Cyrix 6x86 Thermal Design Considerations

Revision 1.1, 12/17/96

Introduction

This Application Report serves as a guide in the thermal design of a lpersonal computer using the Cyrix® 6x86™ 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 6x86 Microprocessor Data Book are expanded and updated by the Appendix in this Application Report.

Heat Flow

The 6x86 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.

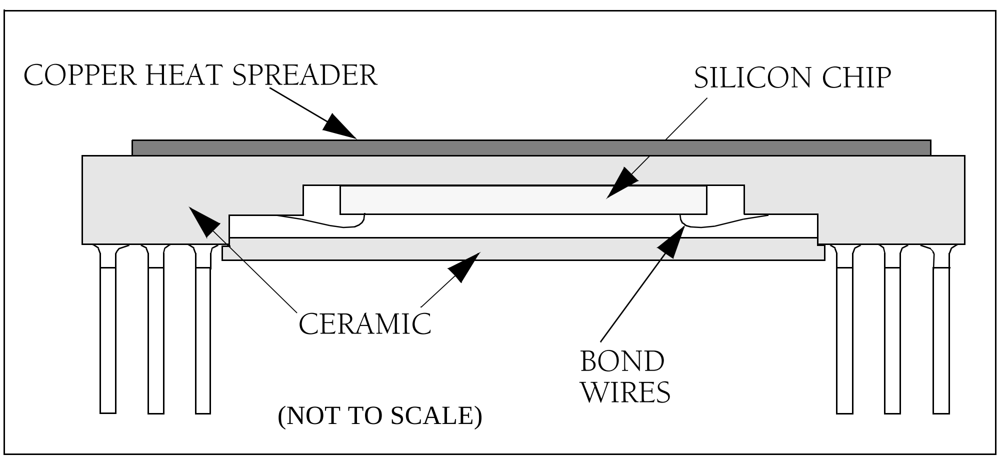

Figure 1. 6x86 PGA Package Cross-Sectional View

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.

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).

$$\theta = \frac{(T_0 - T_1)}{P} \quad \text{°C/W} \qquad \left(\text{similar to: } R = \frac{E}{I} \right)$$

Thermal Resistances

Three thermal resistances (Figure 2) can be used to idealize the heat flow from the case of the 6x86 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).

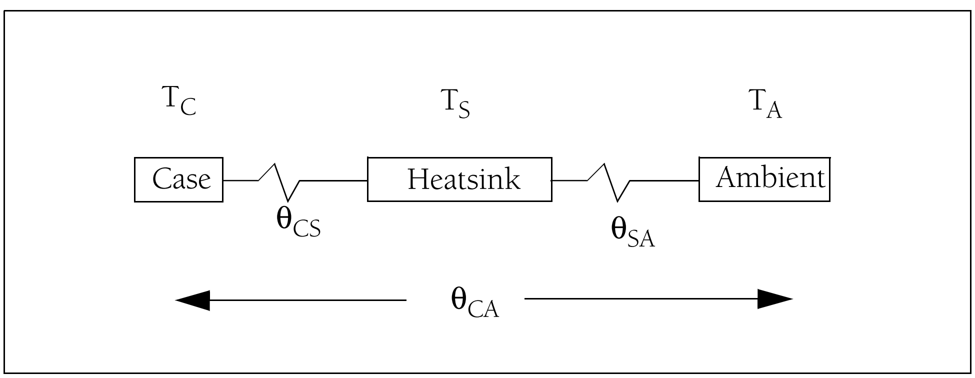

Figure 2. Thermal Resistor Model for Semiconductor

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 6x86 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 case-to-ambient thermal resistance (θ_{CA}) through the use of a heatsink or a heatsink/fan
- increasing the air flow in the electronic enclosure to decrease the ambient temperature (T_A) .

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})[1]:

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

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 0.01 °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 three using a heatsink/fan combination. A heatsink/fan reduces θ_{CA} by increasing the airflow across the heatsink.

1. Some manufacturers use the symbol $R_{\theta SA}$ instead of θ_{SA}.

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.

$$\theta_{CA} = \frac{T_{C(MAX)} - T_{A(MAX)}}{V_{CC(MAX)} * I_{CC(MAX)}} \quad °C/W$$

Table 1. Required θ_{CA} to Maintain 70°C Case Temperature

Part Number	Frequency (MHz)	Maximum Power (W)	θ_{CA} For Different Ambient Temperatures				
			25°C	30°C	35°C	40°C	45°C
6x86 - P120+	100	19.44	2.31	2.06	1.80	1.54	1.29
6x86 - P133+	110	20.88	2.16	1.92	1.68	1.44	1.20
6x86 - P150+	120	21.96	2.05	1.82	1.59	1.37	1.14
6x86 - P166+	133	23.76	1.89	1.68	1.47	1.26	1.05
6x86 - P200+	150	25.20	1.79	1.59	1.39	1.19	0.99

