Intel® Xeon™ Processor with 800 MHz System Bus

Thermal/Mechanical Design Guidelines

June 2004

Order Number: 302661-001

Notice: This document contains information on products in the design phase of development. Do not finalize a design with this information. Revised information will be published when the product is available. Verify with your local Intel sales office that you have the latest datasheet before finalizing a design.

Contents

Figures

Tables

Revision History

Revision Number	Order Number	Description	Date
1.0	302661-001	Initial release of the document.	June 2004

1 Introduction

1.1 Objective

The objective of this document is to describe the reference thermal solution and design parameters required for the Intel® Xeon™ Processor with 800 MHz System Bus. It is also the intent of this document to comprehend and demonstrate the processor cooling solution features and requirements. Furthermore, this document provides an understanding of the processor thermal characteristics, and discusses guidelines for meeting the thermal requirements imposed on the entire life of the processor. The thermal/mechanical solutions described in this document are intended to aid component and system designers in the development and evaluation of processor compatible thermal/mechanical solutions.

1.2 Scope

The thermal/mechanical solutions described in this document pertain only to a solution(s) intended for use with Intel Xeon Processor with 800 MHz System Bus in 1U, 2U, 2U+ and workstation form factors systems.This document contains the mechanical and thermal requirements of the processor cooling solution. In case of conflict, the data in the *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet* supersedes any data in this document. Additional information is provided as a reference in the appendix section(s).

Low voltage (LV) Intel Xeon Processor with 800 MHz System Bus is outside the scope of this document.

1.3 References

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

Table 1-1. Reference Documents

Document	Comment
European Blue Angel Recycling Standards	http://www.blauer-engel.de
Intel® Xeon™ Processor Thermal Design Guidelines	http://www.developer.intel.com
mPGA604 Socket Design Guidelines	http://www.developer.intel.com
Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet	http://www.developer.intel.com
Intel® Xeon™ Processor with 800 MHz System Bus Enabled Components Mechanical Models (in IGES and ProE* format)	http://www.developer.intel.com
Intel® Xeon™ Processor with 800 MHz System Bus Thermal Models (in Flotherm* and Icepak*)	http://www.developer.intel.com

Table 1-1. Reference Documents

Document	Comment
Thin Electronics Bay Specification (A Server System Infrastructure (SSI) Specification for Rack Optimized Servers - CHECK WITH CENGIZ	www.ssiforum.com
ntel® Xeon™ Processor with 800 MHz System Bus Mechanical Models	http://www.developer.intel.com
ntel® Xeon™ Processor with 800 MHz System Bus Enabled Components Thermal Models	http://www.developer.intel.com

NOTE: Contact your Intel field sales representative for the latest revision and order number of this document.

1.4 Definition of Terms

Table 1-2. Terms and Descriptions

Term	Description
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.
FSC	Fan Speed Control
IHS	Integrated Heat Spreader: a component of the processor package used to enhance the thermal performance of the package. Component thermal solutions interface with the processor at the IHS surface.
mPGA604	The surface mount Zero Insertion Force (ZIF) socket designed to accept the Intel Xeon Processor with 800 MHz System Bus.
Offset	A value programmed into each processor during manufacturing that can be obtained by reading the IA_32_TEMPERATURE_TARGET MSR. This is a static and a unique value.
P_{MAX}	The maximum power dissipated by a semiconductor component.
Ψ_{CA}	Case-to-ambient thermal characterization parameter (psi). A measure of thermal solution performance using total package power. Defined as ($T_{CASE} – T_{LA}$) / Total Package Power. Heat source should always be specified for Ψ measurements.
Ψ_{CS}	Case-to-sink thermal characterization parameter. A measure of thermal interface material performance using total package power. Defined as ($T_{CASE} – T_S$) / Total Package Power.
Ψ_{SA}	Sink-to-ambient thermal characterization parameter. A measure of heatsink thermal performance using total package power. Defined as ($T_S – T_{LA}$) / Total Package Power.
T_{CASE}	The case temperature of the processor, measured at the geometric center of the topside of the IHS.
T_{CASE_MAX}	The maximum case temperature as specified in a component specification.
TCC	Thermal Control Circuit: Thermal monitor uses the TCC to reduce the die temperature by using clock modulation when the die temperature is very near its operating limits.
$T_{CONTROL}$	A processor unique value, which defines the lower end of the Thermal Profile and is targeted to be used in fan speed control mechanisms.

Table 1-2. Terms and Descriptions (Cont'd)

Term	Description
TDP	Thermal Design Power should be used for processor/chipset thermal solution design targets. TDP is not the maximum power that the processor/chipset can dissipate.
Thermal Monitor	A feature on the processor that can keep the processor's die temperature within factory specifications under nearly all conditions.
Thermal Profile	Line that defines case temperature specification of a processor at a given power level.
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.
T_{LA}	The measured ambient temperature locally surrounding the processor. The ambient temperature should be measured just upstream of a passive heatsink or at the fan inlet for an active heatsink.
T_{SA}	The system ambient air temperature external to a system chassis. This temperature is usually measured at the chassis air inlets.
U	A unit of measure used to define server rack spacing height. 1U is equal to 1.75 in, 2U equals 3.50 in, etc.

§

2 Thermal/Mechanical Reference Design

2.1 Mechanical Requirements

The mechanical performance of the processor cooling solution must satisfy the requirements described in this section.

2.1.1 Processor Mechanical Parameters

Table 2-3. Processor Mechanical Parameters Table

Parameter	Minimum	Maximum	Unit	Notes
Volumetric Requirements and Keepouts				Refer to drawings in Appendix A
Heatsink Mass		1000 2.2	g lbs	
Static Compressive Load	44 10	222 50	N lbf	1,2,3,4
	44 10	288 65	**N** **lbf**	1,2,3,5
Dynamic Compressive Load	N/A NA	222 N + 0.45 kg * 100 G 50 lbf (static) + 1 lbm * 100 G	**N** **lbf**	1,3,4,6,7
	N/A NA	288 N + 0.45 kg * 100 G 65 lbf (static) + 1 lbm * 100 G	N lbf	1,3,5,6,7
Transient	N/A	445 100	N lbf	1,3,8

Note: In the case of a discrepancy, the most recent Intel Xeon Processor with 800 MHz System Bus supersedes targets listed in the above table.

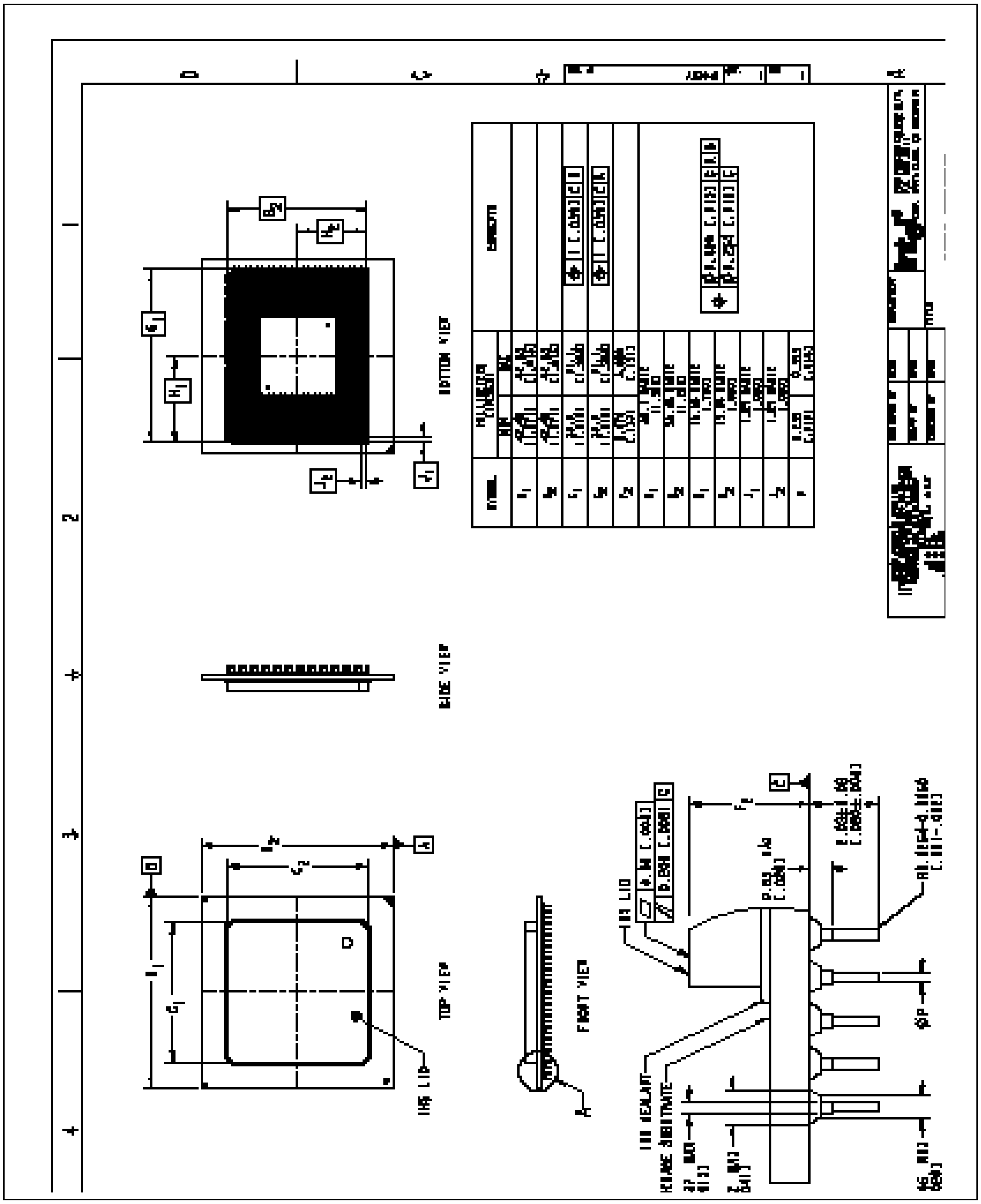
1. These specifications apply to uniform compressive loading in a direction perpendicular to the IHS top surface.
2. This is the minimum and maximum static force that can be applied by the heatsink and retention solution to maintain the heatsink and processor interface.
3. These parameters are based on limited testing for design characterization. Loading limits are for the package only and do not include the limits of the processor socket.
4. This specification applies for thermal retention solutions that allow baseboard deflection.
5. This specification applies for thermal retention solutions that prevent baseboard deflection.
6. Dynamic loading is defined as an 11 ms duration average load superimposed on the static load requirement.

7. Experimentally validated test condition used a heatsink mass of 1 lbm (~0.45 kg) with 100 G acceleration measured at heatsink mass. The dynamic portion of this specification in the product application can have flexibility in specific values, but the ultimate product of mass times acceleration should not exceed this validated dynamic load (1 lbm x 100 G = 100 lb). Allowable strain in the dynamic compressive load specification is in addition to the strain allowed in static loading.
8. Transient loading is defined as a 2-second duration peak load superimposed on the static load requirement, representative of loads experienced by the package during heatsink installation.

2.1.2 Intel® Xeon™ Processor with 800 MHz System Bus Package

The Intel Xeon Processor with 800 MHz System Bus is packaged using the flip-chip micro pin grid array 4 (FC-mPGA4) package technology. Please refer to the *IIntel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet* for detailed mechanical specifications. The Intel Xeon Processor with 800 MHz System Bus mechanical drawing, Figure 2-1, provides the mechanical information for the Intel Xeon Processor with 800 MHz System Bus. The stackup height of the processor in the socket is shown in Appendix A. The drawing is superseded by the drawing in the processor datasheet, should there be any conflict.

Figure 2-1. Intel® Xeon™ Processor with 800 MHz System Bus Mechanical Drawing



The processor connects to the baseboard through a 604-pin surface mount, zero insertion force (ZIF) socket. A description of the socket can be found in the *mPGA604 Socket Design Guidelines*.

The processor package has mechanical load limits that are specified in the processor *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet* and in Table 2-3. These load limits should not be exceeded during heatsink installation, removal, mechanical stress testing, or standard shipping conditions. For example, when a compressive static load is necessary to ensure thermal performance of the Thermal Interface Material (TIM) between the heatsink base and the IHS, it should not exceed the corresponding specification given in the processor EMTS.

The heatsink mass can also add additional dynamic compressive load to the package during a mechanical shock event. Amplification factors due to the impact force during shock must be taken into account in dynamic load calculations. The total combination of dynamic and static compressive load should not then exceed the processor compressive dynamic load specified in the *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet* and in Table 2-3 during a vertical shock. It is not recommended to use any portion of the processor substrate as a mechanical reference or load- bearing surface in either static or dynamic compressive load conditions.

2.1.3 Intel® Xeon™ Processor with 800 MHz System BusConsiderations

An attachment mechanism must be designed to support the heatsink since there are no features on the mPGA604 socket to directly attach a 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, especially ones based on phase change materials, are very sensitive to applied pressure: the higher the pressure, the better the initial performance. TIMs such as thermal greases are not as sensitive to applied pressure. Refer to Chapter 2.4.2 for information on trade-offs made with TIM selection. Designs should consider possible decrease in applied pressure over time due to potential structural relaxation in enabled components.
- Ensuring system electrical, thermal, and structural integrity under shock and vibration events. The mechanical requirements of the attach mechanism depend on the weight of the heatsink and the level of shock and vibration that the system must support. The overall structural design of the baseboard and system must be considered when designing the heatsink attach mechanism. Their design should provide a means for protecting mPGA604socket solder joints as well as preventing package pullout from the socket.

