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

Thermal Design Guide

July 2005

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Revision History

Date	Revision	Description
July 2005	002	Updated Table 4; updated Figure 8; updated referenced document titles.
September 2004	001	Changes to branding. First public release.

1.0   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 (higher operating speeds, GHz) and packaging density (more transistors). As operating frequencies increase and packaging size decreases, the power density increases while the thermal solution space and airflow typically become more constrained or 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 chassis characteristics, new system and component designs may be required to provide adequate cooling for the processor. The goal of this Thermal Design Guide 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 on 90 nm Process in the 775-Land LGA Package for Embedded Applications. The specifications for this processor (also referred to herein as the Intel Pentium 4 Processor in the 775-Land Package) are delineated in the *Intel® Pentium® 4 Processor 570/571, 560/561, 550/551, 540/541, 530/531 and 520/521 Supporting Hyper-Threading Technology Datasheet (Doc. #302351).*

1.1.3   Document Scope

This document discusses the thermal management techniques for the Intel Pentium 4 Processor in the 775-Land Package.

The processor physical dimensions and thermal specifications used in this document are for illustration only. Refer to the *Intel® Pentium® 4 Processor 570/571, 560/561, 550/551, 540/541, 530/531 and 520/521 Supporting Hyper-Threading Technology Datasheet* for product dimensions, thermal power dissipation and maximum case temperature. In case of conflict, the datasheet supersedes this document.

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1.2 References

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

Table 1. Reference Documents

Document	Comment
Fan Specification for 4 Wire PWM Controlled Fans	http://www.formfactors.org/developer%5Cspecs%5CREV1_2_Public.pdf
Intel® Celeron® D Processors 3xx Sequence Datasheet on 90nm Process in 775-Land Package	Intel document #304092
Intel® Pentium® 4 Processor 570/571, 560/561, 550/551, 540/541, 530/531 and 520/521 Supporting Hyper-Threading Technology Datasheet	Intel document # 302351
Intel® Pentium® 4 Processor on 90 nm Process in the 775-Land LGA Package Thermal Design Guide	Intel document #302553
LGA775 Socket Mechanical Design Guide	Intel document #302666
Performance ATX Desktop System Thermal Design Suggestions	http://www.formfactors.org/
Performance microATX Desktop System Thermal Design Suggestions	http://www.formfactors.org/
Server System Infrastructure Thin Electronics Bay Specifications	http://www.ssiforum.org/

1.3 Terms and Definitions

Table 2. Terms and Definitions (Sheet 1 of 2)

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. Also referred to as T_{LA}
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 $(T_C – T_A)$ / 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 $(T_C – T_S)$ / 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 $(T_S – T_A)$ / Total Package Power. **NOTE:** Heat source must be specified for Ψ measurements.

Table 2. Terms and Definitions (Sheet 2 of 2)

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 Intel 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.
FMB	Flexible Motherboard Guideline: an estimate of the maximum value of a processor specification over certain time periods. System designers should meet the FMB values to ensure their systems are compatible with future processor releases. FMB1 and FMB2 are sequential estimates of processor specifications over time.
Thermal Monitor	A feature on the Intel Pentium 4 Processor in the 775-Land LGA Package that attempts to keep the processor's 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 is very near its operating limits.
T_{DIODE}	Temperature reported from the on-die thermal diode.
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 EMTS 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.
U	A unit of measure used to define server rack spacing height. 1U is equal to 1.75 inches, 2U equals 3.50 inches, etc.

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2.0   Processor Thermal/Mechanical Information

2.1   Mechanical Requirements

2.1.1   Processor Package

The Pentium 4 Processor in the 775-Land LGA Package is packaged in a Flip-Chip Land Grid Array (FC-LGA4) package that interfaces with the motherboard via a LGA775 socket. Please 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 supercede dimensions provided in this document.

Figure 1. Package IHS Load Areas
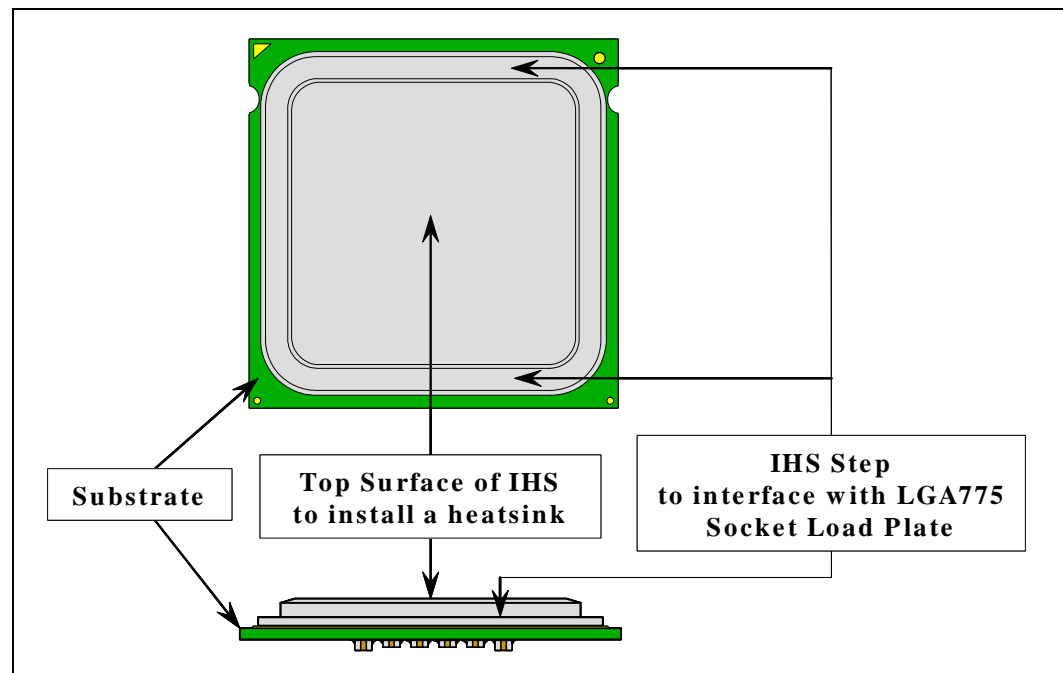
The primary function of the IHS is to transfer the non-uniform heat distribution from the die to the top of the IHS, out of which the heat flux is more uniform and spread over a larger surface area (not the entire IHS area). This allows more efficient heat transfer out of the package to an attached cooling device. The top surface of the IHS is designed to be the interface for contacting a 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. The post-actuated 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 processor datasheet gives details on the IHS geometry and tolerances, and IHS 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 (TIM) 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 not exceed the corresponding specification given in the processor datasheet.

- The heatsink mass can also add additional dynamic compressive load to the package during a mechanical shock event. Amplification factors due to the impact force during shock must be taken into account in dynamic load calculations. The total combination of dynamic and static compressive load should not exceed the processor datasheet compressive dynamic load specification during a vertical shock. For example, with a 0.454 kg [1 lbm] heatsink, an acceleration of 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 TIM 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 processor 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 support the heatsink. In addition to holding the heatsink in place on top of the IHS, this mechanism plays a significant role in the robustness of the system in which it is implemented, in particular:

- Ensuring thermal performance of the 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 weight of the heatsink and the level of shock and vibration that the system must support. The overall structural design of the motherboard and the system have to be considered when designing the heatsink attach mechanism. Their design should provide a means for protecting LGA775 socket solder joints.

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 load on the package between 18 lbf and 70 lbf throughout the life of the product.

This load is required to ensure protect against fatigue failure of socket solder joint for a platform seven year life.

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 processor 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 and Power Dissipation

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 with a 28.7 mm x 28.7 mm [1.13 in x 1.13 in] IHS top surface. Techniques for measuring the case temperature are detailed in Section 3.4.

Figure 2. Processor Case Temperature Measurement Location

Measure T_C at this point
(geometric center of the package)

37.5 mm

37.5 mm
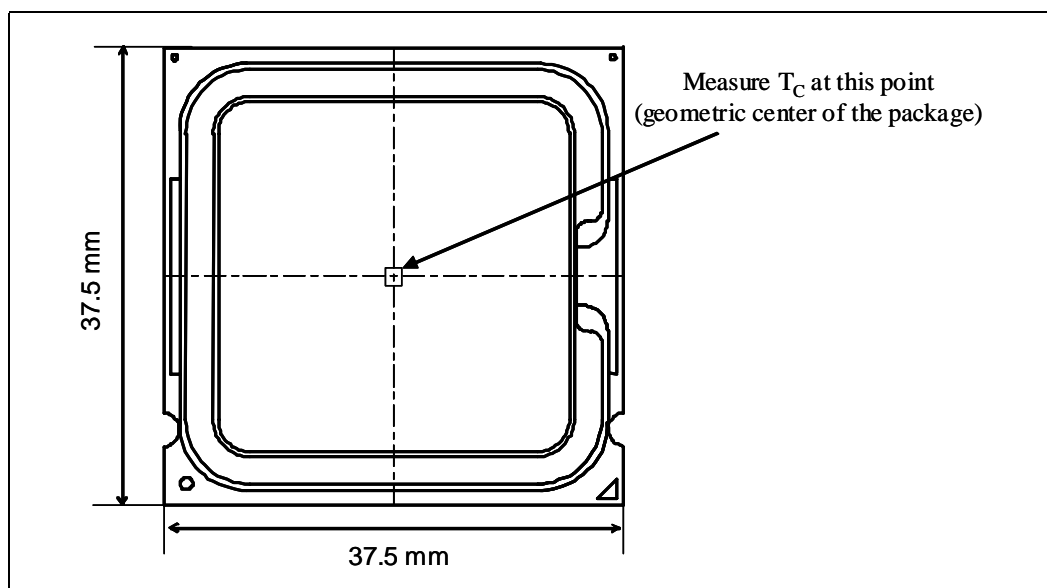
2.2.2 Thermal Profile

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 design. This performance is expressed as the slope on the thermal profile and can be thought of as the Ψ_{CA}. The intercept on the thermal profile assumes a maximum ambient operating condition that is consistent with the available chassis solutions.

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To determine compliance to the thermal profile, a measurement of the actual processor power dissipated is required. The measured power is plotted on the Thermal Profile to determine the maximum case temperature. Using the example in Figure 3, a power dissipation of 70 W has a case temperature of 61 °C. Contact your Intel sales representative for assistance in processor power measurement.

For the Intel 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
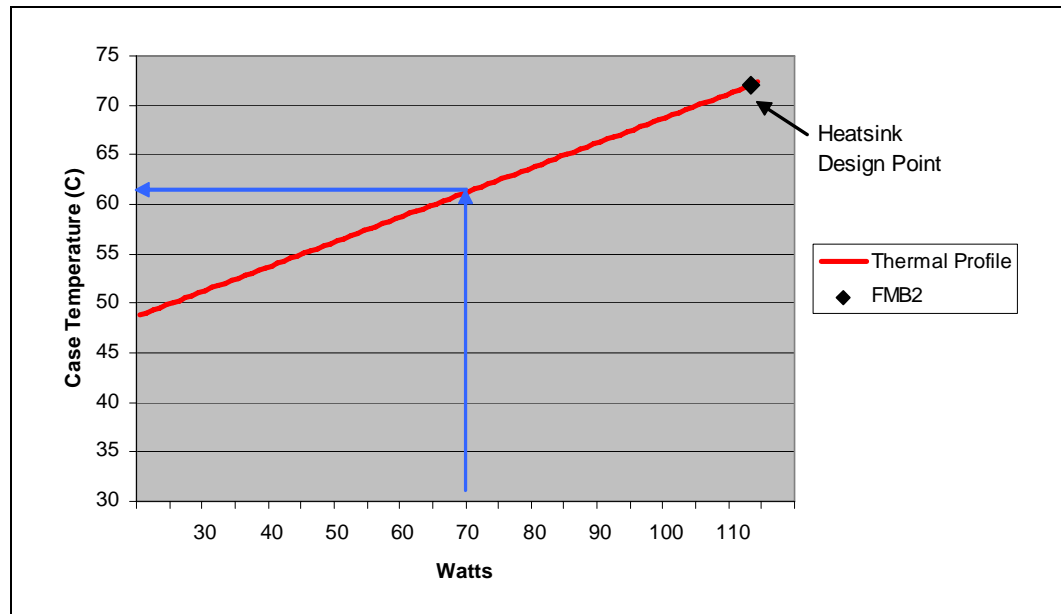
2.2.3 $T_{CONTROL}$

$T_{CONTROL}$ 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 the T_C is not specified. This parameter allows the system integrator a method to reduce the acoustic noise of the processor cooling solution, while maintaining compliance to the processor thermal specification.

The value of $T_{CONTROL}$ is driven by a number of factors. One of the most significant of these is the processor 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 leakage of some parts is offset by a higher value of $T_{CONTROL}$ in such a way that they will behave virtually the same acoustically

This is achieved in part by using the Ψ_{CA} vs. RPM and RPM vs. Acoustics (dBA) performance curves from the Intel enabled thermal solution. A thermal solution designed to meet the thermal profile should perform virtually the same for any value of $T_{CONTROL}$. See Section 4.3, "Acoustic Fan Speed Control" on page 29, for details on implementing a design using Tcontrol and the Thermal Profile.

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 $T_{CONTROL}$.

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 increases 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.

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2.3.1 Heatsink Size

The size of the heatsink is dictated by height restrictions for installation in a system and by the 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.

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 F 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/.

For the 1U and 2U server form factor, it is recommended to use:

- The 1U and 2U motherboard keep-out footprint definition and height restrictions for enabling components, defined for the platforms designed with the LGA775 socket in Appendix E of this design guide. Note that this keep-out footprint is similar to the ATX motherboard keep-out, with minor differences in the areas surrounding the processor package.
- The 1U and 2U primary side constraints defined in the Thin Electronics Bay specification found at http://www.ssiforum.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 weight. 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, "Mechanical Requirements" on page 9, the heatsink weight 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 weight, 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 weight for the Pentium 4 processor in the 775-land LGA package is 450g for the ATX form factor. This weight includes the fan and the heatsink only. The attach mechanism (clip, fasteners, etc.) is not included.

The weight of the heatsinks for server form factors tends to be heavier than desktop form factors and therefore there isn't a recommended maximum weight. These solutions are sometimes fastened to the motherboard with the use of a backplate on the secondary side or in some cases are directly mounted to the server chassis. In all cases, system integrators must ensure that the load specifications for the package are met during shock and vibration testing.

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 cover over it. This cover must be removed prior to heatsink installation.

