



Intel® Pentium® 4 Processor on 90 nm Process in the 775-Land LGA Package

Thermal and Mechanical Design Guidelines

*Supporting Intel® Pentium® 4 Processor 5xx and 6xx Sequences in
the 775-land LGA Package and Intel® Pentium® 4 Processor
Extreme Edition in the 775-land LGA Package*

November 2005



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Revision History

Revision Number	Description	Date
-001	<ul style="list-style-type: none">Initial Release.	June 2004
-002	<ul style="list-style-type: none">Updated to add information for the Intel® Pentium® 4 processor 660, 650, 640, and 630 in the 775-land LGA package and the Intel® Pentium® 4 processor Extreme Edition in the 775-land LGA package	February 2005
-003	<ul style="list-style-type: none">Added information for Intel® Pentium® 4 processor 670Updated the Fan Speed Control tablesUpdated the Fastener Drawings	May 2005
-004	<ul style="list-style-type: none">Added Intel® Pentium® 4 processors 662 and 672 to the list of processors supported by this thermal/mechanical design guide.Added Intel® Pentium® 4 processors 571, 561, 551, 541, 531, and 521 to the list of processors supported by this thermal/mechanical design guide.	November 2005

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1 *Introduction*

1.1 Document Goals and Scope

1.1.1 Importance of Thermal Management

The objective of thermal management is to ensure that the temperatures of all components in a system are maintained within their functional temperature range. Within this temperature range a component 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 affected by the continued push of technology to increase processor performance levels 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 remains the same within the system. The result is an increased importance on system design to ensure that thermal design requirements are met for each component, including the processor, in the system.

1.1.2 Document Goals

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 Intel® Pentium® 4 processor in the 775-Land LGA package.



1.1.3 Document Scope

This design guide supports the following processors:

- Pentium 4 processors 570/571, 560/561, 550/551, 540/541, 530/531, and 520/521 in the 775-land LGA package
- Pentium 4 processor 670/672, 660/662, 650, 640, and 630 in the 775-land LGA package
- Pentium 4 processor Extreme Edition in the 775-land LGA package

In this document, when a reference is made to “the processor” and/or “the Pentium 4 processor in the 775-Land LGA package”, it is intended that this includes all the processors supported by this document. If needed for clarity, the specific processor will be listed.

In this document, when a reference is made to “the datasheet”, the reader should refer to either the *Intel® Pentium® 4 Processors 570/571, 560/561, 550/551, 540/541, 530/531, and 520/521^A – On 90 nm Process in the 775-Land LGA Package and Supporting Hyper-Threading Technology Datasheet* or the *Intel® Pentium® 4 Processor 6xx^A Sequence and Intel® Pentium® 4 Processor Extreme Edition Datasheet – On 90 nm Process in the 775-land LGA Package, supporting Intel® Extended Memory 64 Technology^B, and supporting Intel® Virtualization Technology* as appropriate. If needed for clarity, the specific processor datasheet will be referenced.

Chapter 2 discusses package thermal mechanical requirements to design a thermal solution for the Pentium 4 processor in the 775-land LGA package in the context of personal computer applications. Chapter 3 discusses the thermal solution considerations and metrology recommendations to validate a processor thermal solution. Chapter 4 addresses the benefits of the processor’s integrated thermal management logic for thermal design.

Chapter 5 provides information on the common Intel reference thermal solution for the Pentium 4 processor in the 775-land LGA package discussed in this document. Chapter 6 discusses the implementation of acoustic fan speed control.

THE PHYSICAL DIMENSIONS AND THERMAL SPECIFICATIONS OF THE PROCESSOR THAT ARE USED IN THIS DOCUMENT ARE FOR ILLUSTRATION ONLY. REFER TO THE DATASHEET FOR THE PRODUCT DIMENSIONS, THERMAL POWER DISSIPATION AND MAXIMUM CASE TEMPERATURE. IN CASE OF CONFLICT, THE DATA IN THE DATASHEET SUPERSEDES ANY DATA IN THIS DOCUMENT.



1.2 References

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

Document	Document Link
<i>Intel® Pentium® 4 Processor 6xx^Δ and Intel® Pentium® 4 Processor Extreme Edition Datasheet – On 90 nm Process in the 775-land LGA Package, supporting Intel® Extended Memory 64 Technology^Φ, and supporting Intel® Virtualization Technology.</i>	http://intel.com/design/pentium4/datashts/306382.htm
<i>Intel® Pentium® 4 Processors 570/571, 560/561, 550/551, 540/541, 530/531, and 520/521^Δ Supporting Hyper-Threading Technology – On 90 nm Process in the 775-Land LGA Package and Supporting Intel Extended Memory 64 Technology^Φ Datasheet</i>	http://developer.intel.com/design/Pentium4/datashts/302351.htm
<i>LGA775 Socket Mechanical Design Guide</i>	http://developer.intel.com/design/Pentium4/guides/302666.htm
<i>Boxed Intel® Pentium® 4 Processor in the 775-Land LGA Package - Integration Video</i>	http://www.intel.com/go/integration
<i>Fan Specification for 4-wire PWM Controlled Fans</i>	http://www.formfactors.org/
<i>Performance ATX Desktop System Thermal Design Suggestions</i>	http://www.formfactors.org/
<i>Performance microATX Desktop System Thermal Design Suggestions</i>	http://www.formfactors.org/
<i>Balanced Technology Extended (BTX) System Design Guide</i>	http://www.formfactors.org/

1.3 Definition of Terms

Term	Description
T_A	The measured ambient temperature locally surrounding the processor. The ambient temperature should be measured just upstream of a passive heatsink or at the fan inlet for an active heatsink.
T_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-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 $(T_C - T_A) / \text{Total Package Power}$. Note: Heat source must 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 $(T_C - T_S) / \text{Total Package Power}$. Note: Heat source must be specified for Ψ measurements.
Ψ_{SA}	Sink-to-ambient thermal characterization parameter. A measure of heatsink thermal performance using total package power. Defined as $(T_S - T_A) / \text{Total Package Power}$. Note: Heat source must be specified for Ψ measurements.
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.
LGA775 Socket	The surface mount socket designed to accept the Pentium 4 processor in the 775-land LGA package.
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 in the 775-land LGA package that attempts to keep the processor die temperature within factory specifications.
TCC	Thermal Control Circuit: Thermal Monitor uses the TCC to reduce die temperature by lowering effective processor frequency when the die temperature has exceeded its operating limits.
T_{DIODE}	Temperature reported from the on-die thermal diode.



Term	Description
FSC	Fan Speed Control: Thermal solution that includes a variable fan speed which is driven by a PWM signal and uses the on-die thermal diode as a reference to change the duty cycle of the PWM signal.
$T_{CONTROL_BASE}$	Constant from the processor datasheet that is added to the $T_{CONTROL_OFFSET}$ that results in the value for $T_{CONTROL}$
$T_{CONTROL_OFFSET}$	Value read by the BIOS from a processor MSR and added to the $T_{CONTROL_BASE}$ that results in the value for $T_{CONTROL}$
$T_{CONTROL}$	$T_{CONTROL}$ is the specification limit for use with the on-die thermal diode.
PWM	Pulse width modulation is a method of controlling a variable speed fan. The enabled 4 wire fans use the PWM duty cycle % from the fan speed controller to modulate the fan speed.
Health Monitor Component	Any standalone or integrated component that is capable of reading the processor temperature and providing the PWM signal to the 4 pin fan header.
BTX	Balanced Technology Extended: BTX is an enhanced form factor specification for desktop platforms.
TMA	Thermal Module Assembly. The heatsink, fan and duct assembly for the BTX thermal solution.

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2 Processor Thermal/Mechanical Information

2.1 Mechanical Requirements

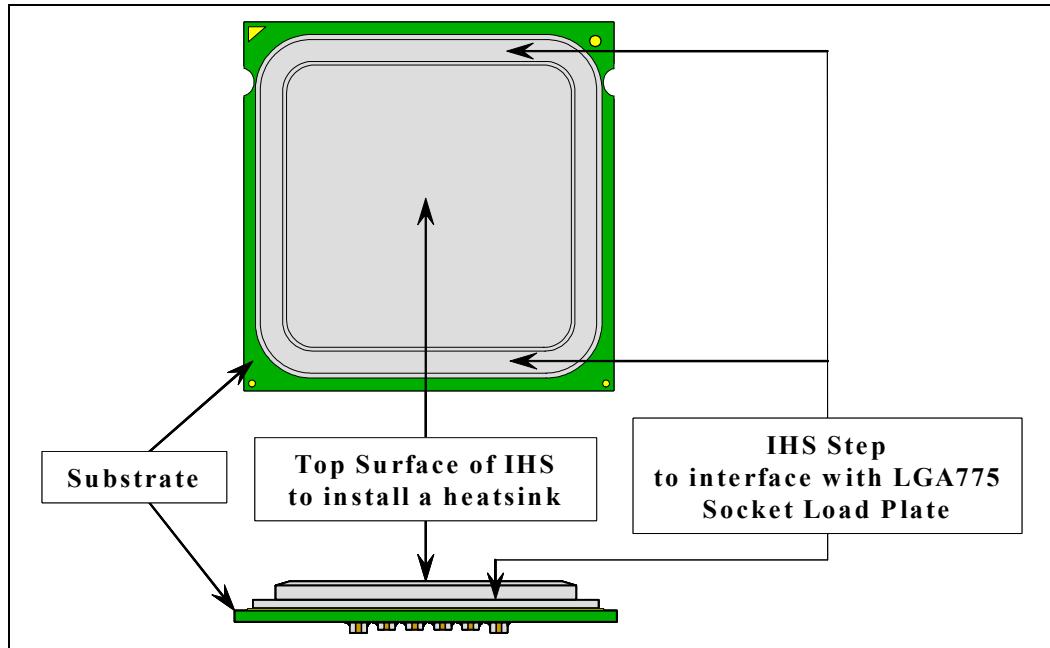
2.1.1 Processor Package

The Pentium 4 processor is packaged in a 775-land LGA package that interfaces with the motherboard via a LGA775 socket. Refer to the processor datasheet for detailed mechanical specifications.

The processor connects to the motherboard through a land grid array (LGA) surface mount socket. The socket contains 775 contacts arrayed about a cavity in the center of the socket with solder balls for surface mounting to the motherboard. The socket is named LGA775 socket. A description of the socket can be found in the *LGA775 Socket Mechanical Design Guide*.

The package includes an integrated heat spreader (IHS) that is shown in Figure 1 for illustration only. Refer to the processor datasheet for further information. In case of conflict, the package dimensions in the processor datasheet supersedes dimensions provided in this document.

Figure 1. Package IHS Load Areas



The primary function of the IHS is to transfer the non-uniform heat distribution 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 top surface of the IHS is designed to be the interface to the heatsink.

The IHS also features a step that interfaces with the LGA775 socket load plate, as described in *LGA775 Socket Mechanical Design Guide*. The load from the load plate is distributed across two sides of the package onto a step on each side of the IHS. It is then distributed by the package across all of the contacts. When correctly actuated, the top surface of the IHS is above the load plate allowing proper installation of a heatsink on the top surface of the IHS. After actuation of the socket load plate, the seating plane of the package is flush with the seating plane of the socket. Package movement during socket actuation is along the Z direction (perpendicular to substrate) only. Refer to the *LGA775 Socket Mechanical Design Guide* for further information about the LGA775 socket.

The datasheet gives details on the IHS geometry and tolerances, and material.

The processor package has mechanical load limits that are specified in the processor datasheet. The specified maximum static and dynamic load limits should not be exceeded during their respective stress conditions. These include heatsink installation, removal, mechanical stress testing, and standard shipping conditions.

- 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.
- When a compressive static load is necessary to ensure mechanical performance, it should remain in the minimum/maximum range specified in the processor datasheet
- The heatsink mass can also generate 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 exceed the processor datasheet compressive dynamic load specification during a vertical shock. For example, with a 0.454 kg [1 lb] heatsink, an acceleration of 50G during an 11 ms trapezoidal shock with an amplification factor of 2 results in approximately a 445 N [100 lbf] dynamic load on the processor package. If a 178 N [40 lbf] static load is also applied on the heatsink for thermal performance of the thermal interface material the processor package could see up to a 623 N [140 lbf]. The calculation for the thermal solution of interest should be compared to the processor datasheet specification.

No portion of the substrate should be used as a load-bearing surface.

Finally, the datasheet provides package handling guidelines in terms of maximum recommended shear, tensile and torque loads for the processor IHS relative to a fixed substrate. These recommendations should be followed in particular for heatsink removal operations.



2.1.2 Heatsink Attach

2.1.2.1 General Guidelines

There are no features on the LGA775 socket to directly attach a heatsink; a mechanism must be designed to attach the heatsink directly to the motherboard. 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. Designs should consider a 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 heatsink attach mechanism depend on the mass 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 have to be considered when designing the heatsink attach mechanism. Their design should provide a means for protecting LGA775 socket solder joints. One of the strategies for mechanical protection of the socket is to use a preload and high stiffness clip. This strategy is implemented by the reference design and described in Section 5.7.

Note: Package pull-out during mechanical shock and vibration is constrained by the LGA775 socket load plate (refer to the *LGA775 Socket Mechanical Design Guide* for further information).

2.1.2.2 Heatsink Clip Load Requirement

The attach mechanism for the heatsink developed to support the Pentium 4 processor in the 775-land LGA package should create a static preload on the package between **18 lbf** and **70 lbf** throughout the life of the product for designs compliant with the Intel reference design assumptions:

- 72 mm x 72 mm mounting hole span (refer to Figure 45)
- And no board stiffening device (backing plate, chassis attach, etc.).

The minimum load is required to protect against fatigue failure of socket solder joint in temperature cycling.

It is important to take into account potential load degradation from creep over time when designing the clip and fastener to the required minimum load. This means that, depending on clip stiffness, the initial preload at beginning of life of the product may be significantly higher than the minimum preload that must be met throughout the life of the product. For additional guidelines on mechanical design, in particular on designs departing from the reference design assumptions refer to Appendix A.

For clip load metrology guidelines, refer to Appendix B.

2.1.2.3 Additional Guidelines

In addition to the general guidelines given above, the heatsink attach mechanism for the Pentium 4 processor in the 775-land LGA package should be designed to the following guidelines:

- *Holds the heatsink in place under mechanical shock and vibration events and applies force to the heatsink base to maintain desired pressure on the thermal interface material.* Note that the load applied by the heatsink attach mechanism must comply with the package specifications described in the processor datasheet. One of the key design parameters is the height of the top surface of the processor IHS above the motherboard. The IHS height from the top of board is expected to vary from 7.517 mm to 8.167 mm. This data is provided for information only, and should be derived from:
 - The height of the socket seating plane above the motherboard after reflow, given in the *LGA775 Socket Mechanical Design Guide* with its tolerances
 - The height of the package, from the package seating plane to the top of the IHS, and accounting for its nominal variation and tolerances that are given in the corresponding processor datasheet.
- *Engages easily, and if possible, without the use of special tools.* In general, the heatsink is assumed to be installed after the motherboard has been installed into the chassis.
- *Minimizes contact with the motherboard surface during installation* and actuation to avoid scratching the motherboard.

2.2

Thermal Requirements

Refer to the datasheet for the processor thermal specifications. The majority of processor power is dissipated through the IHS. There are no additional components (e.g., BSRAMs) that generate heat in this package. The amount of power that can be dissipated as heat through the processor package substrate and into the socket is usually minimal.

Intel has introduced a new method for specifying the thermal limits for the Pentium 4 Processor in the 775-land LGA package. The new parameters are the Thermal Profile and $T_{CONTROL}$. The Thermal Profile defines the maximum case temperature as a function of power being dissipated. $T_{CONTROL}$ is a specification used in conjunction with the temperature reported by the on-die thermal diode. Designing to these specifications allows optimization of thermal designs for processor performance and acoustic noise reduction.

2.2.1

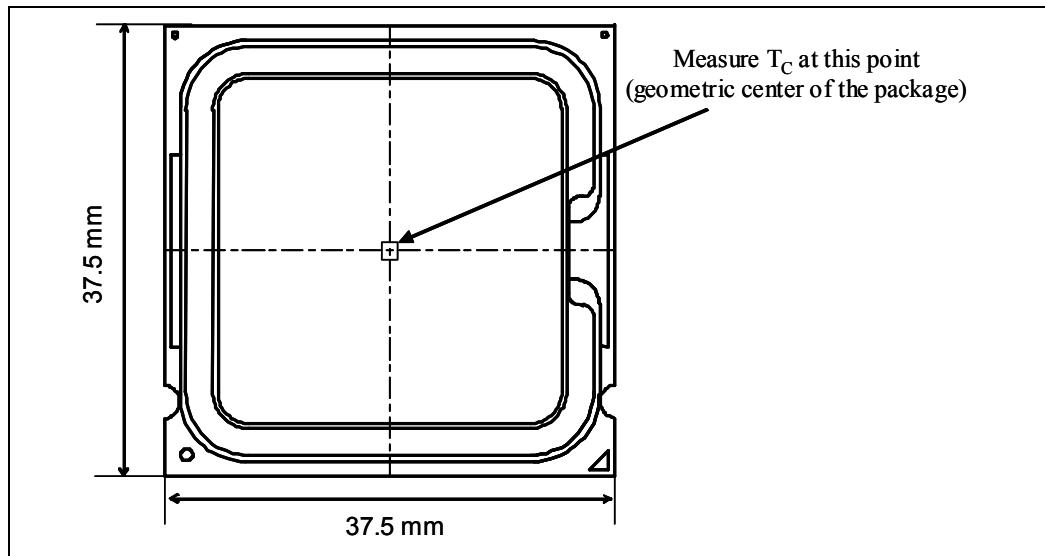
Processor Case Temperature

For the Pentium 4 processor in the 775-land LGA package, the case temperature is defined as the temperature measured at the geometric center of the package on the surface of the IHS. For illustration, Figure 2 shows the measurement location for a 37.5 mm x 37.5 mm [1.474 in x 1.474 in] FCLGA4 package. Techniques for measuring the case temperature are detailed in Section 3.4.

Note: In case of conflict, the package dimensions in the processor datasheet supersedes dimensions provided in this document.



Figure 2. Processor Case Temperature Measurement Location



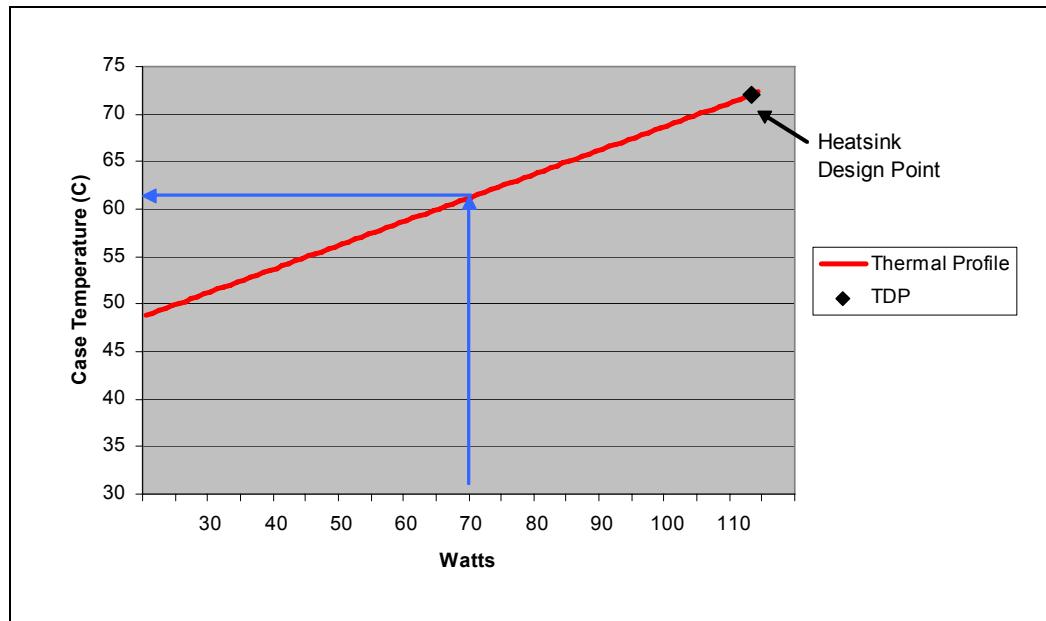
2.2.2 Thermal Profile

The Thermal Profile defines the maximum case temperature as a function of processor power dissipation. The TDP and Maximum Case Temperature 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 thermal resistance of the heatsink attached to the processor, Ψ_{CA} (Refer to Section 3.1). 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 dissipation is required. Contact your Intel sales representative for assistance in processor power measurement. The measured power is plotted on the Thermal Profile to determine the maximum case temperature. Using the example in Figure 3 for a processor dissipating 70 W the maximum case temperature is 61 °C.

For the Pentium 4 processor in the 775-land LGA package, there are two thermal profiles to consider. The Platform Requirement Bit (PRB) indicates which thermal profile is appropriate for a specific processor. This document will focus on the development of thermal solutions to meet the thermal profile for PRB=1. See the processor datasheet for the thermal profile and additional discussion on the PRB.

Figure 3. Example Thermal Profile

2.2.3

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 fan speed can be reduced. This 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 idle power. 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 power of some parts is offset by a higher value of T_{CONTROL} in such a way that they should 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 used to program a fan speed control component. See the processor datasheet for further details on reading the register and calculating T_{CONTROL}.

See Chapter 6, Acoustic Fan Speed Control, for details on implementing a design using T_{CONTROL} and the Thermal Profile.



2.3 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 applied to it. Refer to Section 2.3.4 and Appendix C 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.

2.3.1 Heatsink Size

The size of the heatsink is dictated by height restrictions for installation in a system and by the amount of space available on the motherboard and other considerations for component height and placement in the area potentially impacted by the processor heatsink. The height of the heatsink must comply with the requirements and recommendations published for the motherboard form factor of interest. Designing a heatsink to the recommendations may preclude using it in systems adhering strictly to the form factor requirements, while still in compliance with the form factor documentation.

For the ATX/microATX form factor, it is recommended to use:

- The ATX motherboard keep-out footprint definition and height restrictions for enabling components, defined for the platforms designed with the LGA775 socket in Appendix G of this design guide.
- The motherboard primary side height constraints defined in the *ATX Specification V2.1* and the *microATX Motherboard Interface Specification V1.1* found at <http://www.formfactors.org/>.

The resulting space available above the motherboard is generally not entirely available for the heatsink. The target height of the heatsink must take into account airflow considerations (for fan performance for example) as well as other design considerations (air duct, etc.).

2.3.2 Heatsink Mass

With the need for pushing air cooling to better performance, heatsink solutions tend to grow larger (increase in fin surface) resulting in increased mass. The insertion of highly thermally conductive materials like copper to increase heatsink thermal conduction performance results in even heavier solutions. As mentioned in Section 2.1, the heatsink mass must take into consideration the package and socket load limits, the heatsink attach mechanical capabilities, and the mechanical shock and vibration profile targets. Beyond a certain heatsink mass, the cost of developing and implementing a heatsink attach mechanism that can ensure the system integrity under the mechanical shock and vibration profile targets may become prohibitive.

The recommended maximum heatsink mass for the Pentium 4 processor in the 775-land LGA package is **450g**. This mass includes the fan and the heatsink only. The attach mechanism (clip, fasteners, etc.) is not included.

2.3.3 Package IHS Flatness

The package IHS flatness for the product is specified in the processor datasheet and can be used as a baseline to predict heatsink performance during the design phase.

Intel recommends testing and validating heatsink performance in full mechanical enabling configuration to capture any impact of IHS flatness change due to combined socket and heatsink loading. While socket loading alone may increase the IHS warpage, the heatsink preload redistributes the load on the package and improves the resulting IHS flatness in the enabled state.



2.3.4 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.

2.4 System Thermal Solution Considerations

2.4.1 Chassis Thermal Design Capabilities

The ATX Intel reference thermal solution assumes that the chassis delivers a maximum T_A of 38 °C at the inlet of the processor fan heatsink (refer to Section 5.1.1).

2.4.2 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, acoustic requirements 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 are other solutions that 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 in the 775-land LGA package. 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 attempts to protect the processor during sustained workload above TDP. Implementation options and recommendations are described in Chapter 4.

2.4.3 Summary

In summary, considerations in heatsink design include:

- The local ambient temperature T_A at the heatsink, which is a function of chassis design.
- The thermal design power (TDP) of the processor, and the corresponding maximum T_C as calculated from the thermal profile. These parameters are usually combined in a single cooling performance parameter, Ψ_{CA} (case to air thermal characterization parameter). More information on the definition and the use of Ψ_{CA} is given Section 3.1.
- Heatsink interface to IHS surface characteristics, including flatness and roughness.
- The performance of the thermal interface material used between the heatsink and the IHS.
- The required heatsink clip static load, between 18 lbf to 70 lbf throughout the life of the product (Refer to Section 2.1.2.2 for further information).
- Surface area of the heatsink.
- Heatsink material and technology.
- Volume of airflow over the heatsink surface area.
- Development of airflow entering and within the heatsink area.
- Physical volumetric constraints placed by the system

2.5 System Integration Considerations

Boxed Intel® Pentium® 4 Processor in the 775-Land LGA Package - Integration Video provides best known methods for package and heatsink installation and removal for LGA775 socket based platforms and systems manufacturing. The video is available on the Web, from <http://www.intel.com/go/integration>.

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3 Thermal Metrology

This chapter 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. To define the performance of a thermal solution the “thermal characterization parameter”, Ψ (“psi”) will be used.

3.1 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 heat source and local ambient conditions). The thermal characterization parameter is calculated using total package power.

Note: Heat transfer is a three-dimensional phenomenon that can rarely be accurately and easily modeled by a single resistance parameter like Ψ .