Note: The load applied by the attachment mechanism must comply with the package specifications, along with the dynamic load added by the mechanical shock and vibration requirements, as identified in Chapter 2.1.1.

A potential mechanical solution for heavy heatsinks is the direct attachment of the heatsink to the chassis pan. In this case, the strength of the chassis pan can be utilized rather than solely relying on the baseboard strength. In addition to the general guidelines given above, contact with the baseboard surfaces should be minimized during installation in order to avoid any damage to the baseboard.

The Intel reference design for Intel Xeon Processor with 800 MHz System Bus is using such a heatsink attachment scheme. Refer to Chapter 2.4 for further information regarding the Intel reference mechanical solution.

2.2 Thermal Requirements

A new thermal specification methodology, referred to as the Thermal Profile, is being introduced on the Intel Xeon Processor with 800 MHz System Bus. The intent of the new Thermal Profile specification is to support acoustic noise reduction through fan speed control and ensure the long-term reliability of the processor. This specification requires that the temperature at the center of the processor IHS, known as (T_{CASE}) remains within a certain temperature specification. Compliance with the T_{CASE} specification is required to achieve optimal operation and long-term reliability (See Appendix B for Case Temperature definition and measurement methods).

To ease the burden on thermal solutions, the Thermal Monitor feature and associated logic have been integrated into the silicon of the processor. One feature of the Thermal Monitor is the Thermal Control Circuit (TCC). When active, the TCC lowers the processor temperature by reducing the power consumed by the processor. 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.

By taking advantage of the Thermal Monitor features, system designers may reduce thermal solution cost by designing to The Thermal Design Power (TDP) instead of maximum power. TDP should be used for processor/chipset thermal solution design targets. TDP is not the maximum power that the processor/chipset can dissipate. TDP is based on measurements of processor power consumption while running various high power applications. This data set 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 set is then used to derive the TDP targets published in the processor Intel Xeon Processor with 800 MHz System Bus. The Thermal Monitor can protect the processor in rare workload excursions above TDP. Therefore, thermal solutions should be designed to dissipate this target power level.

The relationship between TDP to the Thermal Profile, and thermal management logic and thermal monitor features, is discussed in the sections to follow. The thermal management logic and thermal monitor features are discussed in extensive detail in Appendix F.

2.2.1 Thermal Profile

The Thermal Profile is a linear line that defines the relationship between a processor's case temperature and its power consumption as shown in Figure 2-3. The equation of the Thermal Profile is defined as:

Equation 4. $y = ax + b$

Where:

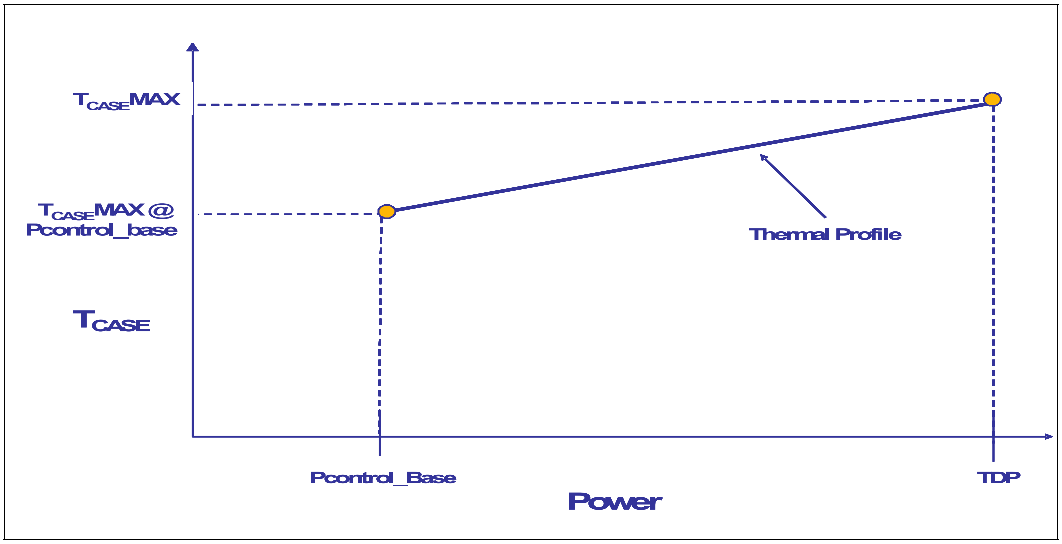
y = Processor case temperature, T_{CASE} (°C)

x = Processor power consumption (W)

a = Case-to-ambient thermal resistance, Ψ_{CA} (°C/W)

b = Processor local ambient temperature, T_{LA} (°C)

Figure 2-2. Thermal Profile Diagram



The higher end point of the Thermal Profile represents the processor's TDP and the associated maximum case temperature (T_{CASE}MAX). The lower end point of the Thermal Profile represents the power value (Pcontrol_base) and the associated case temperature (T_{CASE}MAX@Pcontrol_base) for the lowest possible theoretical value of $T_{CONTROL}$ (see Chapter 2.2.2). The slope of the Thermal Profile line represents the case-to-ambient resistance of the thermal solution with the y-intercept being the local processor ambient temperature. The slope of the Thermal Profile is constant between $P_{CONTROL\ BASE}$ and TDP, which indicate that all frequencies of a processor defined by the Thermal Profile, will require the same heatsink case-to-ambient resistance.

In order to satisfy the Thermal Profile specification, a thermal solution must be at or below the Thermal Profile line for the given processor when its diode temperature is greater than $T_{CONTROL}$ (refer to Chapter 2.2.2). The Thermal Profile allows the customers to make a trade-off between the thermal solution case-to-ambient resistance and the processor local ambient temperature that best suits their platform implementation (refer to Chapter 2.3.3). There can be multiple combinations of thermal solution case-to-ambient resistance and processor local ambient temperature that can meet a given Thermal Profile. If the case-to-ambient resistance and the local ambient temperature are known for a specific thermal solution, the Thermal Profile of that solution can easily be plotted against the Thermal Profile specification. As explained above, the case-to-ambient resistance represents the slope of the line and the processor local ambient temperature represents the y-axis intercept. Hence the T_{CASE} values of a specific solution can be calculated at the TDP and Pcontrol_base power levels. Once these points are determined, they can be joined by a line, which represents the Thermal Profile of the specific solution. If that line stays at or below the Thermal Profile specification, then that particular solution is deemed as a compliant solution.

2.2.2 $T_{CONTROL}$ Definition

$T_{CONTROL}$ is a temperature specification based on a temperature reading from the processor's thermal diode. $T_{CONTROL}$ defines the lower end of the Thermal Profile line for a given processor, and it can be described as a trigger point for fan speed control implementation. The value for $T_{CONTROL}$ is calibrated in manufacturing and configured for each processor individually. For the

Intel Xeon Processor with 800 MHz System Bus, the Tcontrol value is obtained by reading a processor model specific register (MSR) and adding this offset value to a base value. The equation for calculating $T_{CONTROL}$ is:

Equation 5. $T_{CONTROL} = T_{CONTROL\_BASE} + Offset$

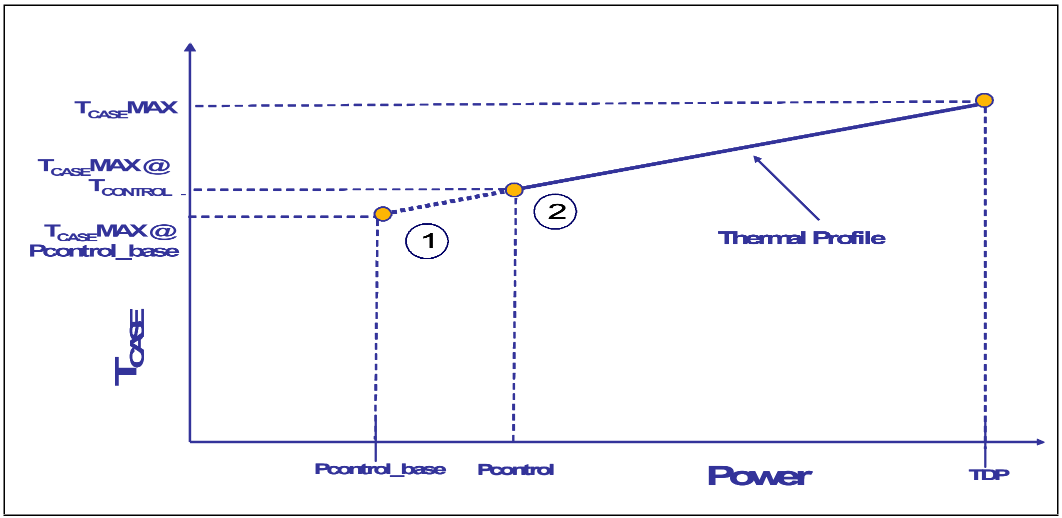
Where:

$T_{CONTROL\_BASE}$ =A fixed base value defined for a given processor generation as published in the processor EMTS.

Offset = A value programmed into each processor during manufacturing that can be obtained by reading the IA32_TEMPERATURE_TARGET MSR. This is a static and a unique value.

The $T_{CONTROL\_BASE}$ value for the Intel Xeon Processor with 800 MHz System Bus is 50°C. The Offset value, which depends on several factors (i.e. leakage current) can be any number between 0 and (T_{CASE}MAX - $T_{CONTROL-BASE}$). Figure 2-3 depicts the interaction between the Thermal Profile and $T_{CONTROL}$ for an Offset value that is greater than 0 (i.e. $T_{CONTROL}$ greater than $T_{CONTROL\_BASE}$).

Figure 2-3. $T_{CONTROL}$ and Thermal Profile Interaction



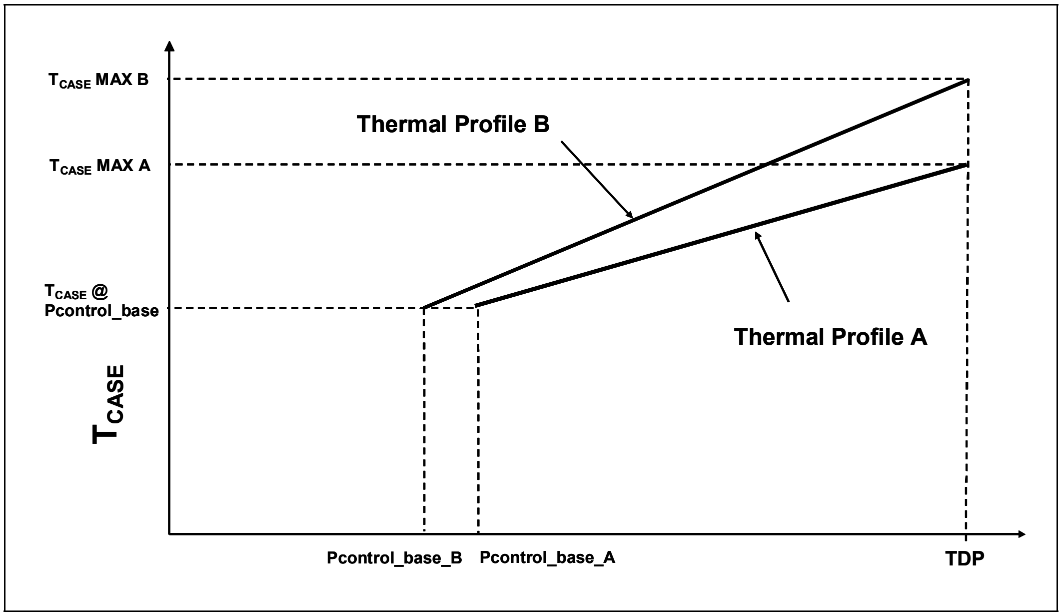
Since $T_{CONTROL}$ is a processor diode temperature value, an equivalent T_{CASE} temperature must be determined to plot the T_{CASE} MAX @ $T_{CONTROL}$ point on the Thermal Profile graph. Location 1 on the Thermal Profile represents a T_{CASE} value corresponding to an Offset of 0 (the theoretical minimum for the given processor family). Any Offset value greater than 0 moves the point where the Thermal Profile must be met upwards, as shown by location 2 on the graph. If the diode temperature is less than $T_{CONTROL}$, then the case temperature is permitted to exceed the Thermal Profile, but the diode temperature must remain at or below $T_{CONTROL}$. In other words, there is no T_{CASE} specification for the processor at power levels less than Pcontrol. The thermal solution for the processor must be able to keep the processor's T_{CASE} at or below the T_{CASE} values defined by the Thermal Profile between the T_{CASE}MAX @$T_{CONTROL}$ and T_{CASE}MAX points at the corresponding power levels.

Refer to Chapter 2.3.1 for the implementation of the $T_{CONTROL}$ value in support of fan speed control (FSC) design to achieve better acoustic performance.

2.2.3 Dual Thermal Profile Concept for the Intel® Xeon™ Processor with 800 MHz System Bus

The Intel Xeon Processor with 800 MHz System Bus is designed to go into various form factors, including the volumetrically constrained 1U and custom blade form factors. Due to certain limitations of such form factors (i.e. airflow, thermal solution height), it is very challenging to meet the thermal requirements of the processor. To mitigate these form factor constraints, Intel has developed a dual Thermal Profile specification, shown in Figure 2-4.