2.3.5   Summary

In summary, considerations in heatsink design include:

- The local ambient temperature T_A at the heatsink, the power being dissipated by the processor, and the corresponding maximum T_C. These parameters are usually combined in a cooling performance parameter, Ψ_{CA} (case to air thermal characterization parameter). More information on the definition and the use of Ψ_{CA} is given in Section 2.4 below.
- 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, "Heatsink Clip Load Requirement" on page 11 for further information).
- Surface area of the heatsink.
- Heatsink material and technology.
- Volumetric airflow rate over the heatsink surface area.
- Development of airflow entering and within the heatsink area.
- Physical volumetric constraints placed by the system.

2.4   System Thermal Solution Considerations

2.4.1   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. For more information on 1U and 2U server refer to the Thin Electronics Bay Specifications at http://www.ssiforum.org.

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

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

To ease the burden on thermal solutions, the Thermal Monitor feature and associated logic have been integrated into the silicon of the Pentium 4 Processor 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 in rare excursions of workload above TDP. Implementation options and recommendations are described in Section 4.0, "Thermal Management Logic and Thermal Monitor" on page 23 and Section 4.2.2, "Thermal Control Circuit" on page 24.

3.0 *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 (heat source, local ambient conditions). The thermal characterization parameter is calculated using total package power. Note that 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:

Equation 1.

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

Where:

Ψ_{CA} = Case-to-local ambient thermal characterization parameter (°C/W)

T_C = Processor case temperature (°C)

T_A = Local ambient temperature in chassis at processor (°C)

P_D = Processor total power dissipation (W) (assumes all power dissipates through the IHS)

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

Equation 2.

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

Where:

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

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

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

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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
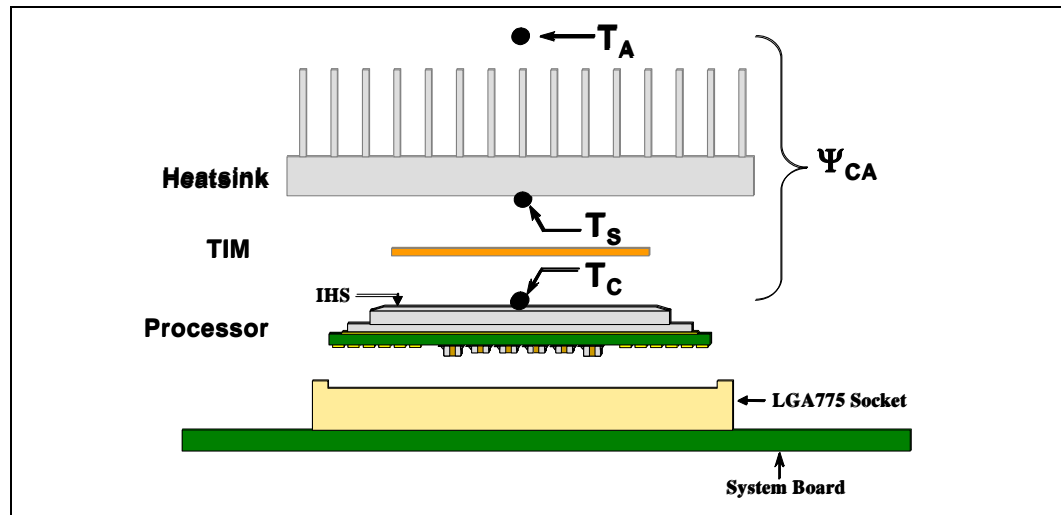
3.1.1 Example

The cooling performance, $\Psi_{CA,}$ is defined using the thermal characterization parameter described in the previous section:

- 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 datasheet TDP is 100 W and the maximum case temperature from the thermal profile for 100W 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:

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

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 Ψ_{CS} 0.10 °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 well-characterized thermal tool, whereas real processors can introduce additional factors that can impact test results. In particular, the power level from actual processors varies significantly, even when running the maximum power application provided by Intel, 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 with the TTV, 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 (or T_{LA}) is the temperature of the ambient air surrounding the processor. For a passive heatsink, T_A is defined as the heatsink approach air temperature; for an actively cooled heatsink, it is the temperature of inlet air to the active cooling fan.

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

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

3.3.1 Measuring 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 3mm 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.

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- 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.

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, disable the fan regulation and power the fan directly, based on guidance from the fan supplier.

Figure 5. Measuring T_{LA}— Active Heatsink
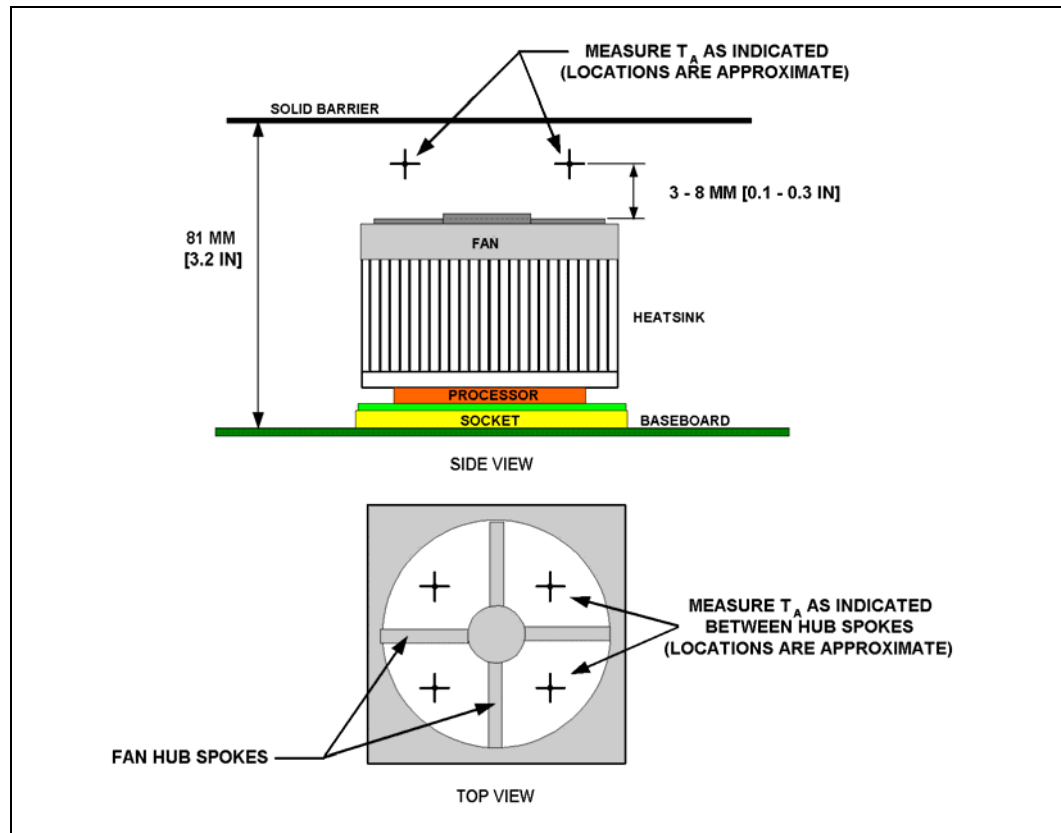
NOTE: Dimensions in drawing not to scale.

3.3.2 Measuring Passive Heatsinks

- Thermocouples should be placed approximately 13 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. The dimension above the baseboard will vary depending on the maximum height in the intended form factor. This placement guideline is meant to minimize the effect of localized hot spots from baseboard components.

Figure 6. Measuring T$_{LA}$— Passive Heatsink
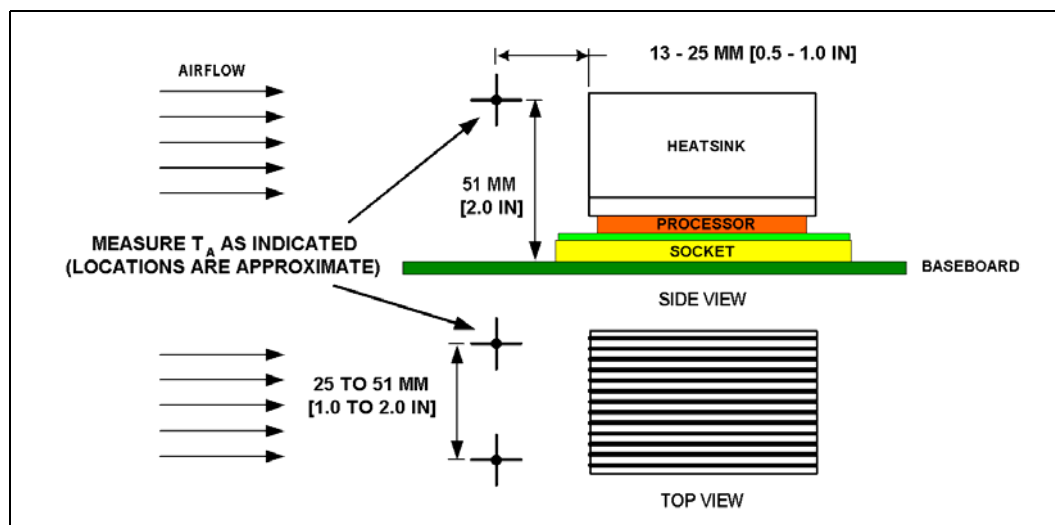
NOTE: Dimensions in drawing not to scale.

3.4 Processor Case Temperature Measurement Guidelines

To ensure functionality and reliability, 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 processor 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, 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 an FC-LGA4 processor package for T$_C$ measurement. This procedure takes into account the specific features of the FC-LGA4 package and of the LGA775 socket for which it is intended.

4.0 Thermal Management Logic and Thermal Monitor

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. The Thermal Monitor includes:

- A bi-directional signal (PROCHOT#) that indicates if the processor has reached its maximum temperature or can be asserted externally to activate the Thermal Control Circuit (TCC).

- A TCC that will attempt to reduce processor temperature by rapidly reducing power consumption when the on-die temperature sensor indicates that it has reached the maximum operating point.

- Registers to determine the processor thermal status.

4.2.1 PROCHOT# Signal

The Intel Pentium 4 processor in the 775-Land LGA Package implements a bi-directional PROCHOT# capability to allow system designs to protect various components from over-temperature situations. The PROCHOT# signal is bi-directional in that it can either signal

when the processor has reached its maximum operating temperature *or* be driven from an external source to activate the TCC. The ability to activate the TCC via PROCHOT# can provide a means for thermal protection of system components.

One application is the thermal protection of voltage regulators (VR). System designers can create a circuit to monitor the VR temperature and activate the TCC when the temperature limit of the VR is reached. By asserting PROCHOT# (pulled-low), 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# 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 deasserted. Assertion of the PROCHOT# signal is independent of any register settings within the processor. It is asserted any time the processor die temperature reaches the trip point. The point where the TCC activates is set to the same temperature at which PROCHOT# asserts.

4.2.2   Thermal Control Circuit

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

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

Figure 7. Concept for Clocks under Thermal Monitor Control
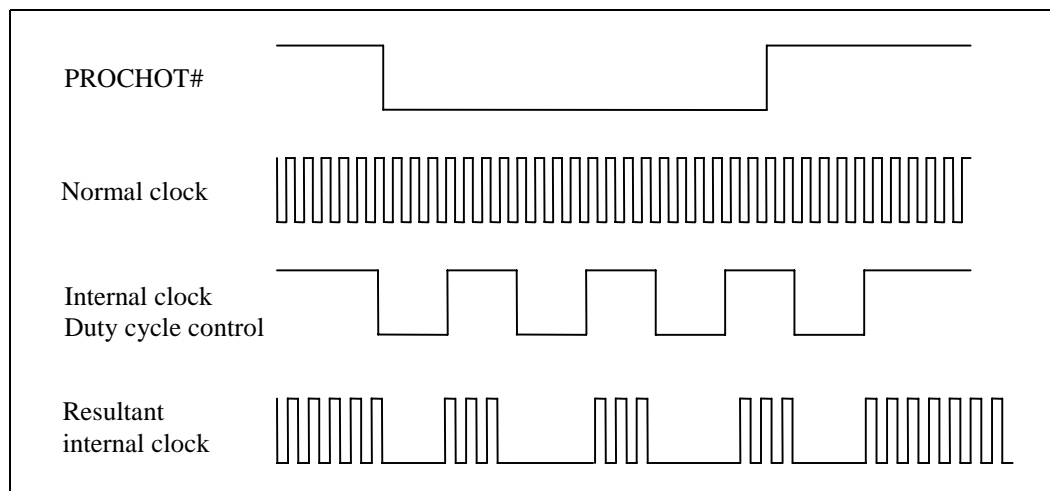
4.2.3 Operation and Configuration

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.

Note: 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 within a few hundred clock cycles after the thermal sensor detects a high temperature, i.e. PROCHOT# assertion. The Thermal Control Circuit and PROCHOT# transition to inactive once the temperature has been reduced below the thermal trip point, although a small time-based hysteresis has been included to prevent multiple PROCHOT# transitions around the trip point. External hardware can monitor PROCHOT# and generate an interrupt 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 ~3 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 µs, and a duty cycle of 1/4 (25%) is selected, the clock-on time would be reduced to approximately 1 µs [on time (1 µs) ÷ total cycle time (3 + 1) µs = 1/4 duty cycle]. Similarly, for a duty cycle of 7/8 (87.5%), the clock on time would be extended to 21 µs [21 ÷ (21 + 3) = 7/8 duty cycle].

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

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

A system designed to meet the thermal profile at TDP and T_{C-MAX} values published in the processor datasheet or 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 .

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 Thermal Monitor 2) 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 planning to use the thermal diode for system or component level fan control to optimize acoustics need to refer to Section 4.3, "Acoustic Fan Speed Control" on page 29.

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 3.   Thermal Diode Interface

Pin Name	Pin Number	Pin Description
THERMDA	B3	Diode anode
THERMDC	C4	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, which are characteristics of the processor on-die thermal diode. The processor datasheet provides specifications 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. 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 on the accuracy of the reported on-die diode temperature. Component vendors offer components that have stated accuracy of ± 3 °C to ± 1 °C. The improved accuracy generally comes from the number of times a current is passed through the diode and the ratio 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:

Equation 3.

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

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).

Equation 4.

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 factor of the on-die thermal diode, N_{TRIM} = the assumed ideality used by the thermal sensor. For the range of temperature where the thermal diode is being measured, 30 - 80° 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 processor pins but does not include 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 Equation 5:

Equation 5.

