Intel® Pentium® 4 Processor on 90 nm Process *Thermal and Mechanical Design Guidelines*

Design Guide

February 2004

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1 Hyper-Threading Technology requires a computer system with an Intel® Pentium® 4 processor supporting HT Technology and an HT Technology enabled chipset, BIOS and operating system. Performance will vary depending on the specific hardware and software you use. See http://www.intel.com/info/hyperthreading/ for more information including details on which processors support HT Technology.

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Revision History

Revision Number	Description	Date
-001	• Initial Release	February 2004

1 Introduction

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 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.

Depending on the type of system and the chassis characteristics, new system and component 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 on 90 nm process.

Chapter 3 discusses thermal solution design for the Pentium 4 processor on 90 nm process in the context of personal computer applications. This section also includes thermal metrology recommendation to validate a processor thermal solution. It also addresses the benefits of the processor's integrated thermal management logic for thermal design.

Chapter 4 provides preliminary information on the Intel reference thermal solution for the Pentium 4 processor on 90 nm process.

Note: The physical dimensions and thermal specifications of the processor that may be used in this document are for illustration only. Refer to the *Pentium 4 processor on 90 nm 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.

1.1 Overview

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 on 90 nm process integrates thermal management logic onto the processor silicon. The Thermal Monitor feature is automatically configured to control the processor temperature. In the event the die temperature reaches a factory-calibrated temperature, the processor will take steps to reduce power consumption, causing 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 thermal solution designed to the TDP and case temperature, T_C, as specified in the *Intel® Pentium® 4 Processor on 90 nm 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 presents the conditions and requirements for designing a heatsink solution for a system based on a Pentium 4 processor on 90 nm 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 minimal thermal resistance 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.

1.2 References

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

Document[1]	Location
Intel® Pentium® 4 Processor on 90 nm Process Datasheet	http://developer.intel.com/design/pentium4/datashts/300561.htm
Intel® 865G/865GV/865PE/865P Chipset Design Guide	http://developer.intel.com/design/chipsets/designex/252518.htm
Intel® 865G/865GV Chipset: Intel® 82865G/82865GV Graphics and Memory Controller Hub (GMCH) Datasheet	http://www.intel.com/design/chipsets/datashts/252514.htm
Intel® Pentium® 4 Processor with 512 KB L2 Cache on 0.13 Micron Process Thermal Design Guidelines	http://developer.intel.com/design/pentium4/guides/252161.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 Processor 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/

NOTES:

1. Contact your Intel field sales representative for information on additional documentation.

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_C	The case temperature of the processor, measured at the geometric center of the topside of the IHS.
T_E	The ambient air temperature external to a system chassis. This temperature is usually measured at the chassis air inlets.
T_S	Heatsink temperature measured on the underside of the heatsink base, at a location corresponding to T_C.
$T_{C\text{-}MAX}$	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.

Term	**Description**
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	The surface mount Zero Insertion Force (ZIF) socket designed to accept the Intel® Pentium® 4 processor on 90 nm 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 on 90 nm 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.
TTV	The Thermal Test Vehicle is a thermal test tool that is used in component heatsink design. The availability of of this tool is limited. Contact your local field sales representative for more information.

2 Mechanical Requirements

2.1 Processor Package

The Pentium 4 processor on 90 nm process is packaged using Flip-Chip Micro Pin Grid Array 4 (FC-mPGA4) package technology. Refer to the *Intel® Pentium® 4 Processor on 90 nm Process Datasheet* for detailed mechanical specifications.

The package includes an integrated heat spreader (IHS). The IHS transfers the non-uniform heat from the die to the top of the IHS, out of which the heat flux is more uniform and spread over a larger surface area (not the entire IHS area). This allows more efficient heat transfer out of the package to an attached cooling device. The IHS is designed to be the interface for contacting a heatsink. Details are in the *Intel® Pentium® 4 Processor on 90 nm 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 processor 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, it should not exceed the corresponding specification 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 must be taken into account in dynamic load calculations. The total combination of dynamic and static compressive load should not then exceed the processor datasheet compressive dynamic load specification during a vertical shock. For example, with a 0.454 kg [1 lbm] heatsink, an acceleration of 50 G during an 11 ms shock with an amplification factor of 2 results in approximately a 445 N [100 lbf] dynamic load on the processor package. If a 445 N [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 890 N [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.

2.2 Heatsink Attach

There are no features on the mPGA478 socket to directly attach a heatsink: a mechanism must be designed to support the heatsink. In addition to holding the heatsink in 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 (TIM) applied between the IHS and the heatsink. TIMs based on phase change materials are very sensitive to applied pressure: the higher the pressure, the better the initial performance. TIMs such as thermal greases are not as sensitive to applied pressure. Refer to Section 3.2.1.2 and Appendix A for information on tradeoffs made with TIM selection. Designs should consider possible decrease in applied pressure over time due to potential structural relaxation in retention components.
- Ensuring system electrical, thermal, and structural integrity under shock and vibration events. The mechanical requirements of the attach mechanism depend on the weight of the heatsink and the level of shock and vibration that the system must support. The overall structural design of the motherboard and the system has to be considered as well when designing the heatsink attach mechanism. The design should provide a means for protecting mPGA478 socket solder joints as well as prevent package pullout from the socket.

A popular mechanical solution for heatsink attach is the use of a retention mechanism and attach clips. In this case, the clips should be designed to the general guidelines given above, in addition to the following:

- Ability to hold the heatsink in place under mechanical 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. Note that the load applied by the clips must comply with the package specifications described in Section 2.1, along with the dynamic load added by the mechanical shock and vibration requirements.
- Engages easily with the retention mechanism tabs, and if possible, without the use of special tools. In general, the heatsink and clip are assumed to be installed after the motherboard has been installed into the chassis.
- Minimizes contact with the motherboard surface during clip attach to the retention mechanism tab features; the clip should not scratch the motherboard.

The Intel reference design for the Pentium 4 processor in the 478-Pin Package (or Pentium 4 processor on 90 nm process) is using a retention mechanism and clip assembly. Refer to Chapter 4 and the document titled *Mechanical Enabling for the Intel® Pentium® 4 Processor in the 478-Pin Package* for further information regarding the Intel reference mechanical solution.

3 Thermal Requirements

3.1 Processor Case Temperature and Power Dissipation

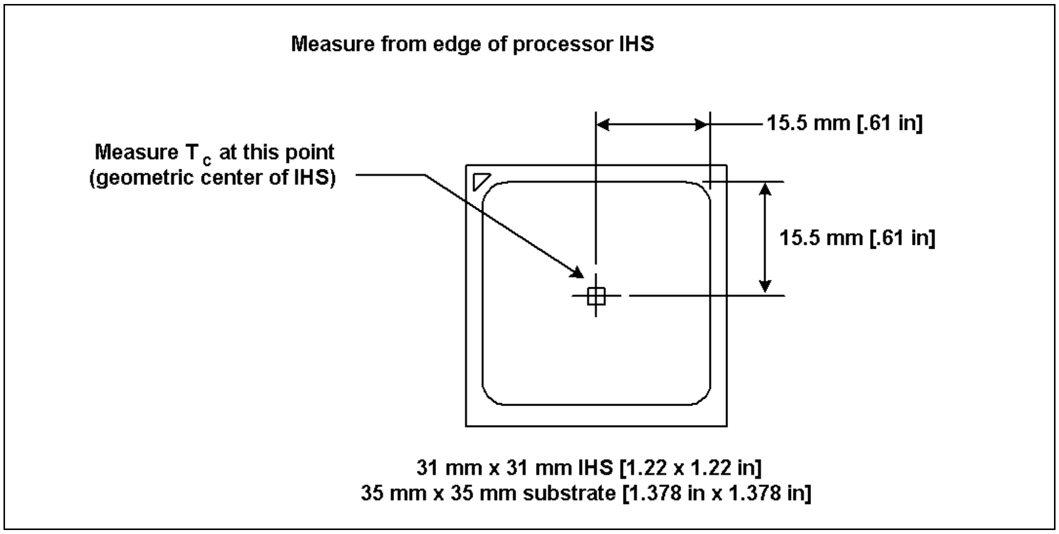
Refer to the *Intel® Pentium® 4 Processor on 90 nm Process Datasheet* for processor thermal specifications.

Thermal specifications for the Pentium 4 processor on 90 nm process is the thermal profile. The thermal profile defines maximum case temperature as a function of power dissipated. The maximum case temperature for the maximum thermal design power (TDP) is the end point of the thermal profile. The thermal profile accounts for processor frequencies and manufacturing variations. Designing to these specifications allows optimization of thermal designs for processor performance (refer to Section 3.4).

The majority of processor power is dissipated up through the Integrated Heat Spreader (IHS). There are no additional components (i.e., BSRAMs) that generate heat on this package. The amount of power that can be dissipated as heat through the processor package substrate and into the socket is usually minimal.

The case temperature is defined as the temperature measured at the geometric center of the top surface of the IHS. This point also corresponds to the geometric center of the package for the Pentium 4 processor on 90 nm process. For illustration, the measurement location for a 35 mm x 35 mm [1.378 in x 1.378 in] FC-mPGA4 package with 31 mm x 31 mm [1.22 in x 1.22 in] IHS is shown in Figure 1. Techniques for measuring the case temperature are detailed in Section 3.3.3. In case of conflict, the package dimensions in the processor datasheet supercede dimensions provided in this document.

Figure 1. Processor Case Temperature Measurement Location



3.2 Intel® Pentium® 4 Processor on 90 nm Process Thermal Solution Design Considerations

3.2.1 Heatsink Solutions

3.2.1.1 Heatsink Design Considerations

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

- **The area of the surface on which the heat transfer takes place**. Without any enhancements, this is the surface of the processor package IHS. One method used to improve thermal performance is by attaching a heatsink to the IHS. A heatsink can increase the effective heat transfer surface area by conducting heat out of the IHS and into the surrounding air through fins attached to the heatsink base.
- **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 improves 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 a higher impact on the overall thermal solution performance as processor cooling requirements become stricter. Thermal interface material (TIM) is used to fill in the gap between the IHS and the bottom surface of the heatsink, and thereby improve the overall performance of the stack-up (IHS-TIM-Heatsink). 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 Section 3.2.1.2 and Appendix A for further information on TIM and on bond line management 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 over the surface, and the cooler the air, the more efficient is the resulting cooling. The nature of the airflow can also enhance heat transfer via convection. Turbulent flow can provide improvement over laminar flow. In the case of a heatsink, the surface exposed to the flow includes in particular 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. Typically, passive heatsinks see lower air speed. These heatsinks are, therefore, typically larger (and heavier) than active heatsinks due to the increase in fin surface required to meet a required 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 travels around the heatsink instead of through it, unless air bypass is carefully managed. Using air-ducting techniques to manage bypass area can be an effective method for controlling airflow through the heatsink.

3.2.1.2 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 over it. This tape must be removed prior to heatsink installation.

3.2.2 System Thermal Solution Considerations

3.2.2.1 Chassis Thermal Design Capabilities

For the Pentium 4 processor on 90 nm process at frequencies published in the *Intel® Pentium® 4 Processor on 90 nm Process Datasheet*, the Intel reference thermal solution assumes that the chassis delivers a maximum T_A of 38 °C at the inlet of the processor fan heatsink.

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 determine the chassis thermal performance, and the resulting ambient temperature around the processor. The size and type (passive or active) of the thermal solution and the amount of system airflow 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 entire 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.

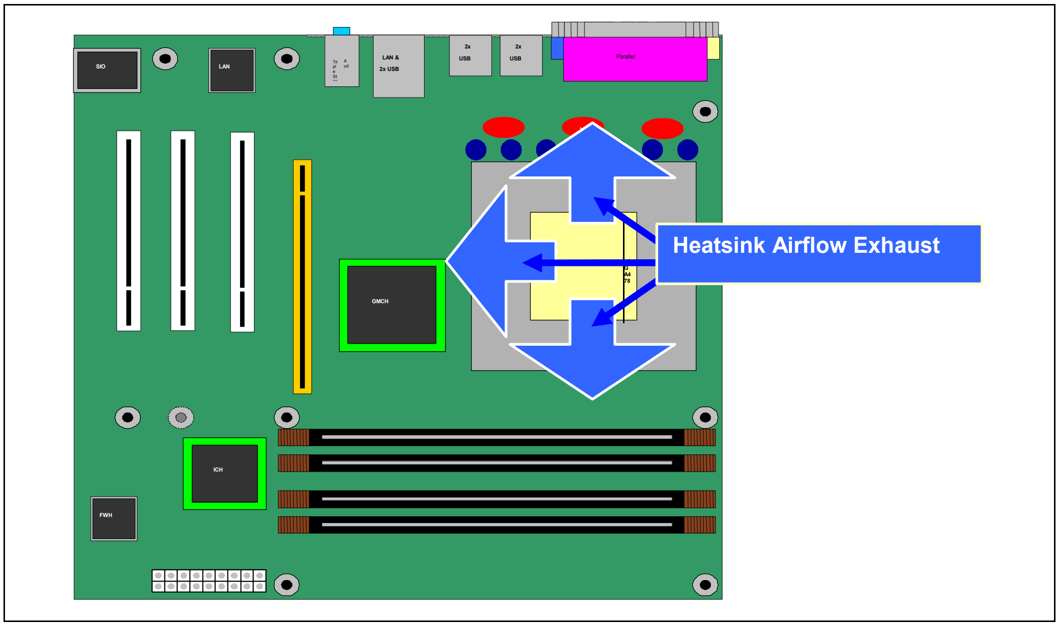
To ease the burden on thermal solutions, the Thermal Monitor feature and associated logic have been integrated into the silicon of the Pentium 4 processor on 90 nm process. By taking advantage of the Thermal Monitor feature, system designers may reduce thermal solution cost by designing to TDP instead of maximum power. Thermal Monitor can protect the processor in rare excursions of workload above TDP. Implementation options and recommendations are described in Section 3.4.

3.2.2.3 Omni Directional Airflow

Intel recommends that the heatsink exhaust air in all directions parallel to the motherboard, thus, allowing airflow in the direction of the memory, chipset, and voltage regulator components. Airflow speed may be difficult to determine; however, it is suggested that the low fan set point flow rate be greater than 150 lfm at board level upstream from the fore mentioned components.

Using the exhaust air from the heatsink may provide a cost effective option for system thermal designers in lieu of additional hardware or fans. Of course, the efficiency of the shared airflow is dependant on many board and system variables (such as, board layout, air velocity profile, air speed, air temperature, chassis configuration, flow obstructions, and other tangible and intangible variables).

Figure 2. Heatsink Exhaust Providing Platform Subsystem Cooling



3.2.3 Characterizing Cooling Performance Requirements

The idea of a “thermal characterization parameter” Ψ (psi) is a convenient way to characterize the performance needed for the thermal solution and to compare thermal solutions in identical situations (same heating source and local ambient conditions). A thermal characterization parameter is convenient in that it is calculated using total package power, whereas actual thermal resistance, Θ (theta), is calculated using actual power dissipated between two points. Measuring actual power dissipated into the heatsink is difficult since some of the power is dissipated via heat transfer into the socket and board. Be aware, however, of the limitations of lumped parameters such as Ψ in a real design. Heat transfer is a three-dimensional phenomenon that can rarely be accurately and easily modeled by lump values.

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

Equation 1

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

Where:

Ψ_{CA} = Case-to-local ambient thermal characterization parameter (°C/W)
T_C = Processor case temperature (°C)
T_A = Local ambient temperature in chassis at processor (°C)
P_D = Processor total package power dissipation (W)

The case-to-local ambient thermal characterization parameter of the processor, 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

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

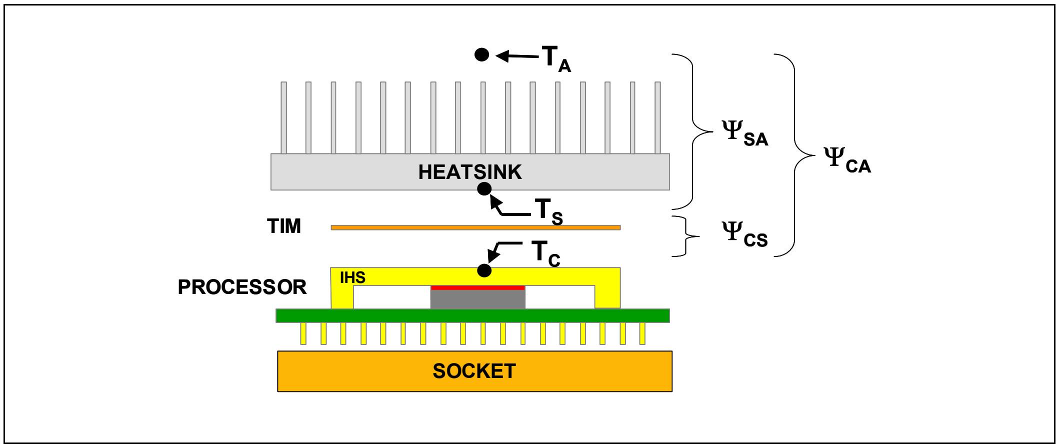
Where:

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 heatsink material, thermal conductivity, and geometry. It is also strongly dependent on the air velocity through the fins of the heatsink.
Figure 3 illustrates the combination of the different thermal characterization parameters.

Figure 3. Processor Thermal Characterization Parameter Relationships



3.2.3.1 Example

The cooling performance, $\Psi_{CA,}$ is then defined using the principle 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, F, given in the processor datasheet.
- Define a target local ambient temperature at the processor, T_A.

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

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

Assume the datasheet TDP is 75 W and the case temperature specification is 65 °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:

Equation 3

$$\Psi_{CA} = (T_{C,F} - T_A) / TDP_F = (65 - 38) / 75 = 0.36\ ^\circ C/W$$

To determine the required heatsink performance, a heatsink solution provider would need to determine Ψ_{CS} performance for the selected TIM and mechanical load configuration. If the heatsink solution were designed to work with a TIM material performing at $\Psi_{CS} \leq 0.05$ °C/W, solving for Equation 2 from above, the performance of the heatsink would be:

Equation 4

$$\Psi_{SA} = \Psi_{CA} - \Psi_{CS} = 0.36 - 0.05 = 0.31\ ^\circ C/W$$

3.3 Thermal Metrology for the Intel® Pentium® 4 Processor on 90 nm Process

3.3.1 Processor Heatsink Performance Assessment

This section discusses guidelines for testing thermal solutions, including measuring processor temperatures. In all cases, the thermal engineer must measure power dissipation and temperature to validate a thermal solution.

Thermal performance of a heatsink should be assessed using a thermal test vehicle (TTV) provided by Intel. The TTV is a well-characterized thermal tool, whereas real processors can introduce additional factors that can impact test results. In particular, the power level from actual processors varies significantly due to 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 an actual processor is beyond the scope of this document.