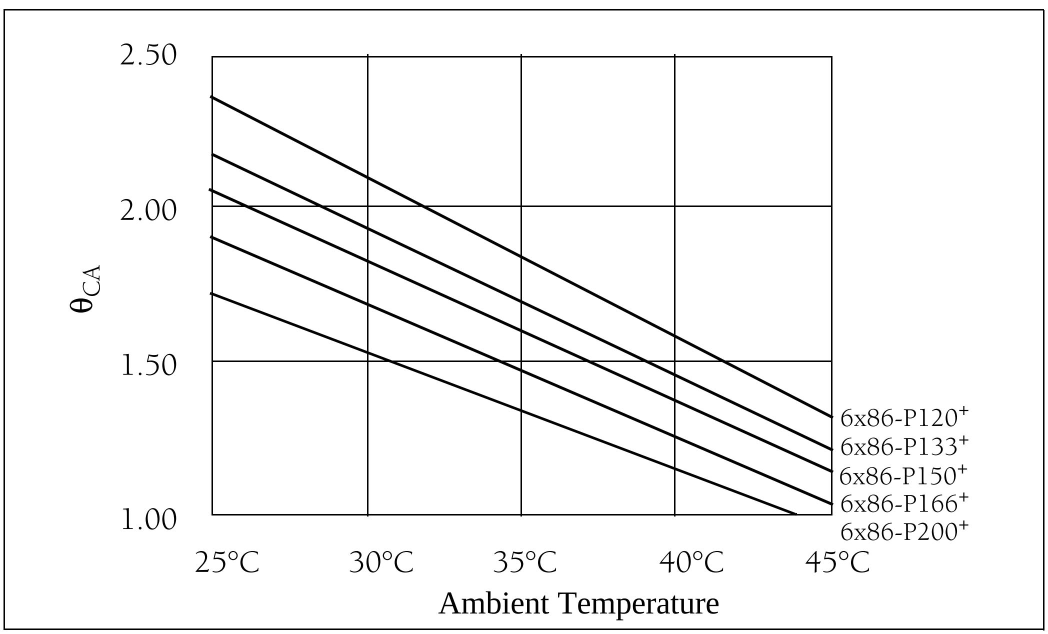

Figure 3. Required θ_{CA} to Maintain 70°C Case Temperature

Recommended Heatsink/Fan

Figure 4 shows a heatsink/fan assembly made by Thermalloy, (Part Number TCM20750, θ_{CA} = 1.28°C/W) that meets the cooling requirements of the 6x86-P90$^+$, 6x86-P120$^+$, 6x86-P133$^+$, and the 6x86-P150$^+$CPU in a typical PC system environment. A slightly larger heatsink/fan assembly (Part Number TCM20789, θ_{CA} = 1.13°C/W) is recommended for the 6x86-P166$^+$CPU.

Table 2. Heatsink/Fan Dimensions

Dimension	TCM20750		TCM20789	
	Inches	mm	Inches	mm
A	1.885	47.88	2.015	51.18
B	1.900	48.26	2.100	53.34
C	0.650	16.51	0.650	16.51
D	1.241	31.51	1.044	26.51
E	1.575	40.00	1.969	50.00