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

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 processor 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

The PROCHOT# signal may be useful as an indication of cooling system failure. Messages could be sent to the system administrator to warn of the cooling failure, while the thermal control circuit would allow the system to continue functioning or allow a graceful system shutdown. If no thermal management action is taken, the silicon temperature may exceed 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.

4.2.9 How On-Die Thermal Diode, $T_{CONTROL}$ and Thermal Profile Work Together

The Pentium 4 Processor in the 775-land LGA package thermal specification is comprised of two parameters, $T_{CONTROL}$ and Thermal Profile. The first step is to ensure the thermal solution by design meets the thermal profile. If the system design will incorporate variable speed fan control Intel recommends monitoring the on-die thermal diode to implement acoustic fan speed control. The value of on-die thermal diode temperature determines which specification must be met.

4.2.9.1 On-Die Thermal Diode Less than $T_{CONTROL}$

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

4.2.9.2 On-Die Thermal Diode Greater than $T_{CONTROL}$

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

4.3 Acoustic Fan Speed Control

For information on acoustic fan speed control see the *Intel® Pentium® 4 Processor on 90 nm Process in the 775-Land LGA Package Thermal Design Guidelines*.

5.0   Intel Enabled Thermal Solutions

5.1   Thermal Solution Requirements

The thermal performance required for the heatsink is determined by calculating the case-to-ambient thermal characterization parameter, Ψ_{CA}, as explained in Section 3.0, "Thermal Metrology" on page 18. This is a basic thermal engineering parameter that may be used to evaluate and compare different thermal solutions in similar boundary conditions. For the Pentium 4, an example of how Ψ_{CA} is calculated is shown in Equation 6.

Equation 6. Case-to-Ambient Thermal Characterization Parameter

$$\Psi_{CA} = \frac{T_{C\max}(^{\circ}C) - T_{LA}(^{\circ}C)}{TDP(W)} = \frac{72.8^{\circ}C - 38^{\circ}C}{115W} = 0.303\frac{^{\circ}C}{W}$$

In this calculation, $T_{C\,max}$ and TDP are taken from the thermal profile specification in the processor datasheet.

Note: In this calculation, the $T_{C\,max}$ and TDP are constant, while Ψ_{CA} will vary according to the local ambient temperature (T_{LA}).

Table 4 shows an example of required thermal characterization parameters for the thermal solution at various T_{LA}s. This table uses the $T_{C\,max}$ and TDP from the processor datasheet. These numbers are subject to change, and in case of conflict, the specifications in the processor datasheet supersede the $T_{C\,max}$ and TDP specifications in this document.

Table 4.   Thermal Characterization Parameter at various T_{LA}s

Intel® Pentium® 4 Processor 551			Required Ψ_{CA} (°C/W) of Thermal Solution at T_{LA} = (°C)			
Frequency	TDP	$T_{C\,MAX}$	44	40	35	30
3.40 GHz	84 W	67.7 °C	0.280	0.330	0.389	0.449

Figure 8 further illustrates the required thermal characterization parameter for the Pentium 4 Processor in the 775-land LGA package at various operating ambient temperatures. The thermal solution design must have a Ψ_{CA} less than the values shown for the given local ambient temperature.

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Figure 8. Thermal Characterization Parameters for Various Operating Conditions
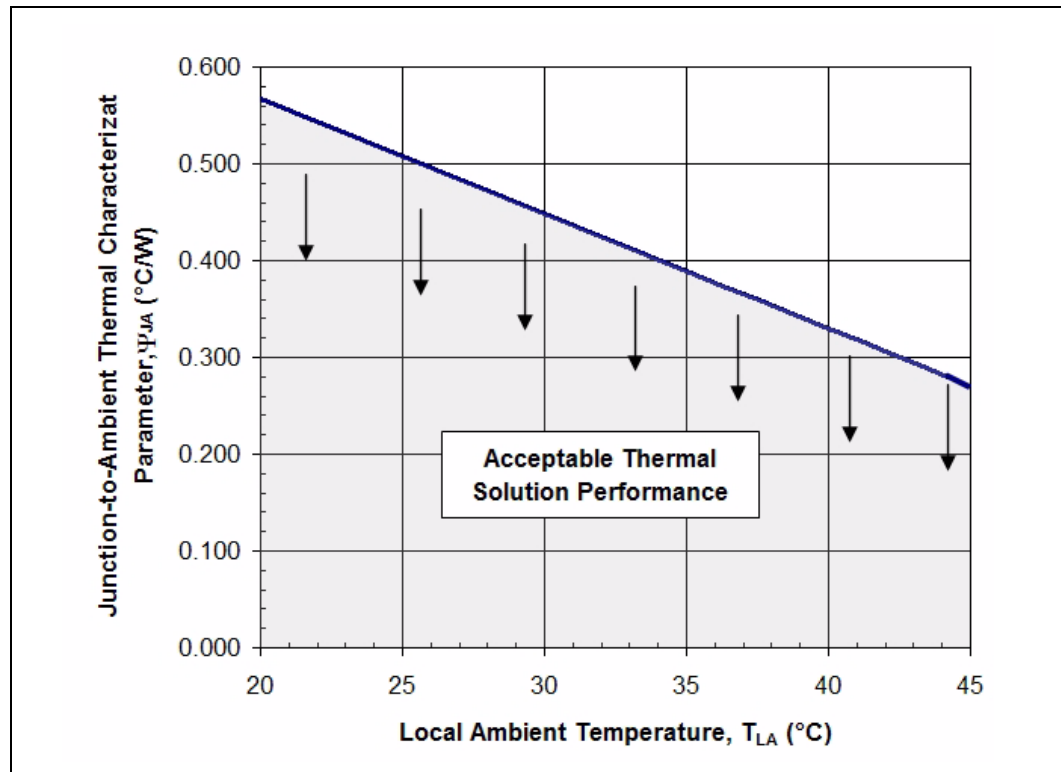
5.2   ATX Form Factor

Intel is enabling the following active thermal solutions for the Pentium 4 Processor in the 775-land LGA package for Embedded Applications in the ATX, similar, or larger form factors.

Table 5.   Enabled Thermal Solutions

Heatsink Manufacturer	Intel Part Number
Sanyo-Denki*	C25697-001
Nidec*	C25704-002

These solutions have been tested in environments with a T_{LA} up to 38° C. However, system-level thermal solution verification should be performed in the final intended use.

5.3   1U Form Factor

Thermal solution design for the 1U form factor is challenging. Due to limited volume for the heatsink, mainly in the direction of heatsink height, and the available amount of airflow, system designers may have to make trade-offs in the system boundary condition requirements (i.e.,

maximum T_{LA}, acoustic requirements, etc.) to meet the processor's thermal requirements. The entire thermal solution, from heatsink design, chassis configuration, and airflow source, must be optimized for server systems to obtain the best performing solution.

Intel has worked with a third-party vendor to enable a heatsink design for the Pentium 4 Processor in the 775-land LGA package for the 1U form factor. This design was optimized for the 1U form factor within the available volume for the thermal solution. The motherboard component keep-ins are shown in Figure 37, "1U/2U Motherboard Component Keep-In Definition, Primary Side" on page 62 and Figure 38, "1U/2U Motherboard Component Keep-In Definition, Secondary Side" on page 63.

This solution requires 100 percent of the airflow to be ducted through the heatsink fins to prevent heatsink bypass. A copper base and copper fin heatsink are attached to the motherboard with the use of a backplate. This solution is shown in Figure 9.

Figure 9. 1U Copper Heatsink
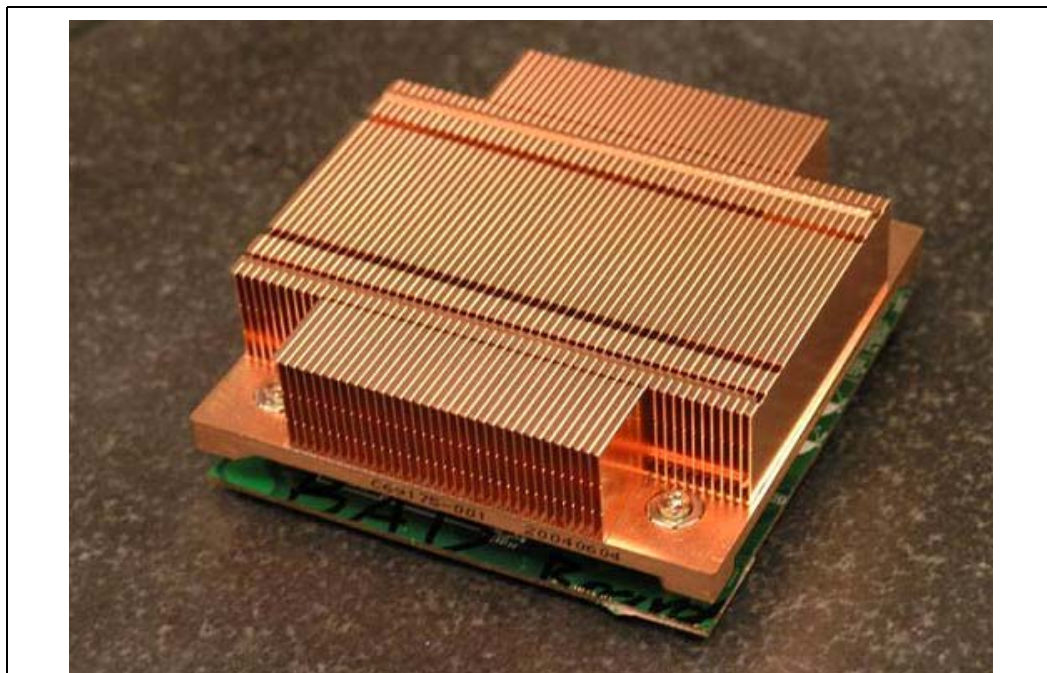
Based on preliminary testing, this heatsink has shown to have a performance (Ψ_{CA}) of 0.325 °C/W with 18 CFM of airflow. This will allow a maximum T_{LA} of 35 °C and meet the processors Thermal Profile specification as described in the processor datasheet. This heatsink solution uses the Honeywell* PCM45F as the Thermal Interface Material (TIM). The performance of the heatsink could improve with more airflow, however the final intended thermal solution including, heatsink, airflow source, TIM, and attach mechanism must be validated by system integrators.

Developers of thermal solutions for the Intel Pentium 4 Processor in the 775-Land LGA Package must ensure that the solution meets the processor thermal specifications as stated in the processor datasheet and follow the recommended motherboard component keep-out as shown in Figure 37 and Figure 38. This keep-out will ensure that the processor thermal solution will not interfere with the voltage regulator components. In addition to this, a thermal solution design must meet the maximum component heights as specified by the 1U *Thin Electronics Bay Specifications* located at http://www.ssiforum.org. Figure 10 illustrates the z-height constraints of the 1U form factor as outlined in the specification.

Figure 10. 1U Thermal Solution Z-Height Constraints
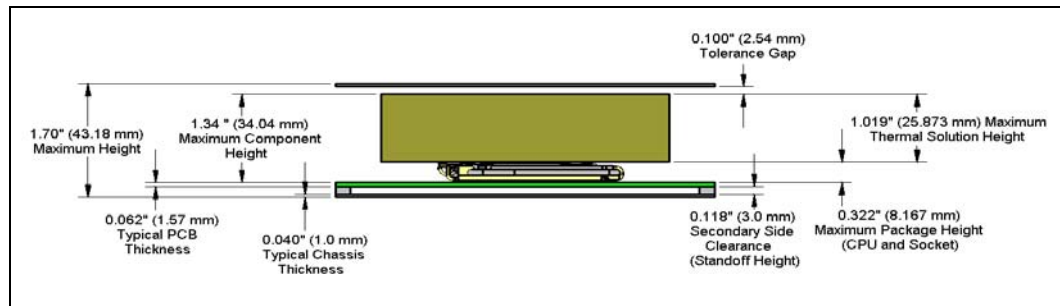
5.4   2U Form Factor

Intel has developed a reference thermal solution design for the Pentium 4 processor in the 775-land LGA package for the 2U form factor. This design was optimized for the 2U form factor within the available volume for the thermal solution. The motherboard component keep-outs can be seen in Figure 37, "1U/2U Motherboard Component Keep-In Definition, Primary Side" on page 62 and Figure 38, "1U/2U Motherboard Component Keep-In Definition, Secondary Side" on page 63.

This solution requires 100% of the airflow to be ducted through the heatsink fins in order to prevent heatsink bypass. It is a copper base and copper fin heatsink that is attached to the motherboard with the use of a backplate. This solution is shown in Figure 11.

Figure 11. 2U Copper Heatsink
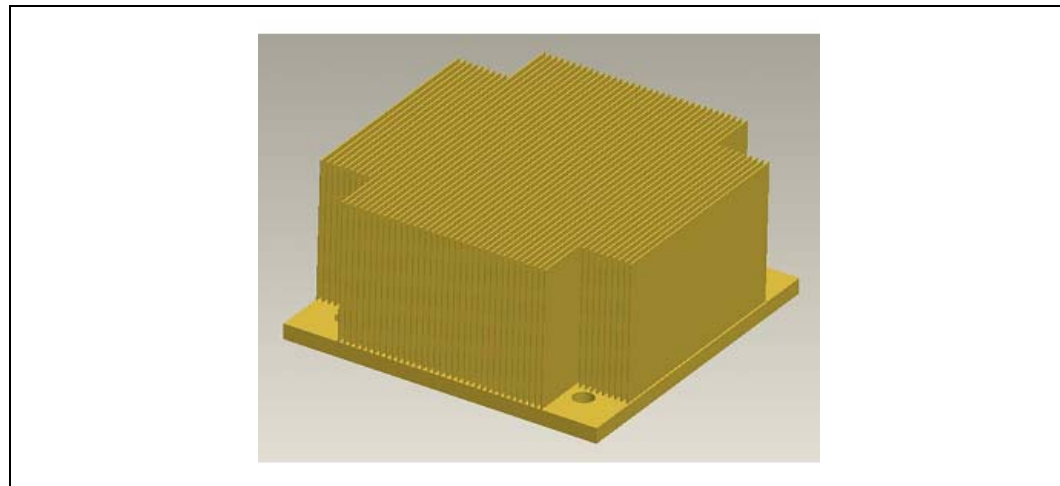
The performance of this thermal solution at multiple airflow rates is shown in Figure 12. The performance test data shown in the chart was collected to ensure that the thermal solution is performing within expectations. This data implies no statistical significance. The final intended thermal solution including, heatsink, airflow source, TIM, and attach mechanism must be validated by system integrators. This heatsink solution uses the Shin-Etsu* G751 as the TIM.

