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AMD-K6®
Processor

Thermal Solution Design

Application Note

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Revision History

Date	Rev	Description
March 1998	E	Improved detail of Figure 1, “Passive Heatsink Thermal Model,” on page 4 and Figure 4, “Voltage Regulator Placement,” on page 7.
March 1998	E	Added system design considerations for fansink implementations. See “Heatsink and Fan” on page 7.
March 1998	E	Combined recommended fansink solutions into one table. See Table 2, “AMD-K6® Processor Model 6 Fansink Recommendations.”
March 1998	E	Added new fansink manufacturers and models to Table 4, “Manufacturer Contact List.”
May 1998	F	Revised “Recommended Fansinks for the AMD-K6® Processor Model 7 and AMD-K6®-2 Processor Model 8” to include AMD-K6-2 processor Model 8 information.
May 1998	F	Revised Table 2, “AMD-K6® Processor Model 6 Fansink Recommendations” and Table 4, “Manufacturer Contact List.”
May 1998	F	Added Table 3, “Additional AMD-K6® Processor Models 7 and AMD-K6®-2 Processor Model 8 Fansink Recommendations.”
Aug 1998	G	Removed package thermal specifications tables. For thermal specifications, added reference to the applicable AMD-K6 and AMD-K6-2 Processor Data Sheets.
Aug 1998	G	Revised Table 2, “AMD-K6® Processor Model 6 Fansink Recommendations” and Table 4, “Manufacturer Contact List.”
Aug 1998	G	Added recommended 350 MHz AMD-K6-2 processor thermal solutions to Table 3, “Additional AMD-K6® Processor Model 7 and AMD-K6®-2 Processor Model 8 Fansink Recommendations.”
Nov 1998	H	Revised Figure 9, “Measuring Case Temperature,” on page 12.
Nov 1998	H	Combined paragraphs “Recommended Fansinks for the AMD-K6® Processor Model 6” and “Recommended Fansinks for the AMD-K6® Processor Model 7 and AMD-K6®-2 Processor Model 8” into one paragraph.
Nov 1998	H	Replaced Recommended Fansinks (Tables 2 and 3) and the Manufacturer Contact List (Table 4) with a reference to the Recommended Thermal Solution section of the AMD website.
Feb 1999	I	Added references for the AMD-K6-III processor, where applicable.
Feb 1999	I	Added Table 1, “AMD-K6® Processor Family T_{CASE} Specifications.”
Feb 1999	I	Revised “Thermal Power Utility” on page 12 to reflect the latest recommended utility.

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Application Note

AMD-K6®

Processor Thermal Solution Design

Unless otherwise noted, the information in this application note pertains to all processors in the AMD-K6® family, which includes the AMD-K6 processor (Models 6 and 7), the AMD-K6-2 processor (Model 8), and the AMD-K6-III processor (Model 9).

Introduction

The operating specification for the AMD-K6 processor family calls for the case temperature (T_{CASE}) to be in the range of 0°C to T_{CASE} Max. It is important to maintain the case temperature within the specification for normal operation. If the specification is exceeded, the result can be functional failures, damage to the device, or reduction in long term reliability. Table 1 on page 1, lists the T_{CASE} specifications for the desktop AMD-K6 processor family.

Table 1. AMD-K6® Processor Family T_{CASE} Specifications

Processor Family	Minimum	Maximum	Note
AMD-K6®	0°C	70°C	
AMD-K6-2	0°C	60°C, 65°C, or 70°C	*
AMD-K6-III	0°C	65°C	

Note:
** Refer to the AMD-K6®-2 Processor Data Sheet, order# 21850 for operating specifications as they apply to each AMD-K6-2 offering.*

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An effective thermal management system is the best way to maintain the case temperature within specification. In addition to the thermal characteristics and power dissipation of the processor, the temperature of the processor case is dependent on internal ambient temperature and air velocity. The internal ambient temperature is affected by several variables—electronic components, peripherals, thermal characteristics of the chassis, and external ambient temperature.

