Intel® Pentium® III Processor in the FC-PGA2 Package

Thermal Design Guidelines

June 2001

Order Number: 249660-001

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Revision History

Rev.	Description	Date
-001	• Initial Release	June 2001

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1. 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, as well as the physical constraints at and above the processor. The processor's temperature depends on the component power dissipation, size and material (effective thermal conductivity) of the integrated heat spreader, and the presence of a thermal cooling solution.

All of these parameters are aggravated by the continued push of technology to increase performance levels (higher operating speeds, GHz) and packaging size and 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.

1.1. Document Scope

This document discusses thermal management techniques for Intel® Pentium® III processors in the FC-PGA2 package with an integrated heat spreader, which is primarily intended for the desktop and server segments. The physical dimensions and power numbers used in this document are for reference only. Please refer to the respective datasheets for the product dimensions, thermal power dissipation, and maximum case temperature. In case of conflict, the specifications in the processor datasheets supercede any data in this document.

1.2. References

Document Title	Order Number
Pentium® III Processor for the PGA370 Socket Datasheet	245264
Intel® Pentium® III Processor with 512Kb L2 Cache Datasheet	249657
370-Pin Socket (PGA370) Design Guidelines	244410
AP-905 Pentium® III Processor Thermal Design Guidelines	245087
FC-PGA2 Package Thermal / Mechanical Solution Functional Specifications	Contact your Intel Field Sales Representative
Performance ATX Desktop System Thermal Design Suggestions v1.0	http://www.formfactors.org
ATX Thermal Design Suggestions v1.0	http://www.formfactors.org
Performance MicroATX Desktop System Thermal Design Suggestions v1.0	http://www.formfactors.org
MicroATX Thermal Design Suggestions v1.0	http://www.formfactors.org
FlexATX Thermal Design Suggestions v1.0	http://www.formfactors.org
Evaluation Board for Microprocessor System Temperature Monitor or EVAL-ADM1021	http://www.analog.com
Analog Devices EVAL-ADM1021 kit datasheet	http://www.analog.com
Maxim Integrated Products MAX1617EV Kit datasheet	http://www.maxim-ic.com

1.3. Definition of Terms

- T_{LA} - the measured ambient temperature locally surrounding the processor. The ambient temperature should be measured just "upstream" of a passive heatsink, or at the fan inlet for an active heatsink. (See Section 7.3: Local-ambient Temperature Measurement Guidelines)
- $T_{AMBIENT-OEM}$ - the target worst-case ambient temperature at a given **external** system location as defined by the system designer (OEM).
- $T_{AMBIENT-EXTERNAL}$ - the measured ambient temperature at the OEM defined external system location.
- $T_{AMBIENT-MAX}$ - the target worst-case local-ambient temperature. It is determined by placing the system in maximum external temperature conditions and measuring the ambient temperature locally surrounding the processor. Under these conditions, $T_{LA} = T_{AMBIENT-MAX}$.
- $T_{CASE-MAX}$ - the maximum allowed case temperature of the processor, as specified in the processor datasheet.
- T_{CASE} - the measured case temperature of the processor.
- TIM - Thermal Interface Material. The thermally conductive compound between the heatsink and the processor case. This material fills the air gaps and voids, and enhances the spreading of the heat from the case to the heatsink.
- θ_{TIM} - the thermal resistance of the thermal interface material. Also referred to as θ_{CS} (case to sink thermal resistance).
- θ_{CA} - the thermal resistance between the processor's case and the ambient air. This is defined and controlled by the system thermal solution.
- P_{MAX} - the maximum processor power, as specified in the processor's datasheet.
- PGA370 Socket - a through-hole mount Zero Insertion Force (ZIF) socket designed to accept the Intel® Pentium® III processor in the FC-PGA2 package.
- FC-PGA2 package - the Flip Chip Pin Grid Array processor package with an integrated heat spreader (IHS).
- ACPI - Advanced Configuration and Power Interface (See http://www.teleport.com/~acpi/)
- Bypass - the area between a passive heatsink or air pass-through and any object that can act to form a duct. For this example it can be expressed as a dimension away from the outside dimension of the fins to the nearest surface.
- TDP - Thermal Design Power. The processor thermal power specification in the processor datasheet. OEMs must design their processor thermal solutions to meet the TDP as listed in the respective datasheets. (Also known as Thermal Design Point.)
- Intel® Pentium® III processor in the FC-PGA2 package - any Pentium® III processor with CPUID 06Bxh, as well as the higher frequencies of Intel® Pentium® III processors with CPUID 068xh (see the *Pentium® III Processor for the PGA370 Socket Datasheet* for further details).

2. 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.

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3. FC-PGA2 Processor Packaging Technology

The Intel® Pentium® III processor is available in Flip Chip Pin Grid Array 2 (FC-PGA2) packaging. The FC-PGA2 package consists of the microprocessor silicon core with integrated L2 cache mounted on a pinned substrate. The silicon core is encased by a heat spreader, which is integrally mounted to the FC-PGA2 substrate. The Integrated Heat Spreader (IHS) is designed to improve thermal performance and is the interface for attaching a heatsink. The processor core is mounted with the back of the die facing up, hence the term "flip chip." The pin grid array on the backside of the interposer is not fully populated and there may be small, low power, surface mounted components in the center of the pin field. The processor package connects to the motherboard by plugging into a 370-pin ZIF socket (PGA370). See Figure 3-1and Table 3-1 (*below*) for a complete mechanical dimensioning. A description of the socket can be found in the *370-Pin Socket (PGA370) Design Guidelines*. Refer to the processor datasheets for package mechanical loading specifications.

