Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Thermal Design Guidelines

Design Guide

Supporting the Intel® Pentium® 4 Processor with Hyper-Threading Technology[1]

November 2002

Document Number: 252161-001

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1 Introduction

1.1 Document Goals and Scope

1.1.1 Importance of Thermal Management

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

In a system environment, the processor temperature is a function of both system and component thermal characteristics. The system level thermal constraints consist of the local ambient air temperature and airflow over the processor as well as the physical constraints at and above the processor. The processor temperature depends in particular on the component power dissipation, the processor package thermal characteristics, and the processor thermal cooling solution.

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

1.1.2 Document Goals

The thermal power of the Intel® Pentium® 4 processor with 512-KB L2 cache on 0.13 micron process is higher, as well as denser, than previous Intel architecture processors. Depending on the type of system and the chassis characteristics, new system designs may be required to provide adequate cooling for the processor. The goal of this document is to provide an understanding of these thermal characteristics and discuss guidelines for meeting the thermal requirements imposed on single processor systems for the entire life of the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process

1.1.3 Document Scope

Chapters 2 and 3 of this document discusses thermal solution design requirements for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process. Chapter 3 includes thermal metrology recommendations to validate a processor cooling solution; it also addresses the benefits of the processor integrated thermal management logic on thermal design.

Chapter 4 provides information on the Intel reference cooling solution for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process that covers the entire life of the processor. This section focuses on the reference solution that has been developed to support the end of life of the processor.

The physical dimensions and thermal specifications of the processor that may be used in this document are for illustration only. Refer to the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet* for the product dimensions, thermal power dissipation, and maximum case temperature. In case of conflict, the data in the datasheet supercedes any data in this document.

1.2 References

Material and concepts available in the following documents may be beneficial when reading this document.

Document	Document Number/ Location
Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Datasheet	http://developer.intel.com/design/pentium4/datashts/298643.htm
Intel® Pentium® 4 Processor in the 478-pin Package Datasheet	http://developer.intel.com/design/pentium4/datashts/249887.htm
Intel® Pentium® 4 Processor in the 478-pin Package / Intel® 850 Chipset Platform Family Design Guide	http://developer.intel.com/design/pentium4/guides/249888.htm
Intel® Pentium® 4 Processor in 478-pin Package and Intel® 845 Chipset Platform for SDR Platform Design Guide	http://developer.intel.com/design/chipsets/designex/298354.htm
Intel® Pentium® 4 Processor in the 478-Pin Package Thermal Design Guidelines	http://developer.intel.com/design/pentium4/guides/249889.htm
Intel® Pentium® 4 Processor 478-Pin Socket (mPGA478B) Design Guidelines	http://developer.intel.com/design/pentium4/guides/249890.htm
Mechanical Enabling for the Intel® Pentium® 4 in the 478-Pin Package	http://developer.intel.com/design/pentium4/guides/290728.htm
Performance ATX Desktop System Thermal Design Suggestions	http://www.formfactors.org/
Performance microATX Desktop System Thermal Design Suggestions	http://www.formfactors.org/

1.3 Definition of Terms

Term	Description
T_A	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.
T_E	The ambient air temperature external to a system chassis. This temperature is usually measured at the chassis air inlets.
T_C	The case temperature of the processor, measured at the geometric center of the topside of the IHS.
T_S	The heatsink temperature generally measured at the geometric center of the bottom surface of a heatsink base.
$T_{C\text{-}MAX}$	The maximum case temperature as specified in a component specification.
Ψ_{CA}	Case-to-ambient thermal characterization parameter (Psi). A measure of thermal solution performance using total package power. Defined as $(T_C - T_A)$ / Total Package Power. Heat source should always be specified for Ψ measurements.
Ψ_{CS}	Case-to-sink thermal characterization parameter. A measure of thermal interface material performance using total package power. Defined as $(T_C - T_S)$ / Total Package Power.
Ψ_{SA}	Sink-to-ambient thermal characterization parameter. A measure of heatsink thermal performance using total package power. Defined as $(T_S - T_A)$ / Total Package Power.
Θ_{CA}	Case-to-ambient thermal resistance (theta). Defined as $(T_C - T_A)$ / Power dissipated from case to ambient.
Θ_{CS}	Case-to-sink thermal resistance. Defined as $(T_C - T_S)$ / Power dissipated from case to sink.
Θ_{SA}	Sink-to-ambient thermal resistance. Defined as $(T_S - T_A)$ / Power dissipated from sink to ambient.
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 transfer of the heat from the processor case to the heatsink.
P_{MAX}	The maximum power dissipated by a semiconductor component.
TDP	Thermal Design Power: a power dissipation target based on worst-case applications. Thermal solutions should be designed to dissipate the thermal design power.
IHS	Integrated Heat Spreader: a thermally conductive lid integrated into a processor package to improve heat transfer to a thermal solution through heat spreading.
mPGA478 Socket	The surface mount, Zero Insertion Force (ZIF) socket designed to accept the Intel® Pentium® 4 processor with 512-KB L2 cache on 0.13 micron process.
ACPI	Advanced Configuration and Power Interface.
Bypass	Bypass is the area between a passive heatsink 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.
Thermal Monitor	A feature on the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process that can keep the processor's die temperature within factory specifications under nearly all conditions.
TCC	Thermal Control Circuit: Thermal Monitor uses the TCC to reduce die temperature by lowering effective processor frequency when the die temperature is very near its operating limits.

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2 Mechanical Requirements

2.1.1 Processor Package

The Pentium 4 processor with 512-KB L2 cache on 0.13 micron process is packaged in a Flip-Chip Pin Grid Array 2 (FC-PGA2) package technology and often referred as the 478-pin package. Refer to the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet* for detailed mechanical specifications.

The package includes an integrated heat spreader (IHS). The IHS spreads the non-uniform heat from the die to the top of the IHS, increasing heat uniformity and reducing the power density due to the larger surface area. This allows more efficient heat transfer from the package to an attached cooling device. The IHS is designed to be the interface for mounting a heatsink. Details can be found in the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet.*

The processor connects to the motherboard through a 478-pin surface mount, zero insertion force (ZIF) socket. A description of the socket can be found in the *Intel® Pentium® 4 Processor 478-Pin Socket (mPGA478) Design Guidelines*.

The processor package has mechanical load limits that are specified in the datasheet. These load limits should not be exceeded during heatsink installation, removal, mechanical stress testing, or standard shipping conditions. For example, when a compressive static load is necessary to ensure thermal performance of the thermal interface material between the heatsink base and the IHS (see Appendix A for more information regarding bond line management), this compressive static load should not exceed the compressive static load given in the processor datasheet.

The heatsink mass can also add additional dynamic compressive load to the package during a mechanical shock event. Amplification factors due to the impact force during shock have to be taken into account in dynamic load calculations. The total combination of dynamic and static compressive load should not exceed the processor datasheet compressive dynamic load specification during a vertical shock. For example, with a 1lbm heatsink, an acceleration of 50 g during a 11ms shock results approximately in a 100 lbf dynamic load on the processor package. If a 100 lbf static load is also applied on the heatsink for thermal performance of the thermal interface material and/or for mechanical reasons, the processor package sees 200 lbf. The calculation for the thermal solution of interest should be compared to the processor datasheet specification.

It is not recommended to use any portion of the substrate as a mechanical reference or load-bearing surface in either static or dynamic compressive load conditions.

2.1.2 Heatsink Attach

There are no features on the mPGA478 socket to directly attach a heatsink. Therefore, a mechanism must be designed to support the heatsink. In addition to holding the heatsink into place on top of the IHS, this mechanism plays a significant role in the robustness of the system in which it is implemented. In particular:

- Ensuring thermal performance of the thermal interface material used between the IHS and the heatsink. Some of these materials are very sensitive to pressure applied to them; the higher the pressure, the better the performance up to a point of diminishing return.
- Ensuring system electrical, thermal and structural integrity under shock and vibration events. The mechanical requirements of the attach mechanism depend on the mass of the heatsink and the level of shock and vibration that the system has to support. The overall structural design of the motherboard and the system has to be considered as well when designing the heatsink attach mechanism, in particular their impact on motherboard stiffening needed to protect mPGA478 socket solder joint, and prevent package pull-out from the socket.

A popular solution for heatsink attach mechanism is to use a retention mechanism and attach clips. In that case, the clips should be designed to the general guidelines given above. More particularly:

- To hold the heatsink in place under shock and vibration events and apply force to the heatsink base to maintain desired pressure on the thermal interface material. The load applied by the clip also plays a role in ensuring that the package does not disengage from the socket during mechanical shock testing. Lastly, the load applied by the clip should provide protection to surface mount components during mechanical shock. Note that the load applied by the clips must comply with the package specifications described Section 2.1.1, along with the dynamic load added by the shock and vibration requirements.
- To engage easily with the retention mechanism tabs, if possible without the use of special tools. This should also take into account that, in general, heatsink and clip are installed once the motherboard has been installed into the chassis.
- To minimize contact with the motherboard surface during clip attach to the retention mechanism tab features; the clip should not scratch or otherwise damage the motherboard.

The Intel Reference design is using such a retention mechanism and clip assembly. Refer to Chapter 4 and the document *Mechanical Enabling for the Intel® Pentium® 4 in the 478-Pin Package* for further information regarding the Intel Reference mechanical solution.

3 Thermal Specifications

3.1 Processor Case Temperature and Power Dissipation

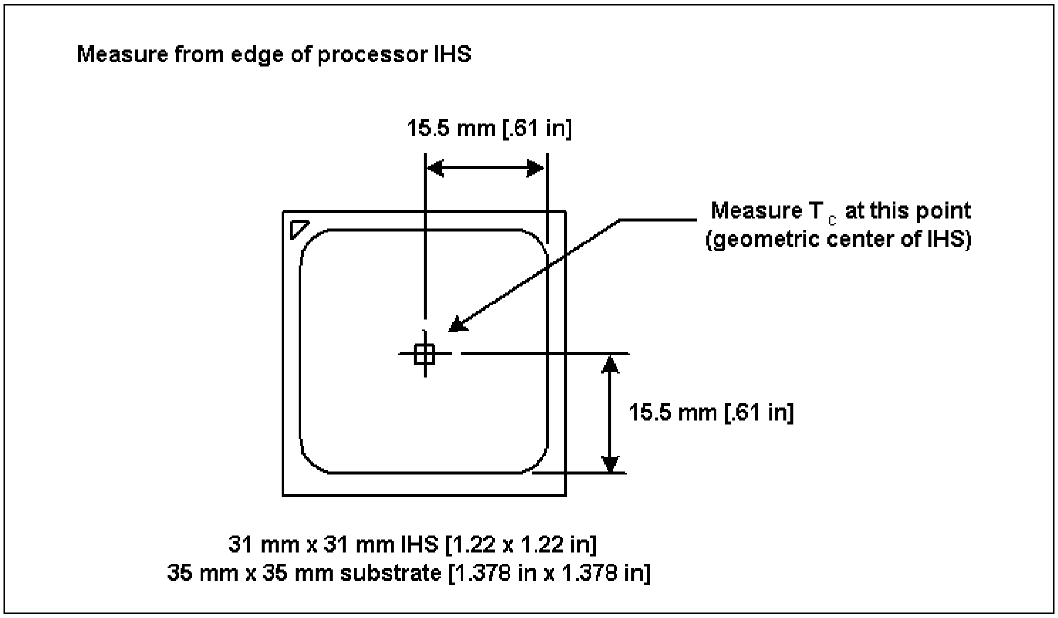
Refer to the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet* for processor thermal specifications.

Thermal specifications for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process are given in terms of maximum case temperature specification and thermal design power (TDP). These values may depend on the processor frequencies and also include manufacturing variations. Designing to these values allows optimizing thermal design for processor performance (refer to Section 3.4).

Processor power is dissipated through the IHS. There is no additional component (i.e., BSRAMs, which generates heat on this package).

The case temperature is defined as the temperature measured at the center of the top surface of the IHS. For illustration, the measurement location for a 35-mm x 35-mm FC-PGA2 package is shown in Figure 1. Techniques for measuring the case temperature are detailed in Section 3.3.3.

Figure 1. Processor Case Temperature Measurement Location



3.2 Designing a Cooling Solution for the Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process

3.2.1 Heatsink Design Considerations

To remove the heat from the processor, three basic parameters have to be considered:

- **The extension of the surface on which the heat exchange takes place**. Without any additional enhancements, this is the surface of the processor package IHS. One method used to improve thermal performance is to increase the surface area of the IHS by attaching a heatsink to it. Heatsinks extend the heat exchange surface through the use of fins that can be of various shapes and are attached to a heatsink base which is then in contact with the IHS.
- **The conduction path from the heat source to the heatsink fins**. Providing a direct conduction path from the heat source to the heatsink fins and selecting materials with higher thermal conductivity typically improve heatsink performance. The length, thickness, and conductivity of the conduction path from the heat source to the fins directly impact the thermal performance of the heatsink. In particular, the quality of the contact between the package IHS and the heatsink base has higher impact on the overall cooling solution performance as processor cooling requirements become stricter. Thermal interface material (TIM) can be used to fill any gaps between the IHS and the bottom surface of the heatsink, thereby improving the overall performance of the stack-up (IHS-TIM-Heatsink). Although, with extremely poor heatsink interface flatness or roughness, TIM may not adequately fill the gap. The TIM thermal performance depends on its thermal conductivity as well as the pressure load applied to it. Refer to Appendix A for further information regarding managing the bond line between the IHS and the heatsink base.
- **The heat transfer conditions on the surface on which heat transfer takes place**. Convective heat transfer occurs between the airflow and the surface exposed to the flow. It is characterized by the local ambient temperature of the air, T_A, and the local air velocity over the surface. The higher the air velocity and turbulence over the surface, and the cooler the air, the more efficient is the resulting cooling. In the case of a heatsink, the surface exposed to the flow includes the fin faces and the heatsink base.

Active heatsinks typically incorporate a fan that helps manage the airflow through the heatsink.

Passive heatsink solutions require in-depth knowledge of the airflow in the chassis. In addition, they may see lower air speeds. These heatsinks are therefore typically larger (and heavier) than active heatsinks due to the increase in fin surface area required to match thermal performance. As the heatsink fin density (the number of fins in a given cross-section) increases, the resistance to the airflow increases. It is more likely that the air will travel around the heatsink instead of through it, unless air bypass is carefully managed. Using air-ducting techniques to manage bypass are an effective method for controlling airflow through the heatsink.

3.2.1.1 Thermal Interface Material

Thermal interface material application between the processor IHS and the heatsink base is generally required to improve thermal conduction from the IHS to the heatsink. 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 should be sized and positioned on the heatsink base in a way that ensures the entire processor IHS area is covered. It is important to compensate for heatsink-to-processor attach positional alignment when selecting the proper thermal interface material size.

When pre-applied material is used, it is recommended to have a protective application tape or enclosure over it. This protective element must be removed prior to heatsink installation.

3.2.1.2 Summary

In summary, considerations in heatsink design include:

- The local ambient temperature T_A at the heatsink, the power being dissipated by the processor, and the corresponding maximum T_C at the processor frequency considered. These parameters are usually combined in a single lump cooling performance parameter, Ψ_{CA} (case to air thermal characterization parameter). More information on the definition and the use of Ψ_{CA} is given Sections 3.2.2.3 and 3.2.2.4.
- Heatsink interface (to IHS) surface characteristics, including flatness and roughness.
- The performance of the thermal interface material used between the heatsink and the IHS.
- Surface area of the heatsink.
- Heatsink material and technology.
- Volume of airflow over the heatsink surface area.
- Development of airflow entering and within the heatsink area.
- Physical volumetric constraints placed by the system.

3.2.2 Looking at the Whole Thermal Solution

3.2.2.1 Chassis Thermal Design Capabilities

Only chassis capable of T_A equal or lower than 45°C can be used for the Pentium 4 Processor with 512-KB L2 Cache on 0.13 micron process to support frequencies between 1.20 GHz thru 2.80 GHz. Chassis that do not meet this recommendation may require more sophisticated, and thus more expensive, cooling solution on the processor to compensate the lack of performance of the chassis.

It is expected that chassis thermal capabilities are improved and can deliver T_A no greater than 42°C for processor frequencies at 3.06 GHz or higher. Refer to Section 3.2.2.2 below for further information.

3.2.2.2 Improving Chassis Thermal Performance

The heat generated by components within the chassis must be removed to provide an adequate operating environment for both the processor and other system components. Moving air through the chassis brings in air from the external ambient environment and transports the heat generated by the processor and other system components out of the system. The number, size and relative position of fans and vents have a decisive impact on the chassis thermal performance, and therefore on the ambient temperature around the processor. The size and type (passive or active) of the thermal cooling device and the amount of system airflow are related and can be traded off against each other to meet specific system design constraints. Additional constraints are board layout, spacing, component placement, and structural considerations that limit the thermal solution size. For more information, refer to the *Performance ATX Desktop System Thermal Design Suggestions* or *Performance microATX Desktop System Thermal Design Suggestions* documents available on the http://www.formfactors.org/ web site.

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.

To develop a reliable, cost-effective thermal solution, thermal characterization and simulation should be carried out at the system level, accounting for the thermal requirements of each component. In addition, acoustic noise constraints may limit the size, number, placement, and types of fans that can be used in a particular design.

To ease the burden on cooling solutions, the Thermal Monitor feature and associated logic have been integrated into the silicon of the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process. By taking advantage of the Thermal Monitor feature, system designers may reduce the cooling system cost while maintaining the processor reliability and performance goals. Implementation options and recommendations are described in Section 3.4.

3.2.2.3 Characterizing Cooling Performance Requirements

The notion of a "thermal characterization parameter" is convenient to characterize the performance needed for the cooling solution and to compare cooling solutions in identical situations. Be aware, however, of its limitation when it comes to a real design. Heat transfer is a three-dimensional phenomenon that can rarely be accurately and easily modeled by lump values.

The thermal characterization parameter value from case-to-local ambient (Ψ_{CA}) is used as a measure of the thermal performance of the overall cooling solution that is attached to the processor package. It is defined by the following equation, and measured in units of °C/W:

Equation 1

$$\Psi_{CA} = (T_C - T_A) / TPD$$

Where:

Ψ_{CA} = Thermal characterization parameter from case-to-local ambient (°C/W)
T_C = Processor case temperature (°C)
T_A = Local ambient temperature in chassis around processor (°C)
TPD = Thermal design power (W) (assume all power goes through the IHS)

The thermal characterization parameter of the processor case-to-local ambient, Ψ_{CA}, is comprised of Ψ_{CS} , the thermal interface material thermal characterization parameter, and of Ψ_{SA}, the sink-to-local ambient thermal characterization parameter:

Equation 2

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

Where:

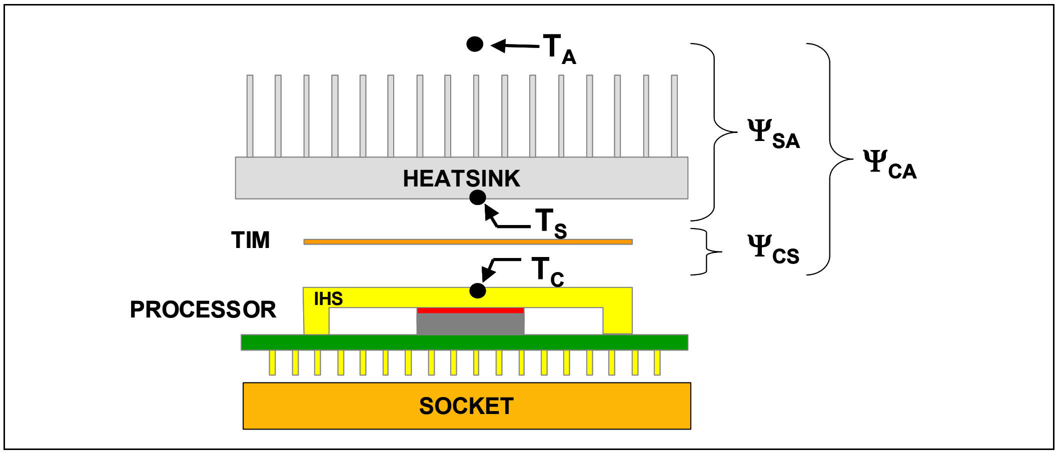
Ψ_{CS} = Thermal characterization parameter of the thermal interface material (°C/W)
Ψ_{SA} = Thermal characterization parameter from heatsink-to-local ambient (°C/W)

Ψ_{CS} is strongly dependent on the thermal conductivity and thickness of the TIM between the heatsink and IHS.