Figure 2-4. Dual Thermal Profile Diagram



The Thermal Profile A is based on Intel's 2U+ air cooling solution. Designing to Thermal Profile A ensures that no measurable performance loss due to Thermal Control Circuit (TCC) activation is observed in the processor. It is expected that TCC would only be activated for very brief periods of time when running a worst-case real world application in a worst-case thermal condition. These brief instances of TCC activation are not expected to impact the performance of the processor. A worst case real world application is defined as a commercially available, useful application which dissipates a power equal to, or above, the TDP for a thermally relevant timeframe. One example of a worst-case thermal condition is when a processor local ambient temperature is at or above 43 °C for Intel Xeon Processor with 800 MHz System Bus Thermal Profile A.

Thermal Profile B supports volumetrically constrained platforms (i.e. 1U, blades, etc), and is based on Intel's 1U air cooling solution. Because of the reduced capability represented by such thermal solutions, designing to Thermal Profile B results in an increased probability of TCC activation and an associated measurable performance loss. Refer to Appendix F for more details on the Thermal Monitor features. Measurable performance loss is defined to be any degradation in the processor's performance greater than 1.5%. The 1.5% number is chosen as the baseline since the run-to-run variation in a given performance benchmark is typically between 1 - 2%.

Although designing to Thermal Profile B results in increased T_{CASE} temperatures compared to Thermal Profile A at a given power level, both of these Themal Profiles ensure that Intel's long-term processor reliability requirements are satisfied. In other words, designing to Thermal Profile

B does not impose any additional risk to Intel's long-term reliability requirements. Thermal solutions that exceed Thermal Profile B specification are considered incompliant and will adversely affect the long-term reliability of the processor.

Refer to the Intel Xeon Processor with 800 MHz System Bus or Chapter 2.2.4 for the Thermal Profile A and Thermal Profile B specifications. Chapter 2.4 of this document also provides details on the 2U+ and 1U Intel reference thermal solutions that are designed to meet the Intel Xeon Processor with 800 MHz System Bus Thermal Profile A and Thermal Profile B respectively.

2.2.4 Performance Targets

The Thermal Profile specifications for this processor are published in the *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet*. These Thermal Profile specifications are to be used as a reference in the subsequent discussions.

The thermal specifications shown in this graph are for reference only. Refer to the *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet* for the Thermal Profile specifications. In case of conflict, the data information in the EMTS supersedes any data in this figure.

Table 2-6 describes thermal performance targets for the processor cooling solution enabled by Intel..

Table 2-6. Intel Reference Heatsink Performance Targets for the Intel® Xeon™ Processor with 800 MHz System Bus

Thermal Solution Type	Target Thermal Profile	T_{LA} Assumption (°C)	TDP (W)	Thermal Performance Target, Ψca (Mean + 3σ)(°C/W)
2U+ Form Factor	Thermal Profile A	40°C	103	305
1U Form Factor	Thermal Profile B	40°C	103	0.384

2.2.5 Altitude

The reference heatsink solutions will be evaluated at sea level (0 meters). The system designers who need to account for altitude effects in the overall system thermal design must make sure that either Thermal Profile A or B specification for the processor is met at the targeted altitude.

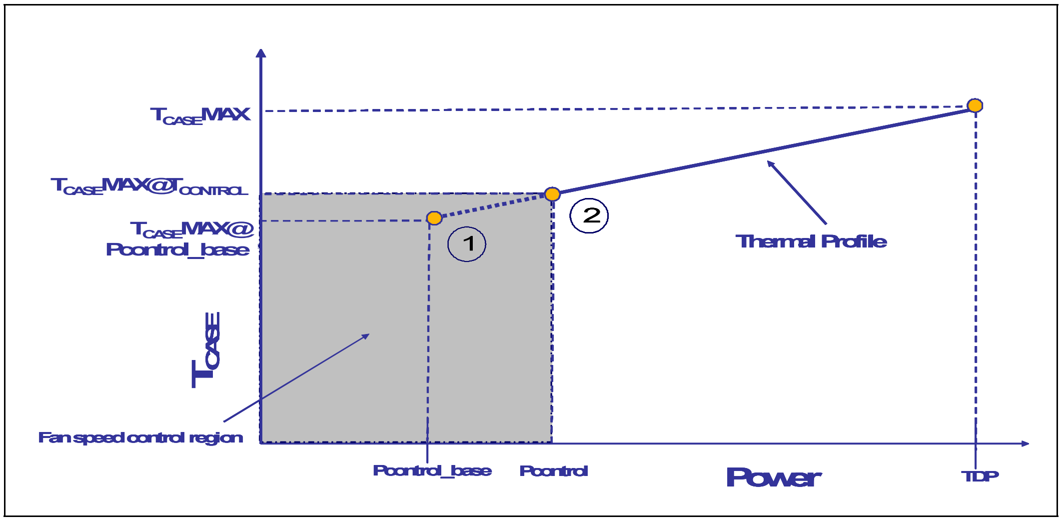
2.3 Characterizing Cooling Solution Performance Requirements

2.3.1 Fan Speed Control

Fan speed control (FSC) techniques to reduce system level acoustic noise are a common practice in server designs. The fan speed is one of the parameters that determine the amount of airflow provided to the thermal solution. Additionally, airflow is proportional to a thermal solution's performance, which consequently determines the T_{CASE} of the processor at a given power level. Since the T_{CASE} of a processor is an important parameter in the long-term reliability of a processor, the FSC implemented in a system directly correlates to the processor's ability to meet the Thermal

Profile and hence the long-term reliability requirements. For this purpose, Intel has defined a new parameter, called $T_{CONTROL}$ as explained in Chapter 2.2.2, to be used in FSC designs to ensure that the long-term reliability of the processor is met while keeping the system level acoustic noise down. Figure 2-5 depicts the relationship between $T_{CONTROL}$ and FSC methodology.

Figure 2-5. $T_{CONTROL}$ and Fan Speed Control



Once the $T_{CONTROL}$ value is determined as explained earlier, the thermal diode temperature reading from the processor can be compared to this $T_{CONTROL}$ value. A fan speed control scheme can be implemented as described inTable 2-7 without compromising the long-term reliability of the processor.

Table 2-7. Fan Speed Control, $T_{CONTROL}$ and T_{DIODE} Relationship

Condition	FSC Scheme
TDIODE = TCONTROL	FSC can adjust fan speed to maintain TDIODE = TCONTROL (low acoustic region).
TDIODE > TCONTROL	FSC should adjust fan speed to keep TCASE at or below the Thermal Profile specification (increased acoustic region).

There are many different ways of implementing fan speed control, including FSC based on processor ambient temperature, FSC based on processor thermal diode temperature (T_{DIODE}) or a combination of the two. If FSC is based only on the processor ambient temperature, low acoustic targets can be achieved under low ambient temperature conditions. However, the acoustics cannot be optimized based on the behavior of the processor temperature. If FSC is based only on the thermal diode, sustained temperatures above $T_{CONTROL}$, drives fans to maximum RPM. If FSC is based both on ambient and thermal diode, ambient temperature can be used to scale the fan RPM controlled by the thermal diode. This would result in an optimal acoustic performance. Regardless of which scheme is employed, system designers must ensure that the Thermal Profile specification is met when the processor diode temperature exceeds the T_{CONTOL} value for a given processor.

2.3.2 Processor Thermal Characterization Parameter Relationships

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 conditions (heating source, local ambient conditions). A thermal characterization parameter is convenient in that it is calculated using total package power, whereas actual thermal resistance, θ (theta), is calculated using actual power dissipated between two points. Measuring actual power dissipated into the heatsink is difficult, since some of the power is dissipated via heat transfer into the socket and board. Be aware, however, of the limitations of lumped parameters such as Ψ when it comes to a real design. Heat transfer is a three-dimensional phenomenon that can rarely be accurately and easily modeled by lump values.

The 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 8. $\Psi_{CA} = (T_{CASE} - T_{LA}) / TDP$

Where:

Ψ_{CA} = Case-to-local ambient thermal characterization parameter (°C/W).
T_{CASE} = Processor case temperature (°C).
T_{LA} = Local ambient temperature in chassis at processor (°C).
P_D = TDP dissipation (W) (assumes all power dissipates through the integrated heat spreader (IHS)).

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

Equation 9. $\Psi_{CA} = \Psi_{CS} + \Psi_{SA}$

Where:

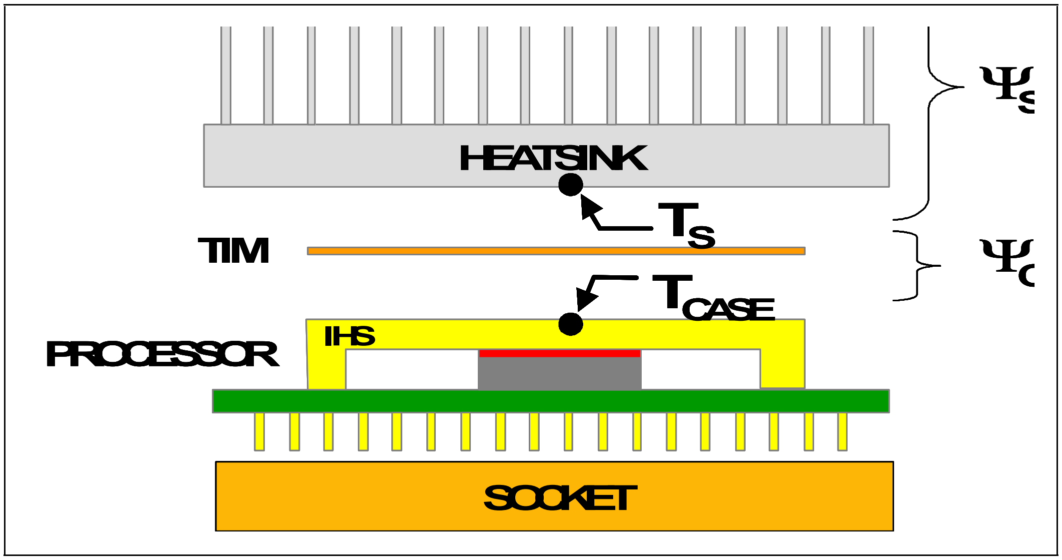
Ψ_{CS} = Thermal characterization parameter of the TIM (°C/W).
Ψ_{SA} = Thermal characterization parameter from heatsink-to-local ambient (°C/W).

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

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

Figure 2-6 illustrates the combination of the different thermal characterization parameters.

Figure 2-6. Processor Thermal Characterization Parameter Relationships



2.3.2.1 Example

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

- Define a target case temperature $T_{CASE\text{-}MAX}$ and corresponding TDP at a target frequency, F, given in the *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet.*
- Define a target local ambient temperature at the processor, T_{LA}.

Since the processor thermal specifications ($T_{CASE\text{-}MAX}$ and TDP) can vary with the processor frequency, it may be important to identify the worse case (lowest Ψ_{CA}) for a targeted chassis (characterized by T_{LA}) 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 *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet* TDP is 85 W and the case temperature specification is 68 °C for a given frequency. Assume as well that the system airflow has been designed such that the local processor ambient temperature is 4 5°C. Then the following could be calculated using equation 1 from above for the given frequency:

Equation 10. $\Psi_{CA} = (T_{CASE} - T_{LA}) / TDP = (68 - 45) / 85 = 0.27\ °C/W$

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

Equation 11. $\Psi_{SA} = \Psi_{CA} - \Psi_{CS} = 0.27 - 0.05 = 0.22$ °C/W

If the local processor ambient temperature is assumed to be 40°C, the same calculation can be carried out to determine the new case-to-ambient thermal resistance:

Equation 12. $\Psi_{CA} = (T_{CASE} – T_{LA}) / TDP = (68 – 40) / 85 = 0.33$ °C/W

It is evident from the above calculations that, a reduction in the local processor ambient temperature has a significant positive effect on the case-to-ambient thermal resistance requirement.

2.3.3 Chassis Thermal Design Considerations

2.3.3.1 Chassis Thermal Design Capabilities and Improvements

One of the critical parameters in thermal design is the local ambient temperature assumption of the processor. Keeping the external chassis temperature fixed, internal chassis temperature rise is the only component that can affect the processor local ambient temperature. Every degree gained at the local ambient temperature directly translates into a degree relief in the processor case temperature.

Given the thermal targets for the processor, it is extremely important to optimize the chassis design to minimize the air temperature rise upstream to the processor (T_{rise}), hence minimizing the processor local ambient temperature.

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, vents and other heat generating components determine the chassis thermal performance, and the resulting ambient temperature around the processor. The size and type (passive or active) of the thermal solution and the amount of system airflow can be traded off against each other to meet specific system design constraints. Additional constraints are board layout, spacing, component placement, and structural considerations that limit the thermal solution size.

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.