Thermal management consists of heatsinks, thermal interface materials, heatsink clips, fans, chassis ventilation, and component placement. This application note is intended to guide the system designer through the process of developing an effective thermal solution for the AMD-K6 processor.

For information about the thermal specifications for the following AMD-K6 processors:

- AMD-K6 processor Model 6 (0.35-µm process technology) and the AMD-K6 processor Model 7 (0.25-µm process technology), refer to the *AMD-K6® Processor Data Sheet*, order# 20695.
- AMD-K6-2 processor Model 8 (0.25-µm process technology), refer to the *AMD-K6®-2 Processor Data Sheet*, order# 21850.
- AMD-K6-III processor Model 9 (0.25-µm process technology), refer to the *AMD-K6®-III Processor Data Sheet*, order# 21918.

System Conditions

The environmental specifications on most systems guarantee operation for external ambients up to 35°C. Most PC chassis/system boxes result in an internal 10°C increase in temperature over the external ambient temperature. In general, this means the thermal solution should be designed to allow an internal ambient (T_A) of 45°C.

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Thermal Solutions

Heatsink

Figure 1 on page 4 shows the thermal model of a processor with a passive thermal solution. The thermal resistance of a heatsink is determined by the heat dissipation surface area, the material and shape of the heatsink, and the airflow volume through the heatsink. In general, the larger the surface area the lower the thermal resistance. Heatsink designs use fins to increase the amount of dissipating surface area in contact with the ambient air. A larger surface area usually results in a lower thermal resistance. Some designs implement cross-cutting along the fins to allow omnidirectional airflow through the heatsink.

The required thermal resistance of a heatsink (θ_{SA}) can be calculated using the following example:

If:

$T_C = 65°C$
$T_A = 45°C$
$P_{MAX} = 29.5W$

Then:

$$\theta_{CA} \leq \left(\frac{T_C - T_A}{P_{MAX}}\right) = \frac{20°C}{29.5W} = 0.678°C/W$$

Where:

T_C = Processor case temperature
T_A = Ambient temperature
P_{MAX} = Maximum power consumption
θ_{CA} = Case-to-ambient thermal resistance

Using an interface material with a low thermal resistance of approximately 0.20°C/W (i.e. thermal grease), the required thermal resistance of the heatsink (θ_{SA}) is calculated as follows:

$$\theta_{SA} = \theta_{CA} - \theta_{IF} = 0.678 - 0.20 = 0.478\ °C/W$$

Where:

θ_{CA} = Case-to-ambient thermal resistance
θ_{IF} = Interface material thermal resistance
θ_{SA} = Sink-to-ambient thermal resistance

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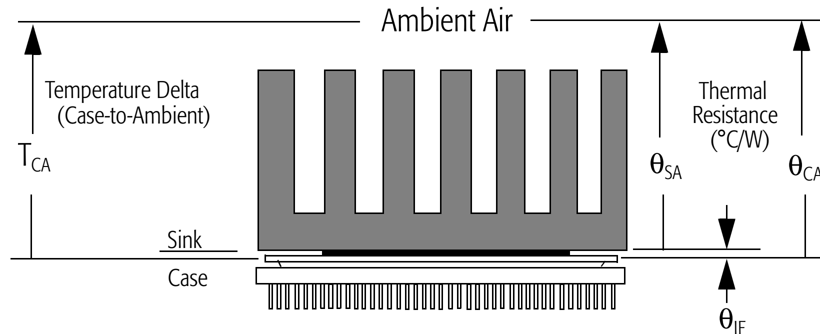

Figure 1. Passive Heatsink Thermal Model

Heat Dissipation Path

Figure 2 illustrates the heat dissipation path of the processor. Due to the lower thermal resistance between the processor die junction and case, most of the heat generated by the processor is transferred from the top surface of the case. The small amount of heat transferred from the bottom side of the processor can be safely ignored due to high thermal resistance (the processor socket blocks convection).