Once the thermal solution is designed and validated with the TTV, it is **strongly** 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 eliminates 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 and hub spokes. 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 3 mm to 8 mm [0.1 to 0.3 in] above the fan hub vertically and halfway between the fan hub and the fan housing horizontally as shown in Figure 4 (avoiding the hub spokes). Using an open bench to characterize an active heatsink can be useful, and usually ensures more uniform temperatures at the fan inlet. However, additional tests that include a solid barrier above the test motherboard surface can help evaluate the potential impact of the chassis. This barrier is typically clear Plexiglas*, extending at least 100 mm [4 in] in all directions beyond the edge of the thermal solution. Typical distance from the motherboard to the barrier is 81 mm [3.2 in]. For even more realistic airflow, the motherboard should be populated with significant elements like memory cards, AGP card, and chipset heatsink. If a barrier is used, the thermocouple can be taped directly to the barrier with a clear tape at the horizontal location 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 in a chassis with a live motherboard, add-in cards, and other system components, it is likely that the T_A measurements will reveal a highly non-uniform temperature distribution across the inlet fan section.

For **passive heatsinks**, thermocouples should be placed approximately 13 mm to 25 mm [0.5 to 1.0 in] away from processor and heatsink as shown in Figure 4. The thermocouples should be placed approximately 51 mm [2.0 in] above the baseboard. This placement guideline is meant to minimize the effect of localized hot spots from baseboard components.

Note: Testing active heatsink with a variable speed fan can be done in a thermal chamber to capture the worst-case thermal environment scenarios. Otherwise, when doing a bench top test at room temperature, the fan regulation prevents the heatsink from operating at its maximum capability. To characterize the heatsink capability in the worst-case environment in these conditions, it is then necessary to disable the fan regulation and power the fan directly, based on guidance from the fan supplier.

Figure 4. Locations for Measuring Local Ambient Temperature, Active Heatsink (not to scale)

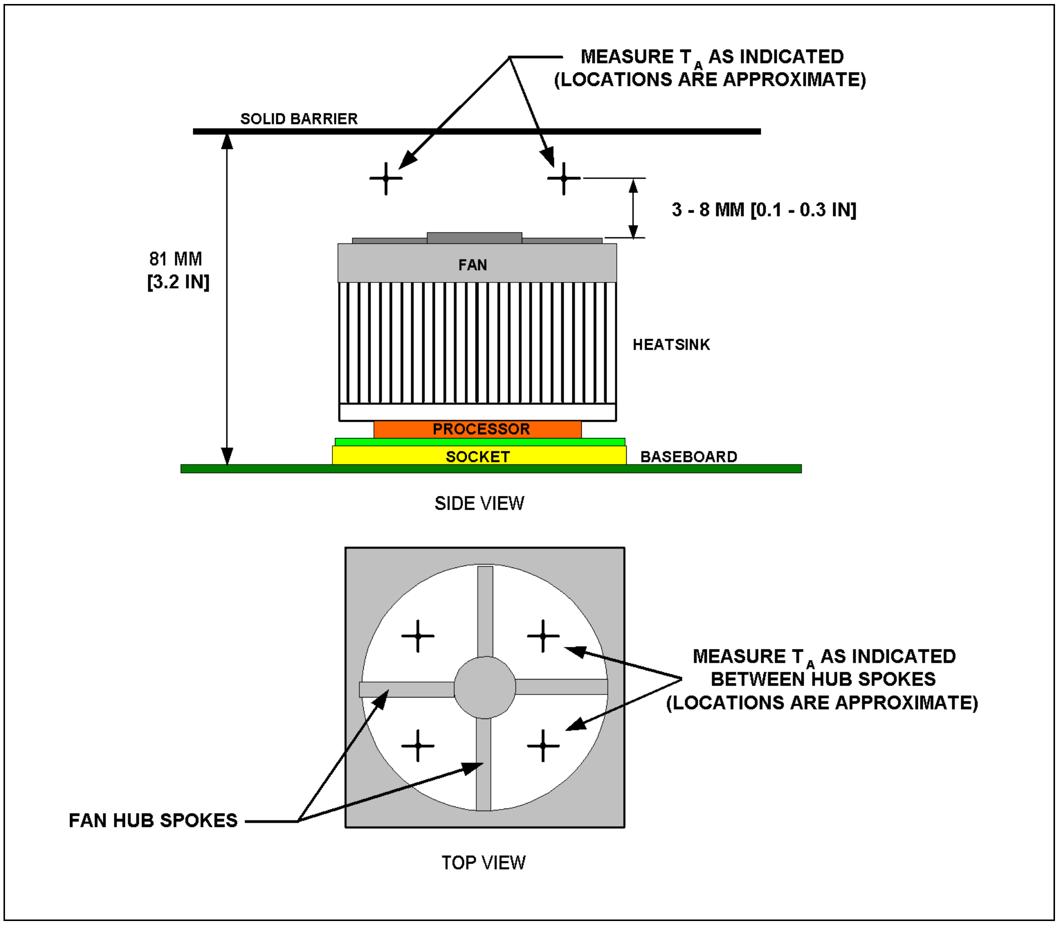
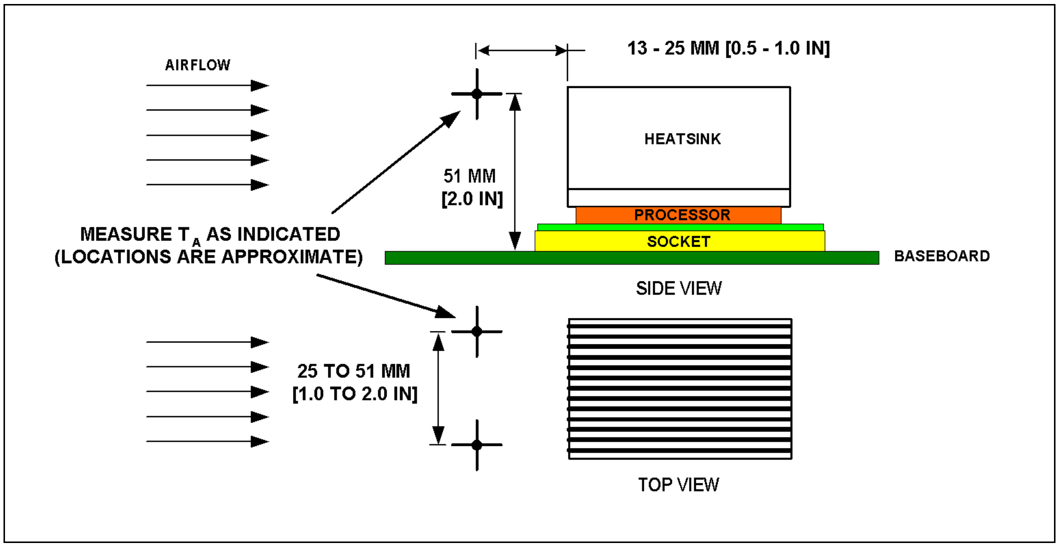


Figure 5. Locations for Measuring Local Ambient Temperature, Passive Heatsink (not to scale)



3.3.3 Processor Case Temperature Measurement Guidelines

To ensure functionality and reliability, the Pentium 4 processor on 90 nm process is specified for proper operation when T_C is maintained at or below the thermal profile as listed in the *Intel® Pentium® 4 Processor on 90 nm 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. Thermocouples are often used to measure T_C. Before any temperature measurements are made, the thermocouples must be calibrated, and the complete measurement system must be routinely checked against known standards. When measuring the temperature of a surface that 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, convection, by conduction through thermocouple leads, or by contact between the thermocouple cement and the case. To minimize these measurement errors, the approach is outlined in Appendix D: T_{CASE} Reference Metrology.

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, 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, and Intel is aggressively pursuing low power design techniques. For example, decreasing the operating voltage, reducing unnecessary transistor activity, and using more power efficient circuits can significantly reduce processor power consumption.

An on-die thermal management feature called Thermal Monitor is available on the Pentium 4 processor on 90 nm process. It provides a thermal management approach to support the continued increases in processor frequency and performance. By using a highly accurate on-die temperature sensing circuit and a fast acting temperature control circuit (TCC), the processor can rapidly initiate thermal management control. The Thermal Monitor can reduce cooling solution cost, by allowing designs to target the thermal design power (TDP) instead of maximum power, without impacting processor reliability or performance.

3.4.2 Thermal Monitor Implementation

On the Pentium 4 processor on 90 nm process, the Thermal Monitor is integrated into the processor silicon. The Thermal Monitor includes:

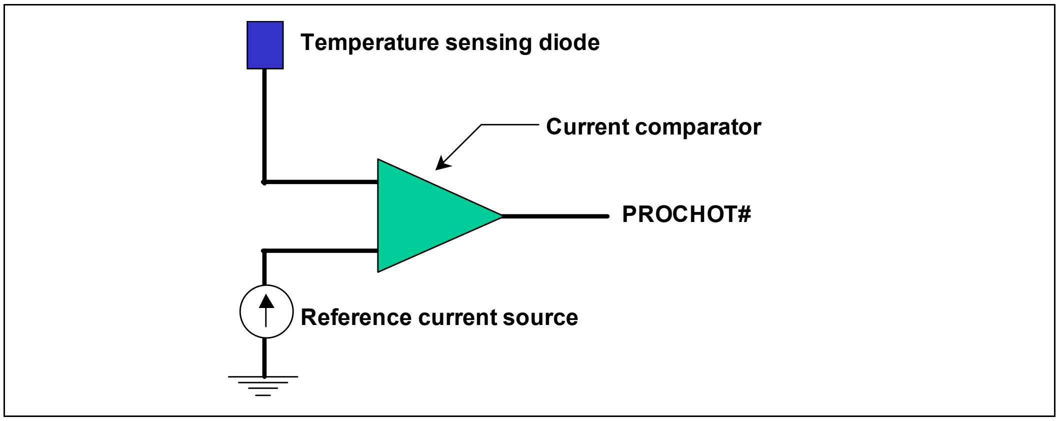
- A highly accurate on-die temperature sensing circuit
- A bi-directional signal (PROCHOT#) that indicates either the processor has reached its maximum operating temperature or can be asserted externally to activate the thermal control circuit (TCC) (see Section 3.4.3 for more details on user activation of TCC via PROCHOT#).
- A thermal control circuit that can reduce processor temperature by rapidly reducing power consumption when the on-die temperature sensor indicates that it has reached the maximum operating point.
- Registers to determine the processor thermal status.

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 6). A voltage applied across the diode induces 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.

The temperature at which PROCHOT# goes active is individually calibrated during manufacturing. The power dissipation of each processor affects the set point temperature. The temperature where PROCHOT# goes active is roughly parallel to the thermal profile. Once configured, the processor temperature at which the PROCHOT# signal is asserted is not re-configurable.

Note: A thermal solution designed to meet the thermal profile and TDP targets should rarely experience activation of the TCC.

Figure 6. Thermal Sensor Circuit



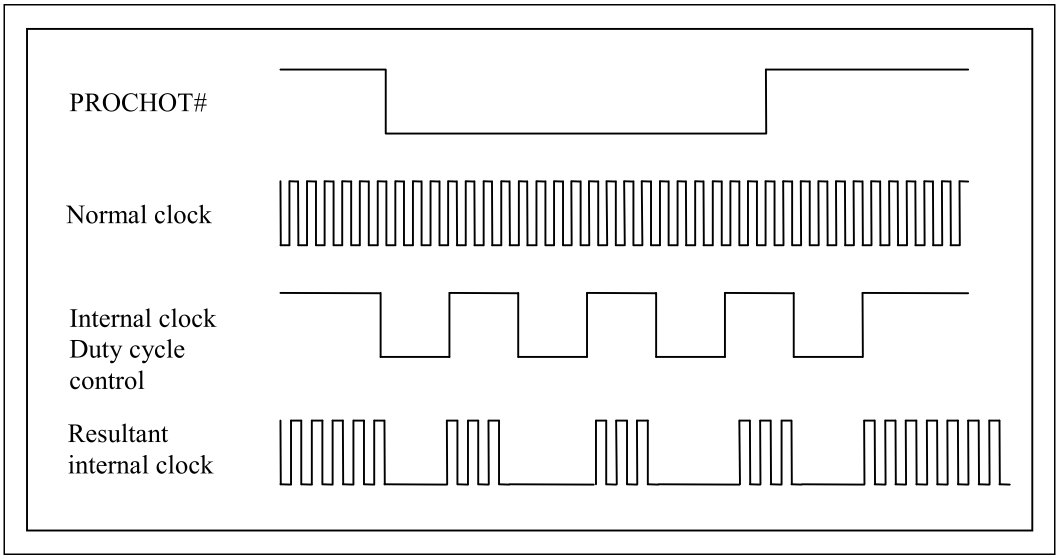
The PROCHOT# signal is available internally to the processor as well as externally. External indication of the processor temperature status is provided through the bus signal PROCHOT#. When the processor temperature reaches the trip point, PROCHOT# is asserted. When the processor temperature is below the trip point, PROCHOT# is de-asserted. 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 activates is set to the same temperature at which the processor is tested and at which PROCHOT# asserts.

3.4.2.1 Thermal Monitor

The thermal control circuit portion of the Thermal Monitor must be enabled for the processor to operate within specifications. The Thermal Monitor's TCC, when active, lowers the processor temperature by reducing the power consumed by the processor. In the original implementation of thermal monitor, this is done by changing the duty cycle of the internal processor clocks, resulting in a lower effective frequency. When active, the TCC turns the processor clocks off and then back on with a predetermined duty cycle. The duty cycle is processor specific, and is fixed for a particular processor. The maximum time period the clocks are disabled is ~3 µs, and is frequency dependent. Higher frequency processors will disable the internal clocks for a shorter time period. Figure 7 illustrates the relationship between the internal processor clocks and PROCHOT#.

Performance counter registers, status bits in model specific registers (MSRs), and the PROCHOT# output pin are available to monitor and control the Thermal Monitor behavior.

Figure 7. Concept for Clocks under Thermal Monitor Control



3.4.3 Bi-Directional PROCHOT#

The Pentium 4 processor on 90 nm process implements a bi-directional PROCHOT# capability to allow system designs to protect various components 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 ability to activate the TCC via PROCHOT# can provide a means for thermal protection of system components.

One application is the thermal protection of voltage regulators (VR). System designers can create a circuit to monitor the VR temperature and activate the TCC when the temperature limit of the VR is reached. By asserting PROCHOT# (pulled-low) and activating the TCC, the VR can cool down as a result of reduced processor power consumption. Bi-directional PROCHOT# can allow VR thermal designs to target maximum sustained current instead of maximum current. Systems should still provide proper cooling for the VR, 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 boot process, the BIOS must enable the thermal control circuit; or a software driver may do this after the operating system has booted. **Thermal Monitor must be enabled to ensure proper processor operation.**

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 the BIOS setting a bit in an MSR (Model Specific Register). Enabling the thermal control circuit allows the processor to attempt 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., PROCHOT# assertion). The thermal control circuit and PROCHOT# transition to inactive once the temperature has been reduced below the thermal trip point, although a small time-based hysteresis has been included to prevent multiple PROCHOT# transitions around the trip point. External hardware can monitor PROCHOT# and generate an interrupt when there is a transition from active-to-inactive or inactive-to-active. PROCHOT# can also be configured to generate an internal interrupt that would initiate an OEM supplied interrupt service routine. Regardless of the configuration selected, PROCHOT# will always indicate the thermal status of the processor.

The power reduction mechanism of thermal monitor can also be activated manually using an "on-demand" mode. Refer to Section 3.4.5 for details on this feature.

3.4.5 On-Demand Mode

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 thermal 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) = 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.

3.4.6 System Considerations

The Thermal Monitor feature may be used in a variety of ways, depending on the system design requirements and capabilities.

Note: **Intel requires the Thermal Monitor and Thermal Control Circuit to be enabled for all Pentium 4 processor on 90 nm process -based systems.** The thermal control circuit is intended to protect against short term thermal excursions that exceed the capability of a well designed processor thermal solution. Thermal Monitor should not be relied upon to compensate for a thermal solution that does not meet the thermal design power (TDP) or the thermal profile.

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 thermal profile at the TDP and $T_{C\text{-}MAX}$ values targets published in the processor 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 more 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 3.4.8.2 and to the *Intel® Pentium® 4 Processor on 90 nm Process Datasheet*.

3.4.7 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 boot process may result in incorrect calibration of operating system software timing loops. The BIOS must disable the thermal control circuit prior to boot and then the operating system or BIOS must enable the thermal control circuit after the operating system boot process completes.

Intel has worked with the major operating system vendors to ensure support for non-execution based operating system calibration loops and ACPI support for the Thermal Monitor feature.

3.4.8 Legacy Thermal Management Capabilities

In addition to Thermal Monitor, the Pentium 4 processor on 90 nm process supports the same thermal management features originally available on the Intel® Pentium® III processor. These features are the on-die thermal diode and THERMTRIP# signal for indicating catastrophic thermal failure.

3.4.8.1 On-Die Thermal Diode

There are two independent thermal sensing devices in the Pentium 4 processor on 90 nm process. One is the on-die thermal diode and the other is in 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 physically isolated devices with no defined 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. The temperature distribution across the die may result in significant temperature differences between the on-die thermal diode and the Thermal Monitor's temperature sensor. This temperature variability across the die is highly dependent on the application being run. As a result, it is not possible to predict the activation of the thermal control circuit by monitoring the on-die thermal diode.

System integrators should note that there is no defined correlation between the on-die thermal diode and the processor case temperature. The temperature distribution across the die is affected by the power being dissipated; type of activity the processor is performing (e.g., integer or floating point intensive) and the leakage current. The dynamic and independent nature of these effects makes it difficult to provide a meaningful correlation for the processor population.

System integrators that plan on using the thermal diode for system or component level fan control to optimize acoustics need to refer to the acoustic fan control, Section 3.6

3.4.8.2 THERMTRIP#

In the event of a catastrophic cooling failure, the processor will automatically shut down when the silicon temperature has reached its operating limit. At this point the system bus signal THERMTRIP# goes active and power must 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 on 90 nm Process Datasheet* for more information about THERMTRIP#.

Like, Thermal Monitor, (PROCHOT# activation temperature), THERMTRIP# is also individually calibrated during manufacturing. The temperature where THERMTRIP# goes active is roughly parallel to the thermal profile and greater than the PROCHOT# activation temperature. Once configured, temperature at which the THERMTRIP# signal is asserted is neither re-configurable nor accessible to the system.

3.4.9 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 normal system shutdown. If no thermal management action is taken, the silicon temperature may exceed the operating limits, causing THERMTRIP# to activate and shut down the processor. Regardless of the system design requirements or thermal solution ability, the Thermal Monitor feature must still be enabled to ensure proper processor operation.

3.5 Thermal Specification

Intel has introduced a new method for specifying the thermal limits for the Pentium 4 processor on 90 nm process. The new parameters are the Thermal Profile and $T_{CONTROL}$. The Thermal Profile defines the maximum case temperature. $T_{CONTROL}$ is a specification used in conjunction with the temperature reported by the on-die thermal diode.