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Figure 12. Case-to-Ambient Thermal Characterization Parameter Ψ_{CA} (°C/W)
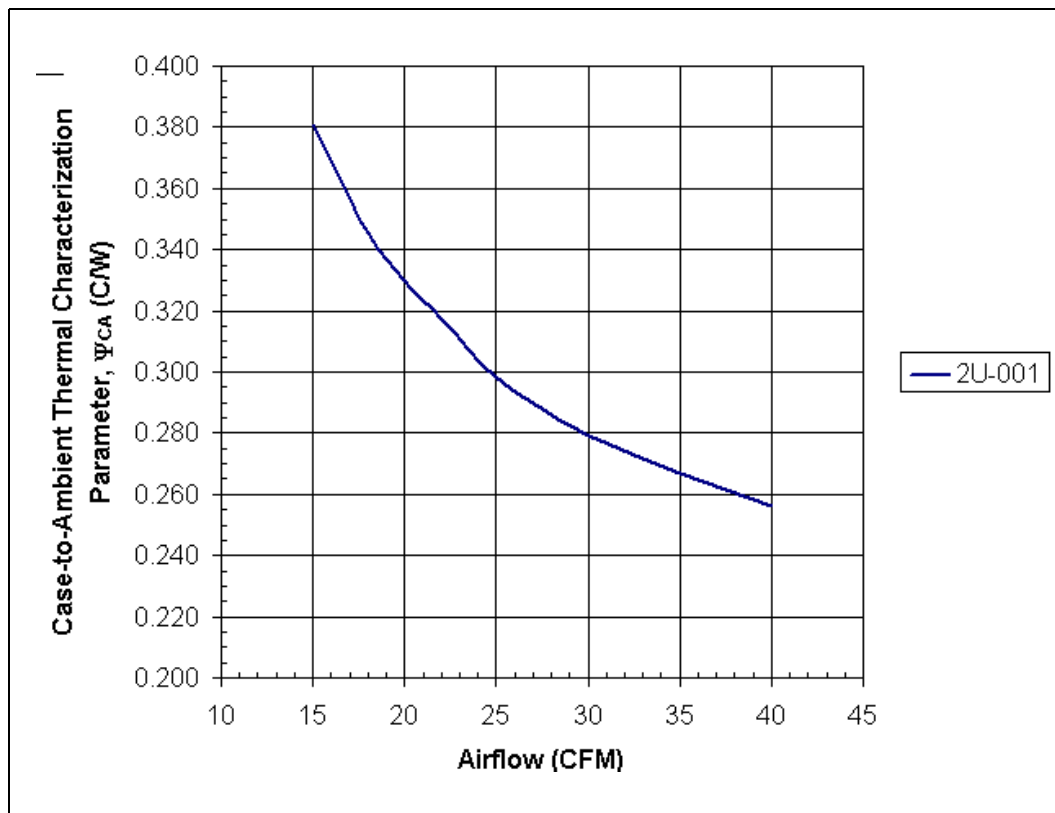
Developers of thermal solutions for the Pentium 4 processor in the 775-land LGA package must ensure that the solution meets the processor thermal specifications as stated in the processor datasheet and follow the recommended motherboard component keep-out as shown in Figure 37 and Figure 38. This keep-out will ensure that the processor thermal solution will not interfere with the voltage regulator components. In addition to this, a thermal solution design must meet the maximum component heights as specified by the 2U *Thin Electronics Bay Specifications* located at http://www.ssiforum.org. Figure 13 illustrates the Z-height constraints of the 2U form factor as outlined in the specification.
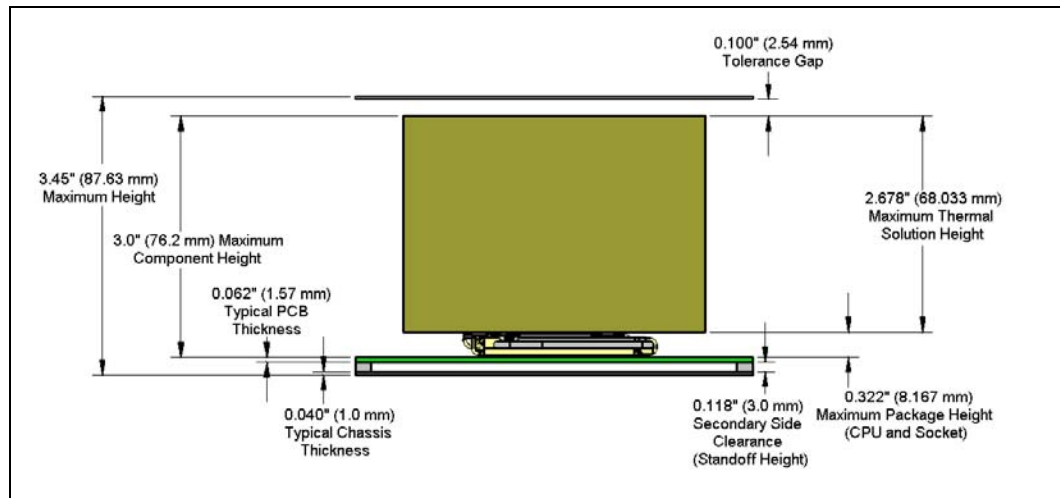
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5.5 Reference Thermal Mechanical Solution

For information regarding the Intel Thermal/Mechanical Reference Design thermal solution and design criteria for the ATX form factor, refer to the *Intel Pentium 4 Processor on 90nm Process in the 775-Land LGA Package Thermal Design Guidelines*.

6.0 Conclusion

As the complexities of today's microprocessors increase, power dissipation requirements become more exacting. Care must be taken to ensure that the additional power is properly dissipated. Heat can be dissipated using passive heatsinks, fans and/or active cooling devices. Incorporating ducted airflow solutions into the system thermal design can yield additional margin.

The Intel Pentium 4 Processor in the 775-Land LGA Package integrates thermal management logic onto the processor silicon. The Thermal Monitor feature attempts to control the processor temperature in the event of a thermal excursion beyond the processor heatsink capability. If the die temperature reaches the factory-calibrated temperature, the Thermal Monitor will take steps to reduce power consumption, causing the processor to cool down. Thermal Monitor cannot compensate for a thermal solution that does not meet the thermal profile and TDP. The use of the on-die thermal diode in an active fan speed control solution can provide acoustic benefits and maintain the processor thermal specification. Various registers and bus signals are available to monitor and control the processor thermal status.

A thermal solution designed to the thermal profile at the thermal design power (TDP), as specified in the processor datasheet, can adequately cool the processor to a level where activation of the Thermal Monitor feature is either very rare or non-existent. Automatic thermal management must be used as part of the total system thermal solution.

The size and type of the heatsink, as well as the output of the fan can be varied to balance size, cost, and space constraints with acoustic noise. This document has presented the conditions and requirements for designing a heatsink solution for a system based on a Pentium 4 processor in the 775-land LGA package. Properly designed solutions provide adequate cooling to maintain the processor thermal specification. This is accomplished by providing a low local ambient temperature and creating a minimal thermal resistance to that local ambient temperature. Fan heatsinks or passive heatsinks with ducted airflow can be used to cool the processor if proper package temperatures cannot be maintained otherwise. By maintaining the processor case temperature at the values specified in the processor datasheet, a system designer can be confident of proper functionality and reliability of these processors.

Appendix A LGA775 Socket Heatsink Loading

A.1   LGA775 Socket Heatsink Considerations

The heatsink clip load is traditionally used for:

- Mechanical performance in shock and vibration.
    - Refer to the *Intel Pentium 4 Processor on 90nm Process in the 775-Land LGA Package Thermal Design Guide* for information on the structural design strategy for the Intel RCBFH-3 Reference Design heatsink.

- 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, the 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 these requirements: Mechanical shock and vibration and TIM performance and LGA775 socket protection against fatigue failure.

A.2   Metric for Heatsink Preload for 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:

- Heatsink mounting hole span

- Heatsink clip/fastener assembly stiffness and creep

- Board stiffness and creep

- Board stiffness 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 diagonally. 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 the LGA775 socket solder joint protection against fatigue failure can be 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   Board Deflection Metric Definition

Board deflection is measured along either diagonal (refer to Figure 14):

$d = dmax - (d1 + d2)/2$

$d' = dmax - (d'1 + d'2)/2$

Configurations in which the deflection is measured are defined in Table 6.

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 6.   Board Deflection Configuration Definitions

Configuration Parameter	Processor + Socket load plate	Heatsink	Parameter Name
d_ref	Yes	No	Beginning of Life (BOL) deflection, no preload
d_BOL	Yes	Yes	BOL deflection with preload
d_EOL	Yes	Yes	End of Life (EOL) deflection

Figure 14. Board Deflection Definition

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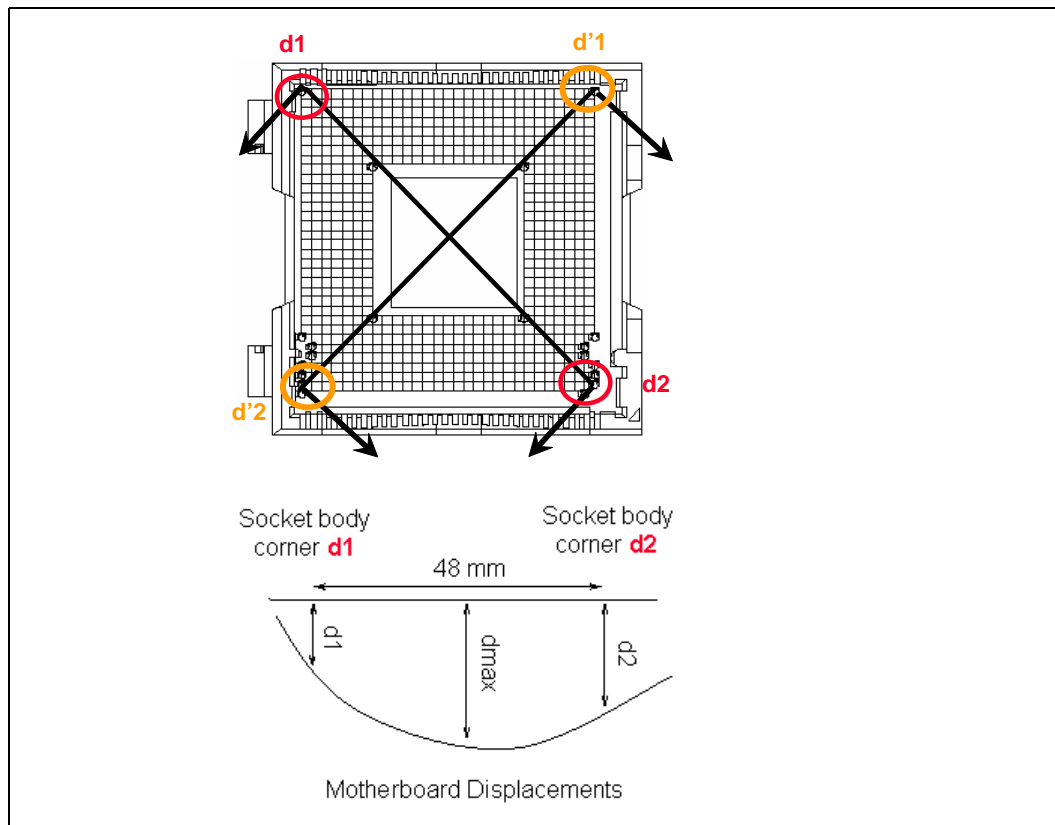
A.2.3　Board Deflection Limits

Deflection limits for the ATX/μATX form factor are:

$$d\_BOL - d\_ref = 0.09 \text{ mm and } d\_EOL - d\_ref = 0.15 \text{ mm}$$

and

$$d'\_BOL - d'\_ref = 0.09 \text{ mm and } d\_EOL' - d\_ref' = 0.15 \text{ mm}$$

Note:　The heatsink preload must remain within the static load limits defined in the processor datasheet at all times.

Note:　Board deflection should not exceed board manufacturer specifications.

A.2.4　Board Deflection Metric Implementation Example

This section is for illustration 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 board vendor.
- Clip stiffness assumed constant – No creep.

Using Figure 15, the heatsink preload at BOL is defined to comply with $d\_EOL - d\_ref = 0.15$ mm, depending on clip stiffness assumption.

Note:　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 board. It assumes no creep to occur in the clip. However, a small amount of creep is accounted for in the plastic fasteners. This situation is somewhat similar to the Intel Reference Design.

The impact of the creep on 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 board 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.

Note: Board and clip creep modify board deflection over time and depend on board stiffness, clip stiffness, and selected materials.

Note: Designers must define the BOL board deflection that will lead to the correct EOL board deflection.

Figure 15. Example: Defining Heatsink Preload Meeting Board Deflection Limit

Kclip (lbf/in)	BOL Preload (lb)	(d_BOL - d_ref) (mm)	EOL Preload (lb)	(d_EOL - d_ref) (mm)
100	21.1	0.09	18.0	0.15
500	29.2	0.13	18.1	0.15
1000	34.4	0.15	18.0	0.15
2000	39.4	0.18	18.0	0.15
3000	42	0.19	18.0	0.15
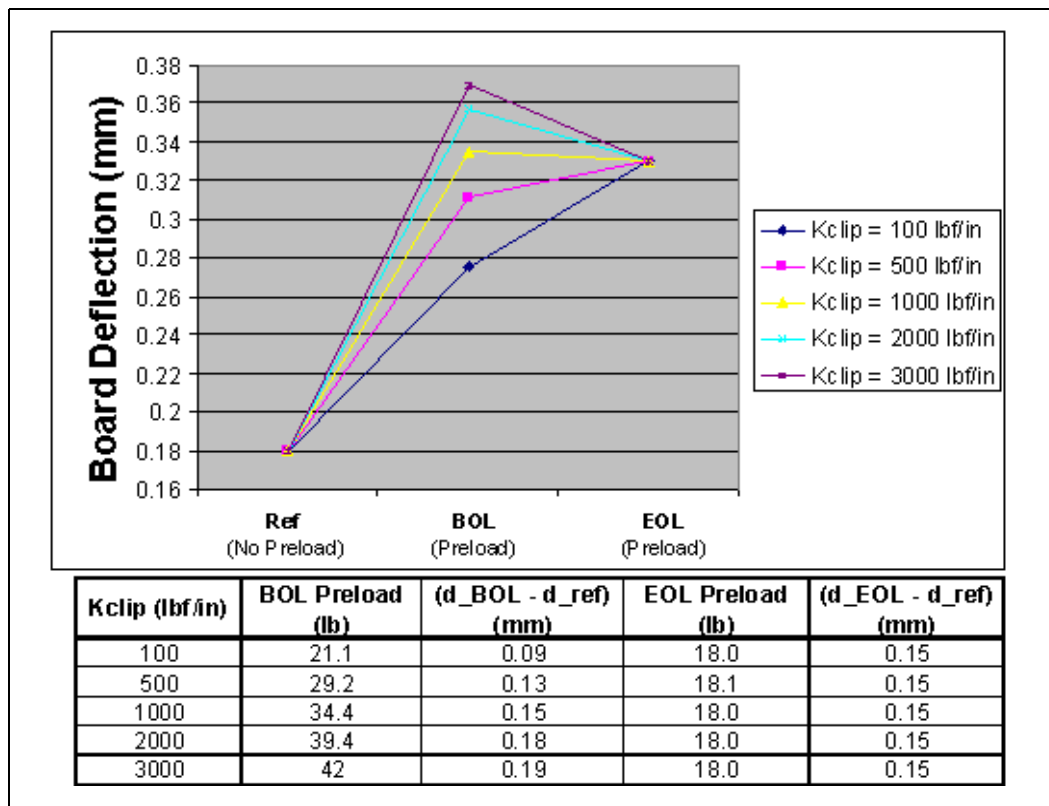
A.2.5   Additional Considerations

Intel recommends to design to {d_BOL - d_ref = 0.15mm} at BOL when EOL conditions are not known or difficult to assess

The following information is given for illustration 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 high 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 0.50mm 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.