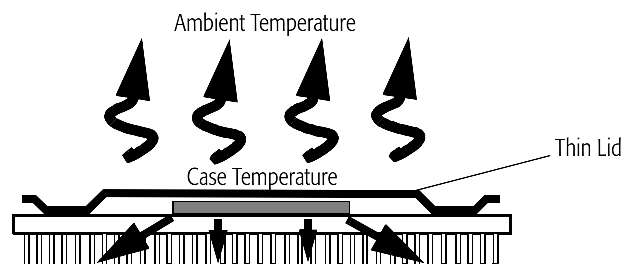

Figure 2. Processor Heat Dissipation Path

Figure 3 on page 5 illustrates the overall thermal resistance model of a socketed AMD-K6 processor with a heatsink attached. The thermal resistance of the primary heat dissipation path is much lower than the secondary heat dissipation path. Therefore, most of the heat is transferred from the top side of the processor. In Figure 3, θ_{CA} represents the thermal resistance from the top of the case to ambient. It includes the thermal resistance of the thermal interface material and the heatsink, which must be considered when designing a thermal solution for the AMD-K6 processor.

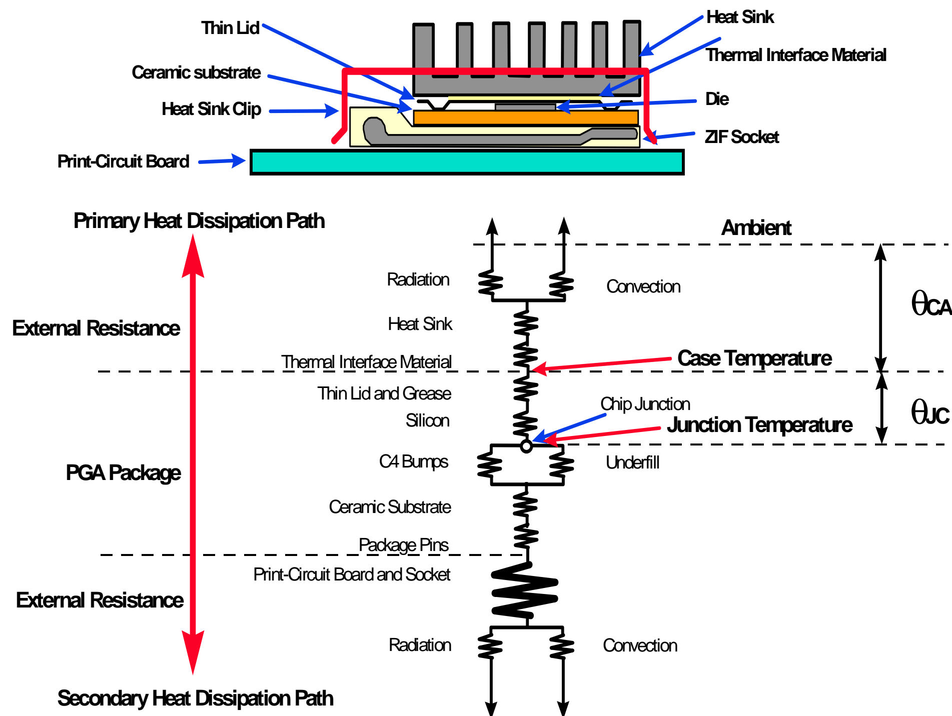

Figure 3. CPGA Package Thermal Resistance Model

Interface Materials

The interface material used between the heatsink and processor is important. The purpose of this material is to fill any microscopic air gaps and ensure a thermally efficient path is established for heat to flow from the package into the heatsink. There are several different types of thermally conductive interface material in use today. The most common are grease, wax, thermal pads/tapes, and epoxy. While dry interfaces (pads and tapes) are often the easiest to use, they have the poorest thermal resistance. They are not recommended because small pockets of air can be trapped during installation. Wet or paste interfaces (grease, gel, wax, and epoxy) have lower thermal resistances and allow air bubbles to migrate out of the interface material.

Although epoxy, when handled correctly, can provide a reasonable thermal interface, it is not a reliable mechanical attachment. Caution should also be taken with pre-applied waxes, because pockets of air (a poor thermal conductor) can be

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trapped beneath the heatsink during assembly. AMD recommends the use of grease and gels as thermal interfaces. These materials are able to maintain the lowest thermal resistance more consistently. In general, these materials can achieve a thermal resistance of 0.15 to 0.3°C/W.