Figure 3-1. FC-PGA2 Mechanical Specifications

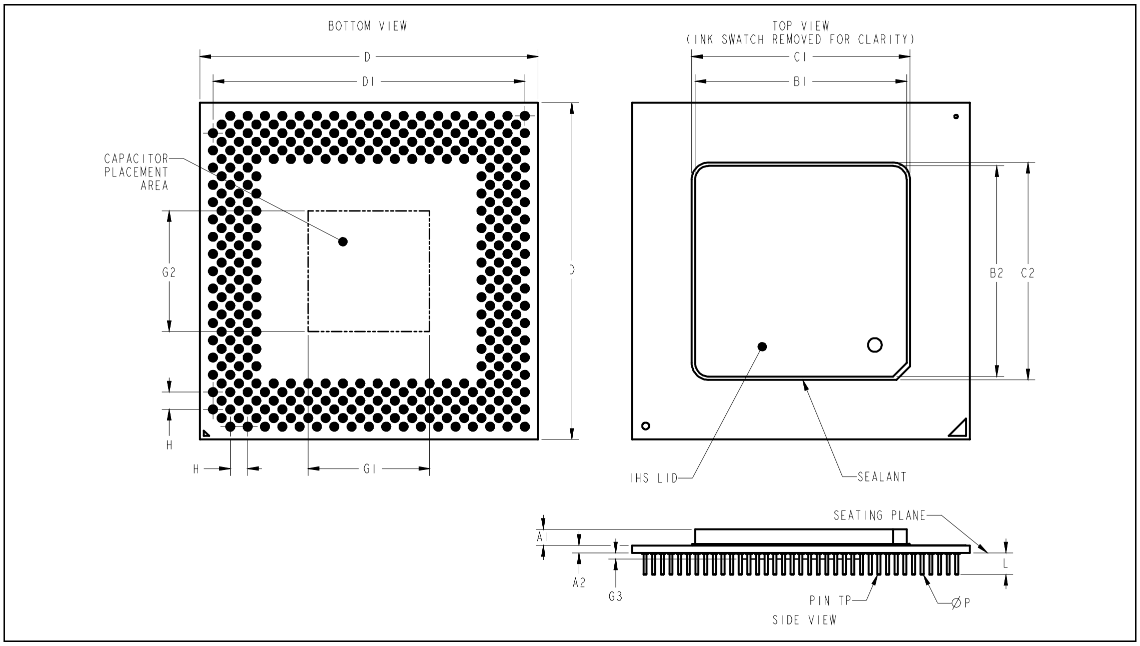

Table 3-1. FC-PGA2 Processor Package Dimensions

Symbol	Millimeters			Inches		
	Minimum	Maximum	Notes	Minimum	Maximum	Notes
A1	2.266	2.690		0.089	0.106	
A2	0.980	1.180		0.038	0.047	
B1	30.800	31.200		1.212	1.229	
B2	30.800	31.200		1.212	1.229	
C1	33.000 max			1.299 max		
C2	33.000 max			1.299 max		
D	49.428	49.632		1.946	1.954	
D1	45.466	45.974		1.790	1.810	
G1	0.000	17.780		0.000	0.700	
G2	0.000	17.780		0.000	0.700	
G3	0.000	0.889		0.000	0.035	
H	2.540		Nominal	0.100		Nominal
L	3.048	3.302		0.120	0.130	
ΦP	0.431	0.483		0.017	0.019	
Pin TP	0.508 Diametric True Position (Pin-to-Pin)			0.020 Diametric True Position (Pin-to-Pin)		

NOTES:

1. Capacitors will be placed on the pin-side of the FC-PGA2 package in the area defined by G1, G2, and G3. This area is a keep-out zone for motherboard designers.
2. In case of conflict, the processor datasheets supercede this document.

4. Thermal Specifications

For the purposes of this design guideline, the following assumptions have been made about the requirements for proper operation and reliability of the processor:

- Considering the power dissipation levels and typical system ambient environments (T_{LA}), the processor's temperature cannot be maintained at or below the specified guidelines without additional thermal enhancement to dissipate the heat generated by the processor.
- The thermal characterization data described in later sections illustrates that both a thermal-cooling device and reasonable system airflow are needed. The size and type (passive or active) of thermal cooling device and the amount of system airflow are related and can be traded against each other to meet specific system design constraints. In typical systems, board layout, spacing, and component placement limit the thermal solution size. 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, number, and 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 Case Temperature

The Integrated Heat Spreader (IHS) is intended to provide the common interface and attach location for all thermal solutions for FC-PGA2 packaged processors. The IHS acts to spread the heat from the small area of the processor die to the larger surface area of the IHS, allowing more efficient heat transfer using heatsink thermal solutions. These solutions can be active or passive. Active solutions are those where a fan is directly attached to the heatsink. A passive heatsink uses system airflow forced in some manner to pass-through the heatsink fins. Considerations in heatsink design include:

- Local-ambient temperature at the heatsink (T_{LA})
- Surface area of the heatsink
- Property of materials (including thermal resistance or conductivity)
- Volume and velocity of airflow over the heatsink surface area
- Power being dissipated by the processor and its associated power density
- Physical volumetric constraints placed by the system

Techniques for measuring case temperatures are provided in Section 7: Thermal Metrology.

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5. Designing for Thermal Performance