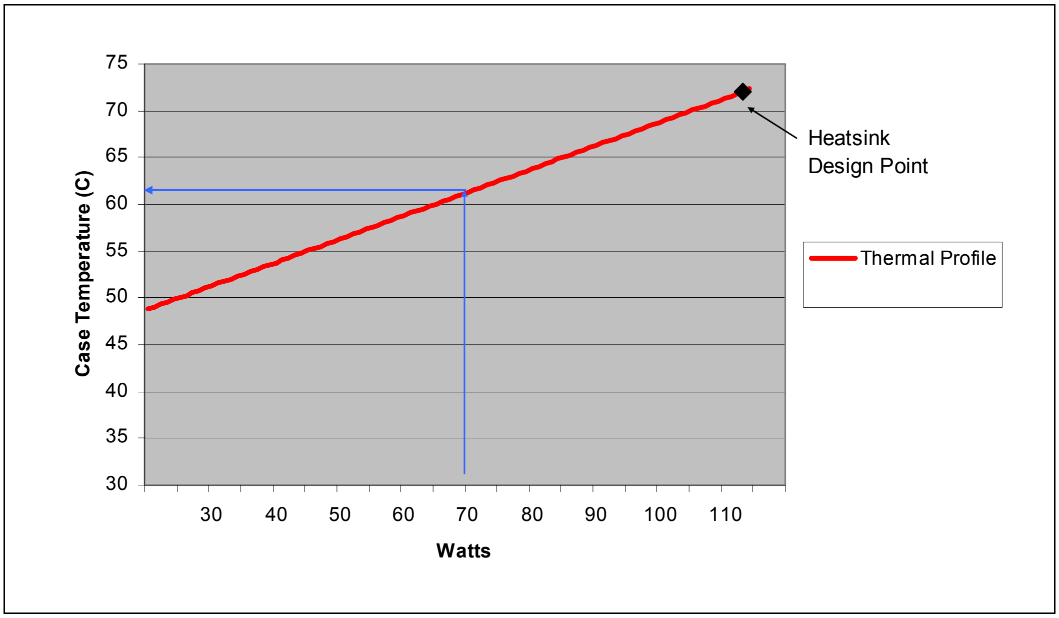
3.5.1 Thermal Profile

The thermal profile defines the maximum case temperature as a function of processor power dissipation. The TDP and maximum case temperature for loadline A of the Pentium 4 processor on 90 nm process are defined as the maximum values of the thermal profile. By design the thermal solutions must meet the thermal profile for all system operating conditions and processor power levels.

The slope of the thermal profile was established assuming a generational improvement in thermal solution performance of about 10% based on previous Intel reference designs. This performance is expressed as the slope on the thermal profile and can be thought of as the ΨCA. The intercept on the thermal profile assumes a maximum ambient operating condition that is consistent with the available chassis solutions.

To determine compliance to the thermal profile, a measurement of the actual processor power dissipated is required. The measured power is plotted on the thermal profile to determine the maximum case temperature. Using the example in Figure 8 a power dissipation of 70 W has a case temperature of 61°C. See the appropriate datasheet for the thermal profile.

Figure 8. Example Thermal Profile



3.5.2 $T_{CONTROL}$

$T_{CONTROL}$ defines the maximum operating temperature for the on-die thermal diode when the thermal solution fan speed is being controlled by the on-die thermal diode. The $T_{CONTROL}$ parameter defines a very specific processor operating region where the T_C is not specified. This parameter allows the system integrator a method to reduce the acoustic noise of the processor cooling solution while maintaining compliance to the processor thermal specification.

The value of $T_{CONTROL}$ is driven by a number of factors. One of the most significant of these is the processor leakage current. As a result a processor with a high $T_{CONTROL}$ will dissipate more power than a part with lower value of $T_{CONTROL}$ when running the same application.

The value of $T_{CONTROL}$ is calculated such that regardless of the individual processor's $T_{CONTROL}$ value, the thermal solution should perform similarly. The higher leakage of some parts is offset by a higher value of $T_{CONTROL}$ in such a way that they will behave virtually the same acoustically

This is achieved in part by using the Ψ_{CA} vs. RPM and RPM vs. Acoustics (dBA) performance curves from the Intel enabled thermal solution. A thermal solution designed to meet the thermal profile should perform virtually the same for any value of $T_{CONTROL}$.

The value for $T_{CONTROL}$ is calculated by the system BIOS based on values read from a factory configured processor register. The result can be use to program a fan speed control component. See the processor datasheet for further details on calculating $T_{CONTROL}$.

3.5.3 How On-die Thermal Diode, $T_{CONTROL}$ and Thermal Profile work together

The Pentium 4 processor on 90 nm process thermal specification is comprised of the two parameters, $T_{CONTROL}$ and thermal profile. The first step is to ensure the thermal solution by design meets the thermal profile. If the system design will incorporate variable speed fan control Intel recommends monitoring the on-die thermal diode to implement acoustic fan speed control. The value of the on-die thermal diode temperature determines which specification must be met.

3.5.3.1 On-die Thermal Diode less than $T_{CONTROL}$

When the thermal solution can maintain the thermal diode temperature to less than $T_{CONTROL}$, then T_C is not specified.

3.5.3.2 On-die Thermal Diode greater than $T_{CONTROL}$

When the on-die thermal diode temperature exceeds $T_{CONTROL}$, then the thermal solution must meet the thermal profile for T_C.for that power dissipation.

3.6 Acoustic Fan Speed Control

Higher processor power can increase the thermal requirement and can, therefore, generate increasingly more noise. Intel has added an option to the processor thermal specifications that allows the system integrator to have a quieter system in the most common usage condition. $T_{CONTROL}$ and the on-die thermal diode provide the system integrator the means to implement a quieter system design.

Acoustic fan control implementations consist of the following items:

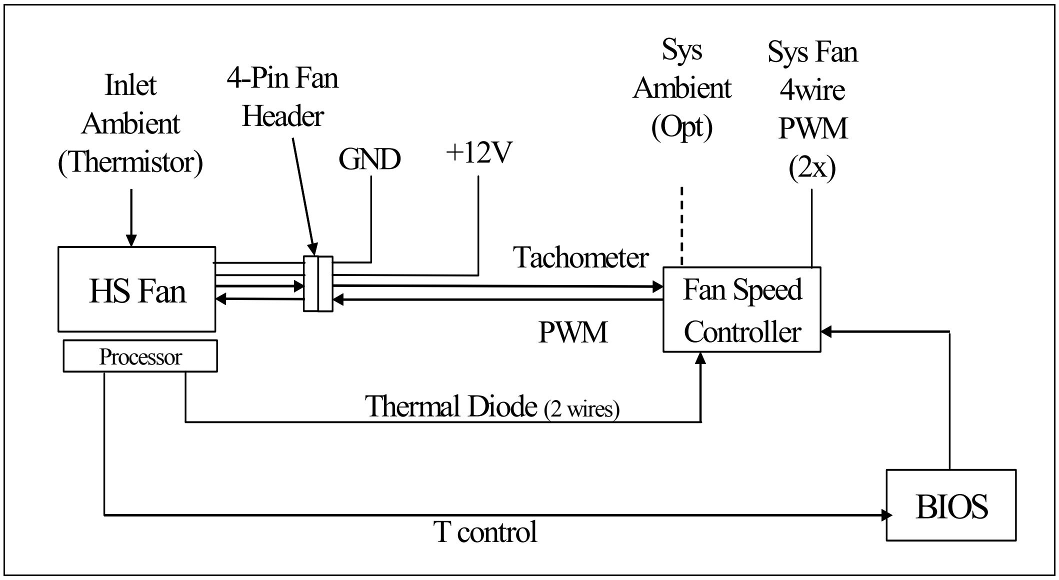
- A motherboard design with a fan speed controller with Pulse Width Modulation (PWM) output and remote thermal diode measurement capability. Consequently, the motherboard has a 4 pin fan header for the processor heatsink fan.
- A processor heatsink with a 4 wire PWM controlled fan.

Fan speed control and PWM output are embedded in a number of components from major manufacturers. These components can be stand alone or a Super IO (SIO). The following vendors have components that would be suitable: Analog Devices*, ITE*, National Semiconductor, SMSC*, and Winbond*. Consult their web sites or local sales representatives for a part suitable for your market needs.

3.6.1 Example Implementation

The system designer must work with the board designer to select the appropriate fan speed controller. For processor fan speed control the Figure 9 shows the major connections.

Figure 9. Example Acoustic Fan Speed Control Implementation

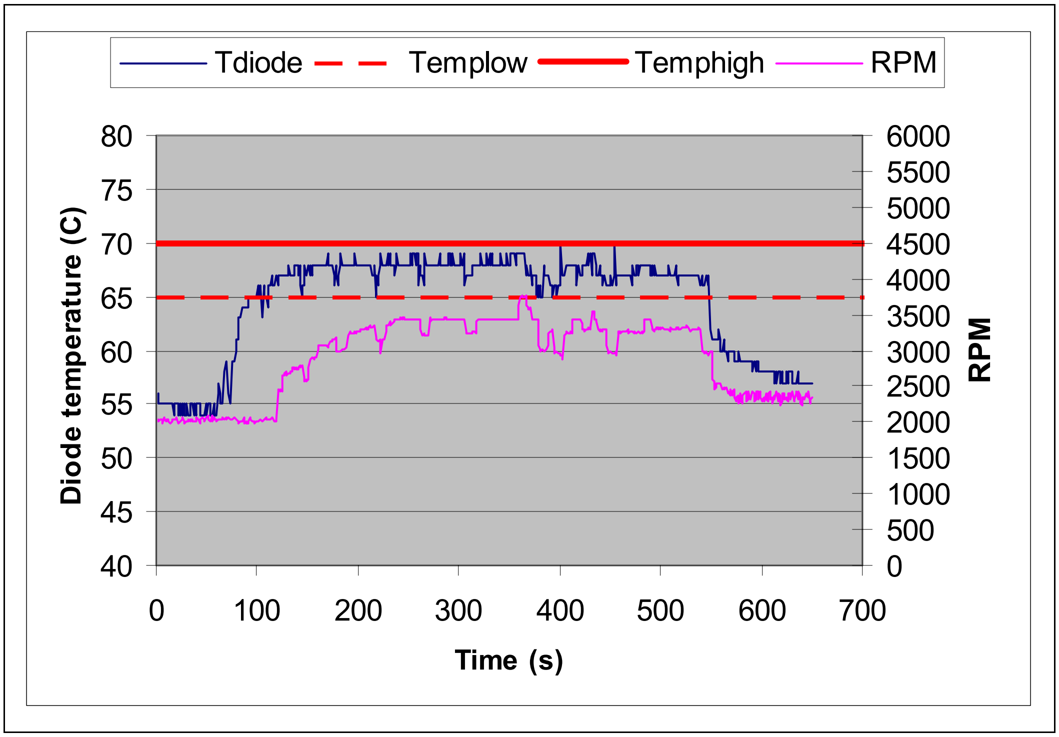


3.6.2 Graphs of Fan Response

In Figure 10 a processor with a $T_{CONTROL}$ value of 70 °C is being measured using the on-die thermal diode. The fan in this example has a thermistor on the fan hub, as does the Intel enabled solution and the Intel boxed processor heatsink. This thermal solution was designed so the fan speed, as controlled by the thermistor, will meet the thermal profile at every ambient temperature. See Chapter 4 for details on the thermistor implementation and the rest of the reference design information.

The processor is running the 3Dmark2001* benchmark. The fan speed controller is programmed to begin accelerating the fan speed at $T_{CONTROL}$ minus 5 °C or 65 °C. As a result, the processor heatsink fan will not accelerate from the minimum programmed fan speed for any T_{diode} value below 65 °C. Once T_{diode} temperature exceeds 65 °C, the fan speed will ramp linearly from the minimum speed to the maximum allowed by the thermistor for that ambient temperature.

Figure 10. Example Fan Speed Response



The choice of accelerating the fan speed over a 5 °C range is an aggressive acoustic solution. For the typical home/office ambient environment and workloads, the fan will remain at the minimum operating speed for most workloads. Once the lower temperature threshold is reached, fan speed change can be rapid. An alternate approach is to have the fan speed ramp over a larger range of T_{diode} (e.g., 10 °C). This will reduce the rate of change for the fan speed, but may raise acoustic level more often at the low ambient condition as the fan response begins at lower T_{diode} temperatures. In either case, the use of a "smoothing" parameter options in the fan speed control chip is recommended to average out short duration temperature spikes.

3.7 Reading the On-Die Thermal Diode Interface

The on-die thermal diode is accessible from a pair of pins on the processor. The fan speed controller remote thermal sense signals should be connected to these pins per the vendor's recommended layout guidelines.

Table 1. Thermal Diode Interface

Pin Name	Pin Number	Pin Description
THERMDA	B3	Diode anode
THERMDC	C4	Diode anode

3.8 Impacts to Accuracy

A number of issues can affect the accuracy of the temperature reported by thermal diode sensors. These include the diode ideality and the series resistance that are characteristics of the processor. The processor datasheet provides the specification for these parameters. The trace layout recommendations between the thermal diode sensors and the processor socket should be followed as listed the vendor datasheets. The design characteristics and usage models of the thermal diode sensors should be reviewed in the datasheets available from the manufacturers.

The choice of a remote diode sensor measurement component has a significant impact to the accuracy of the reported on-die diode temperature. The component vendors offer components that have stated accuracy of ± 3 °C to ± 1 °C. The improved accuracy generally comes from the number times a current is passed through the diode and the difference in currents. Consult the vendor datasheet for details on their measurement process and stated accuracy.

The ideality factor, n, represents the deviation from ideal diode behavior as exemplified by the diode equation:

Equation 5

$$I_{FW} = I_S * (E^{qVD/nkT} - 1)$$

Where:

I_{FW} = Forward bias bias current
I_S = saturation current
q = electronic charge
V = voltage across the diode
k = Boltzmann Constant
T = absolute temperature (Kelvin).

The series resistance, R_T, is provided to allow for a more accurate measurement of the on-die thermal diode temperature. R_T, as defined, includes the pins of the processor but does not include any socket resistance or board trace resistance between the socket and the external remote diode thermal sensor. R_T can be used by remote diode thermal sensors with automatic series resistance cancellation to calibrate out this error term. Another application is that a temperature offset can be manually calculated and programmed into an offset register in the remote diode thermal sensors as exemplified by the equation:

Equation 6

$$T_{error} = (R_T * (N - 1) * I_{FWmin}) / (nk/q * I_N \ln N)$$

Where:

T_{ERROR}= sensor temperature error
N = sensor current ratio
k = Boltzmann Constant
q = electronic charge

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4 Intel® Thermal/Mechanical Reference Design Information

4.1 Intel® Validation Criteria for the Reference Design

4.1.1 Thermal Performance

4.1.1.1 Reference Heatsink Performance Target

Table 2 provides the heatsink performance target for loadline A and loadline B Pentium 4 processor on 90 nm process.

The table also includes a T_A assumption of 38 °C for the Intel reference thermal solution at the processor fan heatsink inlet discussed in Section 3.2.2.1. An external ambient temperature to the chassis of 35 °C is assumed, resulting in a temperature rise, T_R, of 3 °C. Meeting T_A and Ψ_{CA} targets can maximize processor performance (refer to Chapter 3 and Section 3.4).

Refer to the *Intel® Pentium® 4 Processor on 90 nm Process Datasheet* for detailed processor thermal specifications.

Table 2. Reference Heatsink Performance Targets

Processor Frequencies (refer to processor datasheet)	Thermal Performance, Ψca (Mean + 3σ)	T_A Assumption	T_E Assumption
Loadline B	0.34 °C/W	38 °C	35 °C
Loadline A	0.34 °C/W	38 °C	35 °C

4.1.1.2 Acoustics

To optimize acoustic emission by the fan heatsink assembly, it is recommended to develop a solution with a variable speed fan. A variable speed fan allows higher thermal performance at higher fan inlet temperatures (T_A) and lower thermal performance with improved acoustics 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 for a loadline A compliant solution:
   - High set point: $T_A = 38$ °C; $\Psi_{CA} = 0.34$ °C/W (per Table 2 above)
   - Low set point: $T_A = 28$ °C; $\Psi_{CA} = 0.47$ °C/W

Note: The temperature rise (T_R) between external ambient (T_E) and local ambient temperature (T_A) may be greater than 3 °C at the low set point.

2. Fan heatsink assembly acoustic performance:
   - Acoustic performance is defined in term of declared sound power (LwAd) as defined in ISO 9296 standard, and measured according ISO 7779.
   - LwAd should not exceed 5.7 BA at the high set point temperature.
   - LwAd should not exceed 4.5 BA at the low set point temperature.

Note that any form of variable performance thermal solution that relies on the on-die thermal diode must react fast enough to handle any sudden increases in processor workload. Refer to Section 3.4.8.1 for more details.

4.1.1.3 Altitude

The reference heatsink solutions will be evaluated at sea level. However, many companies design products that must function reliably at high altitude, typically 1500 m [5000 ft] or more. Air-cooled temperature calculations and measurements at sea level must be adjusted to take into account altitude effects like variation in 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 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.

4.1.1.4 Reference Heatsink Thermal Validation

The Intel reference heatsink is validated within specific boundary conditions based on the methodology described Section 3.3, and using a thermal test vehicle.

Testing is done on bench top test boards at ambient lab temperature. In particular, for the reference heatsink, the Plexiglas* barrier is installed 81 mm [3.2 in] above the motherboard (refer to Section 3.3.2).

The test results, for a number of samples, are reported in terms of a worst-case mean + 3σ value for thermal characterization parameter using real processors (based on the thermal test vehicle correction factors).

4.1.2 Fan Performance for Active Heatsink Thermal Solution

The fan power requirement for proper operation is a maximum steady state 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 4.1.3) 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 the thermal target (Table 2) at 90% of the rated fan RPM at 12 V.
- In addition to passing the environmental reliability tests described in Section 4.1.3, the fan demonstrates adequate performance after 7,500 on/off cycles with each cycle specified as 3 minutes on, 2 minutes off, at a temperature of 70 °C.

4.1.3 Environmental Reliability Testing

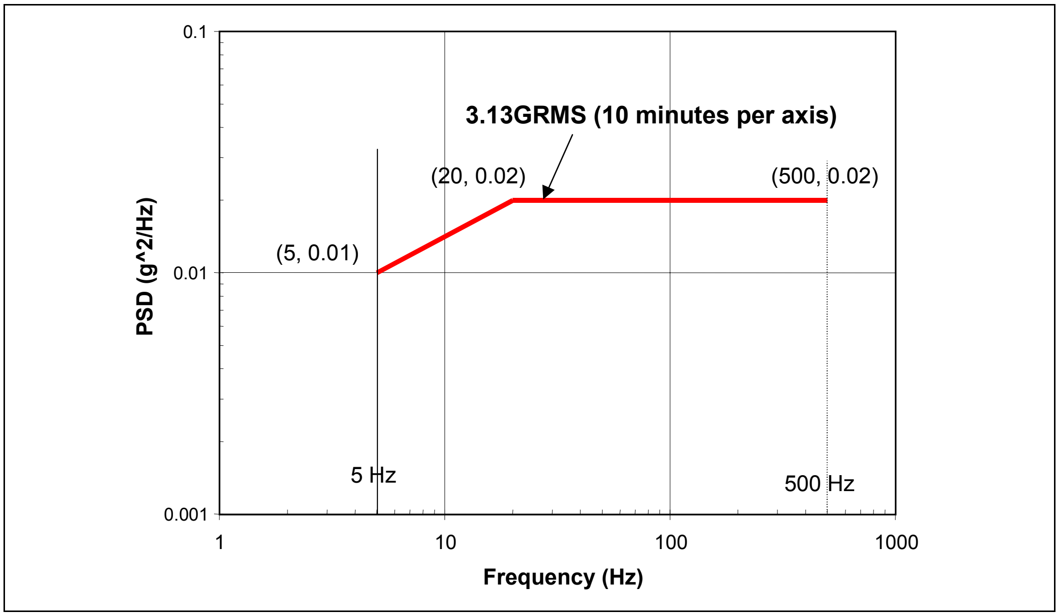
4.1.3.1 Structural Reliability Testing

Structural reliability tests consist of unpackaged, board-level 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.