The application of interface material, in addition to material type, is also important. Its purpose is simply to fill microscopic air gaps and ensure a thermally efficient path for heat transfer. Only a thin layer of interface material is desired between the heatsink and processor. Excessive amounts of interface material will restrict the flow of heat to the heatsink and thereby make the thermal solution less effective.

Due to the light weight of most heatsinks, mechanical clips are the recommended method of attachment. In addition to providing stability, clips provide approximately 10–15 pounds of downward pressure on the heatsink to minimize the thermal resistance of the thermal interface material.

Layout and Airflow Considerations

Voltage Regulator

Voltage regulators, typically power transistors, are used to provide the core and I/O voltages to the processor. In most designs, separate heatsinks are also required to dissipate the heat from the power transistors. The processor heatsink fins should be aligned parallel to the chassis airflow and the voltage regulators as shown in Figure 4 on page 7. With this alignment, the heat generated by the voltage regulators has minimal effect on the processor.

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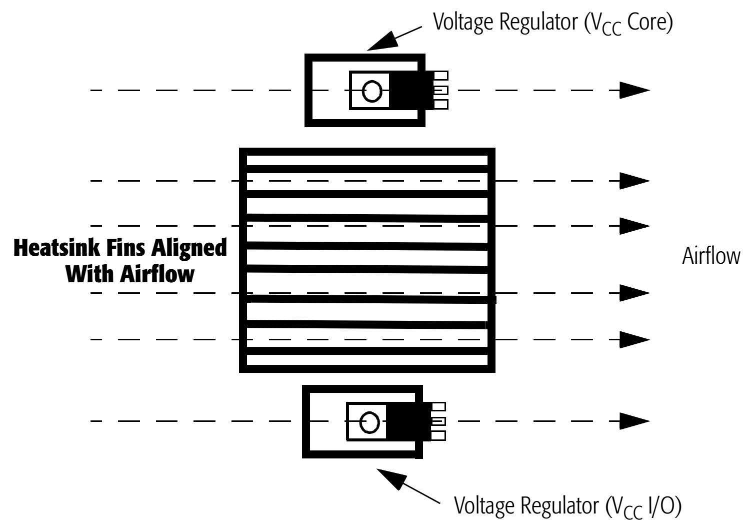

Figure 4. Voltage Regulator Placement

Heatsink and Fan

A heatsink and fan combination, or fansink, can deliver even better thermal performance than a heatsink alone. More importantly, airflow requirements in a system design are not as critical with a fansink. The fan pulls air from above the fan, through the heatsink, and out the heatsink sides. When using a fansink solution, the best location for the voltage regulators is on the side of the processor, in the path of the air exiting the fansink (See Figure 5 on page 8). Such a location guarantees that the heatsinks on both the processor and the regulator receive adequate airflow.

Fansinks are more effective when the following design techniques are employed:

- To avoid impeding airflow within the chassis to the fansink, route ribbon cables between the system motherboard and chassis drive bays.
- To provide a sufficient volume of air to the fansink, maintain a 1/2 inch clearance above the fansink.