Ψ_{SA} is a measure of the thermal characterization parameter from the bottom of the heatsink to the local ambient air. Ψ_{SA} is dependent on the heat sink's material, thermal conductivity, and geometry. It is also strongly dependent on the air velocity through the fins of the heatsink.

Figure 2 illustrates the combination of the different thermal characterization parameters.

Figure 2. Processor Thermal characterization parameter Relationships



3.2.2.4 Example of Heatsink Performance Evaluation

The cooling performance Ψ_{CA} is then defined using the notion of thermal characterization parameter described above:

- Define a target case temperature $T_{C\text{-}MAX,F}$ and corresponding thermal design power TDP_F at a target frequency given in the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet.*
- Define a target local ambient temperature around the processor, T_A.

Since the processor thermal specifications ($T_{C\text{-}MAX}$ and TDP) can vary with the processor frequency, it may be important to identify the worse case (smallest Ψ_{CA}) for a targeted chassis (characterized by T_A) to establish a design strategy such that a given heatsink can meet the thermal requirements of a given range of processor frequencies.

The following provides an illustration of how one might determine the appropriate performance targets. The power and temperature numbers used here are not related to any Intel processor thermal specifications, and are given only to carry out the example.

Assume the TDP is 90W and the case temperature specification is 70 °C. Assume as well that the system airflow has been designed such that the local ambient temperature is 38°C. Then the following could be calculated using equation 1 from above:

$$\Psi_{CA} = (T_{CMAX,F} - T_A) / TDP_F = (70 - 38) / 90 = 0.36 \text{ °C/W}$$

Assuming $\Psi_{CS} = 0.08$ °C/W, solving for equation 2 from above, the performance of the heatsink itself has to be:

$$\Psi_{SA} = \Psi_{CA} - \Psi_{CS} = 0.36 - 0.08 = 0.28 \text{ °C/W}$$

3.3 Thermal Metrology for the Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process

3.3.1 Processor Cooling Solution Performance Assessment

This section discusses guidelines for testing thermal solutions, including measuring processor temperatures. In all cases, power dissipation and temperature measurements must be made to validate a cooling solution.

Thermal performance of a processor heatsink in a chassis should be assessed using a thermal test vehicle (TTV) provided by Intel (refer to Section 3.3.4). A TTV is a well-characterized thermal tool; using real parts introduces other factors that can impact test results. In particular, the power level from real processors varies significantly. This is due to part-to-part variances in the manufacturing process. The TTV provides consistent power and power density for thermal solution characterization and results can be easily translated to real processor performance. Accurate measurement of the power dissipated by a real processor is beyond the scope of this document.

Once the thermal solution and chassis are designed and validated with the TTV, it is recommended to verify functionality of the thermal solution on real processors and on fully integrated systems (see Section 3.4).

3.3.2 Local Ambient Temperature Measurement Guidelines

The local ambient temperature T_A is the temperature of the ambient air surrounding the processor. For a passive heatsink, T_A is defined as the heatsink approach air temperature; for an actively cooled heatsink, it is the temperature of inlet air to the active cooling fan.

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

T_A is best measured by averaging temperature measurements at multiple locations in the heatsink inlet airflow. This method helps reduce error and eliminate minor spatial variations in temperature. The following guidelines are meant to enable accurate determination of the localized air temperature around the processor during system thermal testing.

For **active heatsinks**, it is important to avoid taking measurement in the dead flow zone that usually develops above the fan hub. Measurements should be taken at four different locations uniformly placed at the center of the annulus formed by the fan hub and the fan housing to evaluate the uniformity of the air temperature at the fan inlet. The thermocouples should be placed approximately 2.54 mm to 7.62 mm (0.1 to 0.3 inch) above the fan hub vertically, and halfway between the fan hub and the fan housing horizontally as shown in Figure 3. Testing in an open bench environment to characterize an active heatsink can be useful, and usually ensures more uniform temperatures at the fan inlet. However, additional tests that include a barrier above the test motherboard surface can help evaluate the potential impact of the chassis. This barrier is typically clear Plexiglas*, extending at least 4 inches in all directions beyond the edge of the thermal solution. Typical distance from the motherboard to the barrier is 81mm [3.2in]. For even more realistic airflow, the motherboard should be fully populated with significant elements like memory cards, AGP card, chipset heatsink, and hard drive(s). If a barrier is used, the thermocouple can be taped directly to the barrier at the horizontal locations as previously described, half way between the fan hub and the fan housing. If a variable speed fan is used, it may be useful to add a thermocouple taped to the barrier above the location of the temperature sensor used by the fan to check its speed setting against air temperature. When measuring T_A directly in a chassis with a live motherboard, add-in cards and the other system components, it is likely that T_A shows as highly non-uniform across the inlet fan section.

For **passive heatsinks**, thermocouples should be placed approximately 12.7 mm to 25.4 mm (0.5 to 1.0 inches) away from processor heatsink as shown in Figure 4. The thermocouples should be placed approximately 50.8 mm (2 inches) above the baseboard. This placement guideline is meant to minimize the effect of localized hot spots from baseboard components.

Figure 3. Guideline Locations for Measuring Local Ambient Temperature for an Active Heatsink (not to scale)

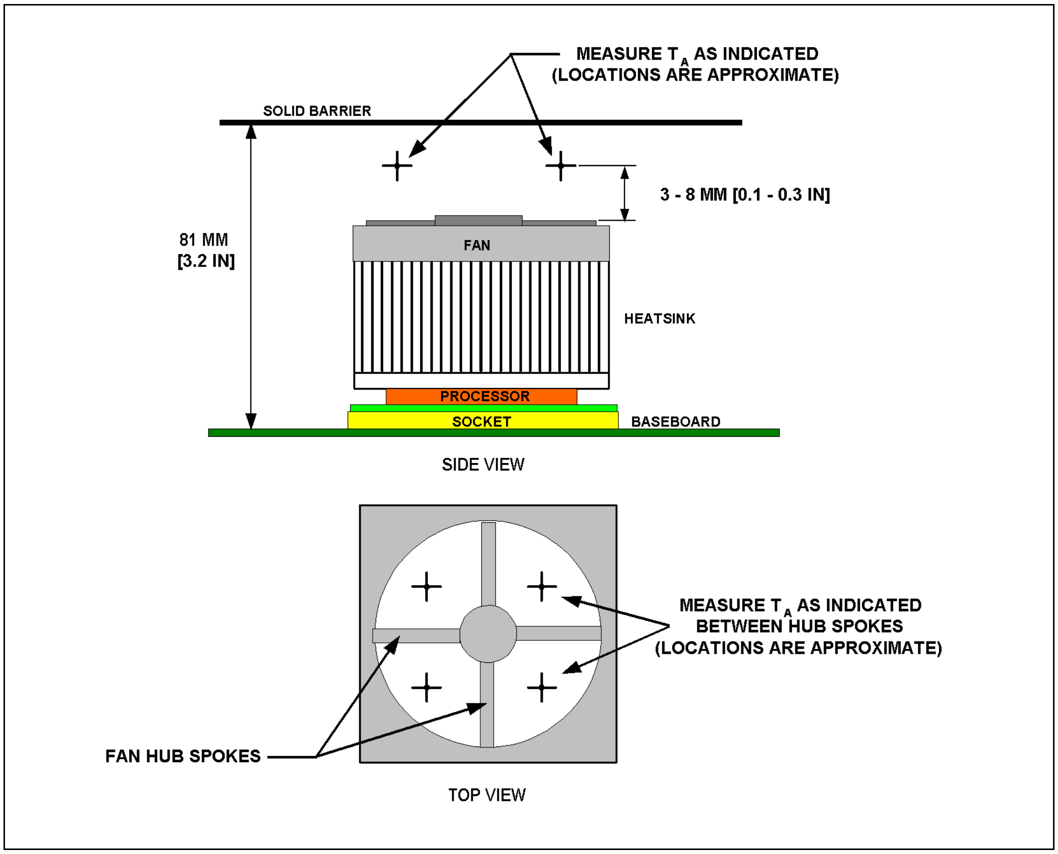
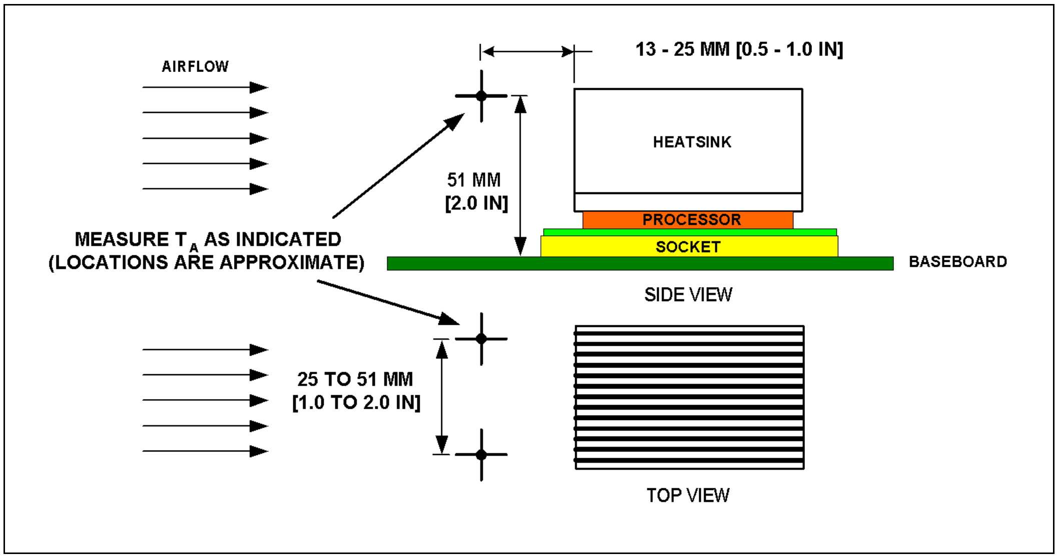


Figure 4. Guideline Locations for Measuring Local Ambient Temperature for a Passive Heatsink (not to scale)



3.3.3 Processor Case Temperature Measurement Guidelines

To ensure functionality and reliability, the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process is specified for proper operation when T_C is maintained at or below the value listed in the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet*. The measurement location for T_C is the geometric center of the IHS. Figure 1 shows the location for T_C measurement.

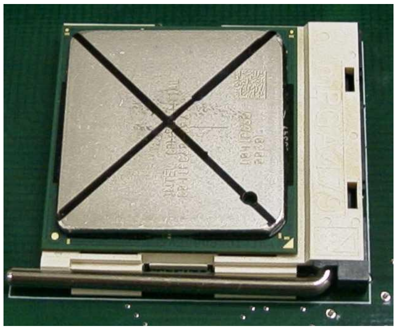
Special care is required when measuring T_C to ensure an accurate temperature measurement. When measuring the temperature of a surface, which is at a different temperature from the surrounding local ambient air, errors could be introduced in the measurements. The measurement errors could be caused by poor thermal contact between the thermocouple junction and the surface of the integrated heat spreader, heat loss by radiation or convection, by conduction through thermocouple leads, or by contact between the thermocouple cement and the heatsink base. To minimize these measurement errors, the approach outlined in the next section is recommended.

3.3.3.1 Thermocouple Attachment

Thermocouples are often used to measure T_C. Before any temperature measurements are made, the thermocouples must be calibrated. This section describes the procedure for attaching a thermocouple to the IHS for the case temperature (T_C) measurement.

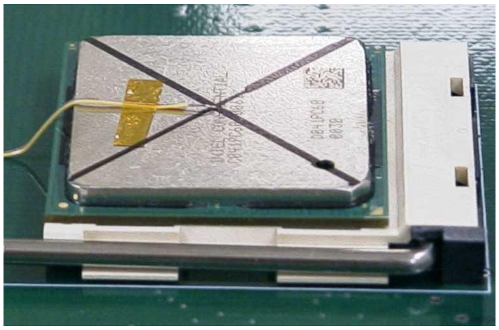
1. Obtain the necessary items needed for the quantity of thermocouple attaches desired:
    - Fine point tweezers
    - Exacto* knife (#11 blade)
    - Thermocouples (Type K, 36 gauge, 36 inch, Teflon* insulation). Ensure that the thermocouple has been properly calibrated
    - 3M* Kapton* tape (or equivalent) cut into strips (1/8 inch X ½ inch)
    - Epoxy (Omegabond* 101 or equivalent)
    - Curing oven or equivalent.
2. Use a scribe to mark at the center of the package (IHS side) where the bead of the thermocouple will be placed. Determine the center of the package by drawing two diagonal lines across the length of the package. The intersection of the two lines is the package center. (See Figure 5).

Figure 5. Desired Thermocouple Location



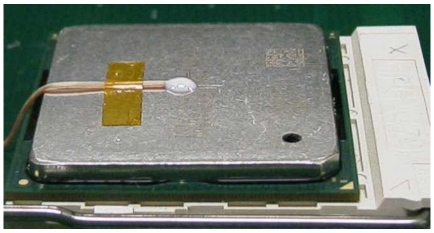
3. After the marks are scribed, clean the desired thermocouple attach location with a mild solvent and a lint-free wipe or cloth. Alcohol or acetone should suffice. Cleanliness of the part is critical for a strong epoxy bond after curing.
4. With thermocouple (T/C) in hand, locate the junction and straighten the wire by hand so that the first 4–6 inches are reasonably straight. Use the fine point tweezers to ensure that the bead and the two protruding wires are straight and untwisted. Ensure the second layer of thermocouple insulation, sometimes clear, is not covering the bead.
5. Place a slight downward bend (~30°) in the protruding wires approximately 1/16 inch from junction using the tweezers. This aids the user in ensuring the thermocouple junction contacts the heat spreader surface.
6. Place the thermocouple on the surface of the part so the bead is contacting the IHS at the desired location. Hold the T/C with one hand and use a pair of tweezers to apply a cut piece of Kapton* tape across the wire approximately about ¼ inch back from the bead. Apply pressure to the tape to ensure a good bond. Apply additional Kapton tape along the length of the wire to ensure a good temporary bond to the part. (See following Figure 6). **Check for electrical continuity between the thermocouple and the IHS using a multimeter**. If there is no electrical continuity between the thermocouple and the IHS, remove the thermocouple and repeat Steps 4–6.

Figure 6. Location of Kapton* Tape for Temporary Bond



7. With the thermocouple temporarily held to the part, apply epoxy to the thermocouple bead for a permanent bond. If applying Omegabond 101 epoxy, a small piece of paper works well for mixing. Follow the manufacturer's instructions for mixing.
8. Use the Exacto* knife or similar to apply the epoxy to the thermocouple bead. Dab glue on the bead and the exposed wires. Use only the appropriate amount of epoxy to cement the thermocouple to the IHS. Excess epoxy will prevent the heatsink from mating flush with the IHS. The entire bead should be submerged and it is best to have insulated wires protruding from the epoxy. (See following Figure 7).

Figure 7. Thermocouple Bead Covered with Epoxy



9. Add other tack-downs of epoxy along the length of wire to provide strain relief for the thermocouple wire. Remove any small epoxy dots or lines that have been accidentally added after the epoxy cures.
10. Follow the epoxy manufacturer's instructions for curing the epoxy. If an oven is used for curing the epoxy, ensure the vibration in the oven is minimal to prevent the thermocouple bead from moving and losing intimate contact with the IHS.
11. Once the epoxy has cured, remove all tape and check for any epoxy residual outside the thermocouple attach area. Run the tip of your finger around the IHS surface to find any small epoxy dots. Remove the non-necessary epoxy residual completely so it does not impact heatsink to IHS mating surface. Clean the IHS surface after conducting this finger test.
12. **Check for electrical continuity between the thermocouple and the IHS again**. If there is no electrical continuity between the thermocouple and the IHS, repeat Steps 4–12.

3.3.3.2 Heatsink Preparation – Rectangular (Cartesian) Geometry

To measure the case temperature, a heatsink must be mounted on the processor or TTV to dissipate the heat to the environment. The heatsink base must be grooved to allow a thermocouple to be routed from the center of the heatsink without altering the IHS for heatsink attachment. The groove in the heatsink has two features. The first is a 4.5 mm (0.180 inch) diameter relief for the thermocouple bead and surrounding epoxy. The second feature is a 1.0 mm (0.040 inch) wide groove that allows the thermocouple wire to be routed to the edge of the IHS/heatsink assembly. The relief and wire routing groove should be shallow enough to avoid significant impact on heatsink performance, while minimizing interference between thermocouple and the heatsink base. Groove depth should be 0.6 to 1.0 mm maximum (0.025 to 0.040 inches). Notice the center of the thermocouple bead relief is located 1.3 mm (0.050 inches) from the centerline of the heatsink. An example of a grooved heatsink base is shown in Figure 8. It must be noted that the center of the circle area needs to be located 1.3 mm (0.05 inches) off center from the location corresponding to the thermocouple bead at the center of the IHS. This offset accommodates the bead of epoxy that covers both the thermocouple and thermocouple wires.

Figure 8. Grooved Heatsink Bottom

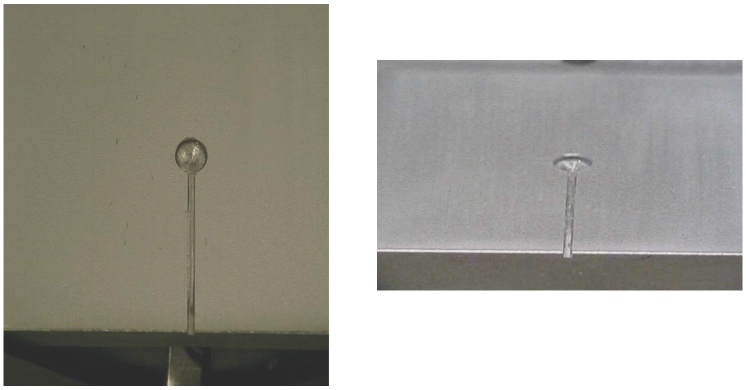
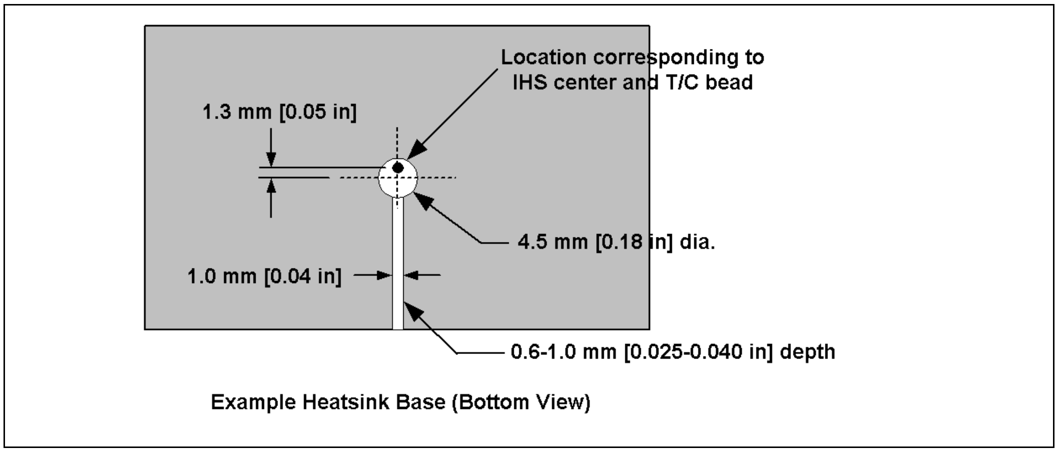


Figure 9. Heatsink Bottom Groove Dimensions



NOTES:

1. Applies to rectangular or cylindrical heatsink base
2. The groove depth (including the circle area) is 0.6 to 1.0 mm (0.025 to 0.040 inches)

3.3.3.3 Heatsink Preparation – Radial (Cylindrical) Geometry

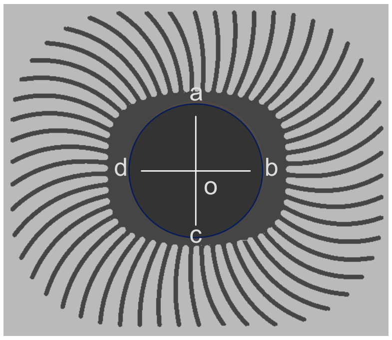
For some heatsinks that have a radial geometry (see Figure 10), it may be necessary to locate the center of the heatsink using features in the fin pattern.