4.1.3.1.1 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 11. Random Vibration PSD



4.1.3.1.2 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, 170 in./sec minimum velocity change (resulting duration: 9–11 ms).
- Setup: Mount sample board on test fixture.

Figure 12. Shock Acceleration Curve

4.1.3.1.3 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 4.1.3.3). The stress test should be then followed by a visual inspection and then BIOS/CPU/Memory test.

4.1.3.1.4 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, if these features exist in the design.
2. Clip must remain latched to retention mechanism windows.
3. Heatsink remains seated and its bottom remains mated flatly against IHS 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.

4.1.3.2 Long-Term Reliability Testing

4.1.3.2.1 Temperature Cycling

Temperature cycling is performed to test for long-term reliability. This test is conducted using the parameters shown in Table 3.

Table 3. 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

4.1.3.3 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 used for this test.

4.1.4 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 that 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.

4.1.5 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.

4.1.6 Geometric Envelope for Intel Reference Thermal Mechanical Design

Figure 26, Figure 27, and Figure 28 in Appendix C 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 design for the Pentium 4 processor in the 478-pin package and the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process.

Figure 26 and Figure 27 show the motherboard keep-outs and height restrictions under the enabling component region. Figure 28 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 26, 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 26 corresponds to the package within the socket in close position.

4.2 Reference Thermal Solution for the Intel® Pentium® 4 Processor on 90 nm Process

The Pentium 4 processor on 90 nm process will re-use the reference thermal solution for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process at 3 GHz and above. **Note that the ability to re-use the 3GHz and higher Pentium 4 processor with 512-KB L2 cache on 0.13 micron process reference solution depends on the ability of a chassis to deliver a local ambient temperature at the processor heatsink of 38 °C.** Table 4 shows the predicted thermal performance, Ψ_{CA}, of the reference thermal solution with a Pentium 4 processor on 90 nm process.

Note that there is an increase in Ψ_{CA} for the same thermal solution used on different processors. This is due to an increase in power density for the Pentium 4 processor on 90 nm process. The high set point Ψ_{CA} for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process was 0.33 °C/W at the high fan set point.

Table 4. Intel® Pentium® 4 Processor on 90 nm Process Reference Thermal Solution Performance

Fan Set Point	Fan Speed	Predicted Thermal Performance, Ψca (Mean + 3σ)	T_A Assumption
High	4400 RPM	0.34 °C/W	T_A = 38 °C
Low	2180 RPM	0.47 °C/W	T_A = 28 °C

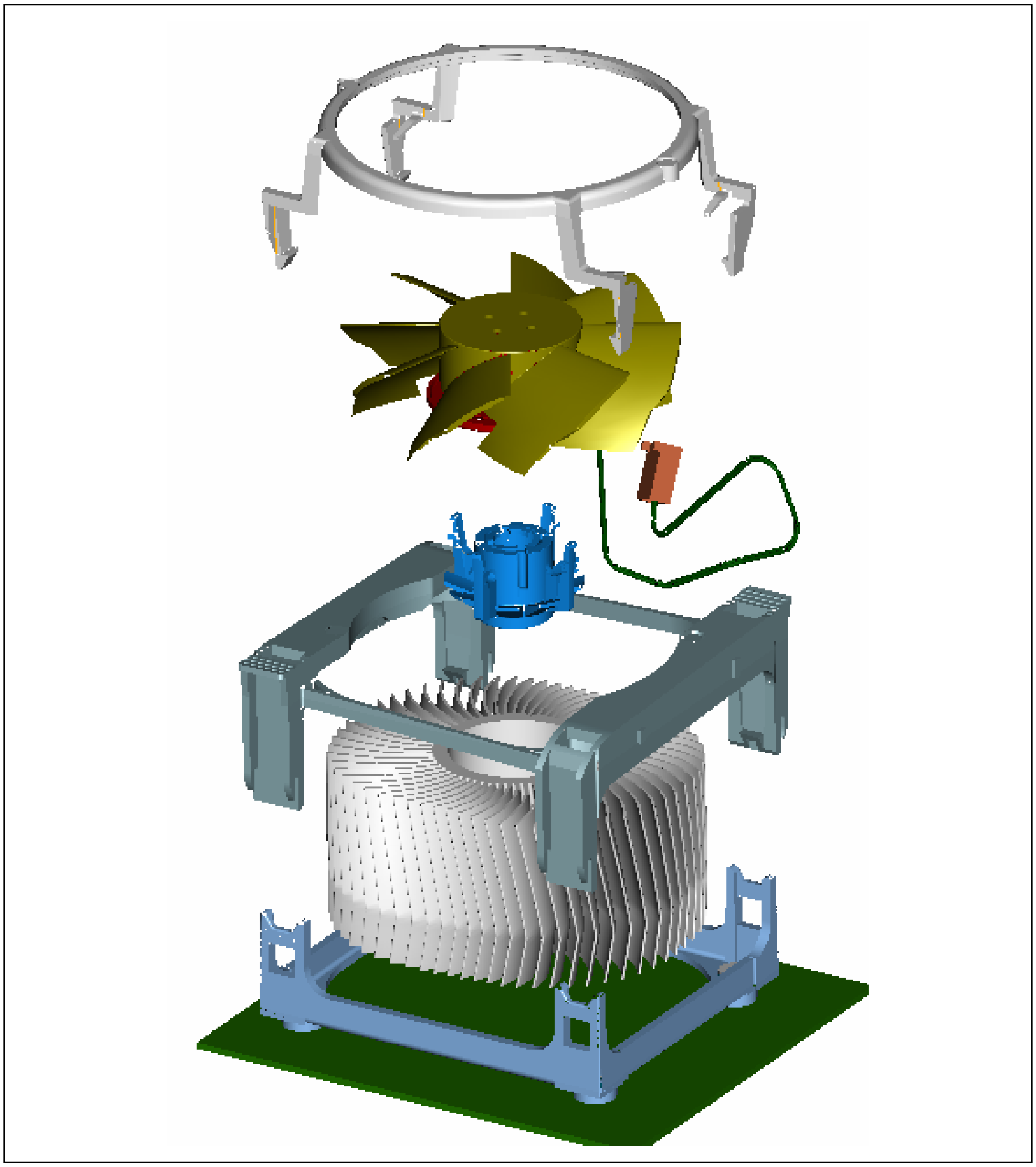
4.2.1 Reference Components Overview

The reference thermal mechanical solution to support the loadline A requirement target of the Pentium 4 processor on 90 nm process consists of the following components:

- Heatsink attach clip
- Retention mechanism
- Heatsink
- Thermal interface material
- Fan and hub assembly
- Fan attach
- Fan guard (optional, non-validated)

These components are shown in an exploded assembly view in Figure 13. The approximate assembly mass is 370 g. Refer to Appendix C for drawings of the individual components.

Figure 13. Exploded View of Reference Thermal Solution Components (with Optional Fan Guard)



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 on 90 nm process will be validated according to the Intel validation criteria given in Section 4.1, using all the reference components as described in this document along with the reference thermal mechanical enabling components for the 865G chipset MCH. 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.

4.2.2 Reference Mechanical Components

4.2.2.1 Heatsink Attach Clip

The heatsink attach clip for the Pentium 4 processor on 90 nm process reference heatsink consists of a one-piece plastic clip (LEXAN* 500ECR) identical to that used for the Pentium 4 processor with 512-KB L2 cache on 0.13 micron process reference heatsink. A drawing of the clip is provided in Appendix C.

4.2.2.2 Retention Mechanism

The retention mechanism for the Pentium 4 processor on 90 nm process thermal mechanical reference solution is identical to the Pentium 4 processor in the 478-pin package reference retention mechanism. A drawing of the retention mechanism is shown in Appendix C.

4.2.2.3 Heatsink

The heatsink consists of 62 extruded aluminum radial fins with an inserted copper core. The fins are bent to direct airflow towards the center of the heatsink core and increase thermal performance. A drawing of the heatsink is shown in Appendix C.

4.2.2.4 Thermal Interface Material

Refer to Section 3.2.1.2 for general information on thermal interface material usage and application consideration on the FC-mPGA4 package.

Thermal interface material for the Intel reference design for the for the Pentium 4 processor on 90 nm process is Shin-etsu* G751 thermally conductive grease.

4.2.2.5 Fan and Hub Assembly

The fan impeller uses eight (8) blades optimized for the reference heatsink design. When used in conjunction with the reference heatsink, a high level of cooling performance is achieved. The fan motor resides in the fan hub, and is attached to the heatsink directly through a fan attach component, avoiding the need for a fan shroud. A sketch of the impeller geometry is available in Appendix C.

The reference fan may experience a startup current draw of 1.5 A for ~ 1 sec duration. This exceeds the maximum steady state current draw of 740 mA stated in Section 4.1.2. Motherboard designers should ensure the fan header can provide this transient current.

4.2.2.6 Fan Attach

The fan and hub assembly is attached to the heatsink assembly through a fan attach component. The plastic fan attach component connects to the fan hub through four (4) tabs and is held in the heatsink core area through barbs molded into the part. The fan attach component is pressed into the heatsink through special tooling. Refer to Appendix C for a drawing of the component.

4.2.2.7 Fan Guard

An optional fan guard is available and is shown in the heatsink assembly drawings in Appendix C. The heatsink thermal performance was validated without the fan guard attached. The fan guard is intended to protect personnel from the fan blades during operation.

4.3 Evaluated Third-Party Thermal Solutions

Solutions that have been independently tested by an Intel-enabled third-party test house are listed on the Intel developer web page at http://developer.intel.com. 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 Extreme Edition supporting Hyper Threading Technology[1]. Chassis that deliver a processor heatsink T_A of 38 °C or less may be able to use these heatsinks to meet Pentium 4 processor on 90 nm process thermal targets.

These suppliers may produce other compliant and non-compliant solutions in addition to the part numbers that are listed below. 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.

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[1] Hyper-Threading Technology requires a computer system with an Intel® Pentium® 4 processor supporting HT Technology and an HT Technology enabled chipset, BIOS and operating system. Performance will vary depending on the specific hardware and software you use. See http://www.intel.com/info/hyperthreading/ for more information including details on which processors support HT Technology.

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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 degrades thermal solution performance. The larger the gap between the two surfaces, the greater the thermal resistance. The thickness of the gap is determined by the flatness 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: Intel Enabled Reference Thermal Solution

This appendix includes supplier information for Intel enabled vendors for the Pentium 4 processor on 90 nm process reference thermal solution.

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

Table 5. Intel Representative Contact for Licensing Information

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

Intel collaborated with EKL AG, and Sunonwealth Electric Machine Industry Co. (Sunon) to complete its newest design of the Radial Curved Bent Fin Heatsink (RCBF-2). EKL assisted Intel with the tooling, component, and assembly manufacturing to validate the second generation 62-fin, RCBF thermal solution. Sunon provided a new fan motor that meets Intel's fan specification for RCBF-2. EKL is licensed to manufacture and sell the RCBF-2 Heatsink assembly and Sunon is licensed to manufacture and sell Intel's innovative impeller design on its fan products. 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 6 lists suppliers that produce Intel enabled reference components.

Table 6. Collaborated Intel Reference Component Thermal Solution Provider(s)

Supplier	Part Description	Part Number(s)	Contact	Phone	email
EKL	Integrated Thermal Solution	C28951-001	Peter Goodman	49-075-61-9837-28	Peter.Goodman@ekl-ag.de
Sunon	Fan Motor and Impeller Assembly	PMD1208PKB1-A(2).S.B511.F	Tom Blaskovich	714-255-0208 ext. 206	tomb@sunon.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.

Additional suppliers are licensed to manufacture and sell the Intel RCBF-2 reference component thermal solution. These suppliers are listed in Table 7. These designs can vary from the original design and performance targets and should be evaluated by OEMs and system integrators. End-users are responsible for the verification of the Intel enabled component offerings with the supplier.

Table 7. Licensed Intel Reference Component Thermal Solution Providers

Supplier	Part Description	Contact/Geo	Phone	E-mail
AVC	Integrated Thermal Solution	Vincent Lee / (N. America)	310-783-5484	vincent@avc.com.tw
CCI	Integrated Thermal Solution	Harry Lin/ (N. America)	714-739-5797	ackinc@aol.com
Foxconn	Integrated Thermal Solution	Julia Jiang / (N. America)	408-919-6178	juliaj@foxconn.com
JMC	Integrated Thermal Solution	Jerry Johns / (N. America)	512-834-8866	jjohns@jmcproducts.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.

Appendix C: Mechanical Drawings

The following table lists the mechanical drawings included in this appendix. These drawings refer to the thermal mechanical enabling components for the Pentium 4 processor on 90 nm process.

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

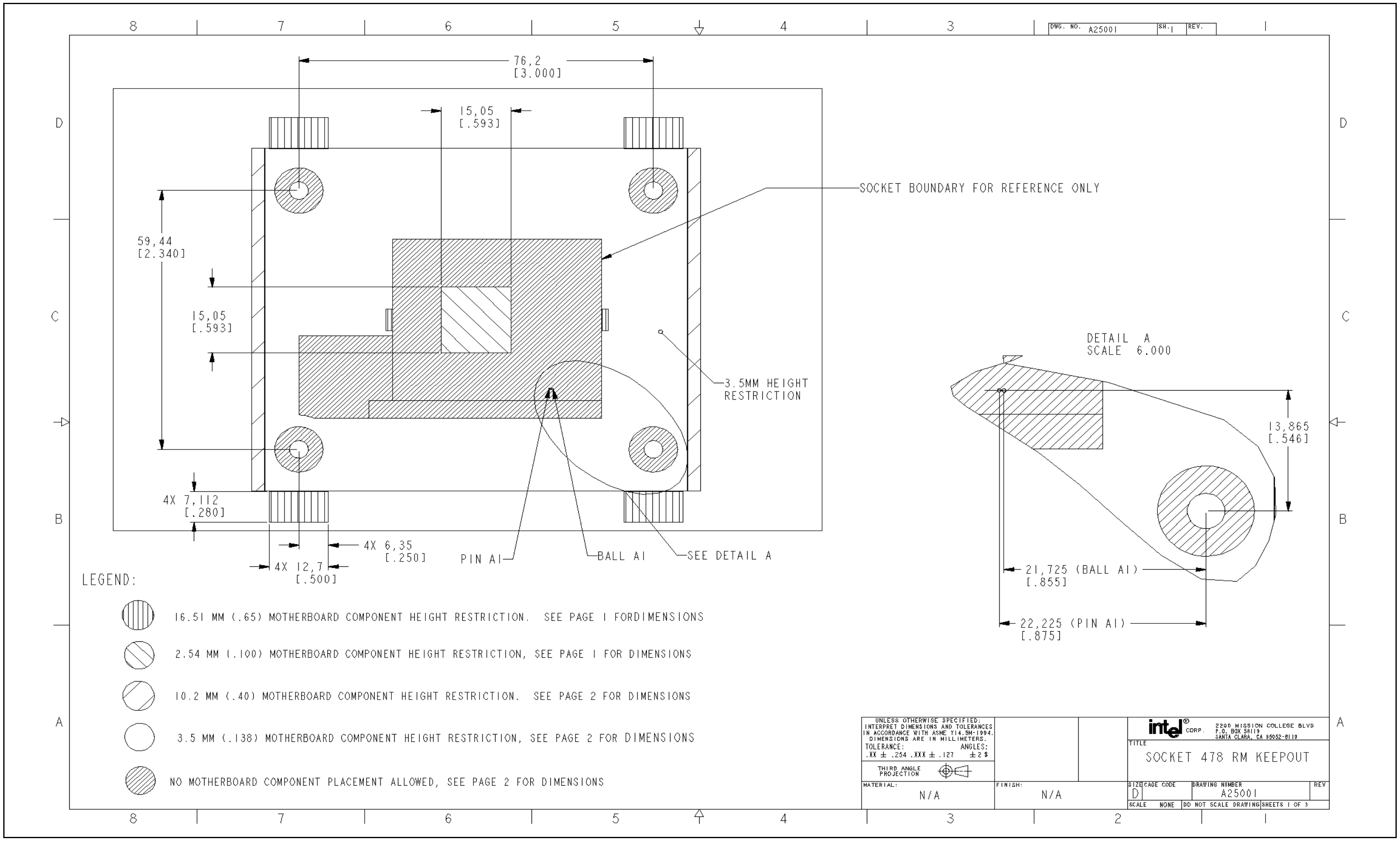


Figure 14. Motherboard Keep-Out Footprint Definition and Height Restrictions for Enabling Components (Sheet 1 of 3)

Figure 15. Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components (Sheet 2 of 3)

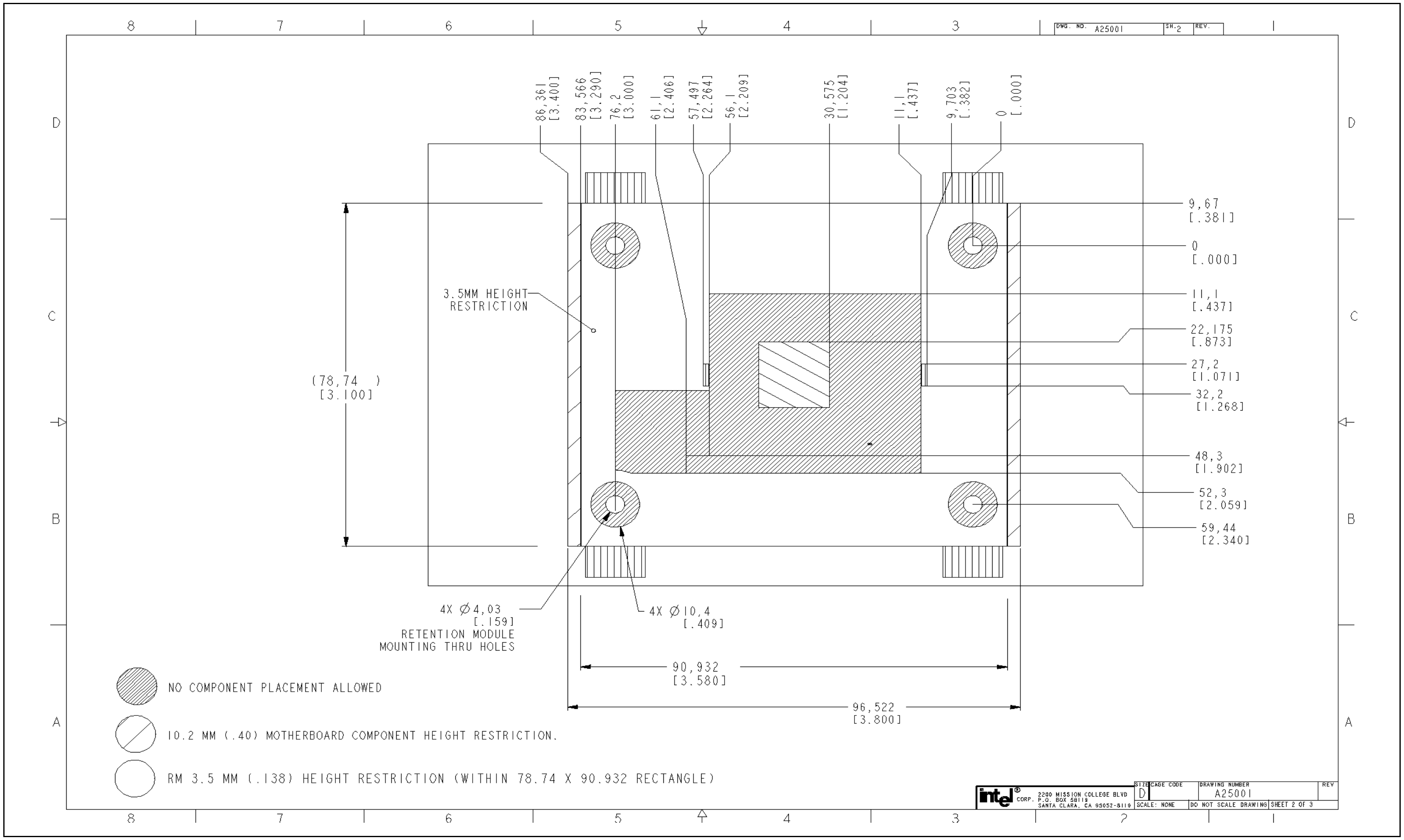


Figure 16. Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components (Sheet 3 of 3)