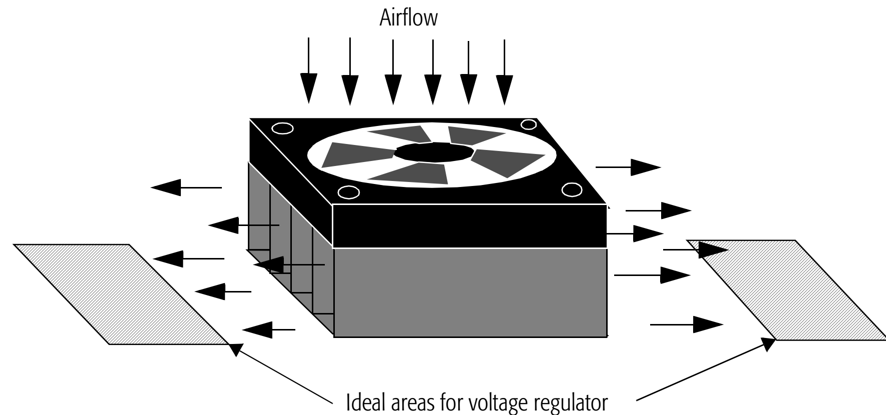

Figure 5. Airflow for a Heatsink with Fan

Airflow Management in a System Design

Complete airflow management in a system is important. In addition to the speed and volume of air, the path of the air is also important. Figure 6 shows the airflow in a dual-fan system. The fan in the front end pulls cool air into the system through intake slots in the chassis. The power supply fan acts as an exhaust and forces the hot air out of the chassis. The thermal performance of the heatsink can be maximized if it is located in the shaded area with the fins oriented parallel to the airflow path.

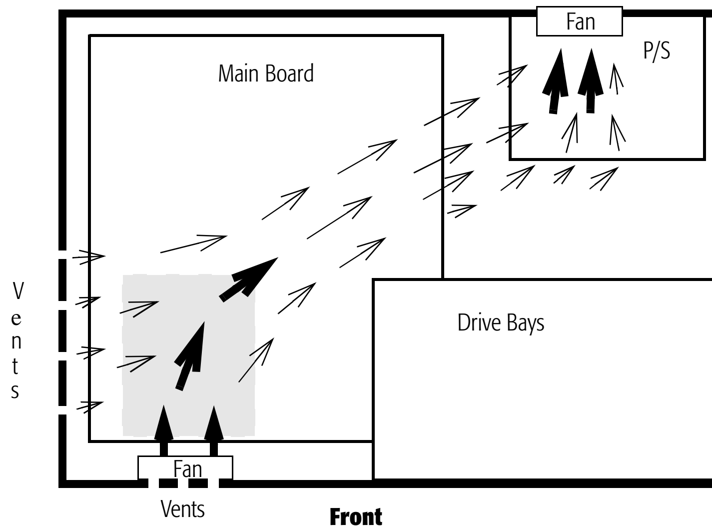

Figure 6. Airflow Path in a Dual-Fan System

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Airflow Management in the ATX Form Factor

Figure 7 shows the airflow management in a system using the ATX form-factor. The orientation of the power supply fan and the motherboard are modified in the ATX platform design. The power supply fan generates airflow through the chassis and across the processor. The processor is located near the power supply fan where it can receive maximum airflow without an auxiliary fan. This arrangement significantly improves the airflow across the processor with minimum installation cost.

