AP-586

APPLICATION NOTE

Pentium® II Processor Thermal Design Guidelines

June 1997

Order Number: 243331-002

CONTENTS

1.0. INTRODUCTION

In a system environment, the processor's temperature is a function of both the system and component thermal characteristics. The system level thermal constraints consist of the local ambient temperature at the processor and the airflow over the processor(s) as well as the physical constraints at and above the processor(s). The processor core's plate temperature depends on the component power dissipation, size and material (effective thermal conductivity) of the cartridge, the type of interconnection to the substrate, the presence of a thermal cooling solution, the thermal conductivity and the power density of the substrate.

All of these parameters are aggravated by the continued push of technology to increase performance levels (higher operating speeds, MHz) and packaging density (more transistors). As operating frequencies increase and packaging size decreases, the power density increases and the thermal cooling solution space and airflow become more constrained. The result is an increased importance on system design to ensure that thermal design requirements are met for each component in the system.

With the introduction of the Pentium® II processor, and the new packaging technology associated with it, new problems have been introduced. New temperature constraint specifications have been created as a result of this new packaging technology.

1.1. Document Goals

The Pentium II processor is the newest addition to the P6 family of microprocessors. Intel's Pentium® Pro processor generated sufficient heat to require an advanced cooling solution in order to meet the case temperature specification in system designs. The Pentium II microprocessor continues the demands on cooling solutions. The additional temperature specification requirements of the Pentium II processor introduce new problems. Depending on the type of system and the chassis characteristics, new designs may be required to provide adequate cooling for the processor. The goal of this document is to provide an understanding of the thermal characteristics of the Pentium II processor and discuss guidelines for meeting the thermal requirements imposed on single and multiple processor systems.

1.2. References

- *Pentium® Pro Processor Thermal Design Guidelines*, AP-525 (Order Number 243331)
- *Pentium® II Processor Mechanical/Assembly/ Manufacturing*, AP-588 (Order Number 243333)
- Pentium® *II Processor Developer's Manual* (Order Number 243341)

2.0. IMPORTANCE OF THERMAL MANAGEMENT

The objective of thermal management is to ensure that the temperature of all components in a system is maintained within functional limits. The functional temperature limit is the range within which the electrical circuits can be expected to meet their specified performance requirements. Operation outside the functional limit can degrade system performance, cause logic errors or cause component and/or system damage. Temperatures exceeding the maximum operating limits may result in irreversible changes in the operating characteristics of the component.

3.0. PENTIUM® II PROCESSOR PACKAGING TECHNOLOGY

The Pentium II processor introduces a new packaging technology known as a Single Edge Contact cartridge (S.E.C. cartridge). The S.E.C. cartridge contains the microprocessor silicon and the second level cache, referred to as an "L2". The cartridge consists of a plastic cover and an aluminum thermal plate. The thermal plate is designed for attaching a heatsink using the techniques described in the *Pentium® II Processor Mechanical/ Assembly/Manufacturing* application note, AP-588. The processor S.E.C. cartridge connects to the motherboard through an edge connector referred to as "Slot 1".

4.0. THERMAL SPECIFICATIONS

The Pentium II processor power dissipation can be found in the *Pentium® II Processor Developer's Manual*; please refer to this document to verify the actual thermal specifications for a particular processor. While the processor core dissipates the majority of the thermal power, the system designer should also be aware of the thermal power dissipated by the second level cache. Systems should design for the highest possible thermal power, even if a processor with lower frequency or smaller second level cache is planned, this will allow the design to accept either processor interchangeably. It is highly recommended that systems be designed to dissipate 37W to 43W per processor, as this will allow the same design to accommodate higher frequency or otherwise enhanced members of the Pentium II processor family.

To ensure proper operation and reliability of the standard Pentium II processor, the thermal solution must maintain the following specification temperatures at or below the following values:

	233 MHz	266 MHz	300 MHz
T_{plate}	75°C	75°C	70°C
T_{cover}	75°C	75°C	70°C

Considering the power dissipation levels and typical system ambient environments of 35°C to 40°C, the Pentium II processor's cover and plate temperatures cannot be maintained at or below 75°C for 233 MHz and 266 MHz, and at or below 70°C for 300 MHz, without additional thermal enhancement to dissipate the heat generated.

The thermal characterization data described in later sections illustrates that both a thermal cooling device and system airflow are needed. The size and type (passive or active) of thermal cooling device and the amount of system airflow are interrelated and can be traded off against each other to meet specific system design constraints. In typical systems, the thermal solution size is limited by board layout, spacing, and component placement. Airflow is determined by the size and number of fans along with their placement in relation to the components and the airflow channels within the system. In addition, acoustic noise constraints may limit the size and/or types of fans that can be used in a particular design.

To develop a reliable, cost-effective thermal solution, all of the above variables must be considered. Thermal characterization and simulation should be carried out at the entire system level accounting for the thermal requirements of each component.

4.1. Processor Cover

The cover temperature is a function of the local ambient temperature, the internal temperature of the processor and the various components internal to the processor. The local ambient temperature is the temperature found within the system chassis surrounding the S.E.C. cartridge as represented in the temperature measurement process found in Section 7.3.3. Section 7.3.2. discusses proper guidelines for measuring the cover temperature. Section 7.3.2. also shows the locations of known hot spots for the 233 MHz, 266 MHz and 300 MHz Pentium II processors.

4.2. Thermal Plate

The thermal plate is intended to provide a common interface for multiple types of thermal solutions and is the attach location for all thermal solutions. These solutions can be active or passive. Active solutions incorporate a fan in the heatsink and may be smaller than a passive heatsink. Considerations in heatsink design are the local ambient temperature at the heatsink, surface area of the heatsink, volume of airflow over the surface area, power being dissipated by the processor and other physical volume constraints placed by the system.

4.3. Power

The processor code dissipates the majority of the thermal power, the system designer should also be aware of the thermal power dissipated by the second level cache. Systems should design for the highest possible thermal power. The combination of the processor core and the second level cache dissipating heat through the thermal plate is the thermal plate power.

The processor power is a result of heat dissipate through the thermal plate and other paths. See Table 1 for standard Pentium II processor thermal specifications.

NOTE

The overall system thermal design must comprehend the processor power. The heatsink should be designed to dissipate the thermal plate power.

Table 1. Pentium® II Processor Thermal Specifications

Processor Core Frequency (MHz)	L2 Cache Size (KB)	Processor Power (W)	Thermal Plate Power (W)
233	512	34.8	33.6
266	512	38.2	37.0
300	512	43.0	41.4

5.0. DESIGNING FOR THERMAL PERFORMANCE

In designing for thermal performance, the goal is to keep the processor(s) within the operational thermal specifications. The inability to do so will shorten the life of the processor(s). It is the goal and requirement of the thermal design to ensure these operational thermal specifications are maintained. The heat generated by the components within the chassis must be removed to provide an adequate operating environment for both the processor and other system components. To do so requires moving air through the chassis to transport the heat generated by the processor for both the processor and other system components.

5.1. Airflow Management

It is important to manage the amount of air that flows within the system as well as how it flows to maximize the amount of air that flows over the processor. System air flow can be increased by adding one or more fans to the system or by increasing the output (faster speed) of an existing system's fan(s). Local air flow can also be increased by managing the local flow direction using baffles or ducts. An important consideration in airflow management is the temperature of the air flowing over the processor(s). Heating effects from add-in boards, DRAM and disk drives greatly reduce the cooling efficiency of this air, as does re-circulation of warm interior air through the system fan. Care must be taken to minimize the heating effects of other system components, and to eliminate warm air circulation.