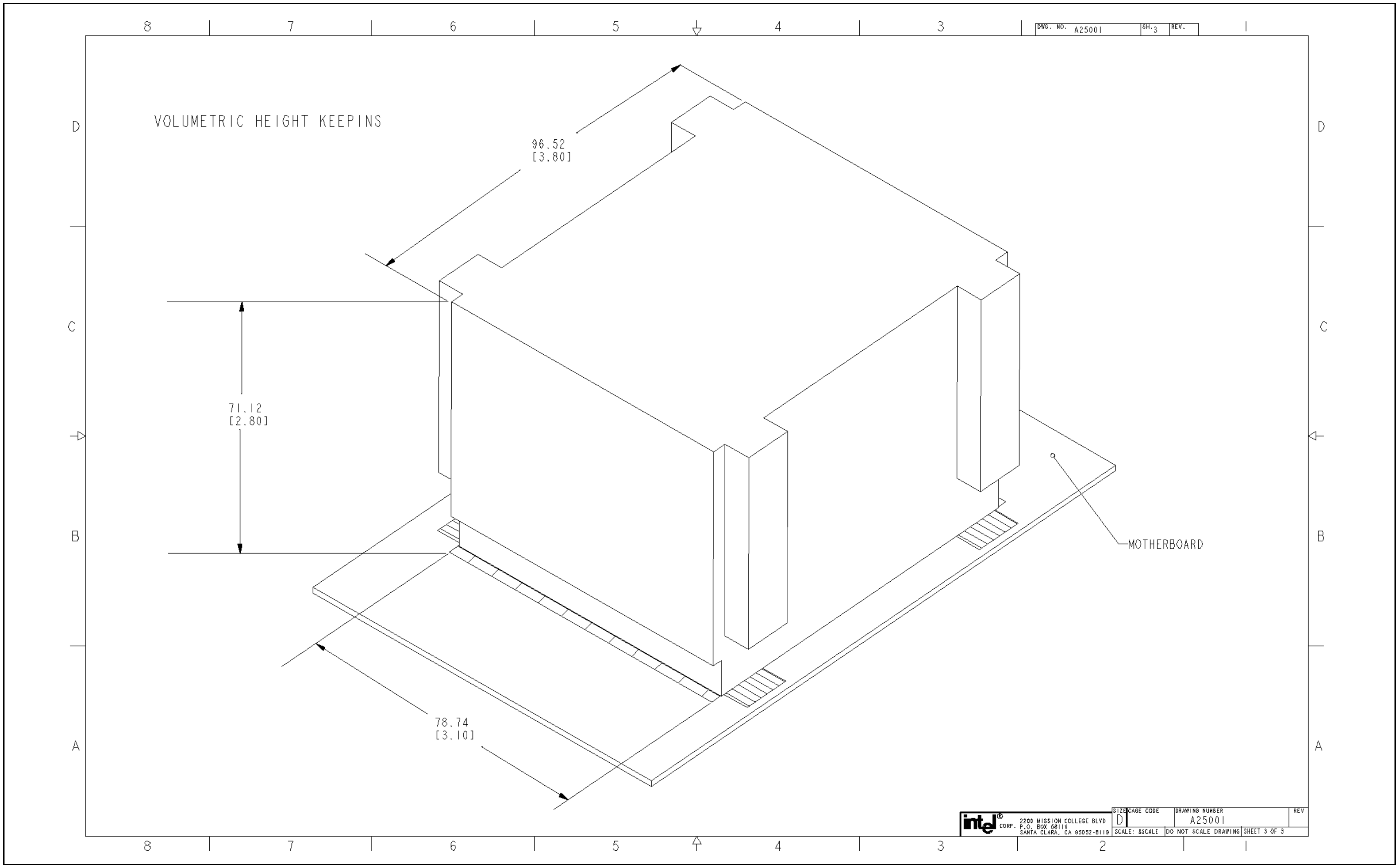


Figure 17. Retention Mechanism (Sheet 1 of 2)

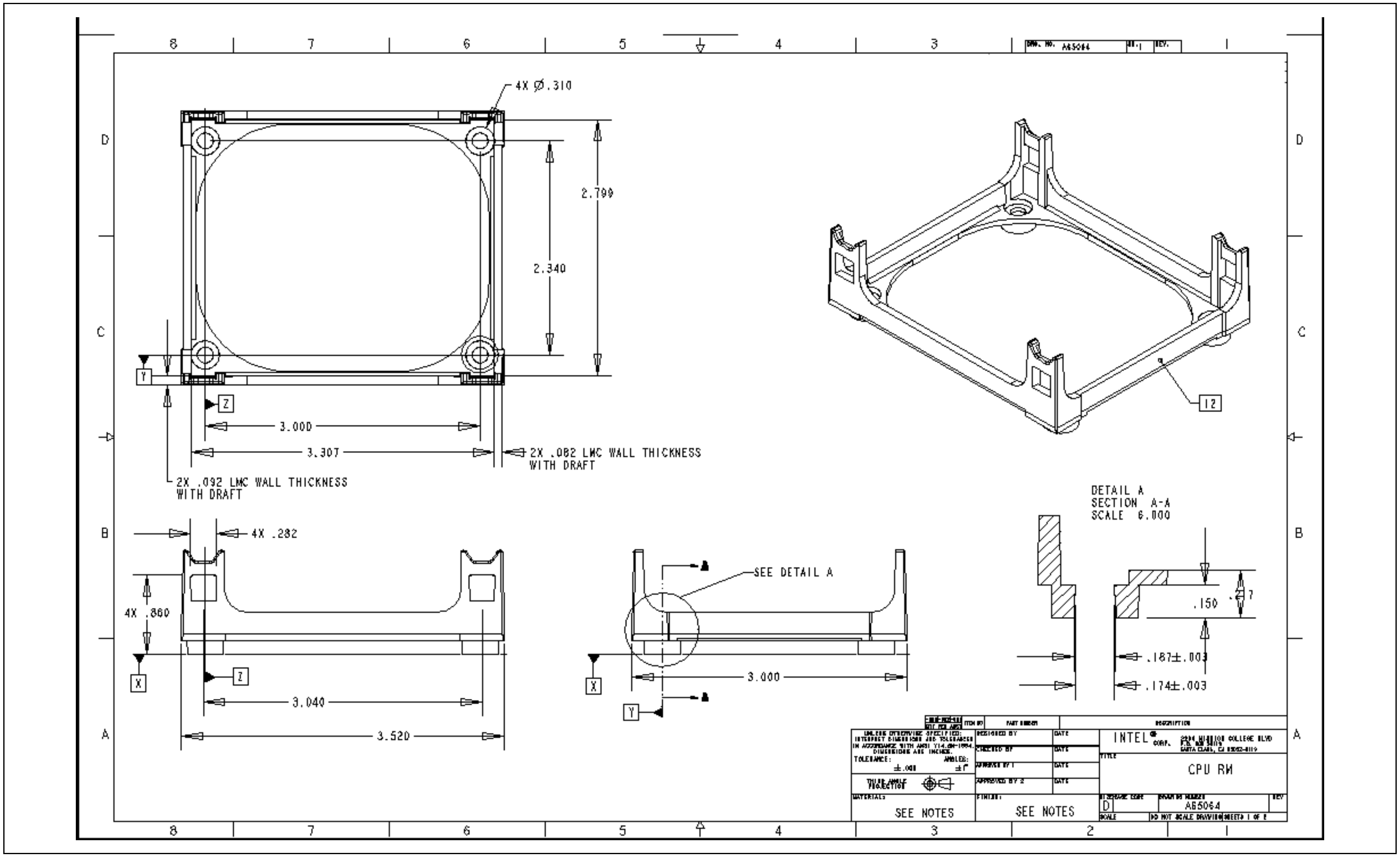
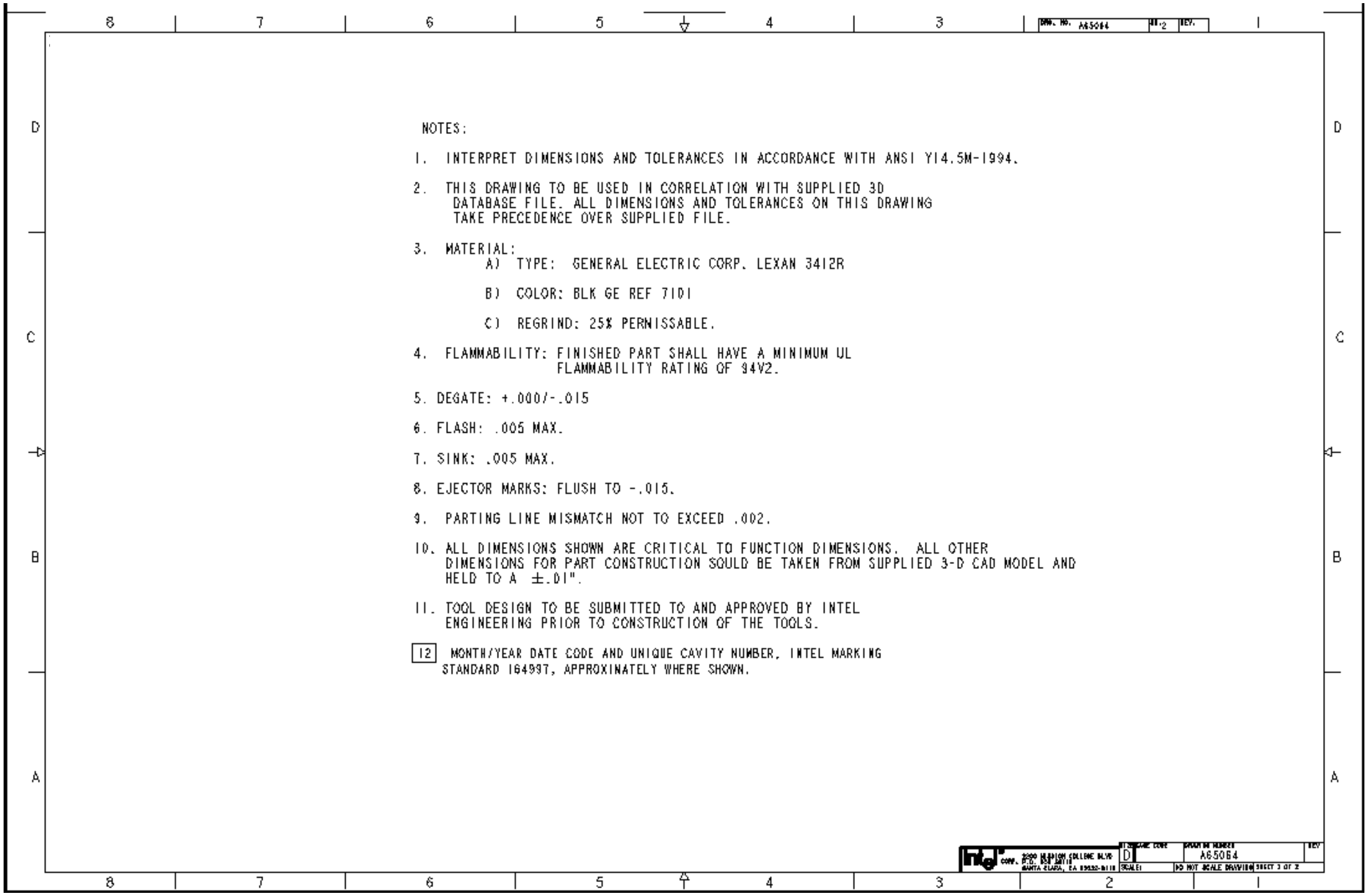


Figure 18. Retention Mechanism (Sheet 2 of 2)



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.

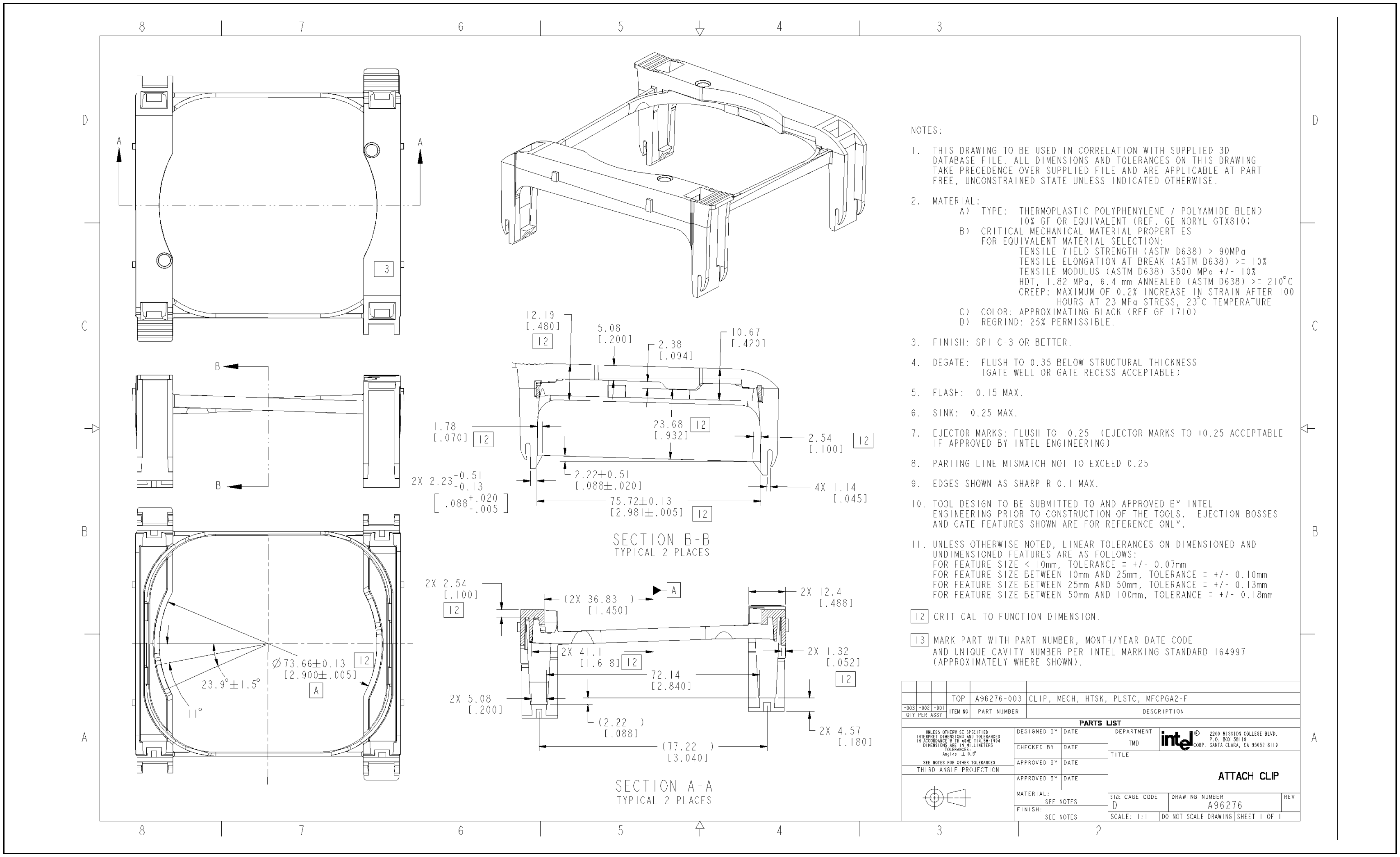
9. PARTING LINE MISMATCH NOT TO EXCEED .002.

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, APPROXINATELY WHERE SHOWN.