2.4 Thermal/Mechanical Reference Design Considerations

2.4.1 Heatsink Solutions

2.4.1.1 Heatsink Design Considerations

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

- **The area of the surface on which the heat transfer takes place -** Without any enhancements, this is the surface of the processor package IHS. One method used to improve thermal performance is by attaching a heatsink to the IHS. A heatsink can increase the effective heat transfer surface area by conducting heat out of the IHS and into the surrounding air through fins attached to the heatsink base.
- **The conduction path from the heat source to the heatsink fins -** Providing a direct conduction path from the heat source to the heatsink fins and selecting materials with higher thermal conductivity typically improves heatsink performance. The length, thickness, and conductivity of the conduction path from the heat source to the fins directly impact the thermal performance of the heatsink. In particular, the quality of the contact between the package IHS and the heatsink base has a higher impact on the overall thermal solution performance as processor cooling requirements become strict. Thermal interface material (TIM) is used to fill in the gap between the IHS and the bottom surface of the heatsink, and thereby improves the overall performance of the thermal stackup (IHS-TIM-Heatsink). With extremely poor heatsink interface flatness or roughness, TIM may not adequately fill the gap. The TIM thermal performance depends on its thermal conductivity as well as the pressure load applied to it. Refer to Chapter 2.4.2 for further information on the TIM 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_{LA}, and the local air velocity over the surface. The higher the air velocity over the surface, the resulting cooling is more efficient. 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 the fin faces and the heatsink base.

An active heatsink typically incorporates 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 slower air speed. Therefore these heatsinks are 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 will travel around the heatsink instead of through it, unless air bypass is carefully managed. Using air-ducting techniques to manage bypass area is an effective method for maximizing airflow through the heatsink fins.

2.4.2 Thermal Interface Material

TIM 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 TIM 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 TIM size.

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

The TIM performance is susceptible to degradation (i.e. grease breakdown) during the useful life of the processor due to the temperature cycling phenomena. For this reason, the measured T_{CASE} value of a given processor can decrease over time depending on the type of TIM material.

2.4.3 Summary

In summary, considerations in heatsink design include:

- The local ambient temperature T_{LA} at the heatsink, airflow (CFM), the power being dissipated by the processor, and the corresponding maximum T_{CASE}. These parameters are usually combined in a single lump cooling performance parameter, Ψ_{CA} (case to air thermal characterization parameter). More information on the definition and the use of Ψ_{CA} is given in Chapter 2.4 and Chapter 2.3.2.
- Heatsink interface (to IHS) surface characteristics, including flatness and roughness.
- The performance of the TIM used between the heatsink and the IHS.
- Surface area of the heatsink.
- Heatsink material and technology.
- Development of airflow entering and within the heatsink area.
- Physical volumetric constraints placed by the system.

2.4.4 Assembly Overview of the Intel Reference Thermal Mechanical Design

The reference design heatsinks that meets the Intel Xeon Processor with 800 MHz System Bus thermal performance targets are called the Common Enabling Kit (CEK) heatsinks, and are available in 1U, 2U& 2U+ sizes. Each CEK consists of the following components:

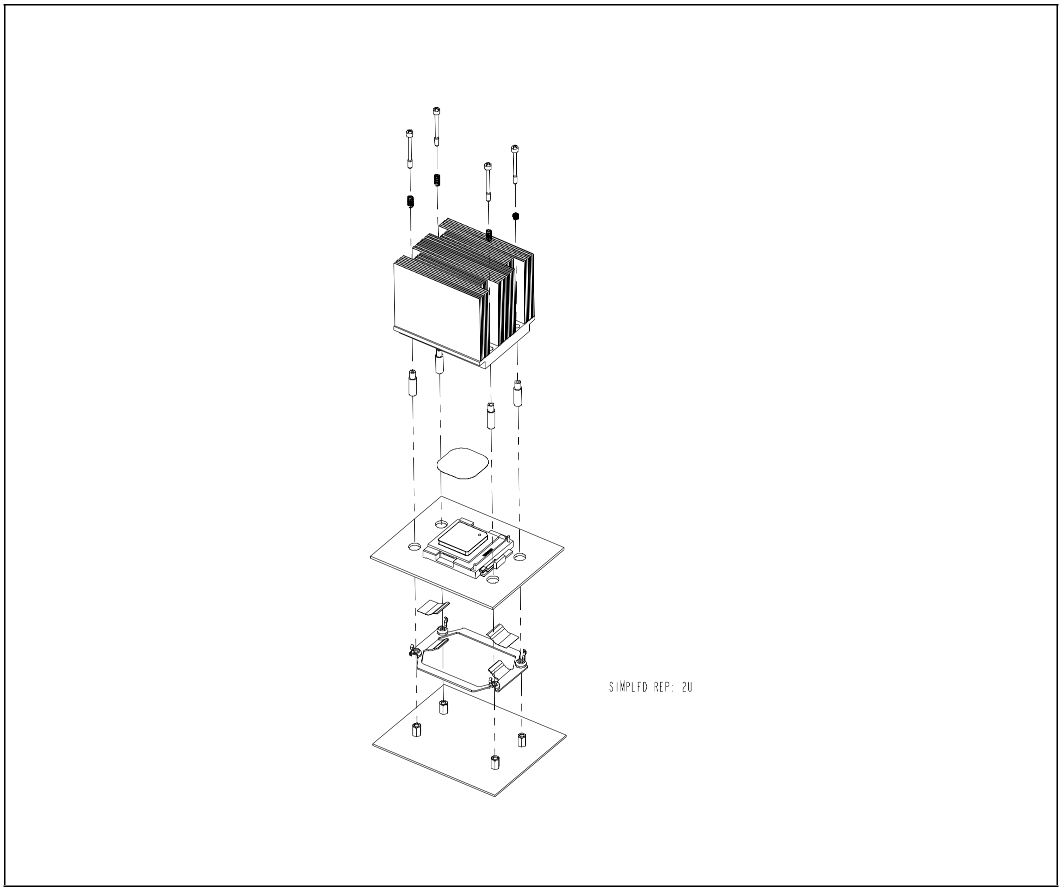
- Heatsink (with captive standoff and screws)
- Thermal Interface Material (TIM-2)
- Hat Spring

2.4.4.1 Geometric Envelope

The baseboard keepout zones on the primary and secondary sides and height restrictions under the enabling component region are shown in detail in Appendix A. The overall volumetric keep in zone encapsulates the processor, socket, and the entire thermal/mechanical enabling solution.

2.4.4.2 Assembly Drawing

Figure 2-7. Exploded View of CEK Thermal Solution Components



The CEK reference thermal solution is designed to extend air-cooling capability through the use of larger heatsinks with minimal airflow blockage and bypass. CEK retention solution can allow the use of much heavier heatsink masses compared to the legacy limits by using a load path directly attached to the chassis pan. The hat spring on the secondary side of the baseboard provides the necessary compressive load for the thermal interface material. The baseboard is intended to be isolated such that the dynamic loads from the heatsink are transferred to the chassis pan via the stiff screws and standoffs. This reduces the risk of package pullout and solder-joint failures.

The baseboard mounting holes for the CEK solution are at the same location as the hole locations used for previous Intel Xeon Processor thermal solution. However, CEK assembly requires 1.016 cm [0.400 in.] large diameter holes to compensate for the hat spring embosses.

The CEK solution is designed and optimized for a baseboard thickness range of 0.157 – 0.231 cm. [0.062-0.093 in]. While the same hat spring can be used for this board thickness range, the heatsink standoff height is different for a 0.157 cm [0.062 in] thick board than it is for a 0.231 cm. [0.093 in] thick board. In the heatsink assembly, the standoff protrusion from the base of the heatsink needs to be 0.06 cm. [0.024 in] longer for a 0.231 cm [0.093 in] thick board, compared to a 0.157 cm [0.062 in] thick board. .If this solution is intended to be used on baseboards that fall outside of this range, then some aspects of the design, including but not limited to the hat spring design and the standoff heights, may need to change. Therefore, system designers need to evaluate the thermal performance and mechanical behavior of the CEK design on baseboards with different thicknesses.

Refer to Appendix A for drawings of the heatsinks and hat spring. The screws and standoffs are standard components that are made captive to the heatsink for ease of handling and assembly.

Electronic versions of mechanical and thermal models of the CEK are available on http://www.developer.intel.com.

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

Note: The thermal mechanical reference design Appendix D for the Intel Xeon Processor with 800 MHz System Bus was verified according to the Intel validation criteria given in Appendix D. Any thermal mechanical design using some of the reference components in combination with any other thermal mechanical solution needs to be fully validated according to the customer criteria. Also, if customer thermal mechanical validation criteria differ from the Intel criteria, the reference solution should be validated against the customer criteria.

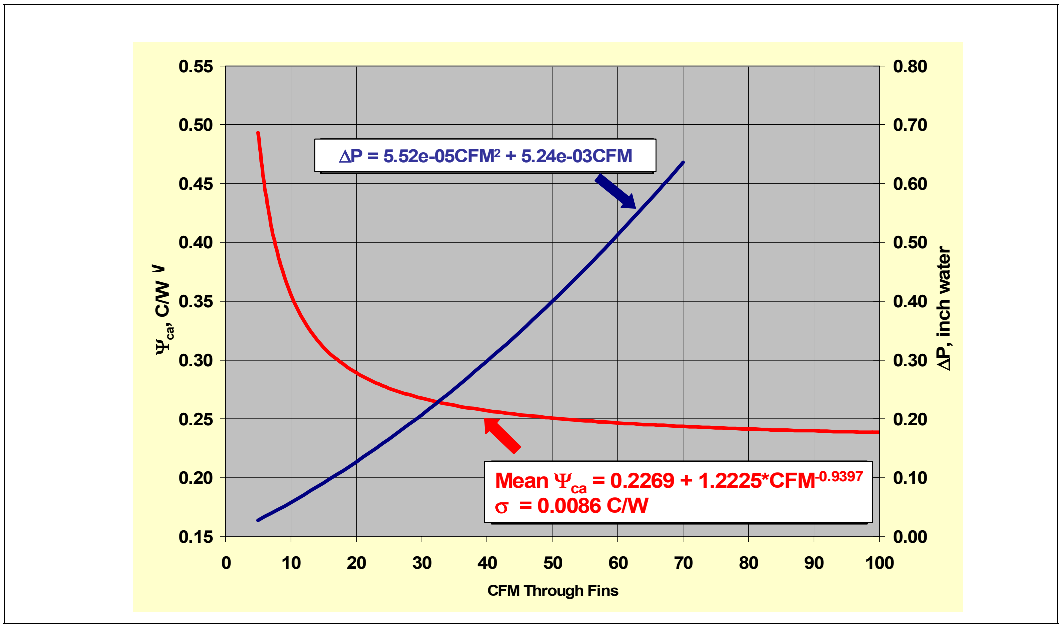
2.4.4.3 Structural Considerations of CEK

As Intel explores methods of keeping thermal solutions within the air-cooling space, the mass of the thermal solutions is increasing significantly. Due to the flexible nature (and associated large deformation) of baseboard-only attachments, Intel reference solutions, such as CEK, are now commonly using direct chassis attach (DCA) as the mechanical retention design. The mass of the new thermal solutions is large enough to require consideration for structural support and stiffening on the chassis.

2.4.5 Thermal Solution Performance Characteristics

The optimization of the CEK heatsinks for thermal performance has been completed. Figure 2-10 and Figure 2-11 show the performance of the 2U+ and 1U passive heatsinks, respectively. These figures show the thermal performance and the pressure drop through fins of the heatsink versus the airflow provided. The best-fit equations for these curves are also provided to make it easier for users to determine the desired value without any error associated with reading the graph.

Figure 2-8. 2U+ CEK Heatsink Thermal Performance



If other custom heatsinks are intended for use with the Intel Xeon Processor with 800 MHz System Bus, they must support the following interface control requirements to be compatible with the reference mechanical components.

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

Requirement 2: Maximum mass and center of gravity.

Current maximum heatsink mass is 1000 grams [2.2 lbs] and the maximum center of gravity 3.81 cm [1.5 in.] above the bottom of the heatsink base.

Requirement 3: Maximum and minimum compressive load.

Any custom thermal solution design should meet the loading specification as documented within this document, and should refer to the *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet* for specific details on package loading specifications.

2.4.6 Thermal Profile Adherence

The 2U+ CEK Intel reference thermal solution is designed to meet the Thermal Profile A for the Intel Xeon Processor with 800 MHz System Bus. From Table 2-6, the three-sigma (mean+3sigma) performance of the thermal solution is computed to be 0. °C/W and the processor local ambient temperature (T_{LA}) for this thermal solution is 40 °C. Hence, the Thermal Profile equation for this thermal solution is calculated as:

Equation 13. $y = 0.305x + 40$

where,

y = Processor T_{CASE} value (°C)

x = Processor power value (W)

Figure 2-13 below shows the comparison of this reference thermal solution's Thermal Profile to the Intel Xeon Processor with 800 MHz System Bus Thermal Profile A specification. The 2U+ CEK solution meets the Thermal Profile A with a 2.5 °C margin at the lower end (Pcontrol_base_A) and a 0.4 °C margin at the upper end (TDP). By designing to Thermal Profile A, it is ensured that no measurable performance loss due to TCC activation is observed under the given environmental conditions.

The 1U CEK Intel reference thermal solution is designed to meet the Thermal Profile B for the Intel Xeon Processor with 800 MHz System Bus. From Table 2-6 the three-sigma (mean+3sigma) performance of the thermal solution is computed to be 0. °C/W and the processor local ambient temperature (T_{LA}) for this thermal solution is 40 °C. Hence, the Thermal Profile equation for this thermal solution is calculated as:

Equation 14.