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:

$$\Psi_{CA} = (T_C - T_A) / P_D \text{ (Equation 1)}$$

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 power dissipation (W) (assumes all power dissipates through the IHS)

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:

$$\Psi_{CA} = \Psi_{CS} + \Psi_{SA} \text{ (Equation 2)}$$

Where:

Ψ_{CS} = Thermal characterization parameter of the thermal interface material (°C/W)

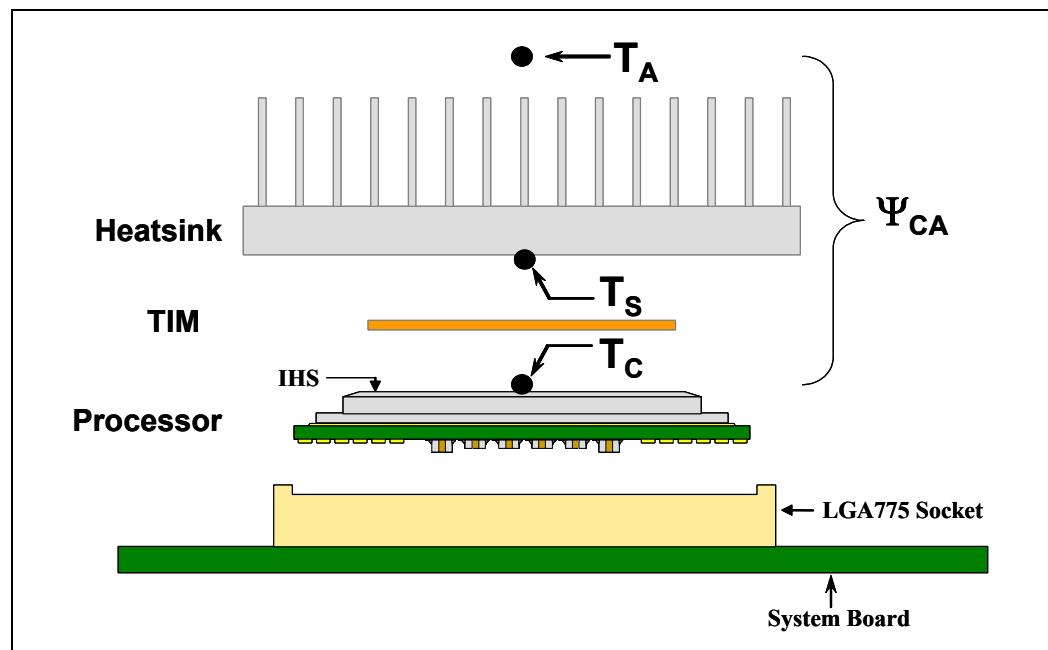
Ψ_{SA} = Thermal characterization parameter from heatsink-to-local ambient (°C/W)

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 4 illustrates the combination of the different thermal characterization parameters.

Figure 4. Processor Thermal Characterization Parameter Relationships



3.1.1 Example

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

- The case temperature T_{C-MAX} and thermal design power TDP given in the processor datasheet.
- Define a target local ambient temperature at the processor, T_A .

Since the processor thermal profile applies to all processor frequencies, it is important to identify the worst 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.

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 TDP, as listed in the processor datasheet, is 100 W and the maximum case temperature from the thermal profile for 100 W is 67 °C. Assume as well that the system airflow



has been designed such that the local ambient temperature is 38 °C. Then the following could be calculated using Equation 1 from above:

$$\Psi_{CA} = (T_C - T_A) / TDP = (67 - 38) / 100 = 0.29 \text{ °C/W}$$

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 $\Psi_{CS} \leq 0.10 \text{ °C/W}$, solving for Equation 2 from above, the performance of the heatsink would be:

$$\Psi_{SA} = \Psi_{CA} - \Psi_{CS} = 0.29 - 0.10 = 0.19 \text{ °C/W}$$

3.2 Processor Thermal Solution Performance Assessment

Thermal performance of a heatsink should be assessed using a thermal test vehicle (TTV) provided by Intel. The TTV is a stable heat source from which the user can take accurate power measurements, whereas actual 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.

Once the thermal solution is designed and validated, it is strongly recommended to verify functionality of the thermal solution on real processors and on fully integrated systems.

Contact your Intel field sales representative for further information on TTV or regarding accurate measurement of the power dissipated by an actual processor.

3.3 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 approaches air temperature; for an actively cooled heatsink, it is the temperature of inlet air to the active cooling fan.

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

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

For **active heatsinks**, it is important to avoid taking measurement in the dead flow zone that usually develops above the fan hub 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

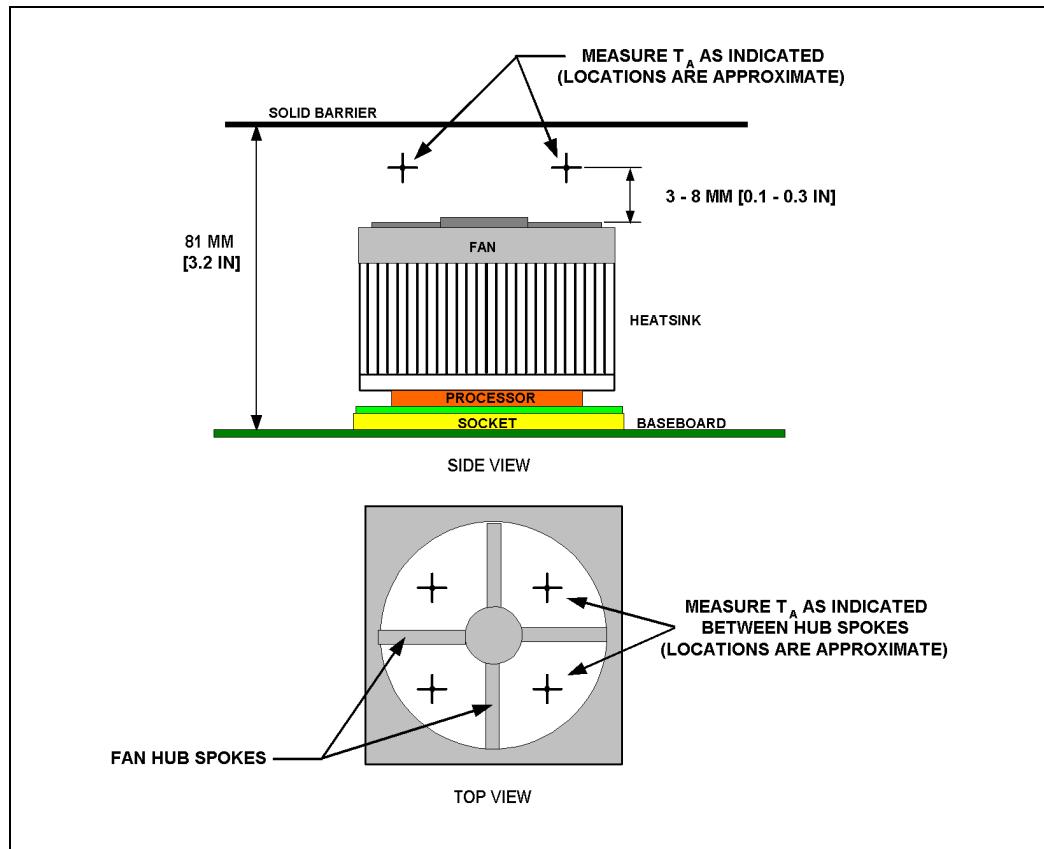
should be placed approximately 3 mm to 8 mm [0.1 to 0.3 in] above the fan hub vertically and halfway between the fan hub and the fan housing horizontally as shown in Figure 5 (avoiding the hub spokes). Using an open bench to characterize an active heatsink can be useful, and usually ensures more uniform 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, graphic 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 6. 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 an 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.

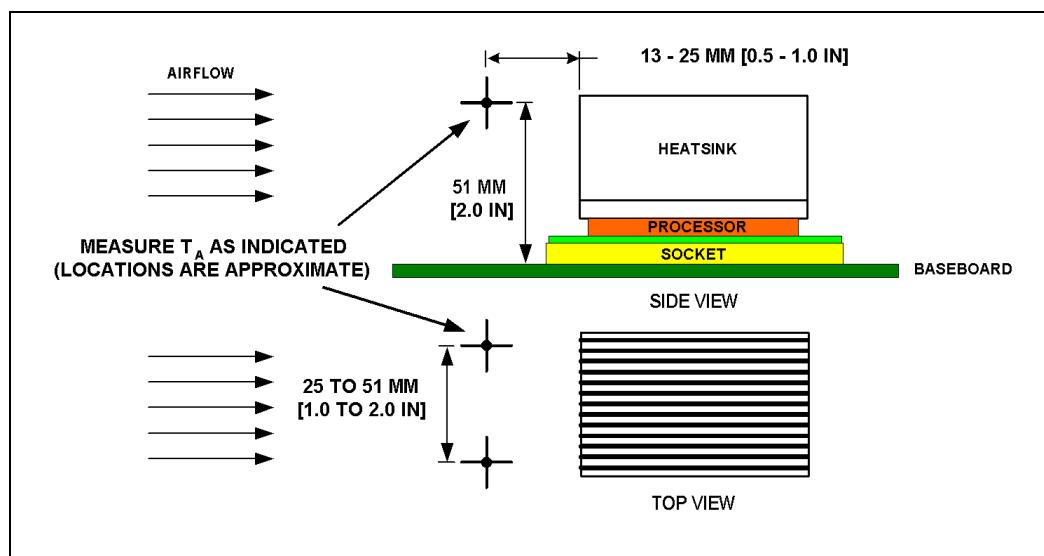


Figure 5. Locations for Measuring Local Ambient Temperature, Active Heatsink



Note: Drawing Not to Scale

Figure 6. Locations for Measuring Local Ambient Temperature, Passive Heatsink



Note: Drawing Not to Scale

3.4 Processor Case Temperature Measurement Guidelines

The Pentium 4 processor in the 775-land LGA package is specified for proper operation when T_C is maintained at or below the thermal profile as listed in the datasheet. The measurement location for T_C is the geometric center of the IHS. Figure 2 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, and/or by contact between the thermocouple cement and the heatsink base.

Appendix D defines a reference procedure for attaching a thermocouple to the IHS of a 775-land LGA processor package for T_C measurement. This procedure takes into account the specific features of the 775-land LGA package and of the LGA775 socket for which it is intended.

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4 *Thermal Management Logic and Thermal Monitor Feature*

4.1 Processor Power Dissipation

An increase in processor operating frequency not only increases system performance, but also increases the processor power dissipation. The relationship between frequency and power is generalized in the following equation: $P = CV^2F$ (where P = power, C = capacitance, V = voltage, F = frequency). From this equation, it is evident that power increases linearly with frequency and with the square of voltage. In the absence of power saving technologies, ever increasing frequencies will result in processors with power dissipations in the hundreds of watts. Fortunately, there are numerous ways to reduce the power consumption of a processor, 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 in the 775-land LGA package. 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 Thermal Control Circuit (TCC), the processor can rapidly initiate thermal management control. The Thermal Monitor can reduce cooling solution cost, by allowing thermal designs to target TDP.

4.2 Thermal Monitor Implementation

On the Pentium 4 processor in the 775-land LGA package, the Thermal Monitor is integrated into the processor silicon includes:

- A bi-directional signal (PROCHOT#) that indicates if the processor has exceeded its maximum temperature or can be asserted externally to activate the Thermal Control Circuit (TCC).
- A Thermal Control Circuit that will attempt to reduce processor temperature by rapidly reducing power consumption when the on-die temperature sensor indicates that it has exceeded the maximum operating point.
- Registers to determine the processor thermal status.



4.2.1 PROCHOT# Signal

The Pentium 4 processor in the 775-land LGA package has 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 exceeded 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), which activates 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# signal only as a backup in case of system cooling failure.

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 PROCHOT# asserts.

The temperature at which the PROCHOT# signal goes active is individually calibrated during manufacturing. The power dissipation of each processor affects the set point temperature. The temperature where PROCHOT# goes active roughly parallels 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 targets should rarely experience activation of the TCC as indicated by the PROCHOT# signal going active.

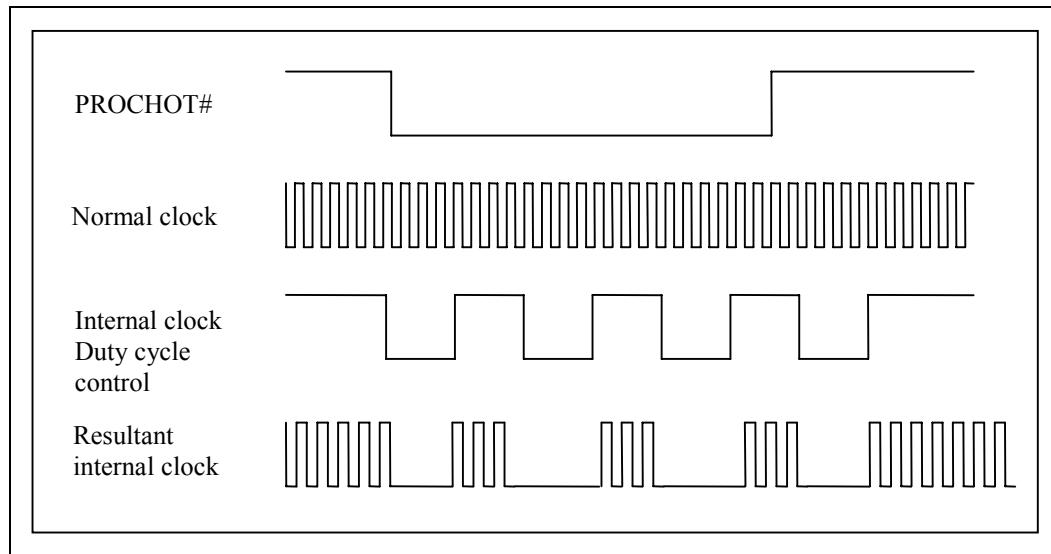
4.2.2 Thermal Control Circuit

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, will attempt to lower the processor temperature by reducing the processor power consumption. 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 $\sim 3 \mu\text{s}$. This time period is frequency dependent and higher frequency processors will disable the internal clocks for a shorter time period. Figure 7 illustrates the relationship between the internal processor clocks and the PROCHOT# signal.

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



Figure 7. Concept for Clocks under Thermal Monitor Control



4.2.3 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. **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 required 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 after the thermal sensor detects a high temperature (i.e., PROCHOT# assertion). The Thermal Control Circuit and PROCHOT# transitions 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 whenever there is a transition from active-to-inactive or inactive-to-active. PROCHOT# can also be configured to generate an internal interrupt which would initiate an OEM supplied interrupt service routine. Regardless of the configuration selected, PROCHOT# will always indicate the thermal status of the processor.

The power reduction mechanism of thermal monitor can also be activated manually using an “on-demand” mode. Refer to Section 4.2.4 for details on this feature.



4.2.4 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 on-demand clock modulation 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 $\sim 3 \mu\text{s}$. 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 $3 \mu\text{s}$, and a duty cycle of $1/4$ (25%) is selected, the clock on time would be reduced to approximately $1 \mu\text{s}$ [on time ($1 \mu\text{s}$) \div total cycle time ($3 + 1 \mu\text{s}$) = $1/4$ duty cycle]. Similarly, for a duty cycle of $7/8$ (87.5%), the clock on time would be extended to $21 \mu\text{s}$ [$21 \div (21 + 3) = 7/8$ 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.

4.2.5 System Considerations

Intel requires the Thermal Monitor and Thermal Control Circuit to be enabled for all Pentium 4 processors in the 775-land LGA package based systems. The thermal control circuit is intended to protect against short term thermal excursions that exceed the capability of a properly designed processor thermal solution. Thermal Monitor should not be relied upon to compensate for a thermal solution that does not meet the thermal profile up to the thermal design power (TDP).

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 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 TDP and T_{C-MAX} values 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 the processor datasheet and to Section 4.2.8 of this Thermal Design Guidelines.

4.2.6 Operating System and Application Software Considerations

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

4.2.7 On-Die Thermal Diode

There are two independent thermal sensing devices in the Pentium 4 processor in the 775-land LGA package. 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. 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 Acoustic Fan Control, Section 6.1.

4.2.7.1 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	AL1	Diode anode
THERMDC	AK1	Diode anode

4.2.7.2 Correction Factors for the On-Die Thermal Diode

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 on-die thermal diode. 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 in 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 $\pm 3^\circ\text{C}$ to $\pm 1^\circ\text{C}$. The improved accuracy generally comes from the number of times a current is passed through the diode and the ratios of the 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:

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

Where I_{FW} = forward bias current, I_S = saturation current, q = electronic charge, V = voltage across the diode, k = Boltzmann Constant and T = absolute temperature (Kelvin). This equation determines the ideality factor of an individual diode.

For the purpose of determining a correction factor to use with the thermal sensor, the ideality equation can be simplified to the following:

$$T_{ERROR} = T_{MEASURED} * (1 - N_{ACTUAL} / N_{TRIM})$$

Where T_{ERROR} = correction factor to add to the reported temperature, $T_{MEASURED}$ = temperature reported by the thermal sensor (Kelvin), N_{ACTUAL} = the ideality of the on-die thermal diode, N_{TRIM} = the assumed ideality used by the thermal sensor. For the range of temperatures where the thermal diode is being measured, $30\text{--}80^\circ\text{C}$ this error term is nearly constant.

The value of N_{TRIM} is available from the datasheet of the device measuring the processor on die thermal diode. N_{ACTUAL} can be assumed to be typical for this equation.

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 pads 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:

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

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



4.2.8 THERMTRIP# Signal

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# activation is independent of processor activity and does not generate any bus cycles. Refer to the datasheet for more information about THERMTRIP#.

The temperature where the THERMTRIP# signal goes active is 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, the temperature at which the THERMTRIP# signal is asserted is neither re-configurable nor accessible to the system.

4.2.8.1 Cooling System Failure Warning

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.

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5 Intel® Thermal/Mechanical Reference Design Information

5.1 Intel Validation Criteria for the Reference Design

5.1.1 Heatsink Performance Target

Table 2 provides the heatsink performance target for the Pentium 4 processor in the 775-land LGA package. The thermal profiles for the Pentium 4 processor 5xx sequence and Pentium 4 processor 6xx sequence and Pentium 4 processor Extreme Edition are derived so that a single thermal solution will satisfy these processors.

The table also includes a T_A assumption of 38 °C for the Intel reference thermal solution at the processor fan heatsink inlet discussed Section 3.3. 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 Sections 2.2, 2.4, and Chapter 4). By minimizing T_R , in the performance chassis, this helps lead to improved acoustics.

Refer to the datasheet for detailed processor thermal specifications.

Table 2. ATX Reference Heatsink Performance Target

Processor Number	Thermal Performance, Ψ_{CA} (Mean + 3 σ)	Comments	T_A Assumption
<i>Intel® Pentium® 4 Processor 670/672, 660/662, 650, 640, and 630</i>	0.28 °C/W	RCBFH-3	$T_A = 38$ °C
<i>Intel® Pentium® 4 Processors 570/571, 560/561, 550/551, 540/541, 530/531, and 520/521</i>	0.29 °C/W	RCBFH-3	$T_A = 38$ °C

NOTES:

1. The target performance in Table 2 is the Thermal Profile for processors with PRB=1.
2. Solutions to support processors with PRB=0 may be derived from designs supporting the thermal profile for processors with PRB=1.
3. Refer to Section 5.6 for complete description of the Intel ATX reference solution RCBFH-3.

5.1.2 Acoustics

To optimize acoustic emission by the fan heatsink assembly the reference design implements 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. Thermistor set points for fan speed in the reference thermal solution
 - High set point: $T_A = 38^\circ\text{C}$; $\Psi_{CA} = 0.29 \text{ }^\circ\text{C/W}$
 - Low set point: $T_A = 30^\circ\text{C}$; $\Psi_{CA} = 0.37 \text{ }^\circ\text{C/W}$

The example above uses settings for the Pentium 4 processor 5xx sequence, but would be similar for the Pentium 4 processor 6xx sequence or Pentium 4 processor Extreme Edition.
2. Fan heatsink assembly acoustic performance:
 - Acoustic performance is defined in terms of declared sound power (LwAd) as defined in ISO 9296 standard, and measured according to 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.

While the fan hub thermistor helps optimize acoustics at high processor workloads by adapting the maximum fan speed to support the processor thermal profile, additional acoustic improvements can be achieved at lower processor workload by using the $T_{CONTROL}$ specifications described in Section 2.2.3. Intel's recommendation is to use the *Fan Specification for 4 Wire PWM Controlled Fans* to implement fan speed control capability based on-die thermal diode temperature. Refer to Chapter 6 for further details.

Note: Heatsinks providing omni-directional airflow may have to provide cooling to other components on the board, like voltage regulator and MCH. This may impact the lowest speed at which the fan may run, and thus impact fan low set point, usually raising the minimum fan speed based on processor thermal specification compliance only. In any case, complying with processor thermal profile must be met at all time.

5.1.3 Altitude

The reference heatsink solution was evaluated at sea level. However, many companies design products that must function reliably at high altitude, typically 1,500 m [5,000 ft] or more. Air-cooled temperature 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.



5.1.4 Reference Heatsink Thermal Validation

The Intel reference heatsink is validated within specific boundary conditions based on the methodology described in Section 5.2.

Testing is done on bench top test boards at ambient lab temperature. In particular, for the reference heatsink, the Plexiglas® barrier is installed 81.28 mm [3.2 in] above the motherboard (refer to Sections 3.3 and 5.6).

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

Note: The above 81.28 mm obstruction height that is used for testing complies with the recommended obstruction height of 88.9 mm for the ATX form factor. However, it would not be sufficient for systems in strict compliance with the ATX specification that defines a 76.2 mm obstruction height in Area A.

5.1.5 Fan Performance for Active Heatsink Thermal Solution

The fan power requirements for proper operation are given in Table 3.

Table 3. Fan Electrical Performance Requirements

Requirement	Value
Peak fan current draw	1.5 A
Average fan current draw	1.1 A
Fan start-up current draw	2.2 A
Fan start-up current draw maximum duration	1.0 second
Fan header voltage	12 V ± 10%
Tachometer output	2 pulse per revolution

In addition to comply with overall thermal requirements (Section 5.1.1), and the general environmental reliability requirements (Section 5.2) the fan should meet the following performance requirements:

- Mechanical wear out represents the highest risk reliability parameter for fans. The capability of the functional mechanical elements (ball bearing, shaft, and tower assembly) must be demonstrated to a minimum useful lifetime of 50,000 hours.
- In addition to passing the environmental reliability tests described in Section 5.2, the fan must demonstrate 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.

See the *Fan Specification for 4-wire PWM Controlled Fans* for additional details on the fan specification.

5.2 Environmental Reliability Testing

5.2.1 Structural Reliability Testing

Structural reliability tests consist of unpackaged, board-level vibration and shock tests of a given thermal solution in the assembled state. The thermal solution should meet the specified thermal performance targets after these tests are conducted; however, the test conditions outlined here may differ from your own system requirements.

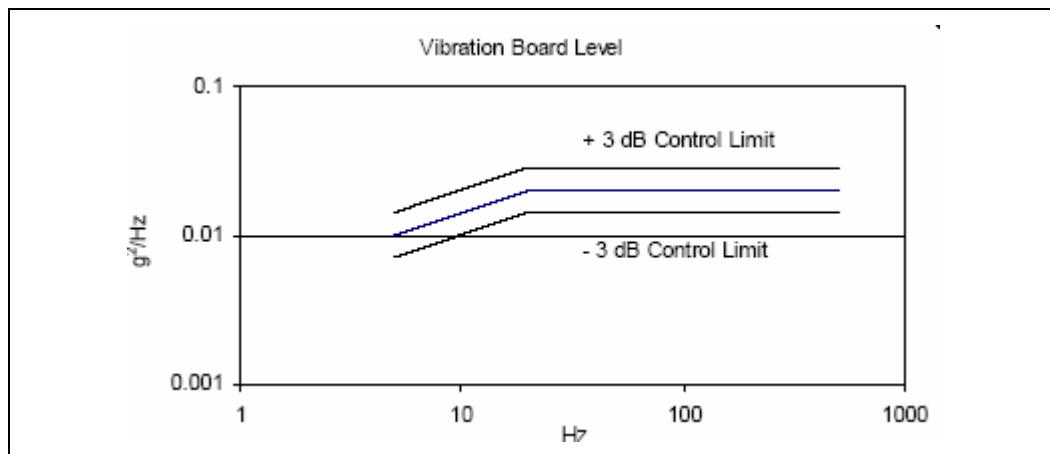
5.2.1.1 Random Vibration Test Procedure

Duration: 10 min/axis, 3 axes

Frequency Range: 5 Hz to 500 Hz

Power Spectral Density (PSD) Profile: 3.13 G RMS

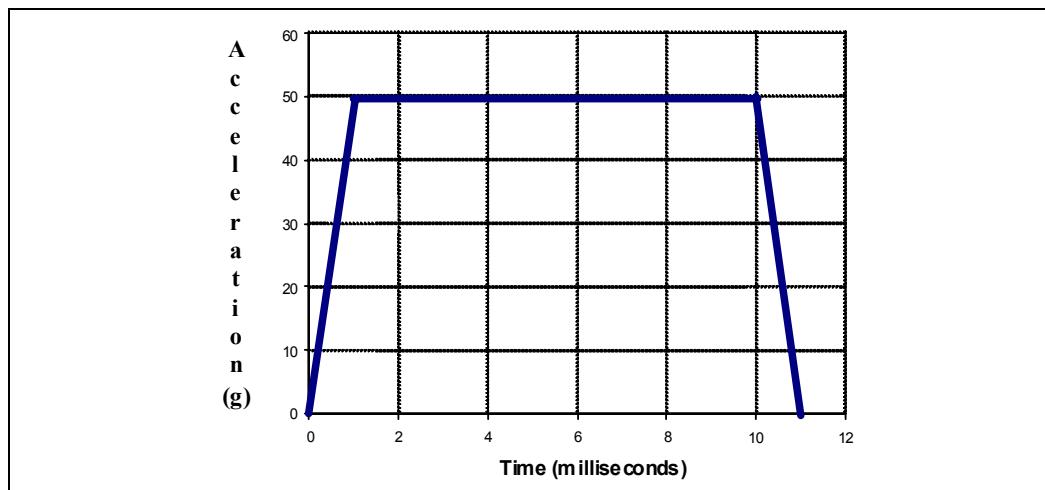
Figure 8. Random Vibration PSD



5.2.1.2 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, 11 ms duration, 170 in/sec minimum velocity change.
- Setup: Mount sample board on test fixture.