Figure 19. Heatsink Retention 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

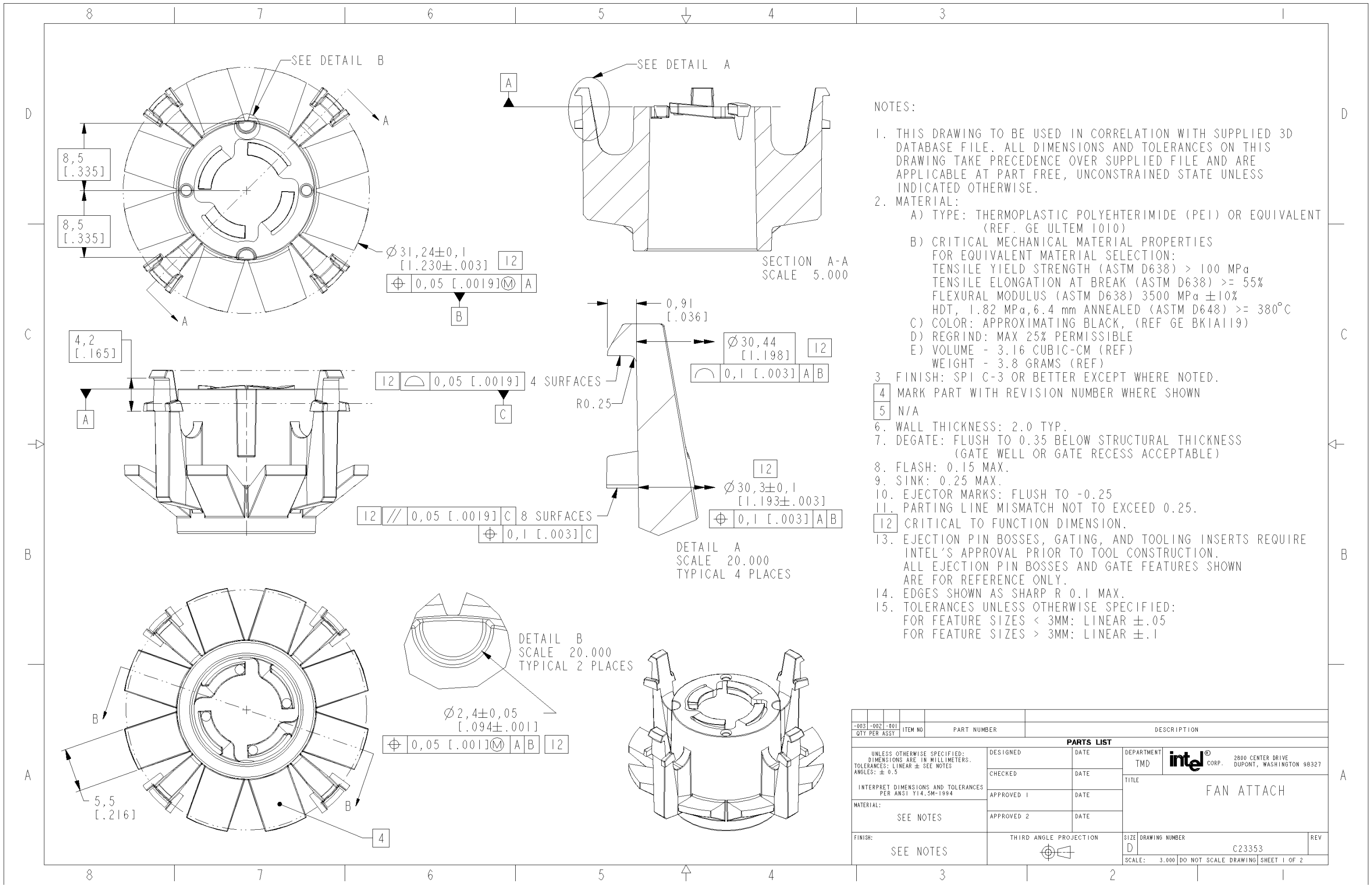
DEPARTMENT TMD

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

TITLE ATTACH CLIP

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

Figure 20. 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 POLYEHTERIMIDE (PEI) OR EQUIVALENT (REF. GE ULTEM 1010)
   - B) CRITICAL MECHANICAL MATERIAL PROPERTIES FOR EQUIVALENT MATERIAL SELECTION:
     TENSILE YIELD STRENGTH (ASTM D638) > 100 MPa
     TENSILE ELONGATION AT BREAK (ASTM D638) >= 55%
     FLEXURAL MODULUS (ASTM D638) 3500 MPa ±10%
     HDT, 1.82 MPa,6.4 mm ANNEALED (ASTM D648) >= 380°C
   - C) COLOR: APPROXIMATING BLACK, (REF GE BK1A119)
   - D) REGRIND: MAX 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

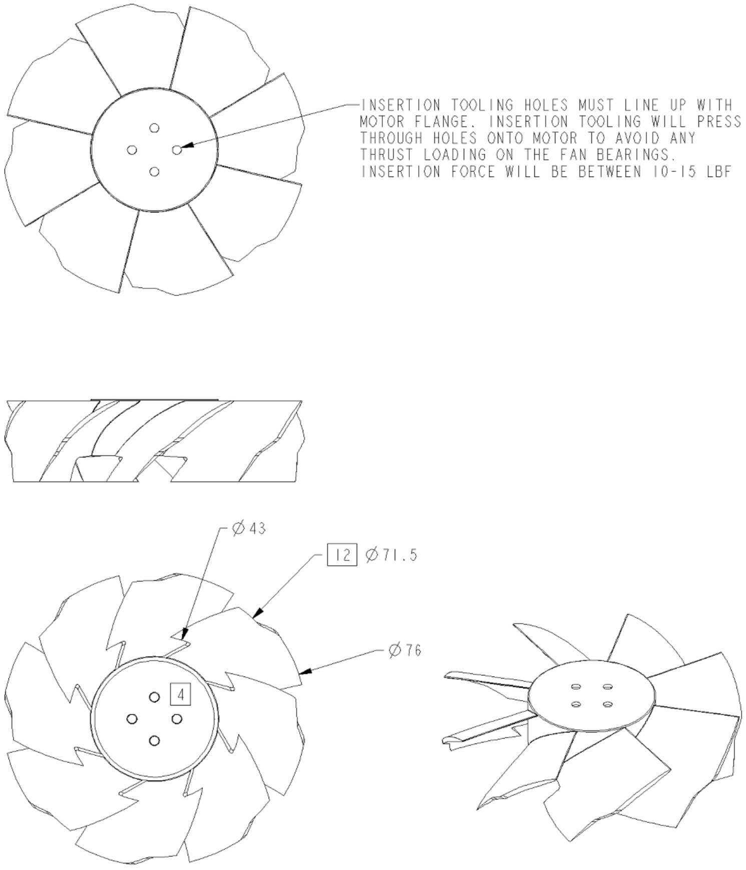
DEPARTMENT: TMD

intel® CORP. 2800 CENTER DRIVE
DUPONT, WASHINGTON 98327

TITLE: FAN ATTACH

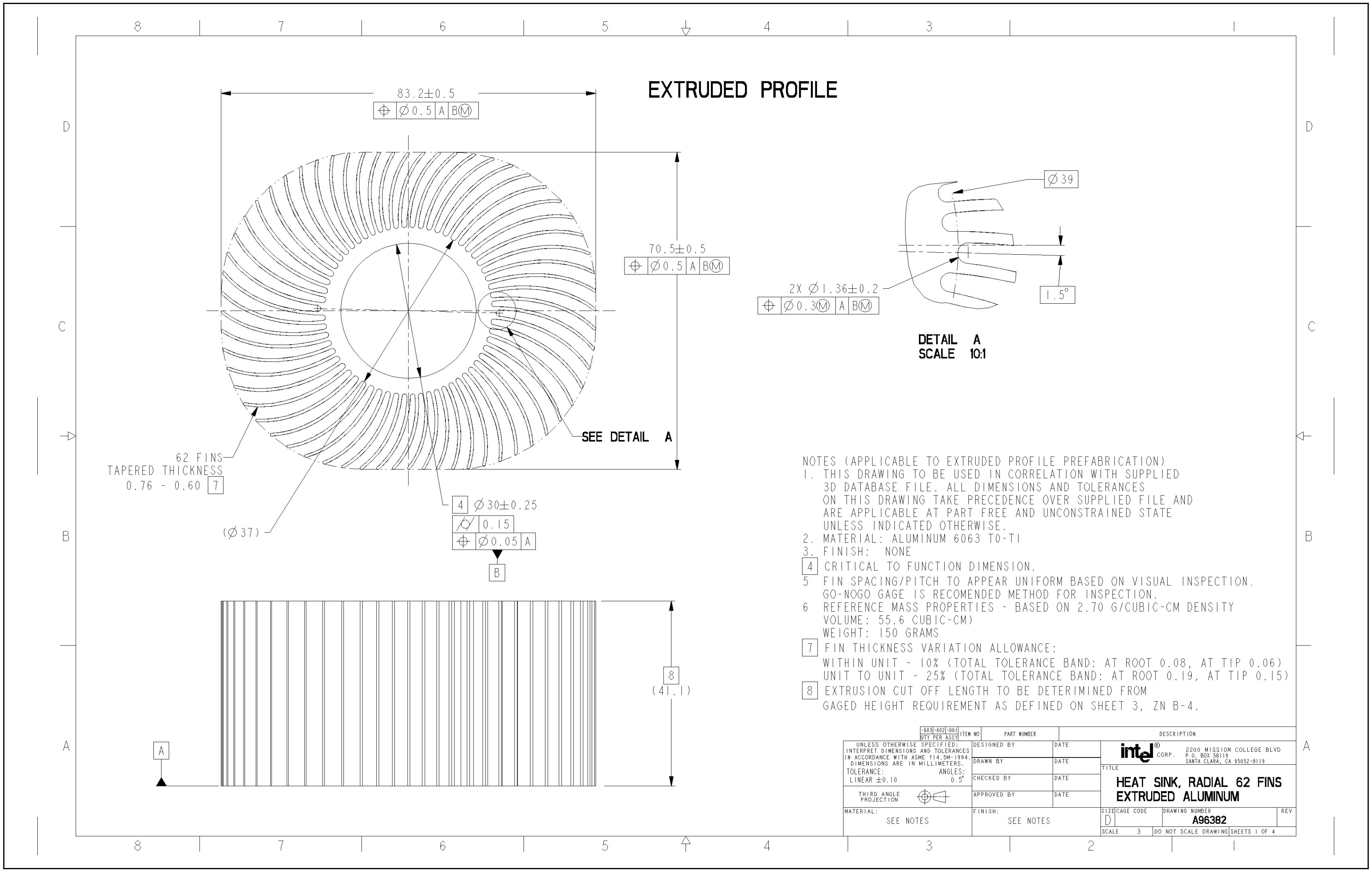
SIZE: D
DRAWING NUMBER: C23353
REV
SCALE: 3.000
DO NOT SCALE DRAWING
SHEET 1 OF 2

Figure 21. Fan Impeller Sketch



INSERTION TOOLING HOLES MUST LINE UP WITH MOTOR FLANGE. INSERTION TOOLING WILL PRESS THROUGH HOLES ONTO MOTOR TO AVOID ANY THRUST LOADING ON THE FAN BEARINGS. INSERTION FORCE WILL BE BETWEEN 10-15 LBF

Figure 22. Heatsink (Sheet 1 of 2)



NOTES (APPLICABLE TO EXTRUDED PROFILE PREFABRICATION)

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 AND UNCONSTRAINED STATE UNLESS INDICATED OTHERWISE.
2. MATERIAL: ALUMINUM 6063 T0-T1
3. FINISH: NONE

4 CRITICAL TO FUNCTION DIMENSION.

5 FIN SPACING/PITCH TO APPEAR UNIFORM BASED ON VISUAL INSPECTION. GO-NOGO GAGE IS RECOMENDED METHOD FOR INSPECTION.

6 REFERENCE MASS PROPERTIES - BASED ON 2.70 G/CUBIC-CM DENSITY
VOLUME: 55.6 CUBIC-CM)
WEIGHT: 150 GRAMS

7 FIN THICKNESS VARIATION ALLOWANCE:
WITHIN UNIT - 10% (TOTAL TOLERANCE BAND: AT ROOT 0.08, AT TIP 0.06)
UNIT TO UNIT - 25% (TOTAL TOLERANCE BAND: AT ROOT 0.19, AT TIP 0.15)

8 EXTRUSION CUT OFF LENGTH TO BE DETERIMINED FROM GAGED HEIGHT REQUIREMENT AS DEFINED ON SHEET 3, ZN B-4.

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

UNLESS OTHERWISE SPECIFIED:
INTERPRET DIMENSIONS AND TOLERANCES
IN ACCORDANCE WITH ASME Y14.5M-1994.
DIMENSIONS ARE IN MILLIMETERS.
TOLERANCE: LINEAR ±0.10
ANGLES: 0.5°
THIRD ANGLE PROJECTION

DESIGNED BY | DATE
DRAWN BY | DATE
CHECKED BY | DATE
APPROVED BY | DATE

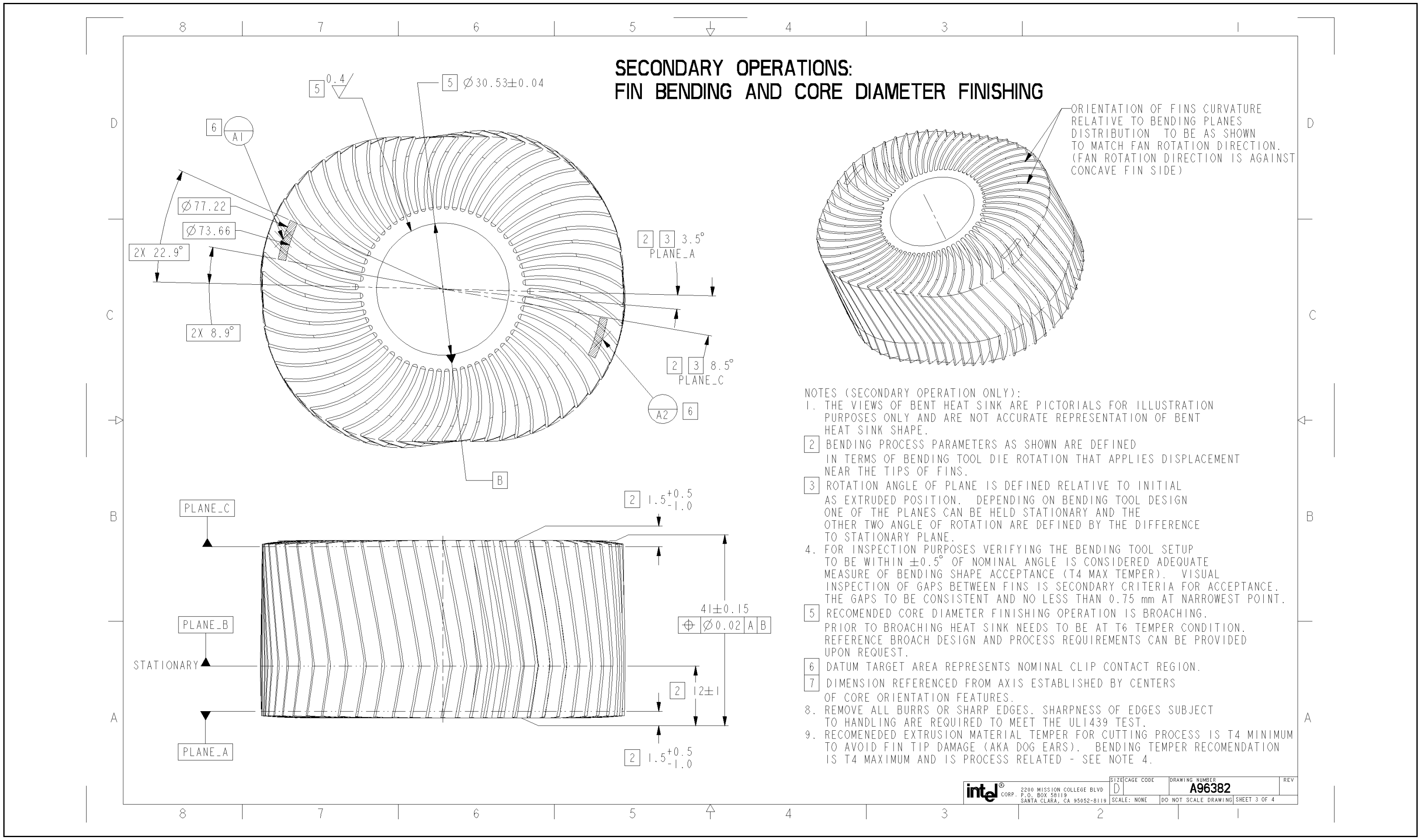
MATERIAL: SEE NOTES
FINISH: SEE NOTES

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

TITLE
HEAT SINK, RADIAL 62 FINS
EXTRUDED ALUMINUM

SIZE D
CAGE CODE
DRAWING NUMBER A96382
REV
SCALE 3
DO NOT SCALE DRAWING
SHEETS 1 OF 4

Figure 23. Heatsink (Sheet 2 of 2)



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 (T4 MAX TEMPER). 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.

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.

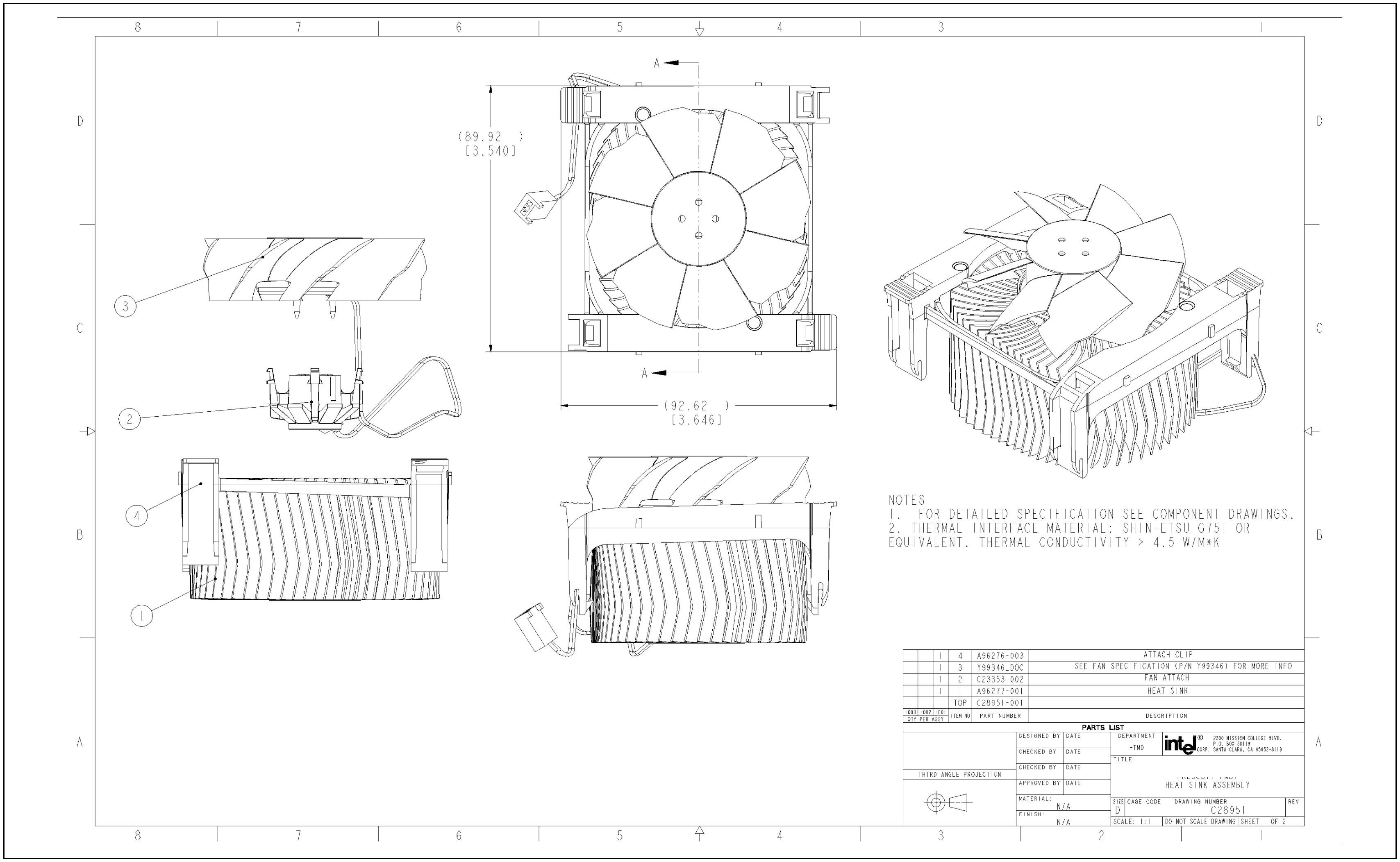
6 DATUM TARGET AREA REPRESENTS NOMINAL CLIP CONTACT REGION.

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

8. REMOVE ALL BURRS OR SHARP EDGES. SHARPNESS OF EDGES SUBJECT TO HANDLING ARE REQUIRED TO MEET THE UL1439 TEST.

9. RECOMENEDED EXTRUSION MATERIAL TEMPER FOR CUTTING PROCESS IS T4 MINIMUM TO AVOID FIN TIP DAMAGE (AKA DOG EARS). BENDING TEMPER RECOMENDATION IS T4 MAXIMUM AND IS PROCESS RELATED - SEE NOTE 4.