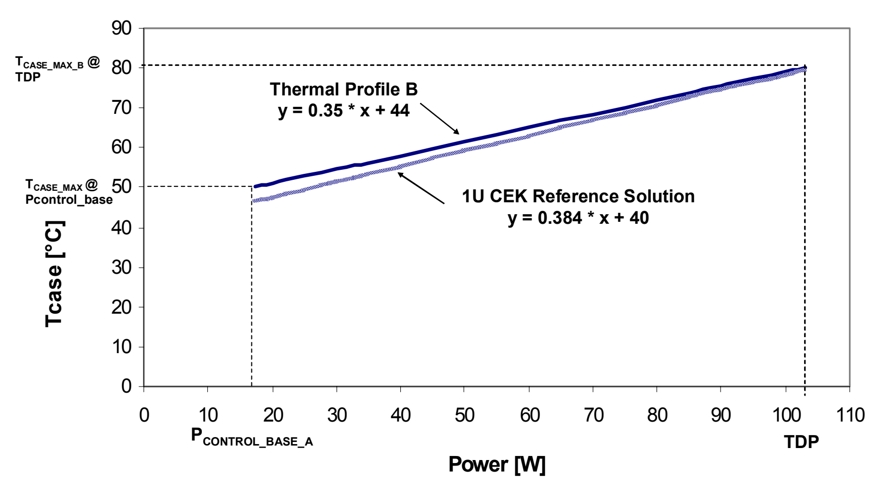
where,

y = Processor T_{CASE} value (°C)

x = Processor power value (W)

Figure 2-9 below shows the comparison of this reference thermal solution's Thermal Profile to the Intel Xeon Processor with 800 MHz System Bus Thermal Profile B specification. The 1U CEK solution meets the Thermal Profile B with a 3.4 °C margin at the lower end (Pcontrol_base_B) and a 0.5°C margin at the upper end (TDP). However, as explained in Chapter 2.2.3, designing to Thermal Profile B results in increased TCC activation and measurable performance loss for the processor. In this case, it is estimated that up to 5% of all the processors in a population that utilizes the 1U CEK reference solution may see TCC activation that results in a measurable performance loss of >1.5% when running an application that consumes power equivalent to TDP.

Figure 2-9. 1U CEK Thermal Adherence to Intel® Xeon™ Processor with 800 MHz System Bus Thermal Profile B

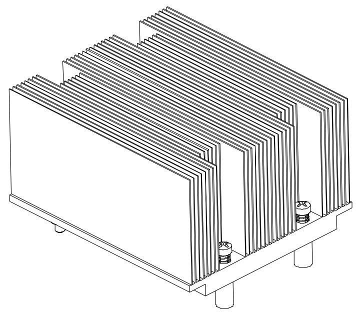


2.4.7 Components Overview

2.4.7.1 Heatsink with Captive Screws and Standoffs

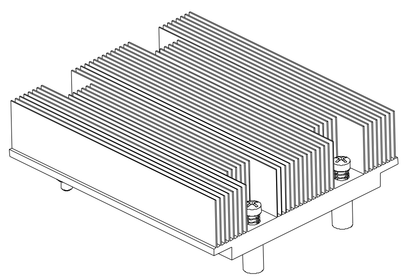
The CEK reference heatsink uses snapped-fin technology for its design. It consists of a copper base and copper fins with Shin-Etsu* G751 thermal grease as the TIM. The mounting screws and standoffs are also made captive to the heatsink base for ease of handling and assembly as shown in Figure 2-10 and Figure 2-11 for the 2U+ and 1U heatsinks, respectively.

Figure 2-10. Isometric View of the 2U+ CEK Heatsink



Note: Refer to Appendix A for more detailed mechanical drawings of the heatsink.

Figure 2-11. Isometric View of the 1U CEK Heatsink



Note: Refer to Appendix A for more detailed mechanical drawings of the heatsink.

The function of the standoffs is to provide a bridge between the chassis and the heatsink for attaching and load carrying. When assembled, the heatsink is rigid against the top of the standoff, and the standoff is rigid to a chassis standoff with the hat spring firmly sandwiched between the two. In dynamic loading situations the standoff carries much of the heatsink load, especially in lateral conditions, when compared to the amount of load transmitted to the processor package. As such, it is comprised of steel. The distance from the bottom of the heatsink to the bottom of the standoff is 1.02 cm [0.402 in.].

The function of the screw is to provide a rigid attach method to sandwich the entire CEK assembly together, activating the hat spring under the baseboard, and thus providing the TIM preload. A screw is an inexpensive, low profile solution that does not negatively impact the thermal performance of the heatsink due to air blockage. Any fastener (i.e. head configuration) can be used as long as it is of steel construction; the head does not interfere with the heatsink fins, and is of the correct length of 1.27 cm [0.50 in.].

Although the CEK heatsink fits into the legacy volumetric keep-in, it has a larger footprint due to the elimination of retention mechanism and clips used in the older enabled thermal/mechanical components. This allows the heatsink to grow its base and fin dimensions, further improving the thermal performance. A drawback of this enlarged size and use of copper for both the base and fins is the increased weight of the heatsink. The CEK heatsink is estimated to weigh twice as much as previous heatsinks used with Intel Xeon Processors. However, the new retention scheme employed by CEK is designed to support heavy heatsinks (approximately up to 1000 grams) in cases of shock, vibration and installation as explained in Appendix A. Some of the thermal and mechanical characteristics of the CEK heatsinks are shown in Table 2-15.

Table 2-15. CEK Heatsink Thermal Mechanical Characteristics

Size	Height (cm) [in.]	Weight (kg) [lbs]	Target Airflow Through Fins (CFM)	Mean Ψ_{ca} (°C/W)	Standard Deviation Ψ_{ca} (°C/W)	Pressure Drop (in H_2O)
2U+	5.08 [2.00]	1.0 [2.2]	22	0.280.245	0.0086	0.17
1U	2.64 [1.04]	680 [1.5]	15	0.352	0.0106	0.24

2.4.7.2 Thermal Interface Material (TIM-2)

A TIM must be applied between the package and the heatsink to ensure thermal conduction. The CEK reference design uses Shin-Etsu* G751 thermal grease.

The recommended grease dispenses weight to ensure full coverage of the processor IHS is given below. For an alternate TIM, full coverage of the entire processor IHS is recommended.

Table 2-16. Recommended Thermal Grease Dispense Weight

Processor	Recommended Thermal Grease	Dispense Weight (mg)
Intel Xeon Processor with 800 MHz System Bus	Shin-Etsu* G751	400

It is recommended that you use thermally conductive grease as the TIM requires special handling and dispense guidelines. The following guidelines apply to Shin-Etsu G751 thermal grease. The use of a semi-automatic dispensing system is recommended for high volume assembly to ensure an accurate amount of grease is dispensed on top of the IHS prior to assembly of the heatsink. A typical dispense system consists of an air pressure and timing controller, a hand held output dispenser, and an actuation foot switch. Thermal grease in cartridge form is required for dispense system compatibility. A precision scale with an accuracy of ±5 mg is recommended to measure the correct dispense weight and set the corresponding air pressure and duration. The IHS surface should be free of foreign materials prior to grease dispense

Additional recommendations include recalibrating the dispense controller settings after any two hour pause in grease dispense. The grease should be dispensed just prior to heatsink assembly to prevent any degradation in material performance. Finally, the thermal grease should be verified to be within its recommended shelf life before use.

The CEK reference solution is designed to apply a compressive load of up to N [lbf] on the TIM to improve the thermal performance.

2.4.7.3 Hat Spring

The hat spring, which is attached on the secondary side of the baseboard, is made from 0.80 mm [0.0315 in.] thick 301 stainless steel half hard. Any future versions of the spring will be made from a similar material. The hat spring has four embosses (called "hats") which, when assembled, rest on the top of the chassis standoffs. The hat spring is located between the chassis standoffs and the heatsink standoffs. The purpose of the hat spring is to provide compressive preload at the TIM interface when the baseboard is pushed down upon it. This spring does not function as a clip of any kind. The two tabs on the spring are used to provide the necessary compressive preload for the TIM when the whole solution is assembled. The tabs make contact on the secondary side of the baseboard. In order to avoid damage to the contact locations on the baseboard, the tabs will be insulated with a 0.127 mm [0.005 in.] thick Kapton* tape (or equivalent). Figure 2-12 shows an isometric view of the hat spring design.

Figure 2-12. Hat Spring Isometric View

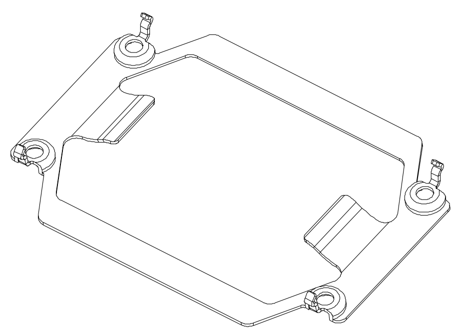
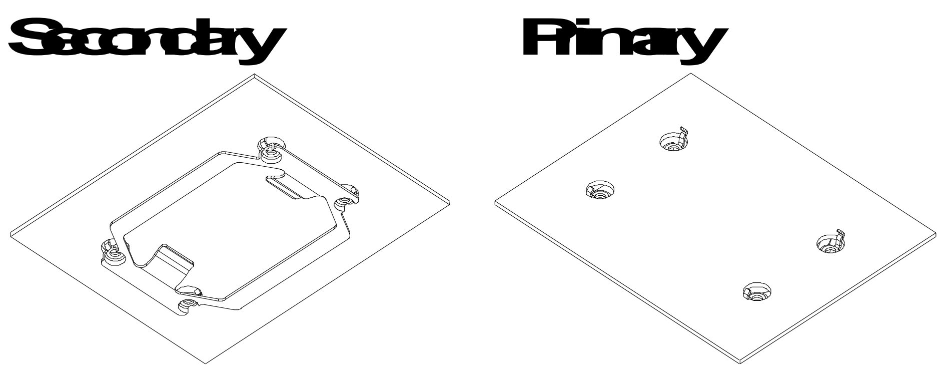


Figure 2-13. Isometric View of Hat Spring Attachment to the Base Board



Please refer to Appendix A for more detailed mechanical drawings of the hat spring. Also, the baseboard keepout requirements shown in Appendix A must be met to use this hat spring design.

2.4.8 Reference Active Thermal Solution for the Intel® Xeon™ Processor with 800 MHz System Bus

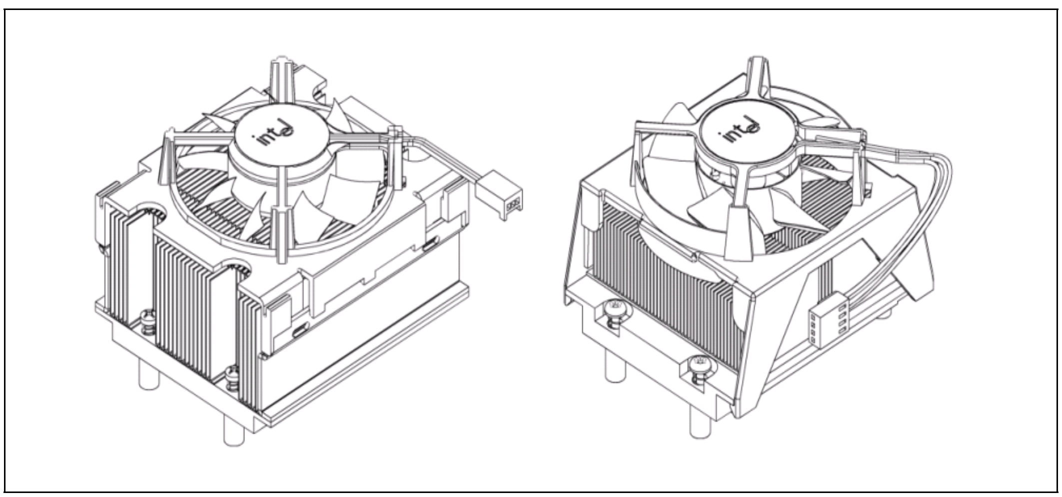
In addition to the 1U and 2U passive CEK heatsinks, Intel is developing an active version of the CEK heatsink for the Intel Xeon Processor with 800 MHz System Bus targeted at workstation chassis as well as server chassis which are 3U and above in height. All three heatsinks will be offered as part of boxed Intel Xeon Processor with 800 MHz System Bus products. These solutions are intended for system integrators who build systems from components available through distribution channels.

The active heatsink is primarily designed to be used in a pedestal chassis where sufficient air inlet space is present and side directional airflow is not an issue. The 1U and 2U passive heatsinkheatsinks require the use of chassis ducting and are targeted for use in rack mount servers. The retention solution used for these products is called the Common Enabling Kit, or CEK. The CEK base is compatible with all three heatsink solutions.

The active heatsink solution for the Intel Xeon Processor with 800 MHz System Bus will be transitioning after initial product introduction from a 3-pin thermistor controlled solution to a 4-pin pulse width modulated (PWM)T-diode controlled solution. This transition is being done to help customers meet acoustic targets in pedestal platforms, through the ability to directly control the active heatsink fan RPM. To properly support this new active heatsink solution it may be necessary to modify existing baseboard designs with 4-pin CPU fan headers. If a 4-pin active fan heatsink solution is plugged into the older 3-pin fan header the heatsink will revert back to a thermistor controlled mode. Please see the Section Chapter 2.5 Electrical Requirements section of this document for more details.

Figure 2-14 is a representation of the active heatsink solution that will be offered as part of a boxed Intel Xeon Processor with 800 MHz System Bus.

Figure 2-14. Active CEK Heatsink 3-Pin & 4-Pin (Representation Only)



2.4.9 Active Heatsink Weight

The 2U+ active heatsink solution will not exceed a mass of 1050 grams. Note that this is per processor, so a dual processor system will have up to 2100 grams total mass in the heatsinks. This large mass will require a minimum chassis stiffness to be met in order to withstand force during shock and vibration.