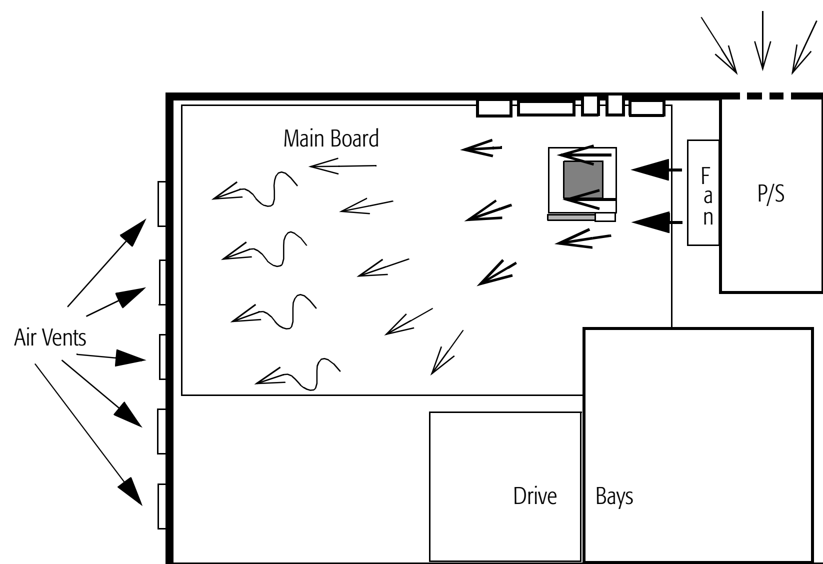

Figure 7. Airflow Path in an ATX Form-Factor System

Additional Box Fans

Additional box fans can enhance the effectiveness of the airflow within the chassis. Table 2 on page 10 summarizes the effect of different numbers and configurations of box fans in the chassis. The purpose of the box fans is to improve circulation of air within the chassis. The box fans used in this experiment were chosen to fit the existing mountings in the chassis. The front fan is an 80-mm 35-CFM fan and the rear fan is a 60-mm 25-CFM fan. The goal of better circulation is to reduce the ambient temperature inside the chassis.

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For the given chassis, different combinations of fans were tested. The tests were performed in an oven with a constant temperature of 35°C, and the internal ambient temperature of the chassis was measured with a thermocouple. The thermocouple was located two inches from the processor as shown in Figure 8 on page 11. A control case was run with no added fans in the chassis and it resulted in an internal ambient of 48.2°C. The best improvement in ambient temperature was observed with the configuration of a single box fan added to the chassis as an intake fan in the rear wall of the system chassis. This fan placement resulted in a decrease in ambient temperature from 48.2°C to 43.6°C. See Table 2 for a complete summary of fan and chassis combinations. Also, note that the best case temperature (T_{CASE}) for the processor was obtained when the internal ambient temperature was held to approximately 44.4°C. As shown in the test, the lowest ambient temperature is not always an indicator of the lowest T_{CASE}. Ambient temperature is very dependent on the airflow path and how it is measured. The only way to completely verify a thermal solution is to measure T_{CASE}.

Table 2. Summary of Chassis Box Fan Configurations

Thermal Test Condition	Test #1	Test #2	Test #3	Test #4
Rear Wall System Fan	Off	Off	Exhaust	Intake
Front Wall System Fan	Off	Intake	Intake	Off
Processor, T_{CASE}	68.8°C	69°C	64.1°C	65.9°C
Internal Ambient Temperature	48.2°C	48.7°C	44.4°C	43.6°C

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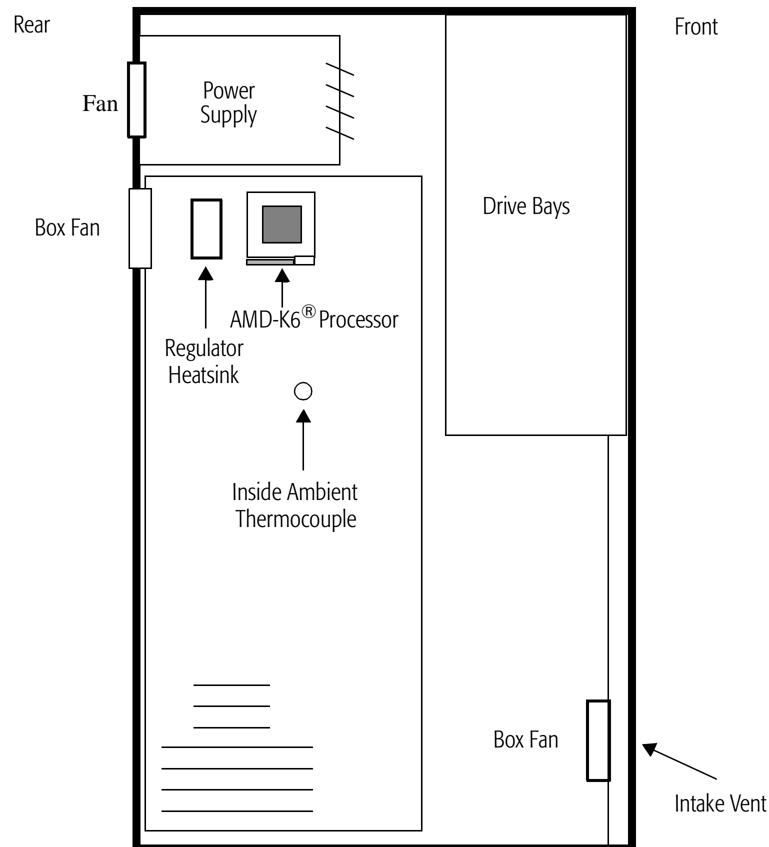