Figure 24. Heatsink Assembly (Non-validated Fan Guard Shown. Sheet 1 of 2)



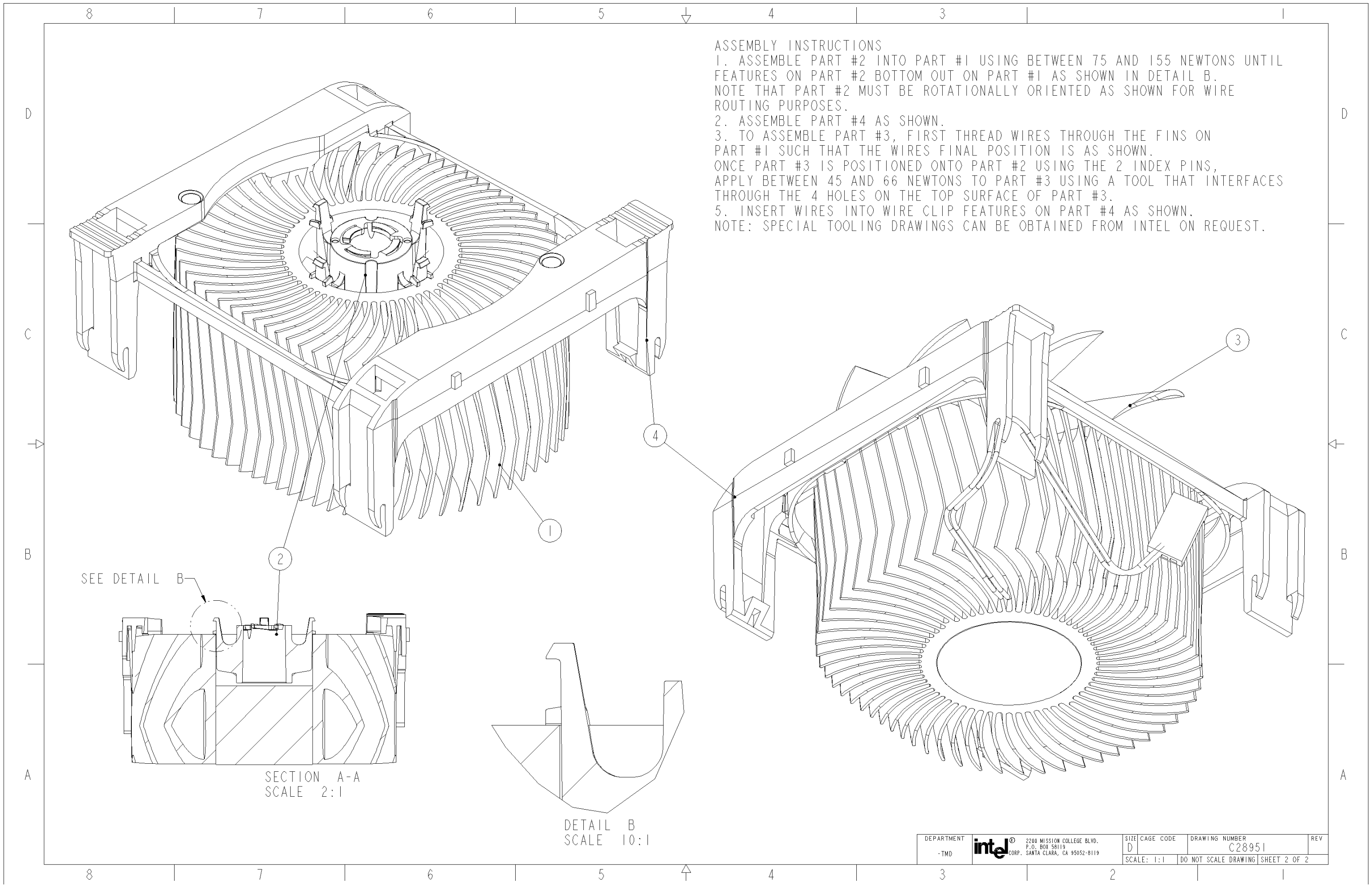
NOTES
1. FOR DETAILED SPECIFICATION SEE COMPONENT DRAWINGS.
2. THERMAL INTERFACE MATERIAL: SHIN-ETSU G751 OR EQUIVALENT. THERMAL CONDUCTIVITY > 4.5 W/M*K

PARTS LIST

QTY PER ASSY -003	QTY PER ASSY -002	QTY PER ASSY -001	ITEM NO	PART NUMBER	DESCRIPTION
		1	4	A96276-003	ATTACH CLIP
		1	3	Y99346_DOC	SEE FAN SPECIFICATION (P/N Y99346) FOR MORE INFO
		1	2	C23353-002	FAN ATTACH
		1	1	A96277-001	HEAT SINK
			TOP	C28951-001	

DESIGNED BY	DATE	DEPARTMENT -TMD	intel® CORP. 2200 MISSION COLLEGE BLVD. P.O. BOX 58119 SANTA CLARA, CA 95052-8119
CHECKED BY	DATE	TITLE HEAT SINK ASSEMBLY	
CHECKED BY	DATE		
APPROVED BY	DATE		
MATERIAL: N/A		SIZE D	CAGE CODE
FINISH: N/A		DRAWING NUMBER C28951	REV
		SCALE: 1:1	DO NOT SCALE DRAWING
		SHEET 1 OF 2	

Figure 25. Heatsink Assembly (Non-validated fan guard shown, Sheet 2 of 2)



ASSEMBLY INSTRUCTIONS

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

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

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Appendix D: T_{CASE} Reference Metrology

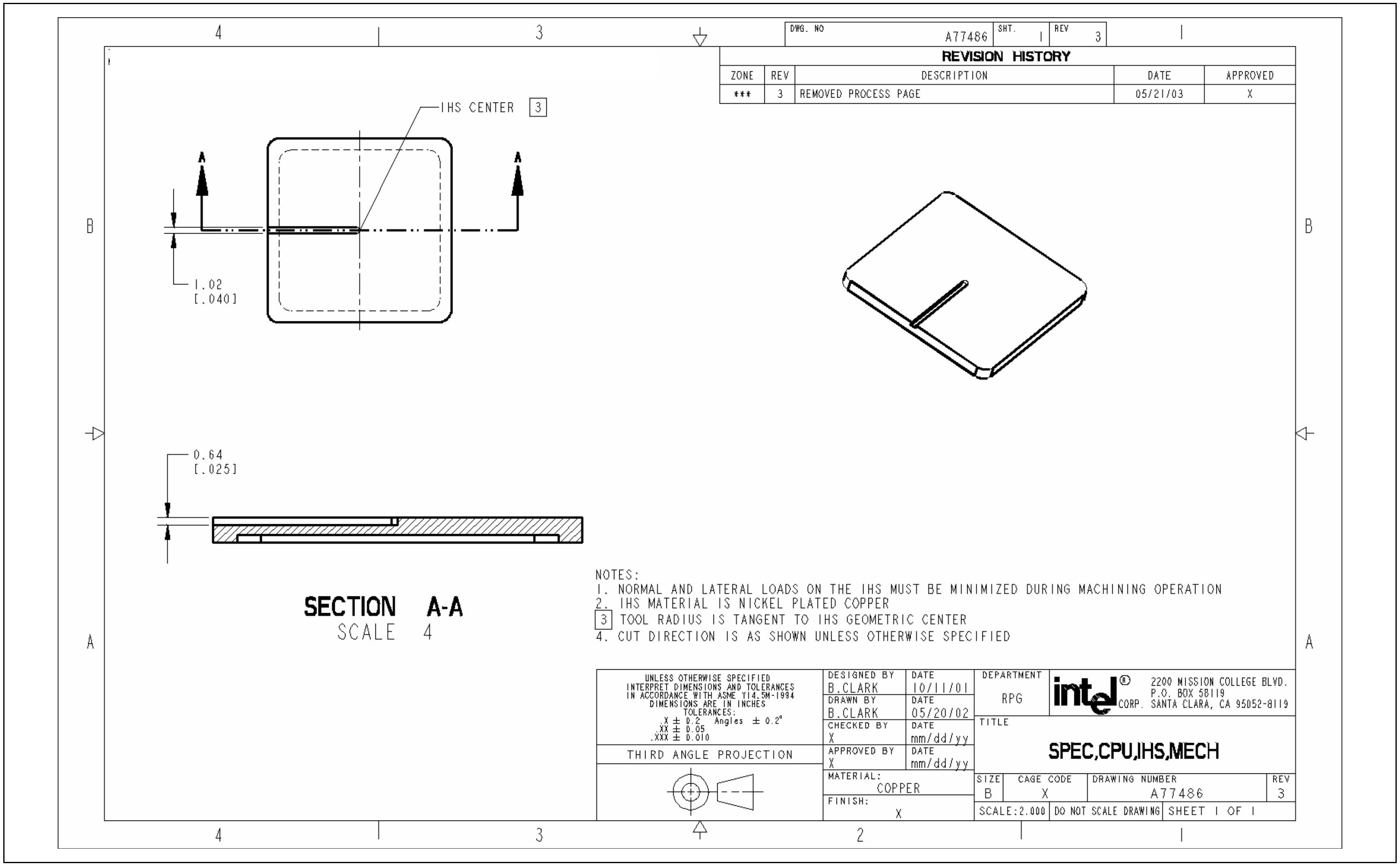
The procedure for attaching thermocouples to the Thermal Test Vehicle (TTV) for use in thermal experiments is described in this appendix. A repeatable and accurate thermocouple attach process reduces overall experimental variation, cuts down on preparation time for measurements, and most importantly yields robust temperature measurements. Elements of this metrology may change in the future to further improve its accuracy and/or precision.

This appendix discusses the TTV preparation, attach, and cure procedure for attaching thermocouples in a 'flat' or 0° orientation on the TTV integrated heat spreader (IHS). This procedure is tailored to the use of 36 gauge thermocouples. A list of necessary items is shown in Table 8.

Thermal Test Vehicle (TTV) Preparation

The TTV assembly process is very similar to the assembly process of the Pentium 4 processor on 90 nm process. To place a thermocouple on the surface of the integrated heat spreader (IHS), a groove must first be machined into the surface. The thermocouple groove must be made by an experienced machinist with precision equipment and adhere to the tolerances listed in Figure 26. Improper or non-compliant manipulation of the IHS surface can cause damage to the TTV or cause erroneous results during the testing procedure. After the machining process, the IHS surface on the TTV should be thoroughly cleaned to remove any debris or residue. Isopropyl alcohol should be used to remove any residue from handling or the machining process.

Figure 26. Integrated Heat Spreader (IHS) Thermocouple Groove Dimension



Thermocouple Attach Procedure

The following items are required for thermocouple removal or reattach.

Table 8. Thermalcouple Attach Material List

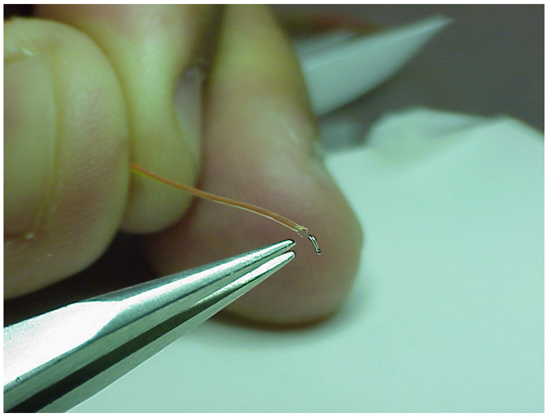
Thermalcouple Attach Material List
Scribe
Fine point tweezers
Exacto* knife (#11 blade)
Thermocouple (36 gauge, 0.9 m [36 in], Teflon insulation)
3M Kapton* tape cut into strips (3 mm x 13 mm [0.125 in x 0.5 in])
Epoxy (Omega Bond* 101)

Thermocouple Preparation

The thermocouple wire must be prepared for attach using the following procedure.

1. Hold the thermocouple (T/C) in hand, locate the beaded end and straighten the wire by hand so that the first 100–150 mm [4-6 in] are reasonably straight.
2. Use fine point tweezers to make sure that the bead and the two wires coming out are straight and untwisted. Make sure that the second layer of insulation, which is sometimes clear, is not covering the bead.
3. Bend both the thermocouple wires slightly at a location approximately 3 mm [0.125 in] away from the thermocouple bead. When this thermocouple is placed on a flat surface the bend serves to spring load the bead and guarantee that the thermocouple bead is making contact with the bottom of the groove when it is inserted into the channel.

Figure 27. Thermocouple Wire Preparation

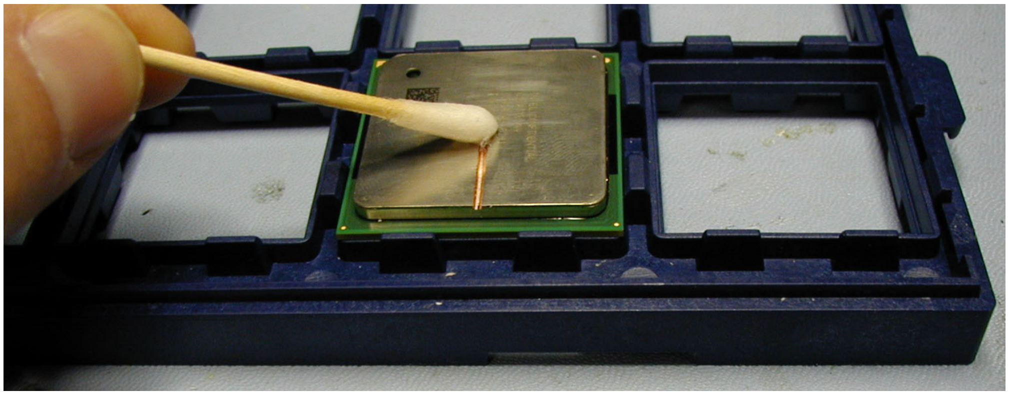


Thermocouple Positioning

Position the thermocouple on the part using the following process.

1) The TTV surface must be thoroughly cleaned in order to ensure a strong bond between the epoxy and the surface of the part to which the thermocouple is being attached. Clean the TTV surface with alcohol using a lint-free wipe or swab.

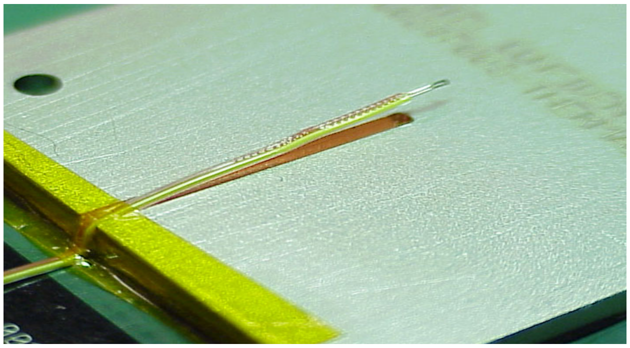
Figure 28. TTV Cleaning Preparation



2) Place the thermocouple into the groove of the integrated heat spreader of the TTV so that the bead is pointing down at the end of the grooved channel. The thermocouple bead should extend past the end of the groove (at the center of the IHS) by approximately 4 mm. See Figure 29.

3) Hold the T/C with one hand and use the tweezers to place a previously cut piece of Kapton* tape on the edge of the IHS as shown in Figure 29. This will hold the wire down into the groove. Rub the tape to allow for a good bond between the tape and the TTV.

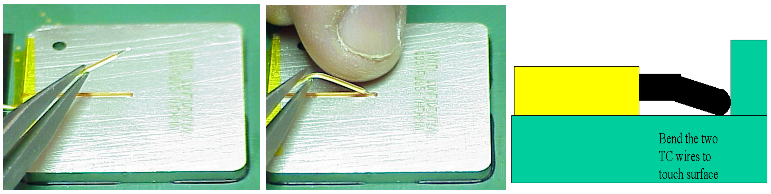
Figure 29. TTV Thermocouple Instrumentation



4) With the T/C temporarily attached to the part, mix the epoxy and prepare it for use. If Omega Bond* 101 epoxy is used, squeeze out equal quantities of the resin and the catalyst onto a piece of paper. Use a stirrer to mix the two ingredients. The end result should be a consistently white viscous paste.

5) Lift the wire at the middle of channel with tweezers and bend the front of wire to place the thermocouple in the channel ensuring the tip is in contact at the bottom end of the groove of the IHS. See Figure 30.

Figure 30. Thermocouple Attach Preparation



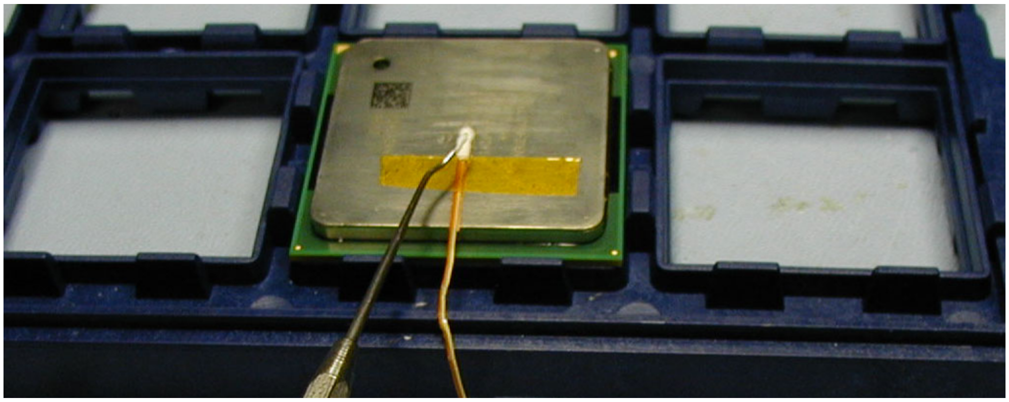
6) **Important!** Using an ohmmeter, measure the thermocouple electrical resistance. The thermocouple resistance should be 25 Ω or less. If there is no continuity, it means that the thermocouple bead is not touching the bottom of the grooved channel and that test results will be inaccurate. If this occurs, start re-attach procedure again.

Epoxy Application

Apply the epoxy to attach the thermocouple using the following procedure.

1) Use a scribe or an Exacto* knife to apply the epoxy over the bead in the channel. If an Exacto knife is used, a #11 blade is recommended because the blade has a sharp point and can also act as a small trowel. Apply epoxy over the bead and on the exposed thermocouple wires. Very little epoxy is needed to attach the thermocouple. The epoxy application should cover the thermocouple bead and some portion of the insulated thermocouple wires. Excess epoxy will be trimmed flush to the IHS in a later step and after the epoxy has cured. It is recommended to minimize the amount of excess epoxy applied outside the grooved channel.