2.5 Electrical Requirements

2.5.1 Fan Power Supply (Active CEK)

Initially the boxed Intel Xeon Processor with 800 MHz System Bus will be introduced with a 3-pin active fan heatsink solution, This heatsink solution requires a constant +12 V supplied to pin 2 and does not support variable voltage speed control or 3-pin PWM control. Fan RPM is automatically varied based on the T_{INLET} temperature measured by a thermistor located at the fan inlet. See Table 2-18 for details on the 3-pin active heatsink solution connectors.

A new 4-pin PWM/T-diode controlled active fan heatsink solution will replace the 3-pin thermistor controlled solution after initial boxed Intel Xeon Processor with 800 MHz System Bus introduction. This new solution is being offered to help provide better control over pedestal chassis acoustics. This is achieved though more accurate measurement of processor die temperature through the processor's temperature diode (T-diode). Fan RPM is modulated through the use an ASIC located on the serverboard, that sends out a PWM control signal to the 4th pin of the connector labeled as **Control**. This heatsink solution also requires a constant +12 V supplied to pin 2 and does not support variable voltage control or 3-pin PWM control.

If the new 4-pin active fan heatsink solution is connected to an older 3-pin baseboard CPU fan header it will default back to a thermistor controlled mode, allowing compatibility with existing designs. It may be necessary to change existing baseboard designs to support this new 4-pin active heatsink solution if PWM/T-diode control is desired. It may also be necessary to verify that the larger 4-pin fan connector will not interfere with other components installed on the baseboard.

The fan power header on the baseboard must be positioned to allow the fan heatsink power cable to reach it. The fan power header identification and location must be documented in the suppliers platform documentation, or on the baseboard itself. The baseboard fan power header should be positioned within 177.8 mm [7 in.] from the center of the processor socket.

Table 2-17. PWM Fan Frequency Specifications (4-Pin Active CEK Heatsink)

Description	Min Frequency	Nominal Frequency	Max Frequency	Unit
PWM Control Frequency Range	21,000	25,000	28,000	Hz

Table 2-18. Fan Specifications (3-pin & 4-pin Active CEK Heatsink)

Description	Min	Typ Steady	Max Steady	Max Startup	Unit
+12 V: 12 volt fan power supply	10.8	12	12	13.2	V
IC: Fan Current Draw	N/A	1	1.25	1.5	A
SENSE: SENSE frequency	2	2	2	2	Pulses per fan revolution

Figure 2-15. Fan Cable Connector Pin Out (3-Pin Active CEK Heatsink)

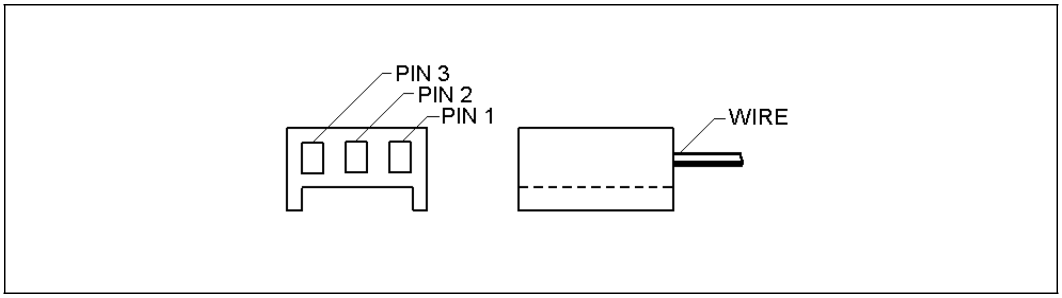


Table 2-19. Fan Cable Connector Pin Out (3-Pin Active CEK Heatsink)

Pin Number	Signal	Color
1	**Ground:**	Black
2	**Power:** (+12 V)	Yellow
3	**Sense:** 2 pulses per revolution	Green

Figure 2-16. Fan Cable Connector Pin Out (4-Pin Active CEK Heatsink)

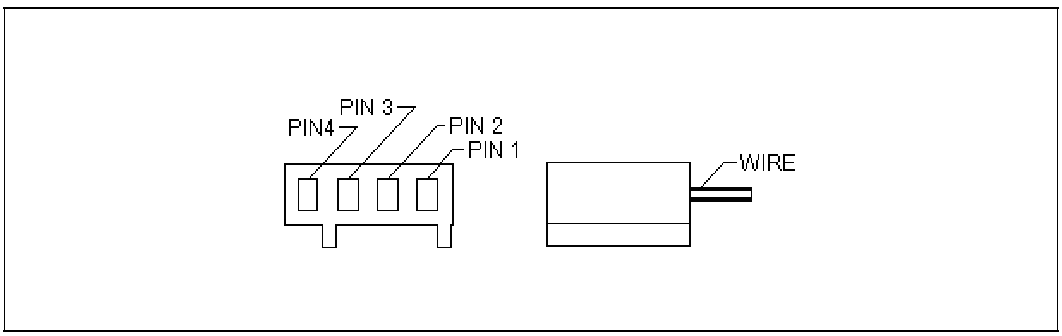


Table 2-20. Fan Cable Connector Pin Out (4-Pin Active CEK Heatsink)

Pin Number	Signal	Color
1	**Ground:**	Black
2	**Power:** (+12 V)	Yellow
3	**Sense:** 2 pulses per revolution	Green
4	**Control:** 21 KHz-28 KHz	Blue

Table 2-21. Fan Cable Connector Supplier & Part Number

Vendor	3-Pin Connector Part Number	4-Pin Connector Part Number
AMP	Fan Connector: 643815-3 Header: 640456-3	N/A
Walden Molex	Fan Connector: 22-01-3037 Header: 22-23-2031	Fan Connector: 47054-1000 Header: 47053-1000
Wieson	N/A	Fan Connector: 2510C888-001 Header: 2366C888-007
Foxconn	N/A	Fan Connector: N/A Header: HF27040-M1

2.5.1.1 2U+ Active CEK Heatsink (2U+ and above pedestal)

This heatsink was designed to help pedestal chassis users meet the thermal processor requirements without the use of chassis ducting. It may be necessary to implement some form of chassis air guide or air duct to meet the T_{LA} temperature of 40 °C depending on the pedestal chassis layout. Also, while the active heatsink solution is designed to mechanically fit into a 2U chassis, it may require additional space at the top of the heatsink to allow sufficient airflow into the heatsink fan. Therefore, additional design criteria may need to be considered if this heatsink is used in a 2U rack mount chassis, or in a chassis that has drive bay obstructions above the inlet to the fan heatsink.

Thermal Profile A should be used to help determine the thermal performance of the platform.

Once again It is recommended that the ambient air temperature outside of the chassis be kept at or below 35 °C. The air passing directly over the processor heatsink should not be preheated by other system components. Meeting the processor's temperature specification is the responsibility of the system integrator.

2.6 Boxed Processor Contents

A direct chassis attach method must be used to avoid problems related to shock and vibration, due to the weight of the heatsink required to cool the processor. The board must not bend beyond specification in order to avoid damage. The boxed processor contains the components necessary to solve both issues. The boxed processor will include the following items:

- Intel Xeon Processor with 800 MHz System Bus
- Unattached (Active or Passive) Heatsink
- 4 screws, 4 springs, and 4 heatsink standoffs (all captive to the heatsink)
- Thermal Interface Material (pre-applied on heatsink)
- Installation Manual
- Intel Inside® Logo

The other items that are required to compete this solution will be shipped with either the chassis or boards. They are as follows:

- CEK Spring (supplied by baseboard vendors)
- Heatsink standoffs (supplied by chassis vendors)

§

Mechanical Drawings A

The mechanical drawings included in this appendix. These drawings refer to the thermal mechanical enabling components for the Intel Xeon Processor with 800 MHz System Bus.

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

Table A-1. Mechanical Drawing List

Drawing Description	Figure Number
2U CEK Heatsink (Sheet 1 of 4)	Figure A-1
2U CEK Heatsink (Sheet 2 of 4)	Figure A-2
2U CEK Heatsink (Sheet 3 of 4)	Figure A-3
2U CEK Heatsink (Sheet 4 of 4)	Figure A-4
CEK Hat Spring (Sheet 1 of 3)	Figure A-5
CEK Hat Spring (Sheet 2 of 3)	Figure A-6
CEK Hat Spring (Sheet 3 of 3)	Figure A-7
Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 1 of 6)	Figure A-8
Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 2 of 6)	Figure A-9
Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 3 of 6)	Figure A-10
Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 4 of 6)	Figure A-11
Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 5 of 6)	Figure A-12
Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 6 of 6)	Figure A-13
1U CEK Heatsink (Sheet 1 of 4)	Figure A-14
1U CEK Heatsink (Sheet 2 of 4)	Figure A-15
1U CEK Heatsink (Sheet 3 of 4)	Figure A-16
1U CEK Heatsink (Sheet 4 of 4)	Figure A-17
4-pin Fan Cable Connector (for active CEK Heatsink)	Figure A-18
4-pin Baseboard Fan Header (for active CEK Heatsink)	Figure A-19

Figure A-1. 2U CEK Heatsink (Sheet 1 of 4)

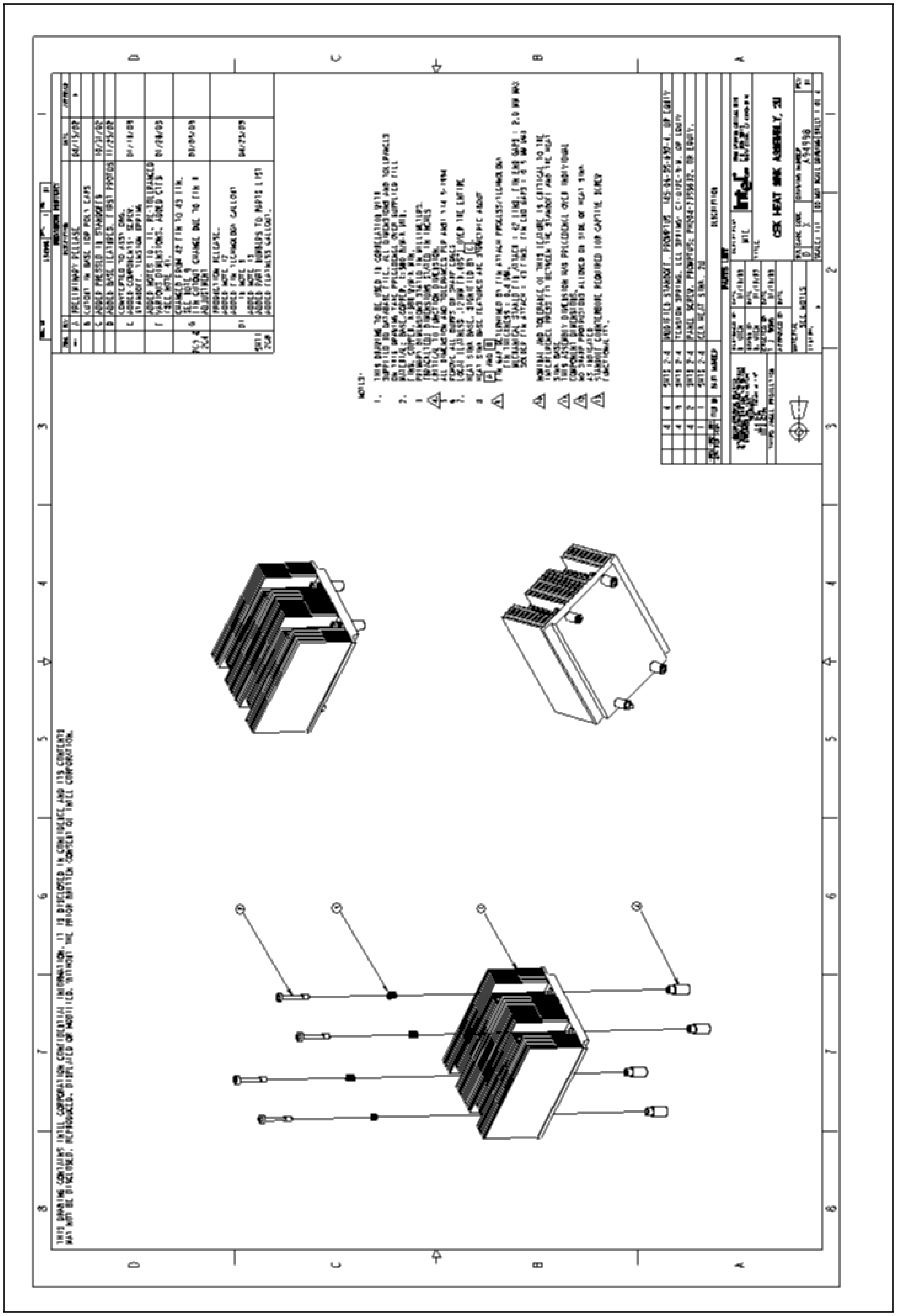


Figure A-2. 2U CEK Heatsink (Sheet 2 of 4)

