Application Note 105
6x86MX Thermal
Design Considerations

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APPLICATION NOTE 105

Thermal Design Considerations

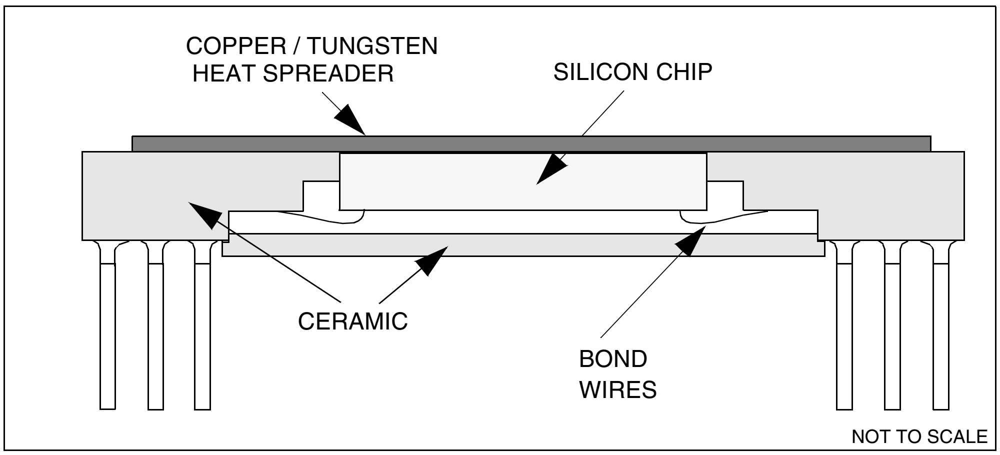
Introduction

This Application Report serves as a guide in the thermal design of a personal computer using the Cyrix® 6x86MX™ Microprocessor. A simplified thermal model is presented that utilizes thermal resistances to describe the heat flow from the CPU. Two case studies are included to show how to measure the thermal performance of the microprocessor in a typical computer enclosure. Additional examples illustrate the calculation of expected maximum case and ambient temperatures. The D.C. Specifications and thermal data in the 6x86MX Microprocessor Data Book are expanded and updated by the Appendix in this Application Report.

Heat Flow

The 6x86MX CPU dissipates as much as 25 watts of power depending on the CPU clock frequency. The CPU is mounted up-side-down in a PGA package (Figure 1). Most of the heat is concentrated at the surface of the semiconductor chip and is passed to the package through three main paths: (1) through the bulk of the silicon chip to where the chip is mounted to the package, (2) through the bond wires to the package, (3) through radiation across the void between the chip and the bottom of the package.

The package is cooled by radiation, convection and conduction. Some heat is conducted through the pins and the socket, but most of the heat passes from the package into the flowing air stream that carries the heat out of the equipment enclosure. The transfer of heat from the package to the ambient air can be greatly enhanced through the use of a heatsink. Our thermal model will concentrate on the heat flow from the case and heatsink to the surrounding air.



6x86MX PGA Package Cross-Sectional View

Thermal Resistance Model

As heat flows from a heat source to a cooler object, there is a temperature drop (T_0-T_1) which is similar to the voltage drop (E) across an electrical resistor. Electrical power dissipated in the chip (P) generates heat. The heat flows away from the source analogous to electrical current (I). By dividing the temperature drop (T_0 - T_1) by the power producing the heat (P), we obtain thermal resistance (θ) expressed in Celsius degrees (°C) per watt (W).

$$\theta = \frac{T_0 - T_1}{P} \qquad \frac{°C}{W}$$

This equation is similar to (the dual of) ohms law:

$$R = \frac{E}{I}$$

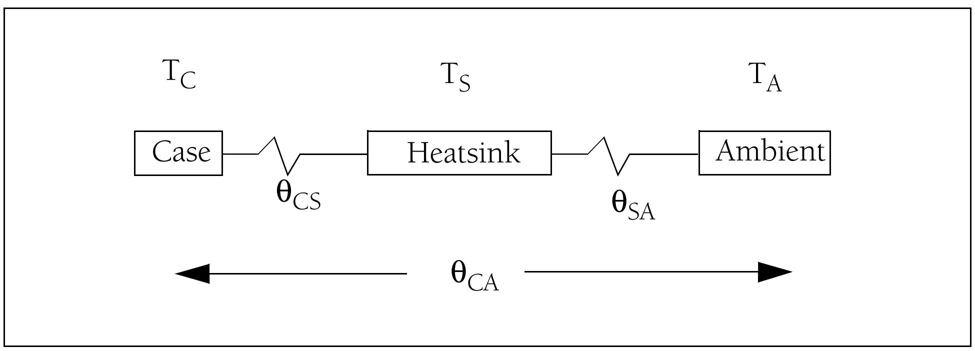
Thermal Resistances

Three thermal resistances (Figure 2) can be used to idealize the heat flow from the case of the 6x86MX CPU to ambient:

θ_{CS} = thermal resistance from case to heatsink in °C/W,
θ_{SA} = thermal resistance from heatsink to ambient in °C/W,
$\theta_{CA} = \theta_{CS} + \theta_{SA}$, thermal resistance from case to ambient in °C/W.

Additional symbols are used for the temperatures of the, case, heatsink and ambient air:
T_C = case temperature (top dead center) in °C,
T_S = heatsink in °C,
T_A = ambient (free air) temperature in °C.

The power applied to the semiconductor is:
P = power applied, $V_{CC} * I_{CC}$ in watts (W).



Thermal Resistor Model for Semiconductor

Controlling Case Temperature

Before power is applied, the case temperature is at ambient.

$$T_C = T_A$$

When power is applied, the case temperature rises as a function of the power applied and of the amount of heat lost to the ambient from the case.

$$T_C = T_A + P * \theta_{CA}$$

The case temperature of the 6x86MX CPU must be controlled in such a way as to maintain a 70°C maximum temperature. The case temperature can be reduced by:

- decreasing the ambient temperature of the room
- improving the air flow geometry in the electronic enclosure to decrease the box ambient temperature (T_A).
- decreasing the case-to-ambient thermal resistance (θ_{CA}) through the use of a heatsink or a heatsink/fan
- reducing the power generated by decreasing the CPU frequency

Heatsinks and Heatsink/Fans

The case-to-air thermal resistance (θ_{CA}) can be greatly decreased through the use of a heatsink. Heatsinks improve radiation and convection efficiency. Using a heatsink, the thermal resistance (θ_{CA}) becomes the sum of the case-to-heatsink thermal resistance θ_{CS} and heatsink-to-ambient thermal resistances (θ_{SA}):

$\theta_{CA} = \theta_{CS} + \theta_{SA.}$

Note: Some manufacturers use the symbol $R_{\theta SA}$ instead of θ_{SA}

To take full advantage of the heatsink, it is important to provide a good case-to-heatsink fit. Using sufficient clamping force between the heatsink and case, and the application of thermal grease can reduce θ_{CS} to about 0.1 °C/W. This allows the following approximation to be made:

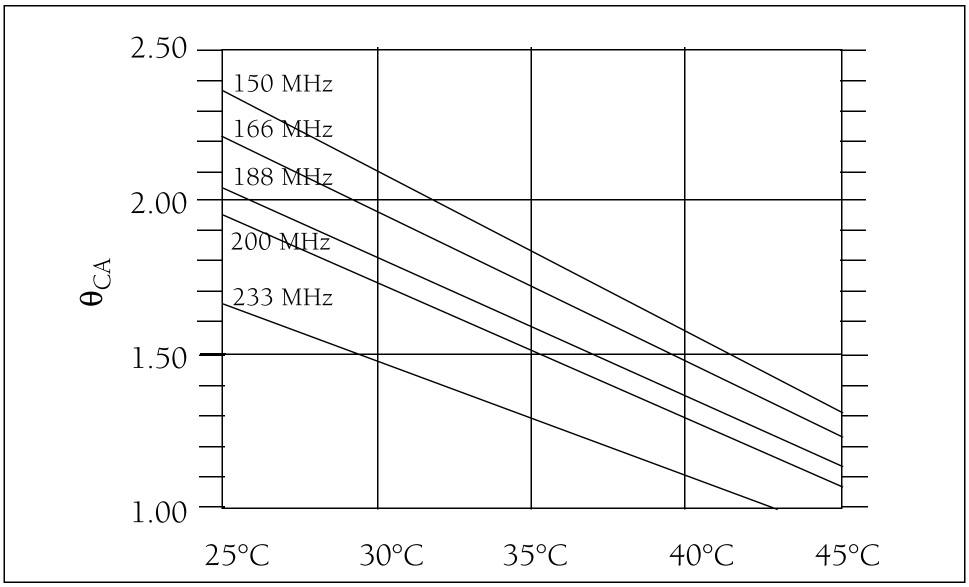
$\theta_{CA} \approx \theta_{SA.}$

The heatsink-to-ambient thermal resistance can be improved by a factor of about five using a heatsink/fan combination. A heatsink/fan reduces θ_{CA} by increasing the airflow across the heatsink.