For example, a clear air path from the external system vents to the system fan(s) will enable the warm air from the Pentium II processors to be efficiently pulled out of the system. If no air path exists across the processors, the warm air from the Pentium II processors will not be removed from the system, resulting in localized heating ("hot spots") around the processors. Heatsink fin designs should be aligned with the direction of the airflow. If the airflow is horizontal the fins should be horizontally extruded. Similarly for a vertical airflow. Heatsink fins should be vertically extruded. Figure 1 shows two examples of air exchange through a PC style chassis. The system on the left is an example of good air exchange incorporating both the power supply fan as well as an additional system fan. The system on the right shows a poorly vented system using only the power supply fan to move the air resulting in inadequate air flow. Re-circulation of warm air is most common between the system fan and chassis, and between the system fan intake and the drive bays behind the front bezel. These paths may be eliminated by mounting the fan flush to the chassis, thereby obstructing the flow between the drive bays and fan inlet, and by providing generous intake vents in both the chassis and the front bezel.

5.2. Extruded Heatsink Solutions

One method used to improve thermal performance is to increase the surface area of the device by attaching a metallic heatsink to the heat plate. Heatsinks are generally extruded from blocks of metal, usually aluminum (due to its low price/performance ratio). To maximize the heat transfer, the thermal resistance from the heatsink to the air can be reduced by maximizing the airflow through the heatsink fins as well as by maximizing the surface area of the heatsink itself.

5.2.1. HEATSINK DESIGN

Though each designer may have mechanical volume restrictions or implementation requirements, the following diagrams illustrate "generic" form factors that are likely to be compatible with a given type of chassis design.

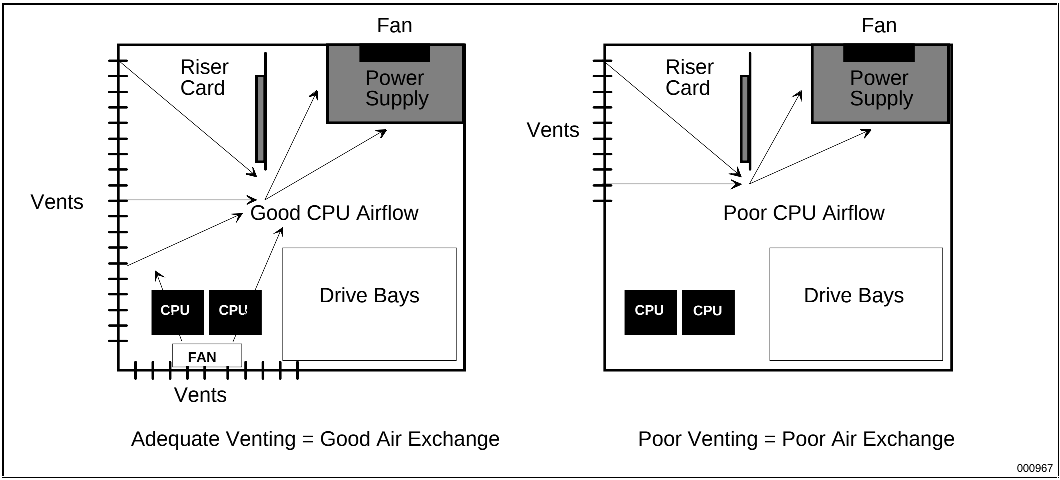


Figure 1. Example of Air Exchange through a PC Chassis

5.2.2. EXAMPLE ATX COMPATIBLE HEATSINKS

Figure 2 and Figure 3 (thermal plate and side view respectively) indicate the space available for the physical outline for a heatsink in an ATX style chassis.

5.2.3. EXAMPLE LOW PROFILE (LPX) COMPATIBLE HEATSINKS

Figure 4 and Figure 5 shows the front and side view respectively indicating the space available for the physical outline for the heatsink in a low profile (LPX) style chassis.

5.2.4. HEATSINK WEIGHT

The maximum weight of the heatsink and attachment mechanisms should not exceed 250 grams. This limit is base on the limits of the proposed processor retention mechanism and heatsink support to withstand mechanical shock and vibration requirements as a full assembly with heatsink attached. Figure 6 provides the maximum distances for the center of gravity for a heatsink to be used with the S.E.C. cartridge. Heatsink design should try to maintain the center of mass within the "safe" area. This is the shaded area shown below.

5.2.4.1. Center of Gravity Calculations

Although commonly calculated through solid modeling programs, the center of gravity can be calculated through straight forward computations described in this section. The center of gravity of an object with a uniform density is the geometrical center of volume of the object. The center of gravity can most easily be determined by dividing the object into smaller objects and averaging each individual centroid with respect to the volumes as shown in the following equations:

$$\sum_{n=1}^{n=m} Xcg_n * volume_n \,/\, total\ volume$$

$$\sum_{n=1}^{n=m} Ycg_n * volume_n \,/\, total\ volume$$

$$\sum_{n=1}^{n=m} Zcg_n * volume_n \,/\, total\ volume$$

Where:

m = number of smaller objects

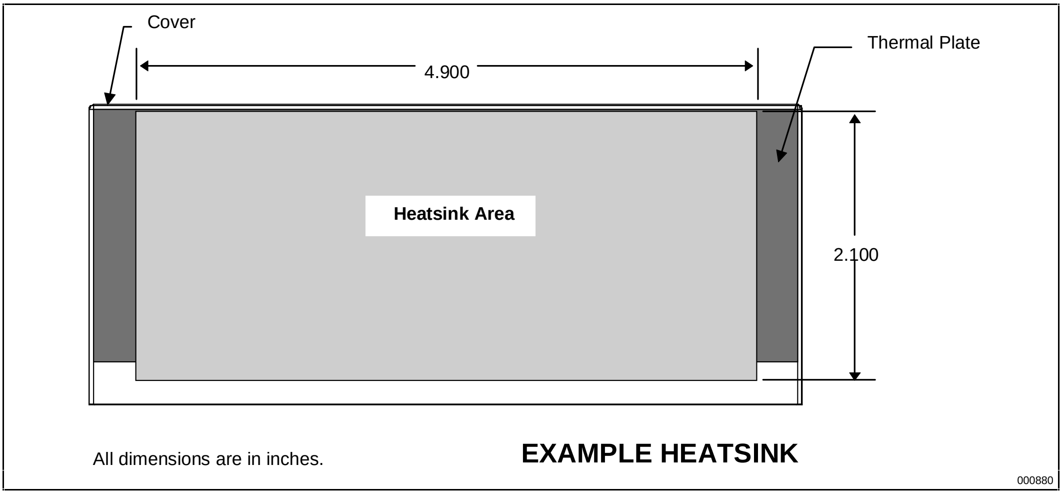


Figure 2. Thermal Plate View of Example ATX Style Heatsink

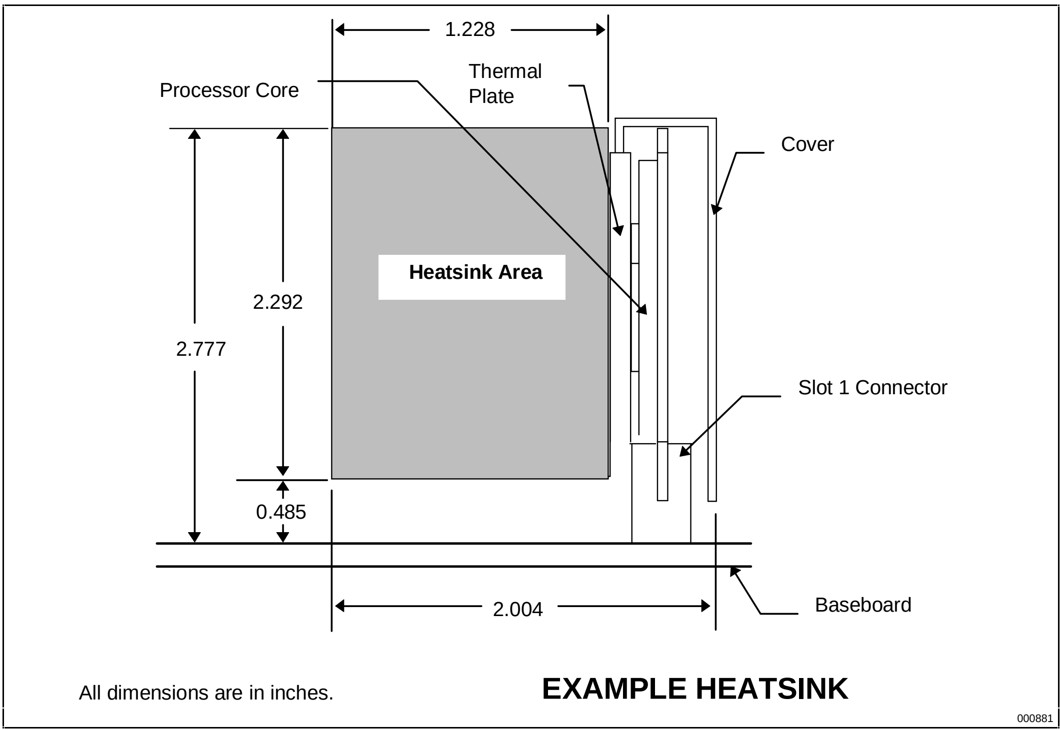


Figure 3. Side View of Example ATX Style Heatsink

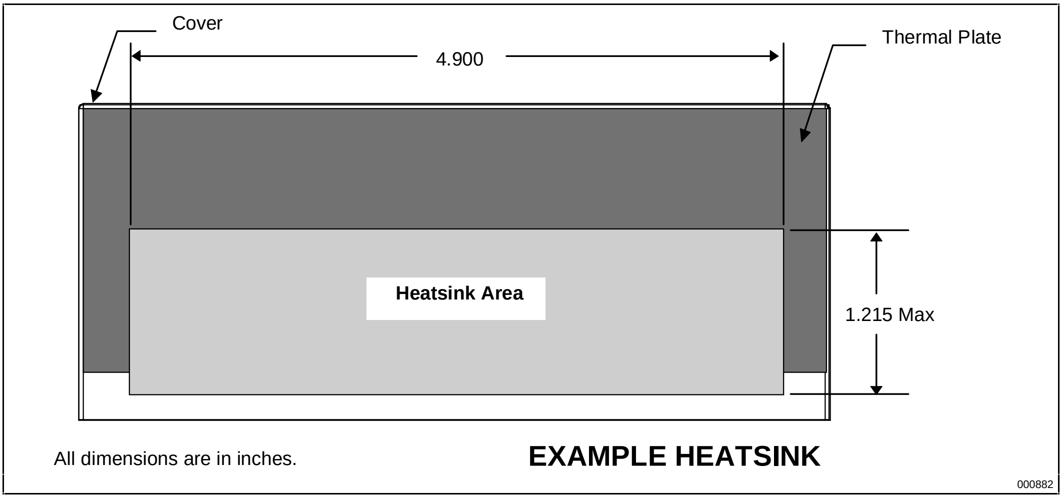


Figure 4. Front View of Example LPX Style Heatsink

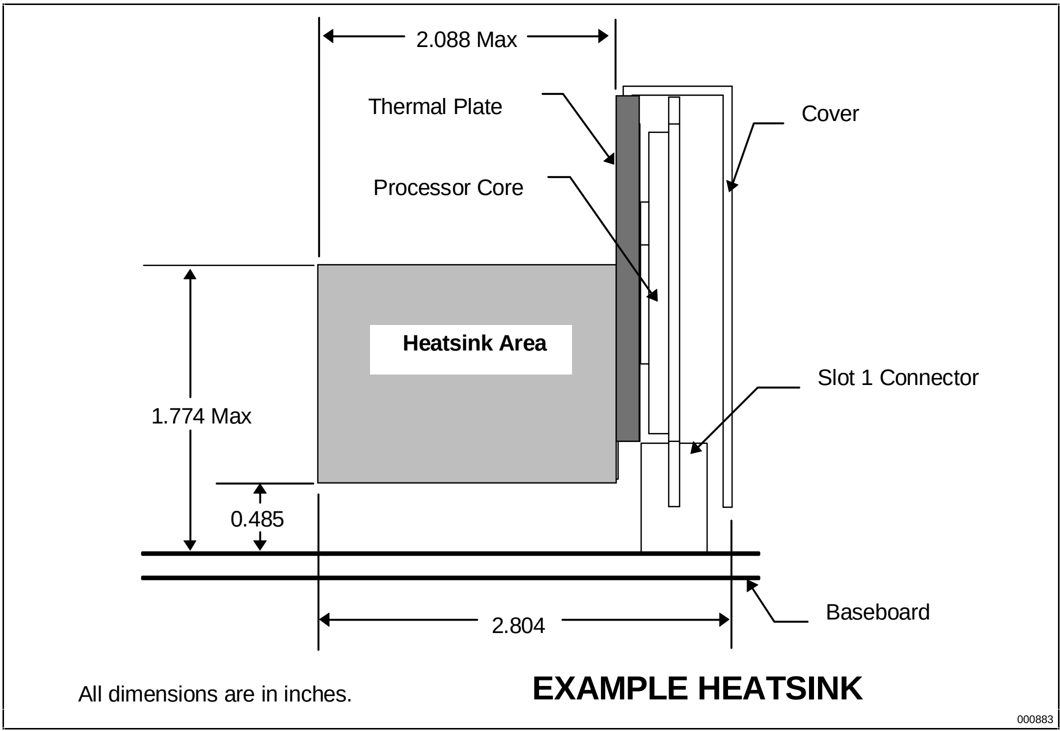
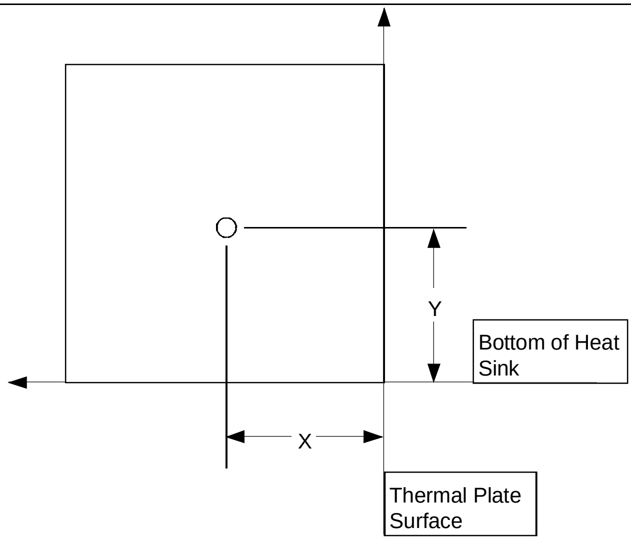


Figure 5. Side View of Example LPX Style Heatsink



Chassis Type	X Cg	Y Cg
ATX	1.2"	1.0"
LPX	1.4"	0.7"

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Figure 6. Maximum Distances for Center of Gravity for Heatsink Types

Each individual cg must be related to a single point of origin. Once the individual cgs are calculated, multiply the individual cg by the individual volume and sum up each of these individual products. A computational example is shown in Figure 7.

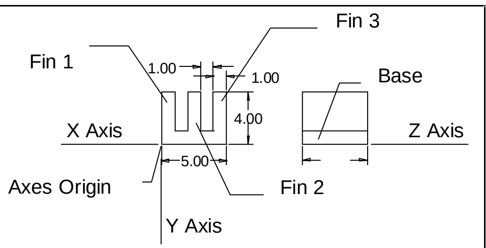

Figure 7. Center of Gravity Calculation Example

The heatsink has a fin thickness of 1 and a square base of 5 by 5. First the heatsink must be split into four different volumes: three fin blocks (1X3X5 each) and one base block (5X1X5). The individual center of gravity with respect to the axis origin is:

Individual Block Centroid and Volume:
Fin 1: Xcg1 = 0.5, Ycg = 2.5, Zcg = 2.5
Fin 1 Volume = 15
Fin 2: Xcg2 = 2.5, Ycg = 2.5, Zcg = 2.5
Fin 2 Volume = 15
Fin 3: Xcg3 = 4.5, Ycg = 2.5, Zcg = 2.5
Fin 3 Volume = 15
Base: Xcgb = 2.5, Ycg = 0.5, Zcg = 2.5
Base Volume = 25
Total Volume = 70

Now that the individual block centroids have been calculated, the average of the centroids with respect to the volumes as described earlier is:

Total Centroid of Heatsink:
Xcg = ((0.5*15)+(2.5*15)+(4.5*15)+(2.5*25)/70
Xcg = 2.5
Ycg = ((2.5*15)+(2.5*15)+(2.5*15)+(0.5*25)/70
Ycg = 1.8
Zcg = ((2.5*15)+(2.5*15)+(2.5*15)+(2.5*25)/70
Zcg = 2.5

5.3. Fans

Fans are needed to move the air through the chassis. The airflow rate of a fan is usually directly related to the acoustic noise level of the fan and system. Maximum acceptable noise levels may limit the fan output or the number of fans selected for a system. Fan/heatsink assemblies are one type of advanced solution which can be used to cool the Pentium II processor. Intel has worked with fan/heatsink vendors and computer manufacturers to make fan/heatsink cooling solutions available in the industry. Please consult such a vendor to acquire the proper solution for your needs.