**Figure 9. Shock Acceleration Curve**

5.2.1.2.1 Recommended Test Sequence

Each test sequence should start with components (i.e., motherboard, heatsink assembly, etc.) that have not been previously submitted to any reliability testing.

The test sequence should always start with a visual inspection after assembly, and BIOS/Processor/Memory test (refer to Section 5.2.3).

Prior to the mechanical shock and vibration stress test, the units under test should be preconditioned for 72 hours at 45 °C. The purpose is to account for load relaxation during burn-in stage.

The stress test should be followed by a visual inspection and then BIOS/Processor/Memory test.

5.2.1.2.2 Post-Test Pass Criteria

The post-test pass criteria are:

1. No significant physical damage to the heatsink attach mechanism (including such items as clip and motherboard fasteners).
2. Heatsink must remain attached to the motherboard.
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 its attach mechanism.
4. No signs of physical damage on motherboard surface due to impact of heatsink or heatsink attach mechanism.
5. No visible physical damage to the processor package.
6. Successful BIOS/Processor/memory post-test of samples.
7. Thermal compliance testing to demonstrate that the case temperature specification can be met.



5.2.2 Power Cycling

Thermal performance degradation due to TIM degradation is evaluated using power cycling testing. The test is defined by 7,500 cycles for the case temperature from room temperature (~23 °C) to the maximum case temperature defined by the thermal profile at TDP.

5.2.3 Recommended BIOS/Processor/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 testing 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.

5.3 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.



5.4 Safety Requirements

Heatsink and attachment assemblies shall be consistent with the manufacture of units that meet the following 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.
- All components (in particular the 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 additional safety feature so that there is no risk of personal injury.

5.5 Geometric Envelope for ATX Intel® Reference Thermal Mechanical Design

Figure 45, Figure 46, and Figure 47 in Appendix G provide detailed reference ATX/μATX motherboard keep-out information for the reference thermal/mechanical enabling design. These drawings include height restrictions in the enabling component region.

The maximum height of the reference solution above the motherboard is 71.12 mm [2.8 inches], and is compliant with the motherboard primary side height constraints defined in the *ATX Specification revision 2.1* and the *microATX Motherboard Interface Specification revision 1.1* found at <http://www.formfactors.org>. The reference solution requires a chassis obstruction height of at least 81.28 mm [3.2 inches], measured from the top of the motherboard (refer to Sections 3.3 and 5.1.4). This allows for appropriate fan inlet airflow to ensure fan performance, and therefore overall cooling solution performance. This is compliant with the recommendations found in both *ATX Specification V2.1* and *microATX Motherboard Interface Specification V1.1* documents.

5.6

ATX Reference Thermal Mechanical Solution for the Intel® Pentium® 4 Processor in the 775-Land LGA Package

The reference thermal solution is an active air-cooled design, with a fan installed at the top of the heatsink. This solution is called the Intel® Radial Curved Bifurcated Fin Heatsink Reference Design (Intel® RCBFH-3 Reference Design).

The reference solution is compliant with the reference ATX motherboard keep-out and height recommendations defined in Section 5.5.

The solution comes as an integrated assembly (Figure 10). An exploded view of the assembly is provided in Figure 11. The solution is purposely designed without a fan guard to optimize thermal and acoustic performance.

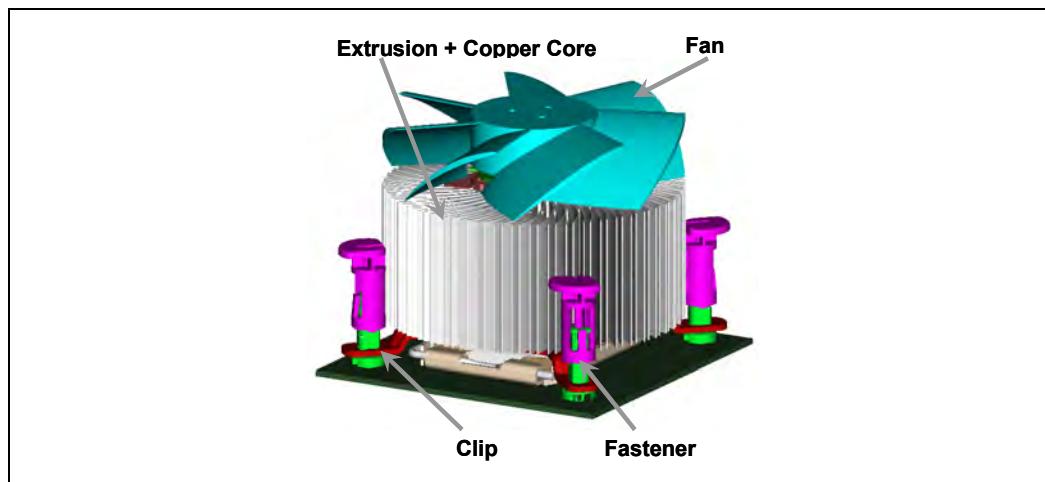
Note: If this fan design is used in your product and you will deliver it to end use customers, you have the responsibility to determine an adequate level of protection (e.g., protection barriers, a cage, or an interlock) against contact with the energized fan by the user during user servicing.

Table 4. Intel® RCBFH-3 Reference Design Performance

Fan Set Point	Fan Speed	Validated Thermal Performance Ψ_{ca} (Mean + 3 σ)	Validated Acoustic Performance (LwAd)	T _A Assumption
High	3600 RPM	0.29 °C/W	5.5 BA	T _A = 38 °C
Low	2400 RPM	0.325 °C/W	4.5 BA	T _A = 30 °C

Note: RCBFH-3 performance in Table 4 is relative to the Intel Pentium® 4 Processor 5xx sequence. Refer to Table 2 for performance of the RCBFH-3 with the other processors.

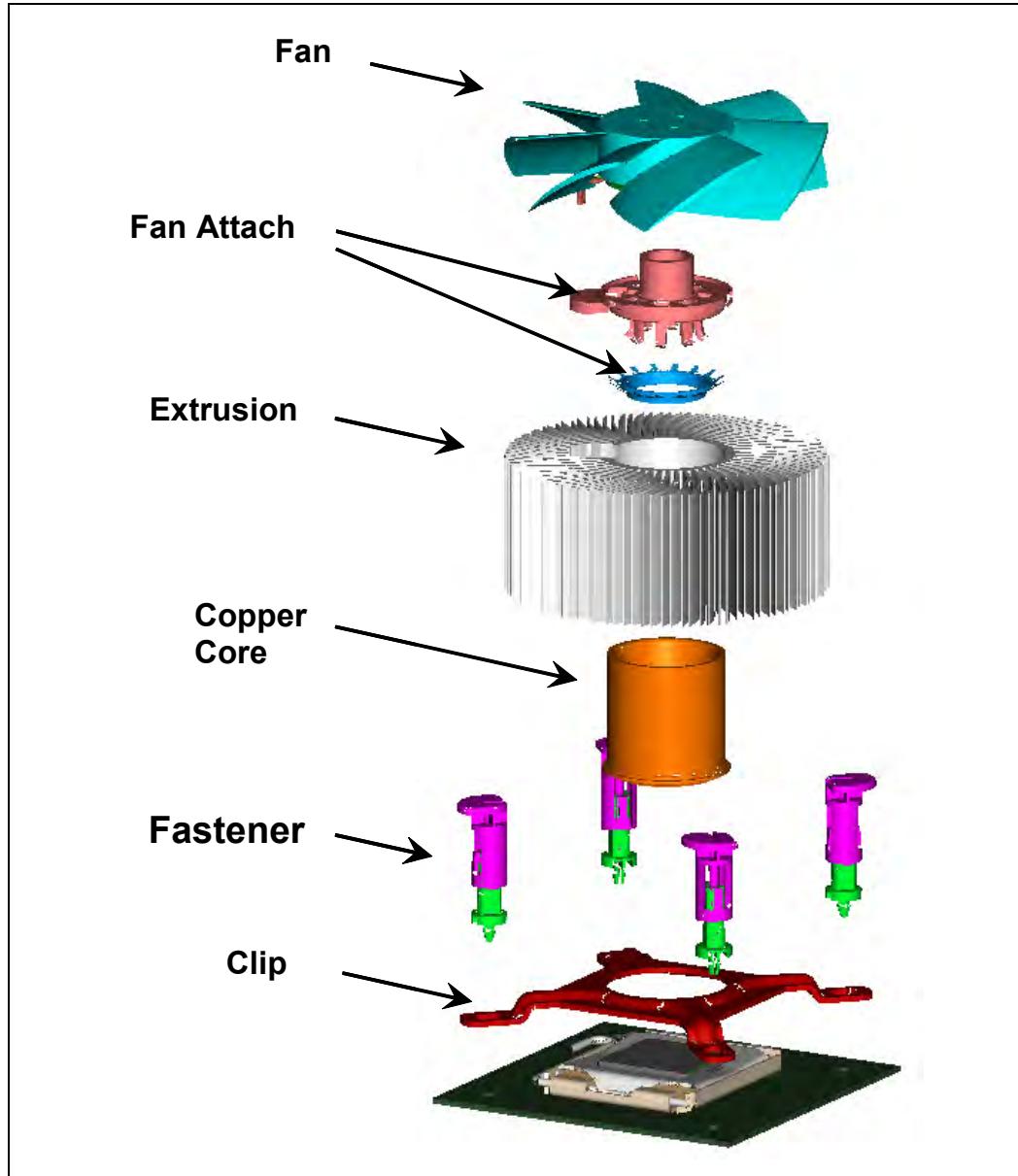
Figure 10. Intel® RCBFH-3 Reference Design





A more detailed drawing of the Intel RCBFH-3 Reference Solution is provided in Figure 55, in Appendix G.

Figure 11. Intel® RCBFH-3 Reference Design (Exploded View)



Development vendor information for the Intel RCBFH-3 Reference Solution is provided in Appendix H.

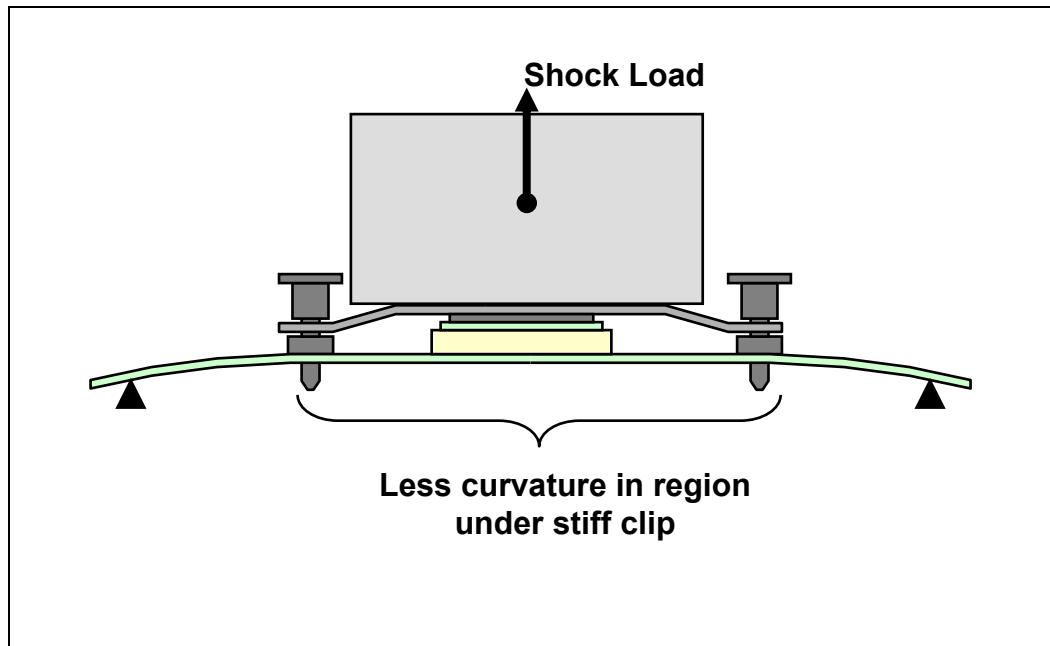
5.7 Reference Attach Mechanism

5.7.1 Structural Design Strategy

Structural design strategy for the Intel RCBFH-3 Reference Solution is to minimize upward board deflection during shock to help protect the LGA775 socket.

The reference design uses a high clip stiffness that resists local board curvature under the heatsink, and minimizes, in particular, upward board deflection (Figure 12). In addition, a moderate preload provides initial downward deflection.

Figure 12. Upward Board Deflection during Shock



The reference metal clip nominal stiffness is 540 N/mm [3100 lb/in]. The combined reference clip and fasteners nominal stiffness is 380 N/mm [2180 lb/in]. The nominal preload provided by the Intel RCBFH-3 reference design is 191.3 N +/- 44.5 N [43 lb ± 10 lb].

Note: Intel reserves the right to make changes and modifications to the design as necessary to the Intel RCBFH-3 reference design, in particular the clip and fastener.



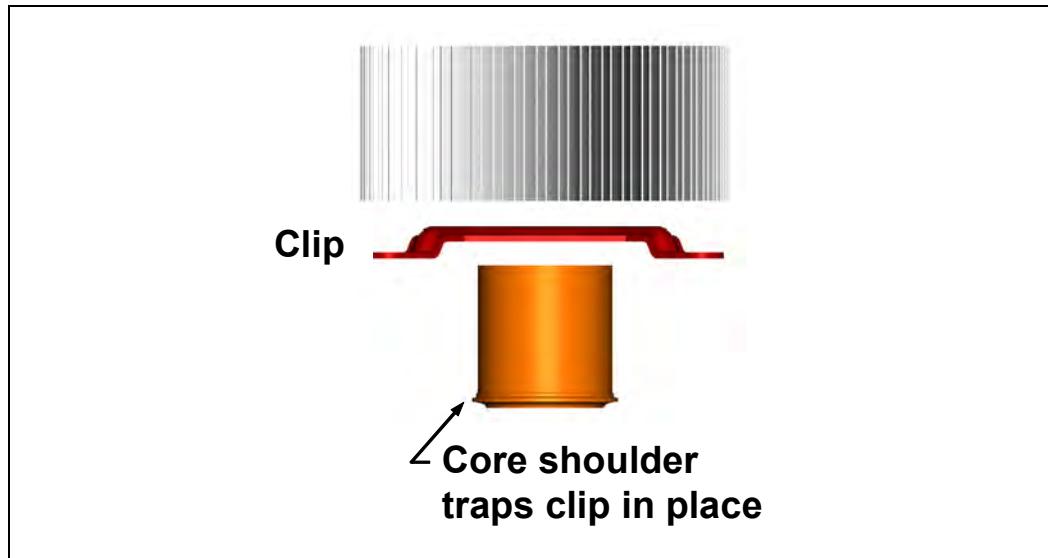
5.7.2 Mechanical Interface to the Reference Attach Mechanism

The attach mechanism component from the Intel RCBFH-3 Reference Design can be used by other 3rd party cooling solutions. The attach mechanism consists of:

- A metal attach clip that interfaces with the heatsink core, see Appendix G, Figure 48, and Figure 49 for the component drawings.
- Four plastic fasteners, see Appendix G, Figure 50, Figure 51, Figure 52, and Figure 53 for the component drawings.

Figure 10 and Figure 11 show the reference attach mechanism as part of the Intel RCBFH-3 Reference Design. The clip is assembled to heatsink during copper core insertion, and is meant to be trapped between the core shoulder and the extrusion as shown in Figure 13. Figure 54 in Appendix G provides additional details.

Figure 13. Reference Clip/Heatsink Assembly





The mechanical interface with the reference attach mechanism is defined in Figure 14 and Figure 15. Complying with the mechanical interface parameters is critical to generating a heatsink preload compliant with the minimum preload requirement given in Section 2.1.2.2.

Additional requirements for the reference attach mechanism (clip and fasteners) include:

- Total assembly weight, including heatsink/fan weight (≤ 450 g), clip and fasteners < 480 g
- Whole assembly center of gravity ≤ 25.4 mm, measured from the top of the IHS
 - Whole assembly = Heatsink + Fan + Attach clip + Fasteners

Vendor information for the reference plastic fastener assembly is given in Appendix H.

For heatsink installation procedure, Refer to the video entitled *Boxed Intel® Pentium® 4 Processor in the 775-Land LGA Package - Integration Video*. This video is available on the Web, at <http://www.intel.com/go/integration>.

Caution: Assess the potential risk of Musculoskeletal Disorders.

Many factors impact the risk of introducing **Musculoskeletal Disorders (MSDs)** when installing and assembling computers and similar equipment. Along with common injuries such as cuts, lacerations and bruises, frequent and prolonged repeated forceful exertions can cause soreness, aches, pains, and fatigue, in hands, wrists and shoulders and can lead to chronic MSDs.

To minimize the risk of **MSDs** use of the correct tools and assembly techniques and supporting equipment is recommended. Intel can assist in the selection of a tool for the installation of this heat sink when the risk of MSD needs to be minimized. Contact your Intel field sales representative for assistance.

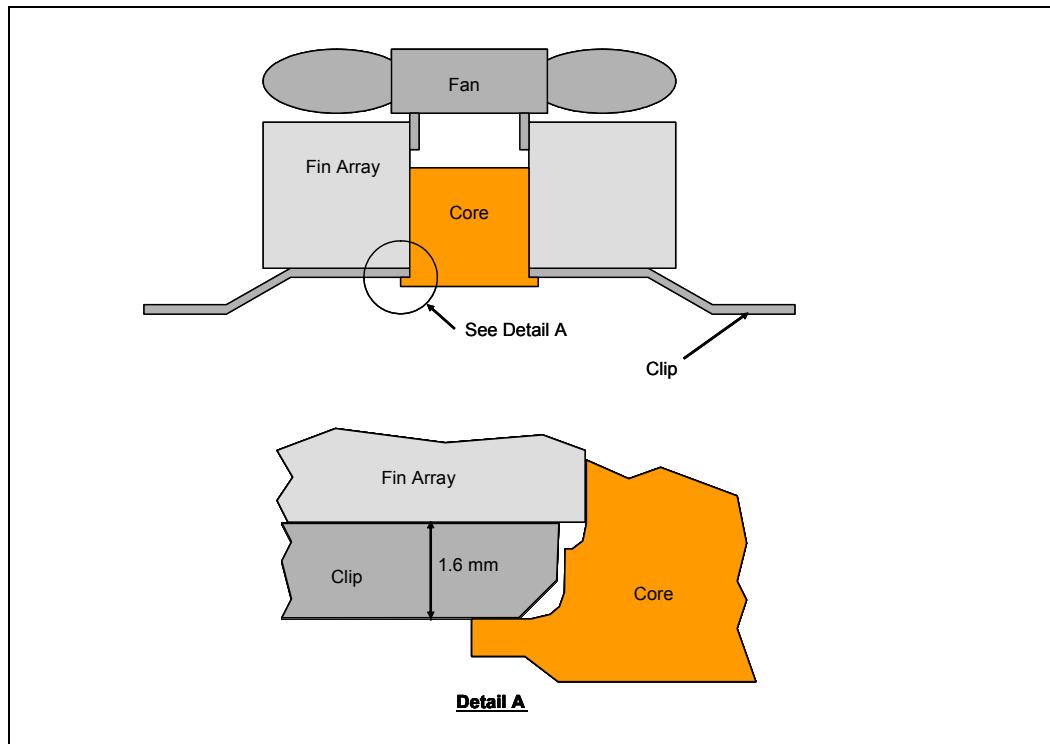
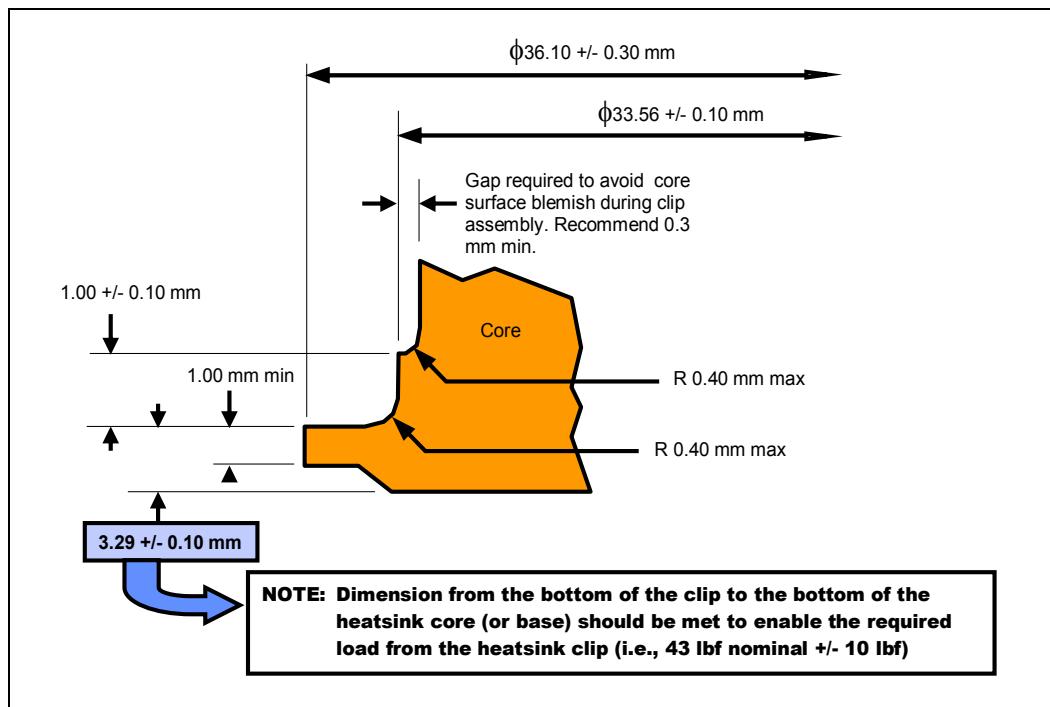
Additional information on preventing MSDs may be found by contacting your local government agency in charge of the assessment of worker health and safety. References can be found at the following WEB sites:

Canadian Centre for Occupational Health and Safety:

<http://www.ccohs.ca/oshanswers/ergonomics/handtools/workspace.html>

United States Government OSHA web site:

<http://www.osha.gov/index.html>

**Figure 14. Critical Parameters for Interfacing to Reference Clip****Figure 15. Critical Core Dimension**

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6 Acoustic Fan Speed Control

6.1 Acoustic Fan Speed Control

As processor power has increased, the required thermal solutions have generated increasingly more noise. Intel has added an option to the processor thermal specifications that allows the system integrators to have a quieter system under typical usage. $T_{CONTROL}$ 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 designed with a fan speed controller with the following functionality:
 - PWM fan control output
 - Remote thermal diode measurement capability
- A motherboard with a 4-pin fan header for the processor heatsink fan.
- Processor heatsink with 4-wire PWM controlled Fan.
A thermistor in the fan hub is recommended, but not a requirement. The reference solution and the Boxed Pentium 4 Processor in 775-land LGA package have implemented a thermistor into the design.

The following sections will discuss the necessary steps to implement Acoustic Fan Speed Control.

6.2 Thermal Solution Design

6.2.1 Compliance to Thermal Profile

The first step is to select or design a processor thermal solution that meets the thermal profile for the Pentium 4 Processor in the 775-land LGA Package. See Section 2.2.2 for the definition of the thermal profile then consult the processor datasheet.

The designer needs to ensure that when the heat sink fan is operating at full speed the thermal solution will meet the T_{C-MAX} limits at TDP. The slope of the thermal profile allows the designer to make tradeoffs in thermal performance versus the inlet temperature to the processor fan heatsink.

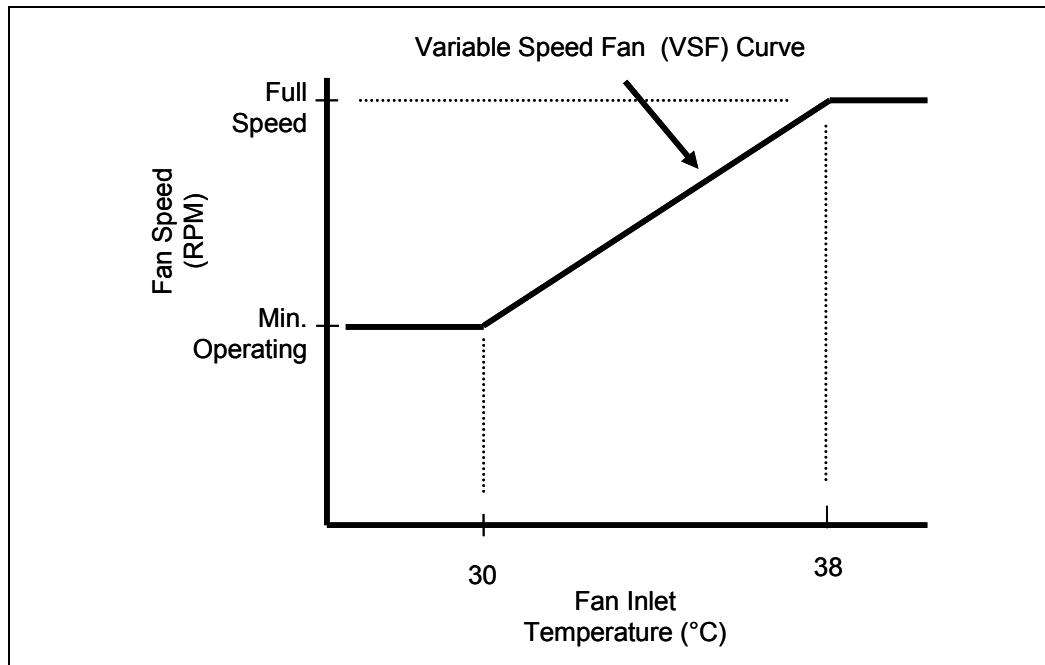
6.2.2 Determine Thermistor Set Points

A thermistor implemented in the hub of a fan is a first level of fan speed control. It provides an easy and cost effective means to begin acoustic noise reduction. It will, by design, run the fan at an appropriate speed based on the ambient conditions.

Chapter 5 discussed in detail the reference thermal solution, including the target Ψ_{CA} , fan speed and temperatures to ensure that T_{C-MAX} is not exceeded for TDP power at a given ambient temperature. The resulting variable speed fan (VSF) curve is the upper limit on fan speed.

