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Technical Papers and Publications

# Calibrating The Internal Thermal Diode In An Intel PIII CPU

**Notes: This procedure is only applicable to Intel PIII processors.**
The internal diodes in the Intel P4 and AMD CPUs that are read by the motherboard or external circuitry are not located in the hot parts of the cores. Since the diodes are some distance away from the actual heat sources, they are subject to compression errors similar to external measurements. (Compression errors are inevitable whenever there is thermal resistance between a heat source and a measurement device.) The exact amount of thermal resistance between the heat sources and the diodes in Intel P4 and AMD CPUs is currently unknown, but it is enough to significantly affect the temperatures measured by the diodes.

All modern Intel CPUs have a thermal diode built in amongst the millions of transistors, capacitors, and resistors that comprise the actual core of the processor. Since this diode is right there in the middle of the action, it provides the most relevant CPU temperature readings. When you change the thermal compound or heatsink, the thermal diode will show the true effect of the change on the actual active part of the CPU that the cooling system is cooling. External measurements with thermocouples or thermistors will always be compromised by the thermal resistance of the heat path to the exterior device, the lack of an isothermal environment for the external device and thus the influence of the local environment. (Case ambient temperature, motherboard temperature, airflow at the measuring location, etc.)

Unfortunately, very few motherboards incorporate the circuitry required to read the thermal diode and the diode/motherboard combination can display temperatures that are off by up to 6C or so from the actual temperature. This error is constant, so it does not affect the usefulness of the internal diode as a test device. A change to the cooling system that changes the temperature reading by 3C IS a 3C change regardless of whether the diode shows it as 43 to 40, or 38 to 35, or 40 to 37. The diode may lie, but it always tells the same lie.

But you can make it stop lying. There is a simple procedure for calibrating the internal diode on your motherboard---assuming you are lucky enough to have one of the motherboards capable of reading the diode---so that the CPU temperatures you see are the actual internal CPU temperatures.

The basis of this calibration is that a change in the speed of the CPU will cause a proportional change in the heat output of the CPU. So if we change the operating speed of the CPU by 50 percent the power dissipation of the CPU will also increase by 50 percent.

This allows us to develop the formula when we are able to test the thermal diode temperature of an Intel or AMD CPU at two different speeds:

MHz1 ÷ MHz2 = Theoretical Power Dissipation Ratio

Diode temp above ambient at MHz1 ÷ Diode temp above ambient at MHz2 = Theoretical Power Dissipation Ratio

And then to solve for the diode error when the diode temps do not equal the Theoretical PD Ratio:

(Diode temp above ambient at MHz1 – Error) ÷ (Diode temp above ambient at MHz2 – Error) = Theoretical PD Ratio

(Please note that the diode could require either a positive or negative compensation. For clarity, we will express all the formulas as "– Error" however your particular CPU diode/motherboard combination may require a "+ Error" compensation.)

What is needed to calibrate the internal diode in your CPU:

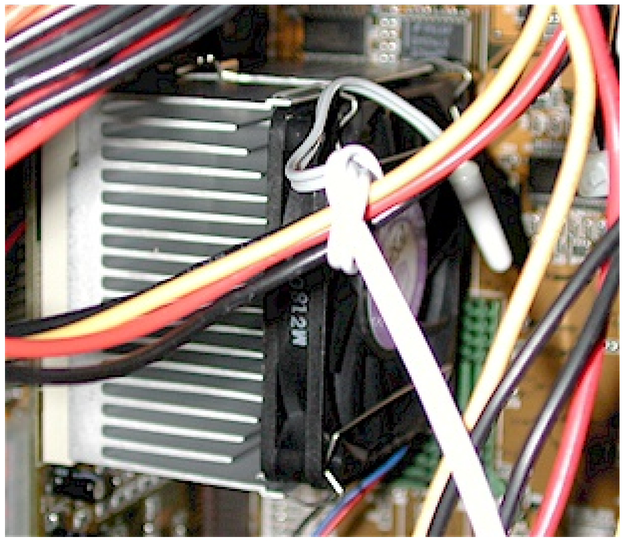
A motherboard (and slotket if used) that is capable of reading the Intel internal thermal diode.
A program that can display the temperature of the thermal diode and allows for compensation.
Motherboard Monitor is an excellent example.

Available here: http://www.download.com/Motherboard-Monitor/3000-2086_4-10518386.html

A program to stress the CPU while still allowing you to monitor the temperatures. (Rc5, CPU Burn2, etc.)

An indoor/outdoor thermometer with the outdoor sensor on a wire so that it can be placed inside the computer near the intake of the fan.

**Step by Step Procedure:**



1. Put the sensor for the indoor/outdoor thermometer approximately 1 inch in front of the heatsink intake fan intake as shown in the photo to the right.
   (If you have a fan set to blow out from the heatsink, turn it around for this calibration procedure. If you normally use an ORB type cooler, change to a conventional cooler to calibrate the diode. The Orb type coolers pull in air from all sides and it is impossible to accurately measure the average temperature of the intake air.)