5.3.1. PLACEMENT

Proper placement of the fans can ensure that the processor is being properly cooled. Because of the difficulty in building, measuring and modifying a mechanical assembly, models are typically developed and used to simulate a proposed prototype for thermal effectiveness to determine the optimum location for fans and vents within a chassis. Prototype assemblies can also be built and tested to verify if the system components and processor thermal specifications are met.

An intake air fan ideally is centered vertically and placed along one axis with respect to the S.E.C. cartridge with a heatsink. The fan should also be approximately 2 inches from the leading edge of the S.E.C. cartridge with a heatsink. Figure 8 and Figure 9 show the recommended fan placement for an ATX form factor layout and a LPX form factor, respectively.

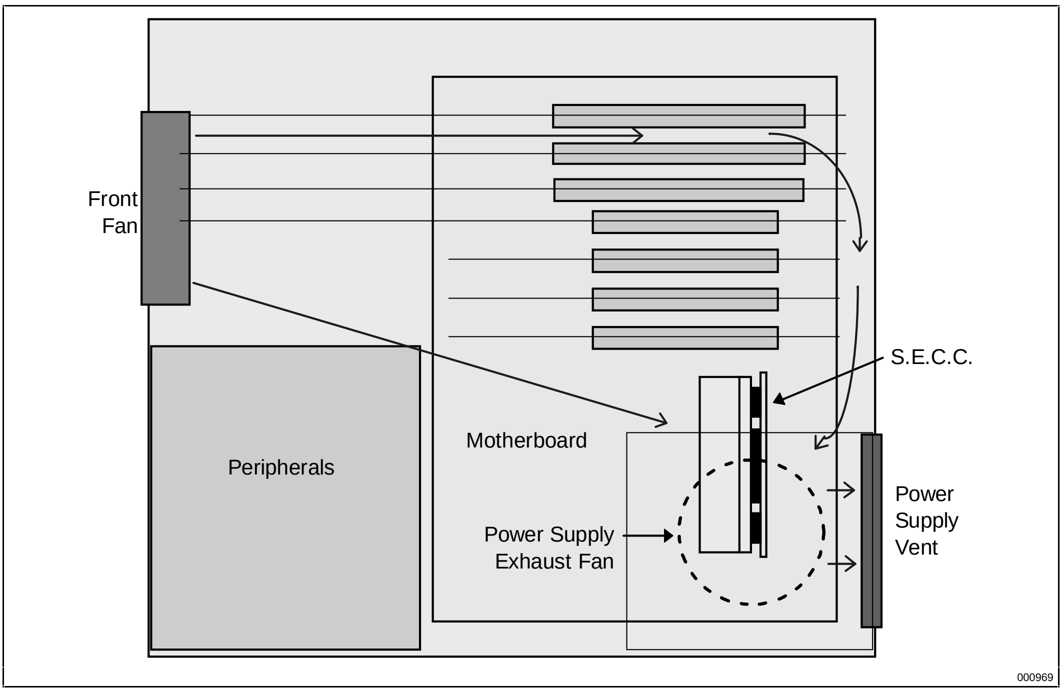

Figure 8. Fan Placement and Layout of an ATX Form Factor Chassis– Top View

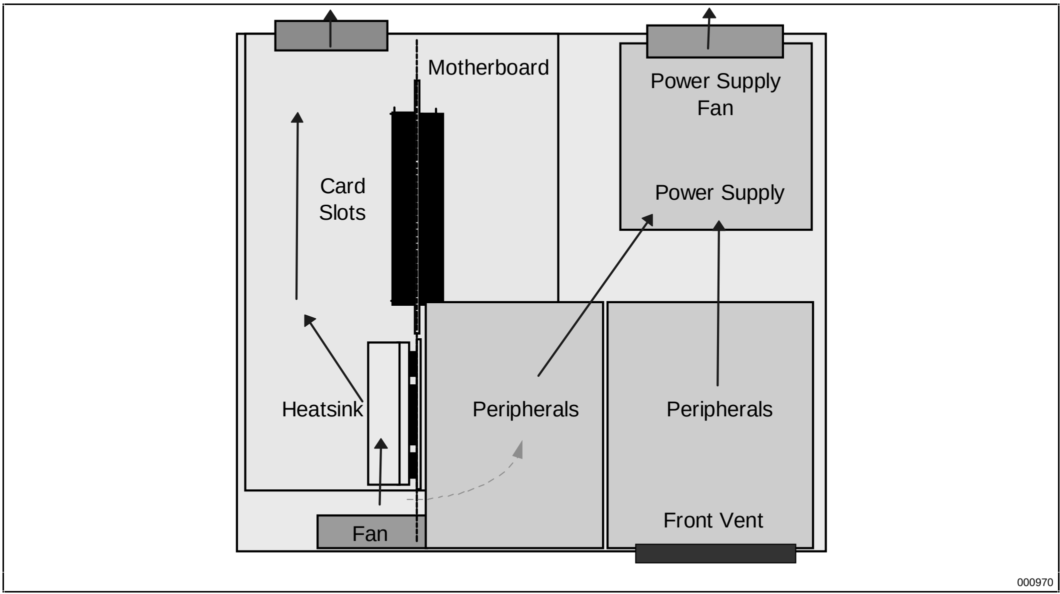

Figure 9. Fan Placement and Layout of a LPX Form Factor Chassis– Top View

5.3.2. DIRECTION

If the fan(s) are not moving air across the heatsink, then little cooling can occur. Hence the processor will operate well above the recommended specification values. Two possibilities exist for blowing air across the heatsink of a Pentium II processor. Air can be blown down vertically or horizontally across the heatsink. This may depend on the layout of other components on the board and/or within the chassis. Preferably the intake fan should blow through the S.E.C. cartridge heatsink lengthwise. The heatsink fins can be shorter in this case. For a vertically extruded heatsink the fins might need to be longer. Both of these factors are considerations when laying out components on the board and in the chassis.

The direction of the air flow can be modified with baffles or ducts to direct the air flow over the processor. This will increase the local flow over the processor and may eliminate the need for a second, larger or higher speed fan.

5.3.3. SIZE AND QUANTITY

It does not necessarily hold true that the larger the fan the more air it blows. A small blower using ducting might direct more air over the heatsink than a large fan blowing non-directed air over the heatsink. The following provide some guidelines for size and quantity of the fan(s).

The fan should be a minimum of 80 mm (3.150") square, with a minimum airflow of approximately 40 CFM (cubic feet per minute), or approximately 400 LFM (linear feet per minute). Ideally two (2) fans should be used. The intake air fan would blow directly into the S.E.C. cartridge with heatsink, while a second fan (most likely in the power supply) would exhaust the air out of the system.

5.3.4. VENTING

Intake venting should be placed at the front (user side) of the system. Location should be with consideration for cooling of processor and peripherals (drives and add-in cards). A good starting point would be the lower 50% of the Front Panel (Bezel). Intake venting directly in front of the intake fan is the most optimal location. The ideal design will provide airflow directly over the processor heatsink.

5.3.4.1. Placement

In most cases, exhaust venting in conjunction with an exhaust fan is usually sufficient at the power supply. However, depending on the number, location and types of add-in cards, exhaust venting may be necessary near the cards. This should be modeled or prototyped for the optimum thermal potential. Hence a system should be modeled for the worst case, i.e., all expansion slots should be occupied with typical add-in options.