Note: The heatsink preload must remain below the maximum load limit of the package at all times. Refer to processor datasheet.

Note: Board deflection should not exceed board manufacturer specifications.

A.2.5.1   Board Stiffening Considerations

To protect the 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 Section A.2.1, Section A.2.2 and Section 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 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 to bend underneath the socket.

A.3   Heatsink Selection Guidelines

Evaluate carefully heatsinks coming with board 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 Pentium 4 Processor in the 775-Land LGA Package.

- The Intel RCBFH-3 Reference Design available from licensed suppliers.

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, then select Support Component.

Appendix B Heatsink Clip Load Metrology

B.4   Overview

This section describes a procedure for measuring the load applied by the heatsink/clip/fastener assembly to a processor package. This procedure is recommended to verify that 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.

B.5   Test Preparation

B.5.6   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.5.8, "Typical Test Equipment" on page 44.

To install the load cells, machine a pocket in the heatsink base as shown in Figure 16 and Figure 17. 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 board (Refer to Figure 17).

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 minimized as it will create additional load by artificially raising the heatsink base. The measurement offset depends on the whole assembly stiffness (i.e. board, clip, fastener, etc.). For example, the Intel RCBFH-3 Reference Heatsink Design clip and fastener 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 16 shows an example using the Intel RCBFH-3 Reference Heatsink designed for the Pentium 4 processor in the 775–land LGA package.

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 before installing to minimize variation.

B.5.7   Remarks: Alternate Heatsink Sample Preparation

Ensuring 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 measures loads representative of the non-modified design is:

1. 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.

2. Machine back the heatsink base by approximately 0.25 mm [0.01"] so that the load cell tips protrude beyond the base.

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These steps should preserve the original stack height of the heatsink assembly without affecting the stiffness of the heatsink significantly.

Figure 16. Load Cell Installation in Machined Heatsink Base Pocket – Bottom View
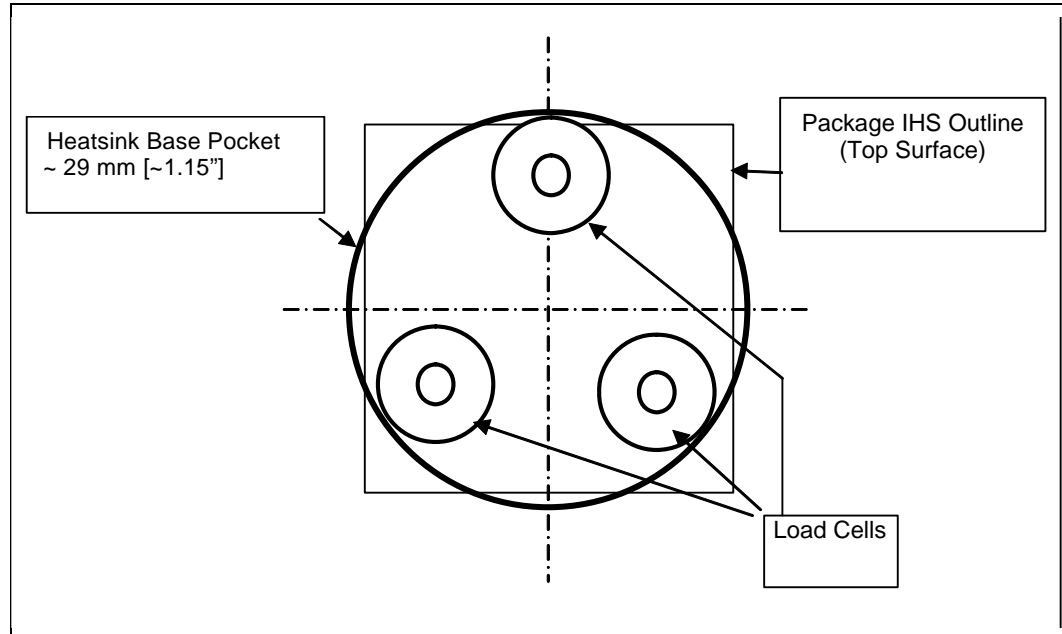

Figure 17. Load Cell Installation in Machined Heatsink Base Pocket – Side View
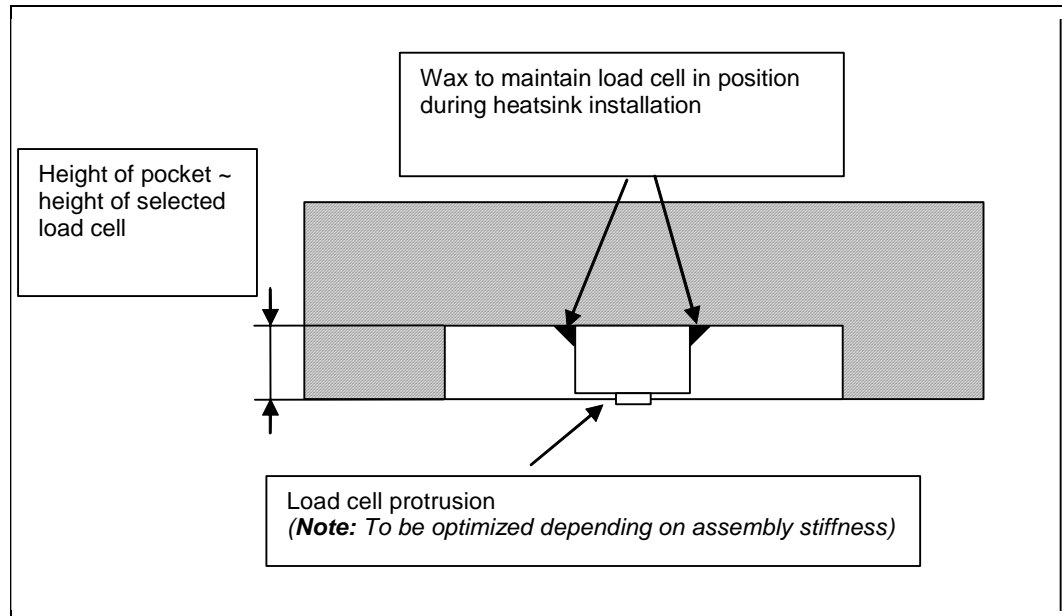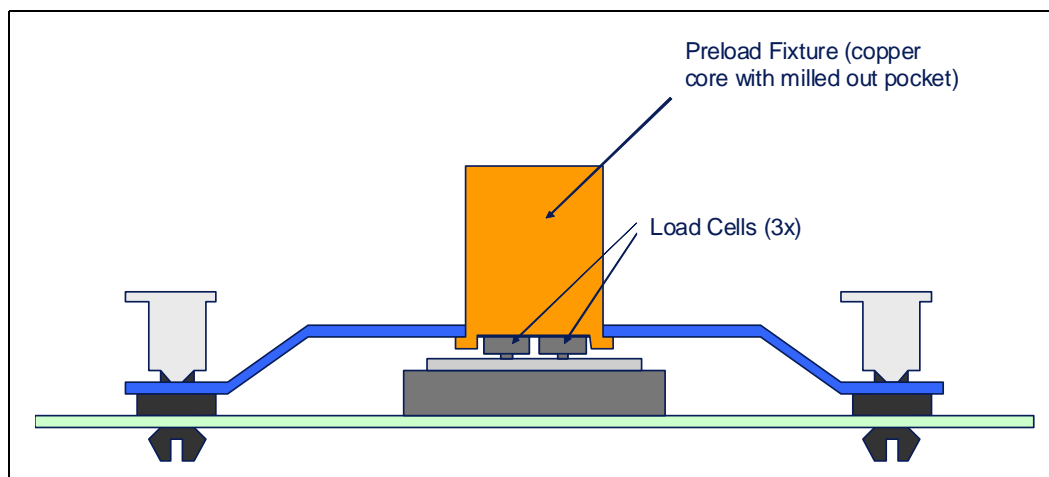
Figure 18. Preload Test Configuration

B.5.8 Typical Test Equipment

For the heatsink clip load measurement, use test equipment equivalent to that listed in Table 7.

Table 7. Typical Test Equipment

Item	Description	Part Number
Load cell Notes: 1, 5	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) Notes: 2, 3, 4	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 best to operate in the high end of the load cell capability if possible. 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 VDC 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 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.

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B.6 Test Procedure Examples

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

Any mechanical device used along with the heatsink attach mechanism must be included in the test setup (e.g., backplate, attach to chassis, etc.). Before any test, make sure that the load cell has been calibrated against known loads, following load cell vendor's instructions.

B.6.9 Time-Zero, Room Temperature Preload Measurement

1. Preassemble mechanical components on the board as needed before mounting the board on an appropriate support fixture that replicates the board attach to a target chassis.

   For example: A standard ATX board should sit on ATX-compliant standoffs. If the attach mechanism includes fixtures on the back 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 the board as shown for the Intel® RCBFH-3 reference heatsink example in Figure 18 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 three 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.6.10 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 ℃ or 85 ℃, 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 three hours.

   — 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.

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.7   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.8   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.9   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 Methodology

D.10   Objective and Scope

This appendix defines a reference procedure for attaching a thermocouple to the IHS of an FC-LGA4 processor package for T_C measurement. This procedure takes into account the specific features of the FC-LGA4 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.11   Definitions

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

Table 8.   Definitions

Term	Definition
TTV	Thermal Test Vehicle
IPA	Isopropyl Alcohol
DMM	Digital Multi Meter
IHS	Integrated Heat Spreader

D.12   Supporting Test Equipment

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

Table 9.   Supporting Test Equipment (Sheet 1 of 2)

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

Table 9.   Supporting Test Equipment (Sheet 2 of 2)

Item	Description	Part Number
Thermocouple	Omega *,40 gauge, "T" Type	5SRTC-TT-T-40-72
Calibration and Control		
Ice Point Cell	Omega*, stable 0 ºC 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 (1 each U-31CF), (1 each UX-6-6), (1 each USM6) and (1 each UPN) More information is available at: http://www.narishige.co.jp/you_ltd/english/products/set/you-set.htm#3

D.13   Thermal Calibration and Controls

It is recommended that full and routine calibration of temperature measurement system be performed before attempting to perform temperature case measurement of TTVs and live products. 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: It is recommended to follow company standard procedures and wear safety items like glasses for cutting the IHS and gloves for chemical handling.

Note: Ask your Intel field sales representative if you need assistance to groove and/or install a thermocouple according to the reference process.
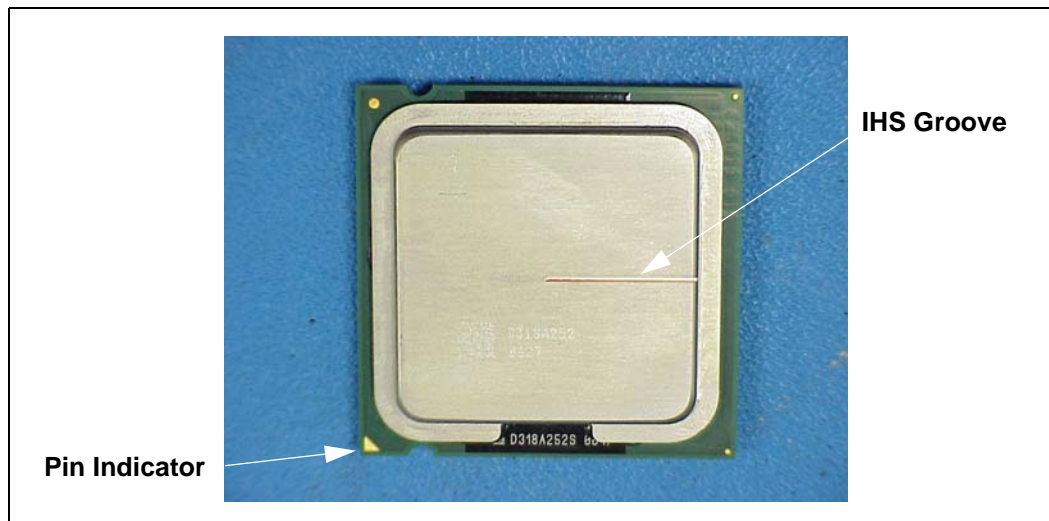
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D.14   IHS Groove

Cut a groove in the package IHS according to Figure 19.