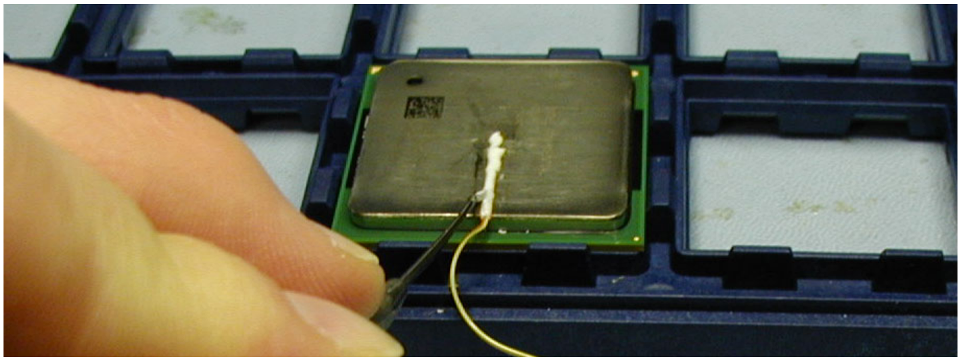
Figure 31. TTV Initial Glue Application



2) Let the epoxy cure for eight (8) hours at room temperature. Minimize any movement and/or vibration since it will tend to cause the T/C bead to float up and create non-continuity. **CAUTION!** During the drying process, the thermocouple continuity can become compromised. Be sure to check again with an ohm-meter.

3) Once the part(s) are dry, finish applying glue in the remaining area in the channel. Repeat steps 1 and 2.

Figure 32. TTV Final Glue Application

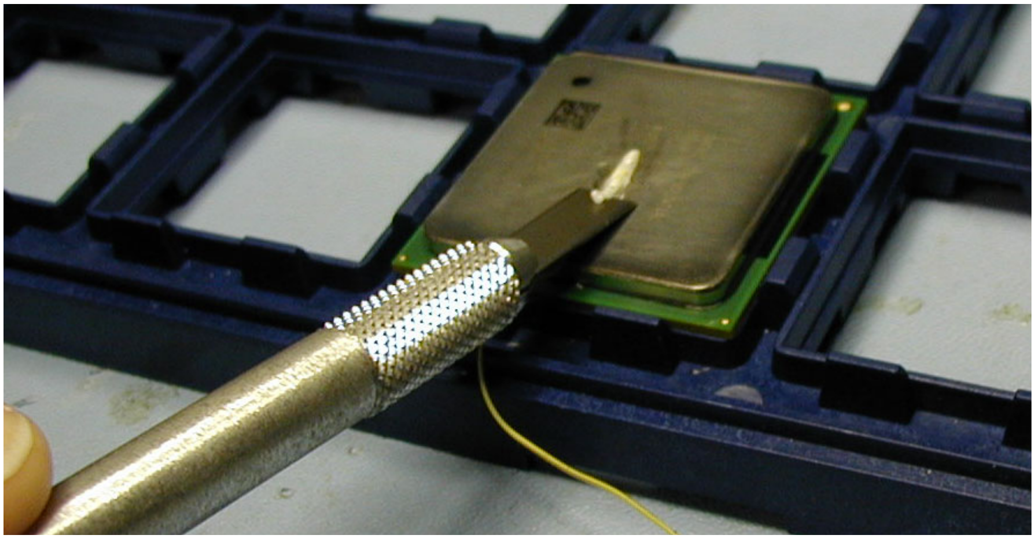


4) Remove parts and allow them to cool. Remove all tape and check for any unwanted epoxy dots or lines. Use the Exacto* knife to remove the extraneous epoxy from the surface.

5) Using an ohmmeter, measure the thermocouple electrical resistance to ensure a value of 25 Ω or less.

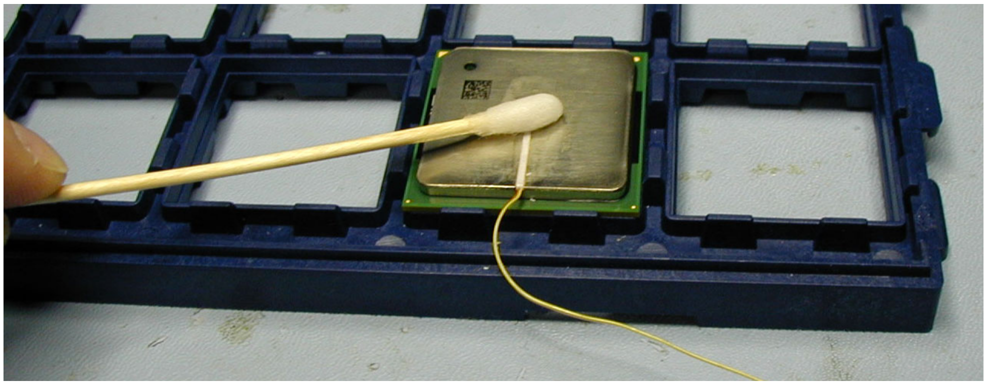
6) Trim the excess glue from the IHS surface as shown below. **CAUTION!** Be sure not to damage the surface of the IHS. Any deep scratches can cause erroneous test results.

Figure 33. Trimming of Excess Glue



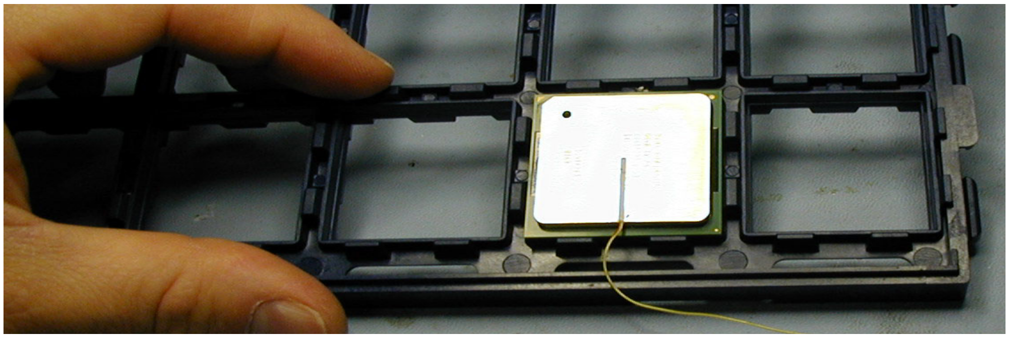
7) Thoroughly clean the part before beginning any test procedures.

Figure 34. Final TTV Cleaning



8) Inspect the final package for any remaining glue particles.

Figure 35. TTV Final Inspection



Appendix E: TTV Metrology

Thermal Test Vehicle (TTV) Information

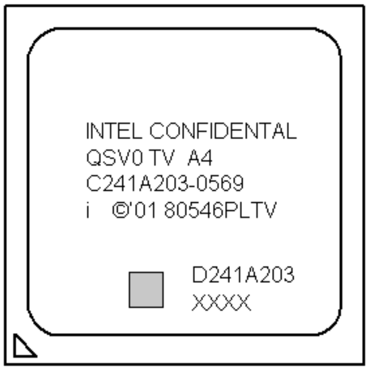
Introduction

The Pentium 4 processor on 90 nm process Thermal Test Vehicle (TTV) is a FC-mPGA4 package assembled with a thermal test die. The TTV is designed for use in platforms targeted for the Pentium 4 processor on 90 nm process.

Thermal solution performance should be characterized using the TTV. The TTV provides a well-characterized tool suitable for simulating processor thermal behavior well before actual parts are available. A resistance-type heater band covers the surface area of the test die and is used to simulate the heat generation of an actual processor core. The power dissipation is uniform across the test die and requires correction factors to account for non-uniform heat dissipation in an actual processor.

The part number for the Pentium 4 processor on 90 nm process TTV is QSV0. Figure 36 shows the markings on the top of the TTV IHS.

Figure 36. Intel® Pentium® 4 Processor on 90 nm Process Thermal Test Vehicle Topside Markings



The room temperature resistance of the heater is 23 Ω ± 3 Ω. This resistance value will increase as the die temperature increases. The heater resistance should always be measured for each TTV prior to testing. The TTV is not sensitive to static electricity.

TTV Preparation

The IHS surface should be cleaned with alcohol prior to any thermal testing to remove any dirt or residue. A clean surface will aid in achieving a good thermal interface between the processor and heatsink. Visually inspect the TTV to ensure that none of the pins are bent or damaged.

TTV Connections for Power-Up

The TTV heater is connected to external pins and 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 (VCC and VSS). The power and ground pin-out of the TTV match the power and ground pin-out of the actual processor, allowing use of a standard motherboard for power-up.

Obtain an unpopulated motherboard designed to accept the 478-pin mPGA socket and either the Pentium 4 processor on 90 nm process or the Pentium 4 processor in the 478-pin package. An example motherboard is shown in Figure 37. Mount a 478-pin mPGA socket to the board using a SMT process as shown in Figure 38.

Figure 37. Unpopulated Motherboard

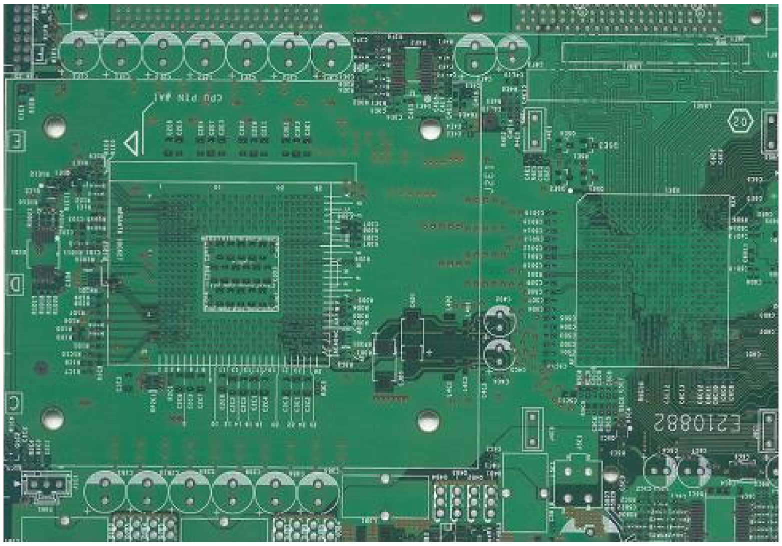
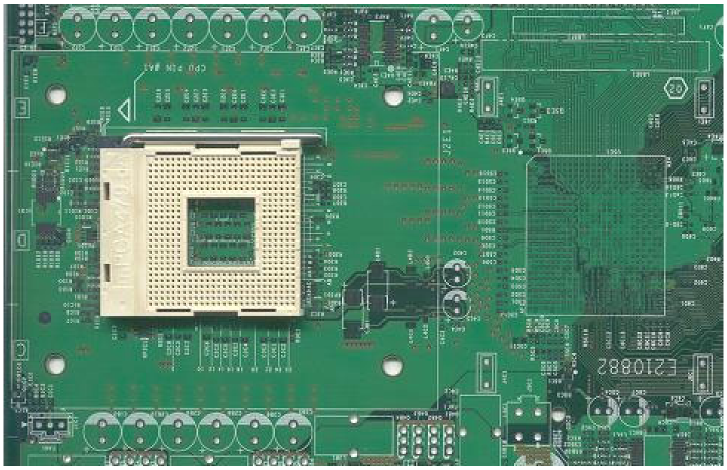
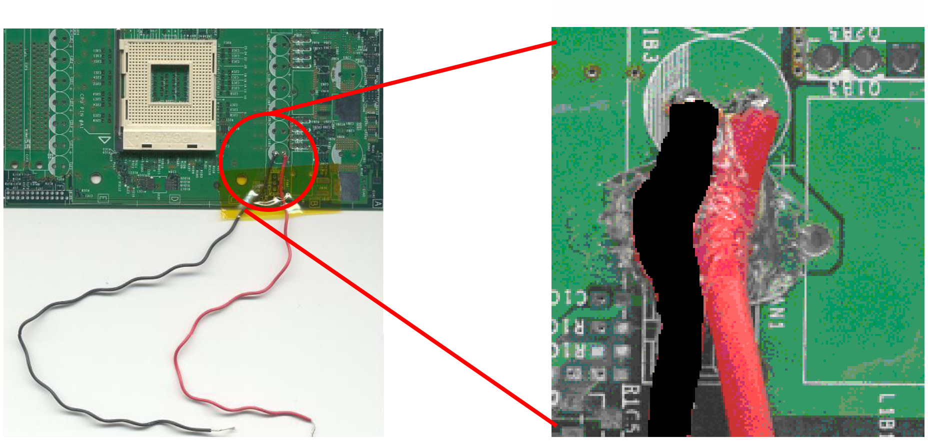


Figure 38. Motherboard with Socket Attached



The heater can be accessed by soldering wires to the power and ground sides of one of the capacitor pads. This establishes connections between the power supply and power/ground planes on the motherboard. Since the heater is a simple resistor, the polarity of the power supply connection is arbitrary.

Figure 39. Power Supply Connection to Motherboard



Measure the resistance between the power and ground planes with the socket empty to make sure that the planes are separated (i.e., open circuit). With some Digital Multi-Meters, a measurement of “O.L” will be seen. If a resistance is measured, the planes are short-circuited. Correct the situation and achieve isolated planes before proceeding.

Insert a TTV into the socket and measure the resistance. A value of 23 Ω ± 3 Ω should be measured. If the resistance deviates significantly, there may exist a wiring problem, a damaged TTV, and/or a short-circuit between power and ground planes.

Recommended DC Power Supply Ratings

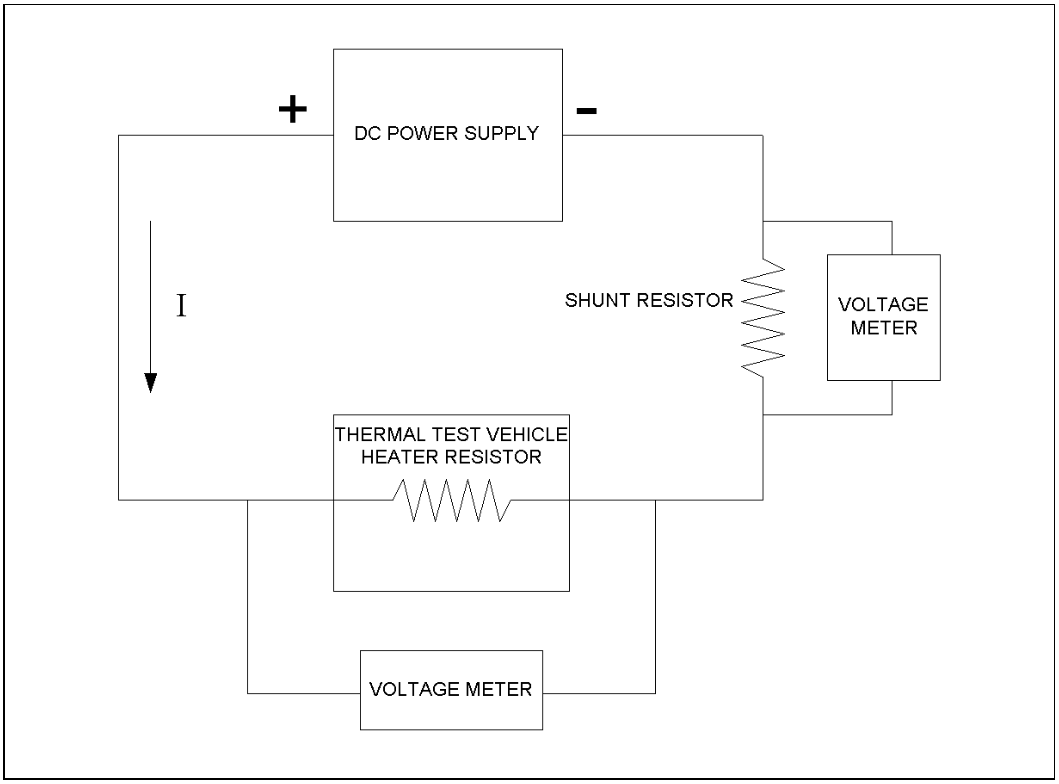
The recommended DC power supply rating is 120 V and 4 A. The power dissipation should be maintained below 110 W and the TTV case temperature should be maintained below 80°C during thermal testing. By violating the constraints, the TTV operational life will be reduced and/or the unit may fail to function. Note that the reliability of TTV is limited and the TTV is not designed for long-term testing purposes. The TTV should not be powered on without an attached heatsink or damage to the TTV could occur.

Thermal Measurements

Refer to Section 3.3.2 for T_A measurement methodology. Refer to Appendix D for thermocouple attachment to the HIS. Use the following instructions for performing thermal characterization parameter measurements using the TTV:

1. Attach a thermocouple at the center of the package (IHS-side) using the proper thermocouple attach procedure (refer to Appendix D).
2. Connect the thermocouple to a meter or data logger.
3. Apply thermal interface materials to either IHS top surface or on the surface of heatsink base.
4. 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.).
5. Place the TTV in the test environment (e.g., a test bench, a wind tunnel or a computer chassis).
6. Connect the heater resistor of TTV to a DC power supply. Connect shunt resistor and voltage meters as shown in Figure 40. Use a shunt resistor with a 0.01 Ω resistance so that the power draw of the TTV will be unaffected.

Figure 40. Electrical Connection for Heater



7. Refer to Section 3.3.2 to setup the thermocouples used for T_A measurement, and connect them to a thermocouple meter or data logger.
8. 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.
9. Calculate the actual power P_D applied to the heater resistor by multiplying the readings from the TTV voltage meter and the calculated shunt resistor current (Current = V_{SHUNT} / R_{SHUNT}). 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. Die resistance variations restrict the capability of predicting the power supply voltage and current settings. (Table 9 can be used as a general reference or starting point to acquire the desired actual power.)

Table 9. Desired Power Targets

Desired Die Power Level	Power Supply Setting
70	40 V and 1.5 A
80	49 V and 1.6 A
90	53V and 1.7 A
100	56V and 1.8 A
110	60 V and 1.9 A

10. Wait for one hour to reach the stable condition before reading the case temperature (T_C) and the local ambient temperatures (T_A) from the thermocouples. If a data logger is used, sample two minutes of steady state data at 1 Hz and average the temperatures over that time period. Average all the T_A thermocouple temperatures to arrive at a single T_A measurement.
11. Calculate the raw case-to-ambient thermal characterization parameter (Ψ_{CA}) based on equation 1 given in Section 3.2.3. This equation is shown below.

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

12. Multiply raw result with Ψ_{CA} correction factor in Table 10 to arrive at final adjusted Ψ_{CA}.

TTV Correction Factors for Intel® Pentium® 4 Processor on 90 nm Process

Thermal characterization parameter measurements made with a thermal test vehicle must be corrected for the non-uniform power dissipation of actual processors. Table 10 provides correction factors for using a Pentium 4 processor on 90 nm process TTV to assess the thermal characterization parameter of Pentium 4 processor on 90 nm process heatsinks. The value of a thermal characterization parameter is derived from the value measured on the TTV and the corresponding correction factor according to equation:

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

This formula can be applied to Ψ_{CS} and Ψ_{SA} measurements as well.

Table 10. Intel® Pentium® 4 Processor on 90 nm Process TTV Correction Factors

Thermal Characterization Parameter	**Correction factor using Intel® Pentium® 4 Processor on 90 nm Process TTV**
Ψ_{CS}	1.103
Ψ_{SA}	1.006
Ψ_{CA}	1.030

Note: The Ψ_{CS} and Ψ_{SA} correction factors should be used whenever possible since the Ψ_{CA} correction factor is based on the Intel reference solution and depend on the TIM used. The Ψ_{CA} correction factor provided should be used only when the ratio of Ψ_{CS} to Ψ_{SA} is ~0.32.