2. Start the computer. Run the computer at the highest speed that you have found to be totally stable. (It was probably already there, right?) For example, on a PIII 700, this may be 933MHz.
   (133 bus speed)

3. Set the monitoring program to the shortest measurement intervals possible. Start the program to stress the CPU. You should see the CPU instantly jump up a couple of degrees or more. If the temperature takes 10 or 15 seconds to begin rising, you are not reading the internal diode.

4. Allow all the temperatures to stabilize. Note the CPU temperature from the monitoring program and the heatsink fan intake temperature as shown by the indoor/outdoor thermometer.

5. Without changing the CPU voltage, configure the computer to run at the slowest speed possible. For example, on the PIII 700, this would be 466MHz. (66.6MHz bus speed)

6. Start the temperature monitoring and CPU stress programs. Allow all the temperatures to stabilize. Note the CPU temperature from the monitoring program and the heatsink fan intake temperature as shown by the indoor/outdoor thermometer.

7. Now you have 4 temperatures; the diode temperature at the high CPU speed (HS) and at the low CPU speed (LS) and the heatsink fan intake air temperature at both HS and LS. To start the calibration, we need one more number, the theoretical ratio between the two CPU speeds. So divide the HS by the LS. This is your ratio. Fro example, with our PIII 700 CPU, when we divide the HS (933) by the LS (466), we come up with a Theoretical PD Ratio of 2.00. (2 decimal places is enough.)

**8.** And here comes the math. the formula is: (HS diode temp – HS heatsink intake air temp) ÷ (LS diode temp-LS heatsink intake air temp) = Theoretical PD Ratio.

If your CPU diode/motherboard combination does not require any correction, then the equation will result in an equality. If your combination does require some correction like most do, then the temperature rise ratio will not equal the Theoretical PD Ratio.

If you end up with a number that is smaller than the Theoretical PD Ratio, then your CPU diode/motherboard combination is reading high and requires subtracting the same number of degrees from both the HS and LS diode reading. If the result of the equation is larger than the Theoretical PD Ratio, then your CPU diode/motherboard combination is reading low and requires adding the same number of degrees to both the HS and LS diode readings.

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**Here are actual numbers from 2 of our Intel CPUs:**

CPU #1: 700MHz PIII    Tested at 933MHz and 466MHz

High speed (HS) diode temperature:  45C      Heatsink fan intake air temperature: 26C
Low speed (LS) diode temperature:   38C      Heatsink fan intake air temperature: 26C
Theoretical PD Ratio:   2.00   (933 ÷ 466)

So we try the equation...

45C – 26C = 19       38C – 26C = 12       19 ÷ 12 = 1.58     The ratio is too low. we need to subtract a few degrees from both the HS and LS diode temps.

Let's try subtracting 3C and see how that works...
42C – 26C = 16       35C – 26C = 9       16 ÷ 9 = 1.78
We're closer to the Theoretical PD Ratio of 2.00, but not there yet.

Let's try subtracting 5C from both the low and high speed diode temperatures and see how that works...
40C – 26C = 14       33C – 26C = 7       14 ÷ 7 = 2.00
The measured ratio matches the Theoretical PD Ratio so the correction factor for this CPU diode/motherboard combination is –5C.

Now let's change the heatsink and see if the numbers hold up... On goes a crummy heatsink.

High speed (HS) diode temperature:  54C    Fan intake air temperature: 27C
Low speed (LS) diode temperature:   43C    Fan intake air temperature: 27C
Theoretical PD Ratio:    2.00    (933 ÷ 466)

We apply the –5C correction

49C – 27C = 22       38C – 27C = 11       22 ÷ 11 = 2.00   Perfect!  The –5C correction checks out.

We click on the compensation tab in Motherboard Monitor and put in –5C for the CPU diode temperature.

CPU #2: Celeron II 600   Tested at 927MHz and 600MHz

High speed (HS) diode temperature:  45C    Heatsink fan intake air temperature: 25.3C
Low speed (LS) diode temperature:   38C    Heatsink fan intake air temperature: 24.3C
Theoretical PD Ratio:    1.55   (927 ÷ 600)

45C – 25.3C = 19.7       38C – 24.3C = 13.7      19.7 ÷ 13.7 = 1.44   The ratio is too low. we need to subtract a few degrees from both the HS and LS diode temps.

We'll cut to the chase and subtract 3C from the HS and LS temperatures.
42C – 25.3C = 16.7       35C – 24.3C = 10.7      16.7 ÷ 10.7 = 1.56
As close as we will get with a whole number correction.

So the correction factor for this CPU diode /motherboard combination is –3C. We click on the compensation tab in Motherboard Monitor and put in –3C for the CPU diode temperature.

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While this "practical" calibration of the CPU diode/motherboard combination is probably not as accurate as one done to exacting laboratory standards and is subject to the limitations inherent in the full degree temperature steps, testing with a variety of CPUs, motherboards and heatsinks has proven the procedure to be viable. Once you calibrate your CPU diode/motherboard combination, you can not only accurately express changes to the cooling solution as relative values, (a 3C change) but also as absolute values. (I.e. 44C to 41C). You will be one of the few computer users who knows the TRUE internal temperature of their CPU. When you post to one of these mostly useless temperature comparison threads, you can post that your temperature is by calibrated internal thermal diode.