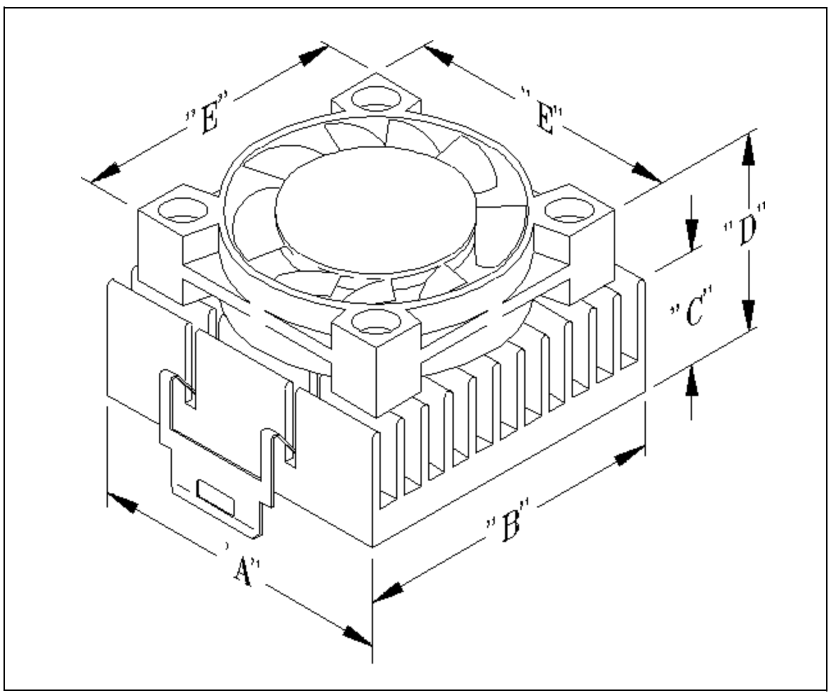

Figure 4. Typical HeatSink/Fan

Expected Results for 120 MHz 6x86 CPU with Recommended Heatsink/Fan

The maximum CPU power dissipation is calculated

$P_{MAX} = V_{CC\ (MAX)} * I_{CC(MAX)}$

$= 3.6\ V * 6.1\ A$

$= 21.96\ W$

Assuming the maximum ambient temperature of 40°C within the electronic enclosure and the case-to-ambient thermal resistance of 1.28°C/W, the maximum case temperature can be calculated using the equation below

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

$= 40°C + 21.96\ W * 1.28°C/W$

$= 68°C$

The nominal CPU power dissipation is calculated

$P = V_{CC} * I_{CC}$

$= 3.3\ V * 5.1\ A$

$= 16.83\ W$

Assuming the nominal ambient temperature of 30°C within the electronic enclosure and the case-to-ambient thermal resistance of 1.28°C/W, the nominal case temperature can be calculated using the equation below

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

$= 30°C + 16.83\ W * 1.28°C/W$

$= 52°C$

Expected Results for 133 MHz 6x86 CPU with Recommended Heatsink/Fan

The maximum CPU power dissipation is calculated

$P_{MAX} = V_{CC\ (MAX)} * I_{CC(MAX)}$

$= 3.6\ V * 6.6\ A$

$= 23.76\ \ W$

Assuming the maximum ambient temperature of 35°C within the electronic enclosure and the case-to-ambient thermal resistance of 1.13°C/W, the maximum case temperature can be calculated using the equation below

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

$= 40°C + 23.8\ W * 1.13°C/W$

$= 67°C$

The nominal CPU power dissipation is calculated

$P \quad = V_{CC} * I_{CC}$

$= 3.3\ V * 5.5\ A$

$= 18.15\ \ W$

Assuming the ambient temperature of 30°C within the electronic enclosure and the case-to-ambient thermal resistance of 1.13°C/W, the nominal case temperature can be calculated using the equation below

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

$= 30°C + 18.15\ W * 1.13°C/W$

$= 51°C.$

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.