For example, the 62-fin radial heatsink of the Intel reference design for the Pentium 4 processor in the 478-pin package described in the note below, requires the following procedure:

1. Identify fin gap (a) as shown in Figure 10.
2. Count ¼ of the total amount of fin gaps in clockwise direction; identify fin gap (b).
3. Repeat for fin gap (c) and fin gap (d).
4. Scribe lines (a-c) and (b-d) across the core area of the radial heatsink.
5. Locate heatsink center at the intersection of lines (a-c) and (b-d).
6. Machine a groove 1 mm (0.040 inches) wide, 0.6 mm (0.025 inches) deep along line (o-a).
7. Locate the center for the circle area 1.3 mm (0.050 inches) off the heatsink centerline, along line (o-a).
8. Machine the circle area 4.5 mm (0.180 inches) diameter, 0.6 mm (0.025 inches) deep to accommodate the thermocouple and epoxy bead.

Note: This procedure takes into account the fact that the center of the IHS and the center of the heatsink coincide for this particular design.

Figure 10. Radial Heatsink Geometry



3.3.3.4 Thermal Measurement

1. Attach a thermocouple at the center of the package (IHS-side) using the proper thermocouple attach procedure (refer to Section 3.3.3.1).
2. Connect the thermocouple to a thermocouple meter.
3. Mill groove on heatsink base (refer to Section 3.3.3.2 or to Section 3.3.3.3).
4. Apply thermal interface material to either IHS top surface or on the surface of heatsink base.
5. Mount the heatsink to the processor package with the intended heatsink attach clip and all relevant mechanical interface components (e.g., retention mechanism, processor EMI attenuation solutions, etc.).
6. Refer to Section 3.3.2 to setup the thermocouples used for T_A measurement, and connect them to a thermocouple meter.
7. Depending on the overall experimental setup, the time needed to have stable thermal conditions may vary. T_A and T_C measurements are valid once constant (refer to Section 3.3.4.4 for application to the thermal test vehicle).

Note: This methodology requires special care when assembling the grooved heatsink to the top of the IHS with the thermocouple attached. Mismatch between the heatsink groove and the thermocouple wires and bead may lead to inaccurate measurements, and even thermocouple damage, in particular when compressive load is required to get better performance from the thermal interface material.

3.3.4 Thermal Test Vehicle Information

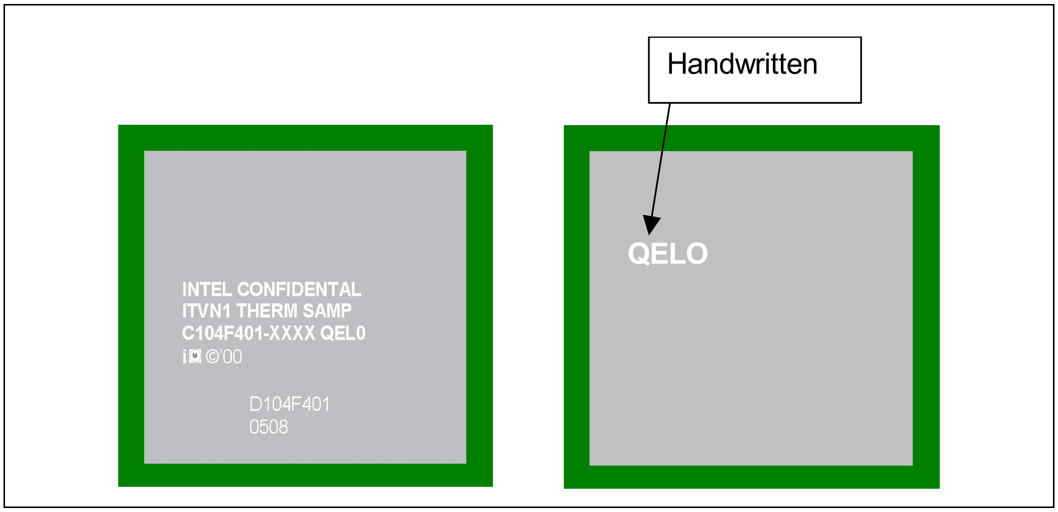
3.3.4.1 Introduction

The Pentium 4 processor with 512-KB L2 cache on 0.13 micron process Thermal Test Vehicle (TTV) is a FC-PGA2 package assembled with a thermal test die. The TTV is designed for use in platforms targeted for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process. The Pentium 4 processor TTVs are in limited supply; contact your local Intel field office for eligibility and availability.

Cooling solution performance should be defined using the TTV only. Not only does the TTV provide a well-characterized tool suitable for thermal testing, it also allows simulating processor thermal targets before real processors are available. The correction factor of the TTV to real processors, given in Section 3.3.4.5, Table 2, is then used to define the performance of the solution on real processors.

The part number for the TTV is A47244-01. There were two builds of TTV's. The TTV will either have a, "ITVN1 THERM SAMP" marking or a handwritten part code "QEL0" on the topside of the IHS. Samples of both markings are shown in Figure 11.

Figure 11. Thermal Test Vehicle Markings



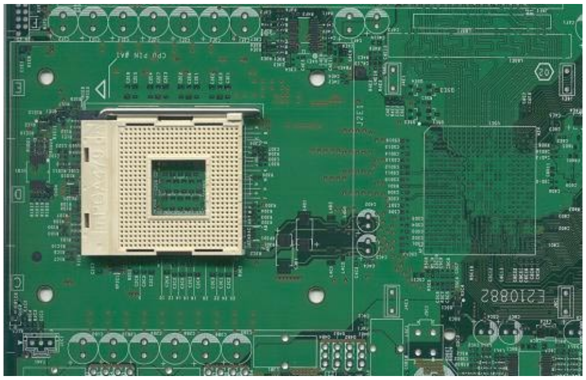
3.3.4.2 Thermal Test Die

A resistance-type heater covers nearly the entire surface area of the test die and is used to simulate the heat generation of an actual processor die.

The room temperature resistance of the ITVN1 heater is about 60 Ω, ±5% and the QEL0 heater is about 51 Ω, ±5%. This resistance value will increase as the die temperature increases.

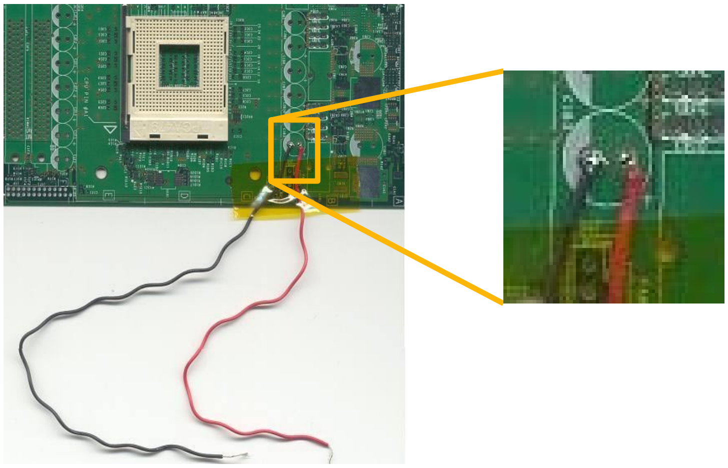
The heater is connected to external pins so that it can be powered by an external DC power supply. The resistance heater of the thermal die is terminated at the power and ground pins of the package. The power and ground pin-out of the TTV must match the power and ground pin-out of the actual processor. Intel recommends the TTV be used with a bare motherboard designed for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process (See Figure 12).

Figure 12. Un-populated Mainboard



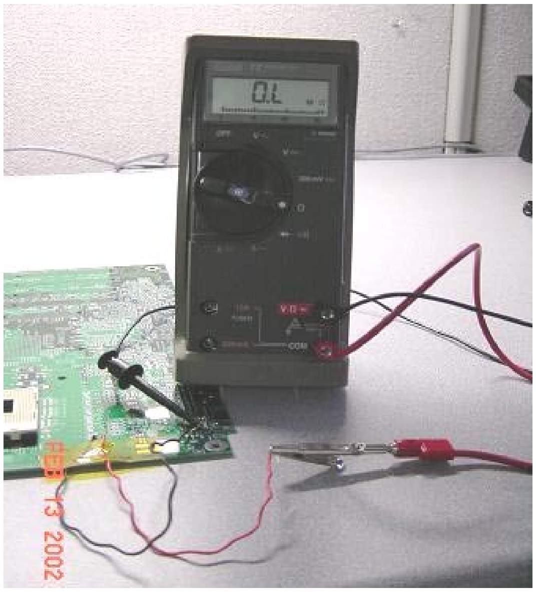
The TTV heater can be accessed by attaching wires to the processor power and ground planes by tapping through voltage regulator capacitor pads (See Figure 13).

Figure 13. Mainboard Wire Attach Location for TTV Heater Access



It is recommended the resistance between the power and ground planes be measured with the socket empty to make sure that the planes are separated (i.e., open circuit). See Figure 14.

Figure 14. Measured Resistance Between Processor Power and Ground Planes



With the TTV in the socket, the resistance can be measured as above and the value should be 60 Ω, ±5%. If not, there may be a wiring problem or the TTV may be damaged.

The recommended DC-power supply rating is listed in Table 1. The power supply should be able to deliver more current if necessary to cover for die resistance variations.

Table 1. Recommended DC Power Supply Ratings

Target Die Power Level	Power Supply Rating
20 W	40 V and 1 A
25 W	45 V and 1 A
30 W	45 V and 1 A
35 W	50 V and 1 A
40 W	55 V and 1 A
50 W	60 V and 1.5 A
60 W	65 V and 1.5 A
70 W	70 V and 1.5 A
75 W	75 V and 1.5 A

The power dissipation should be maintained at or below 75 W and the IHS temperature should be maintained to less than 80°C during the thermal testing. The TTV should not be power on without a properly installed heatsink. By violating these constraints, the TTV lifetime will be reduced. It must be noted that the reliability of TTV is limited and the TTV is not designed for long-term testing purposes. The heaters on the thermal testing devices are metal resistors. The polarity does not matter: Positive and negative terminals are interchangeable.

Note: TTV is not sensitive to static electricity.

3.3.4.3 Alternate Method for TTV Connections

If a bare motherboard cannot be obtained, any motherboard designed for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process can be used. The following the steps must be followed for the TTV to function correctly.

- The powering the TTV can be accessed by de-populating the power decoupling capacitors and attaching wires to the power and ground sides of one of the capacitor. It is recommended that all decoupling capacitors be removed because the high voltages required for the TTV may exceed the maximum voltage rating of the capacitors.
- The voltage regulator inductors should also be removed to isolate the VR from the TTV power supply.
- The power and ground planes must be separated for the TTV to work properly. Therefore, the motherboard schematics need to be used to determine what components need removed to separate the power and ground planes. The resistance between the power and ground planes should be open (infinite) with the socket empty. If the power and ground planes are not separate, than not all of the necessary components have been removed and the TTV will not function correctly.

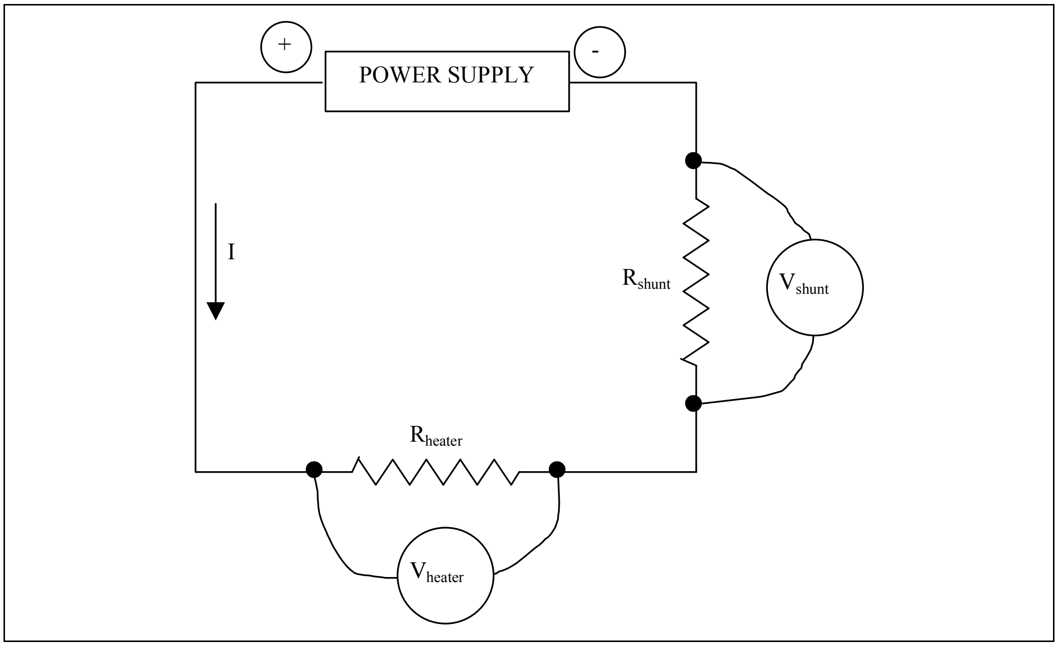
3.3.4.4 Thermal Measurements

Refer to Section 3.3.2 for T_A measurement methodology. Refer to Section 3.3.3.1 for thermocouple attachment to the IHS and to Section 3.3.3.2 and Section 3.3.3.3 for the heatsink preparation.

For TTV thermal measurement itself, use the following instructions, instead of the general thermal measurement instructions given in Section 3.3.3.4:

1. Measure the resistance of the heater resistor of TTV at the room temperature to check for the reasonable readings. If reasonable reading of ~60 W for the ITVN1 TTV and ~50 W for the QELO TTV is not obtained the TTV may be damaged, the wire connection is not correct, or the necessary board components have not been removed. In case a shortage occurs between the positive and negative terminals, do not perform the test as damage could occur to the power supply.
2. Attach a thermocouple at the center of the package (IHS-side) using the proper thermocouple attach procedure (refer to Section 3.3.3.1).
3. Connect the thermocouple to a thermocouple meter.
4. Mill groove on heatsink base, as recommended in Section 3.3.3.2 and Section 3.3.3.3.
5. Apply thermal interface materials to either IHS top surface or the surface of heatsink base.
6. Mount the heatsink to the TTV with the intended heatsink attach clip and all relevant mechanical interface components (e.g., retention mechanism, processor EMI attenuation solutions, etc.).
7. Place the TTV in the test environment (e.g., a test bench, a wind tunnel or a computer chassis).
8. Connect the heater resistor of the TTV to a DC power supply. Connect voltage meters as shown in Figure 15

Figure 15. TTV Wiring Diagram



9. Refer to Section 3.3.2 to setup the thermocouples used for T_A measurement, and connect them to a thermocouple meter.
10. Set the voltage of the DC power supply to the value calculated from the targeted power level and the heater resistance, if the DC-power supplier uses a voltage-control mode e.g., $\text{Voltage} = \sqrt{\text{Heater Resistance} \times \text{Power}}$. Alternatively, an appropriate current can be set to the DC-power supplier if the DC-power supplier uses a current-control mode.
11. Calculate the actual power TDP applied to the heater resistor by multiplying the reading from the voltage meter at the TTV with the current through the shunt resistor. The current through the shunt resistor is calculated by dividing the reading from voltage meter at the shunt resistor by the resistance of the shunt resistor. The shunt resistor is used to eliminate inaccuracies of the current measurement through the TTV package. The location of each voltage meter is shown in the figure in Step 8. As the heater heats up, the heater resistance will increase slightly and the current will decrease resulting in a small drop of power if a voltage-control mode is used. The power supply voltage has to be increased to compensate for the drop in the current to maintain a constant power. Wait for one hour to reach the stable condition before reading the case temperature (T_C) and the local ambient temperature (T_A) from the thermocouple.
12. Calculate the case-to-ambient thermal characterization parameter resistance (Ψ_{CA}) based on equation 1 given in Section 3.2.2.3. This equation is shown below.

$$\Psi_{CA} = (T_C - T_A) / TDP$$

3.3.4.5 TTV Correction Factor to the Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process

Correction factors usually need to be applied to predict the thermal solution performance on the real processors arts from thermal performance measured on a thermal test vehicle. Table 2 provides these correction factors for the TTV used to simulate the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process. The value of a thermal characterization parameter is derived from the value measured on the TTV and the corresponding correction factor according to the following equation:

$$\{\text{Processor } \Psi_{CA}\} = \{\text{TTV } \Psi_{CA}\} \times \text{Correction factor}$$

This formula transposes to Ψ_{CS} and Ψ_{SA}.

Table 2. TTV Correction Factors

Thermal characterization parameter	Correction Factor
Ψ_{CS}	1.151
Ψ_{SA}	1.014
Ψ_{CA}	1.053

Ψ_{CA} correction factor should only be used when the ratio Ψ_{CS}/Ψ_{SA} is similar to the Intel reference design (~ 0.53). If this ratio is significantly different, then it is recommended to use individual Ψ_{CS} and Ψ_{SA} correction factors and add corrected Ψ_{CS} and Ψ_{SA} to get Ψ_{CA}.

3.4 Thermal Management Logic and Thermal Monitor Feature

3.4.1 Processor Power Dissipation

An increase in processor operating frequency not only increases system performance, but also increases the processor power dissipation. The relationship between frequency and power is generalized in the following equation: $P=CV^2F$ (where P = power, C = capacitance, V = voltage, F = frequency). From this equation, it is evident that power increases linearly with frequency and with the square of voltage. In the absence of power saving technologies, ever increasing frequencies will result in processors with power dissipations in the hundreds of Watts. Fortunately, there are numerous ways to reduce the power consumption of a processor. Decreasing the voltage and transistor size are two examples, a third is clock modulation, which is used extensively in laptop designs.

Clock modulation is defined as periodically removing the clock signal from the processor core, which effectively reduces its power consumption to a few Watts. A zero-Watt power dissipation level is not achievable due to transistor leakage current and the need to keep a few areas of the processor active (cache coherency circuitry, phase lock loops, interrupt recognition, etc.). Therefore, by cycling the clocks on and off at a 50% duty cycle for example, the average power dissipation can drop by up to 50%. Note that the processor performance also drops by about 50% during this period, since program execution halts while the clocks are removed. Varying the duty cycle has a corresponding influence on power dissipation and processor performance. The duty cycle is specific to the processor (typically 30–50%).

Laptop systems use clock modulation to control system and processor temperatures. By using various external measurement devices, laptops monitor the processor case temperature and turn on fans or initiate clock modulation to reduce processor power dissipation and ensure that all elements of the system operate within their temperature specifications. Unfortunately, using external thermocouples connected to the processor package to monitor and control a thermal management solution has some inherent disadvantages. Thermal conductivity through the processor package creates a temperature gradient between the processor case and silicon. This temperature difference may be large with the silicon temperature always being higher than the case temperature. Since thermocouples measure case temperature, not silicon temperature, significant added margin may be necessary to ensure the processor silicon does not exceed its maximum specification (i.e., clock modulation may have to be turned on when the case temperature is significantly below its maximum specification to ensure the processor does not overheat). This added margin might have a substantial, and unacceptable, impact on system performance.

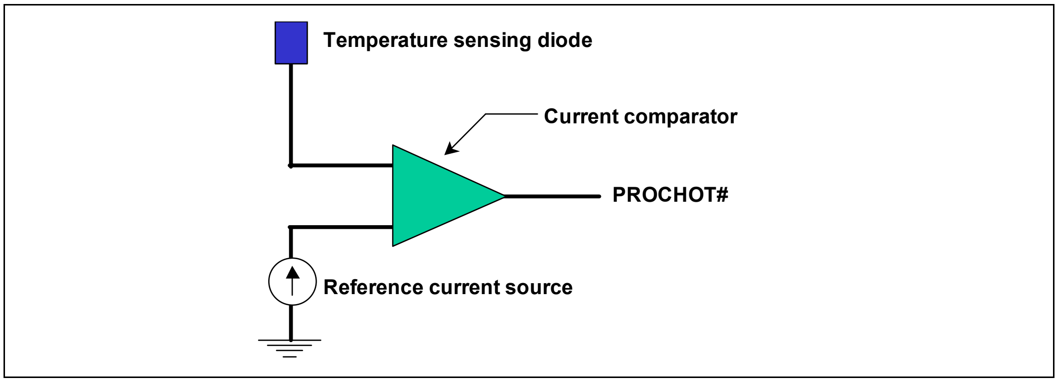
Thermal ramp rates, or change in die temperature over a specified time period ($\Delta T/\Delta t$), may be extremely high in high power processors where ramp rates in excess of 50°C/s may occur in the course of normal operation. With this type of thermal characteristic, it would not be possible to control fans or other cooling devices based on processor case temperature. By the time the fans have spun up to speed, the processor may be well beyond a safe operating temperature,. Just as large added margins would be necessary to account for package thermal gradients, equally large margins would also be necessary if temperature-controlled fans were implemented.