5.3.4.2. Area and/or Size

The area and/or size of the intake vents should consider the size and shape of the fan(s). Adequate air volume must be obtained and thus will require adequate sized vents. Intake vents should be located in front of the intake fan(s) and adjacent to the drive bays. Venting should be approximately 50% to 60% open in the EMI containment area due to EMI constraints. Outside the EMI containment area, the open percentage can be greater if needed for aesthetic appeal (i.e., bezel/cosmetics). For more information concerning EMI constraints and Pentium II processor based system design, see the *Pentium® II Processor EMI Design Guidelines* application note (Order Number 243334). Outside the EMI containment area, the open percentage can be greater if needed for aesthetic appeal (i.e., Front bezel/cosmetics).

5.3.4.3. Vend Shape

Round, staggered pattern openings are best for EMI containment, acoustics and airflow balance. For material related to EMI considerations, please see the *Pentium® II Processor EMI* application note (Order Number 243334).

6.0. ALTERNATIVE COOLING SOLUTIONS

In addition to extruded heatsink and system fans, other solutions exist for cooling integrated circuit devices. For example, ducted blowers, heat pipes and liquid cooling are all capable of dissipating additional heat. Due to their varying attributes, each of these solutions may be appropriate for a particular system implementation.

6.1. Ducting

Ducts can be designed to isolate the processor(s) from the effects of system heating (such as add-in cards), and to maximize the processor cooling temperature budget. Air provided by a fan or blower can be channeled directly over the processor and heatsink, or split into multiple paths to cool multiple processors. This method can also be employed to provide some level of redundancy in a system requiring redundant capabilities for fault tolerance. This is accomplished by channeling air from two or more fans through the same path across a processor. Each fan, or each set of fans, must be designed to provide sufficient cooling in the event that the other has failed.

6.1.1. DUCTING PLACEMENT

When ducting is to be used, it should direct the airflow evenly from the fan through the length of the heatsink. This should be accomplished, if possible, with smooth, gradual turns as this will enhance the airflow characteristics. Sharp turns in ducting should be avoided. Sharp turns increase friction and drag and will greatly reduce the volume of air reaching the processor heatsink.

6.2. Fan Heatsink

An active fan heatsink can be employed as an alternative mechanism for cooling the Pentium II processor. This is the most universally acceptable solution for most chassis. Adequate clearance must be provided around the fan heatsink to ensure unimpeded air flow for proper cooling. The Intel boxed processor utilizes this implementation and is shown here as an example of a fan heatsink implementation. The space requirements and dimensions for the fan heatsink on the Intel boxed processor are shown in Figure 10 (front view), Figure 11 (side view) and Figure 12 (top view). All dimensions are in inches.

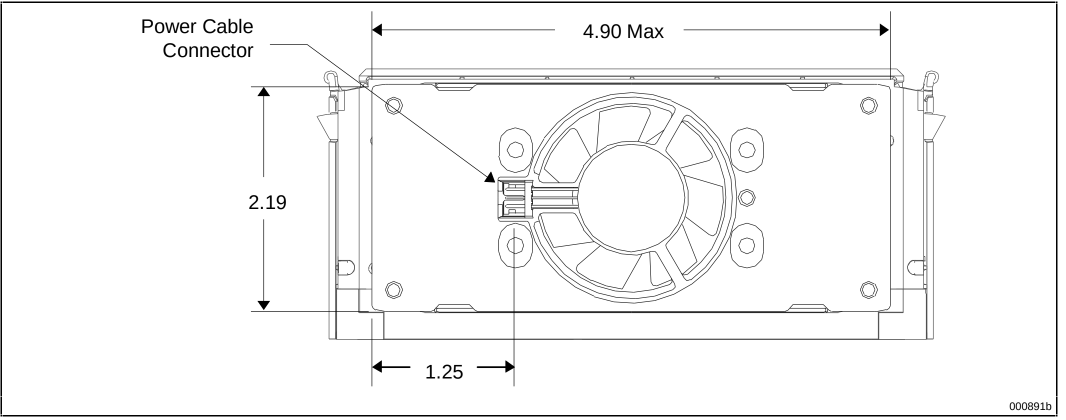

Figure 10. Front View Space Requirements for the Fan Heatsink

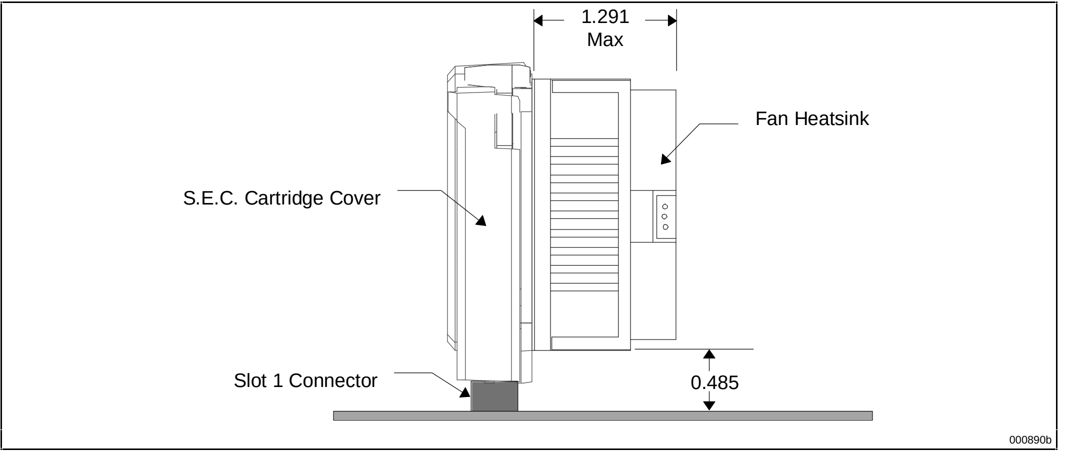

Figure 11. Side View Space Requirements for the Fan Heatsink (Supports not shown.)

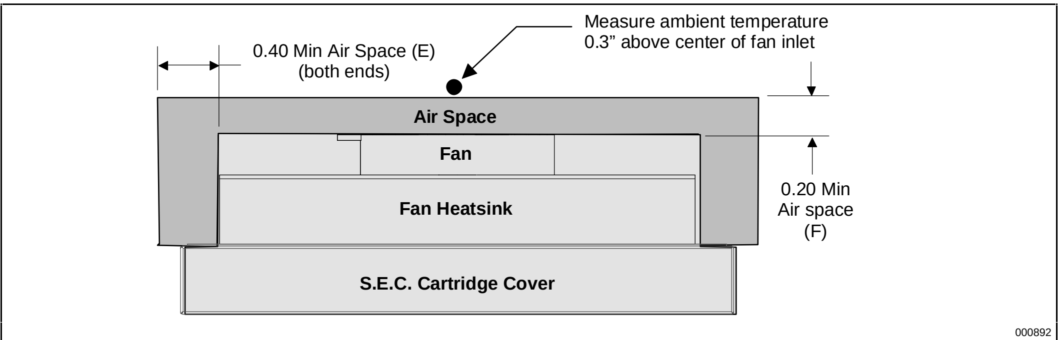

Figure 12. Top View Space Requirements for the Fan Heatsink

6.3. Fan Heatsink Measurements

A fan heatsink must be able to keep the thermal plate temperature, T_{plate}, within the specifications. This will require that the airflow through the fan heatsink be unimpeded and the air temperature entering the fan is below 45°C, see Figure 12 for measurement location. The fan heatsink thermal resistance will be less than 0.73°C/W between the temperature of the air entering the fan and the temperature of the processor thermal plate, (T_{plate}).

Airspace is required around the fan to ensure that the airflow through the fan heatsink is not blocked. Blocking the airflow to the fan heatsink reduces the cooling efficiency and decreases fan life. Figure 12 illustrates an acceptable airspace clearance for the fan heatsink.