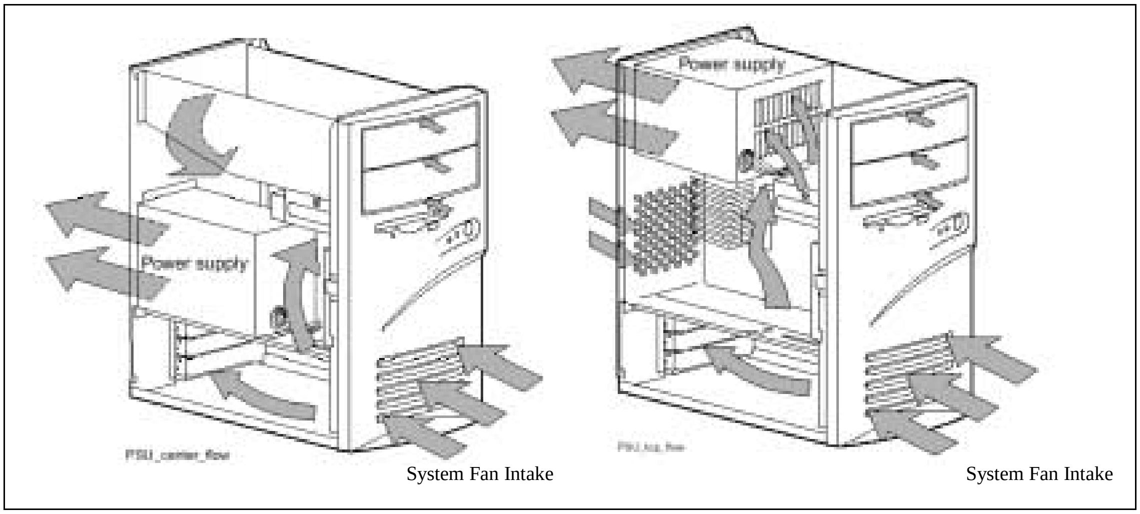
5.1. Airflow Management

It is important to manage the volume and velocity of air that flows within the system, as well as how it flows, to maximize the amount of cool air that flows over the processor. Total system airflow can be increased by adding one or more fans to the system, or by increasing the output (increasing the speed or size) of an existing system fan(s). Managing the airflow direction using baffles or ducts can also increase local airflow. An important consideration in airflow management is the temperature of the air flowing over the processor. Heating effects from chipset, voltage regulators, add-in boards, memory, 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 re-circulation.

If no air path exists across the processor heatsink, the warm air from the processor will not be removed from the system, resulting in localized heating ("hot spots") around the processor(s). Passive heatsink fin designs should be aligned with the direction of the airflow.

Figure 5-1 shows two examples of air exchange through a µATX style PC chassis. The system on the left is an example of a center mounted power supply, and the one on the right is an example of a top mounted power supply. Both are examples of good air exchange incorporating the power supply fan as well as an additional system fan (additional system fan shown as the three large arrows entering the front bezel). For further information, reference the system thermal design suggestions for the appropriate form factor available at http://www.formfactors.org/.

Figure 5-1. Example of Air Exchange Through a µATX PC Chassis



5.2. Recommended Fan Performance and Limitations

For active thermal solutions, the fan must often demonstrate a functional lifetime of 40,000 hours or greater. In addition, the fan should demonstrate performance to the reliability criteria outlined in the *FC-PGA2 Package Thermal/Mechanical Solution Functional Specifications*.

5.3. Bypass

Bypass is the distance around a passive heatsink where air may travel without passing through the fins of the heatsink. A heatsink will have infinite bypass if it is sitting in free space, while a heatsink that has a duct, or other devices surrounding it which are 0.2 in (5.1mm) away from the outer edges of the heatsink, has a bypass of 0.2 in (5.1mm). A smaller bypass forces more air to pass through the fins of the heatsink, instead of around the heatsink. This is especially important as the heatsink fin density increases. The higher the fin density, the more resistance the heatsink poses to the air and the more likely the air will travel around the heatsink instead of through it unless the bypass is small. Air traveling around the heatsink will have no affect on cooling the processor.

5.4. Heatsink Solutions and Keep-in Areas

One method used to improve thermal performance is to increase the surface area of the device by attaching a metallic heatsink. 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. Although there have been many advancements in fin density and geometries that allow for a better performing heatsink, an active or more advanced thermal solution may be needed. Intel is enabling reference active and passive heatsinks for FC-PGA2 packaged processors. Please see the *FC-PGA2 Package Thermal/Mechanical Solution Functional Specifications* for further details.

5.5. Thermal Interface Management

To optimize the heatsink design for FC-PGA2 packaged processors, it is important to understand the impact of factors related to the interface between the processor and the heatsink base. Specifically, the interface material bond line thickness, area, and bulk thermal conductivity should be managed to realize the most effective thermal solution.

Thermal interface material must be applied between the processor IHS and the heatsink to improve thermal conduction from the IHS to the heatsink. Thermal interface material also serves as a mechanical load element during mechanical stress testing (i.e. mechanical shock). Many thermal interface materials can be pre-applied to the heatsink base prior to shipment from the heatsink supplier and allow direct heatsink attach, without the need for a separate thermal interface material dispense or attach process in the final assembly factory.

All thermal interface materials must be sized and positioned on the heatsink base in a way that ensures the entire processor IHS area is covered. It will be important to compensate for heatsink-to-processor attach positional alignment when selecting the proper thermal interface material size.

If a pre-applied thermal interface material is specified, it may have a protective application tape. This tape must be removed prior to heatsink attach.

5.5.1. Bond Line Thickness

Any gap between the processor's heat spreader 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 integrated heat spreader, the thickness of the thermal interface material (i.e. thermal grease) used between these two surfaces, and the clamping force applied by the heatsink retention clip(s). In comparison with FC-PGA packaged processors, the addition of the IHS will distribute the vertical force created by the attach clip(s). For the same applied force (e.g. the same heatsink attach clip configuration), this will result in lower pressure applied to the thermal interface material. This will lead to an increase in thermal interface bond line thickness and thermal resistance.

5.5.2. Interface Material Area

The size of the contact area between the integrated heat spreader and the heatsink base will impact the thermal resistance; increasing contact area typically decreases thermal resistance. It is recommended that the thermal interface material should cover the entire surface of the integrated heat spreader area (31mm x 31mm) to optimize the thermal interface performance on FC-PGA2 packaged processors.

5.5.3. Interface Material Performance

Two factors impact the performance of the interface material between the processor 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 the 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 larger the temperature drop is across the interface and the more efficient the thermal solution must be to achieve the desired cooling.

The wetting or filling characteristic of the thermal interface material is its ability, under the load applied by the heatsink retention mechanism, to spread and fill the gap between the processor 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. Thermal interface material area-size also becomes significant, as the larger the desired area-size, the higher the force required to spread the thermal interface material.