An on-die thermal management feature called Thermal Monitor is available on the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process. This feature is the same as the one found on the Pentium 4 processor. It provides a thermal management approach to support the continued increases in processor frequency and performance. It resolves the issues discussed above so that external thermocouples are no longer needed. By using an accurate on-die temperature sensing circuit and a fast acting temperature control circuit, the processor can rapidly initiate thermal management control. As a result, added thermal margins can be significantly reduced and the resulting system performance impact can be minimized if not eliminated.

3.4.2 Thermal Monitor Implementation

On the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process, the Thermal Monitor is integrated into the processor silicon. The Thermal Monitor includes a highly accurate on-die temperature sensing circuit, a signal (PROCHOT#) that indicates the processor has reached its maximum operating temperature, registers to determine status, and a thermal control circuit that can reduce processor temperature by controlling the duty cycle of the processor clocks. The processor temperature is determined through an analog thermal sensor circuit comprised of a temperature sensing diode, a factory calibrated reference current source, and a current comparator (See Figure 16). A voltage applied across the diode will induce a current flow that varies with temperature. By comparing this current with the reference current, the processor temperature can be determined. The reference current source corresponds to the diode current when at the maximum permissible processor operating temperature. Each processor is individually calibrated during manufacturing to eliminate any potential manufacturing variations. Once configured, the processor temperature at which the PROCHOT# signal is asserted (trip point) is not re-configurable.

Figure 16. Thermal Sensor Circuit

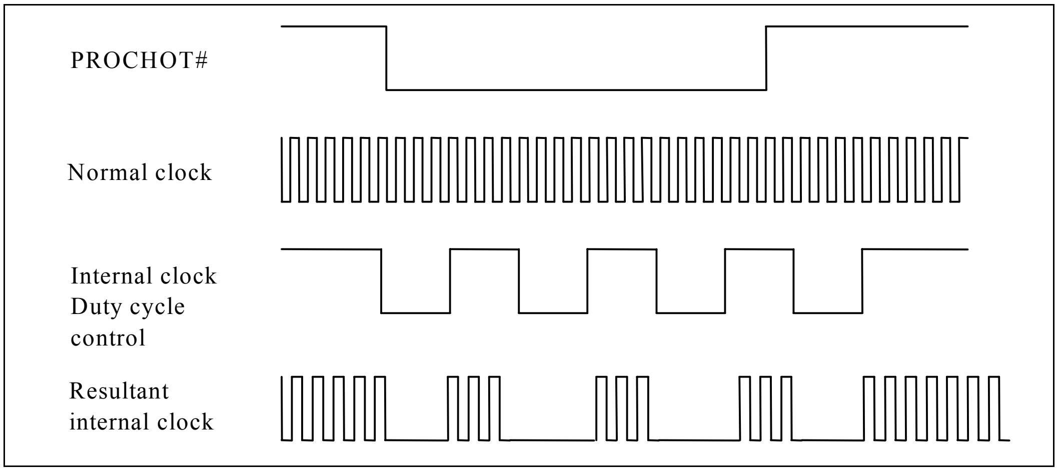


The PROCHOT# signal is available internally to the processor as well as externally. External indication of the processor temperature status is provided through the bus signal PROCHOT#. When the processor temperature reaches the trip point, PROCHOT# is asserted. When the processor temperature is below the trip point, PROCHOT# is deasserted. Assertion of the PROCHOT# signal is independent of any register settings within the processor. It is asserted any time the processor die temperature reaches the trip point. The point where the thermal control circuit goes active is set to the same temperature at which the processor is tested.

The Thermal Monitor's thermal control circuit (TCC), when active, lowers the processor temperature by reducing the duty cycle of the internal processor clocks. **The thermal control circuit portion of the Thermal Monitor must be enabled by the system BIOS for the processor to be operating within specifications.** When active, the TCC turns the processor clocks off and then back on with a predetermined duty cycle. The actual duty cycle varies from one product to another. Refer to Figure 17 for an illustration. Cycle times are processor speed dependent and decrease as processor core frequencies increase.

An ACPI register, performance counter registers, status bits in model specific register (MSR), and the PROCHOT# output pin are available to monitor and control the Thermal Monitor.

Figure 17. Concept for Clocks under Thermal Monitor Control



3.4.3 Bi-Directional PROCHOT#

The Pentium 4 processor with 512-KB L2 cache on 0.13 micron process also implements a bi-directional PROCHOT# capability to allow systems to protect Voltage Regulators (VRs) from over-temperature situations. The PROCHOT# signal is bi-directional in that it can either signal when the processor has reached its maximum operating temperature *or* be driven from an external source to activate the TCC. The feature is intended to offer thermal protection for VRs designed to handle maximum sustain current instead of maximum theoretical current. PROCHOT# should be asserted (pulled low) externally to activate the TCC when the VR thermal limits are reached, thereby allowing the VR to cool down with reduced processor power consumption. Systems should still provide proper cooling for the VRs, and rely on bi-directional PROCHOT# only as a backup in case of system cooling failure.

3.4.4 Operation and Configuration

To maintain compatibility with previous generations of processors, which have no integrated thermal logic, the thermal control circuit portion of Thermal Monitor is disabled by default. During the power-on process, the BIOS must enable the thermal control circuit; or a software driver may do this after the operating system has booted.

The thermal control circuit feature can be configured and monitored in a number of ways. OEMs are expected to enable the thermal control circuit while using various registers and outputs to monitor the processor thermal status. The thermal control circuit is enabled by BIOS setting a bit in an MSR (model specific register). Enabling the thermal control circuit allows the processor to maintain a safe operating temperature without the need for special software drivers or interrupt handling routines. When the thermal control circuit has been enabled, processor power consumption will be reduced within a few hundred clock cycles after the thermal sensor detects a high temperature (i.e., within a few hundred clock cycles of PROCHOT# assertion). The thermal control circuit and PROCHOT# go inactive once the temperature has been brought back down below the thermal trip point, although a small hysteresis (~1 °C) has been included to prevent multiple PROCHOT# transitions around the trip point. External hardware can monitor PROCHOT# and generate an interrupt whenever there is a transition from active-to-inactive or inactive-to-active. PROCHOT# can also be configured to generate an internal interrupt which would initiate an OEM supplied interrupt service routine. Regardless of the configuration selected, PROCHOT# will always indicate the thermal status of the processor.

For testing purposes, the thermal control circuit may also be activated by setting bits in the ACPI MSRs. The MSRs may be set based on a particular system event (e.g., an interrupt generated after a system event), or may be set at any time through the operating system or custom driver control thus forcing the thermal control circuit on. This is referred to as "on-demand" mode. Activating the thermal control circuit may be useful for cooling solution investigations or for performance implication studies. When using the MSRs to activate the Thermal Monitor feature, the duty cycle is configurable in steps of 12.5%, from 12.5% to 87.5%.

For any duty cycle, the maximum time period the clocks are disabled is ~3 µs. This time period is frequency dependent, and decreases as frequency increases. To achieve different duty cycles, the length of time that the clocks are disabled remains constant, and the time period that the clocks are enabled is adjusted to achieve the desired ratio. For example, if the clock disable period is 3 µs, and a duty cycle of ¼ (25%) is selected, the clock on time would be reduced to approximately 1 µs [on time (1 µs) ÷ total cycle time (3 + 1) µs = ¼ duty cycle]. Similarly, for a duty cycle of 7/8 (87.5%), the clock on time would be extended to 21 µs [21 ÷ (21 + 3) µs = 7/8 duty cycle].

In a high temperature situation, if the thermal control circuit and ACPI MSRs (automatic and on-demand modes) are used simultaneously, the fixed duty cycle determined by automatic mode would take precedence.

3.4.5 System Considerations

The Thermal Monitor feature may be used in a variety of ways, depending upon the system design requirements and capabilities. *Intel requires the thermal control circuit to be enabled for all Intel Pentium 4 processor with 512-KB L2 cache on 0.13 micron process based systems.* At a minimum, the thermal control circuit supplies an added level of protection against processor over-temperature failure.

To minimize the cost of a processor thermal solution, system designers are encouraged to take advantage of the Thermal Monitor feature capability. The Thermal Monitor feature allows processor thermal solutions to design to the thermal design power (TDP) target, as opposed to maximum processor power consumption. Designing to the lower TDP target results in a lower thermal solution cost, while still maintaining a level of processor performance that is virtually indistinguishable from systems designed to manage maximum power dissipation levels. Each application program has its own unique power profile, although the profile has some variability due to loop decisions, I/O activity and interrupts. In general, compute intensive applications with a high cache hit rate dissipate more processor power than applications that are I/O intensive or have low cache hit rates.

The processor thermal design power (TDP) is based on measurements of processor power consumption while running various high power applications. This data is used to determine those applications that are interesting from a power perspective. These applications are then evaluated in a controlled thermal environment to determine their sensitivity to activation of the thermal control circuit. This data is used to derive the TDP targets published in the processor datasheet.

A system designed to meet the TDP and T_C targets published in the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet* greatly reduces the probability of real applications causing the thermal control circuit to activate under normal operating conditions. Systems that do not meet these specifications could be subject to frequent activation of the thermal control circuit depending upon ambient air temperature and application power profile. Moreover, if a system is significantly under designed, there is a risk that the Thermal Monitor feature will not be capable of maintaining a safe operating temperature and the processor could shutdown and signal THERMTRIP#.

For information regarding THERMTRIP#, refer to Section 3.4.7.2 and to the processor datasheet.

3.4.6 Operating System and Application Software Considerations

The Thermal Monitor feature and its thermal control circuit work seamlessly with ACPI compliant operating systems. The Thermal Monitor feature is transparent to application software since the processor bus snooping, ACPI timer, and interrupts are active at all times.

Activation of the thermal control circuit during a non-ACPI aware operating system power-on process may result in incorrect calibration of operating system software timing loops. The BIOS must disable the thermal control circuit prior to power-on and then the operating system or BIOS must enable the thermal control circuit after the operating system power-on process completes.

Intel is working with the major operating system (OS) suppliers to ensure support for non-execution based operating system calibration loops and ACPI support for the Thermal Monitor feature. Per Microsoft, Microsoft Windows* 98SE, and Windows* 2000 operating systems use non-execution based calibration loops and therefore should have no issues with the Thermal Monitor feature. When installing Microsoft Windows NT* 4.0 operating system, the user must ensure the APIC-based HAL is used. It is expected that other operating system solutions (Linux*, Unix*, etc.) will provide updates to ensure compatibility.

3.4.7 Legacy Thermal Management Capabilities

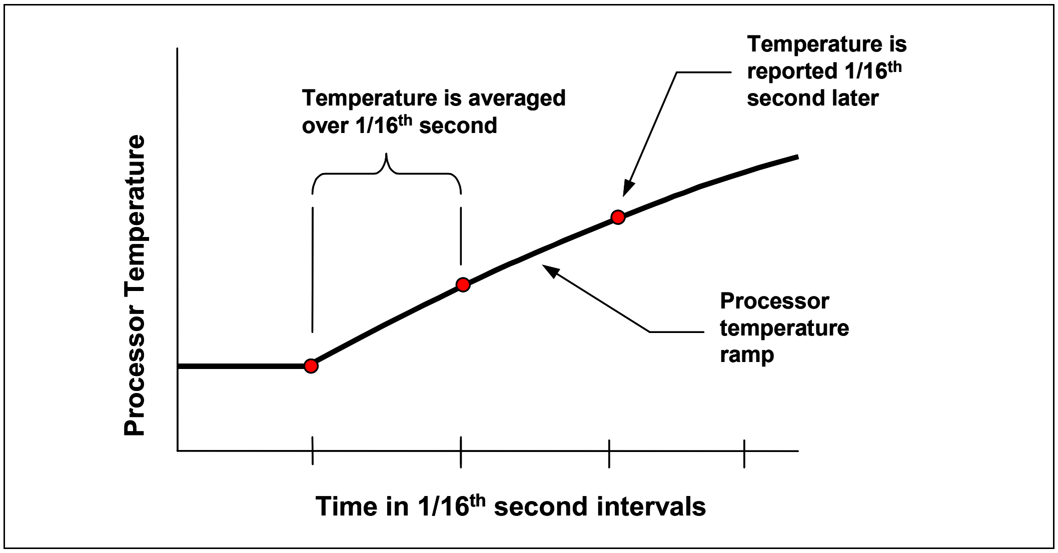
In addition to Thermal Monitor, the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process supports the same thermal management features as available on the Intel® Pentium® III processor. These features are the on-die thermal diode and THERMTRIP# signal for indicating catastrophic thermal failure.

3.4.7.1 Thermal Diode

The Pentium 4 processor with 512-KB L2 cache on 0.13 micron process incorporates an on-die thermal diode, which can be used with an external device (thermal diode sensor) to monitor long-term temperature trends. By averaging this data over long time periods (hours/days vs. min/sec), it may be possible to derive a trend of the processor temperature. Analysis of this information could be useful in detecting changes in the system environment that may require attention. Design characteristics and usage models of the thermal diode sensors are described in datasheets available from the thermal diode sensor manufacturers.

The processor thermal diode should not be relied upon to turn on fans, warn of processor cooling system failure, or predict the onset of the thermal control circuit. As mentioned earlier, the processor high thermal ramp rates make this unfeasible. An illustration of this is as follows. Many thermal diode sensors report temperatures a maximum of 8 times per second. Within the 1/8th (0.125 s) second time period, the temperature is averaged over 1/16th of a second. In a scenario where the silicon temperature ramps at 50 °C/s, or approximately 6°C/0.125 s, the processor will be ~4.5 °C above the temperature reported by the thermal sensor. (Change in diode temperature averaged over 1/16th seconds = ~1.5°C; temperature reported 1/16th second later at 1/8th second when the actual processor temperature would be 6°C higher, see Figure 18).

Figure 18. Thermal Diode Sensor Time Delay



3.4.7.2 THERMTRIP#

In the event of a catastrophic cooling failure, the processor will automatically shut down when the silicon temperature has reached approximately ~135 °C. At this point the system bus signal THERMTRIP# goes active and power needs to be removed from the processor. THERMTRIP# stays active until RESET# has been initiated. THERMTRIP# activation is independent of processor activity and does not generate any bus cycles. Refer to the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet* for more information about THERMTRIP#.

3.4.7.3 Thermal Measurement Correlation

There are two independent thermal sensors in the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process. One is the on-die thermal diode described in Section 3.4.7.1. The other is the temperature sensor used for the Thermal Monitor and for THERMTRIP#. The Thermal Monitor's temperature sensor and the on-die thermal diode are independent and isolated devices with no direct correlation to one another. Circuit constraints and performance requirements prevent the Thermal Monitor's temperature sensor and the on-die thermal diode from being located at the same place on the silicon. As a result, it is not possible to predict the activation of the thermal control circuit by monitoring the on-die thermal diode.

3.4.8 Cooling System Failure Warning

If desired, the system may be designed to cool the maximum processor power. In this situation, it may be useful to use the PROCHOT# signal as an indication of cooling system failure. Messages could be sent to the system administrator to warn of the cooling failure, while the thermal control circuit would allow the system to continue functioning or allow a graceful system shutdown. If no thermal management action is taken, the silicon temperature may exceed ~135°C causing THERMTRIP# to go active and shut down the processor. Regardless of the system design requirements or cooling solution ability, the Thermal Monitor feature must still be enabled to guarantee proper processor operation.

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4 Intel Thermal Mechanical Reference Design Information

Intel develops thermal and mechanical reference components to demonstrate cooling capabilities for current and future microprocessors. This section outlines the requirements used in developing and evaluating these reference designs.

Taking into account the wide heatsink performance range needed to support the entire life of the Pentium 4 Processor with 512-KB L2 cache on 0.13 micron process, several cooling solutions may be developed accordingly. Table 3 gives details how this is broken down from the Intel Reference Design perspective. It includes the reference heatsink performance target for frequencies at 3.06 GHz or higher.

The table also includes the T_A assumption at the processor fan heatsink inlet discussed in Section 3.2.2.1. Combining the target T_A with the target Ψ_{CA} enables to get the optimum performance from the processor (refer to Chapter 3 and Section 3.4).

Refer to the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet* for detailed processor thermal specifications.

Table 3. Reference Heatsink Thermal Performance Targets

Target Frequencies (Refer to processor Datasheet)	Thermal Performance Targets, Ψca (Mean + 3σ)	T_A Assumption	Notes
1.40 GHz – 2.80 GHz	0.40 °C/W	$T_A = 45$ °C	1
3.06 GHz or higher	0.33 °C/W	$T_A = 42$ °C	1

NOTES:

1. T_C and TDP are constant, while Ψ_{CA} may vary according to T_A. The T_A values given in this table reflect the assumption of Intel for the reference design that there will be thermal performance improvements for the chassis for processors operating at 3.06 GHz or higher.

4.1 Intel Validation Criteria for the Reference Design

4.1.1 Acoustics

To optimize acoustic emission by the fan heatsink assembly, it is recommended to develop a solution with a **variable speed fan**. It allows attaining thermal performance requirements at higher fan inlet temperatures (T_A) and lower noise at lower fan inlet temperatures. The required fan speed necessary to meet thermal specifications can be controlled by the fan inlet temperature and should comply with requirements below:

1. Fan set points
   - High set point: T_A = 42 °C; Ψ_{CA} = 0.33 °C/W (per Table 3)
   - Low set point: T_A = 32 °C; Ψ_{CA} = 0.46 °C/W
   - Fan speed is linear between low set point and high set point.
2. Fan heatsink assembly acoustic performance:
   - Acoustic performance is defined in terms of declared sound power (LwAd) as defined in ISO 9296 standard, and measured according ISO 7779.
   - LwAd does not exceed 5.7 BA at the high set point temperature.
   - LwAd does not exceed 4.5 BA at the low set point temperature.

4.1.2 Altitude

The reference heatsink solutions will be evaluated at sea level. However, many companies design products that must function reliably at high altitude, typically 1,500 m (5,000 ft) or more. Air-cooled temperature calculation and measurement at sea level must be adjusted to take into account altitude effects like different air density and overall heat capacity. This often leads to some degradation in thermal solution performance compared to what is obtained at sea level, with lower fan performance and higher surface temperatures. The system designer needs to account for this altitude effects in the overall system thermal design to make sure that the T_C requirement for the processor is met at the targeted altitude.

4.1.3 Reference Heatsink Thermal Validation

The Intel reference heatsink is validated within specific boundary conditions based on the methodology described in Section 3.3, using a thermal test vehicle (refer to Section 3.3.4).

Testing is done on bench-top test boards at ambient lab temperature. In particular, for the 3.06 GHz or higher reference heatsink, the Plexiglas* barrier is installed 3.2” above the motherboard (refer to Section 3.3.2).

The test results are reported in terms of performance on real parts (using the thermal test vehicle correlation), and of mean + 3σ value. See Table 5 for more information.

4.1.4 Fan Performance for Active Heatsink Thermal Solution

The fan power requirement for proper operation is a maximum current of 740 mA at 12 V.

In addition to comply with overall thermal requirements (Section 4.1.1), and the general environmental reliability requirements (Section 4.1.5) the fan should meet the following performance requirements:

- The expected fan minimum functional lifetime is 40,000 hours at 45 °C.
- The thermal solution is capable of meeting end-of-line performance for frequencies at 3.06 GHz or higher at 100% of the rated fan RPM at 12 V. End-of-life fan component reliability can also be evaluated by de-rating the fan RPM @ 12 V by 90%.
- In addition to withstanding the environmental reliability tests described in Section 4.1.5, the fan still demonstrates performance after 7,500 on/off cycles with each cycle specified as 3 minutes on, 2 minutes off, at a temperature of 70 °C.

4.1.5 Environmental Reliability Testing

4.1.5.1 Structural Reliability Testing

Structural reliability tests consist of unpackaged, board-level mechanical vibration and shock tests of a given thermal solution in assembled state, as well as long-term reliability testing (temperature cycling, bake test). The thermal solution should be capable of sustaining thermal performance after these tests are conducted; however, the conditions of the tests outlined here may differ from your own system requirements.

