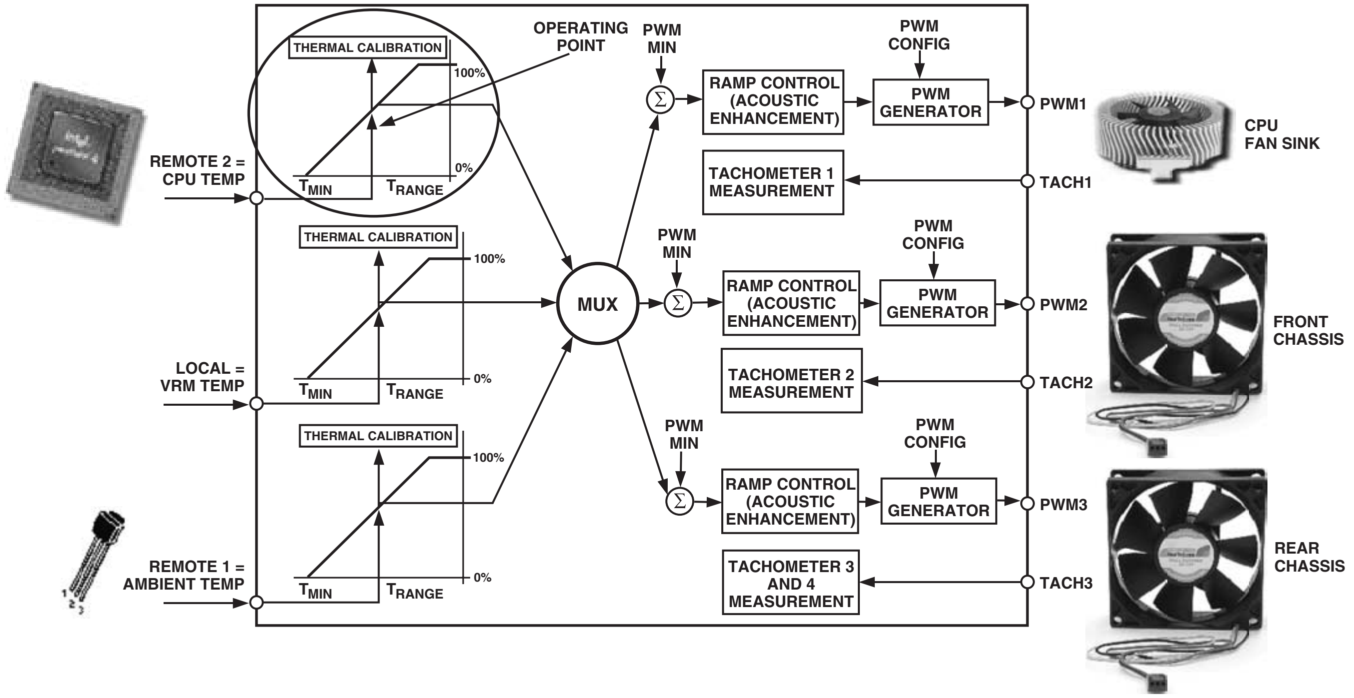


Figure 21. Operating Point Value Dynamically Adjusts Automatic Fan Control Settings

STEP 9: DETERMINING THE HIGH AND LOW LIMITS FOR EACH TEMPERATURE CHANNEL

The low limit defines the temperature at which the T_{MIN} value will start to be increased if temperature falls below this value. This has the net effect of reducing the fan speed, allowing the system to get hotter. An interrupt can be generated when the temperature drops below the low limit.