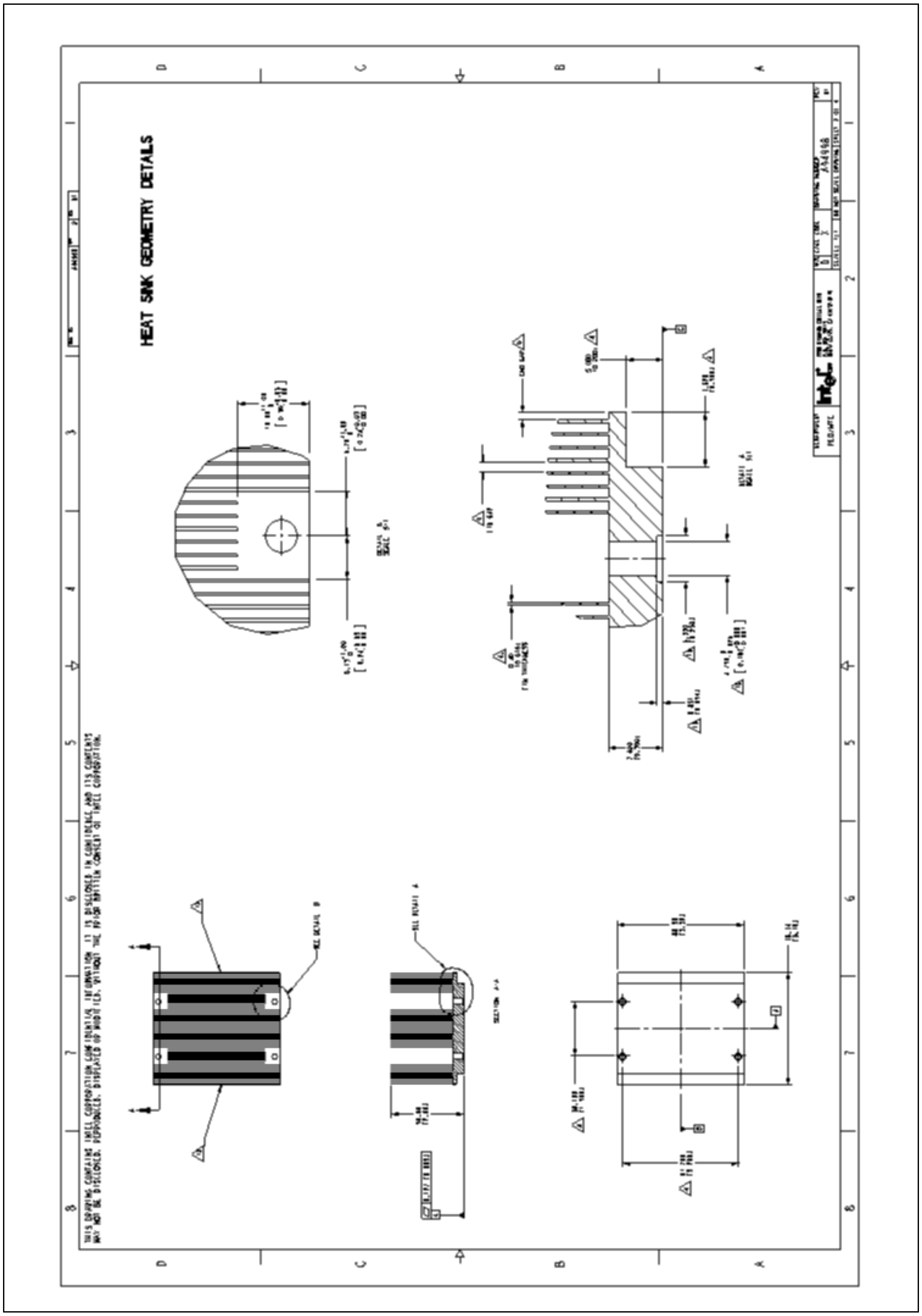


Figure A-3. 2U CEK Heatsink (Sheet 3 of 4)

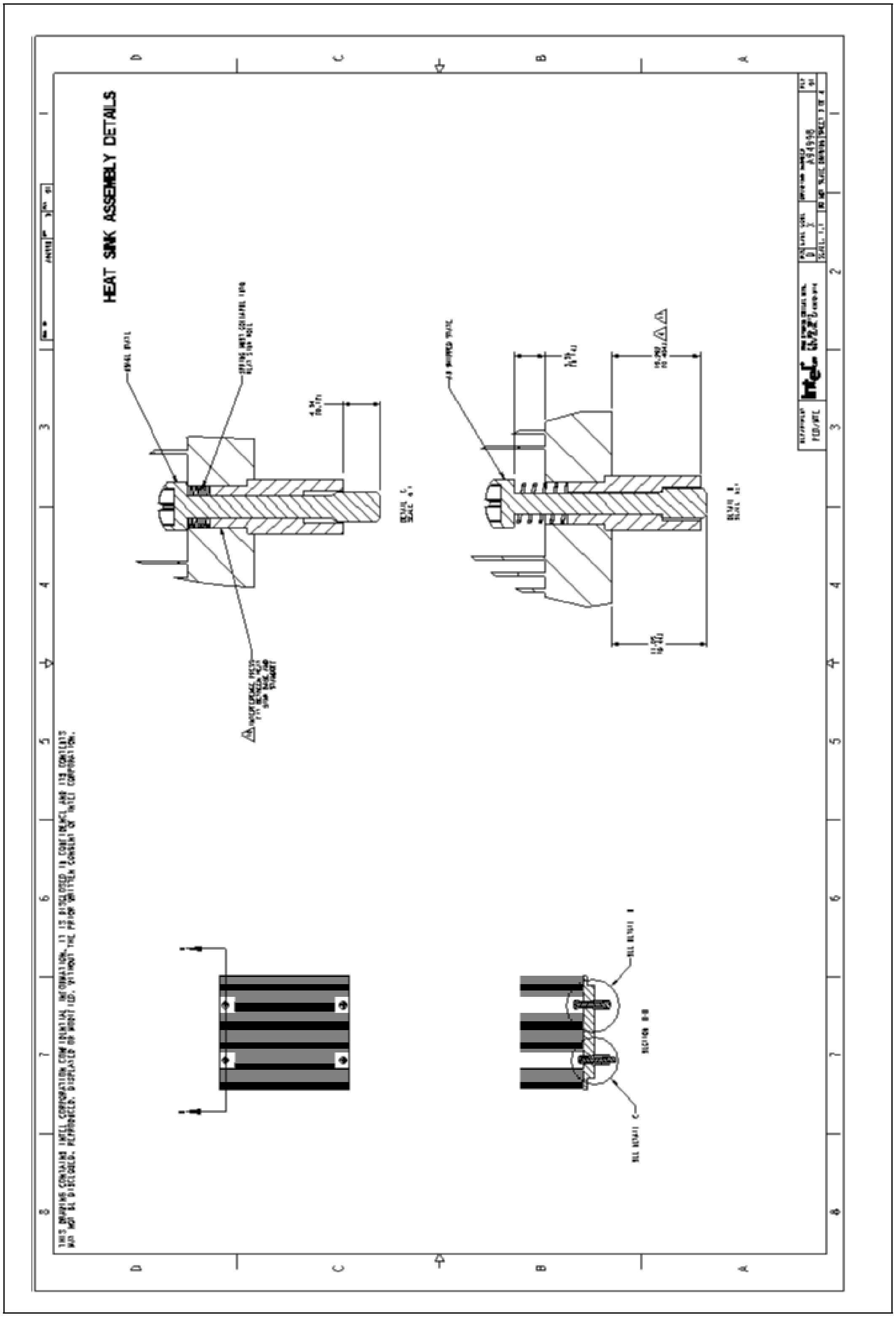


Figure A-4. 2U CEK Heatsink (Sheet 4 of 4)

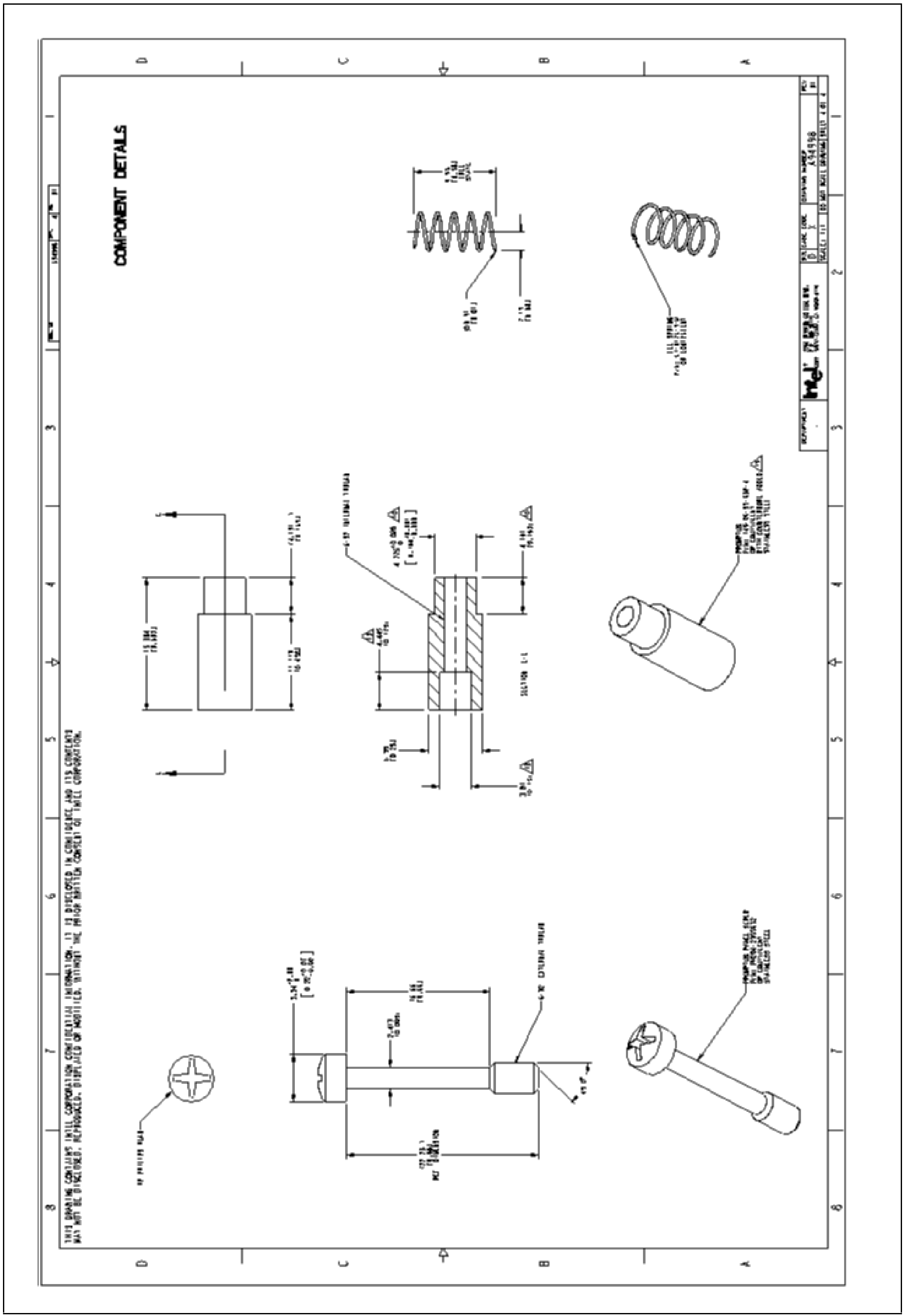


Figure A-5. CEK Hat Spring (Sheet 1 of 3)

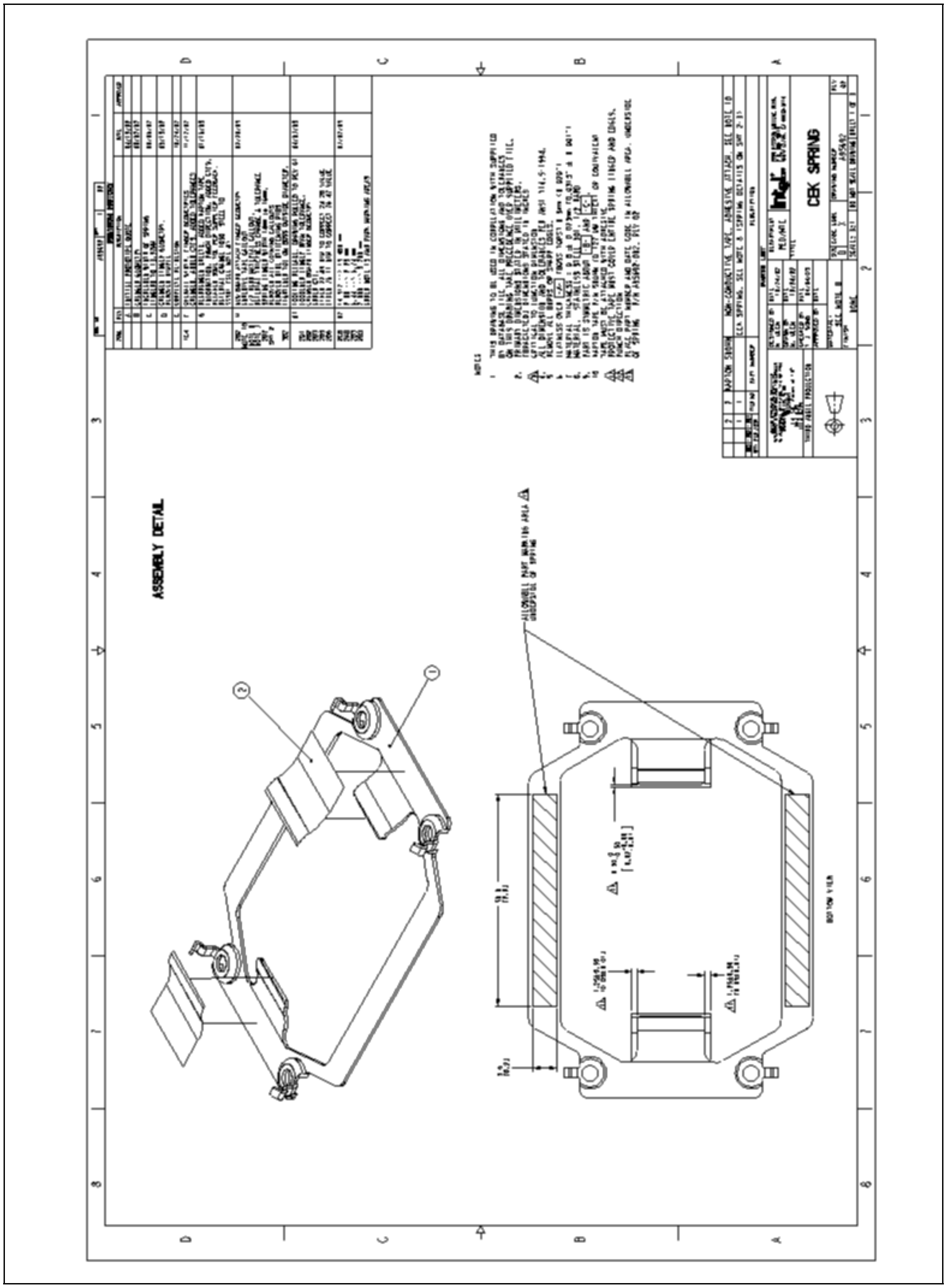


Figure A-6. CEK Hat Spring (Sheet 2of 3)