5.6. Fans

Fans are needed to move the air through the chassis and/or directly through the processor heatsink. 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. The maximum noise levels may differ from country to country. Fan/heatsink assemblies are one type of advanced solution that can be used to cool the 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.

5.6.1. 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 for thermal evaluation, models are typically developed and used to simulate a proposed design for thermal effectiveness, and to determine the optimum location for fans and vents within a chassis. Investments for prototype assemblies can then be made to verify that the system components and processor thermal specifications are met.

5.6.2. Fan Direction

If the fan(s) are not moving air across the processor heatsink, cooling will not occur. This may cause the processor to operate well above the recommended specification values. Two possibilities exist for blowing air across a passive heatsink. 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. The intake fan should blow through a passive heatsink parallel to the fins if possible. Both of these factors are considerations when laying out components on the board and in the chassis.

The direction of the airflow can be modified with baffles or ducts to direct the airflow over the processor. This will increase the local flow over the processor and may eliminate the need for a second fan, a larger fan, or a higher speed fan. For an actively cooled heatsink, the system airflow direction may not be as critical for proper thermal performance, but it will be important to manage warm air re-circulation.

5.6.3. 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.

5.6.4. Venting

Intake venting should be placed at the front (user side) of the system. They should be located to optimize 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 vents directly in front of the intake fan, is the optimal location. The ideal design will provide airflow directly over the processor heatsink.

5.6.4.1. Placement

In most cases, an exhaust fan and vent located at the power supply is sufficient. 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. A system should be modeled for the worst case, i.e., all expansion slots should be occupied with typical add-in options.

5.6.4.2. Area and Size

The area and size of the intake vents should be designed with the size and shape of the fan(s) in mind. Adequate air volume requires appropriately sized vents. Intake vents should be located in front of the intake fan(s) and adjacent to the drive bays. Vents 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).

5.6.4.3. Vent Shape

Round, staggered pattern openings are best for EMI containment, acoustics, and airflow balance.

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6. Alternative Cooling Solutions

In addition to passive heatsinks, fan heatsinks 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. More information on this topic can be located on Intel's web site at http://developer.intel.com/.

6.1. Ducting

Ducts can be designed to isolate the processor from the effects of system heating (such as add-in cards), and to maximize the processor cooling temperature budget. Typical temperature rise from external ambient to the local-ambient near the processor can be greater than 10°C. Air provided by a fan or blower can be channeled to the processor and heatsink with little or no rise from the external ambient temperature.

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 reduce air impedance. Sharp turns in ducting should be avoided as they increase friction and drag and will greatly reduce the volume of air reaching the processor heatsink.

6.2. System Components

6.2.1. Placement

Peripherals such as CD-ROMs, floppy drives, and hard drives can be placed to take advantage of the 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 vents if they are downstream of the processor to minimize temperature rise.

6.2.2. Power

Some types of drives, such as a floppy drive, do not dissipate much heat, while others (read/write CD-ROMs, hard drives) dissipate a great deal of heat. These hotter components should be placed near fans or vents 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.

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7. Thermal Metrology for FC-PGA2 Packaged Processors

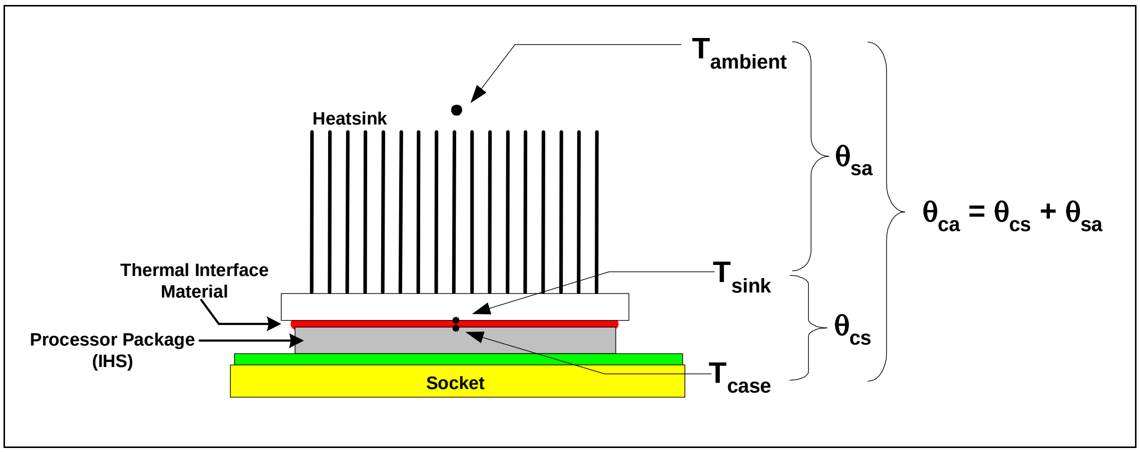
The following sections will discuss the thermal metrology used on the FC-PGA2 packaged processors. These techniques should be followed to evaluate thermal performance of proposed solutions. Carefully read the following instructions and interpretation steps to validate your cooling solution.

7.1. Thermal Resistance

The thermal resistance value from case to local-ambient (θ_{CA}) for a FC-PGA2 package 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 case to local-ambient, θ_{CA}, is comprised of the case-to-sink thermal resistance (θ_{CS}), and the sink to local-ambient thermal resistance (θ_{SA}) (see Figure 7-1). The θ_{CS} value is strongly dependent on the thermal conductivity and thickness of the TIM between the heatsink and surface of the processor.

θ_{SA} is a measure of the thermal resistance from the bottom of the heatsink cooling solution to the local-ambient air. θ_{SA} is dependent on the heatsink's material, thermal conductivity, and geometry, and is strongly dependent on the air velocity through the fins of the heatsink.