Figure 8. Standard Mid-Tower Case

Thermal Evaluation

Measuring Case Temperature

The processor case temperature is measured to ensure that the thermal solution meets the processor's operational specification. This temperature should be measured on the top center of the package where most of the heat is dissipated. Figure 9 on page 12 shows the correct location for measuring the case temperature. If a heatsink is installed while measuring, the thermocouple must be installed into the heatsink via a small hole drilled through the heatsink base (for example, 1/16 of an inch). The thermocouple is then attached to the base of the heatsink and the small hole filled using thermal epoxy, allowing the tip of the thermocouple to touch the top of the processor case.

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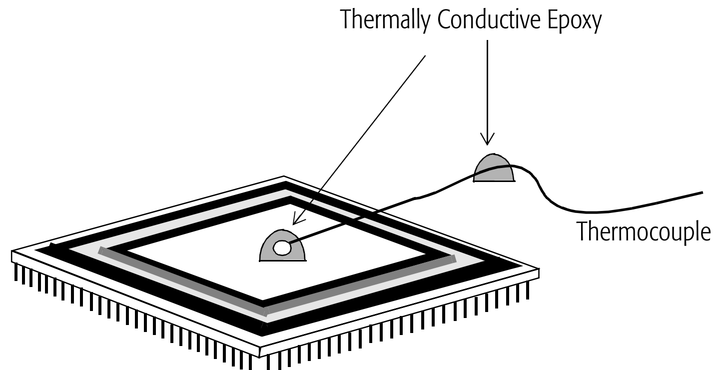

Figure 9. Measuring Case Temperature

Thermal Power Utility

A software utility has been developed to assist in testing thermal solutions. This utility executes a tight loop of instructions whose addressing and data have been defined to put the AMD-K6 processor in a state that dissipates the maximum thermal power. This utility can be used to determine if a given thermal solution is sufficient to maintain the specified T_{CASE} limit.

To use this utility, execute the DOS program, Maxpwr99.exe as follows: (***Note:*** *Do not execute the utility in a DOS window or with a memory manager loaded.*)

```
c:\>Maxpwr99.exe
```

The program executes in an infinite loop until exited. While executing, the processor's case temperature can be measured. In addition, the actual power dissipation should be determined by measuring the voltage and current supplied to the processor.

Note: *Use a daughter card to allow the processor current to be measured in series with an Ohmmeter. Take all measurements close to the processor (use short lead wires).*

If the processor power is less than the maximum thermal power specification, a linear estimate must be used to determine if the thermal solution maintains the case temperature below its specified limit.

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The Maxpwr99.exe utility is available under a nondisclosure agreement. Contact your local AMD sales office for information.

Recommended Thermal Solutions for the AMD-K6® Processor Family

AMD continually works with heatsink and fan manufacturers to identify thermal solutions for the AMD-K6 processor family. A list of solutions that maintain the case temperature of the AMD-K6 processor below the specified maximum temperature is available in the *Recommended Thermal Solutions* section of the AMD website, www.amd.com.

Most of the solutions listed are available as-is and can be ordered as a combination or kit from the manufacturer. These solutions are available as a heatsink and fan combination. Other solutions require the use of a specific fan, mounted on top of the heatsink, capable of sufficient air flow (for example, 24 CFM for the 233-MHz AMD-K6 processor). In such cases, the fan and heatsink can be ordered separately from each manufacturer.

Additional Information

For more information about the following AMD-K6 processors:

- AMD-K6 processor Models 6 and 7, see the *AMD-K6® Processor Data Sheet*, order# 20695 or contact your local AMD sales representative.
- AMD-K6-2 processor Model 8, see the *AMD-K6®-2 Processor Data Sheet*, order# 21850 or contact your local AMD sales representative.
- AMD-K6-III processor Model 9, see the *AMD-K6®-III Processor Data Sheet*, order# 21918 or contact your local AMD sales representative.

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