The benefit of this upper limit will become more apparent when the fan speed controller is responding to the on-die thermal diode temperatures.

Figure 16. Thermistor Set Points



6.2.3 Minimum Fan Speed Set Point

The final aspect of thermal solution design is to determine the minimum speed at which the fan will be allowed to operate. This value can be driven by the cooling requirements for another portion of the design, such as the processor voltage regulator, or by functional limits of the fan design.

Per the *Fan Specification for 4 wire PWM Controlled Fans*, there are three possible options to consider:

- Type A: The fan will run at minimum RPM for all PWM duty cycle values less than minimum duty cycle. This would be programmed into the fan controller located on the fan hub. It can not be overridden by the external fan speed control.
- Type B: The fan will run at minimum RPM for all non-zero PWM duty cycle values less than minimum duty cycle and the fan will turn off at 0% PWM duty cycle.
- Type C: The fan will stop running when the current provided to the motor windings is insufficient to support commutation. The fan would turn off at 0% PWM duty cycle input.

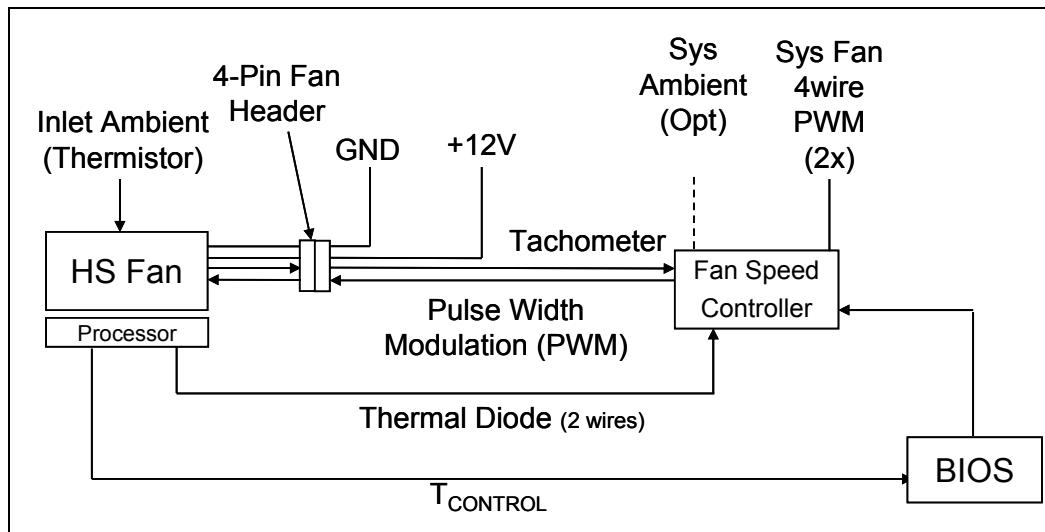
For the reference thermal solution, Type A was implemented.



6.3 Board and System Implementation

Once the thermal solution is defined, the system designer and board designer can define the fan speed control implementation. The first step is to select the appropriate fan speed controller (FSC). Figure 17 shows the major connections for a typical implementation.

Figure 17. Example Acoustic Fan Speed Control Implementation



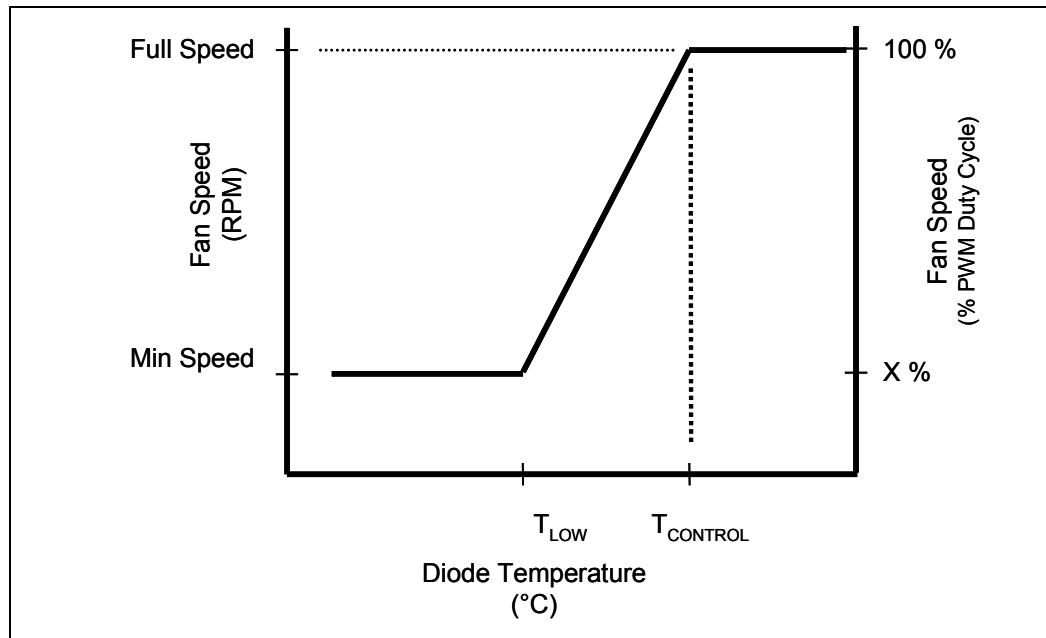
A number of major manufacturers have FSC components that include the necessary functionality to measure the temperature of the on-die thermal diode and output a PWM signal. These components can be a discrete device or a super I/O (SIO) with the functionality embedded. The following vendors currently have components that could be suitable: Analog Devices, ITE, Maxim, National Semiconductor, SMSC and Winbond. Consult their web sites or local sales representatives for a part suitable for your design. See Appendix E for further details on the motherboard requirements

6.3.1 Choosing Fan Speed Control Settings

Fan speed control algorithms allow the system thermal engineer a number of options to consider. The typical control settings that need to be considered are:

- The temperature when the fan will begin to accelerate in response to the on-die thermal diode temperature (T_{LOW})
- The temperature where the fan speed is operating at full speed (100% PWM duty cycle). By specification this is $T_{CONTROL}$
- The minimum fan speed (PWM duty cycle). For any on-die thermal diode temperature less than T_{LOW} the fan will run at this speed

These are the minimum parameters required to implement acoustic fan speed control. See Figure 18 for an example. There may be vendor specific options that offer enhanced functionality. See the appropriate vendor datasheet on how to implement those features.

Figure 18. Fan Speed Control

6.3.1.1 Temperature to begin Fan Acceleration

The first item to consider is the value for T_{LOW} . The FSC device needs a minimum temperature to set as the threshold to begin increasing PWM duty cycle to the fan.

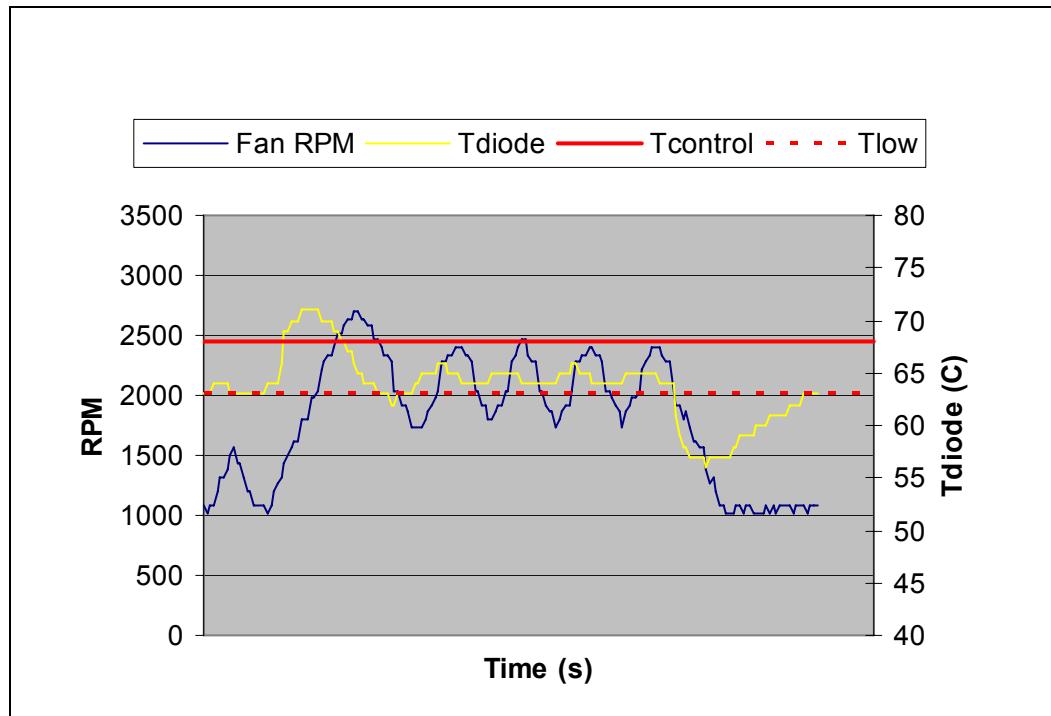
The system designer might initially consider a small temperature range ($T_{CONTROL} - T_{LOW} = T_{RANGE}$), such as 5 °C to accelerate the fan. That would delay the fan accelerating for the longest period after an increase in T_{DIODE} . There are a number of issues that should be considered with this strategy:

- There is little granularity in the fan speeds. For each 1 °C of increase in diode temperature = 20% jump in PWM duty cycle %.
- Fan speed oscillation as the thermal solution chases the diode temperature.
- Having T_{DIODE} overshoot $T_{CONTROL}$ and the thermal profile causing the Thermal Control Circuit to activate to reduce the temperature.

The first two cases can create a poor acoustic response for the user. For the third case, the user could notice a drop in performance as the thermal control circuit reduces the power. Figure 19 is an example of this situation. The system begins at idle and a moderate workload is applied (less than TDP).



Figure 19. Temperature Range = 5 °C

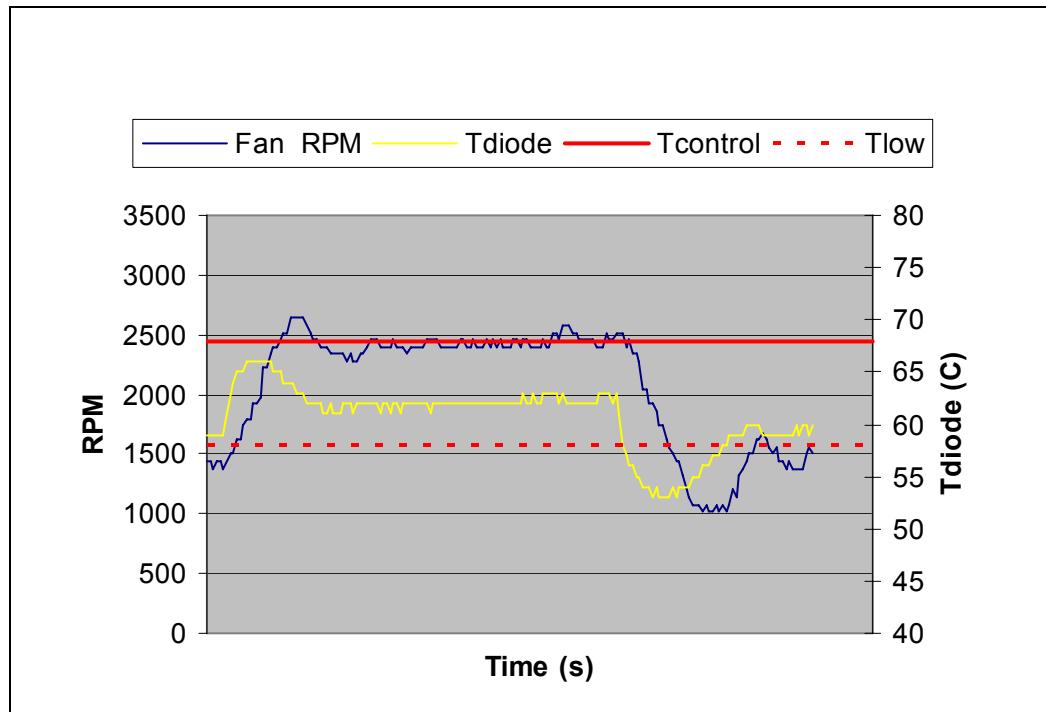


An alternate would be to consider a slightly larger value such as $T_{RANGE} = 10 \text{ } ^\circ\text{C}$. In this case the design is trading off the acoustic margin for thermal margin.

- There is increased granularity in the fan speeds.
- Fan speed oscillations are significantly reduced
- Maximum fan speed is lower

The rate of change of Ψ_{CA} vs. RPM is an exponential curve with a larger decrease at the beginning of the fan acceleration than as the maximum speed is approached. By having the fan start to accelerate at a lower T_{DIODE} reading the thermal solution can keep up with the rate of change in processor power. The rate of change in acoustics (dBA) is more linear with RPM. When comparing these two metrics, the choice of a larger T_{RANGE} value becomes a more acceptable trade off. Figure 20 graphs the system at the same conditions as in Figure 19, but $T_{RANGE} = 10^\circ$.

Figure 20. Temperature Range = 10 °C



It should be noted that having T_{DIODE} above $T_{CONTROL}$ is expected for near TDP power levels and high system ambient. See Section 6.5 for additional discussion on $T_{CONTROL}$ versus Thermal Profile.

For use with the Intel® Boxed Pentium 4 Processor in 775-Land LGA Package on the enabled reference solution, a T_{RANGE} value of 10 °C is recommended for ATX chassis.

6.3.1.2 Minimum PWM Duty Cycle

The final step in determining the FSC setting is to determine the minimum PWM Duty cycle. This is the fan speed for any $T_{DIODE} < T_{LOW}$. The selection of this value is dependent on:

- Acoustic target at system idle
- Voltage regulator cooling

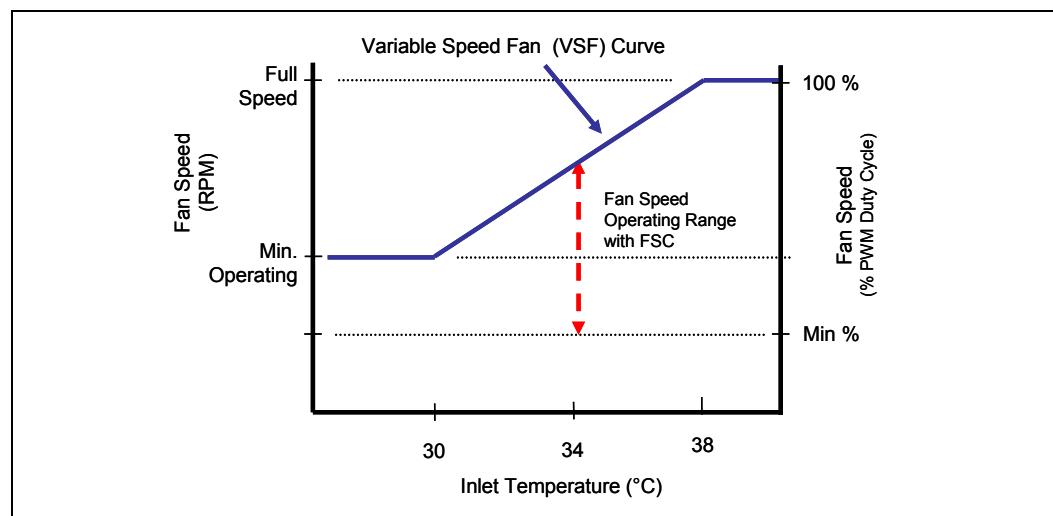
For a motherboard design intending to use the Intel Boxed Pentium 4 Processor in 775-land LGA Package or the enabled reference thermal solution the recommended minimum PWM duty cycle is 30%.



6.4 Combining Thermistor and Thermal Diode Control

There is no closed loop control between the FSC and the thermistor, but they work in tandem to provide the maximum fan speed reduction. As discussed in Section 6.2.2, the thermistor establishes the VSF curve. This curve will determine the maximum fan speed as a function of the ambient temperature and by design provides a Ψ_{CA} sufficient to meet the thermal profile. The FSC, by measuring the processor on-die thermal diode will command the fan to reduce speed below the VSF curve in response to processor workload. Conversely if the processor workload increases the FSC will command the fan via the PWM duty cycle to accelerate the fan up to the limit imposed by the VSF curve.

Figure 21. Diode and Thermistor



6.5 Interaction of Thermal Profile and T_{CONTROL}

The Pentium 4 processor in the 775-land LGA packaged thermal specification is comprised of the two parameters, T_{CONTROL} and the maximum case temperature defined by the Thermal Profile. The minimum requirement for thermal compliance is to ensure the thermal solution, by design, meets the thermal profile.

If the system design will incorporate variable speed fan control, Intel requires 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.

- On-die Thermal Diode less than T_{CONTROL}
 - When the thermal solution can maintain the thermal diode temperature to less than T_{CONTROL} then the fan speed can be reduced.
- On-die Thermal Diode equal to T_{CONTROL}
 - The PWM duty cycle must be = 100%
- On-die Thermal Diode greater than T_{CONTROL}
 - The T_c must be maintained at or below the Thermal Profile for the measured power dissipation.

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Appendix A LGA775 Socket Heatsink Loading

A.1 LGA775 Socket Heatsink Considerations

Heatsink clip load is traditionally used for:

- Mechanical performance in mechanical shock and vibration
 - Refer to Section 5.7.1 above for information on the structural design strategy for the Intel RCBFH-3 Reference Design
- Thermal interface performance
 - Required preload depends on TIM
 - Preload can be low for thermal grease

In addition to mechanical performance in shock and vibration and TIM performance, LGA775 socket requires a minimum heatsink preload to protect against fatigue failure of socket solder joints.

Solder ball tensile stress is originally created when, after inserting a processor into the socket, the LGA775 socket load plate is actuated. In addition, solder joint shear stress is caused by coefficient of thermal expansion (CTE) mismatch induced shear loading. The solder joint compressive axial force (F_{axial}) induced by the heatsink preload helps to reduce the combined joint tensile and shear stress.

Overall, the heatsink required preload is the minimum preload needed to meet all of the above requirements: Mechanical shock and vibration and TIM performance and LGA775 socket protection against fatigue failure.

A.2 Metric for Heatsink Preload for ATX/ μ ATX Designs Non-Compliant with Intel Reference Design

A.2.1 Heatsink Preload Requirement Limitations

Heatsink preload by itself is not an appropriate metric for solder joint force across various mechanical designs and does not take into account for example (not an exhaustive list):

- Heatsink mounting hole span
- Heatsink clip/fastener assembly stiffness and creep
- Board stiffness and creep
- Board stiffness is modified by fixtures like backing plate, chassis attach, etc.

Simulation shows that the solder joint force (F_{axial}) is proportional to the board deflection measured along the socket diagonal. The matching of F_{axial} required to protect the LGA775 socket solder joint in temperature cycling is equivalent to matching a target MB deflection.

Therefore, the heatsink preload for LGA775 socket solder joint protection against fatigue failure can be more generally defined as the load required to create a target board downward deflection throughout the life of the product.

This board deflection metric provides guidance for mechanical designs that differ from the reference design for ATX//μATX form factor.

A.2.2 Motherboard Deflection Metric Definition

Motherboard deflection is measured along either diagonal (refer to Figure 22):

$$d = d_{\max} - (d_1 + d_2)/2$$

$$d' = d_{\max} - (d'_1 + d'_2)/2$$

Configurations in which the deflection is measured are defined in the Table 5.

To measure board deflection, follow industry standard procedures (such as IPC) for board deflection measurement. Height gauges and possibly dial gauges may also be used.

Table 5. Board Deflection Configuration Definitions

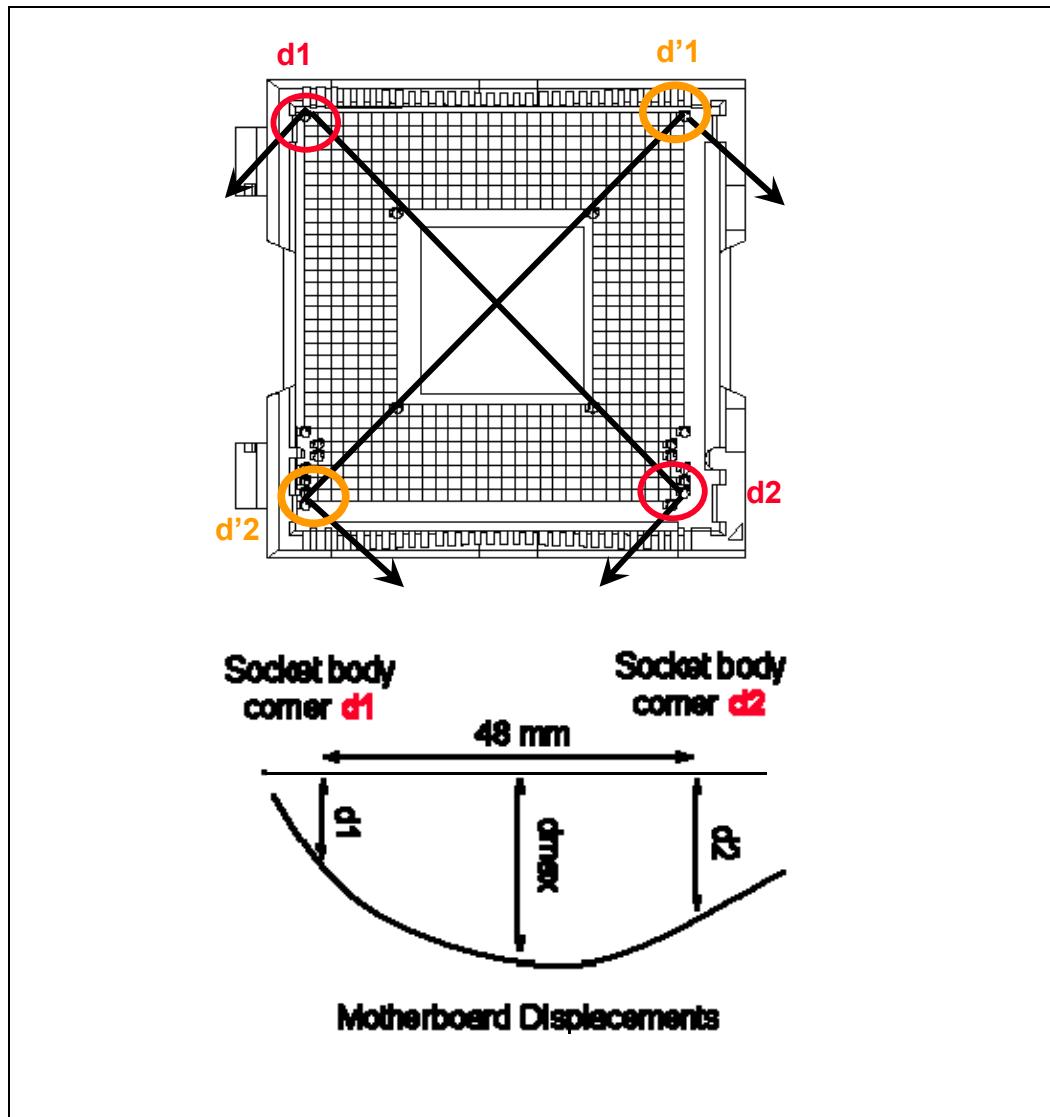
Configuration Parameter	Processor + Socket Load Plate	Heatsink	Parameter Name
d_ref	yes	no	BOL deflection, no preload
d_BOL	yes	yes	BOL deflection with preload
d_EOL	yes	yes	EOL deflection

BOL: Beginning of Life

EOL: End of Life



Figure 22. Board Deflection Definition



A.2.3 Board Deflection Limits

Deflection limits for the ATX/ μ ATX form factor are:

$$d_{BOL} - d_{ref} \geq 0.09 \text{ mm and } d_{EOL} - d_{ref} \geq 0.15 \text{ mm}$$

And

$$d'_{BOL} - d'_{ref} \geq 0.09 \text{ mm and } d'_{EOL} - d'_{ref} \geq 0.15 \text{ mm}$$

NOTES:

1. The heatsink preload must remain within the static load limits defined in the processor datasheet at all times.
2. Board deflection should not exceed motherboard manufacturer specifications.

A.2.4 Board Deflection Metric Implementation Example

This section is for illustration purposes only, and relies on the following assumptions:

- 72 mm x 72 mm hole pattern of the reference design
- Board stiffness = 900 lb/in at BOL, with degradation that simulates board creep over time
 - Though these values are representative, they may change with selected material and board manufacturing process. Check with your motherboard vendor.
- Clip stiffness assumed constant – No creep.

Using Figure 23, the heatsink preload at beginning of life is defined to comply with $d_{EOL} - d_{ref} = 0.15$ mm depending on clip stiffness assumption.

Note that the BOL and EOL preload and board deflection differ. This is a result of the creep phenomenon. The example accounts for the creep expected to occur in the motherboard. It assumes no creep will occur in the clip. However, there is a small amount of creep accounted for in the plastic fasteners. This situation is somewhat similar to the Intel Reference Design.

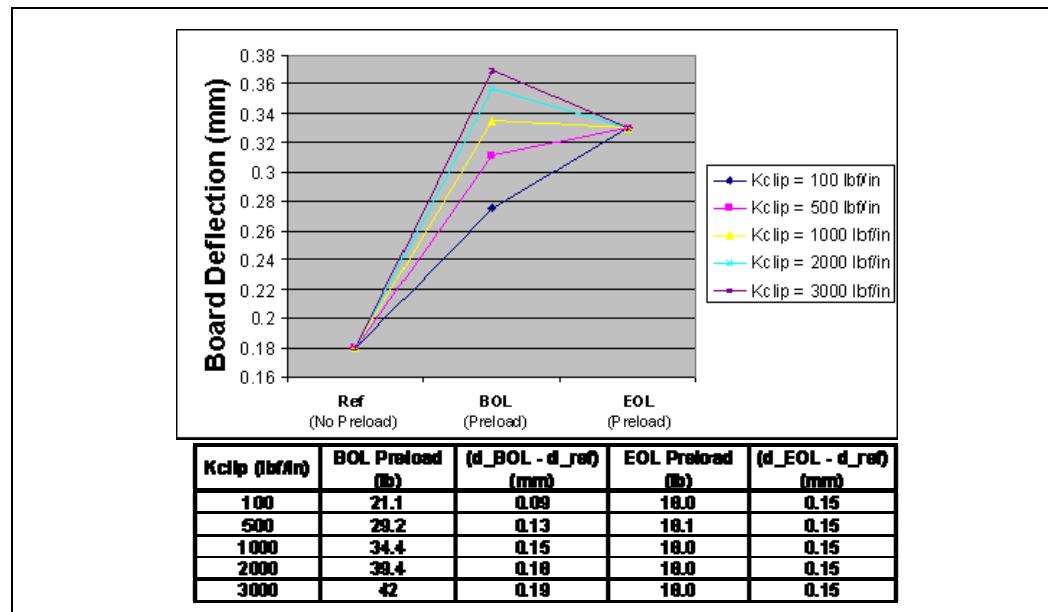
The impact of the creep to the board deflection is a function of the clip stiffness:

- The relatively compliant clips store strain energy in the clip under the BOL preload condition and tend to generate increasing amounts of board deflection as the motherboard creeps under exposure to time and temperature.
- In contrast, stiffer clips store very little strain energy, and therefore do not generate substantial additional board deflection through life.