Figure 7-1. Processor-Heatsink Thermal Resistance Relationships



The thermal parameters are related by the following equations:

Equation 1. Case to Ambient Thermal Resistance

$$\theta_{CA} = (T_{CASE} - T_{LA}) / TDP$$

Equation 2. Case to Ambient Thermal Resistance

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

Where:

θ_{CA}	=	thermal resistance from case to local-ambient (°C/W)
T_{CASE}	=	processor case temperature (°C)
T_{LA}	=	local-ambient temperature in chassis around processor (°C)
TDP	=	processor Thermal Design Power dissipation (W) (assume all power goes to the case)
θ_{CS}	=	case-to-sink thermal resistance (°C/W)
θ_{SA}	=	sink to local-ambient thermal resistance (°C/W)

7.2. Thermal Solution Performance

All processor thermal solutions interface to the processor at the IHS. The system thermal solution must adequately control the local-ambient air around the processor (T_{LA}). The lower the thermal resistance between the processor and the local-ambient air, the more efficient the thermal solution is. The required θ_{CA} is dependent upon the maximum allowed processor temperature (T_{CASE}), the local-ambient temperature (T_{LA}) and the processor thermal design power (TDP). For actual specifications on FC-PGA2 packaged processors, refer to the processor datasheet.

Use Equation 1 and Equation 2 (*above*) to determine a target θ_{CA} and θ_{SA} using the following assumptions.

T_{CASE}	=	67 °C, hypothetical maximum case temperature specification
T_{LA}	=	Assume 45°C, a typical value for desktop systems
TDP	=	Assume 30 W, hypothetical thermal design power
θ_{CS}	=	Assume 0.15 °C/W, hypothetical TIM resistance

Solving for the equation 1 from above:

$$\theta_{CA} = (T_{CASE} - T_{LA}) / TDP$$
$$= (67 – 45) / 30$$
$$= 0.73 \text{ °C/W}$$

Solving for equation 2 from above:

$$\theta_{CA} = \theta_{CS} + \theta_{SA}$$
$$\theta_{SA} = \theta_{CA} - \theta_{CS}$$
$$= 0.73 – 0.15$$
$$= 0.58 \text{ °C/W}$$

7.3. Local-ambient Temperature Measurement Guidelines

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

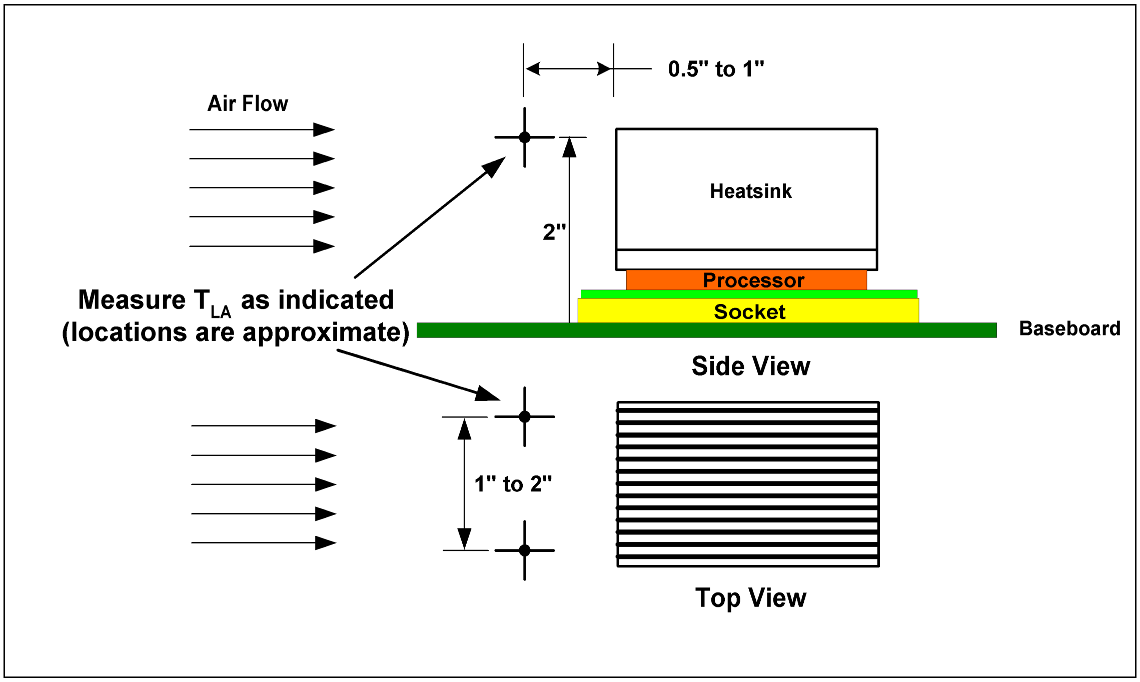
It is worthwhile to determine the local-ambient temperature in the chassis around the processor to better understand the effect it may have on the case temperature.

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.

7.3.1. Local-ambient Temperature Measurement for a Passive Heatsink

- During system thermal testing, a minimum of two thermocouples should be placed approximately 0.5 to 1.0 inches (12.7 to 25.4 mm) away from the leading edge of the heatsink fins as shown in Figure 7-2. The two thermocouples should be placed 2.0 (50.8 mm) inches apart (see top view in Figure 7-2). 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 (50.8 mm) above the baseboard. This placement guideline is meant to minimize localized hot spots from baseboard components.
- T_{LA} should be the average of the thermocouple measurements during system thermal testing.