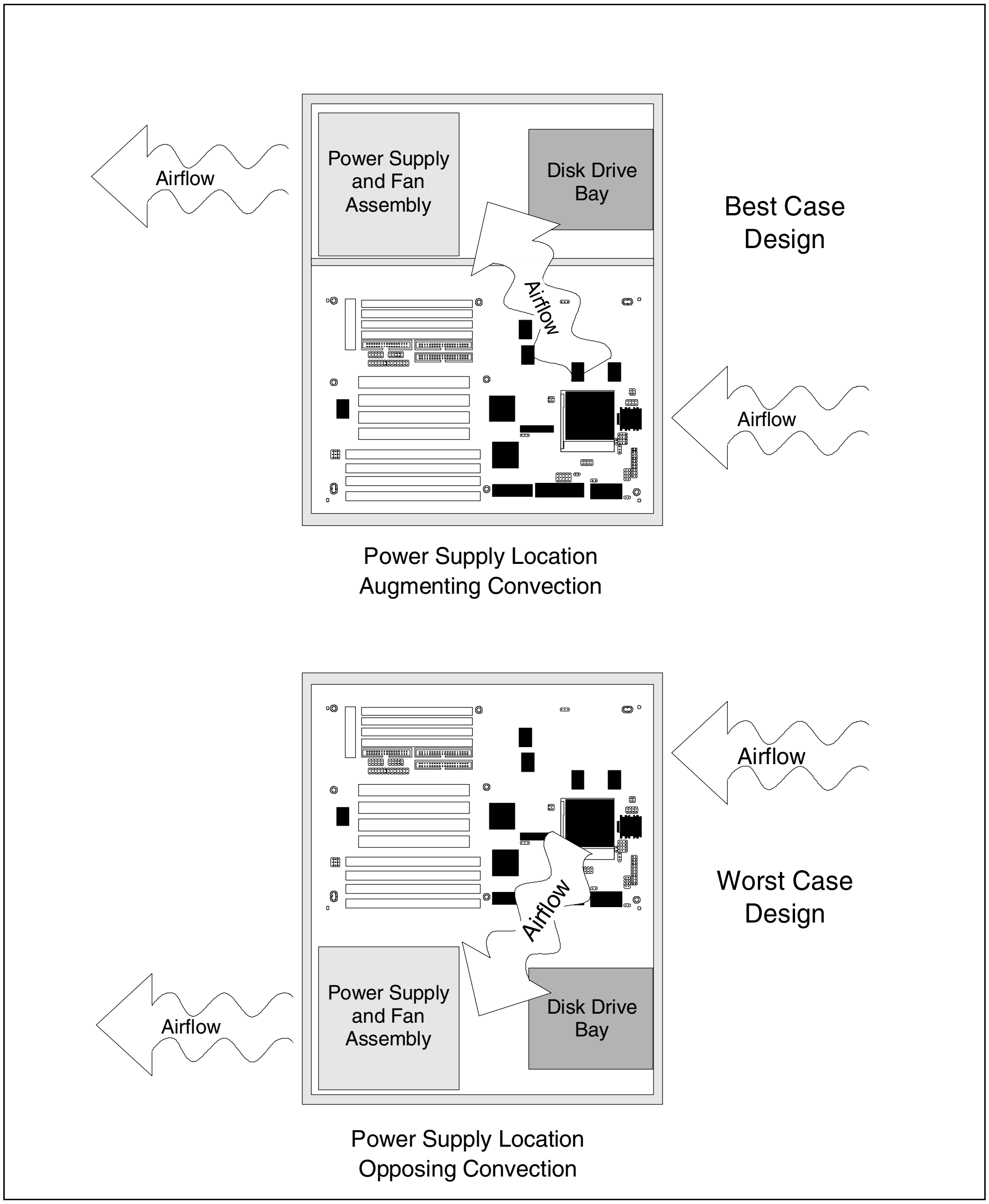

Figure 5. Power Supply Locations Augmenting and Opposing Convectional Air Flow

APPENDIX A
A Typical Case Study

IMPORTANT NOTE

The following thermal case study 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 6x86 CPU Data Book concerning maximum recommended operating conditions and maximum absolute maximum ratings.

Purpose:

The purpose of this case study is to determine, the temperature of the 6x86 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 6x86 CPUs running at different clock frequencies were tested.

Equipment

The following equipment was used in the case study:

1. 7 x 13 x 15 inch mini-tower
2. 230-watt power supply (with exhaust fan) mounted in top portion of mini-tower.
3. Three Omega HH-25KC Digital Thermometers.
4. One 6x86-120GP (120 MHz) and one 6x86-133GP (133 MHz) Cyrix 6x86 CPUs.
5. ECS TS54P-AIO motherboard.
6. LandMark 2.0 benchmark software.
7. One 6x86-P150$^+$GP Cyrix CPU with Thermalloy heatsink/fan Model No. 20750 with a θ_{CA} of 1.28 °C/W.
8. One 6x86-P166$^+$GP Cyrix CPU with Thermalloy heatsink/fan Model No. 20789 with a θ_{CA} of 1.13 °C/W.

Actual Results

For the 6x86-P150$^+$GP with TMC20750 heatsink/fan, the nominal case temperature was 56°C.
The ambient temperature inside the enclosure was 32°C.
The ambient temperature outside the enclosure was 24°C.

For the 6x86-P166$^+$GP with TMC20789 heatsink/fan, the case temperature was 51°C.
The ambient temperature inside the enclosure was 32°C.
The ambient temperature outside the enclosure was 24°C.

APPENDIX B
6x86 Specifications

The data in this section represent devices that operate at a nominal supply voltage of 3.30 V as show in Table B-1 below.

Table B-1. 6x86 Specifications Related to Thermal Design

SYMBOL	DESCRIPTION	MIN	TYP	MAX	UNITS	LOCATION IN DATA BOOK
V_{CC}	Supply Voltage	3.15	3.30	3.6	V	Table 4-3
T_C	Recommended Maximum Operating Case Temperature	0°C		70°C		Table 4-3
I_{CC}	Active I_{CC} 6x86-P90+GP 80 MHz 6x86-P120+GP 100 MHz 6x86-P133+GP 110 MHz 6x86-P150+GP 120 MHz 6x86-P166+GP 133 MHz 6x86-P200+GP 150 MHz		 3.9 4.5 4.8 5.1 5.5 5.9	 4.7 5.4 5.8 6.1 6.6 7.0	A	 Table 4-4
I_{CCSM}	Suspend Mode I_{CC} 6x86-P90+GP 80 MHz 6x86-P120+GP 100 MHz 6x86-P133+GP 110 MHz 6x86-P150+GP 120 MHz 6x86-P166+GP 133 MHz 6x86-P200+GP 150 MHz		 43 48 50 51 54 64	 75 80 83 86 95 105	mA	 Table 4-4
I_{CCSS}	Standby I_{CC} (Suspend Mode and CLK Stopped)		35 mA	55 mA	mA	Table 4-4