6.4. System Components

6.4.1. PLACEMENT

Peripherals such as CD-ROM's, floppy drives, hard drives, etc. can be placed to take advantage of fan's movement of ambient air (i.e., near intake or exhaust fans or venting). Some add-in cards often have a low tolerance for temperature rise. These components should be placed near additional venting if they are downstream of the S.E.C. cartridge to minimize temperature rise.

6.4.2. POWER

Some types of drives, such as a floppy drive, do not dissipate much heat, while others(read/write CD-ROM, SCSI drives) dissipate a great deal of heat. These hotter components should be placed near fans and/or venting whenever possible. The same can be said for some types of add-in cards. Some PCI cards are very low wattage (5W) while others can be as high as 25 watts, per PCI specification. Great care should be taken to ensure that these cards have sufficient cooling.

7.0. THERMAL PARAMETERS

Component power dissipation results in a rise in temperature relative to the temperature of a reference point. The amount of rise in temperature depends on the net thermal resistance between the component's cartridge and the reference point. Thermal resistance is the key factor in determining the power handling capability of any electronic package.

7.1. Thermal Resistance

The thermal resistance value for the plate-to-ambient (Θ_{PA}) is used as a measure of the cooling solution's thermal performance. Thermal resistance is measured in units of °C/W. The thermal resistance of the plate-to-local ambient, Θ_{PA}, is comprised of the plate-to-sink thermal resistance (Θ_{PS}) and the sink-to-local ambient thermal resistance (Θ_{SA}). Θ_{PS} is a measure of the thermal resistance along the heat flow path from the top of the processor cartridge to the bottom of the thermal cooling solution. (See Figure 13.) This value is strongly dependent on the thermal conductivity and thickness of the material used for the interface between the heatsink and thermal plate of the processor. Θ_{SA} is a measure of the thermal resistance from the bottom of the cooling solution to the local ambient air. Θ_{SA} is dependent on the heatsink's material, thermal conductivity, geometry, and is strongly dependent on the air velocity through the fins of the heatsink.

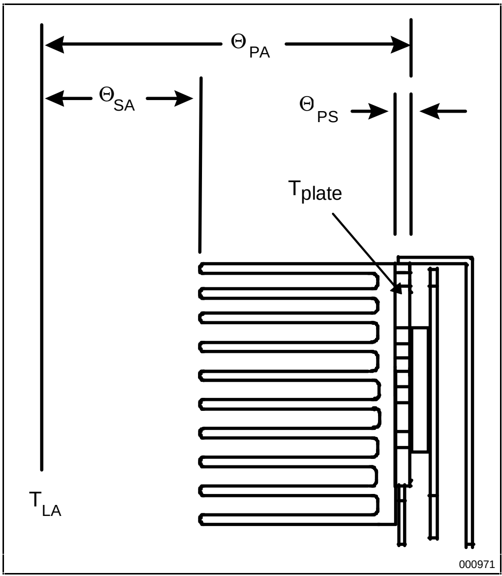

Figure 13. Thermal Resistance Relationships

The thermal parameters are related by the following equations:

$$\Theta_{PA} = (T_{plate} - T_{LA}) / P_D$$

$$\Theta_{PA} = \Theta_{PS} + \Theta_{SA}$$

Where:

Θ_{PA} = Thermal resistance from plate-to-local ambient (°C/W)

T_{plate} = Processor thermal plate temperature (°C)

T_{LA} = Local ambient temperature in chassis around processor (°C)

P_D = Device power dissipation (W) (assume no power goes to the other side)

Θ_{PS} = Thermal resistance from plate-to-sink (°C/W)

Θ_{SA} = Thermal resistance from heatsink-to-local ambient (°C/W)

7.2. Thermal Solution Performance

All processor thermal solutions should attach to the thermal plate. The thermal solution must adequately control the thermal plate and the local ambient air around the processor ($\Theta_{thermal\ plate\ to\ local\ ambient}$). The lower the thermal resistance between the thermal plate and the local ambient air, the more efficient the thermal solution is. The required $\Theta_{thermal\ plate\ to\ local\ ambient}$ is dependent upon the maximum allowed thermal plate temperature (T_{plate}), the local ambient temperature (T_{LA}) and the thermal plate power ($P_{thermal\ plate\ power}$). This can be expressed in the following mathematical equation:

$$\Theta_{PA} = (T_{plate} - T_{LA}) / P_{thermal\ plate}$$

The maximum T_{plate} and the thermal plate power are listed in Table 2. T_{LA} is a function of the system design. Table 3 provides the resultant thermal solution performance for a 266 MHz Pentium II processor at different local ambient air temperatures around the processor.

Table 2. Pentium® II Processor Thermal Plate Power

Processor Core Frequency (MHz)	L2 Cache Size (KB)	Thermal Plate Power (W)	Max Thermal Plate Temperature (T_{plate} – °C)
233	512	37.0	75
266	512	33.6	75
300	51241.4	41.4	70

Table 3. Thermal Solution Performance for a 266 MHz Pentium® II Processor at Thermal Plate Power of 37.0 Watts

Thermal Solution Performance	$T_{ambient}$		
Θ_{PA}	35°C	40°C	45°C
(°C/watt)	1.08	0.95	0.81

The Θ_{PA} value is made up of two primary components: the thermal resistance between the thermal plate and heatsink (Θ_{PS}) and the thermal resistance between the heatsink and local ambient air around the processor (Θ_{SA}). A critical, but controllable factor to decrease the resultant value of Θ_{PS} between the thermal plate and heatsink. Thermal interfaces are addressed in a later section. The other controllable factor (Θ_{SA}) is resultant in the design of the heatsink and airflow around the heatsink. Heatsink design constraints are discussed in a later section.

7.3. Measurements for Thermal Specifications

To appropriately determine the thermal properties of the system, measurements must be made. Guidelines have been established for proper techniques for measuring processor temperatures. The following sections describe these guidelines for measurement.

7.3.1. THERMAL PLATE MEASUREMENTS

To ensure functionality and reliability, the Pentium II processor is specified for proper operation when T_{plate} (thermal plate temperature) is maintained at or below 75°C for 233 MHz and 266 MHz, and a T_{plate} at or below 70°C for 300 MHz. The surface temperature of the thermal plate directly above the center of the processor core is measured. Figure 14 shows the location for T_{plate} measurement.

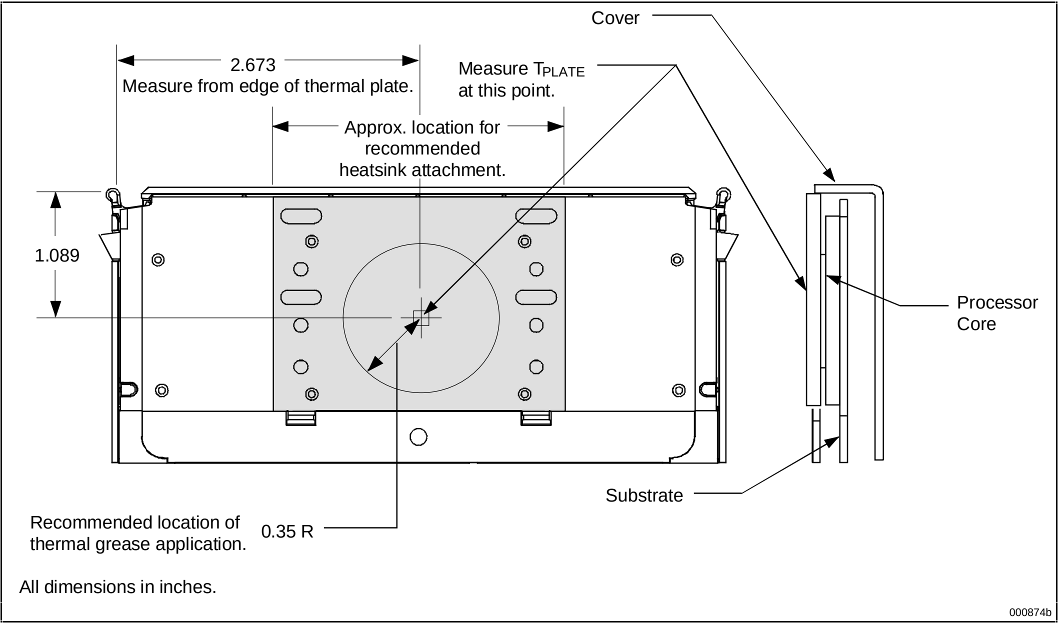

Figure 14. Processor Thermal Plate Temperature Measurement Location

Special care is required when measuring the T_{plate} temperature to ensure an accurate temperature measurement. Thermocouples are often used to measure T_{plate}. Before any temperature measurements are made, the thermocouples must be calibrated. When measuring the temperature of a surface which is at a different temperature from the surrounding local ambient air, errors could be introduced in the measurements. The measurement errors could be due to having a poor thermal contact between the thermocouple junction and the surface of the thermal plate, heat loss by radiation, convection, by conduction through thermocouple leads, or by contact between the thermocouple cement and the heatsink base. To minimize these measurement errors, the following approach is recommended:

- Use 36 gauge or finer diameter K, T, or J type thermocouples.
- Ensure that the thermocouple has been properly calibrated.
- Attach the thermocouple bead or junction to the top surface of the thermal plate at the location specified in Figure 14 using high thermal conductivity cements.
- The thermocouple should be attached at a 0° angle if there is no heatsink interference with the thermocouple attach location or leads (refer to Figure 15).
- The thermocouple should be attached at a 90° angle if a heatsink is attached to the thermal plate and the heatsink covers the location specified for T_{plate} measurement (refer to Figure 16).
- The hole size through the heatsink base to route the thermocouple wires out should be smaller than 0.150" in diameter.
- Make sure there is no contact between the thermocouple cement and heatsink base. This contact will affect the thermocouple reading.

7.3.2. CARTRIDGE COVER MEASUREMENT GUIDELINES

The S.E.C. cartridge cover temperature specification is a maximum of 75°C for 233 MHz and 266 MHz, and a maximum of 70°C for 300 MHz. There are several components on the substrate that comprise the Pentium II processor. Each of these components generate heat and since some components may reside on the opposite side of the substrate from the processor core, the cover too will have to meet a specified temperature for proper operation.

Known hot spots on the cover are shown in Figure 17. It is recommended that thermocouples be located at or near these hot spot locations when measuring T_{cover} for a particular chassis and system configuration. Similar techniques presented in Section 7.3.1. for measuring thermal plate temperature can be used for the cover measurements. The KPOWER.EXE application should be running when the T_{cover} measurement is made. Please contact your local Intel Field Sales representative to receive a copy.

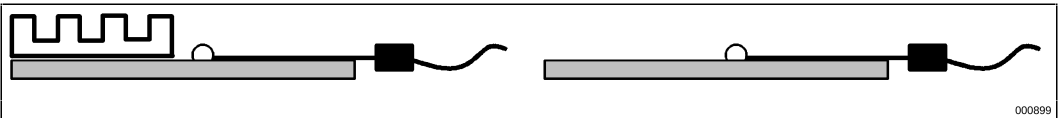

Figure 15. Technique for Measuring T_{plate} with 0° Angle Attachment

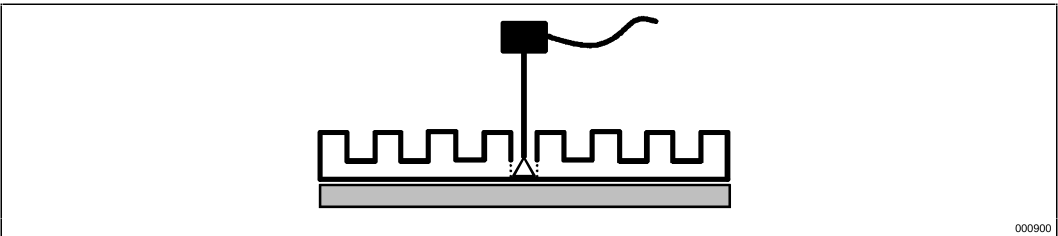

Figure 16. Technique for Measuring T_{plate} with 90° Angle Attachment

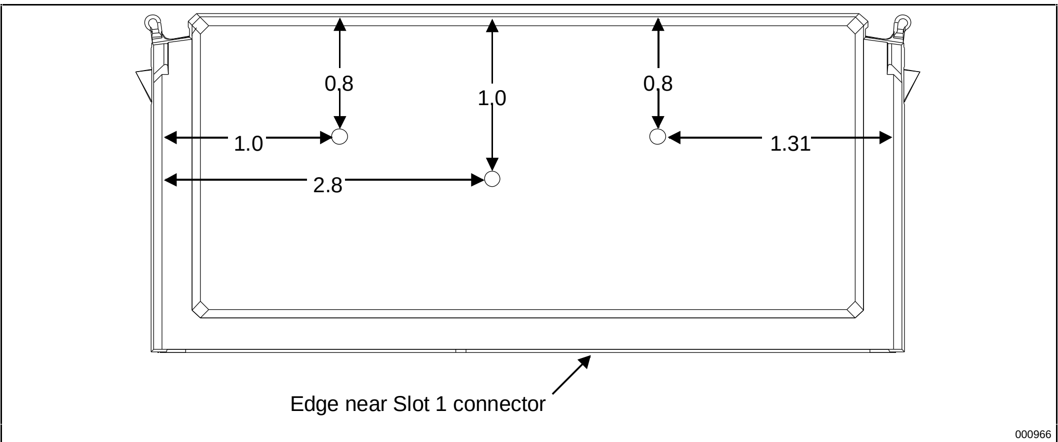

Figure 17. Location of Known Hot Spots on the Pentium® II Processor Cover

7.3.3. LOCAL AMBIENT TEMPERATURE MEASUREMENT GUIDELINES

Local ambient temperature, T_{LA}, is the temperature of the ambient air surrounding the cartridge. In a system environment, ambient temperature is the temperature of the air upstream of the cartridge and in its close vicinity; or in an active cooling system, it is the inlet air to the active cooling device.

NOTE

An ambient temperature is not specified for the Pentium II processor. The only restriction is that T_{cover} (cover temperature) and T_{plate} (thermal plate temperature) be met.

It is worthwhile to determine the local ambient temperature in the chassis around the processor to better understand the effect it may have on the thermal plate temperature and the cover temperature. To determine the T_{LA} values, the following equations may be used:

$$T_{cover} = T_{LA} + (P_D * \Theta_{CA})$$

Where:

T_{LA} = Local ambient temperature (°C)

T_{cover} = Cover temperature of the device under test (°C)

P_D = Total power dissipated by the Pentium II processor (W)

Θ_{CA} = Cover-to-local ambient thermal resistance (°C/W)

The following guidelines are meant to alleviate the non-uniform measurements found in typical systems. The local ambient temperature is best measured as an average of the localized air surrounding the processor. The following guidelines are meant to enable accurate determination of the localized air temperature around the processor during system thermal testing. These guidelines are meant as a reasonable expectation to ensure the product specifications are met.

- During system thermal testing, a minimum of two thermocouples should be placed approximately 0.5" away from the S.E.C. cartridge cover and heatsink as shown in Figure 18. This placement guideline is meant to minimize localized hot spots due to the processor, heatsink, or other system components.
- The thermocouples should be placed approximately 2 inches above the baseboard. This placement guideline is meant to minimize localized hot spots from baseboard components.
- The T_{LA} should be the average of the thermocouple measurements during system thermal testing.