NOTES:

1. Board and clip creep modify board deflection over time and depend on board stiffness, clip stiffness, and selected materials.
2. Designers must define the BOL board deflection that will lead to the correct end of life board deflection.

Figure 23. Example: Defining Heatsink Preload Meeting Board Deflection Limit





A.2.5 Additional Considerations

Intel recommends designing to $\{d_{BOL} - d_{ref} = 0.15\text{mm}\}$ at BOL when EOL conditions are not known or difficult to assess.

The following information is given for illustration purposes only. It is based on the reference keep-out, assuming there is no fixture that changes board stiffness:

d_{ref} is expected to be 0.18 mm on average, and be as high as 0.22 mm.

As a result, the board should be able to deflect 0.37 mm minimum at BOL.

Additional deflection, as much as 0.09 mm may be necessary to account for additional creep effects impacting the board/clip/fastener assembly. As a result, designs could see as much as 0.50 mm total downward board deflection under the socket.

In addition to board deflection, other elements need to be considered to define the space needed for the downward board total displacement under load, like the potential interference of through-hole mount component pin tails of the board with a mechanical fixture on the back of the board.

NOTES:

1. The heatsink preload must remain below the maximum load limit of the package at all times (Refer to processor datasheet).
2. Board deflection should not exceed motherboard manufacturer specifications.

A.2.5.1 Motherboard Stiffening Considerations

To protect LGA775 socket solder joint, designers need to drive their mechanical design to:

- Allow downward board deflection to put the socket balls in a desirable force state to protect against fatigue failure of socket solder joint (refer to Sections A.2.1, A.2.2, and A.2.3).
- Prevent board upward bending during mechanical shock event.
- Define load paths that keep the dynamic load applied to the package within specifications published in the processor datasheet.

Limiting board deflection may be appropriate in some situations like:

- Board bending during shock.
- Board creep with high heatsink preload.

However, the load required to meet the board deflection recommendation (refer to Section A.2.3) with a very stiff board may lead to heatsink preloads exceeding package maximum load specification. For example, such a situation may occur when using a backing plate that is flush with the board in the socket area, and prevents the board from bending underneath the socket.

A.3 Heatsink Selection Guidelines

Evaluate carefully heatsinks that use motherboard stiffening devices (like backing plates), and conduct board deflection assessments based on the board deflection metric.

Solutions derived from the reference design comply with the reference heatsink preload, for example:

- The Intel Boxed Pentium 4 Processor in the 775-land LGA package.
- The Intel RCBFH-3 Reference Design available from licensed suppliers (refer to Appendix H for contact information).

Intel is also collaborating with vendors participating in its third party test house program to evaluate third party solutions. Vendor information will be available and updated regularly after product launch at <http://developer.intel.com>. After selecting the processor, go to the processor technical information page, and then select “Support component”.

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Appendix B Heatsink Clip Load Metrology

B.1 Overview

This section describes a procedure for measuring the load applied by the heatsink/clip/fastener assembly on a processor package.

This procedure is recommended to verify the preload is within the design target range for a design, and in different situations. For example:

- Heatsink preload for the LGA775 socket.
- Quantify preload degradation under bake conditions.

Note: This document reflects the current metrology used by Intel. Intel is continuously exploring new ways to improve metrology. Updates will be provided later as this document is revised as appropriate.

B.2 Test Preparation

B.2.1 Heatsink Preparation

Three load cells are assembled into the base of the heatsink under test, in the area interfacing with the processor Integrated Heat Spreader (IHS), using load cells equivalent to those listed in Section B.2.2.

To install the load cells, machine a pocket in the heatsink base, as shown in Figure 24 and Figure 25. The load cells should be distributed evenly, as close as possible to the pocket walls. Apply wax around the circumference of each load cell and the surface of the pocket around each cell to maintain the load cells in place during the heatsink installation on the processor and motherboard (Refer to Figure 25).

The depth of the pocket depends on the height of the load cell used for the test. It is necessary that the load cells protrude out of the heatsink base. However, this protrusion should be kept minimal, as it will create additional load by artificially raising the heatsink base. The measurement offset depends on the whole assembly stiffness (i.e. motherboard, clip, fastener, etc.). For example, the Intel RCBFH-3 Reference Heatsink Design clip and fasteners assembly has a stiffness of around 380 N/mm [2180 lb/in]. In that case, a protrusion of 0.038 mm [0.0015"] will create an extra load of 15 N [3.3 lb]. Figure 26 shows an example using the Intel RCBFH-3 Reference Heatsink designed for the Pentium 4 processor in the 775-land LGA package.

Note: When optimizing the heatsink pocket depth, the variation of the load cell height should also be taken into account to make sure that all load cells protrude equally from the heatsink base. It may be useful to screen the load cells prior to installation to minimize variation.

Remarks: Alternate Heatsink Sample Preparation

As just mentioned, making sure that the load cells have minimum protrusion out of the heatsink base is paramount to meaningful results. An alternate method to make sure that the test setup will measure loads representative of the non-modified design is:

- Machine the pocket in the heat sink base to a depth such that the tips of the load cells are just flush with the heat sink base.
- Then machine back the heatsink base by around 0.25 mm [0.01"], so that the load cell tips protrude beyond the base.

Proceeding this way, the original stack height of the heatsink assembly should be preserved. This should not affect the stiffness of the heatsink significantly.

Figure 24. Load Cell Installation in Machined Heatsink Base Pocket (Bottom View)

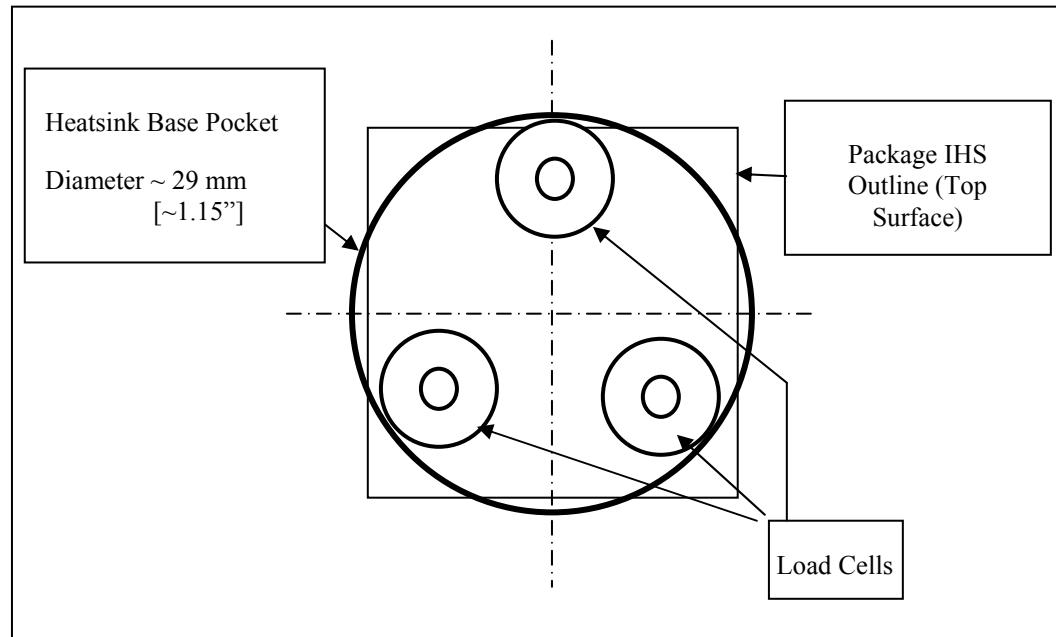




Figure 25. Load Cell Installation in Machined Heatsink Base Pocket (Side View)

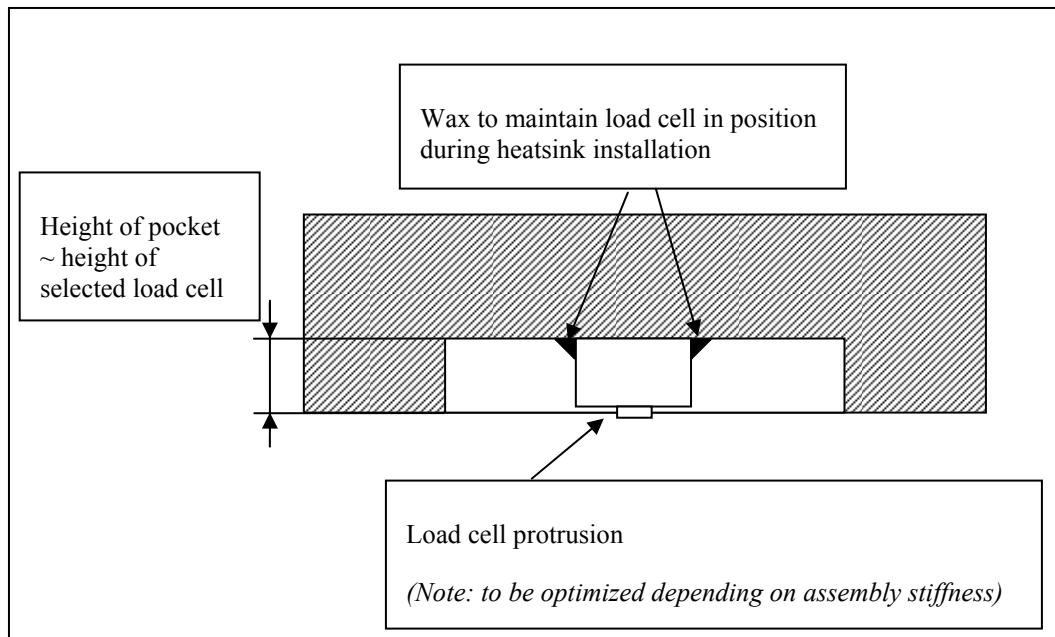
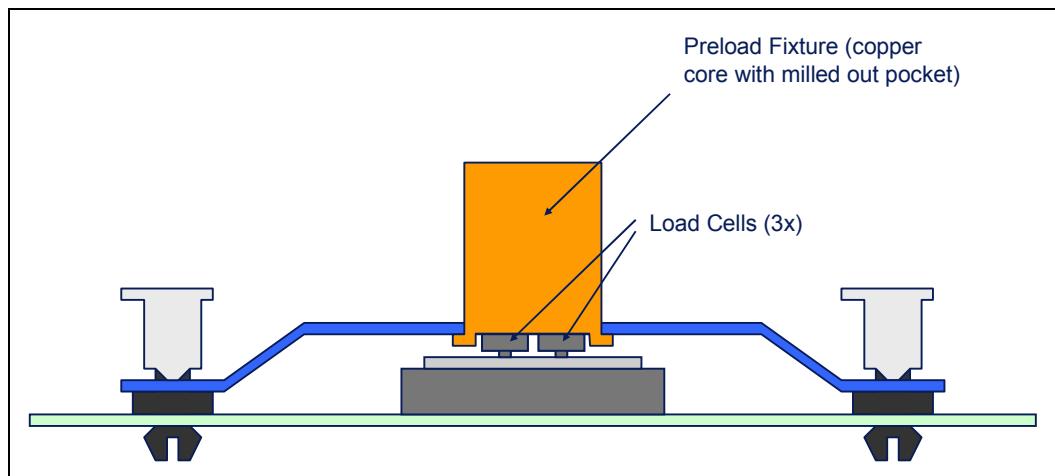


Figure 26. Preload Test Configuration



B.2.2 Typical Test Equipment

For the heatsink clip load measurement, use equivalent test equipment to that listed in Table 6.

Table 6. Typical Test Equipment

Item	Description	Part Number (Model)
Load cell <i>Notes: 1, 5</i>	Honeywell-Sensotec* Model 13 subminiature load cells, compression only Select a load range depending on load level being tested. www.sensotec.com	AL322BL
Data Logger (or scanner) <i>Notes: 2, 3, 4</i>	Vishay Measurements Group Model 6100 scanner with a 6010A strain card (one card required per channel).	Model 6100

NOTES:

1. Select load range depending on expected load level. It is usually better, whenever possible, to operate in the high end of the load cell capability. Check with your load cell vendor for further information.
2. Since the load cells are calibrated in terms of mV/V, a data logger or scanner is required to supply 5 volts DC excitation and read the mV response. An automated model will take the sensitivity calibration of the load cells and convert the mV output into pounds.
3. With the test equipment listed above, it is possible to automate data recording and control with a 6101-PCI card (GPIB) added to the scanner, allowing it to be connected to a PC running LabVIEW* or Vishay's StrainSmart* software.
4. **IMPORTANT:** In addition to just a zeroing of the force reading at no applied load, it is important to calibrate the load cells against known loads. Load cells tend to drift. Contact your load cell vendor for calibration tools and procedure information.
5. When measuring loads under thermal stress (bake for example), load cell thermal capability must be checked, and the test setup must integrate any hardware used along with the load cell. For example, the Model 13 load cells are temperature compensated up to 71 °C, as long as the compensation package (spliced into the load cell's wiring) is also placed in the temperature chamber. The load cells can handle up to 121 °C (operating), but their uncertainty increases according to 0.02% rdg/°F.

B.3 Test Procedure Examples

The following sections give two examples of load measurement. However, this is not meant to be used in mechanical shock and vibration testing.

Any mechanical device used along with the heatsink attach mechanism will need to be included in the test setup (i.e., back plate, attach to chassis, etc.).

Prior to any test, make sure that the load cell has been calibrated against known loads, following load cell vendor's instructions.



B.3.1 Time-Zero, Room Temperature Preload Measurement

1. Pre-assemble mechanical components on the board as needed prior to mounting the motherboard on an appropriate support fixture that replicates the board attach to a target chassis.
 - For example: standard ATX board should sit on ATX compliant stand-offs. If the attach mechanism includes fixtures on the back side of the board, those must be included, as the goal of the test is to measure the load provided by the actual heatsink mechanism.
2. Install the test vehicle in the socket
3. Assemble the heatsink reworked with the load cells to motherboard as shown for the Intel RCBFH-3 reference heatsink example in Figure 26, and actuate attach mechanism.
4. Collect continuous load cell data at 1 Hz for the duration of the test. A minimum time to allow the load cell to settle is generally specified by the load vendors (often in the order of 3 minutes). The time zero reading should be taken at the end of this settling time.
5. Record the preload measurement (total from all three load cells) at the target time and average the values over 10 seconds around this target time as well, i.e. in the interval , for example over [target time – 5 seconds ; target time + 5 seconds].

B.3.2 Preload Degradation under Bake Conditions

This section describes an example of testing for potential clip load degradation under bake conditions.

1. Preheat thermal chamber to target temperature (45 °C or 85 °C for example)
2. Repeat time-zero, room temperature preload measurement
3. Place unit into preheated thermal chamber for specified time
4. Record continuous load cell data as follows:
 - Sample rate = 0.1 Hz for first 3 hrs
 - Sample rate = 0.01 Hz for the remainder of the bake test
5. Remove assembly from thermal chamber and set into room temperature conditions
6. Record continuous load cell data for next 30 minutes at sample rate of 1 Hz.

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Appendix C 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.

C.1 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).

C.2 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.

C.3 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 drops 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 D Case Temperature Reference Metrology

D.1 Objective and Scope

This appendix defines a reference procedure for attaching a thermocouple to the IHS of a 775-land LGA processor package for T_C measurement. This procedure takes into account the specific features of the 775-land LGA package and of the LGA775 socket for which it is intended.

It describes the recommended equipment for the reference thermocouple installation, including tools and adhesive part numbers.

D.2 Definitions

Definitions of common acronyms used in this appendix are given in the table below:

Item	Definition
IPA	Isopropyl Alcohol
DMM	Digital Multi Meter
IHS	Integrated Heat Spreader

D.3 Supporting Test Equipment

To apply the reference thermocouple attach procedure, it is recommended to use the equipment (or equivalent) provided in the following table.

Item	Description	Part Number
Measurement and Output		
Microscope	Olympus Light microscope or equivalent	SZ-40
DMM	Digital Multi Meter for resistance measurement	Not Available
Test Fixture(s)		
Micromanipulator (See Note below)	Micromanipulator set from YOU, Ltd. or equivalent. Mechanical 3D arm with needle (not included) to maintain TC bead location during the attach process.	YOU-3
Miscellaneous Hardware		
Loctite 498 Adhesive	Super glue w/thermal characteristics	49850
Adhesive Accelerator	Loctite 7452 for fast glue curing	18490
Kapton Tape	For holding thermocouple in place	Not Available
Thermocouple	Omega, 40 gauge, "T" Type	5SRTC-TT-T-40-72
Calibration and Control		
Ice Point Cell	Omega, stable 0 °C temperature source for calibration and offset	TRCIII
Hot Point Cell	Omega , temperature source to control and understand meter slope gain	CL950-A-110

Note: Three axes set consists of (1ea. U-31CF), (1ea. UX-6-6), (1ea. USM6), and (1ea. UPN-1). More information available at: http://www.narishige.co.jp/you_ltd/english/products/set/you-set.htm#3



D.4 Thermal Calibration and Controls

It is recommended that full and routine calibration of temperature measurement equipment be performed before attempting to perform temperature case measurement of processors. Intel recommends checking the meter probe set against known standards. This should be done at 0 °C (using ice bath or other stable temperature source) and at an elevated temperature, around 80 °C (using an appropriate temperature source).

Wire gauge and length also should be considered as some less expensive measurement systems are heavily impacted by impedance. There are numerous resources available throughout the industry to assist with implementation of proper controls for thermal measurements.

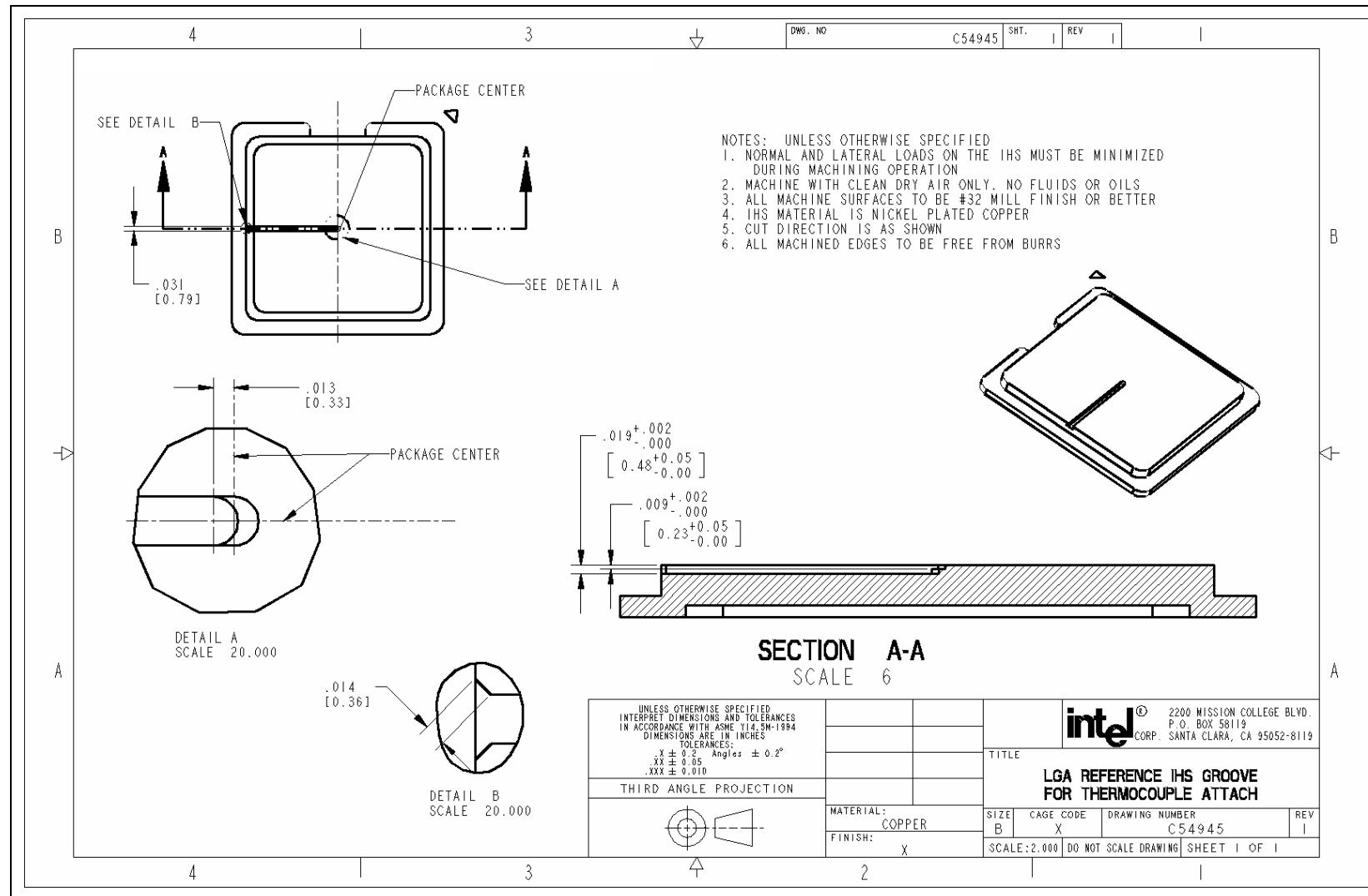
Note:

1. It is recommended to follow standard safety procedures and wear safety items like glasses for cutting the IHS and gloves for chemical handling.
2. Ask your Intel field sales representative if you would like assistance to groove and/or install a thermocouple according to the reference process.

D.5 IHS Groove

Cut a groove in the package IHS according to the drawing given in Figure 27.

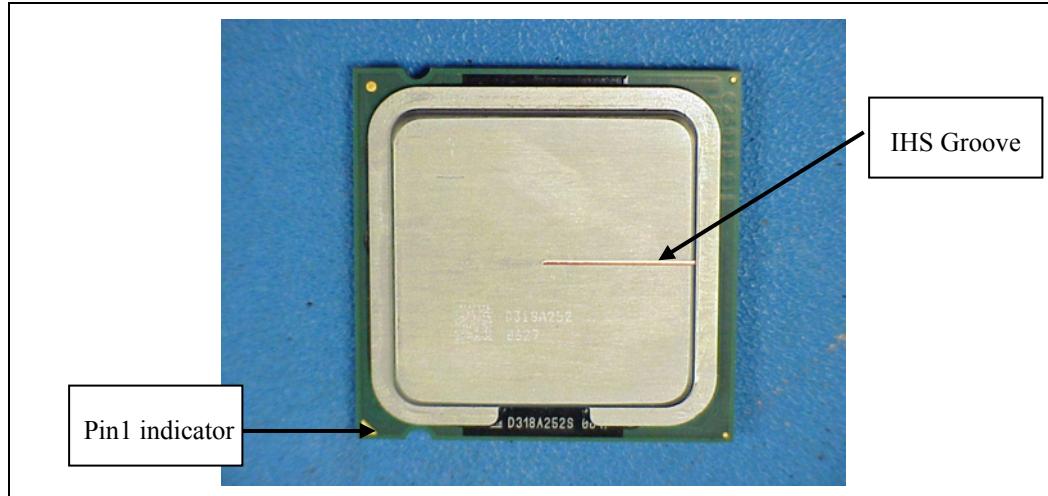
Figure 27. 775-Land LGA Package Reference Groove Drawing





The orientation of the groove relative to the package pin 1 indicator (gold triangle in one corner of the package) is shown in Figure 28 for the 775-land LGA package IHS.

Figure 28. IHS Reference Groove on the 775-Land LGA Package



When the processor is installed in the LGA775 socket, the groove is perpendicular to the socket load lever, and on the opposite side of the lever, as shown in Figure 29.

Figure 29. IHS Groove Orientation Relative to the LGA775 Socket



Select a machine shop that is capable of complying with drawing specified tolerances. IHS channel geometry is critical for repeatable placement of the thermocouple bead, ensuring precise thermal measurements. The specified dimensions minimize the impact of the groove on the IHS under the socket load. A larger groove may cause the IHS to warp under the socket load such that it does not represent the performance of an ungrooved IHS on production packages.

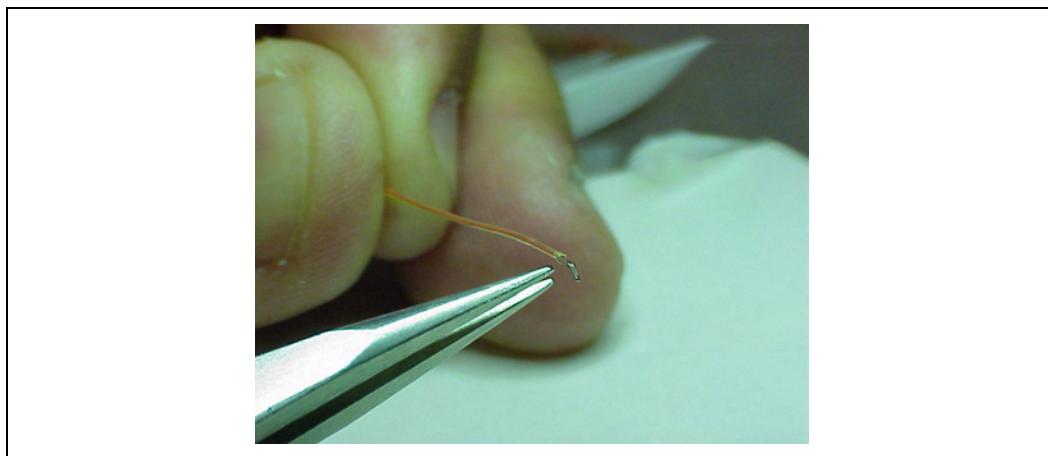
Inspect parts for compliance to specifications before accepting from machine shop.