Required Case-to-Ambient Thermal Resistance

If the maximum ambient temperature $T_{A(MAX)}$ inside the electronic enclosure is known, the required case-to-ambient thermal resistance can be calculated. The results of this calculation can be used to select which type of heatsink or heatsink /fan is required. The equation below calculates the thermal resistance of the heatsink required for an application. The table and chart below are based on Vcc2 = 2.9 V and Vcc3 = 3.3 V.

$$\theta = \frac{T_{C(MAX)} - T_{A(MAX)}}{V_{CC(MAX)} \times I_{CC(MAX)}} \quad \frac{°C}{W}$$



Required θ_{CA} to Maintain 70°C Case Temperature

FREQUENCY (MHz)	POWER* (W)	Θ_{CA} FOR DIFFERENT AMBIENT TEMPERATURES				
		25°C	30°C	35°C	40°C	45°C
150	18.7	2.37	2.11	1.84	1.58	1.31
166	20.2	2.22	1.97	1.72	1.48	1.23
188	21.8	2.05	1.82	1.60	1.37	1.14
200	22.9	1.96	1.74	1.52	1.30	1.08
225	26.1	1.71	1.52	1.33	1.14	0.95
233	27.0	1.66	1.47	1.29	1.10	0.92

*Note: Power based on Max Active Power values with Vcc2 = 2.9 V.
Refer to *Cyrix 6x86MX Processor Data Book*, Table 4-6, Page 4-5.

Required θ_{CA} to Maintain 70° Case Temperature

Expected Results for 166 MHz 6x86MX CPU with Recommended Heatsink/Fan

The maximum CPU power dissipation is found in Table 4-6 in the 6x86MX Data Book. (Table 4-5 in the 6x86MX Data Book is used for power supply design.)

$P_{MAX} = 20.2\ W$

Assuming the maximum ambient temperature of 40°C within the electronic enclosure and the case-to-ambient thermal resistance of 1.09°C/W, the maximum case temperature can be calculated using the equation below

$$T_{C(MAX)} = T_{A(MAX)} + P_{(MAX)} * \theta_{CA}$$

$$= 40°C + 20.2\ W * 1.09°C/W$$

$$= 62.8°C$$

The nominal CPU power dissipation is found in Table 4-6 of the 6x86MX Data Book.

$P_{TYP} = 10\ W$

Assuming the nominal ambient temperature of 30°C within the electronic enclosure and the case-to-ambient thermal resistance of 1.09°C/W, the nominal case temperature can be calculated using the equation below

$$T_C = T_A + P * \theta_{CA}$$

$$= 30°C + 10\ W * 1.09°C/W$$

$$= 40.9°C$$

Expected Results for 200 MHz 6x86MX CPU with Recommended Heatsink/Fan

The maximum CPU power dissipation is found in Table 4-6 in the 6x86MX Data Book. (Table 4-5 in the 6x86MX Data Book is used for power supply design.)

$P_{MAX} = 22.9\ W$

Assuming the maximum ambient temperature of 40°C within the electronic enclosure and the case-to-ambient thermal resistance of 1.09°C/W, the maximum case temperature can be calculated using the equation below

$$T_{C(MAX)} = T_{A(MAX)} + P_{(MAX)} * \theta_{CA}$$

$$= 40°C + 22.9\ W * 1.09°C/W$$

$$= 65.0°C$$

The nominal CPU power dissipation is found in Table 4-6 of the 6x86MX Data Book.