Figure 7-2. Local-ambient Thermocouple Measurement Locations (Passive Heatsink)

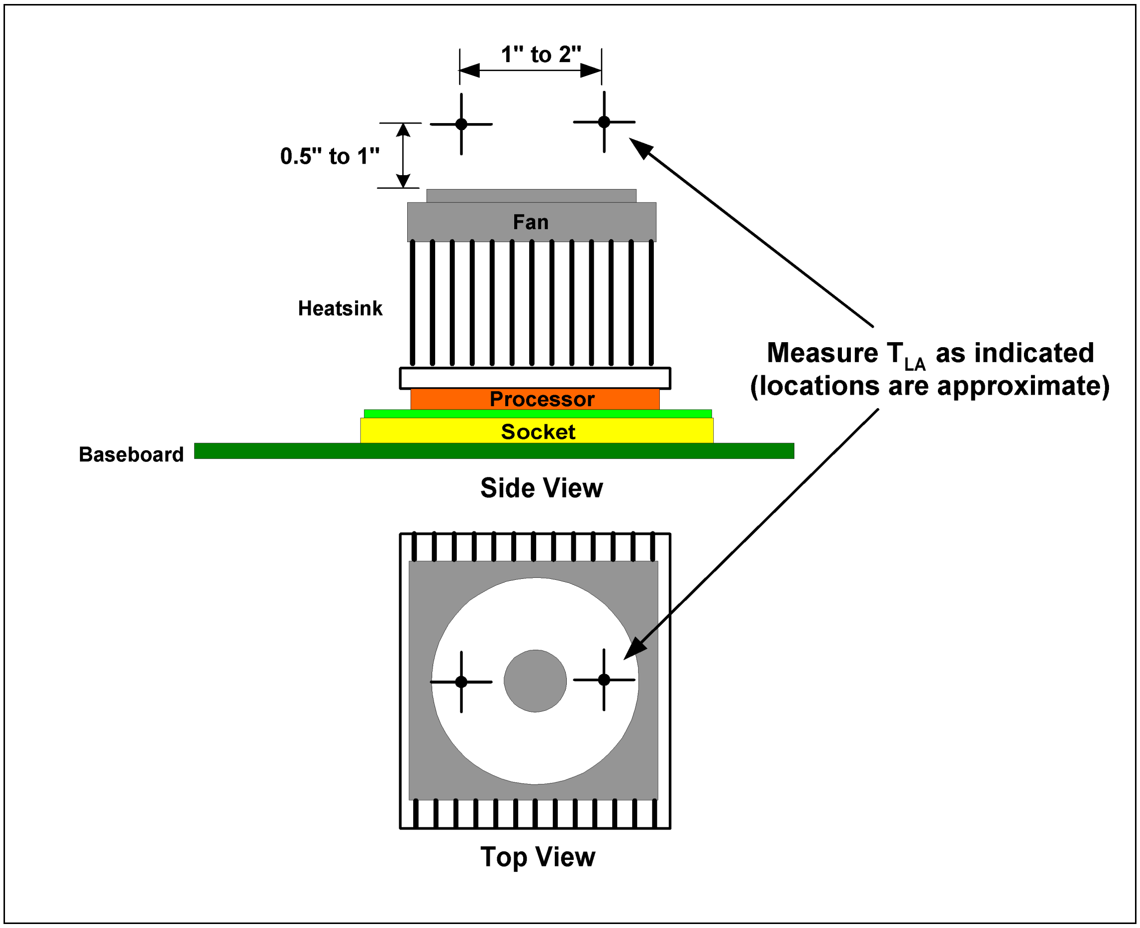


Note: Figure is not to scale. Locations are approximate and may vary depending on your system configuration.

7.3.2. Local-ambient Temperature Measurement for an Active Heatsink

- During system thermal testing, a minimum of two thermocouples should be placed approximately 0.5 to 1.0 inches (12.7 to 25.4 mm) above the fan inlet as shown in Figure 7-3. The two thermocouples should be placed 1.0 to 2.0 (25.4 to 50.8 mm) inches apart. This placement guideline is meant to minimize localized hot spots due to the processor, heatsink, or other system components.
- The thermocouples should be centered relative to the fan and heatsink (see top view in Figure 7-3).
- T_{LA} should be the average of the thermocouple measurements during system thermal testing.

Figure 7-3. Local-ambient Thermocouple Measurement Locations (Active Heatsink)



Note: Figure is not to scale. Locations are approximate and may vary depending on your system configuration.

7.4. Processor Measurements for Thermal Specifications

Temperature measurements must be made to accurately determine processor thermal performance. Guidelines have been established for proper techniques for measuring processor temperatures. The following sections describe these guidelines for temperature measurement.

7.4.1. Processor Case Temperature Measurements

To ensure functionality and reliability, the FC-PGA2 packaged processors are specified for proper operation when T_{CASE} is maintained at or below the value listed in their respective processor datasheets. The measurement location for T_{CASE} is the geometric center of the IHS. Figure 7-4 shows the location for T_{CASE} measurement.

Special care is required when measuring the T_{CASE} to ensure an accurate temperature measurement. Thermocouples are often used to measure T_{CASE} and should be calibrated before any temperature measurements are made. 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 integrated heat spreader, 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:

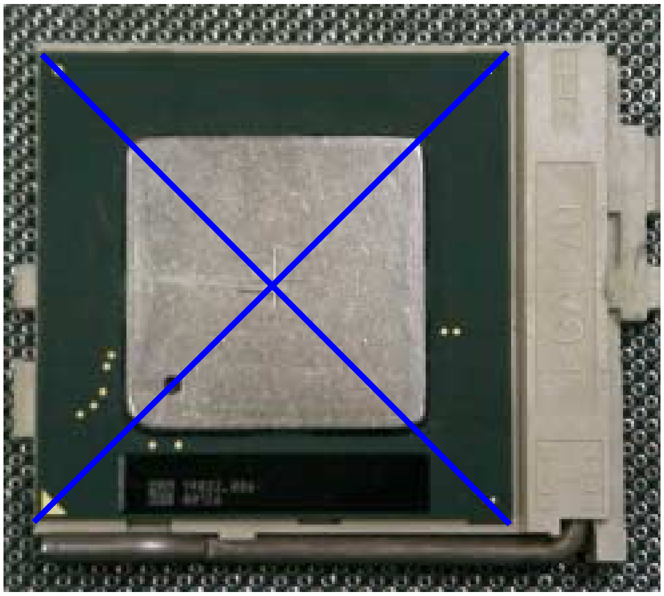
1. Obtain the necessary items needed for the quantity of thermocouple attachments and samples desired. A list of necessary items is shown in Table 7-1.