**Figure 19. FC-LGA4 Package Reference Groove Drawing**
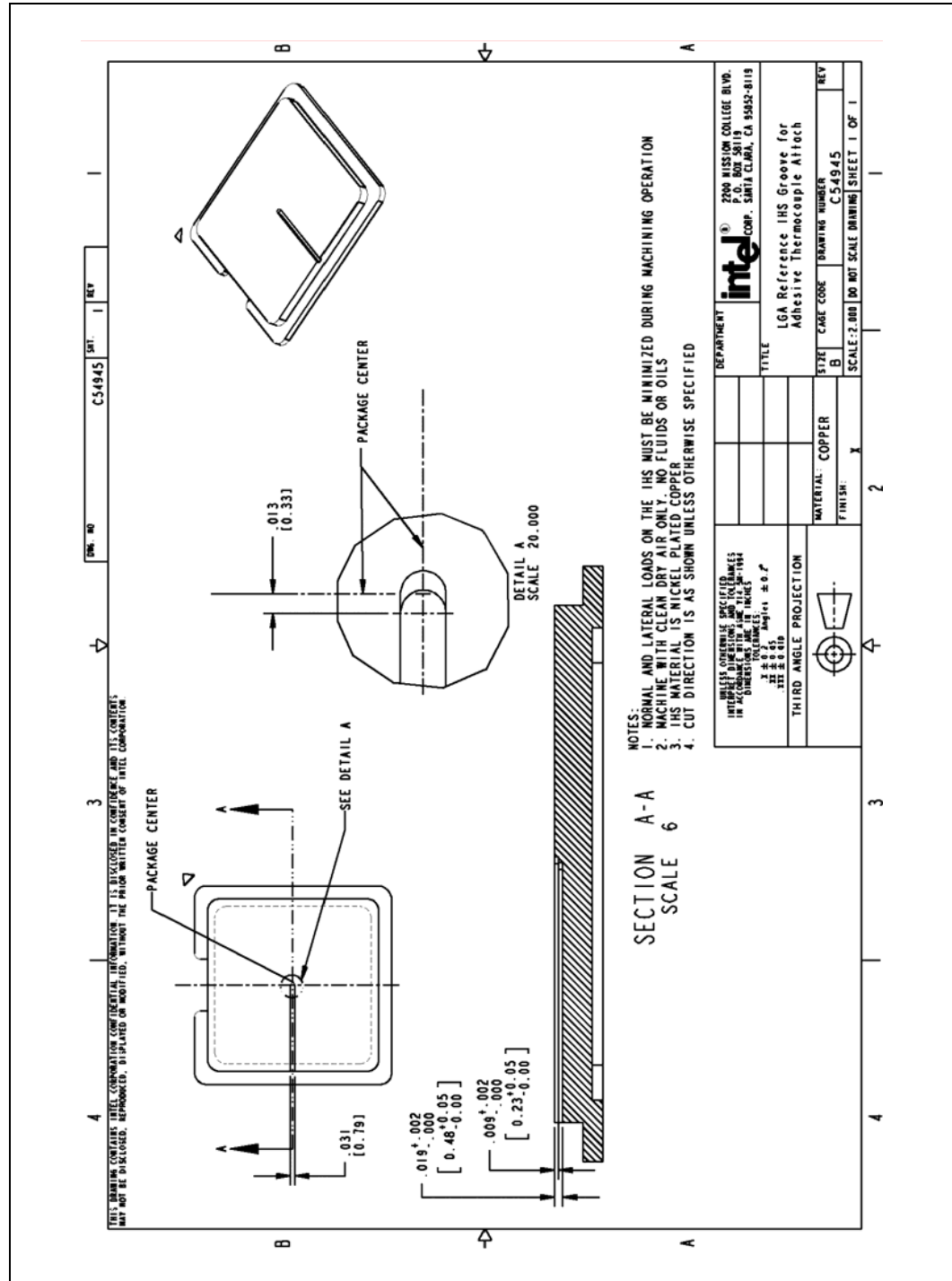
The orientation of the groove relative to the package pin 1 indicator (gold triangle in one corner of the package) is shown. Figure 20 for the FC-LGA4 package IHS.

Figure 20. IHS Reference Groove on the FC-LGA4 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 Figure 21.

Figure 21. IHS Groove Orientation Relative to the LGA775 Socket
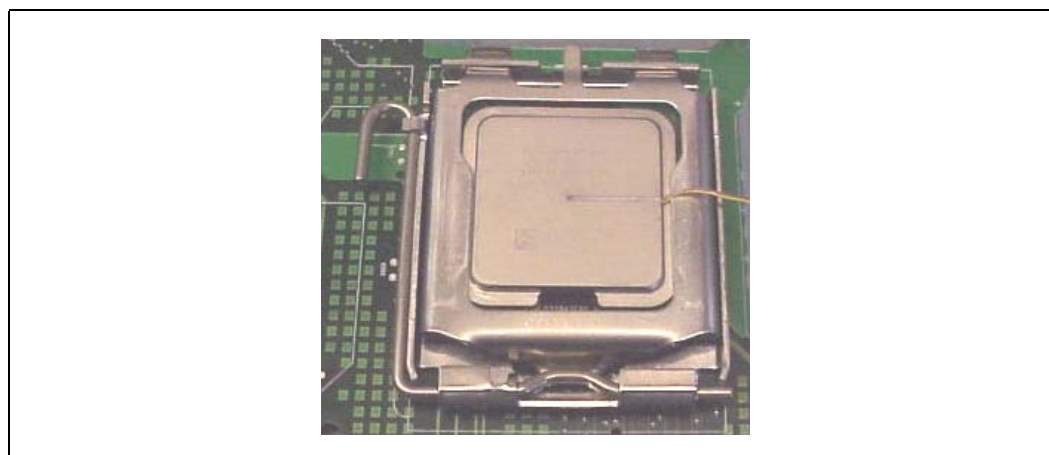
Select a machine shop that is capable of holding drawing specified tolerances. IHS channel geometry is critical for repeatable placement of the thermocouple bead, ensuring precise thermal measurements. The specified dimensions minimize the impact of the groove on the IHS under the socket load. A larger 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.

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D.15 Thermocouple Attach Procedure

D.15.1 Thermocouple Conditioning and Preparation

1. Use a calibrated thermocouple as specified in Section D.12 and Section D.13.

2. Measure the thermocouple resistance by holding both wires on one probe and the tip of the thermocouple to the other probe of the DMM. The measurement should be about~75 ohms for 40-gauge type T thermocouple.

3. Straighten the wire for about 38 mm [1½ 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 [.030 inch] from the tip (Figure 22).
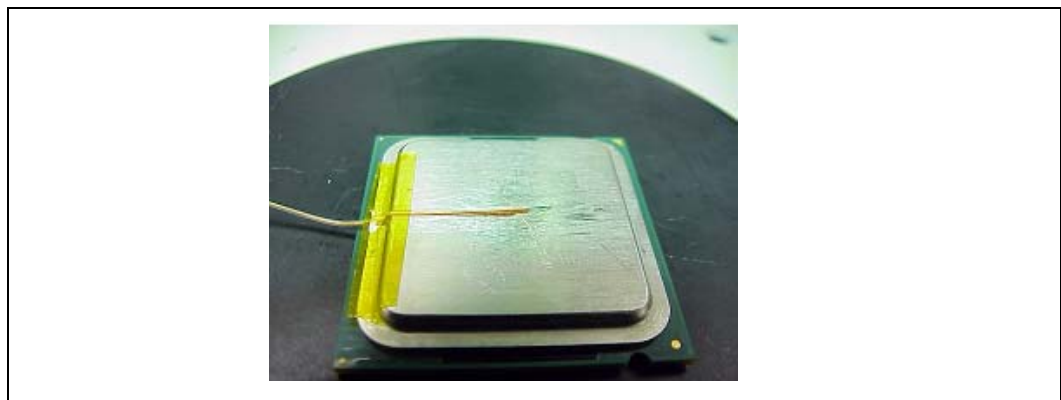
Figure 22. Bending the Tip of the Thermocouple
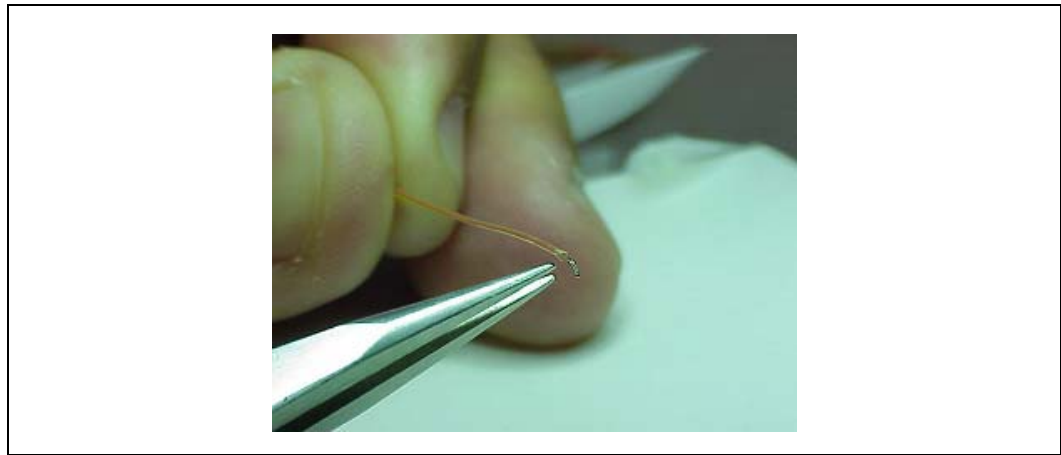
D.15.2 Thermocouple Attachment to the IHS

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 [.125 inch] past the end of groove. Secure it with Kapton* tape (Figure 23).

Figure 23. 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 24 and Figure 25).

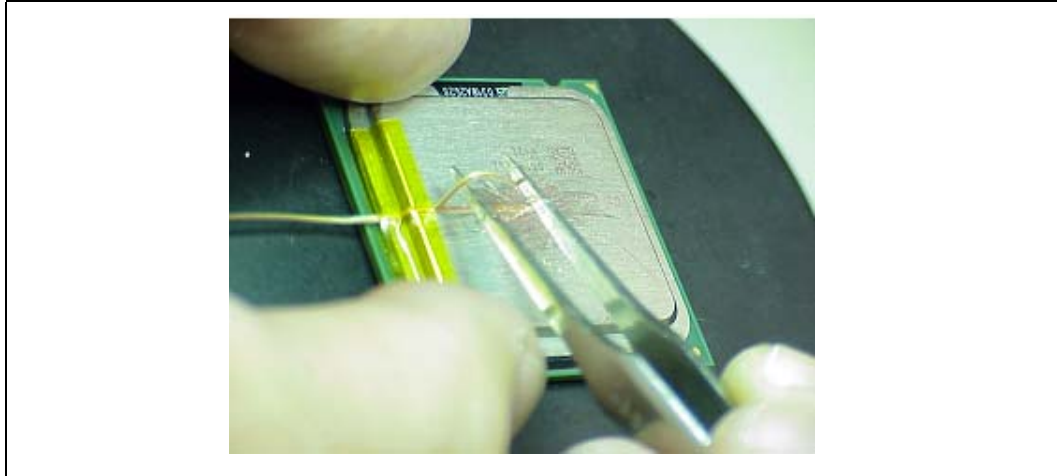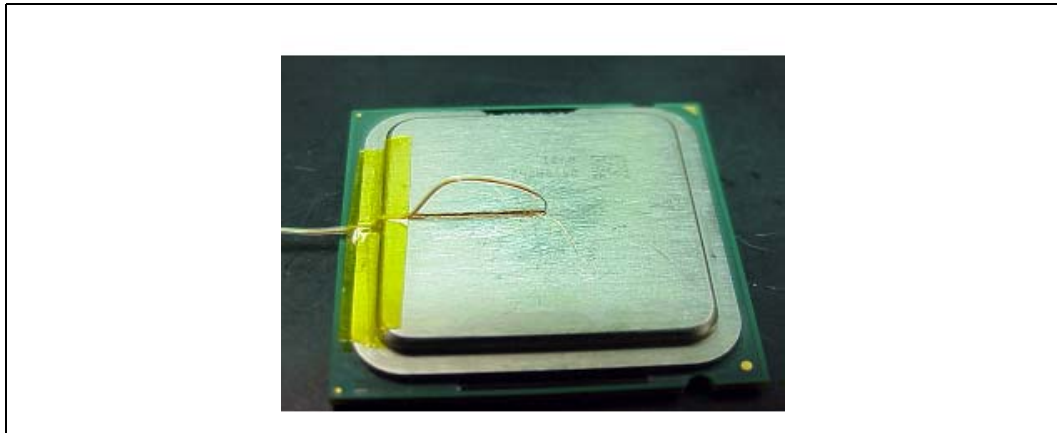**Figure 24. Thermocouple Bead Placement (View 1)**

Figure 25. Thermocouple Bead Placement (View 2)

8. Place the TTV under the microscope unit (similar to the one used in Figure 29) to continue with process. It is also recommended to use a fixture (like processor tray or a plate) to help holding the unit in place for the rest of the attach process.

9. Press the wire down about 6mm [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 26). Refer to Figure 27 for detailed bead placement.

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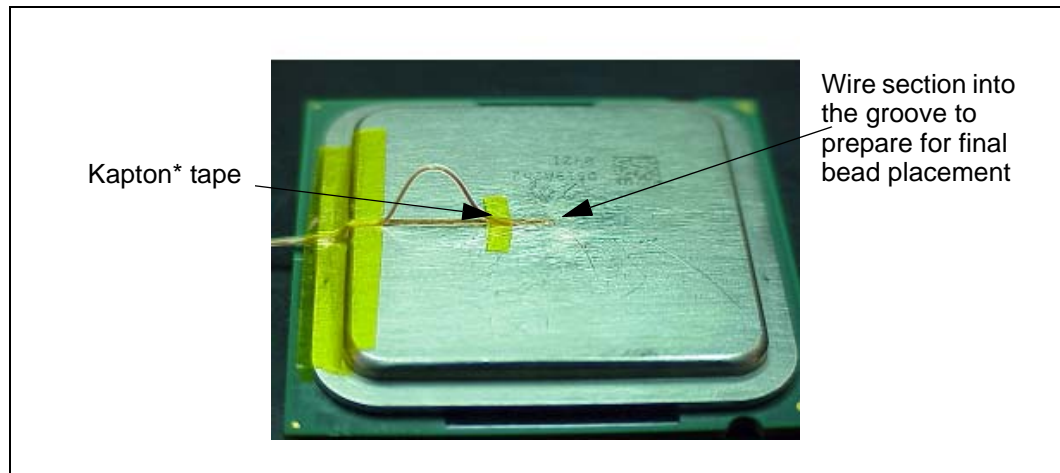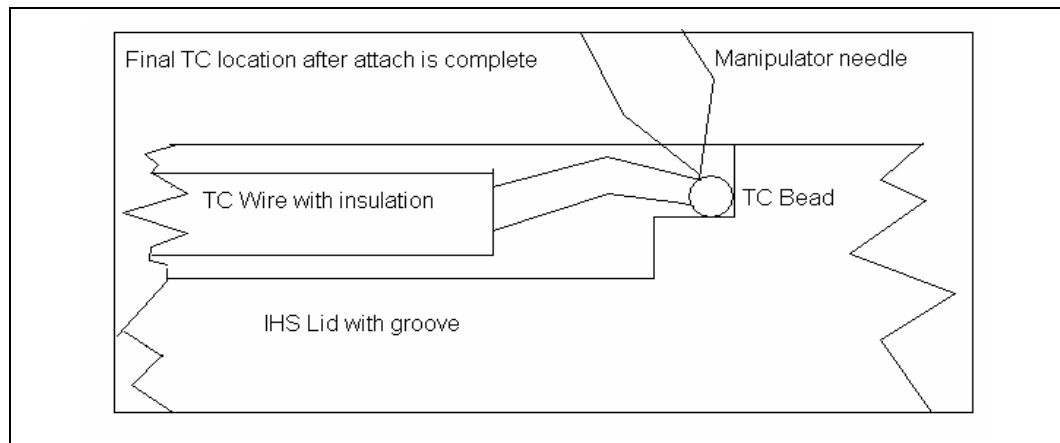
Figure 26. Position Bead on Groove Step

Kapton* tape

Wire section into the groove to prepare for final bead placement

Figure 27. Detailed Thermocouple Bead Placement

Final TC location after attach is complete | Manipulator needle

TC Wire with insulation | TC Bead

IHS Lid with groove

10. Using the micromanipulator, install the needle near to the end of groove on top of thermocouple. Using the X, Y & Z axes on the arm place the tip of needle on top of the thermocouple bead. Press down until the bead is seated at the end of groove on top of the step (see Figure 27 and Figure 28).