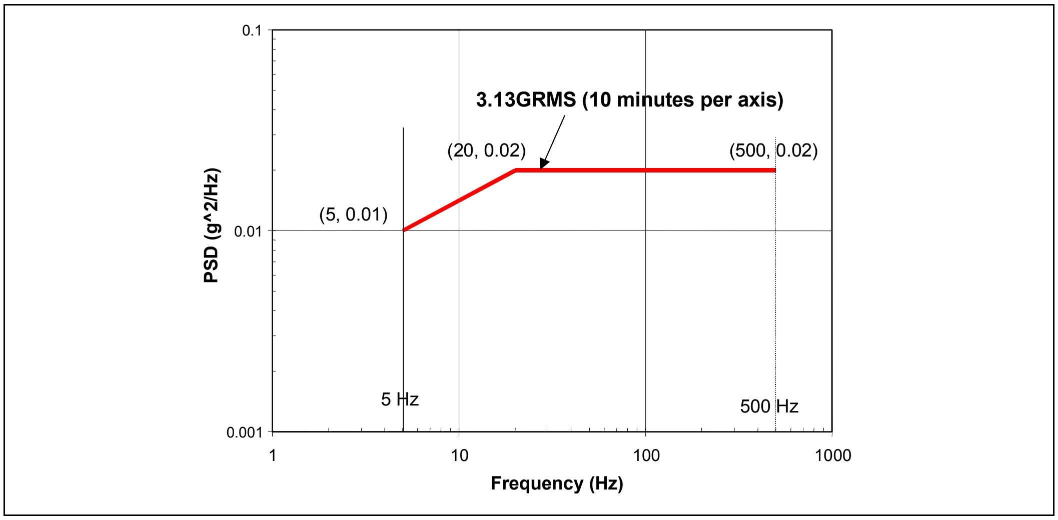
4.1.5.2 Random Vibration Test Procedure

Duration: 10 min/axis, 3 axes

Frequency Range: 5 Hz to 500 Hz

Power Spectral Density (PSD) Profile: 3.13 g RMS

Figure 19. Random Vibration PSD

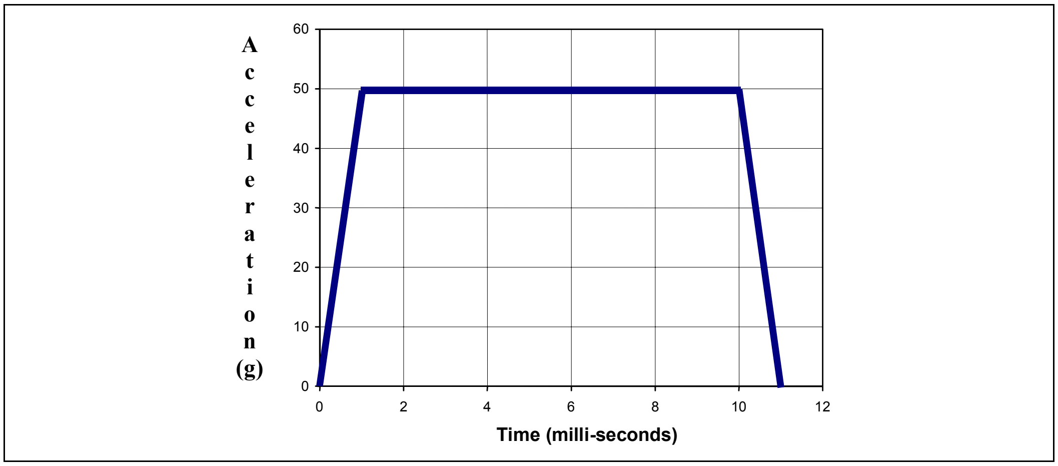


4.1.5.3 Shock Test Procedure

Recommended performance requirement for a motherboard:

- Quantity: 3 drops for + and - directions in each of 3 perpendicular axes (i.e., total 18 drops).
- Profile: 50 G trapezoidal waveform, 11 ms duration, 170 in./s minimum velocity change.
- Setup: Mount sample board on test fixture.

Figure 20. Shock Acceleration Curve



4.1.5.4 Recommended Test Sequence

Each test sequence should start with components (i.e., motherboard, heatsink assembly, etc.) that have never been previously submitted to any reliability testing.

The test sequence should always start with a visual inspection after assembly, and BIOS/CPU/Memory test (refer to Section 4.1.6.2). The stress test should be then followed by a visual inspection and then BIOS/CPU/Memory test.

4.1.5.5 Post-Test Pass Criteria

The post-test pass criteria are:

1. No significant physical damage to the retention mechanism windows, including any indication of shearing, cracks in the retention mechanism body, or evidence of significant clip lever penetration into the fan shroud.
2. Clip must remain latched to retention mechanism windows.
3. Heatsink remains seated and its bottom remains mated flatly against processor die surface. No visible gap between the heatsink base and processor IHS. No visible tilt of the heatsink with respect to the retention mechanism.
4. No signs of physical damage on motherboard surface due to impact of heatsink or heatsink attach clip.
5. No visible physical damage to the processor package.
6. Successful BIOS/Processor/memory test of post-test samples.
7. Thermal compliance testing to demonstrate that the case temperature specification can be met.

4.1.6 Long-Term Reliability Testing

4.1.6.1 Temperature Cycling

Temperature cycling is performed to test for long-term reliability. This test is conducted using the parameters shown in Table 4.

Table 4. Temperature Cycling Parameters

Parameters	Unit
Number of Cycles	1000 Cycles
Maximum Temperature	85 °C
Minimum Temperature	-40 °C
Dwell Time @ Maximum and Minimum Temperatures	15 Minutes
Minimum to Maximum Temperature Ramp Rate	15 °C/Minute
Maximum to Minimum Temperature Ramp Rate	15 °C/Minute

4.1.6.2 Recommended BIOS/CPU/Memory Test Procedures

This test is to ensure proper operation of the product before and after environmental stresses, with the thermal mechanical enabling components assembled. The test shall be conducted on a fully operational motherboard that has NOT been exposed to any battery of tests prior to the test being considered.

Testing setup should include the following components, properly assembled and/or connected:

- Appropriate system motherboard
- Processor
- All enabling components, including socket and thermal solution parts
- Power supply
- Disk drive
- Video card
- DIMM
- Keyboard
- Monitor

The pass criterion is that the system under test shall successfully complete the checking of BIOS, basic processor functions and memory, without any errors. *Intel PC Diags* is an example of software that can be utilized for this test.

4.1.7 Material and Recycling Requirements

Material shall be resistant to fungal growth. Examples of non-resistant materials include cellulose materials, animal and vegetable based adhesives, grease, oils, and many hydrocarbons. Synthetic materials such as PVC formulations, certain polyurethane compositions (e.g., polyester and some polyethers), plastics which contain organic fillers of laminating materials, paints, and varnishes also are susceptible to fungal growth. If materials are not fungal growth resistant, then MIL-STD-810E, Method 508.4 must be performed to determine material performance.

Material used shall not have deformation or degradation in a temperature life test.

Any plastic component exceeding 25 grams must be recyclable per the European Blue Angel recycling standards.

4.1.8 Safety Requirements

Heatsink and attachment assemblies shall be consistent with the manufacture of units that meet the safety standards:

- UL Recognition-approved for flammability at the system level. All mechanical and thermal enabling components must be a minimum UL94V-2 approved.
- CSA Certification. All mechanical and thermal enabling components must have CSA certification.
- Heatsink fins must meet the test requirements of UL1439 for sharp edges.
- If the International Accessibility Probe specified in IEC 950 can access the moving parts of the fan, consider adding safety feature so that there is no risk of personal injury to one’s finger.

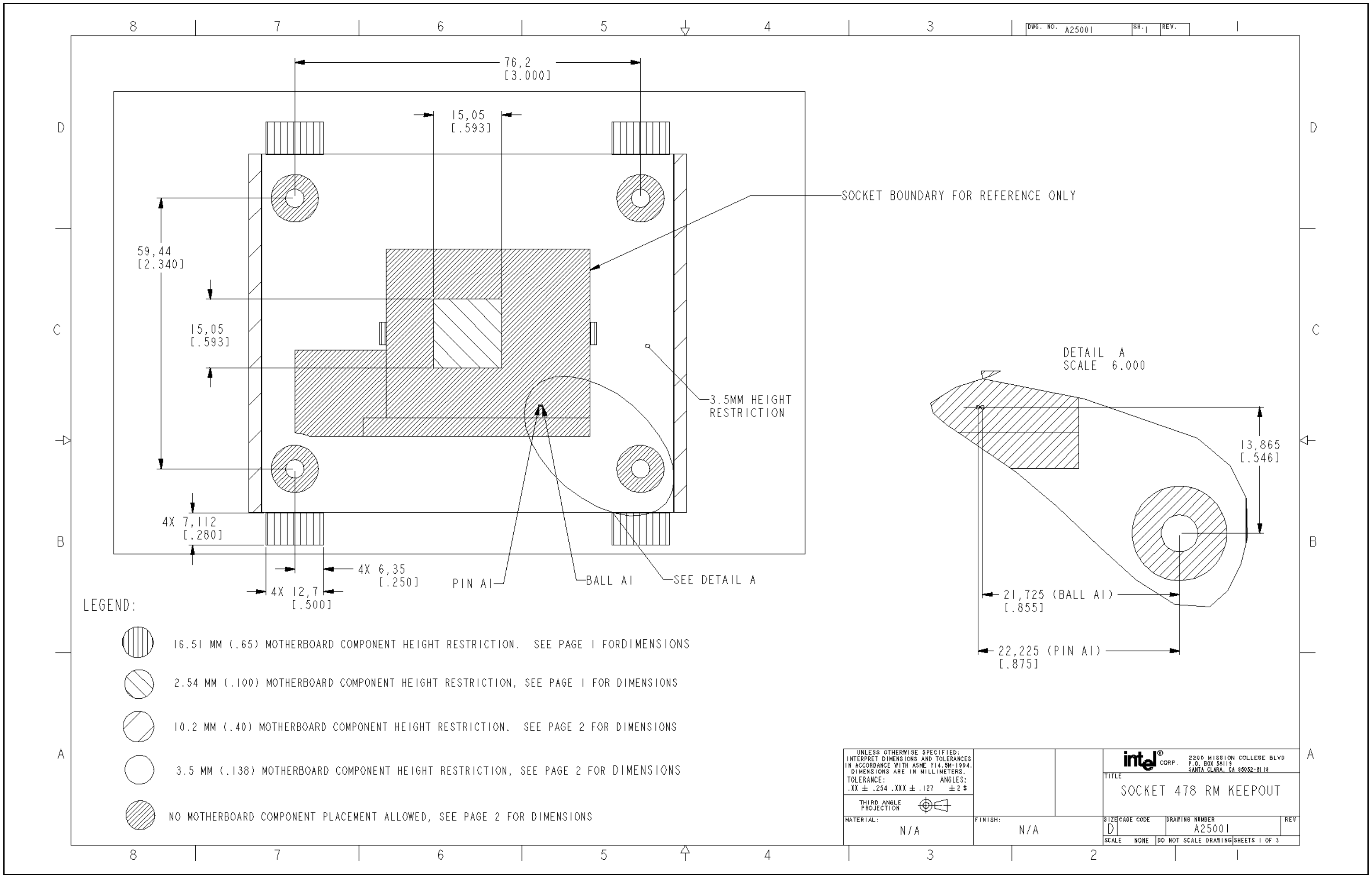
4.2 Geometrical Envelope for Intel Reference Thermal Mechanical Design

Figure 21, Figure 22, and Figure 23 show the overall keep-out and keep-in dimensions for the reference thermal/mechanical enabling design. These dimensions are identical to the ones used for the Intel Reference Solution for the Pentium 4 processor in the 478-pin package.

Figure 21 and Figure 22 show the motherboard keep-outs and height restrictions under the enabling component region. Figure 23 shows the overall volumetric keep-in for the enabling component assembly. This volumetric space encapsulates the processor, the socket, and the entire thermal/mechanical enabling solution (for example, for the reference design this includes: fan heatsink assembly, retention mechanism, and attach clips).

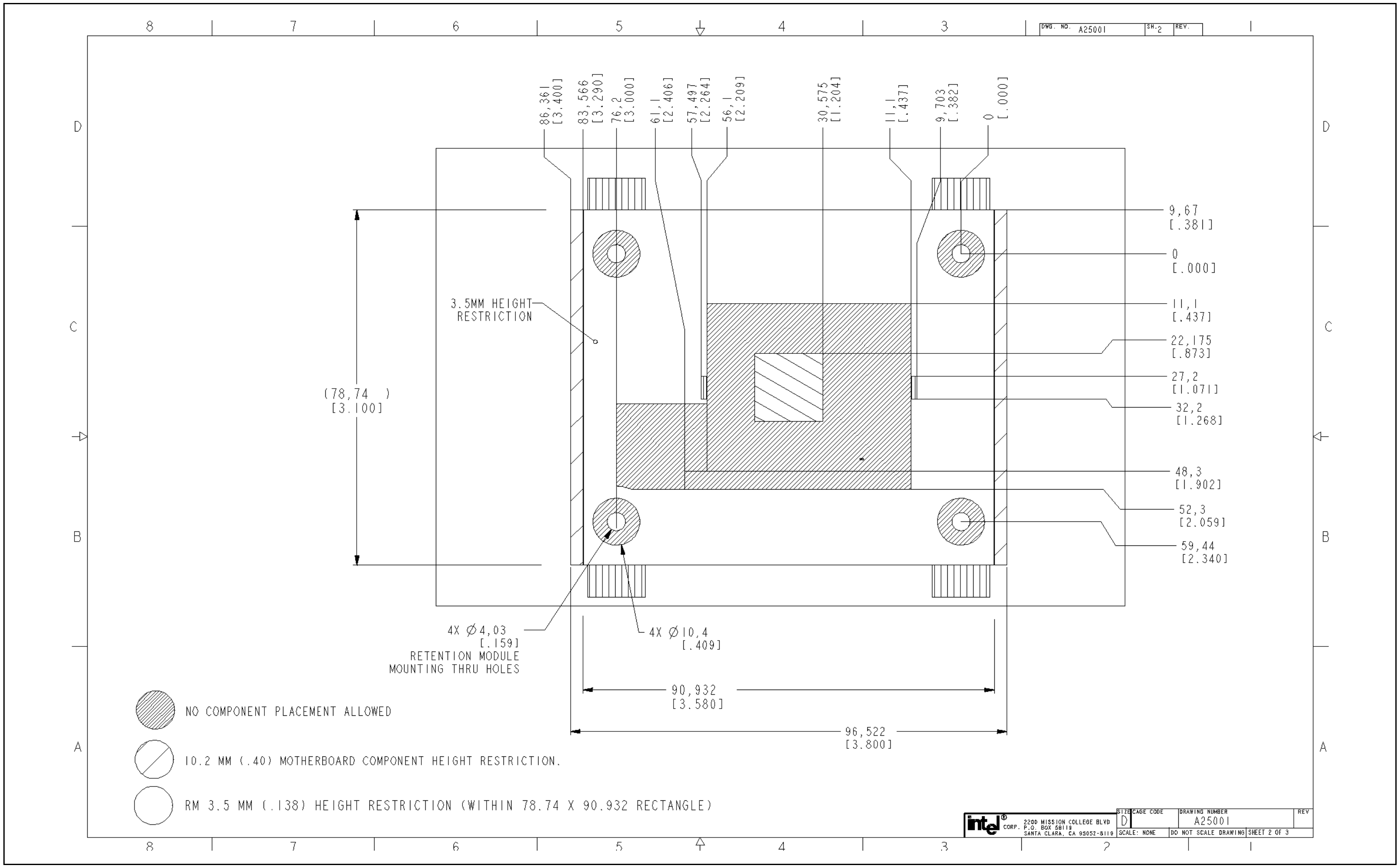
Note: Pin A1 and Ball A1, as referred to in Figure 21, do not physically exist on the 478-pin package and the 478-pin socket respectively. However, they may be used as a reference for design purposes. Motherboard designers should focus exclusively on Ball A1 callouts to determine position of the hole respective to the socket when working of the board layout. By design, the processor is then centered within the hole pattern when the socket is in the closed position. Pin A1 is associated specifically with the package, and its position on the drawing Figure 21 corresponds to the package within the socket in close position.

Figure 21. Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components – 1



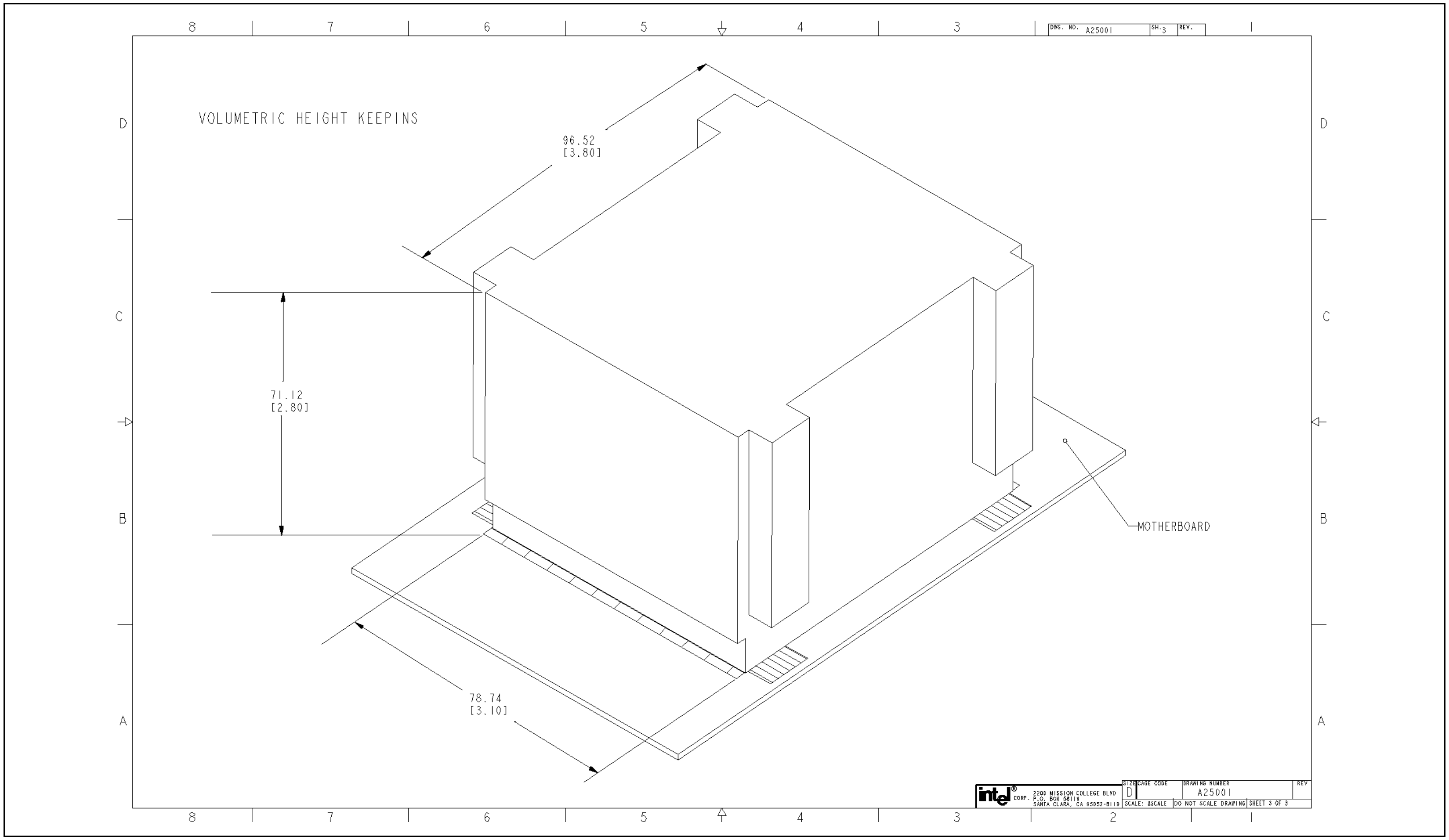
NOTE: Length in mm (inches)

Figure 22. Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components – 2



NOTE: Length in mm (inches)

Figure 23. Volumetric Keep-in for Enabling Components



NOTES:

1. Length in mm (inches)
2. Cooling Reference Solution for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process

4.3 3.06 GHz or Higher Intel Reference Thermal Solution

As mention in the previous section, Intel develops thermal and mechanical reference components to demonstrate cooling capabilities for current and future microprocessors. This section details information on the reference components designed to meet target frequencies at 3.06 GHz or higher.