Table 7-1. List of Items for Thermocouple Attach

FC-PGA2 Packaged Processor
Modified heatsink (see section 7.4.1.1)
Fine point tweezers
Thermocouples (Type K, 36 gauge, 36 inch, Teflon* insulation)
Ex-acto* knife (#11 blade)
3M* Kapton* tape cut into strips (1/8" X ½")
Epoxy cement

2. Use a scribe to mark the geometric center on the topside of the IHS package. This represents the location where the bead of the thermocouple will be placed. The center of the package can be obtained by measurement, or by drawing two diagonal lines across the length of the package. The cross-point will be the geometric center of the package (see Figure 7-4).

Figure 7-4. Locating Geometric Center of Processor

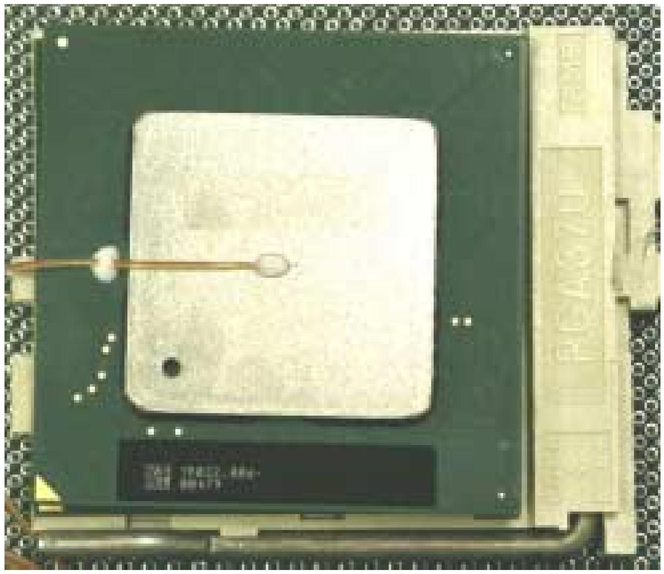


3. After the marks are scribed, clean the desired thermocouple attach location with a mild solvent and a lint-free wipe or cloth. Alcohol or acetone should suffice. Remember that the cleaner the part is, the stronger the bond will be after curing.
4. Straighten the thermocouple wire by hand so that the first 4-6 inches are reasonably straight. Use fine point tweezers to make sure that the bead and the two wires coming out are straight and untwisted. Make sure that the second layer of thermocouple insulation, sometimes clear, is not covering the bead.
5. Create a slight downward bend in the wires about a 1/16” from the bead. Once the thermocouple is in place, this will ensure that the thermocouple is making contact with the surface.
6. Place the thermocouple bead on the geometric center of the IHS (previously scribed). Apply tape across the wire about ¼” back from the bead to hold the thermocouple in place. Apply pressure to the tape to ensure a good bond. Apply additional tape pieces along the length of the wire to ensure a good temporary bond to the part (see Figure 7-5). Check the electrical continuity between the thermocouple and the IHS using a multimeter. If there is no electrical continuity between the thermocouple and the IHS, repeat steps 4 through 6.

Figure 7-5. Thermocouple Preparation

7. With the thermocouple in place, the epoxy can now be mixed and applied. Follow the manufacturer's directions for mixing the epoxy.
8. Use a clean, finely pointed applicator to apply the epoxy to the bead. Dab the epoxy bond on the bead and the exposed wires. Use only the appropriate amount of glue to cement the thermocouple down. The entire bead should be submerged and it is best to have insulated wires protruding from the glue (see Figure 7-6).
9. Additional beads of epoxy can be added, off of the IHS surface, along the length of wire to provide additional attachment for the thermocouple wire. Only one bead should be on the IHS surface.

Figure 7-6. Thermocouple Adhesive Placement



10. To cure the epoxy, put the part(s) in an oven set @ 150°F (65°C) for a period of 1 hour. Make sure the vibration in the oven is minimal to prevent the thermocouple bead from moving. Another alternative is to cure the epoxy at room temperature for at least 12 hours. (Some epoxy may have different cure times. Refer to the manufacturer's instructions.)
11. Once the epoxy has cured, remove all tape and check for any residual epoxy outside the thermocouple attach area on the IHS. Run the tip of your finger around the IHS surface to find any small glue dots. Remove any residual glue to prevent any impact on bond line or heatsink attach.
12. Verify the cured adhesive bead at the IHS center is smaller than 0.15 inches (3.8mm) in diameter and 0.025 inches (0.63mm) in height so as to fit in the hole drilled in the heatsink base. Trim as necessary.
13. Check the electrical continuity between the thermocouple and the IHS again. If there is no electrical continuity between the thermocouple and the IHS, repeat steps 4 through 12.
14. Place the TIM on the heatsink base. If it is a semi-liquid type apply it on the IHS around the thermocouple. The clamping force will spread the TIM. If the TIM is a solid type, punch a 0.15 inch (3.8mm) diameter hole in the center of the TIM pad and cut a line from a side to the hole. This will allow the installation of the TIM to the IHS with the thermocouple already attached to the IHS.

7.4.1.1. Heatsink Preparation

In order to measure the case temperature as accurately as possibly, the heatsink must be modified to allow for the thermocouple wires and attach points. Depending on the chosen solution the dimensions may vary. It is imperative that the modifications made to the heatsink align to the location of the thermocouple wires and attach point when properly installed. Any discrepancy will cause the heatsink to not sit properly on the IHS surface and provide erroneous data. Figure 7-7 shows the modification on a typical heatsink base. Figure 7-8 shows the groove dimensions required to route a thermocouple to the center of the heatsink without interfering the IHS to heatsink attachment. The depth for the entire groove including the circle area is 0.025 in (0.63 mm). The groove should be 0.04 in (1.0 mm) wide. It must be noted that the center of the circle area needs to be located 0.05 in (1.3 mm) off center from the location corresponding to the thermocouple bead. This is because the epoxy covers both the bead and the exposed thermocouple wires so that the circle area needs to accommodate the whole epoxy location. It is left to the designer to perform the appropriate tolerance stack-up and to define the placement dimensioning for a specific heatsink design.