Figure 28. 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 step (Figure 29).

**Figure 29. 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 30).

Figure 30. Applying the Adhesive on the Thermocouple Bead

13. Measure the resistance from the thermocouple end wires again using the DMM to ensure the bead is still properly contacting the IHS.

D.15.3   Curing Process

1. Let the thermocouple attach set in the open-air for at least half an hour. It is not recommended to use any curing accelerator for this step, as rapid contraction of the adhesive during curing may weaken bead attach on the IHS.

2. Reconfirm electrical connectivity with DMM before removing the micromanipulator.

3. Remove the 3D Arm needle by holding down the TTV unit and lifting the arm.

4. Remove the Kapton* tape, straighten the wire in the groove so it lays flat all the way to the end of the groove (Figure 31).

Figure 31. Thermocouple Wire Management in the Groove
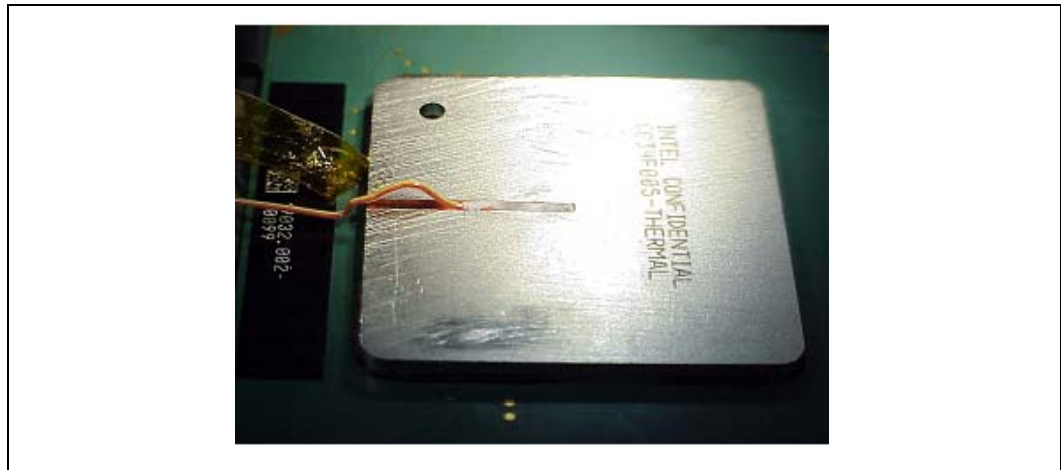
5. Using a blade to shave excess adhesive above the IHS surface (Figure 32).
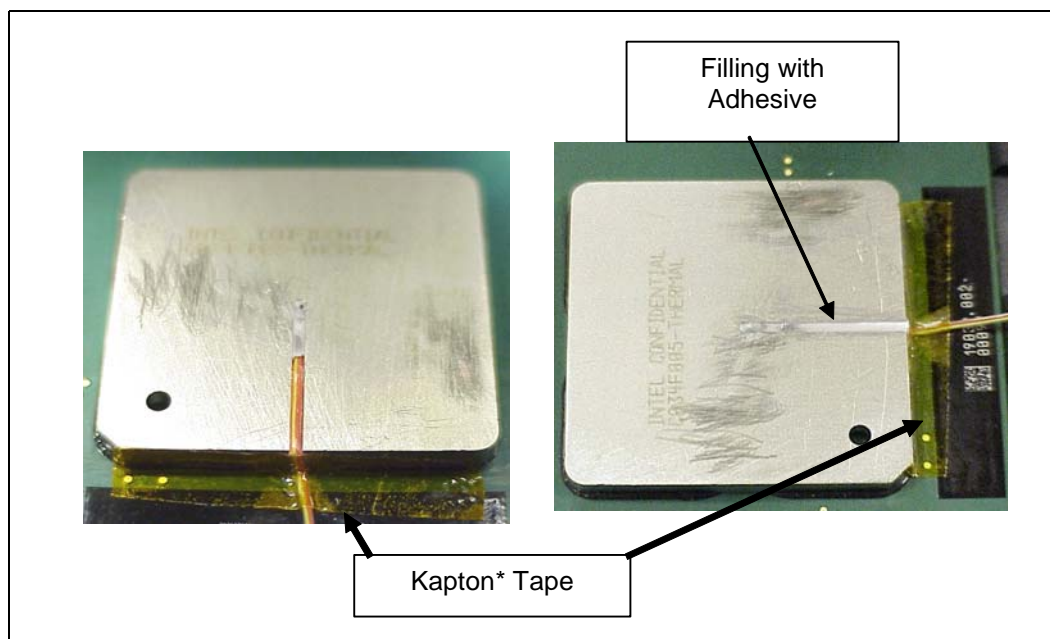
Note: Take usual precautions when using open blades.

Figure 32. Removing Excess Adhesive from IHS

6. Install new Kapton* tape to hold the thermocouple wire down and fill the rest of groove with adhesive (See Figure 33). Make sure the wire and insulation is entirely within the groove and below the IHS surface.

Figure 33. Filling the Groove with Adhesive

7. Curing time for the rest of the adhesive in the groove can be reduced using Loctite* Accelerator 7452.

8. Repeat Step 5 to remove any access adhesive to ensure flat IHS for proper mechanical contact to the heatsink surface.

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Appendix E Board Level PWM and Fan Speed Control Requirements

To utilize all of the features in the Intel reference heatsink design or the Intel boxed processor design, system integrators should verify the following functionality is present in the board design. Please refer to the *Fan Specification for 4-Wire PWM Controlled Fans*.

Requirements Classification:

- Required – an essential part of the design necessary to meet specifications. Should be considered a pass or fail in selection of a board.

- Recommended – necessary 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 of 21-28 KHz (required).

- PWM output set to 25 KHz (recommended) this value is the design target for the reference and for the Intel boxed processor solutions.

- Has external/remote thermal diode measurement capability (required).

- External/remote thermal diode sampling rate = 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. (recommended).

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.

The BIOS must be enabled to program the following data into the fan speed controller.

- Turns on PWM functionality within the required frequency range (required).

- Has the minimum and maximum values for the fan speed (RPM) ramp (required).

- Has minimum temperature where the fan speed will begin ramping. (required).

- Has maximum temperature used for the fan speed (RPM) ramp set equal to $T_{CONTROL}$ (required).

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.

Appendix F 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 Intel Pentium 4 Processor in the 775-Land LGA Package.

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

Table 10. Mechanical Drawings

Drawing Description	Page
ATX/µATX Motherboard Keep-Out Footprint Definition and Height Restrictions for Enabling Components, Sheet 1	59
ATX/µATX Motherboard Keep-Out Footprint Definition and Height Restrictions for Enabling Components, Sheet 2	60
ATX/µATX Motherboard Keep-Out Footprint Definition and Height Restrictions for Enabling Components, Sheet 3	61
1U/2U Motherboard Component Keep-In Definition, Primary Side	62
1U/2U Motherboard Component Keep-In Definition, Secondary Side	63