The reference components in this section are made available for purchase through the listed reference design suppliers. Refer to Appendix C: Intel Enabled Reference Thermal Solution for more information. In addition, the reference component designs are also available for adoption by suppliers and heatsink integrators pending completion of appropriate licensing contracts. For more information on licensing, contact your local field sales office.

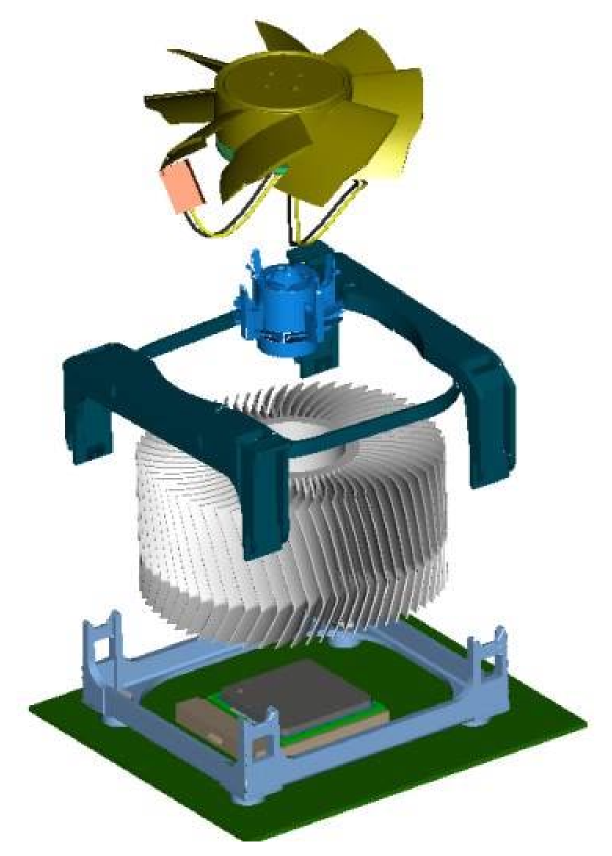
4.3.1 Reference Components Overview

The reference thermal mechanical solution that supports frequencies at 3.06 GHz or higher, consists of:

- Heatsink clip
- Fan & Fan Attach
- Heatsink
- Thermal interface material
- Retention mechanism

Refer to Appendix B: Mechanical Drawings for drawings of the individual components.

Figure 24. Exploded Reference Design Concept Sketch



Note: Intel reserves the right to make changes and modifications to the design as necessary.

Note: The thermal mechanical reference design for the Pentium 4 processor in the 478-pin package will be validated according to the Intel validation criteria given in Section 4.1, and using all the reference components as described in this document along with the reference thermal mechanical enabling components for the respective MCH/GMCH, including but not limited to the following chipsets: Intel® 845 chipset, Intel® 845E chipset, Intel® 845G chipset, Intel® 845GL chipset. Any thermal mechanical design using some of the reference components in combination with any other thermal mechanical solution needs to be fully validated according to the customer criteria. Also, if customer thermal mechanical validation criteria differ from the Intel criteria, the reference solution should be validated against the customer criteria.

4.3.2 Enabled Reference Components

4.3.2.1 Retention Mechanism

The retention mechanism for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process thermal mechanical reference solution is identical to the Pentium 4 processor in the 478-pin package reference retention mechanism.

4.3.2.2 Heatsink Attach Clip Information

The 3.06 GHz or higher heatsink attach clip has been redesigned for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process. This new clip features a tool-less design and is constructed without the levers used on the previous design. The clip is pre-formed to provide the appropriate level of preload (~51 Lbs) necessary to meet the design requirements. The clip is designed to retain 380 g. For more information, see Appendix B: Mechanical Drawings.

4.3.3 Heatsink Mechanical Design Guidelines

The reference mechanical components are meant to interface with the Intel reference fan heatsink that will be developed for frequencies at 3.06 GHz or higher for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process.

Other custom heatsinks must support the following interface control requirements to be compatible with the reference mechanical components:

Requirement 1: Heatsink/fan/shroud assembly must stay within the volumetric keep-in.

Requirement 2: Max mass and Center of Gravity

Heatsink assemblies that attach to the reference retention mechanism should not exceed 450 grams mass (combination of heatsink and fan assembly). This represents the design limit for the proposed processor retention mechanism and 478-pin socket to withstand mechanical shock and vibration requirements. The 3.06 GHz or higher clip is designed to a mass limit of 380 grams.

The combined center of gravity of the heatsink /fan /shroud assembly must be no greater than 0.85 inch above the bottom surface of the heatsink base.

4.3.4 Thermal Interface Material

Refer to Section 3.2.1.1 for general information on thermal interface material usage and application consideration on the FC-PGA2 package.

Thermal interface material for the 3.06 GHz or higher Intel reference design is ShinEtsu* G751 thermal grease.

4.3.5 Enabled Reference Design Test Results

Table 5 represents a results summary based on internal testing of the reference thermal solution. End users are responsible for the verification of the Intel enabled component offerings with the supplier. OEMs, ODMs, and System Integrators are responsible for thermal, mechanical, and environmental validation of the reference solution.

Table 5. Reference Design Results Summary

Test	Success Criterion	Results	Disposition
Mechanical Shock	0/12 continuity	0/12 failures	Pass
	0/12 visual inspection	0/12 failures	Pass
Vibration	0/12 continuity	0/12 failures	Pass
	0/12 visual inspection	0/12 failures	Pass
Clip Actuation Force	≤ 15lb	15.1 lb average for 16 samples	Fail – no plans to correct
Volumetric Keep-In Compliance	No dimensional violations	0/16 failures	Pass
Thermal	≤ 0.33 C/W - high fan set-point	0.31 C/W (m+3s)	Pass
	≤ 0.46 C/W - low fan set-point	0.41 C/W (m+3s)	Pass
Thermal (post-shock & vibe)	≤ 0.33 C/W - high fan set-point	0.30 C/W (m+2.7s)	Pass
Thermal (post-Temp cycling)	≤ 0.33 C/W - high fan set-point	TBD	TBD
	≤0.46 C/W - low fan set-point	TBD	TBD
Acoustic	≤ 6.7 BA (55 dBA) - high fan set-point [target: 5.7 BA (45 dBA)]	LwAd = 6.3 BA (LpAm = 49 dBA)	Pass
	≤ 4.5 BA (31 dBA) - low fan set-point	LwAd = 4.2 BA (LpAm = 31 dBA)	Pass

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5 Conclusion

As the complexities of today's microprocessors increase, the power dissipation requirements become more exacting. 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. Incorporating ducted airflow solutions into the system thermal design can yield additional margin.

The Pentium 4 processor with 512-KB L2 cache on 0.13 micron process has thermal management logic integrated into the processor silicon. Their circuits may be configured to automatically control the processor temperature through the use of the Thermal Monitor feature. In the event it reaches a factory-calibrated temperature, the processor periodically stops the internal clocks in order to reduce power consumption and allow the processor to cool down and stay within thermal specifications. Various registers and bus signals are available to monitor and control the processor thermal status. A cooling solution designed to the thermal design power (TDP) as specified in the *Intel® Pentium® 4 Processor with 512-KB L2 Cache on 0.13 Micron Process Datasheet* can adequately cool the processor to a level where activation of the Thermal Monitor feature is either very rare or non-existent. Various levels of performance versus cooling capacity are available and must be understood before designing a chassis. Automatic thermal management must be used as part of the total system thermal solution.

The size and type of the heatsink, as well as the output of the fan can be varied to balance size, cost, and space constraints with acoustic noise. This document has presented the conditions and requirements for designing a heatsink solution for a system based on a Pentium 4 processor with 512-KB L2 cache on 0.13 micron process. Properly designed solutions provide adequate cooling to maintain the processor thermal specification. This is accomplished by providing a low local ambient temperature and creating a solution with a minimal thermal characterization parameter to that local ambient temperature. Fan heatsinks or ducting can be used to cool the processor if proper package temperatures cannot be maintained otherwise. By maintaining the processor case temperature at the values specified in the processor datasheet, a system designer can be confident of proper functionality and reliability of these processors.

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Appendix A: Thermal Interface Management

To optimize a heatsink design, it is important to understand the impact of factors related to the interface between the processor 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.

Bond Line Management

Any gap between the processor integrated heat spreader (IHS) and the heatsink base will impact thermal solution performance. The larger the gap between the two surfaces, the greater the thermal characterization parameter. The thickness of the gap is determined by the flatness and roughness of both the heatsink base and the integrated heat spreader, plus the thickness of the thermal interface material (for example thermal grease) used between these two surfaces and the clamping force applied by the heatsink attach clip(s).

Interface Material Area

The size of the contact area between the processor and the heatsink base will impact the thermal resistance. There is, however, a point of diminishing returns. Unrestrained incremental increases in thermal interface material area do not translate to a measurable improvement in thermal performance.

Interface Material Performance

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

- Thermal resistance of the material
- 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 material 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 (heatsink, fan) 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. In this case, thermal interface material area also becomes significant; the larger the desired thermal interface material area, the higher the force required to spread the thermal interface material.

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Appendix B: Mechanical Drawings

The following table lists the mechanical drawings included in this Section. These drawings refer to the thermal mechanical enabling components for the 3.06 GHz or higher Intel reference thermal design for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process.

Note: Intel reserves the right to make changes and modifications to the design as necessary.

Drawing Description	Figure	Page Number
Retention Mechanism – 1 of 2	Figure 25	62
Retention Mechanism – 2 of 2	Figure 26	63
Fan Clip	Figure 27	64
Fan Attach	Figure 28	65
Fan Impeller Sketch[1]	Figure 29	66
Heatsink Drawing – 1 of 2	Figure 30	67
Heatsink Drawing – 2 of 2	Figure 31	68
Fan Heatsink Assembly – 1 of 2	Figure 32	69
Fan Heatsink Assembly – 2 of 2	Figure 33	70

NOTES:

1. Detailed fan drawings are available pending the completion of appropriate licensing agreements. Contact your local Intel field sales office for more information.

Figure 25. Retention Mechanism – 1 of 2

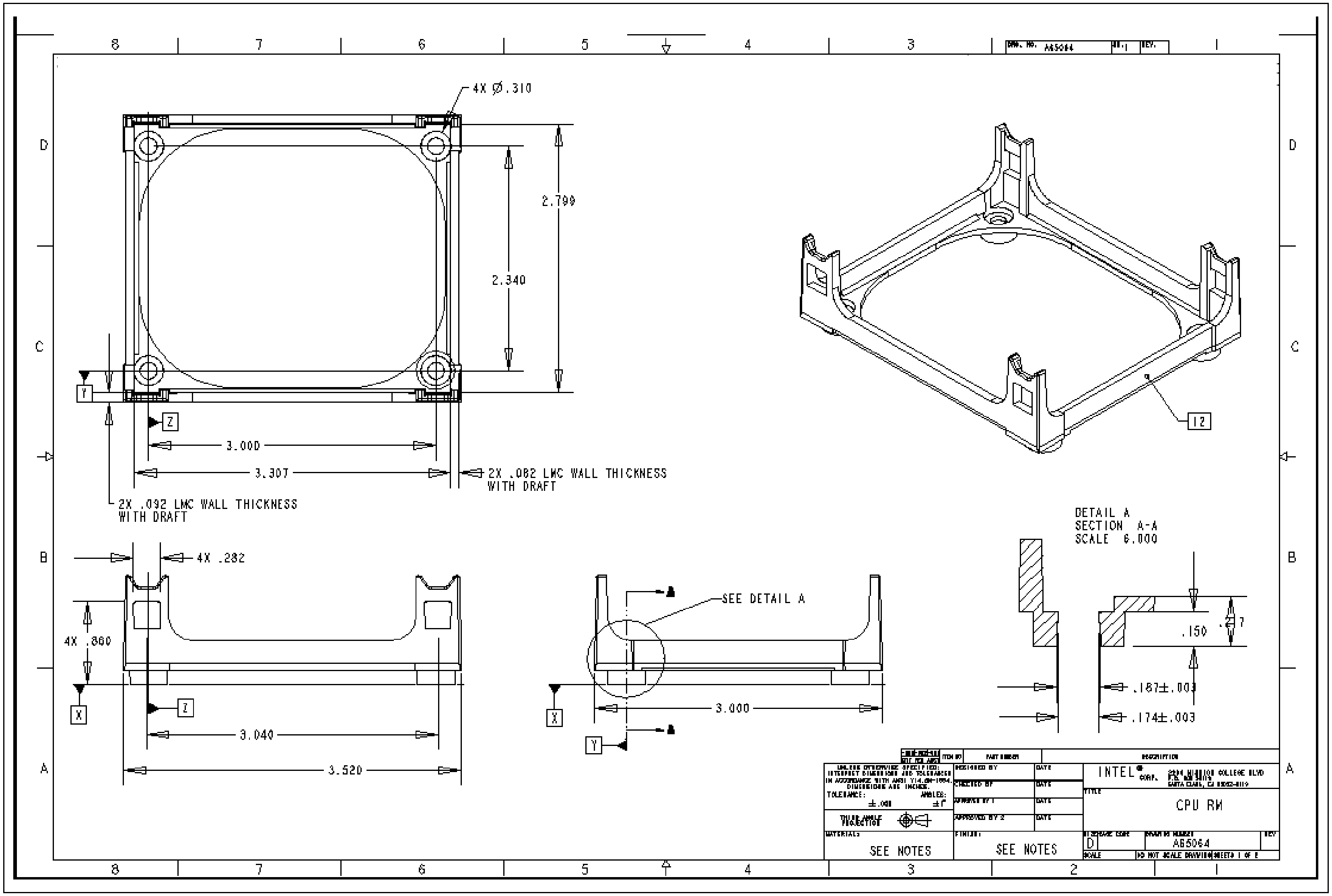
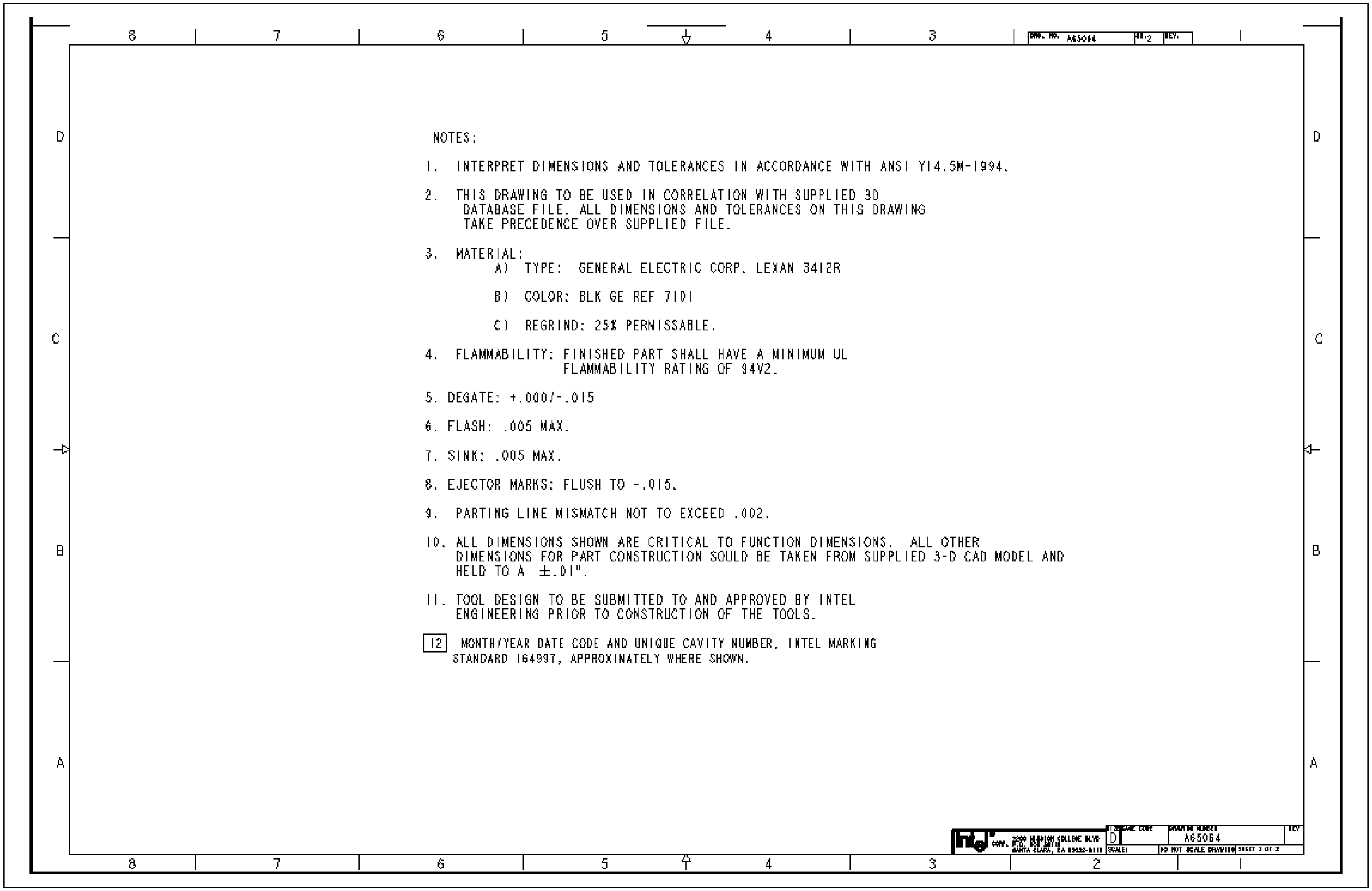


Figure 26. Retention Mechanism – 2 of 2

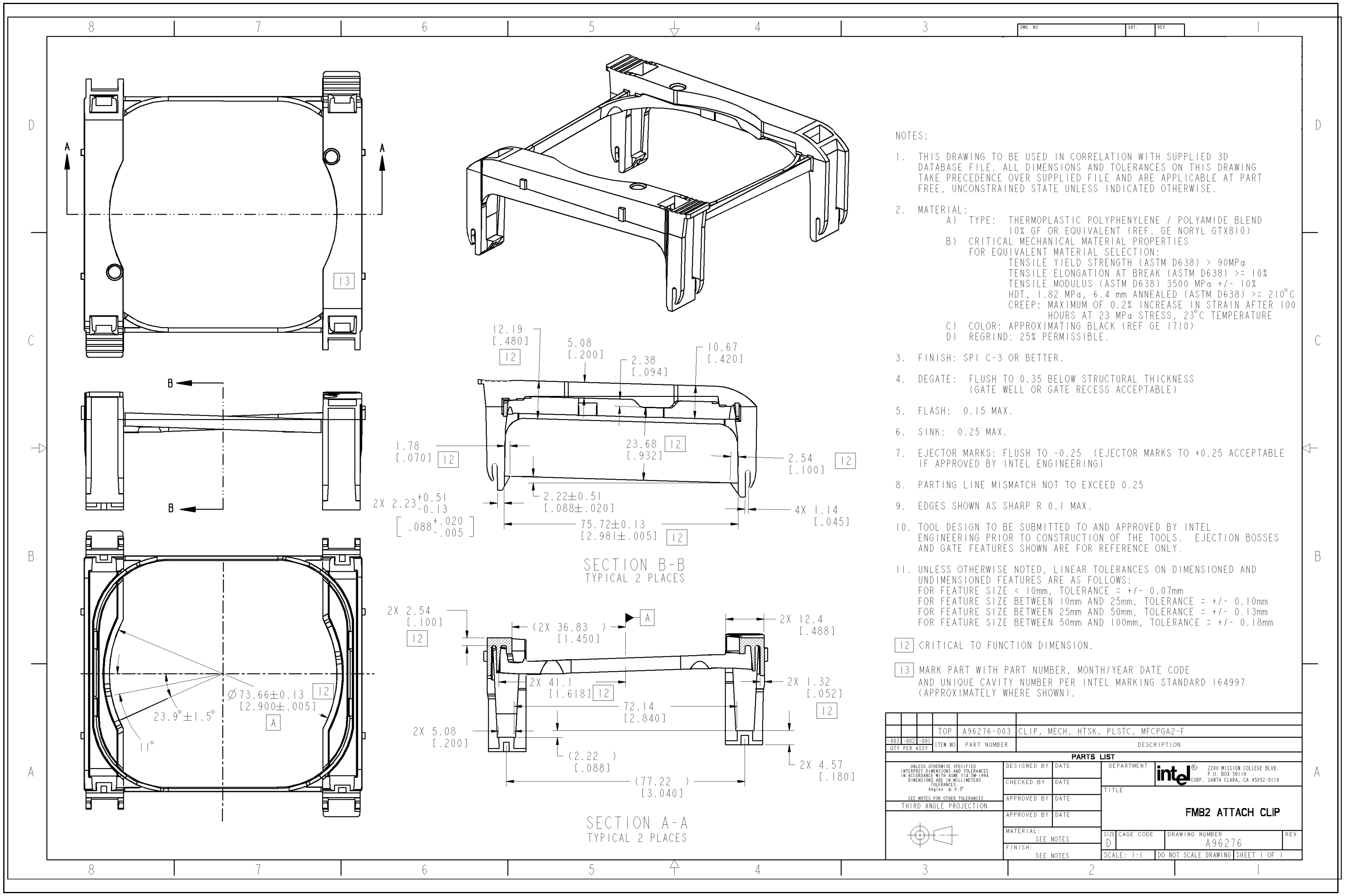


NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES IN ACCORDANCE WITH ANSI Y14.5M-1994.
2. THIS DRAWING TO BE USED IN CORRELATION WITH SUPPLIED 3D DATABASE FILE. ALL DIMENSIONS AND TOLERANCES ON THIS DRAWING TAKE PRECEDENCE OVER SUPPLIED FILE.
3. MATERIAL:
   - A) TYPE: GENERAL ELECTRIC CORP. LEXAN 3412R
   - B) COLOR: BLK GE REF 7101
   - C) REGRIND: 25% PERMISSABLE.
4. FLAMMABILITY: FINISHED PART SHALL HAVE A MINIMUM UL FLAMMABILITY RATING OF 94V2.
5. DEGATE: +.000/-.015
6. FLASH: .005 MAX.
7. SINK: .005 MAX.
8. EJECTOR MARKS: FLUSH TO -.015.
9. PARTING LINE MISMATCH NOT TO EXCEED .002.
10. ALL DIMENSIONS SHOWN ARE CRITICAL TO FUNCTION DIMENSIONS. ALL OTHER DIMENSIONS FOR PART CONSTRUCTION SOULD BE TAKEN FROM SUPPLIED 3-D CAD MODEL AND HELD TO A ±.01".
11. TOOL DESIGN TO BE SUBMITTED TO AND APPROVED BY INTEL ENGINEERING PRIOR TO CONSTRUCTION OF THE TOOLS.