D.6 Thermocouple Attach Procedure

D.6.1 Thermocouple Conditioning and Preparation

1. Use a calibrated thermocouple as specified in Sections D.3 and D.4.
2. Measure the thermocouple resistance by holding both wires on one probe and the tip of thermocouple to the other probe of the DMM (measurement should be about~75 ohms for 40-gauge type T thermocouple).
3. Straighten the wire for about 38 mm [1 ½ inch] from the bead to place it inside the channel.
4. Bend the tip of the thermocouple at approximately 45 degree angle by about 0.8 mm [0.030 inch] from the tip (Figure 30).

Figure 30. Bending the Tip of the Thermocouple

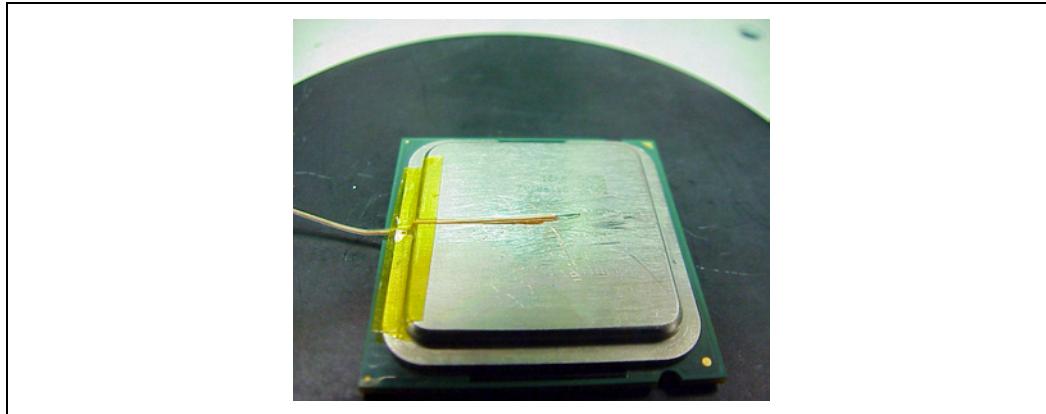


D.6.2 Thermocouple Attachment to the IHS

5. Clean groove with IPA and a lint free cloth removing all residues prior to thermocouple attachment.
6. Place the thermocouple wire inside the groove; letting the exposed wire and bead extend about 3.2 mm [0.125 inch] past the end of groove. Secure it with Kapton tape (Figure 31).

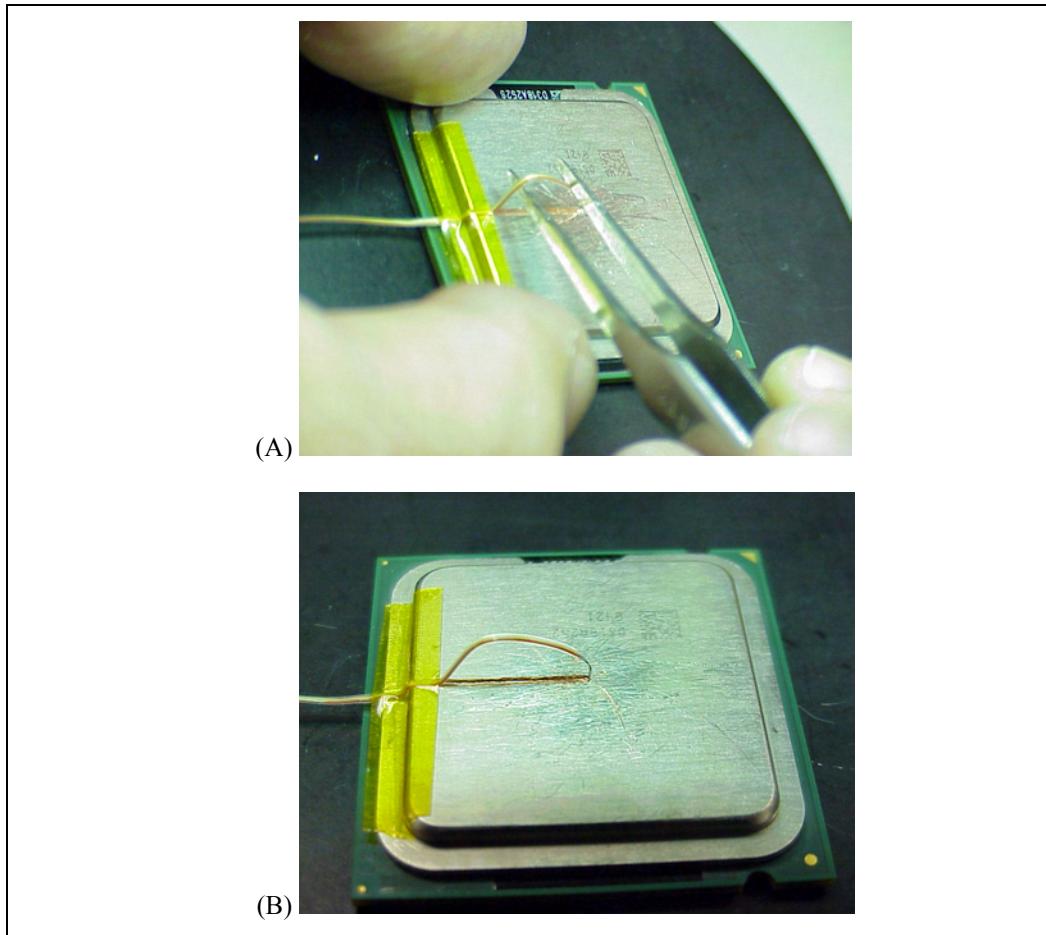


Figure 31. Securing Thermocouple Wires with Kapton Tape Prior to Attach



7. Lift the wire at the middle of groove with tweezers and bend the front of wire to place the thermocouple in the channel ensuring the tip is in contact with the end of the channel grooved in the IHS (Figure 32-A and B).

Figure 32. Thermocouple Bead Placement



8. Place the processor under the microscope unit (similar to the one used in Figure 36) to continue with the process. It is also recommended to use a fixture (like a processor tray or a plate) to help hold the unit in place for the rest of the attach process.
9. Press the wire down about 6 mm [0.125"] from the thermocouple bead using the tweezers. Look in the microscope to perform this task. Place a piece of Kapton tape to hold the wire inside the groove (Figure 33). Refer to Figure 34 for detailed bead placement.

Figure 33. Position Bead on the Groove Step

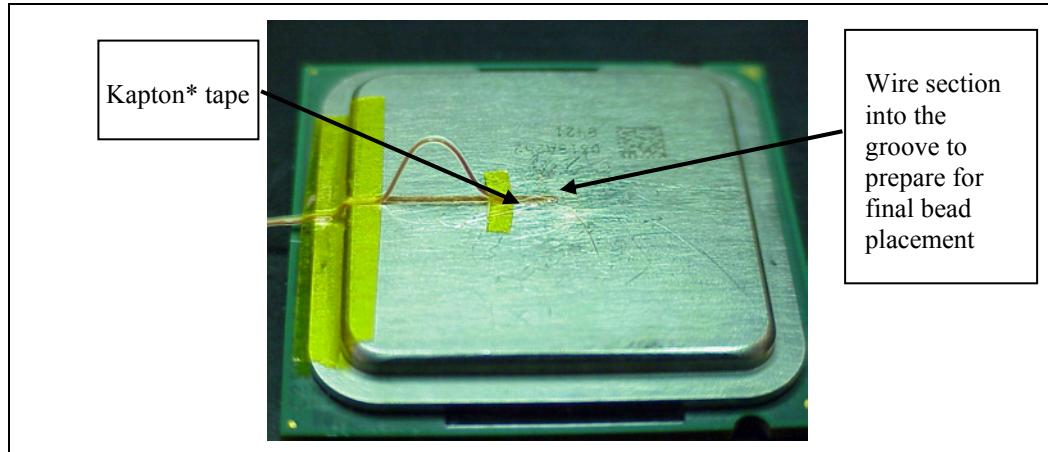
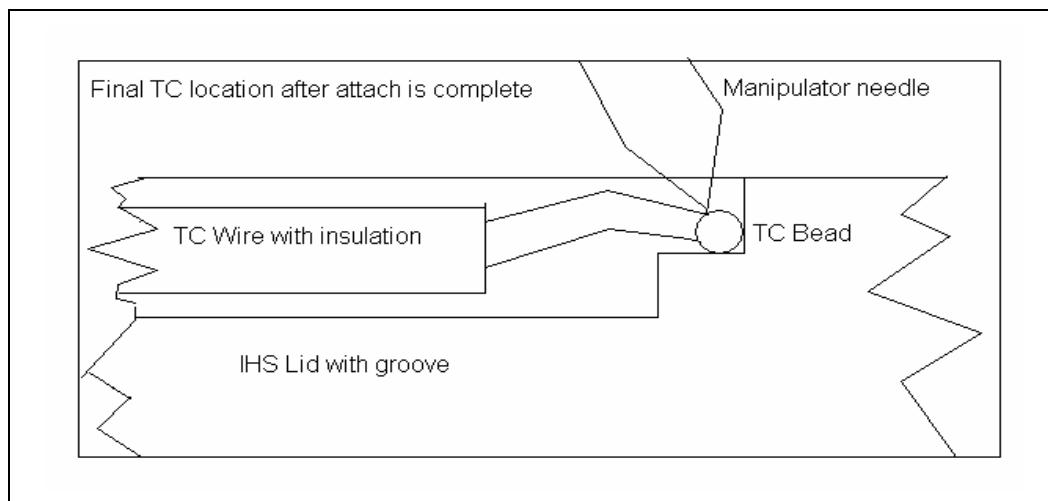


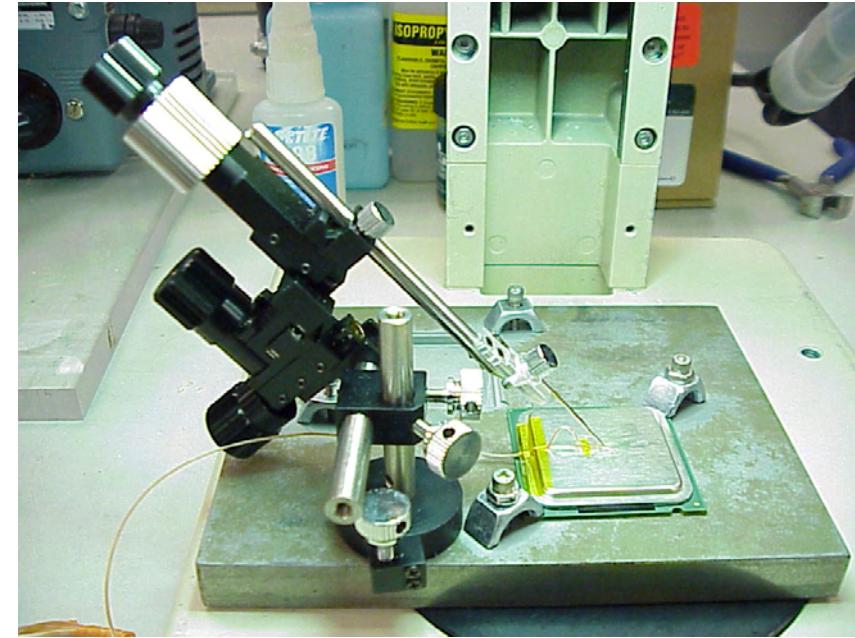
Figure 34. Detailed Thermocouple Bead Placement



10. Using the micromanipulator, install the needle near to the end of the groove on top of the thermocouple. Using the X, Y, and Z axes on the arm place the tip of the needle on top of the thermocouple bead. Press down until the bead is seated at the end of the groove on top of the step (see Figure 34 and Figure 35).



Figure 35. Using 3D Micromanipulator to Secure Bead Location



11. Measure resistance from thermocouple end wires (hold both wires to a DMM probe) to the IHS surface. This should be the same value as measured during the thermocouple conditioning see Section D.6.1, step 2 and Figure 36.

Figure 36. Measuring Resistance between Thermocouple and IHS



12. Place a small amount of Loctite 498 adhesive in the groove where the bead is installed. Using a fine point device, spread the adhesive in the groove around the needle, the thermocouple bead and the thermocouple wires already installed in the groove during step 5 above. Be careful not to move the thermocouple bead during this step (Figure 37).

Figure 37. Applying the Adhesive on the Thermocouple Bead

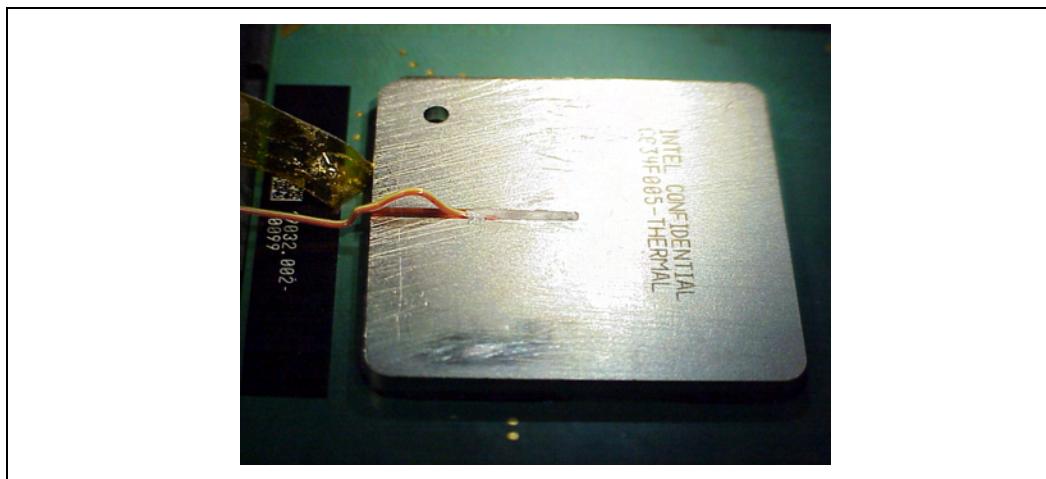


13. Measure the resistance from the thermocouple end wires again using the DMM (refer to Section D.6.1, step 2) and to ensure the bead is still properly contacting the IHS.

D.6.3 Curing Process

14. Let the thermocouple attach set in the open-air for at least 1/2 Hr. It is not recommended to use any curing accelerator like Loctite Accelerator 7452 for this step, as rapid contraction of the adhesive during curing may weaken bead attach on the IHS.
15. Reconfirm electrical connectivity with DMM before removing the micromanipulator (Figure 36) (see Section D.6.1, step 2 and above).
16. Remove the 3D Arm needle by holding down the processor unit and lifting the arm.
17. Remove the Kapton tape, straighten the wire in the groove so it lays flat all the way to the end of the groove Figure 38.

Figure 38. Thermocouple Wire Management in the Groove





18. Use a blade to carefully shave excess adhesive above the IHS surface (Figure 39).

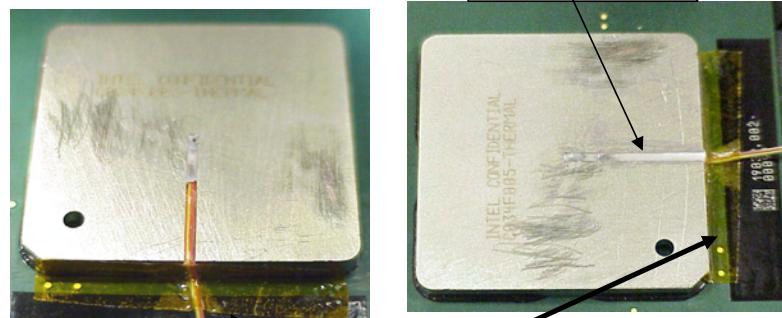
Note: Take usual safety precautions when using open blades and performing this operation.

Figure 39. Removing Excess Adhesive from IHS



19. Install new Kapton tape to hold the thermocouple wire down and fill the rest of the groove with adhesive (see Figure 40). Make sure the wire and insulation is entirely within the groove and below the IHS surface.

Figure 40. Filling the Groove with Adhesive



20. Curing time for the rest of the adhesive in the groove can be reduced using Loctite Accelerator 7452.
21. Repeat step 5 to remove any access adhesive to ensure flat IHS for proper mechanical contact to the heatsink surface.

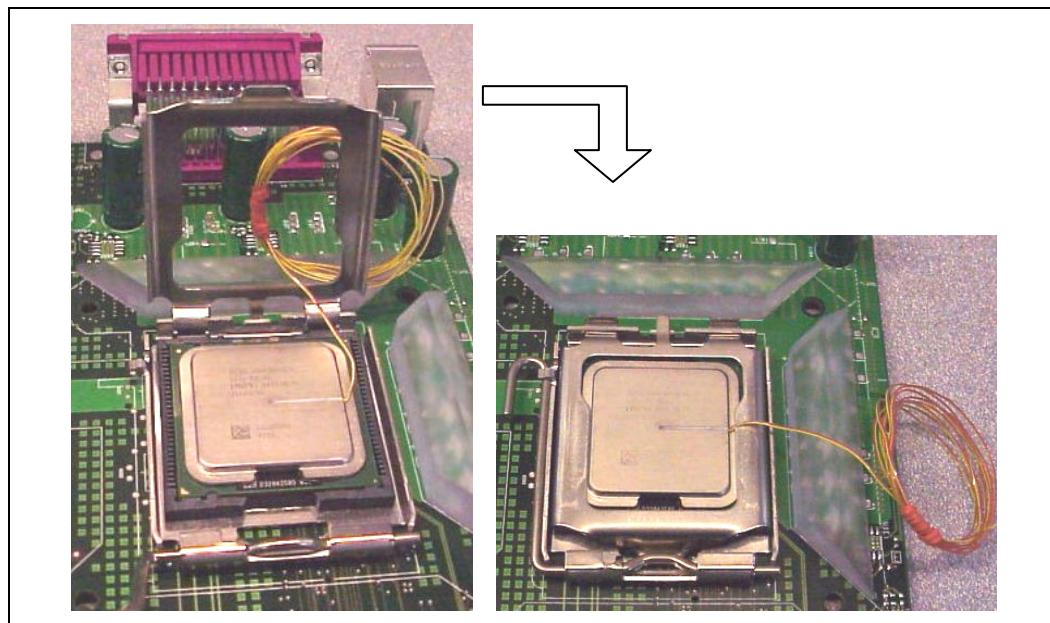
D.7 Thermocouple Wire Management

When installing the processor into the socket, make sure that the thermocouple wires exit above the load plate as shown in Figure 41. Pinching the thermocouple wires between the load plate and the IHS will likely damage the wires.

Note: When thermocouple wires are damaged, the resulting reading maybe incorrect. For example, if there are any cuts into the wires insulation where the wires are pinched between the IHS and the load plate, the thermocouple wires can get in contact with each other at this location. In that case, the reported temperature would be at the edge of the IHS/socket load plate area. This temperature is usually much lower than the temperature at the center of the IHS.

Prior to installing the heatsink, make sure that the thermocouple wires remain below the IHS top surface, by running a flat blade on top of the IHS for example.

Figure 41. Thermocouple Wire Management



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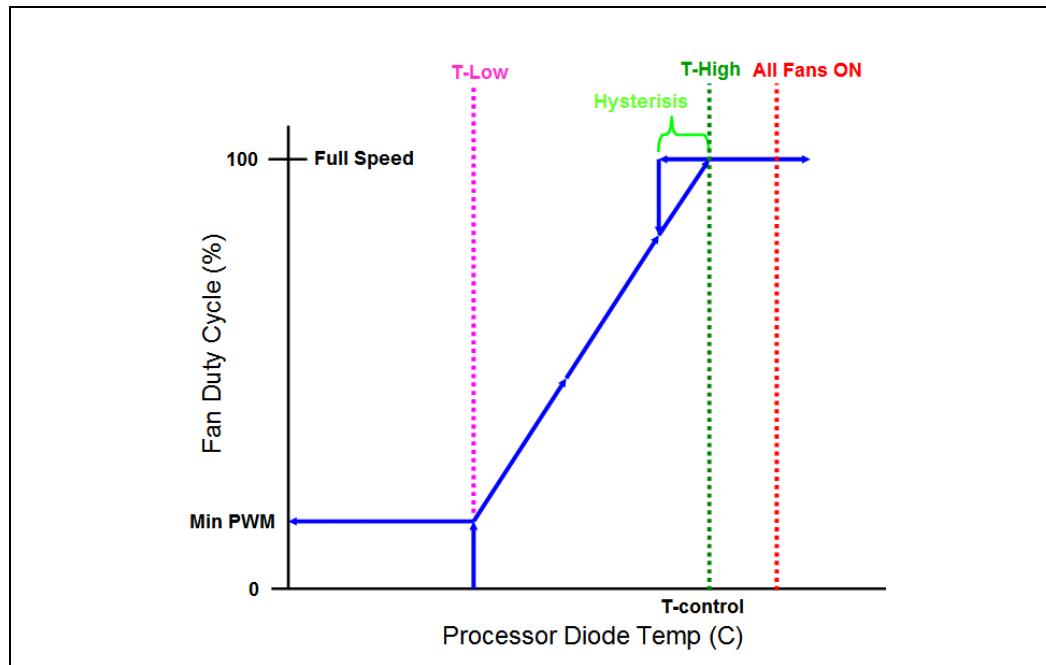
Appendix E Board Level PWM and Fan Speed Control Requirements

To use all of the features in the Intel reference heatsink design or the Boxed Intel Pentium 4 Processor in 775-land LGA package, system integrators should verify the following functionality is present in the board design. Refer to the *Fan Specification for 4 wire PWM Controlled Fans* and Chapter 5 for complete details on the Intel enabled thermal solution.

The basics of Fan Speed Control are discussed in Chapter 6; as a review, the FSC definitions are listed in Table 7.

Table 7. FSC Definitions

Item	Definition
T_{DIODE}	Temperature reported from the processor on-die thermal diode.
$T_{CONTROL}$	$T_{CONTROL}$ is the specification limit for use with the on-die thermal diode
T_{LOW}	The temperature above which the fan will begin to accelerate in response to the on-die thermal diode temperature.
Hysteresis	The number of degrees below $T_{CONTROL}$ the fans will remain on before slowing down.
T_{HIGH}	The temperature at which the fan is operating at full speed (100% PWM Duty Cycle). By specification this is $T_{CONTROL}$.
All Fans ON	The processor temperature at which all fans in the system are increased to 100% Duty Cycle.
Min PWM	Minimum pulse width modulation (% duty cycle) that the fans will run at when T_{DIODE} is less than T_{LOW} .
Spin-up	Amount of time fan is run at 100% duty cycle to overcome fan inertia.
PWM Freq	The operating frequency of the PWM signal.
$T_{AVERAGING}$	The time (in seconds) that elapses while the fan is gradually sped up in response to a processor temperature spike.

Figure 42. FSC Definitions Example

Requirements Classification

- Required – an essential part of the design necessary to meet specifications. Should be considered a pass or fail criterion in selection of a board.
- Suggested – highly desired for consistency among designs. May be specified or expanded by the system integrator.

The motherboard needs to have a fan speed control component that has the following characteristics:

- PWM output programmable to 21–28 kHz (required). PWM output set to 25 kHz (Suggested) as this value is the design target for the reference and for the Boxed Pentium 4 Processor.
- External/remote thermal diode measurement capability (required).
- External/remote thermal diode sampling rate \geq 4 times per second (required).
- External/remote diode measurement is calibrated by the component vendor to account for the diode ideality and package series resistance as listed in the appropriate datasheet. (Suggested).

Note: If the fan speed controller is not calibrated with the diode ideality and package series resistance, verify the board manufacturer has made provisions within the BIOS setup or other utility to input the corrections factors.

Note: The BIOS, at a minimum, must program the settings in Table 8 or Table 9 into the fan speed controller. The values are the minimum required to establish a fan speed control algorithm consistent with this document, the reference thermal solution and Boxed Processor thermal solution.

**Table 8. ATX FSC Settings**

Parameter	Classification	Processor Thermal Diode	PWM Output	Notes
T _{HIGH}	Required	T _{CONTROL}		3
T _{LOW}	Required	T _{CONTROL} – 10 °C		3
Minimum PWM Duty Cycle	Required		20%	
PWM Frequency	Required		21–28 kHz	1
Spin-up time	Suggested		250 – ~500 ms	2
T _{AVERAGING}	Suggested	35 sec		
When T _{DIODE} < T _{LOW}	Suggested	Minimum PWM%		
All Fans ON	Suggested	T _{CONTROL} + 3 °C		
Hysteresis	Suggested	2 °C		

NOTES:

1. A PWM output set to 25 kHz is the design target for the reference and for the Boxed Intel Processor and the reference design.
2. Use the lowest time available in this range for the device selected.
3. To ensure compliance with the thermal specification, thermal profile and usage of the T_{DIODE} for fan speed control these setting should not be user configurable.

Table 9. Balanced Technology Extended (BTX) FSC Settings

Parameter	Classification	Processor Thermal Diode	System Ambient Diode	PWM Output	Notes
T _{HIGH}	Required	T _{CONTROL}	54 °C		3,5
T _{LOW}	Required	T _{CONTROL} – 7 °C	47 °C		3,5
Minimum PWM Duty Cycle	Required			PWM 1 (TMA) - 20%	
PWM Frequency	Required			21–28 kHz	1
Spin Up Time	Suggested			250 – ~ 500 ms	2
T _{AVERAGING}	Suggested	4.0 sec	4.0 sec		3
When T _{DIODE} < T _{LOW}	Suggested	Minimum PWM%	Minimum PWM%		
All Fans On	Suggested	T _{CONTROL} + 3 °C	65 °C		
Hysteresis	Suggested	2 °C	4 °C		

NOTES:

1. A PWM frequency of 25 kHz is the design target for the reference and for the Intel® Boxed Processor and the reference design.
2. Use the lowest time available in this range for the device selected
3. T_{AVERAGEING} = represents the amount of delay time before responding to the temperature change, defined in fan speed control device (sometimes called ramp range control or spike smoothing). Please select the lowest setting available close to 4.0 seconds by the fan speed control device
4. The Fan Speed Controller, or Health Monitor Component, takes the result of the two fan speed ramps (processor and system) and drives the TMA fan to the highest resulting PWM duty cycle (%)
5. For BTX systems, a second thermal sensor is recommended to capture chassis ambient temperature (for more detail, see Appendix E).
6. To ensure compliance with the thermal specification, thermal profile and usage of the T_{DIODE} for fan speed control these setting should not be user configurable.