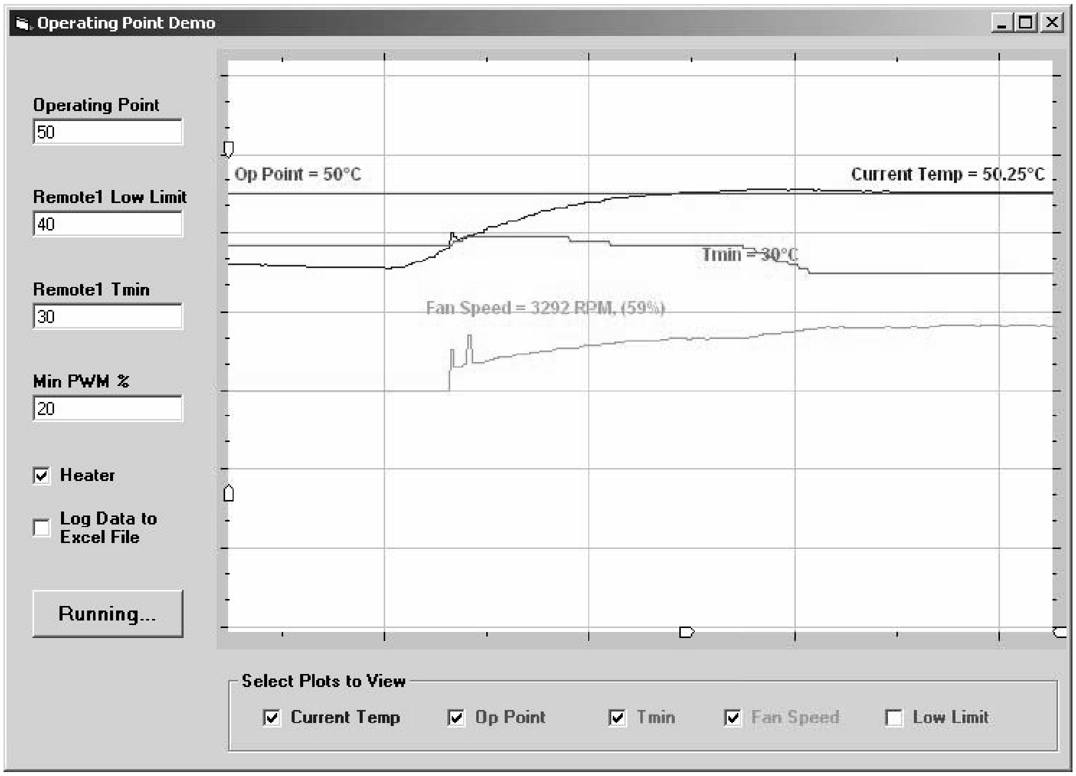
The high limit defines the temperature at which the T_{MIN} value will start to be reduced if temperature increases above this value. This has the net effect of increasing fan speed in order to cool down the system. An interrupt can be generated when the temperature rises above the high limit.

PROGRAMMING HIGH AND LOW LIMITS

There are six limit registers; a high limit and low limit are associated with each temperature channel. These 8-bit registers allow the high and low limit temperatures to be programmed with 1°C resolution.

TEMPERATURE LIMIT REGISTERS

Reg. 0x4E Remote 1 Temp Low Limit = 0x81
Reg. 0x4F Remote 1 Temp High Limit = 0x7F
Reg. 0x50 Local Temp Low Limit = 0x81
Reg. 0x51 Local Temp High Limit = 0x7F
Reg. 0x52 Remote 2 Temp Low Limit = 0x81
Reg. 0x53 Remote 2 Temp High Limit = 0x7F



Operating Point: 50
Remote1 Low Limit: 40
Remote1 Tmin: 30
Min PWM %: 20
☑ Heater
☐ Log Data to Excel File

☑ Current Temp ☑ Op Point ☑ Tmin ☑ Fan Speed ☐ Low Limit

Figure 22. Dynamic T_{MIN} Control in Operation

HOW DOES DYNAMIC T_{MIN} CONTROL WORK?

The basic premise is as follows:

1. Set the target temperature for the temperature zone, which could be, for example, the Remote 1 thermal diode. This value is programmed to the Remote 1 operating Temperature register.
2. As the temperature in that zone (Remote 1 temperature) rises toward and exceeds the operating point temperature, T_{MIN} is reduced and the fan speed increases.
3. As the temperature drops below the operating point temperature, T_{MIN} is increased, reducing the fan speed.

The loop operation is not as simple as described above. There are a number of conditions governing situations in which T_{MIN} can increase or decrease.

SHORT CYCLE AND LONG CYCLE

The ADT7460/ADT7463 implement two loops, a short cycle and a long cycle. The short cycle takes place every n monitoring cycles. The long cycle takes place every 2n monitoring cycles. The value of n is programmable for each temperature channel. The bits are located at the following register locations:

Remote 1 = CYR1 = Bits <2:0> of Calibration Control Register 2 (Addr = 0x37)
Local = CYL = Bits <5:3> of Calibration Control Register 2 (Addr = 0x37)
Remote 2 = CYR2 = Bits <7:6> of Calibration Control Register 2 and Bit 0 of Calibration Control Register 1 (Addr = 0x36)

Table II. Cycle Bit Assignments

CODE	Short Cycle	Long Cycle
000	8 cycles (1 s)	16 cycles (2 s)
001	16 cycles (2 s)	32 cycles (4 s)
010	32 cycles (4 s)	64 cycles (8 s)
011	64 cycles (8 s)	128 cycles (16 s)
100	128 cycles (16 s)	256 cycles (32 s)
101	256 cycles (32 s)	512 cycles (64 s)
110	512 cycles (64 s)	1024 cycles (128 s)
111	1024 cycles (128 s)	2048 cycles (256 s)

Care should be taken in choosing the cycle time. A long cycle time means that the T_{MIN} is not updated very often; if your system has very fast temperature transients, the dynamic T_{MIN} control loop will always be lagging. If you choose a cycle time that is too fast, the full benefit of changing T_{MIN} may not have been realized and you change again on the next cycle; in effect you would be overshooting. It is necessary to carry out some calibration to identify the most suitable response time.

E03235–0–2/03(0)

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