Figure 7-7. Example of Machined Heatsink with Thermocouple Groove

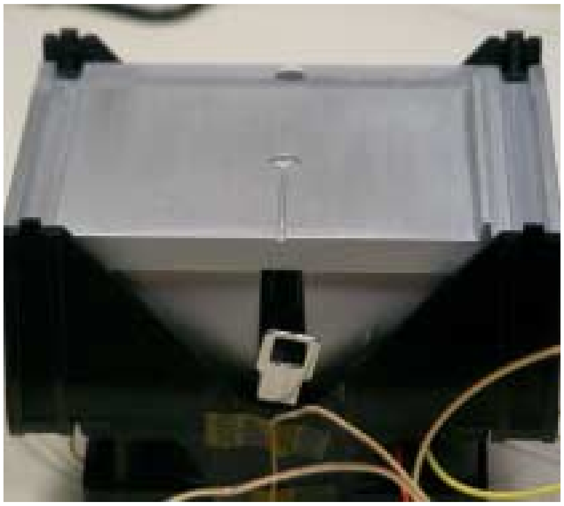
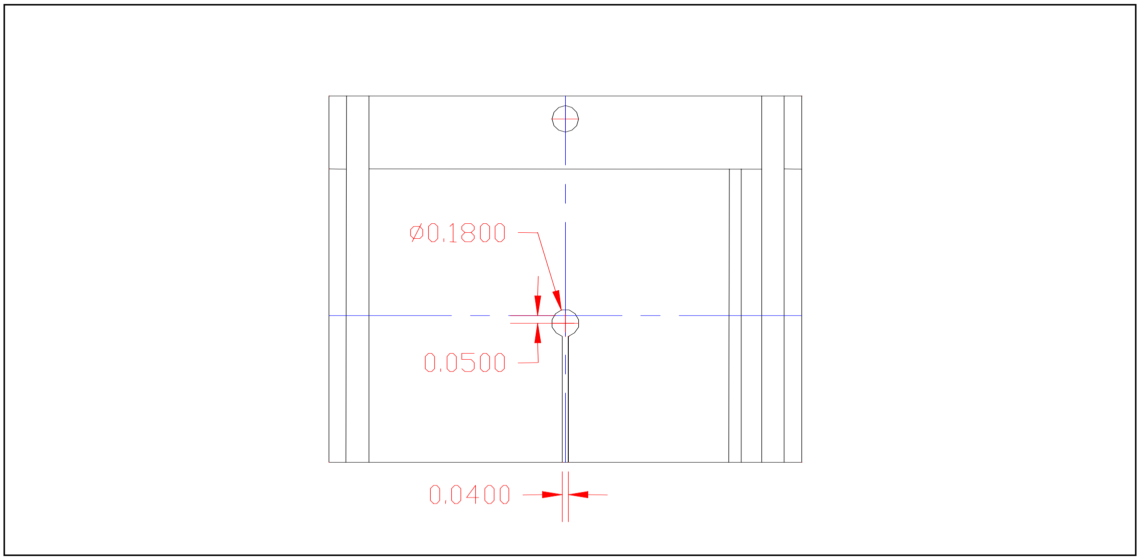


Figure 7-8. Example of Dimensioning for Thermocouple Groove



Note: Dimensions are in inches. Centerlines in drawing correspond to the thermocouple location (geometric center of IHS).

7.4.2. About the High Power Application

The High Power Application software (a.k.a. "HIPWR30.EXE" or "HIPWRMP2.EXE") is intended for thermal evaluation purposes only. This software is not a general-purpose application. The software may not generate the absolute worst-case thermal power dissipation as defined in the processor datasheets. Differences between the observed thermal power measurements and the maximum power dissipation indicated in the datasheets can be attributed to processor manufacturing process variation, system voltage regulation configuration differences, and potential High Power Application software optimizations. This software does provide system designers with an application that will power a processor to very near the TDP identified in the processor datasheets and is intended to be a tool for the analysis and validation of system cooling solutions.

All systems should be designed with the ability to dissipate the thermal design power (TDP) indicated in the datasheets. The High Power Application software, utilizing the methodologies presented in this document, can enable system designers to design and validate robust cooling solutions that can adequately cool the processor at the maximum specifications.

The High Power Application software maximizes the current consumption of the processor core. All execution stages and various functional units of the core and L1 cache are fully utilized. The software performs minimal system bus accesses, with minimal L2 cache utilization. This mode of operation produces a large amount of thermal power from the processor.

Contact your Intel Field Sales representative to obtain a copy of the software.

7.4.3. Executing the High Power Application Software

The High Power Application software is a 32 bit Windows NT* or Windows* 95/98 application. The application should be executed from a DOS window command prompt from within the Windows NT or

Windows 95/98 environment, and not from a DOS only environment. The High Power Application software puts the processor into an infinite loop and locks the command prompt environment. The "HIPWR30.EXE" and "HIPWRMP2.EXE" utilities have an on-screen message with version number information and usage help. To halt execution of the application, use the Windows NT Task Manager or Windows 95/98 Task Bar to stop execution of the command prompt environment. For maximum processor power consumption, the software should be the only application executing on the system under evaluation. It is recommended that the Windows NT or Windows 95/98 operating environment be configured to the default OS settings.

8. 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 thermal solutions can be achieved through the use of ducting.

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 an FC-PGA2 packaged processor based system. Properly designed solutions provide adequate cooling to keep the processor within thermal specifications. This is accomplished by providing a low local-ambient temperature and creating a minimal thermal resistance between the processor core and the local-ambient airflow. Active fan heatsinks or ducting can be used to cool the processor(s) if proper case and package temperatures cannot be maintained otherwise. By maintaining the processor's case temperature at or below the values specified in the processor datasheet, a system can guarantee proper functionality and reliability of these processors.