$\boxed{12}$ MONTH/YEAR DATE CODE AND UNIQUE CAVITY NUMBER. INTEL MARKING STANDARD 164997, APPROXIMATELY WHERE SHOWN.

Figure 27. Clip



NOTES:

1. THIS DRAWING TO BE USED IN CORRELATION WITH SUPPLIED 3D DATABASE FILE. ALL DIMENSIONS AND TOLERANCES ON THIS DRAWING TAKE PRECEDENCE OVER SUPPLIED FILE AND ARE APPLICABLE AT PART FREE, UNCONSTRAINED STATE UNLESS INDICATED OTHERWISE.

2. MATERIAL:
   - A) TYPE: THERMOPLASTIC POLYPHENYLENE / POLYAMIDE BLEND 10% GF OR EQUIVALENT (REF. GE NORYL GTX810)
   - B) CRITICAL MECHANICAL MATERIAL PROPERTIES FOR EQUIVALENT MATERIAL SELECTION:
     - TENSILE YIELD STRENGTH (ASTM D638) > 90MPa
     - TENSILE ELONGATION AT BREAK (ASTM D638) >= 10%
     - TENSILE MODULUS (ASTM D638) 3500 MPa +/- 10%
     - HDT, 1.82 MPa, 6.4 mm ANNEALED (ASTM D638) >= 210°C
     - CREEP: MAXIMUM OF 0.2% INCREASE IN STRAIN AFTER 100 HOURS AT 23 MPa STRESS, 23°C TEMPERATURE
   - C) COLOR: APPROXIMATING BLACK (REF GE 1710)
   - D) REGRIND: 25% PERMISSIBLE.

3. FINISH: SPI C-3 OR BETTER.

4. DEGATE: FLUSH TO 0.35 BELOW STRUCTURAL THICKNESS (GATE WELL OR GATE RECESS ACCEPTABLE)

5. FLASH: 0.15 MAX.

6. SINK: 0.25 MAX.

7. EJECTOR MARKS: FLUSH TO -0.25 (EJECTOR MARKS TO +0.25 ACCEPTABLE IF APPROVED BY INTEL ENGINEERING)

8. PARTING LINE MISMATCH NOT TO EXCEED 0.25

9. EDGES SHOWN AS SHARP R 0.1 MAX.

10. TOOL DESIGN TO BE SUBMITTED TO AND APPROVED BY INTEL ENGINEERING PRIOR TO CONSTRUCTION OF THE TOOLS. EJECTION BOSSES AND GATE FEATURES SHOWN ARE FOR REFERENCE ONLY.

11. UNLESS OTHERWISE NOTED, LINEAR TOLERANCES ON DIMENSIONED AND UNDIMENSIONED FEATURES ARE AS FOLLOWS:
    FOR FEATURE SIZE < 10mm, TOLERANCE = +/- 0.07mm
    FOR FEATURE SIZE BETWEEN 10mm AND 25mm, TOLERANCE = +/- 0.10mm
    FOR FEATURE SIZE BETWEEN 25mm AND 50mm, TOLERANCE = +/- 0.13mm
    FOR FEATURE SIZE BETWEEN 50mm AND 100mm, TOLERANCE = +/- 0.18mm

12 CRITICAL TO FUNCTION DIMENSION.

13 MARK PART WITH PART NUMBER, MONTH/YEAR DATE CODE AND UNIQUE CAVITY NUMBER PER INTEL MARKING STANDARD 164997 (APPROXIMATELY WHERE SHOWN).

-003	-002	-001	ITEM NO	PART NUMBER	DESCRIPTION
			TOP	A96276-003	CLIP, MECH, HTSK, PLSTC, MFCPGA2-F

QTY PER ASSY

PARTS LIST

UNLESS OTHERWISE SPECIFIED
INTERPRET DIMENSIONS AND TOLERANCES
IN ACCORDANCE WITH ASME Y14.5M-1994
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
Angles ± 0.5°
SEE NOTES FOR OTHER TOLERANCES

THIRD ANGLE PROJECTION

DESIGNED BY | DATE
CHECKED BY | DATE
APPROVED BY | DATE
APPROVED BY | DATE
MATERIAL: SEE NOTES
FINISH: SEE NOTES

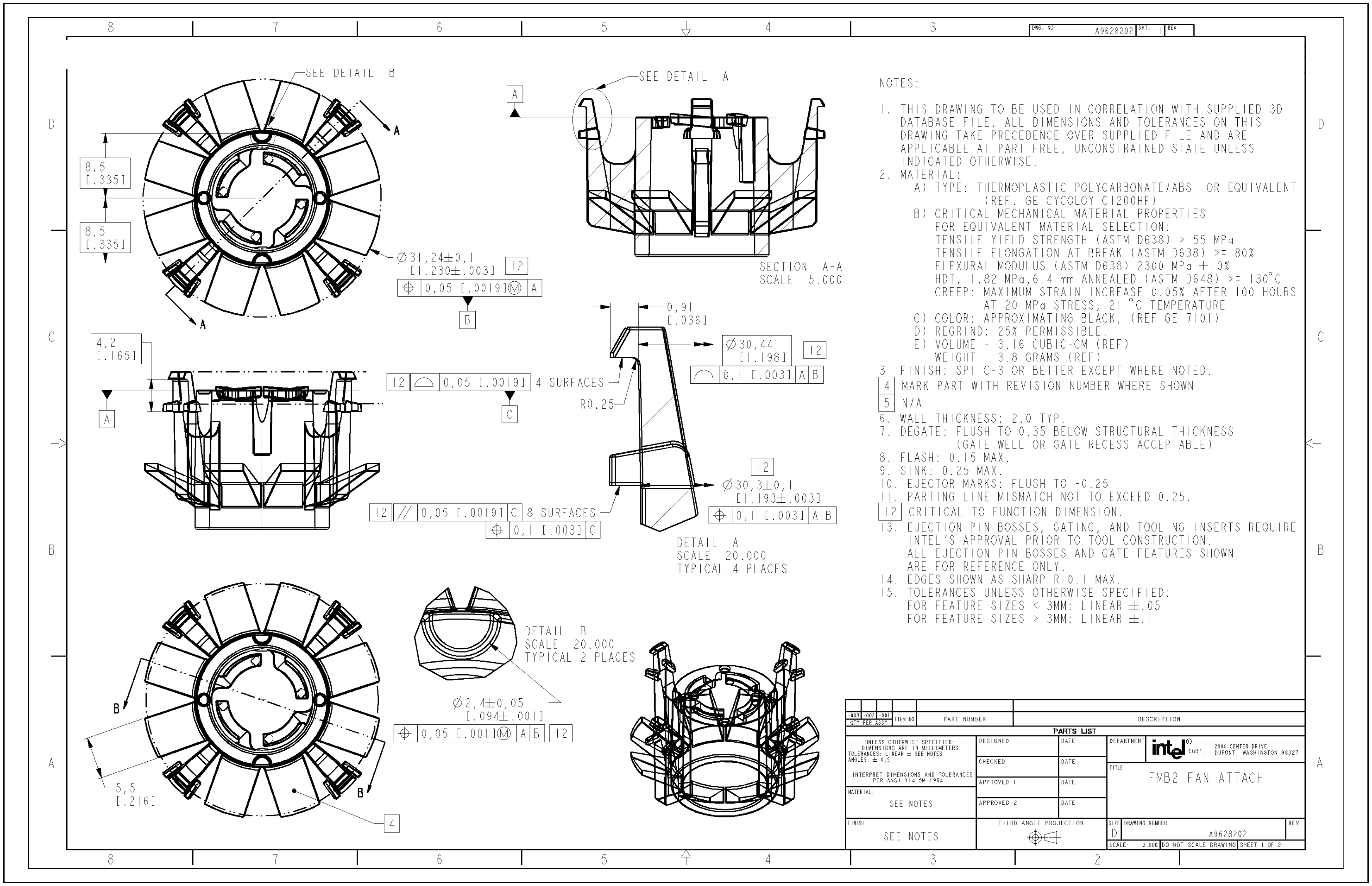
DEPARTMENT

2200 MISSION COLLEGE BLVD.
P.O. BOX 58119
CORP. SANTA CLARA, CA 95052-8119

TITLE
FMB2 ATTACH CLIP

SIZE D | CAGE CODE | DRAWING NUMBER A96276 | REV
SCALE: 1:1 | DO NOT SCALE DRAWING | SHEET 1 OF 1

Figure 28. Fan Attach



NOTES:

1. THIS DRAWING TO BE USED IN CORRELATION WITH SUPPLIED 3D DATABASE FILE. ALL DIMENSIONS AND TOLERANCES ON THIS DRAWING TAKE PRECEDENCE OVER SUPPLIED FILE AND ARE APPLICABLE AT PART FREE, UNCONSTRAINED STATE UNLESS INDICATED OTHERWISE.
2. MATERIAL:
   A) TYPE: THERMOPLASTIC POLYCARBONATE/ABS OR EQUIVALENT (REF. GE CYCOLOY C1200HF)
   B) CRITICAL MECHANICAL MATERIAL PROPERTIES FOR EQUIVALENT MATERIAL SELECTION:
      TENSILE YIELD STRENGTH (ASTM D638) > 55 MPa
      TENSILE ELONGATION AT BREAK (ASTM D638) >= 80%
      FLEXURAL MODULUS (ASTM D638) 2300 MPa ±10%
      HDT, 1.82 MPa,6.4 mm ANNEALED (ASTM D648) >= 130°C
      CREEP: MAXIMUM STRAIN INCREASE 0.05% AFTER 100 HOURS AT 20 MPa STRESS, 21 °C TEMPERATURE
   C) COLOR: APPROXIMATING BLACK, (REF GE 7101)
   D) REGRIND: 25% PERMISSIBLE.
   E) VOLUME - 3.16 CUBIC-CM (REF)
      WEIGHT - 3.8 GRAMS (REF)
3. FINISH: SPI C-3 OR BETTER EXCEPT WHERE NOTED.
4. MARK PART WITH REVISION NUMBER WHERE SHOWN
5. N/A
6. WALL THICKNESS: 2.0 TYP.
7. DEGATE: FLUSH TO 0.35 BELOW STRUCTURAL THICKNESS (GATE WELL OR GATE RECESS ACCEPTABLE)
8. FLASH: 0.15 MAX.
9. SINK: 0.25 MAX.
10. EJECTOR MARKS: FLUSH TO -0.25
11. PARTING LINE MISMATCH NOT TO EXCEED 0.25.
12. CRITICAL TO FUNCTION DIMENSION.
13. EJECTION PIN BOSSES, GATING, AND TOOLING INSERTS REQUIRE INTEL'S APPROVAL PRIOR TO TOOL CONSTRUCTION. ALL EJECTION PIN BOSSES AND GATE FEATURES SHOWN ARE FOR REFERENCE ONLY.
14. EDGES SHOWN AS SHARP R 0.1 MAX.
15. TOLERANCES UNLESS OTHERWISE SPECIFIED:
    FOR FEATURE SIZES < 3MM: LINEAR ±.05
    FOR FEATURE SIZES > 3MM: LINEAR ±.1

-003	-002	-001	ITEM NO	PART NUMBER	DESCRIPTION
QTY PER ASSY					

PARTS LIST

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS.
TOLERANCES: LINEAR ± SEE NOTES
ANGLES: ± 0.5

INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M-1994

MATERIAL: SEE NOTES

FINISH: SEE NOTES

DESIGNED DATE
CHECKED DATE
APPROVED 1 DATE
APPROVED 2 DATE

THIRD ANGLE PROJECTION

DEPARTMENT
intel® CORP. 2800 CENTER DRIVE
DUPONT, WASHINGTON 98327

TITLE FMB2 FAN ATTACH

SIZE D
DRAWING NUMBER A9628202
REV
SCALE: 3.000
DO NOT SCALE DRAWING
SHEET 1 OF 2

Figure 29. Fan Impeller Sketch

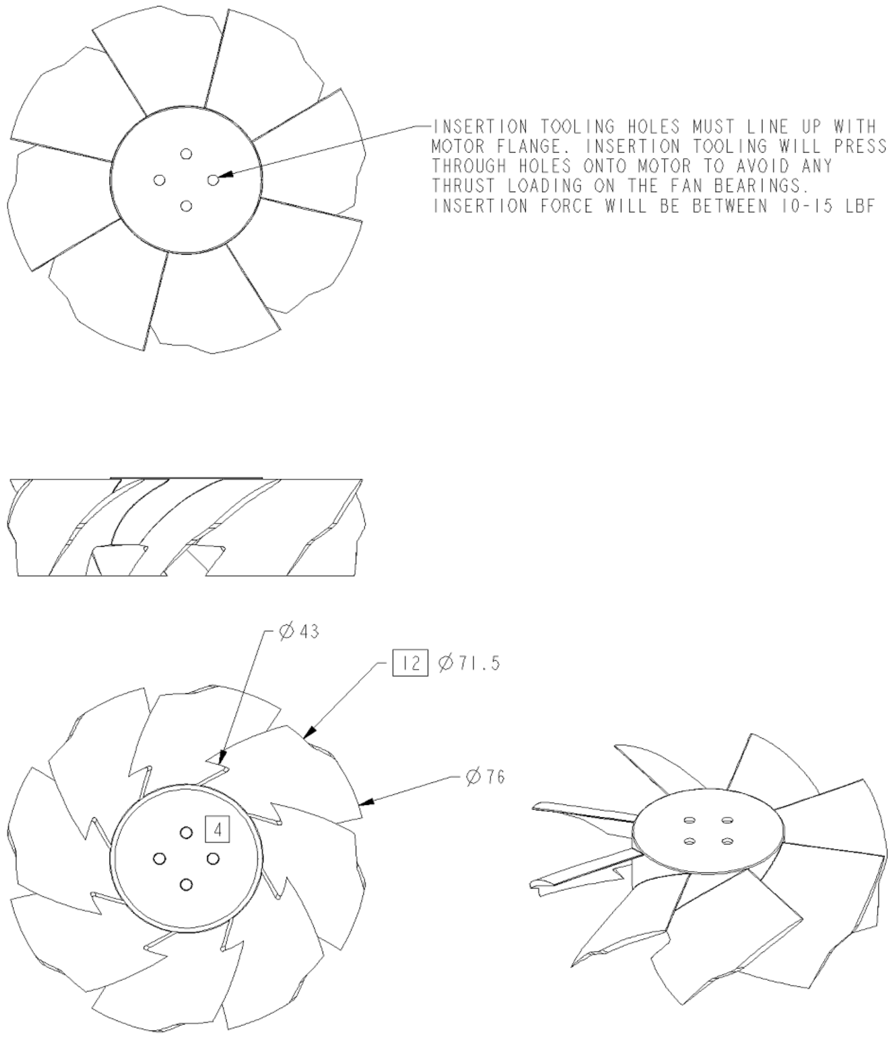


Figure 30. Heatsink Drawing - 1 of 2

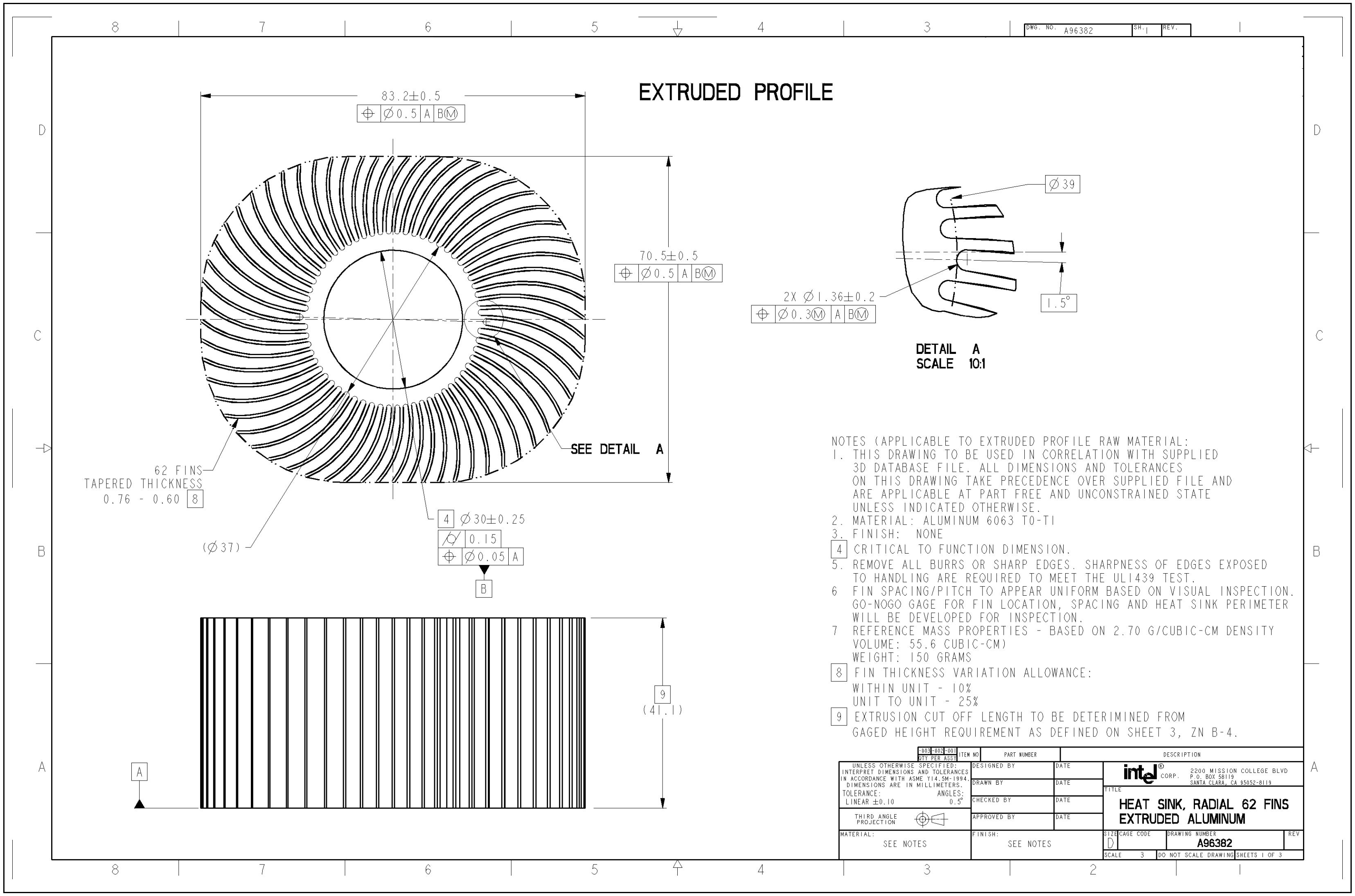
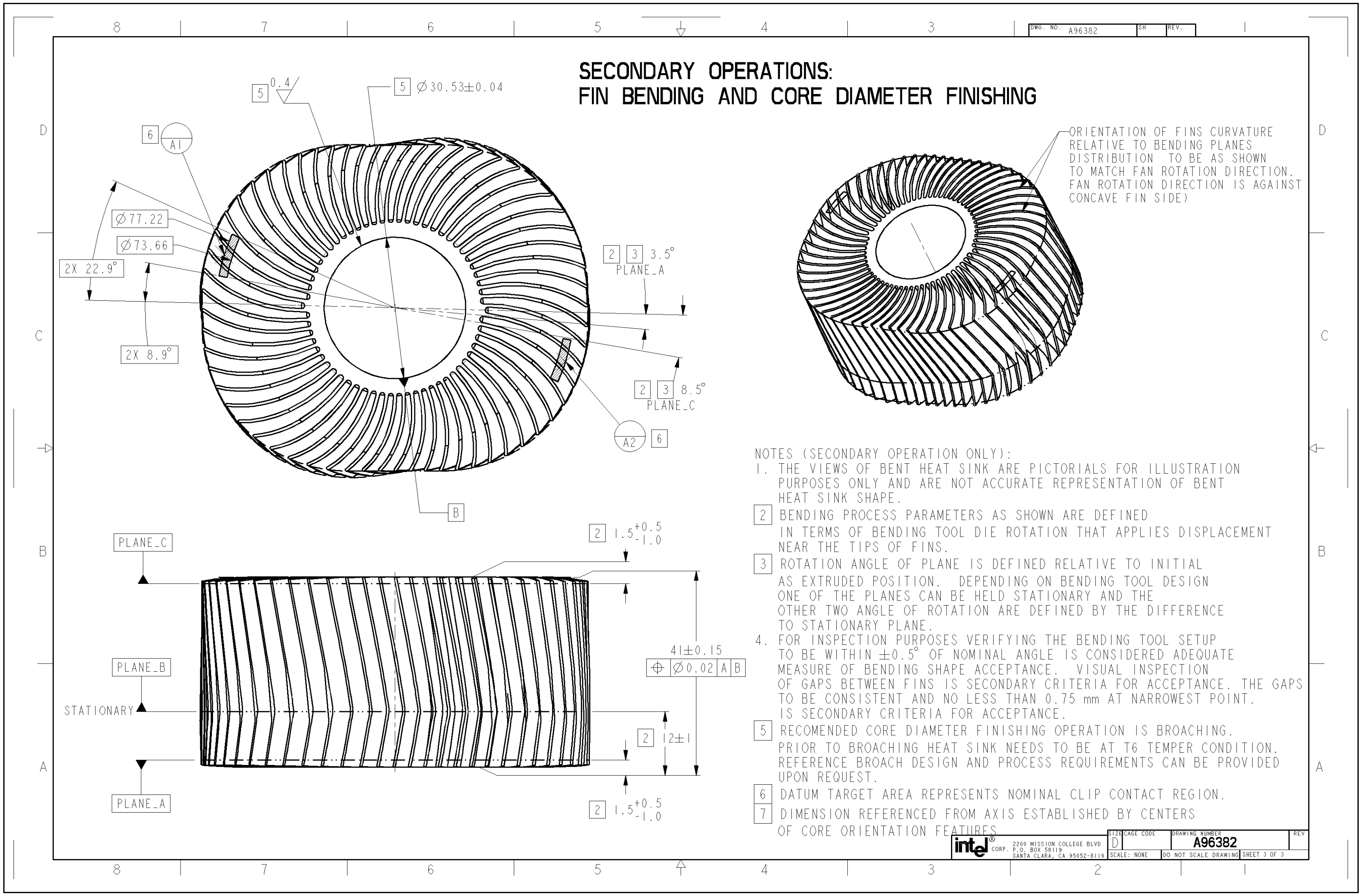


Figure 31: Heatsink Drawing – 2 of 2



SECONDARY OPERATIONS:
FIN BENDING AND CORE DIAMETER FINISHING

ORIENTATION OF FINS CURVATURE RELATIVE TO BENDING PLANES DISTRIBUTION TO BE AS SHOWN TO MATCH FAN ROTATION DIRECTION. FAN ROTATION DIRECTION IS AGAINST CONCAVE FIN SIDE)

NOTES (SECONDARY OPERATION ONLY):

1. THE VIEWS OF BENT HEAT SINK ARE PICTORIALS FOR ILLUSTRATION PURPOSES ONLY AND ARE NOT ACCURATE REPRESENTATION OF BENT HEAT SINK SHAPE.

2 BENDING PROCESS PARAMETERS AS SHOWN ARE DEFINED IN TERMS OF BENDING TOOL DIE ROTATION THAT APPLIES DISPLACEMENT NEAR THE TIPS OF FINS.

3 ROTATION ANGLE OF PLANE IS DEFINED RELATIVE TO INITIAL AS EXTRUDED POSITION. DEPENDING ON BENDING TOOL DESIGN ONE OF THE PLANES CAN BE HELD STATIONARY AND THE OTHER TWO ANGLE OF ROTATION ARE DEFINED BY THE DIFFERENCE TO STATIONARY PLANE.

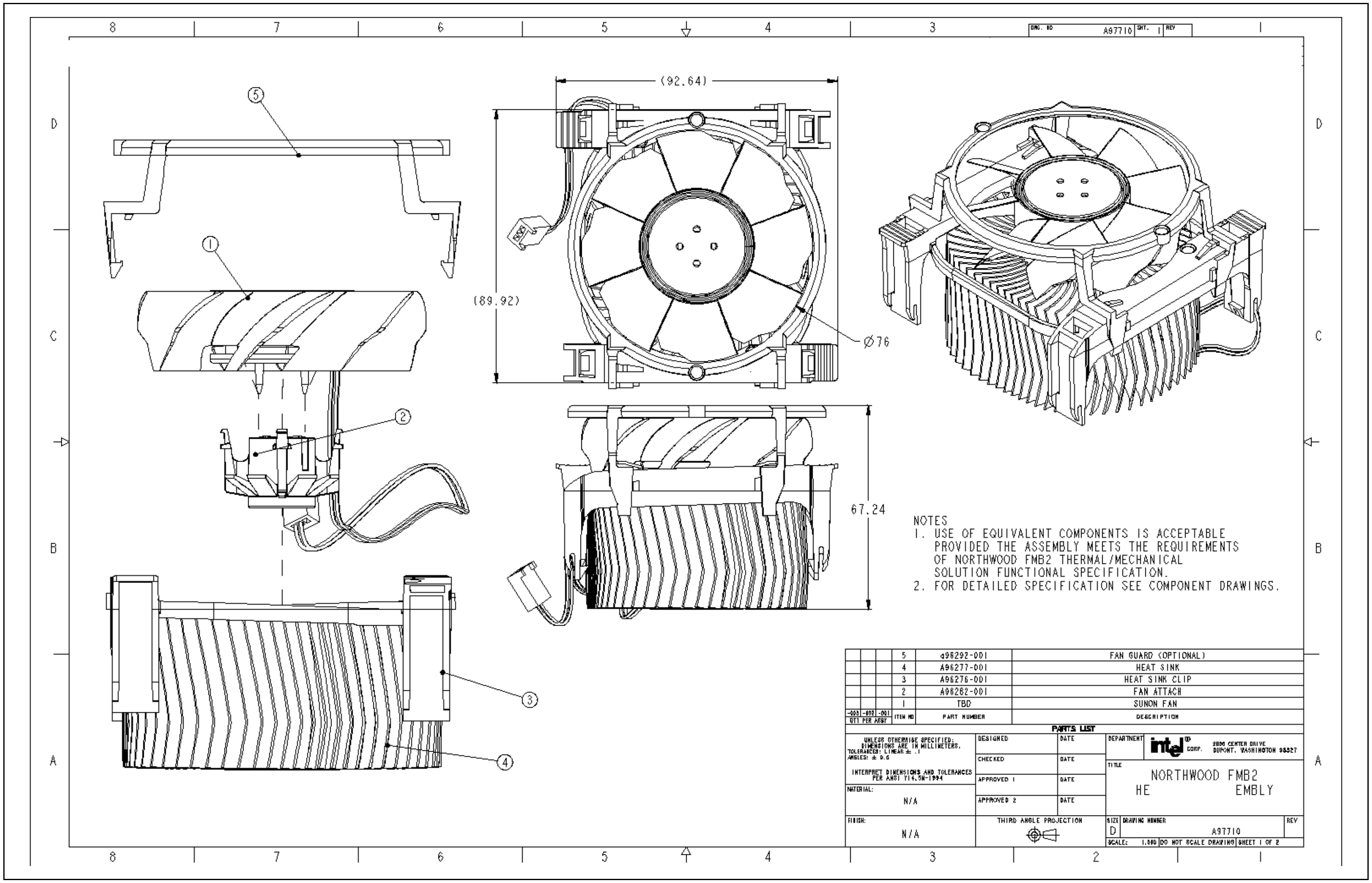
4. FOR INSPECTION PURPOSES VERIFYING THE BENDING TOOL SETUP TO BE WITHIN ±0.5° OF NOMINAL ANGLE IS CONSIDERED ADEQUATE MEASURE OF BENDING SHAPE ACCEPTANCE. VISUAL INSPECTION OF GAPS BETWEEN FINS IS SECONDARY CRITERIA FOR ACCEPTANCE. THE GAPS TO BE CONSISTENT AND NO LESS THAN 0.75 mm AT NARROWEST POINT. IS SECONDARY CRITERIA FOR ACCEPTANCE.

5 RECOMENDED CORE DIAMETER FINISHING OPERATION IS BROACHING. PRIOR TO BROACHING HEAT SINK NEEDS TO BE AT T6 TEMPER CONDITION. REFERENCE BROACH DESIGN AND PROCESS REQUIREMENTS CAN BE PROVIDED UPON REQUEST.

6 DATUM TARGET AREA REPRESENTS NOMINAL CLIP CONTACT REGION.

7 DIMENSION REFERENCED FROM AXIS ESTABLISHED BY CENTERS OF CORE ORIENTATION FEATURES

Figure 32. Fan Heatsink Assembly (with non-validated fan guard) – 1 of 2



NOTES
1. USE OF EQUIVALENT COMPONENTS IS ACCEPTABLE PROVIDED THE ASSEMBLY MEETS THE REQUIREMENTS OF NORTHWOOD FMB2 THERMAL/MECHANICAL SOLUTION FUNCTIONAL SPECIFICATION.
2. FOR DETAILED SPECIFICATION SEE COMPONENT DRAWINGS.

-003	-002	-001	ITEM NO	PART NUMBER	DESCRIPTION
			5	a96292-001	FAN GUARD (OPTIONAL)
			4	A96277-001	HEAT SINK
			3	A96276-001	HEAT SINK CLIP
			2	A98262-001	FAN ATTACH
			1	TBD	SUNON FAN

QTY PER ASSY

PARTS LIST

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS.
TOLERANCES: LINEAR ± .1
ANGLES: ± 0.5

INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M-1994

MATERIAL: N/A

FINISH: N/A

DESIGNED DATE
CHECKED DATE
APPROVED 1 DATE
APPROVED 2 DATE

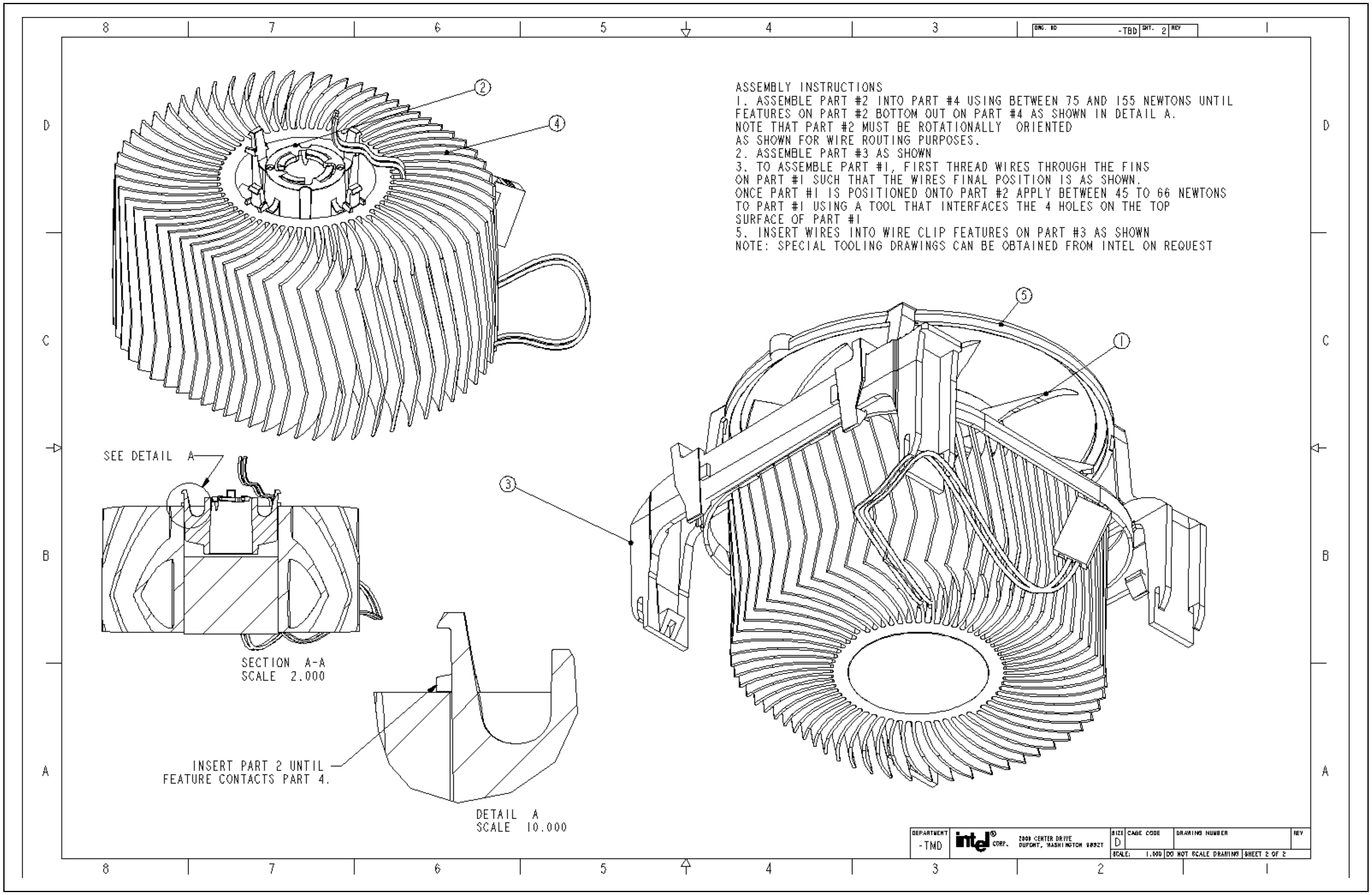
THIRD ANGLE PROJECTION

DEPARTMENT
intel® CORP. 2800 CENTER DRIVE DUPONT, WASHINGTON 98327

TITLE
NORTHWOOD FMB2
HE EMBLY

SIZE D DRAWING NUMBER A97710 REV
SCALE: 1.000 DO NOT SCALE DRAWING SHEET 1 OF 2

Figure 33. Fan Heatsink Assembly (with non-validated fan guard) – 2 of 2



ASSEMBLY INSTRUCTIONS

1. ASSEMBLE PART #2 INTO PART #4 USING BETWEEN 75 AND 155 NEWTONS UNTIL FEATURES ON PART #2 BOTTOM OUT ON PART #4 AS SHOWN IN DETAIL A. NOTE THAT PART #2 MUST BE ROTATIONALLY ORIENTED AS SHOWN FOR WIRE ROUTING PURPOSES.
2. ASSEMBLE PART #3 AS SHOWN
3. TO ASSEMBLE PART #1, FIRST THREAD WIRES THROUGH THE FINS ON PART #1 SUCH THAT THE WIRES FINAL POSITION IS AS SHOWN. ONCE PART #1 IS POSITIONED ONTO PART #2 APPLY BETWEEN 45 TO 66 NEWTONS TO PART #1 USING A TOOL THAT INTERFACES THE 4 HOLES ON THE TOP SURFACE OF PART #1
5. INSERT WIRES INTO WIRE CLIP FEATURES ON PART #3 AS SHOWN

NOTE: SPECIAL TOOLING DRAWINGS CAN BE OBTAINED FROM INTEL ON REQUEST

SEE DETAIL A

SECTION A-A
SCALE 2.000

INSERT PART 2 UNTIL FEATURE CONTACTS PART 4.

DETAIL A
SCALE 10.000

Appendix C: Intel Enabled Reference Thermal Solution

This appendix includes supplier information for Intel enabled vendors for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process.

As mentioned earlier, the reference component designs are available for adoption by suppliers and heatsink integrators pending completion of appropriate licensing contracts. For more information on licensing, contact the Intel representative below.

Table 6. Intel Representative Contact for Licensing Information

Company	Contact	Phone	Email
Intel Corporation	Tony De Leon	(253) 371-9339	tony.deleon@intel.com

Table 7 lists suppliers that produce Intel enabled reference components. The part numbers listed below identifies these reference components. End-users are responsible for the verification of the Intel enabled component offerings with the supplier. OEMs and System Integrators are responsible for thermal, mechanical, and environmental validation of these solutions.

Table 7. Intel Reference Component Thermal Solution Provider(s)

Supplier	Part Description	Part Number(s)	Contact	Phone	Email
EKL	Integrated Thermal Solution	A97710-001	Peter Goodman	49-075-61-9837-28	peter.goodman@ekl-ag.de
Foxconn	Retention Mechanism	A65064-001	Julia Jiang	408-919-6178	juliaj@foxconn.com

Note: These vendors and devices are listed by Intel as a convenience to Intel's general customer base, but Intel does not make any representations or warranties whatsoever regarding quality, reliability, functionality, or compatibility of these devices. This list and/or these devices may be subject to change without notice.

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Appendix D: Evaluated Third-Party Thermal Solutions

This section represents solutions that have been independently tested by an Intel-enabled third party test house. These solutions have been tested and found to be compliant with the minimum thermal and mechanical performance criteria for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process and the Pentium 4 processor supporting Hyper-Threading Technology[1].

These suppliers may produce other compliant and non-compliant solutions in addition to the part numbers that are listed in Table 8. OEM, System Integrators, and End Users are responsible for ensuring that any solution chosen meets the thermal, mechanical, and environmental needs of their particular system or configuration. Please reference, http://developer.intel.com/design/Pentium4/components/index.htm , for the most recent information.

Table 8. Independently Evaluated Thermal Solutions

Supplier	Part Number(s)	Contact / (Geography)	Phone	Email
AVC	Z7U2403002	Vincent Lee / (North America)	310-783-5484	vincent@avc.com.tw
		Sam Chen / (Asia)	886-2-22996930 ext. 137	sam@avc.com.tw
Cooler Master	KI4-75H52A	Jensen Kuo / (North America)	510-770-8566	Jensenk@coolermaster.com
		Jerry Chen / (Asia)	886-2-3234-0050	jerryc@coolermaster.com.tw
Furukawa	HS2424	Katsu Mizushima (North America)	408-232-9306	katsumizushima@mindspring.com
TaiSol	CCP445172	Mian Huang Wibowo / (North America)	650-655-7204	mian@taisol.com
		Jane Yui / (Asia)	886-2-2698-1165	jane.yui@taisol.com.tw
Thermaltake	A1481	David Hwang / (North America)	909-595-0896	davidh@thermaltake.com
		Michael Lee / (Asia)	886-2-26626501 ext. 58	michael@thermaltake.com