$P_{TYP} = 13.2\ W$

Assuming the nominal ambient temperature of 30°C within the electronic enclosure and the case-to-ambient thermal resistance of 1.09°C/W, the nominal case temperature can be calculated using the equation below

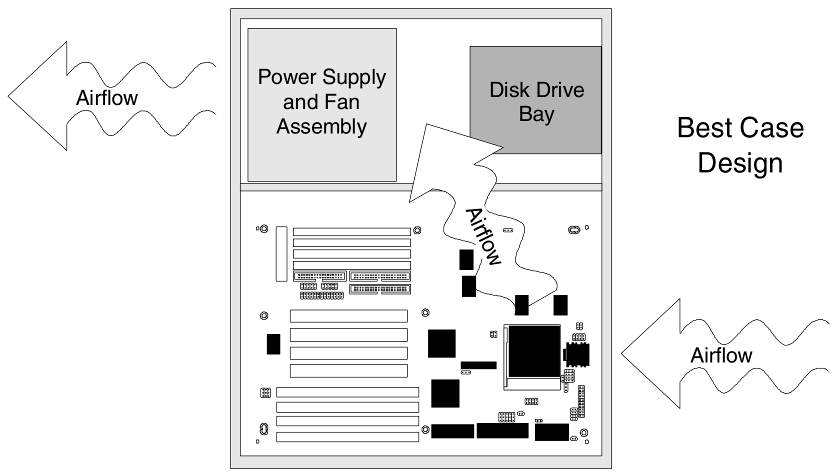
$$T_C = T_A + P * \theta_{CA}$$

$$= 30°C + 13.2\ W * 1.09°C/W$$

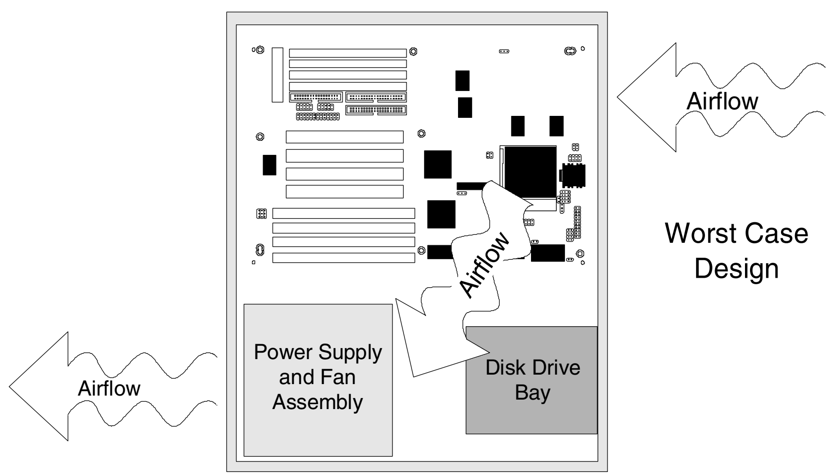
$$= 44.4°C$$

Reducing Ambient Temperature

The position of the power supply and fan assembly can oppose or aid convectional air flow. The ambient air inside a typical tower case can be made as much as five degrees cooler by moving the power supply and fan assembly near the top of the case so the hotter air can be exhausted.



Power Supply Location
Augmenting Convection



Power Supply Location
Opposing Convection

Appendix A. Typical Thermal Testing Methodology

IMPORTANT NOTE

The following thermal testing methodology is exemplary in nature and may not reflect actual results or conditions. Failure to perform thermal testing and/or evaluation could lead to CPU failure or the risk of fire. Be sure to read and understand the information located in the 6x86MX CPU Data Book concerning maximum recommended operating conditions and maximum absolute maximum ratings.

Purpose:

The purpose of this methodology is to determine, the temperature of the 6x86MX CPU’s case and the ambient temperature inside a mini-tower enclosure. These readings are to be made after temperature stabilization has taken place and also while running software that places heavy demands on the CPU. Room temperature should simulate a warm office temperature (25°C). Two 6x86MX CPUs running at different clock frequencies should be tested.

Suggested Equipment

The following equipment should be used in a typical thermal test on a 6x86MX CPU:

- 7 x 13 x 15 inch mini-tower
- 230-watt power supply (with exhaust fan) mounted in top portion of mini-tower.
- Three Omega HH-25KC Digital Thermometers.
- The CPUs to be tested such as the:
  6x86MX-PR166GP (150 MHz) and the
  6x86MX- PR200GP (166 MHz)
  Cyrix 6x86MX CPUs.
- ECS TS54P-AIO motherboard.
- LandMark 2.0 benchmark software.
- A selection of Fan/Heatsink options. Refer to Application Note 104, *Heatsink, Fan, Voltage Regulator, Chipset and BIOS Reference* for a list of vendors and their web pages.

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Rev 1.3 Rewritten for 6x86MX
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