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Figure 34. ATX/µATX Motherboard Keep-Out Footprint Definition and Height Restrictions for Enabling Components, Sheet 1
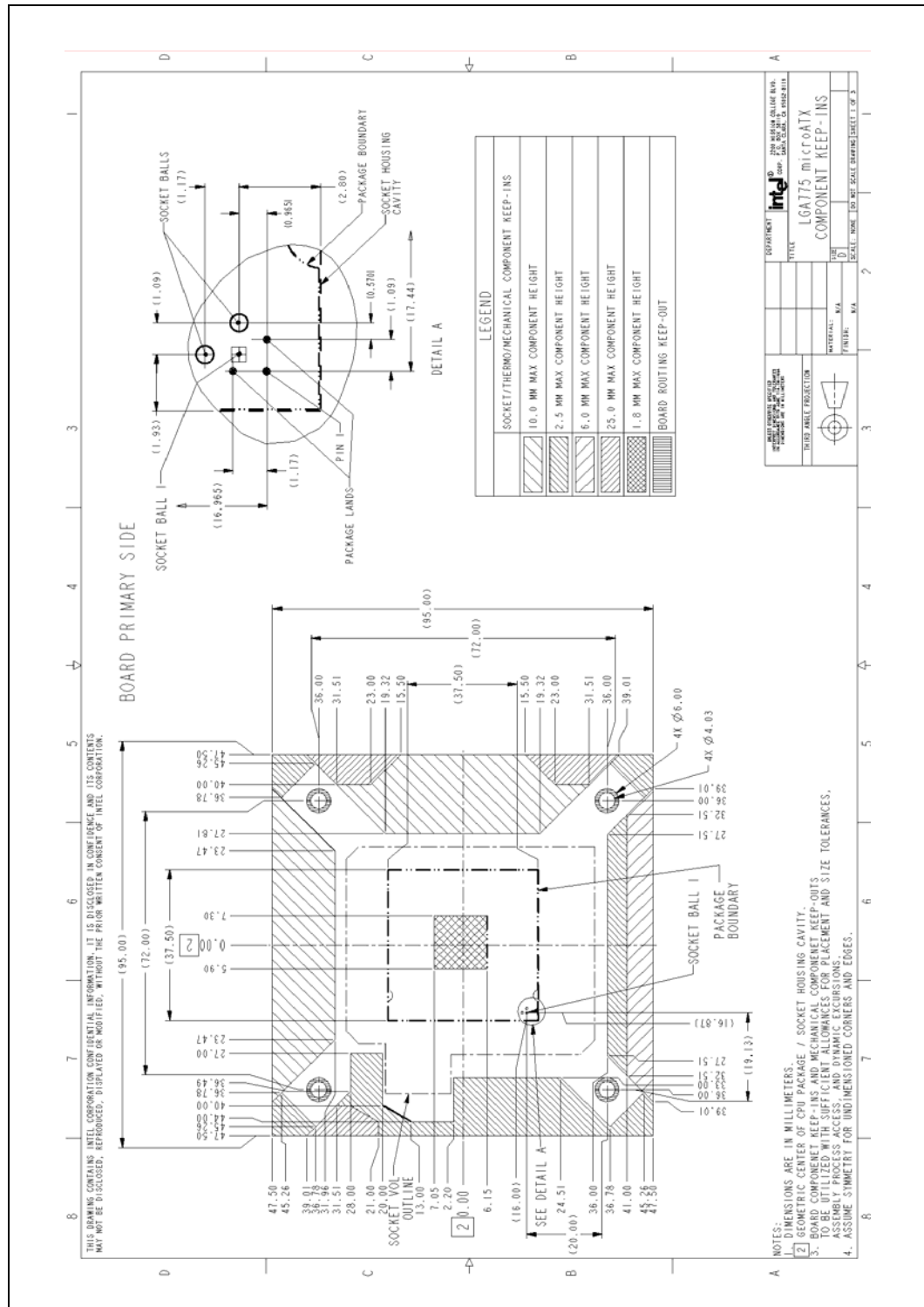
Figure 35. ATX/µATX Motherboard Keep-Out Footprint Definition and Height Restrictions for Enabling Components, Sheet 2
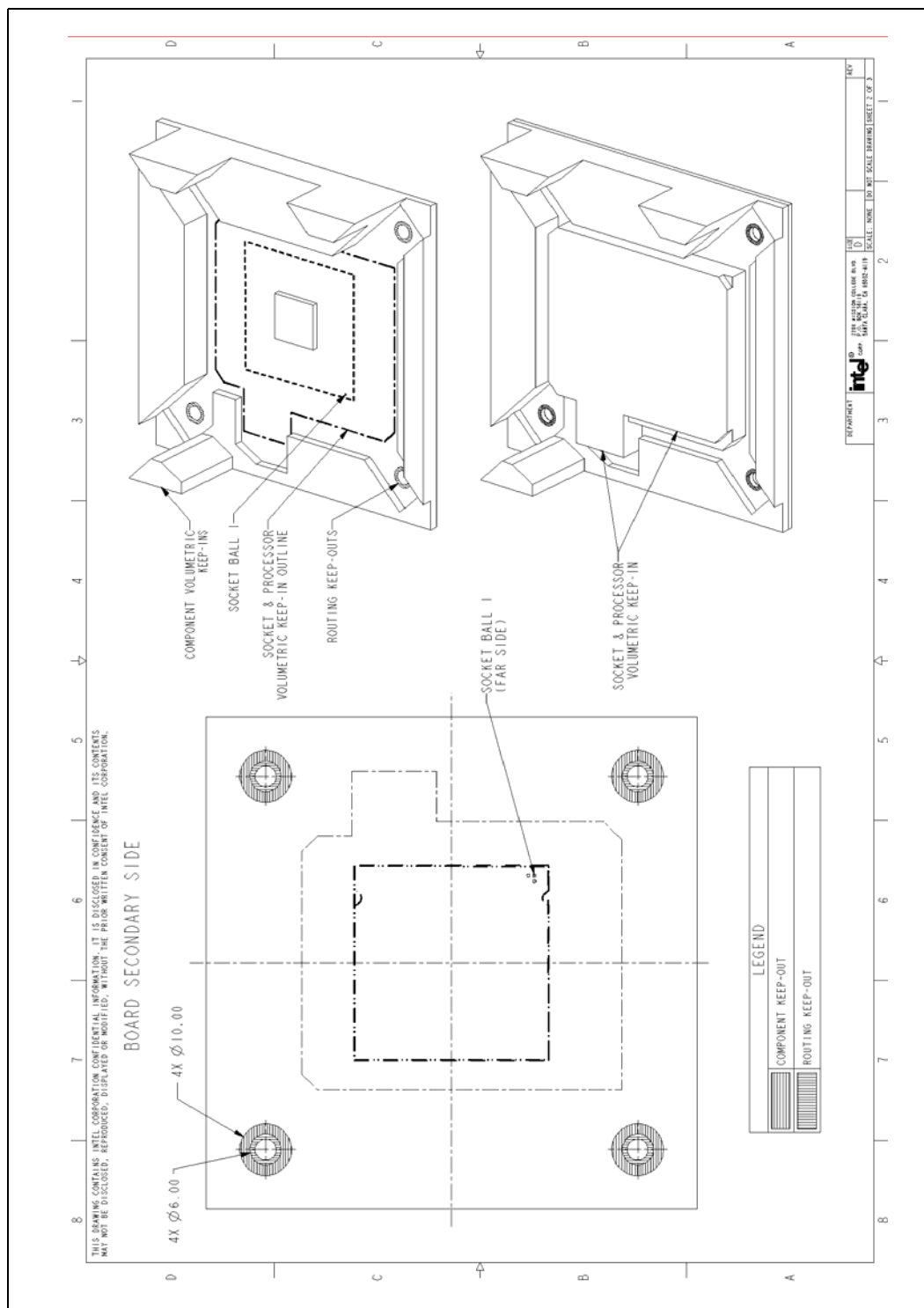
Figure 36. ATX/µATX Motherboard Keep-Out Footprint Definition and Height Restrictions for Enabling Components, Sheet 3
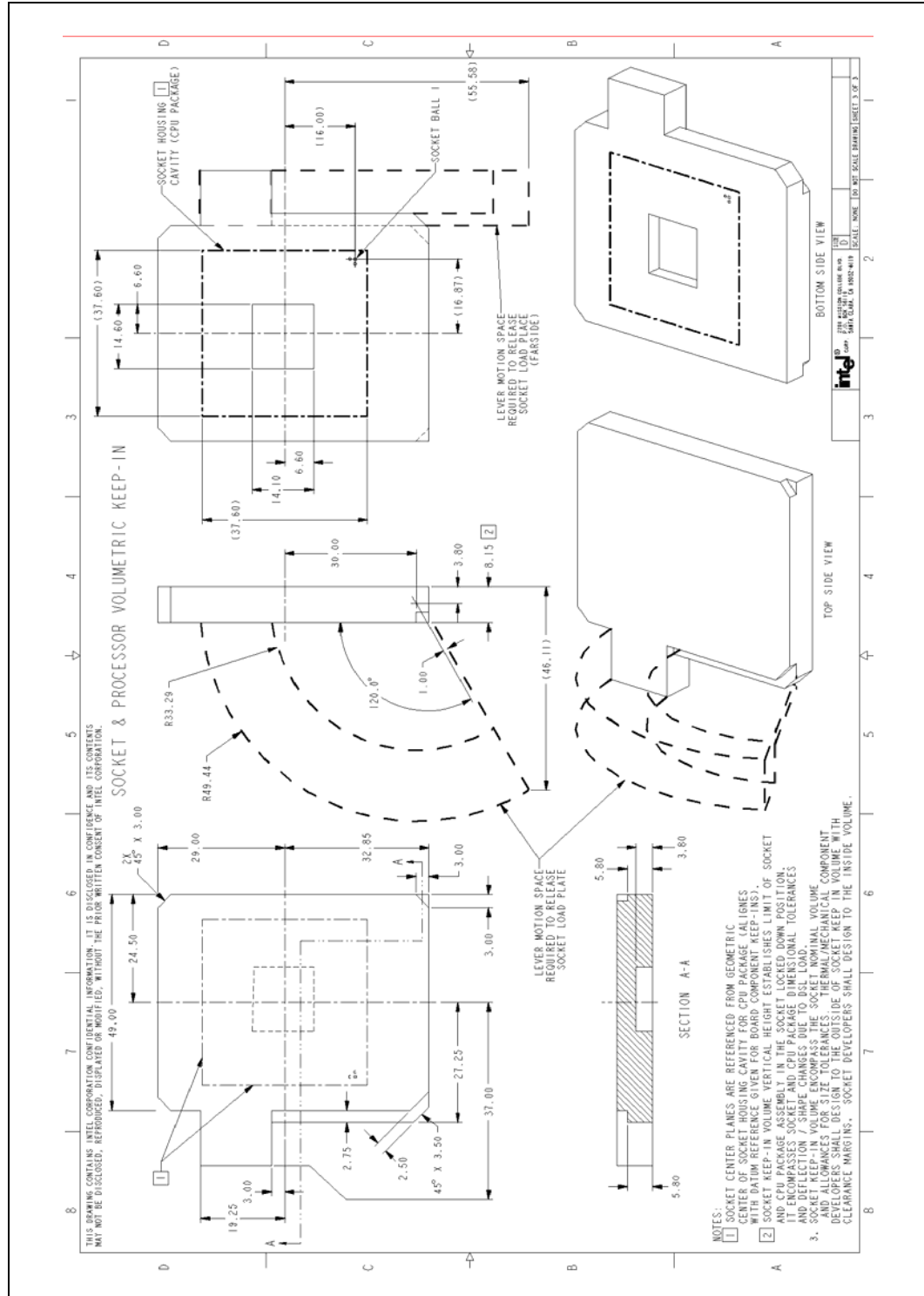
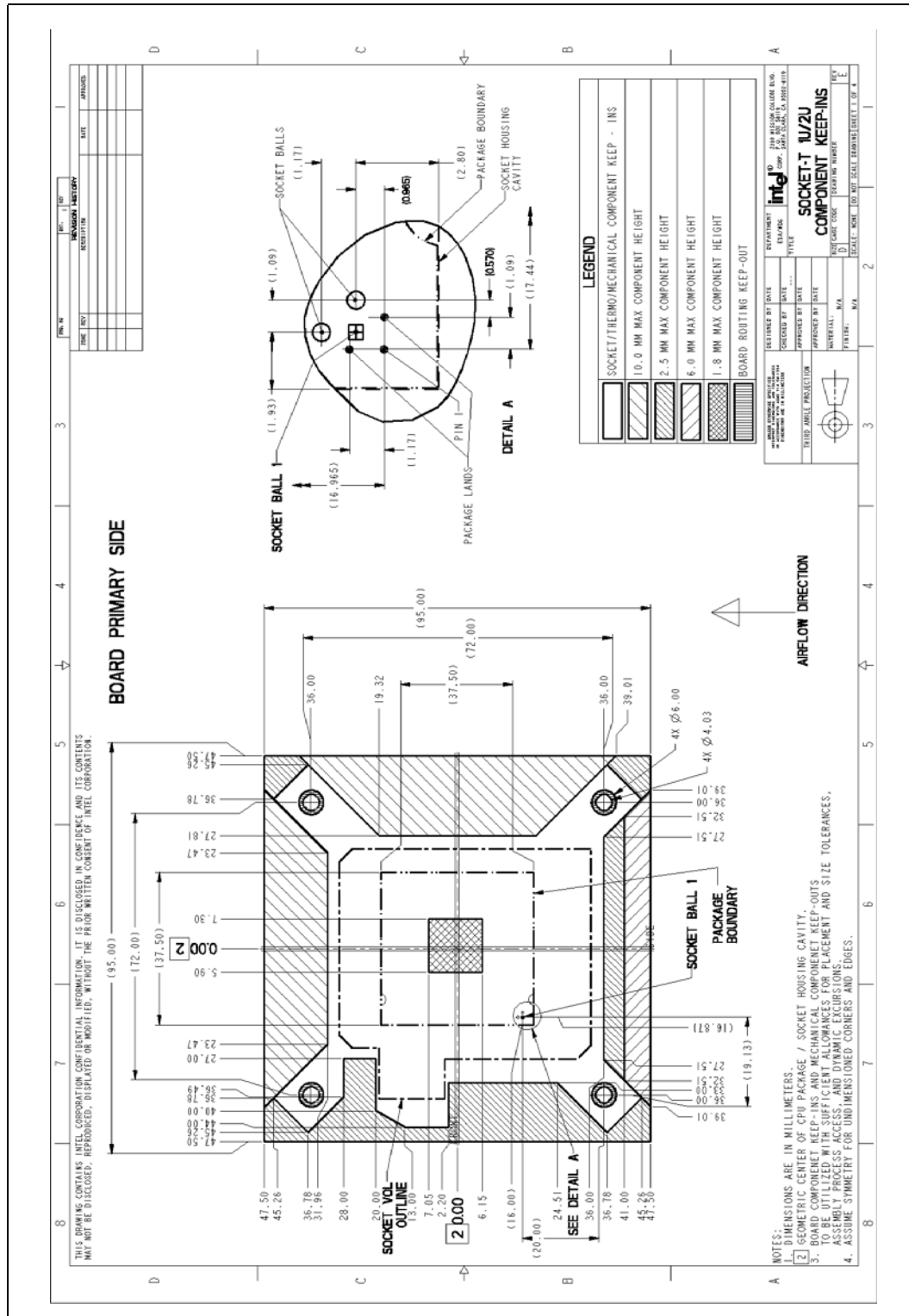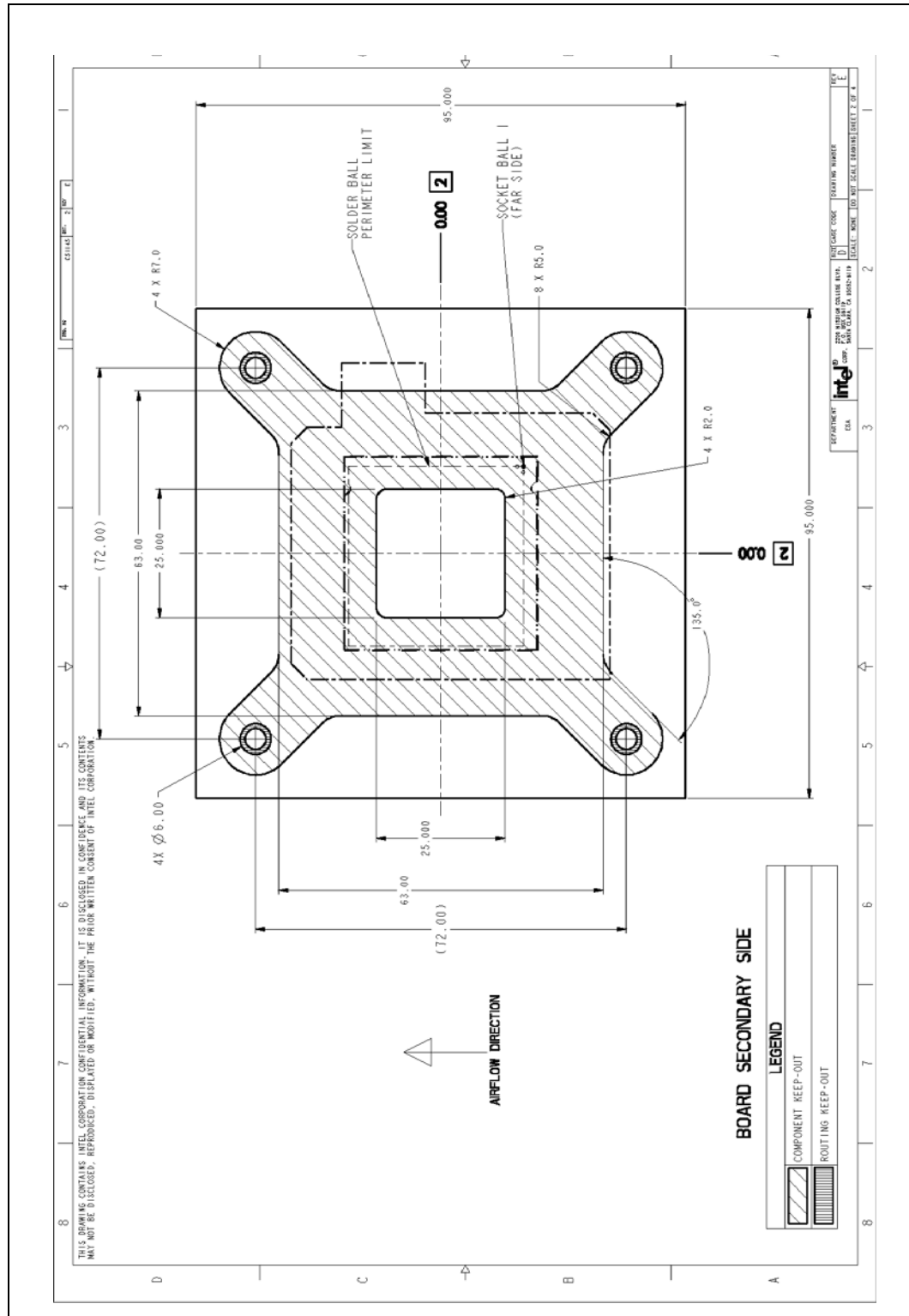**Figure 37. 1U/2U Motherboard Component Keep-In Definition, Primary Side**

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Figure 38. 1U/2U Motherboard Component Keep-In Definition, Secondary Side

Appendix G   Vendor Information

This appendix includes supplier information for Intel enabled vendors for the Intel Pentium 4 Processor in the 775-Land LGA Package thermal solutions.

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

Table 11. Intel Reference Component Thermal Solution Provider

Supplier	Part Description	Part Number	Contact	Phone	Email
Sanyo-Denki*	Active fan heatsink for the Intel Pentium 4 Processor in the 775-Land LGA Package	C25697	Haruhiko (Harry) Kawasumi	310-783-5430	haruhiko@sanyo-denki.com
Nidec America Corporation*		C25704	Karl Mattson	360-666-2445	Karl.mattson@nidec.com
AVC* (ASIA Vital Components Co., Ltd.*)	1U heatsink	C69175	David Chao	+886-2-22996930 Ext: 619	david_chao@avc.com.tw
CoolerMaster*	2U reference solution	PSC-2U-001	Wendy Lin	(908) 252-9400	wendy@coolermaster.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.