Note: The fan speed component vendors provide libraries that are used by the BIOS writer to program the component registers with the parameters listed above. Consult the appropriate vendor datasheet for detailed information on programming their component.

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Appendix F Balanced Technology Extended (BTX) System Thermal Considerations

There are anticipated system operating conditions in which the processor power may be low but other system component powers may be high. If the only Fan Speed Control (FSC) circuit input for the Thermal Module Assembly (TMA) fan is from the processor diode, then the fan speed and system airflow is likely to be too low in this operating state. Therefore, it is recommended that a second FSC circuit input be acquired from an ambient temperature monitor location within the system.

The location of the System Monitor thermal sensor is best determined through extensive system-level numerical thermal modeling or prototype thermal testing. In either case, the temperature of critical components or the air temperature near critical components should be assessed for a range of system external temperatures, component powers, and fan speed operating conditions. The temperature at the selected location for the System Monitor Point should be well correlated to the temperatures at or near critical components. For instance, it may be useful to monitor the temperature near the PSU airflow inlet, near the graphics add-in card, or near memory.

The final system integrator is typically responsible for ensuring compliance with the component temperature specifications at all operating conditions and, therefore, should be responsible for specifying the System Monitor thermal sensor location. However, it is not always possible for a board supplier – especially a channel board supplier – to know the system into which a board will be installed. It is, therefore, important for BTX board suppliers to select a System Monitor thermal sensor location that will function properly in most systems.

A BTX system should be designed such that the TMA exhaust is the primary airflow stream that cools the rest of the system. The airflow passes through the chipset heatsink and its temperature will rise as the memory controller chipset power increases. Since chipset power will increase when other subsystems (e.g., memory, graphics) are active, a System Monitor thermal sensor located in the exhaust airflow from the chipset heatsink is a reasonable location.

It is likely that a thermal sensor that is not mounted above the board and in the chipset exhaust airflow will reflect board temperature and not ambient temperature. It is therefore recommended that the Thermal sensor be elevated above the board.

The thermal sensor location and elevation are reflected in the Flotherm thermal model airflow illustrations (see Figure 43 and Figure 44). The Intel® Boxed Boards in BTX form factor have implemented a System Monitor thermal sensor. The following thermal sensor or its equivalent can be used for this function:

Part Number: C83274-002 BizLink USA Technology, Inc. 44911 Industrial Drive Fremont, CA 94538 USA (510)252-0786 phone (510)252-1178 fax sales@bizlinktech.com	Part Number: 68801-0170 Molex Incorporated 2222 Wellington Ct. Lisle, IL 60532 1-800-78MOLEX phone 1-630-969-1352 fax amerinfo@molex.com
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Figure 43. System Airflow Illustration with System Monitor Point Area Identified

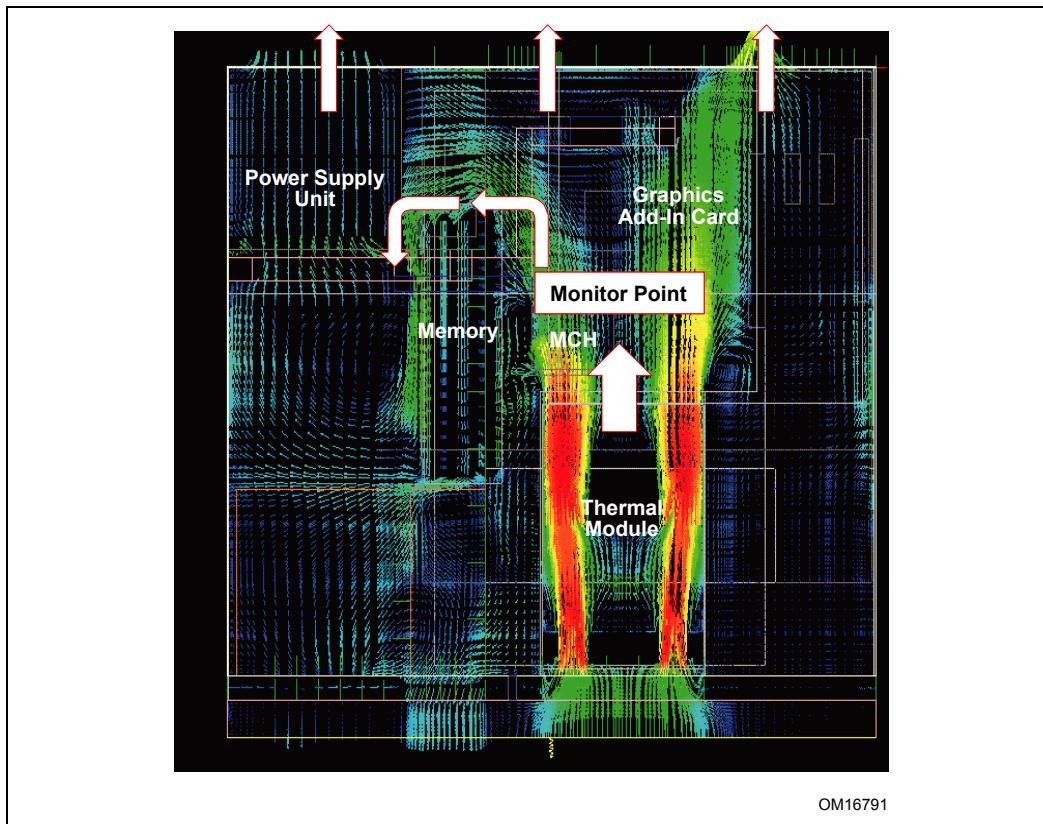
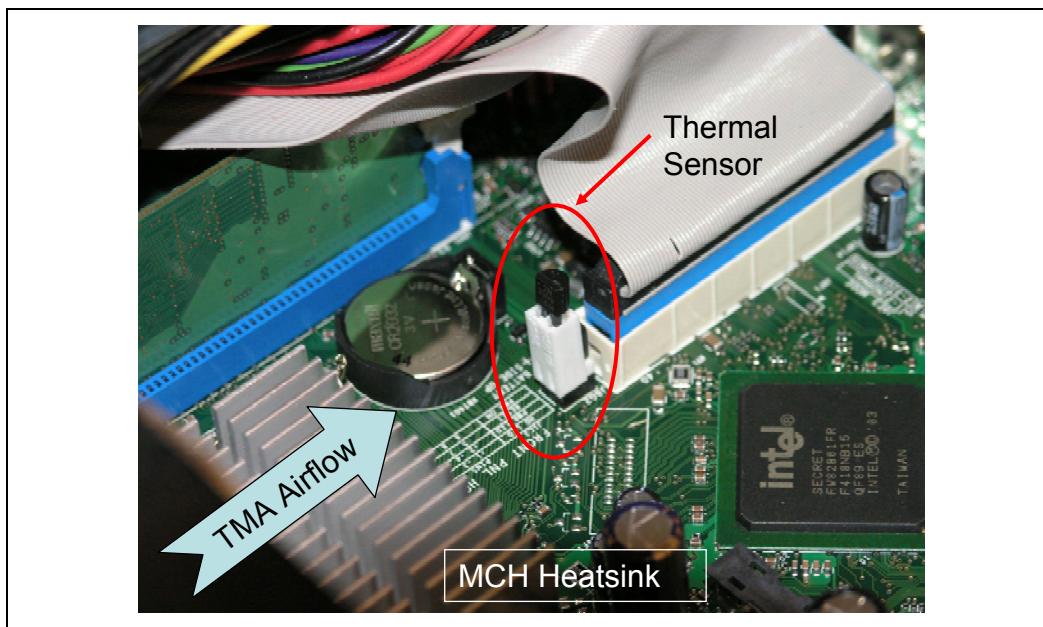


Figure 44. Thermal Sensor Location Illustration





Appendix G Mechanical Drawings

The following table lists the mechanical drawings included in this appendix. These drawings refer to the reference thermal mechanical enabling components for the Pentium 4 processor in the 775-land LGA package.

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

Drawing Description	Page Number
ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components – Sheet 1	94
ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components – Sheet 2	95
ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components – Sheet 3	96
Reference Clip Drawings – Sheet 1	97
Reference Clip Drawings – Sheet 2	98
Reference Fastener – Sheet 1	99
Reference Fastener – Sheet 2	100
Reference Fastener – Sheet 3	101
Reference Fastener – Sheet 4	102
Clip/Heatsink Assembly	103
Intel(R) RCBFH-3 Reference Solution Assembly	104

Figure 45. ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components – Sheet 1

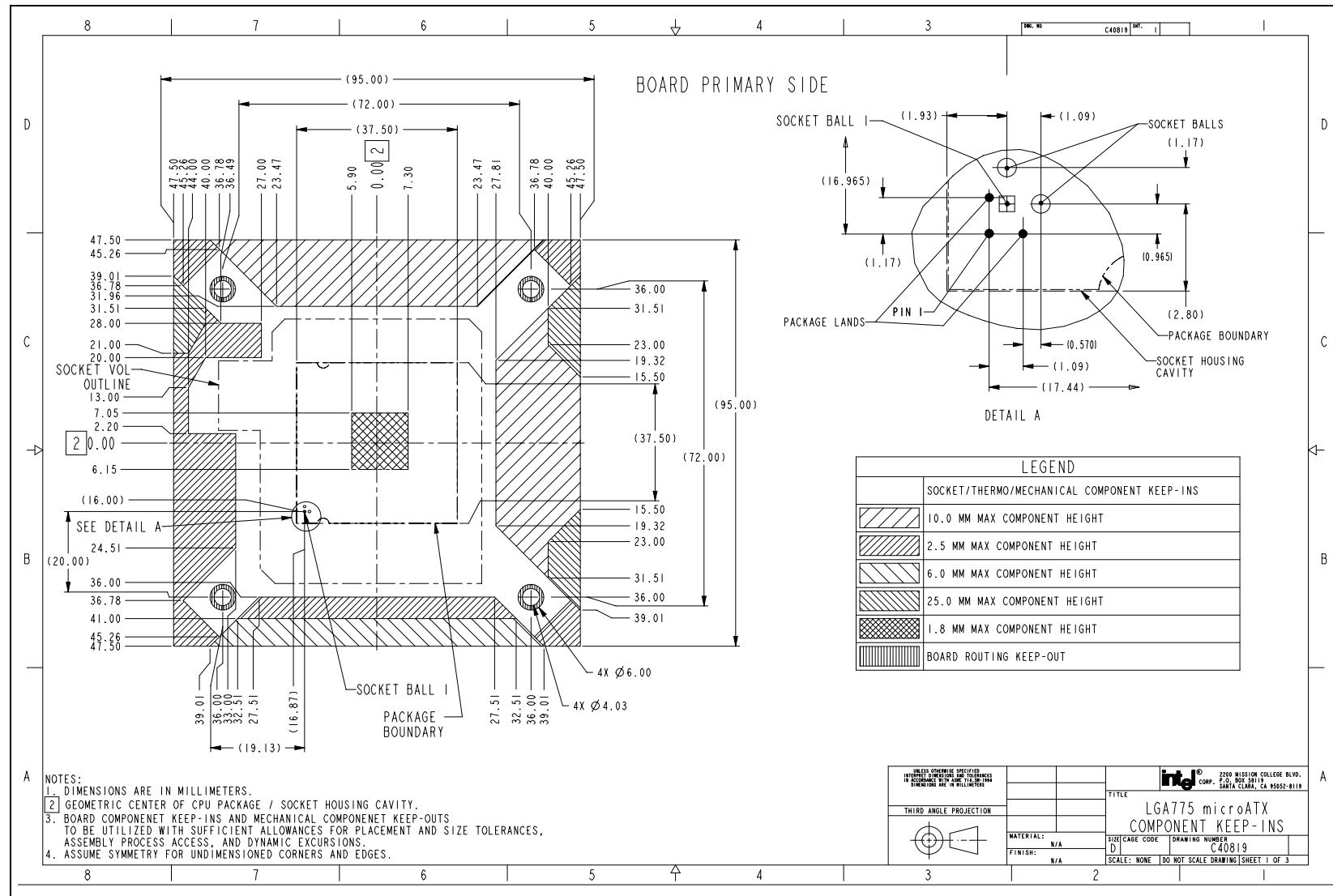




Figure 46. ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components – Sheet 2

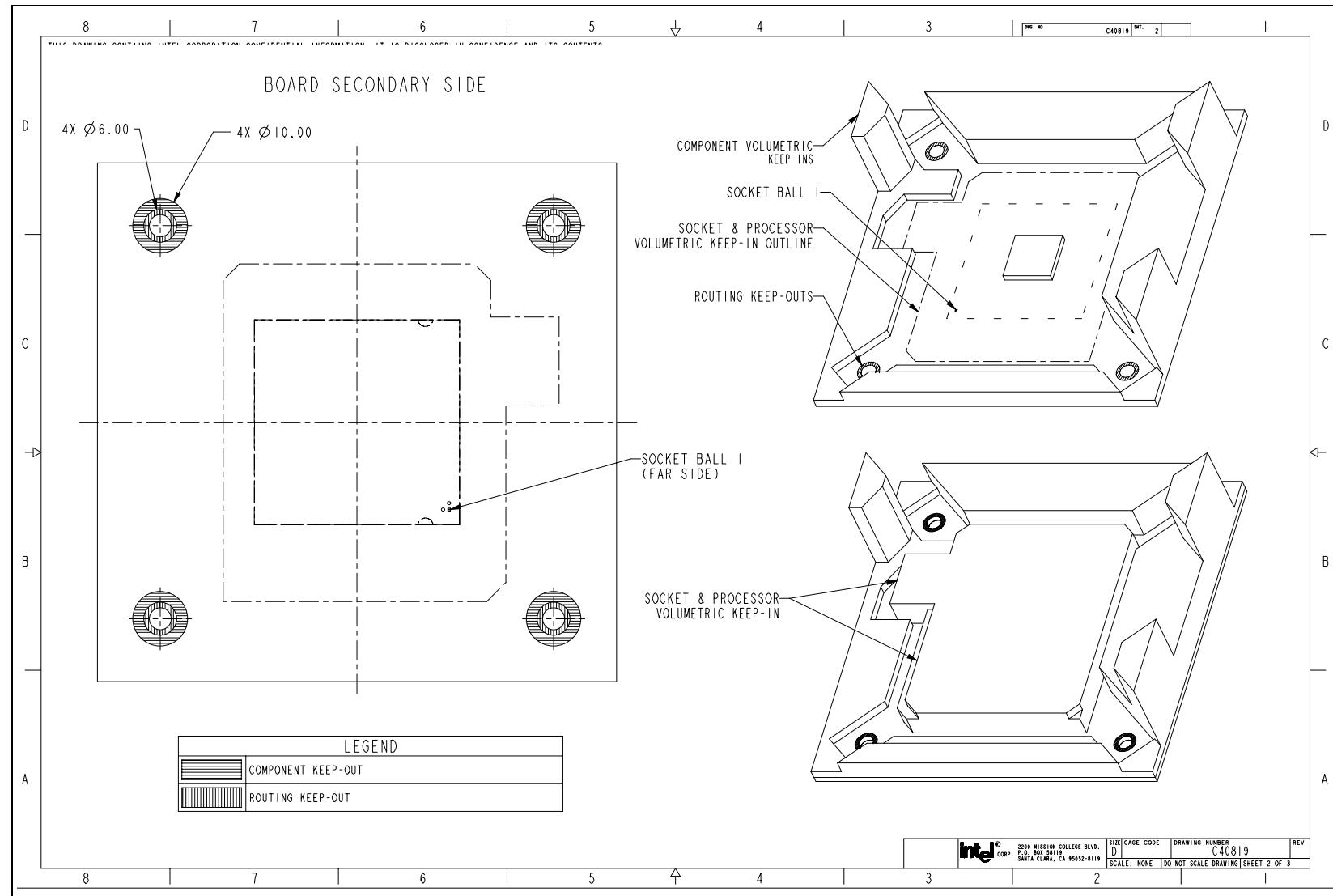


Figure 47. ATX/μATX Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components – Sheet 3