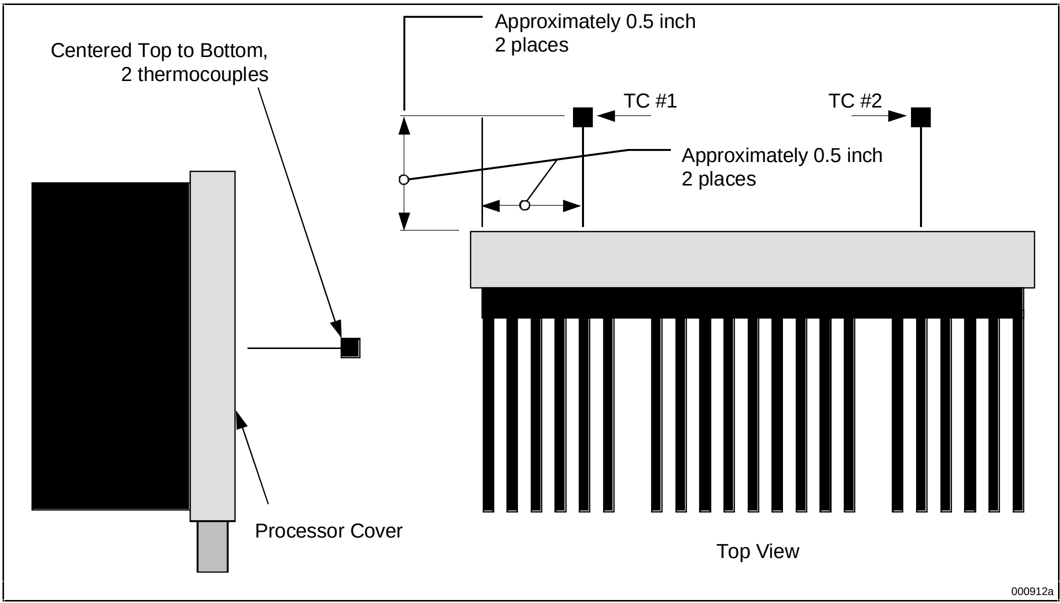

Figure 18. Guideline Locations for Local Ambient Temperature

7.4. Thermal Interface Management

To optimize the heatsink design for the Pentium II processor, it is important to understand the impact of factors related to the interface between the thermal plate and the heatsink base. Specifically, the bond line thickness, interface material area and interface material thermal conductivity should be managed to realize the most effective thermal solution.

7.4.1. BOND LINE MANAGEMENT

The gap between the thermal plate and the heatsink base will impact thermal solution performance. The larger the gap between the two surfaces, the greater the thermal resistance. The thickness of the gap is determined by the flatness of both the heatsink base and the thermal plate, plus the thickness of the thermal interface material (i.e., thermal grease) used between these two surfaces.

The worst case flatness of the thermal plate will be 0.005" over the entire thermal plate surface. The attach area on the thermal plate will have the flatness specified as no greater than 0.001" per inch. The flatter the heatsink base, the thinner the resultant bond line that can be achieved. In addition, the attach mechanism for the heatsink needs to be able to supply sufficient clamping force to spread the interface material out to form the thinnest film possible.

7.4.2. INTERFACE MATERIAL AREA

The size of the contact area between the thermal plate and the heatsink base will impact the thermal resistance. There is, however, a point of diminishing returns. Unrestrained incremental increases in thermal grease area do not translate to a measurable improvement in thermal performance. Figure 19 illustrates the results of empirical measurements of two different types of grease based on thermal conductivity. The bulk thermal conductivity of type A grease is 0.5 to 1.5 W/mK and type B grease is 2 to 3 W/mK. In addition to the diminishing returns seen with larger grease areas, the overall flatness that can be achieved tends to decrease. The decrease in flatness would have a negative impact of potentially increasing the resistance across the interface between the thermal plate and the heatsink.

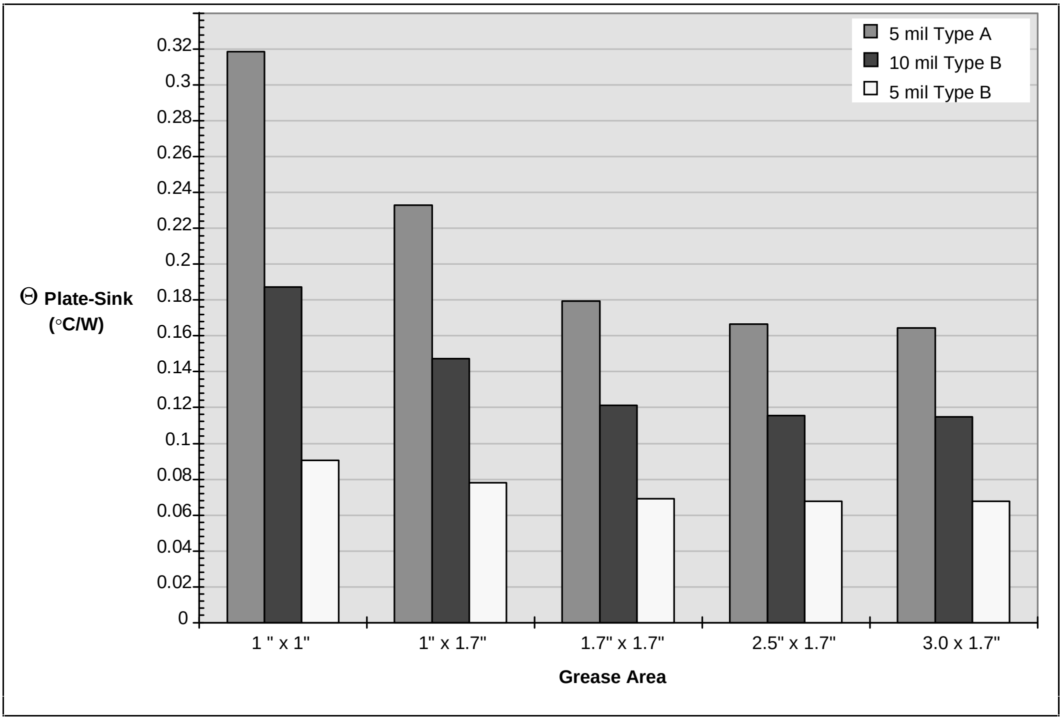

Figure 19. Impact of Contact Area and Grease Properties of the Interface Material

7.4.3. INTERFACE MATERIAL PERFORMANCE

Two factors impact the performance of the interface material between the thermal plate and the heatsink base:

1. Thermal resistance of the material
2. Wetting/filling characteristics of the material

Thermal resistance is a description of the ability of the thermal interface material to transfer heat from one surface to another. The higher the thermal resistance, the less efficient an interface is at transferring heat. The thermal resistance of the interface material has a significant impact on the thermal performance of the overall thermal solution. The higher the thermal resistance, the higher the temperature drop across the interface and the more efficient the thermal solution must be.

The wetting/filling of the thermal interface material is its ability, under the load applied by the heatsink attach mechanism, to spread and fill the gap between the thermal plate and the heatsink. Since air is an extremely poor thermal conductor, the more completely the interface material fills the gaps, the lower the temperature drop across the interface. In this case, grease area-size also becomes significant, as the larger the desired grease area size, the higher the force required to spread the thermal interface material.

Thermal pads are available from various vendors and may provide an adequate thermal interface solution. Also, some vendors can supply their heatsinks with pre-applied thermal grease to reduce the handling, assembly time and assembly steps to attach a thermal solution.

8.0. CONCLUSION

As the complexity of today's microprocessors continues to increase, so do the power dissipation requirements. Care must be taken to ensure that the additional power is properly dissipated. Heat can be dissipated using passive heatsinks, fans and/or active cooling devices.

Further solutions can be achieved through the use of ducting solutions.

The simplest and most cost effective method is to use an extruded heatsink and a system fan. The size of the heatsink and the output of the fan can be varied to balance size and space constraints with acoustic noise. This document has presented the conditions and requirements for properly designing a heatsink solution for a Pentium II processor based system. Properly designed solutions provide adequate cooling to maintain the Pentium II processor's cover temperature and thermal plate temperature at or below 75°C for 233 MHz and 266 MHz, and at or below 70°C for 300 MHz. This is accomplished by providing a low local ambient temperature and creating a minimal thermal resistance to that local ambient temperature. Active fan heatsinks or ducting can be used to cool the processor(s) if proper cover and thermal plate temperatures cannot be maintained otherwise. By maintaining the Pentium II processor's cover temperature and thermal plate temperature at the values specified in the *Pentium® II Processor Developer's Manual*, a system can guarantee proper functionality and reliability of these processors.