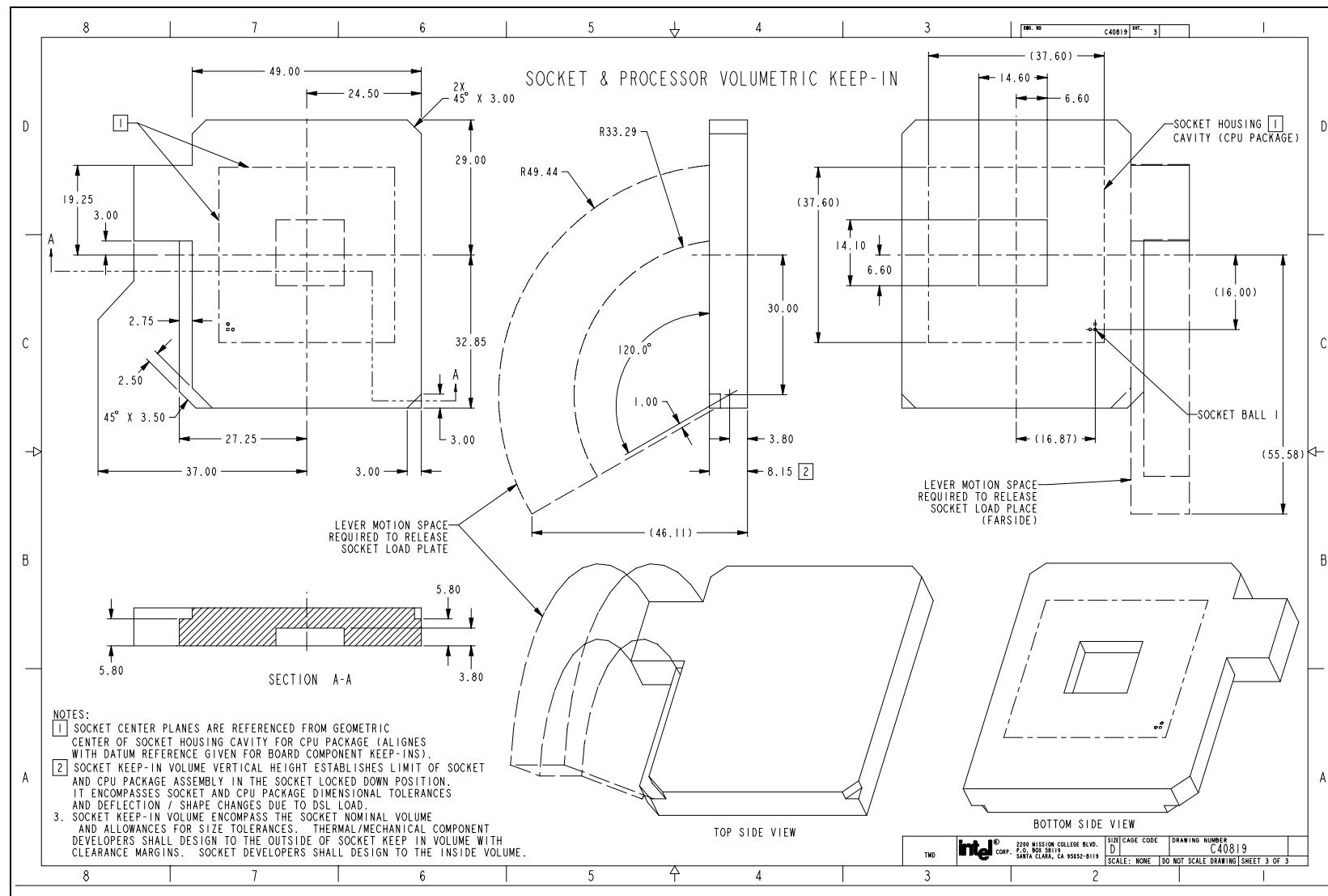




Figure 48. Reference Clip Drawings – Sheet 1

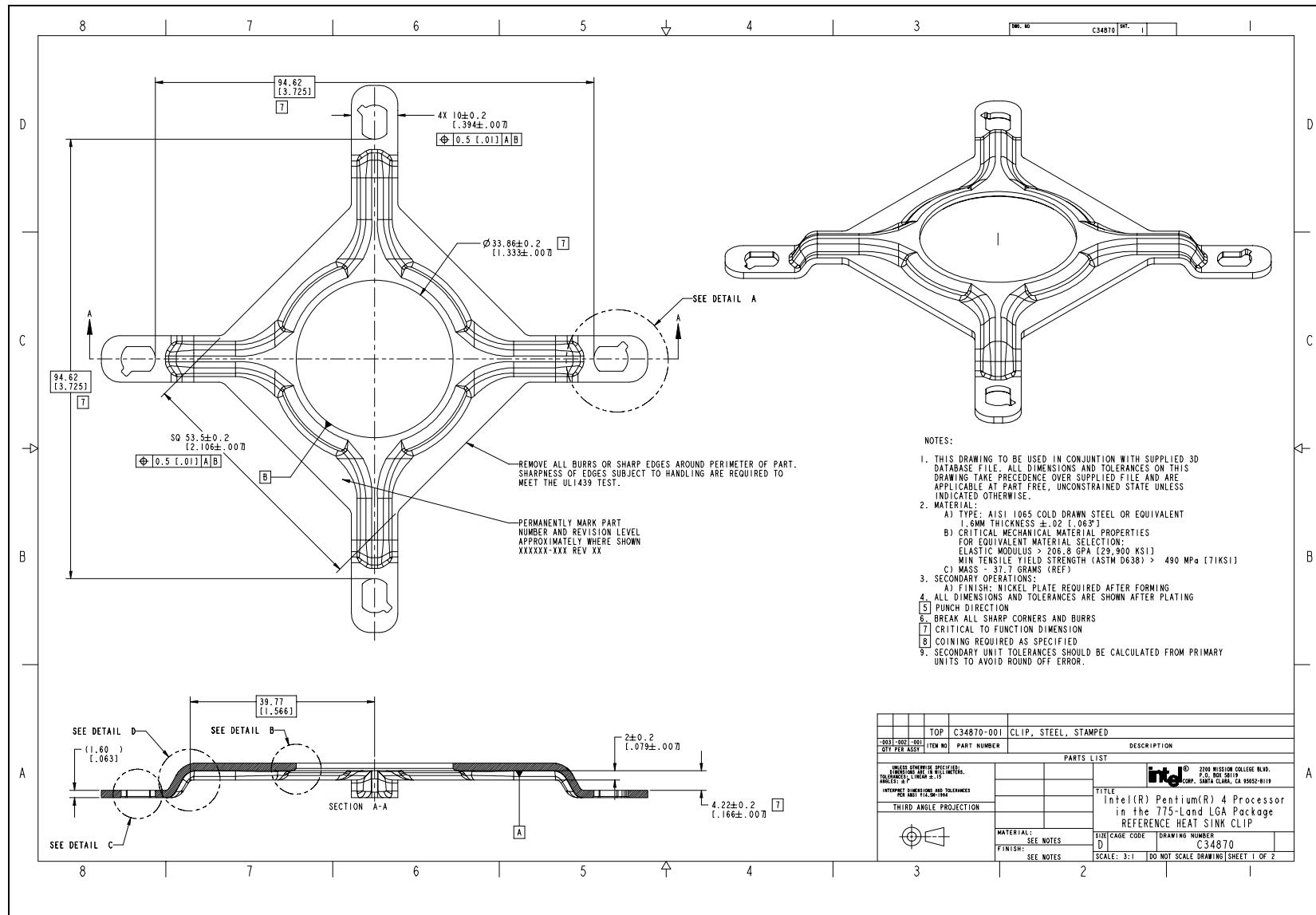


Figure 49. Reference Clip Drawings – Sheet 2

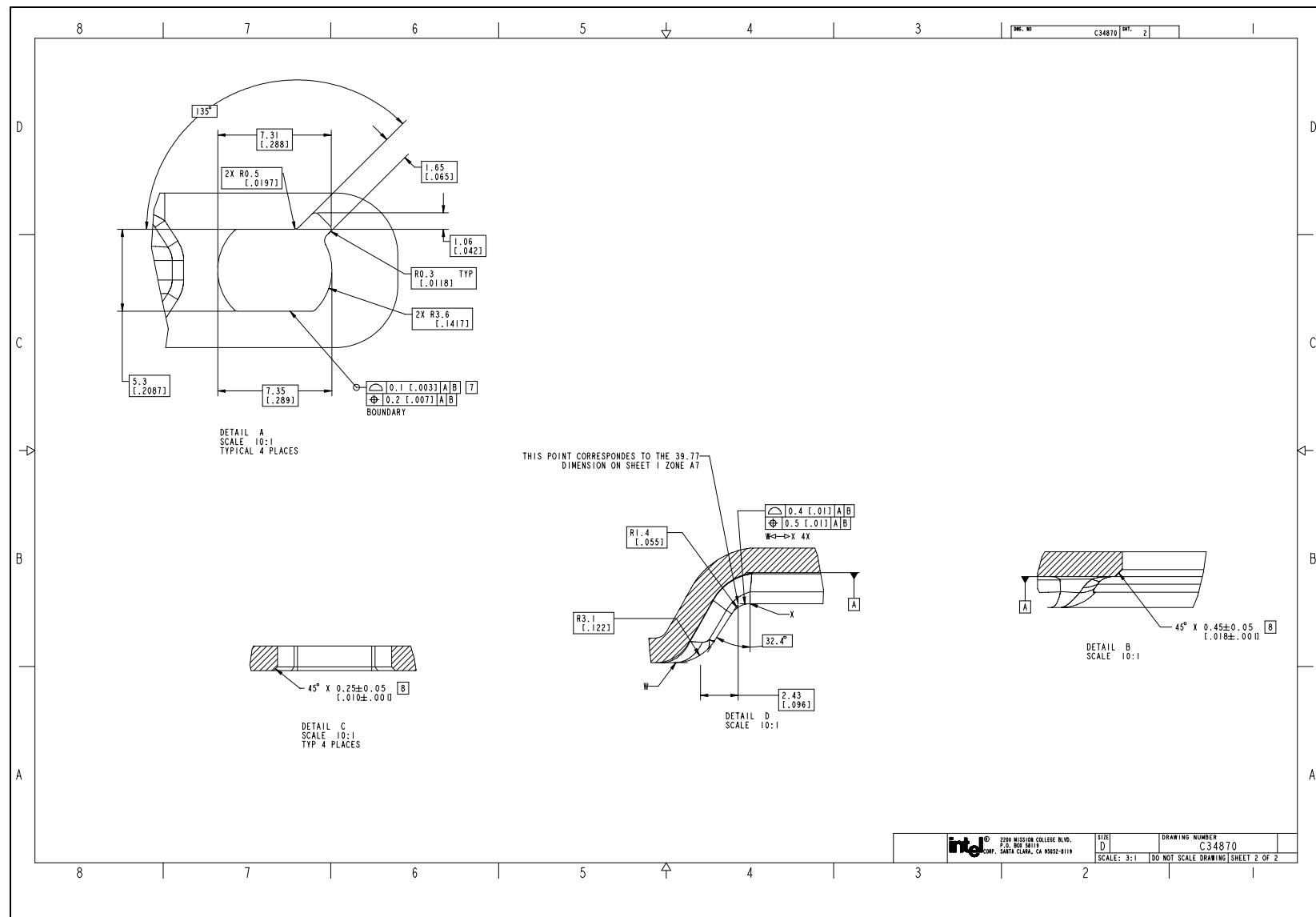




Figure 50. Reference Fastener – Sheet 1

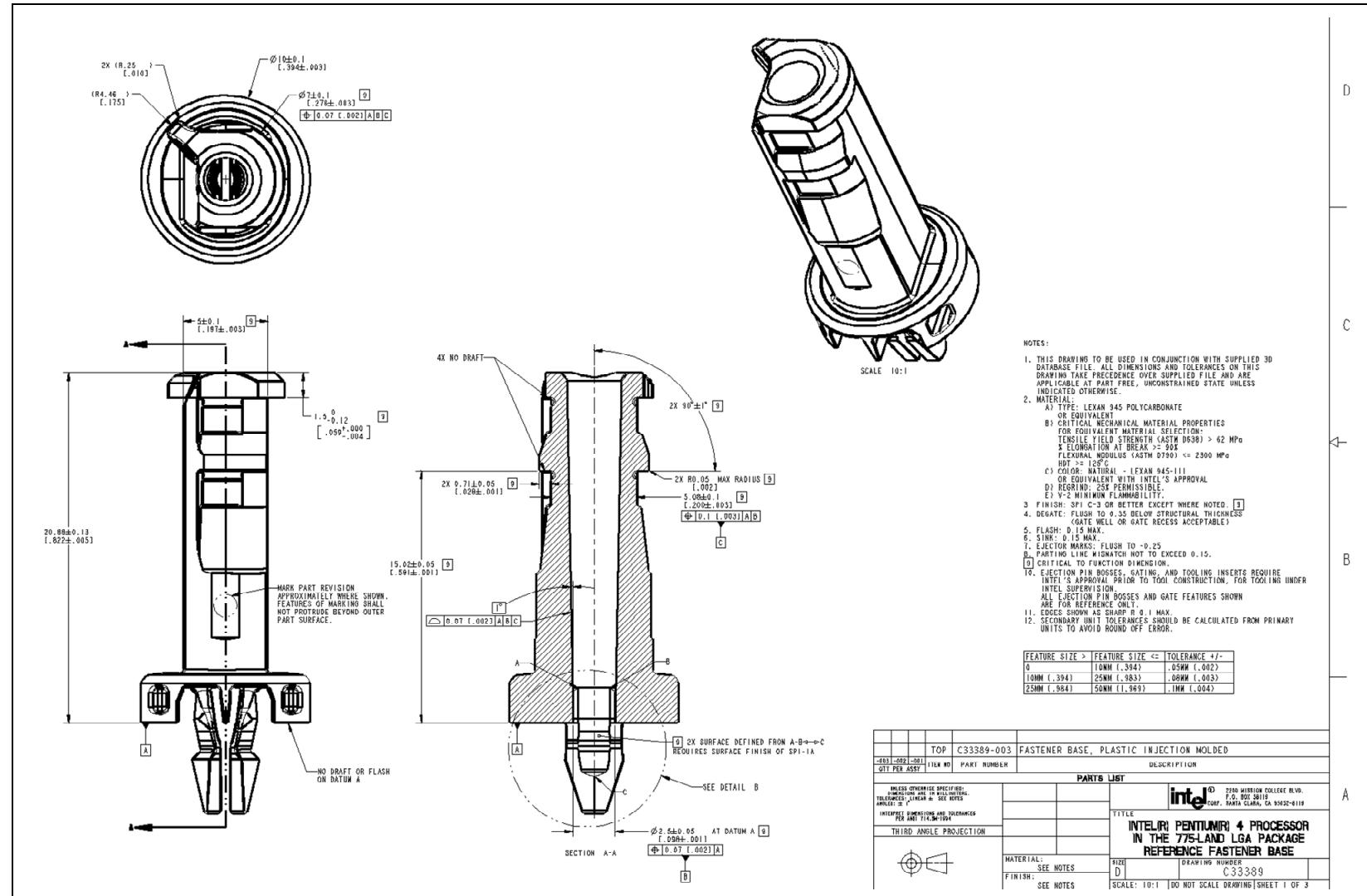


Figure 51. Reference Fastener – Sheet 2

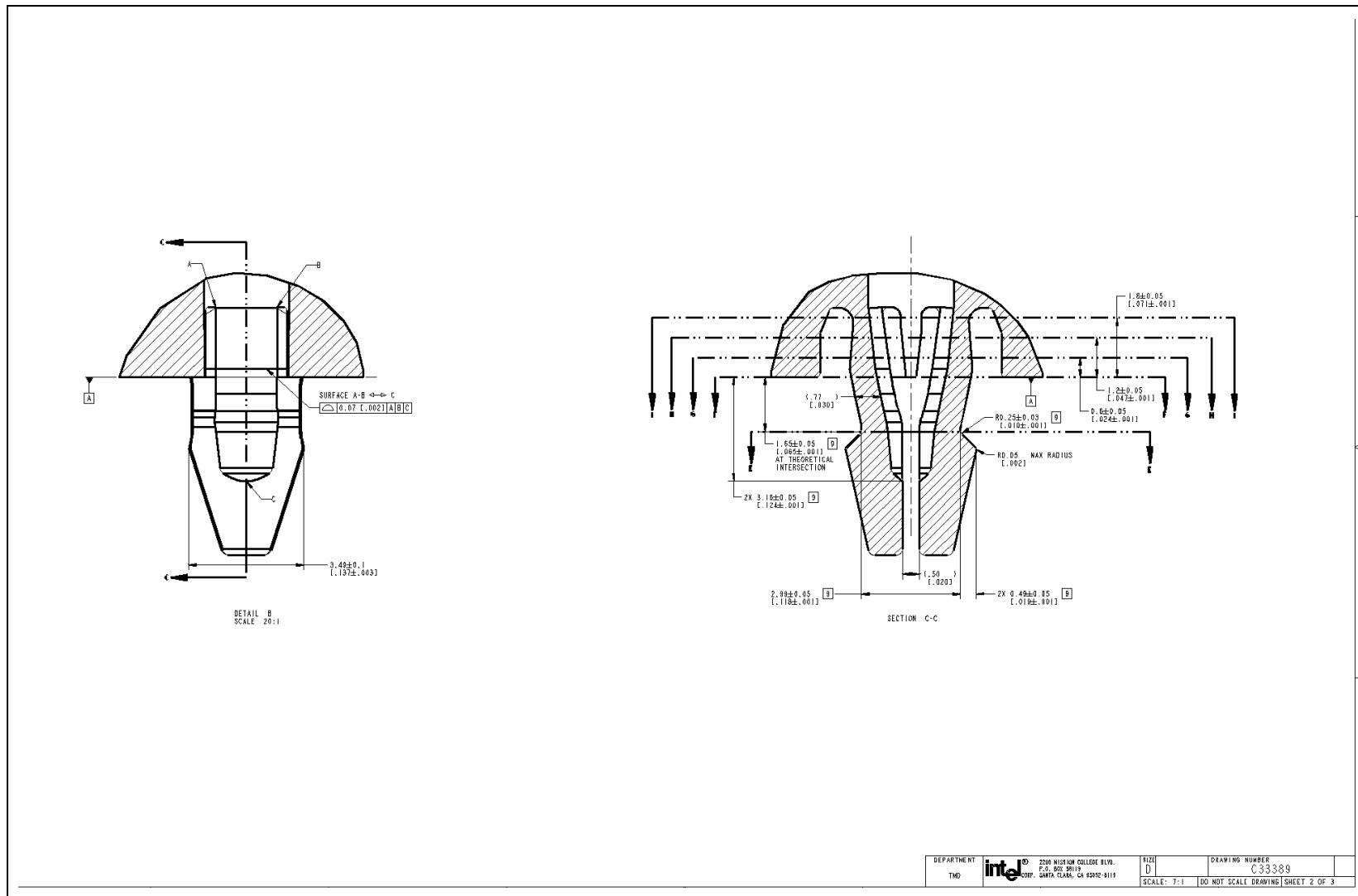




Figure 52. Reference Fastener – Sheet 3

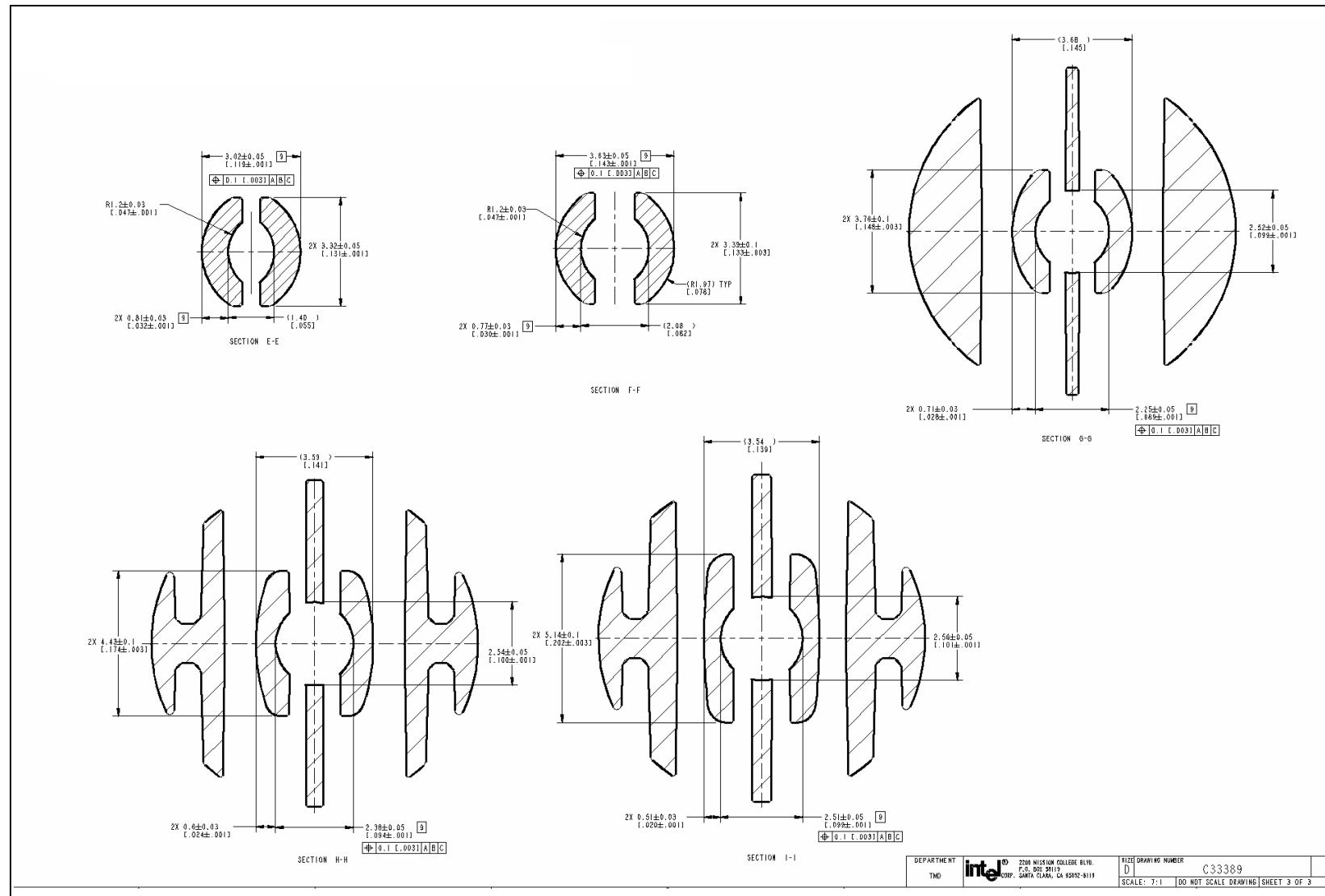


Figure 53. Reference Fastener – Sheet 4

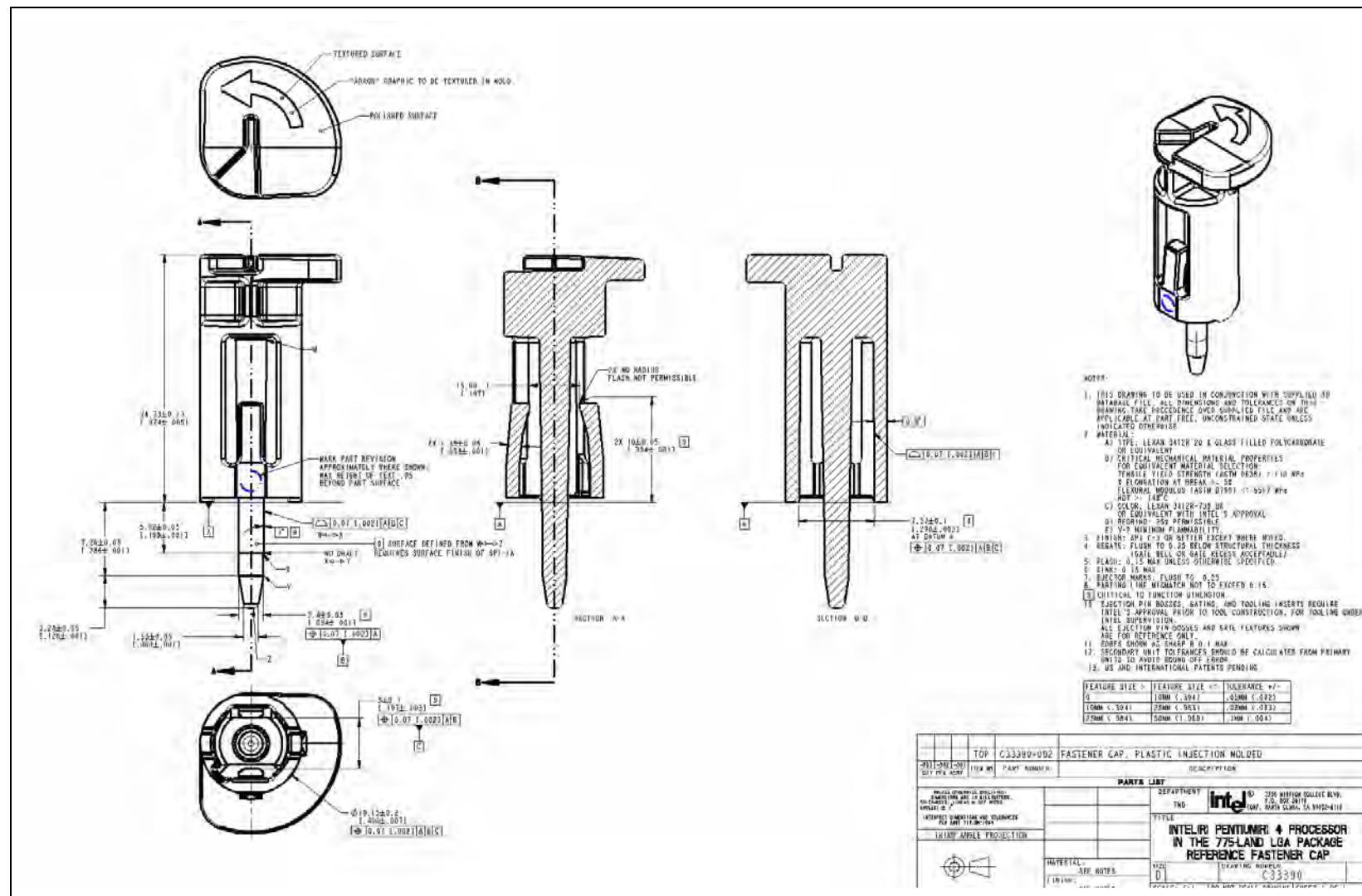




Figure 54. Clip/Heatsink Assembly

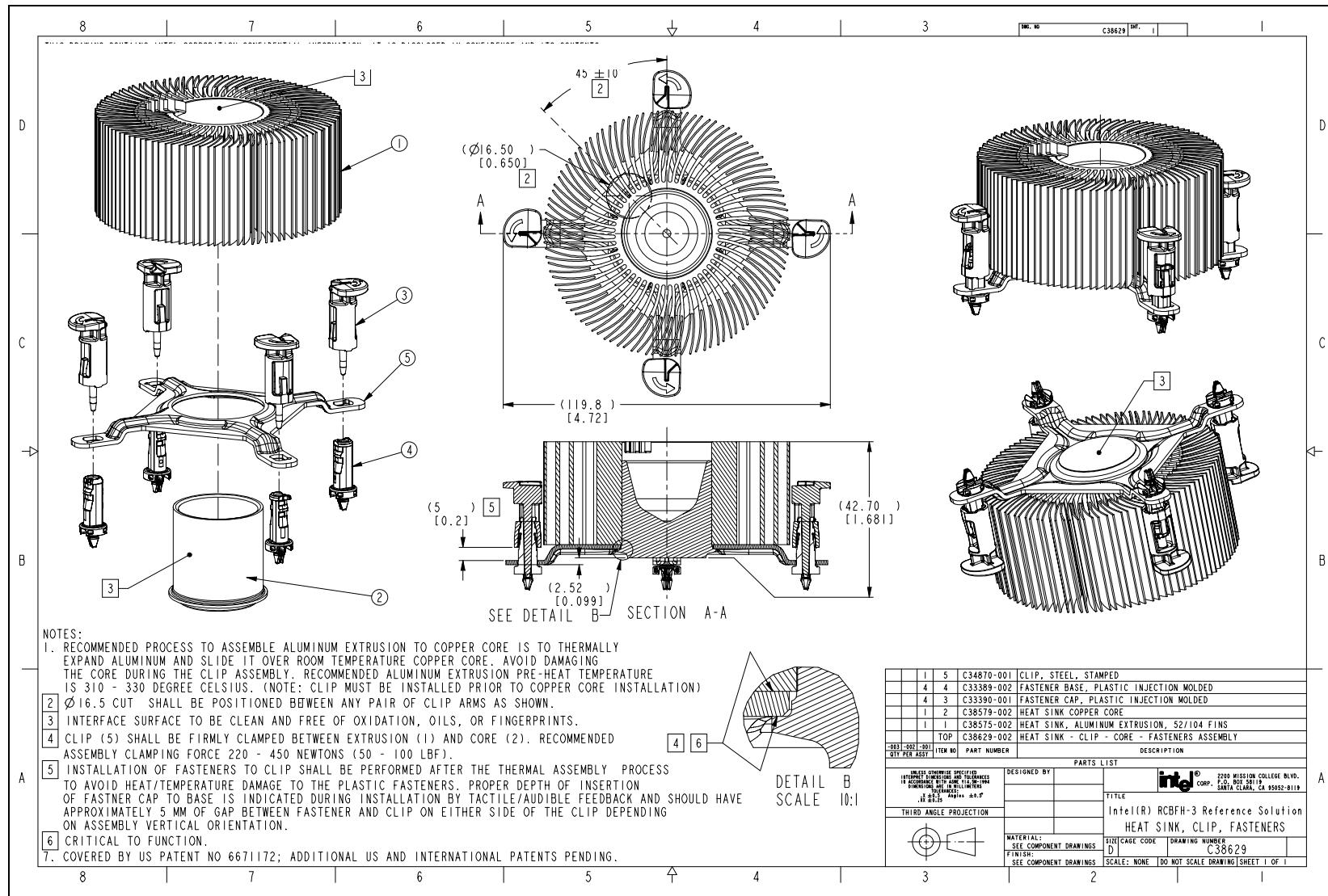
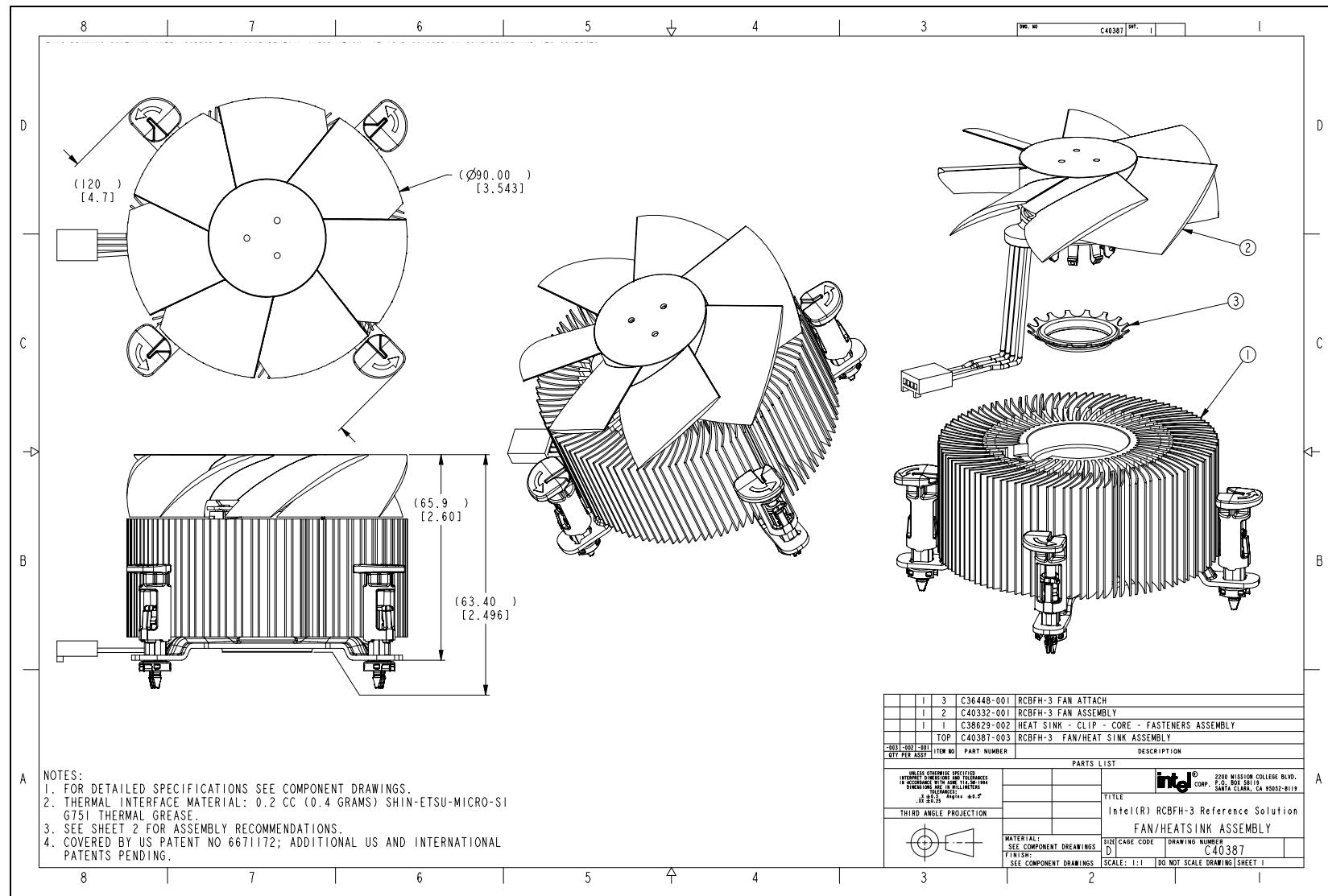


Figure 55. Intel(R) RCBFH-3 Reference Solution Assembly





Appendix H Intel Enabled Reference Solution Information

This appendix includes current supplier information for Intel enabled vendors for the Pentium 4 processor in the 775-land LGA package 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, contact the Intel representative mentioned in Table 10.

Table 10. Intel Representative Contact for Licensing Information

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

Table 11 lists current suppliers that produce Intel enabled reference components. The part numbers listed below identifies these reference components. End-users are responsible for the verification of the Intel enabled component offerings with the supplier. OEMs and System Integrators are responsible for thermal, mechanical, and environmental validation of these solutions.

Table 11. Intel Reference Component Thermal Solution Provider

Supplier	Part Description	Part Number	Contact	Phone	Email
CCI (Chuan-Choung Technology Corp.)	Intel® RCBFH-3 Reference Heatsink	C40387	Harry Lin Monica Chih	714-739-5797 +886-2-29952666 Extension 131	ackinc@aol.com monica_chih@ccic.com.tw
AVC (ASIA Vital Components Co., Ltd)	Intel® RCBFH-3 Reference Heatsink	C40387	David Chao	+886-2-22996930 Extension: 619	david_chao@avc.com.tw
Sunon	RCBFH-3 Fan Assembly	N/A	Tom Blaskovich	714-255-0208 extension 206	tomb@sunon.com
ITW Fastex	RCBFH-3 Fastener	Base: C33389 Cap: C33390	Ron Schmidt	847-299-2222	rschmidt@itwfastex.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. §