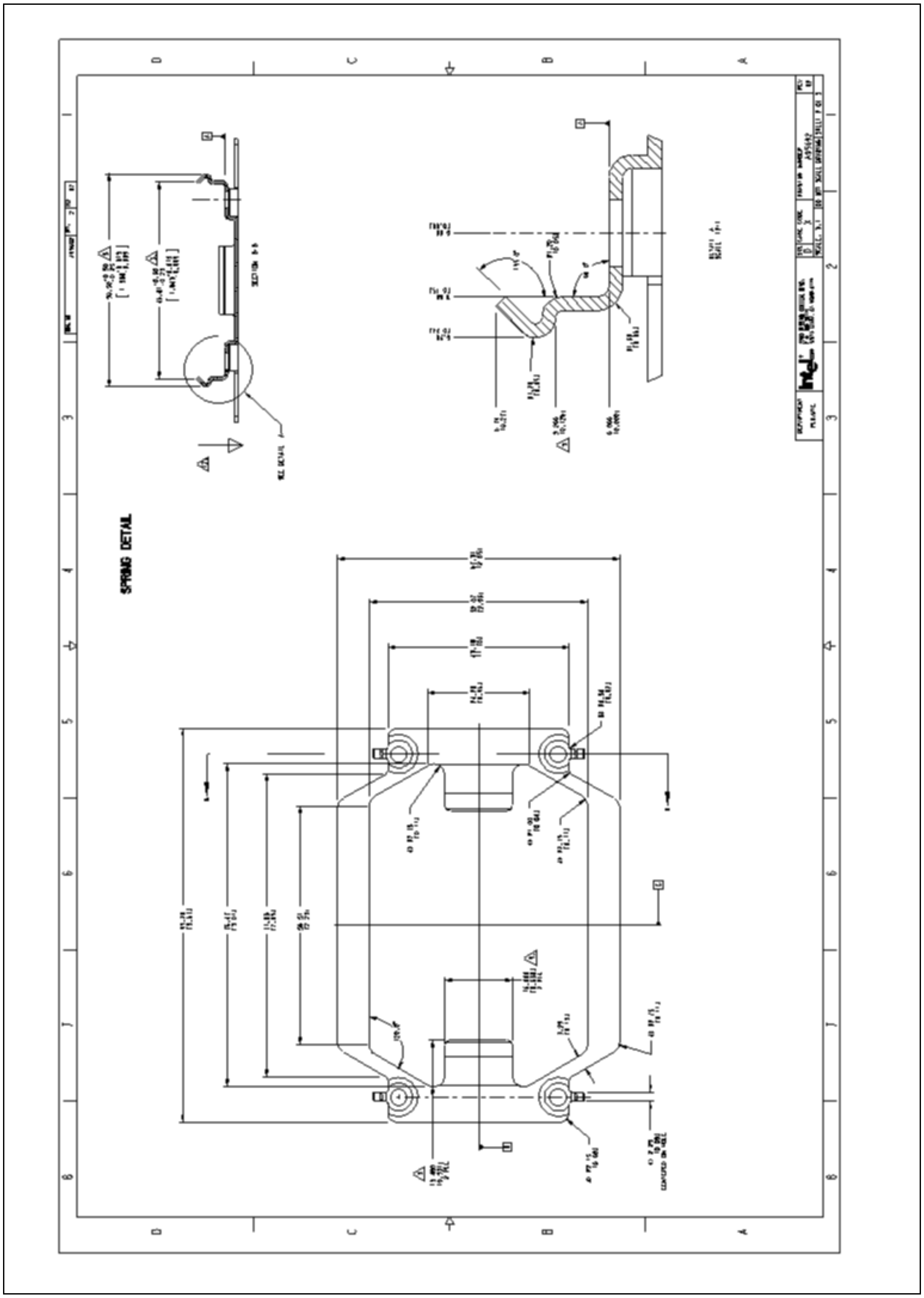


Figure A-7. CEK Hat Spring (Sheet 3 of 3)

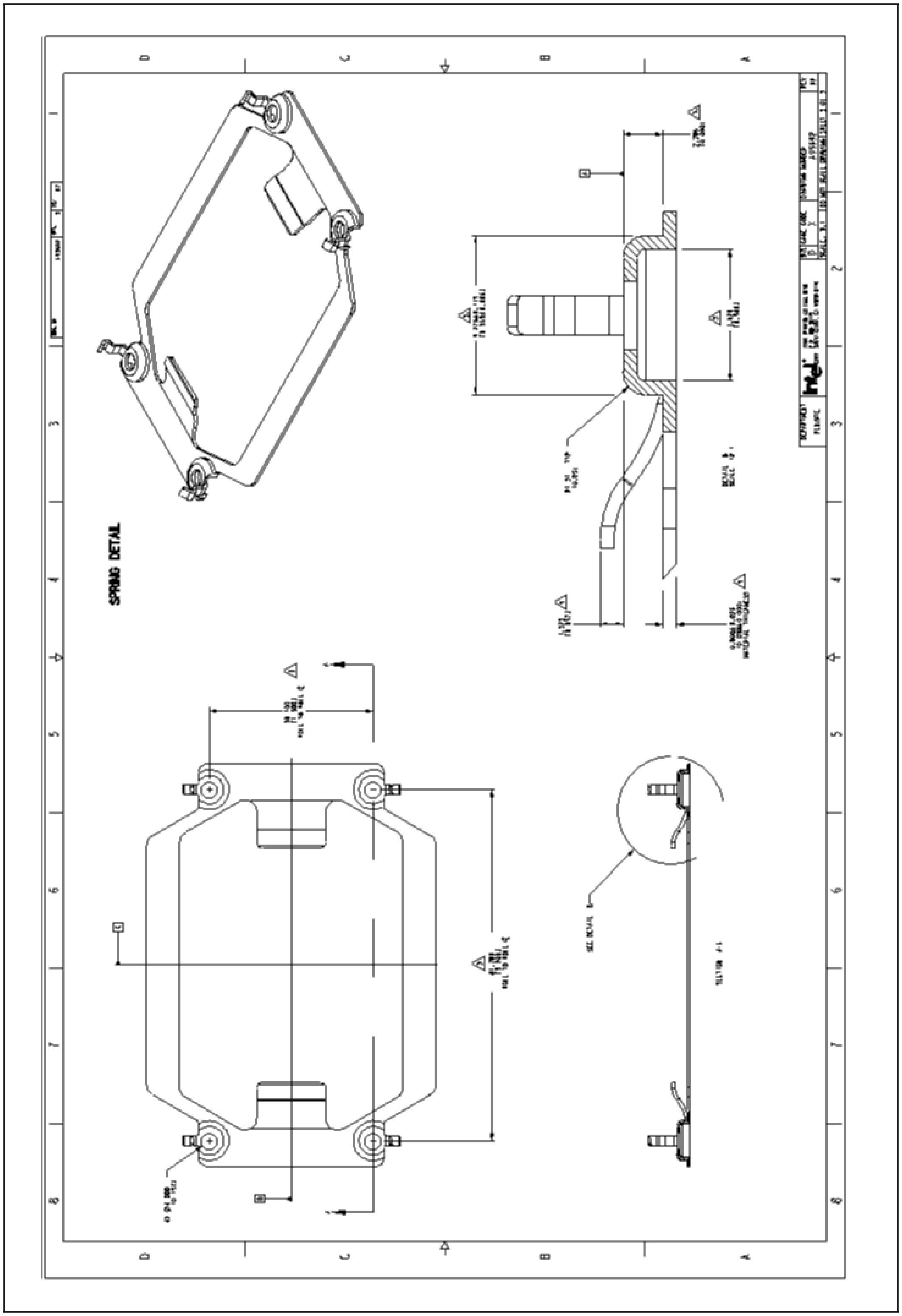


Figure A-8. Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 1 of 6)

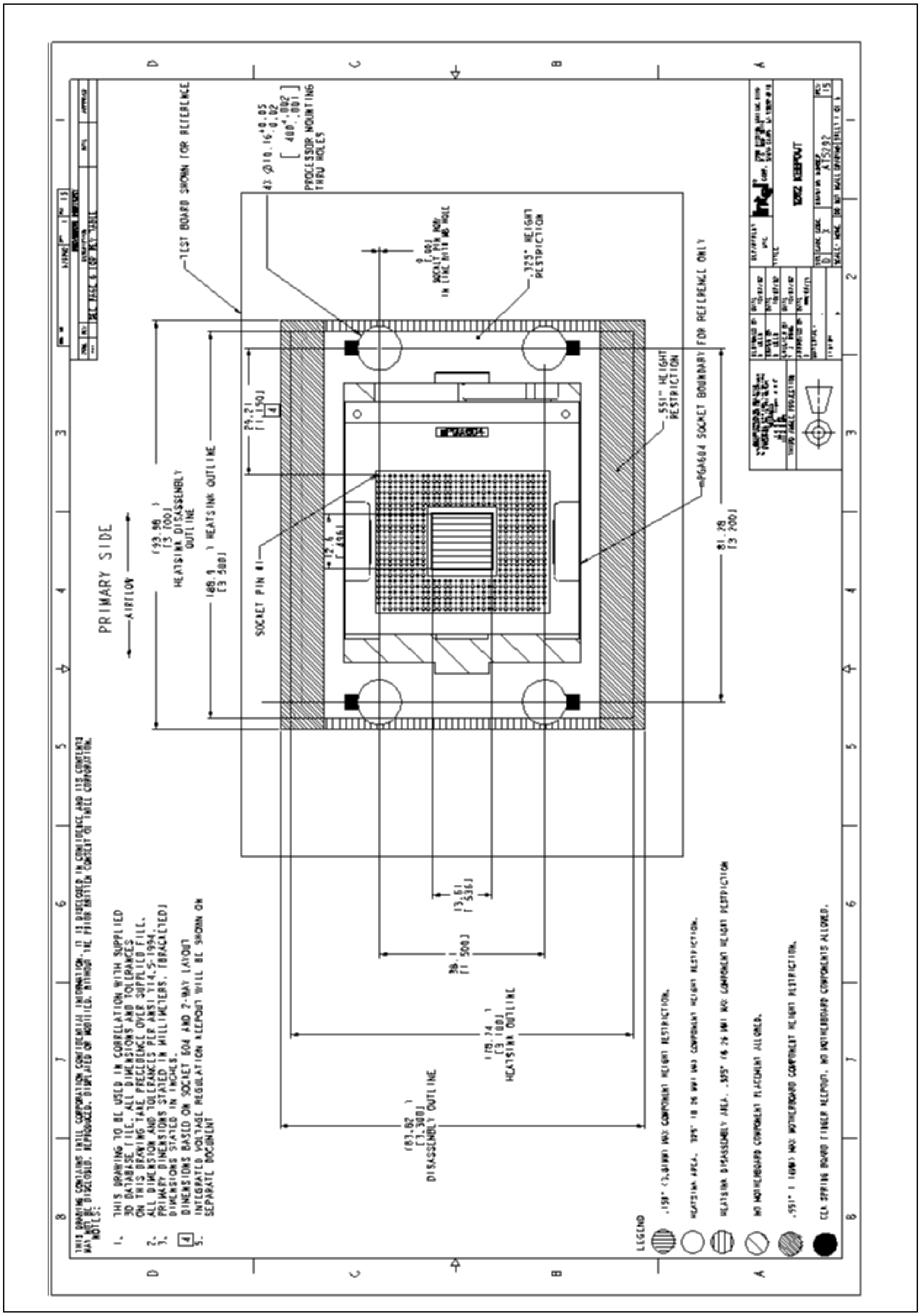


Figure A-9. Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 2 of 6)

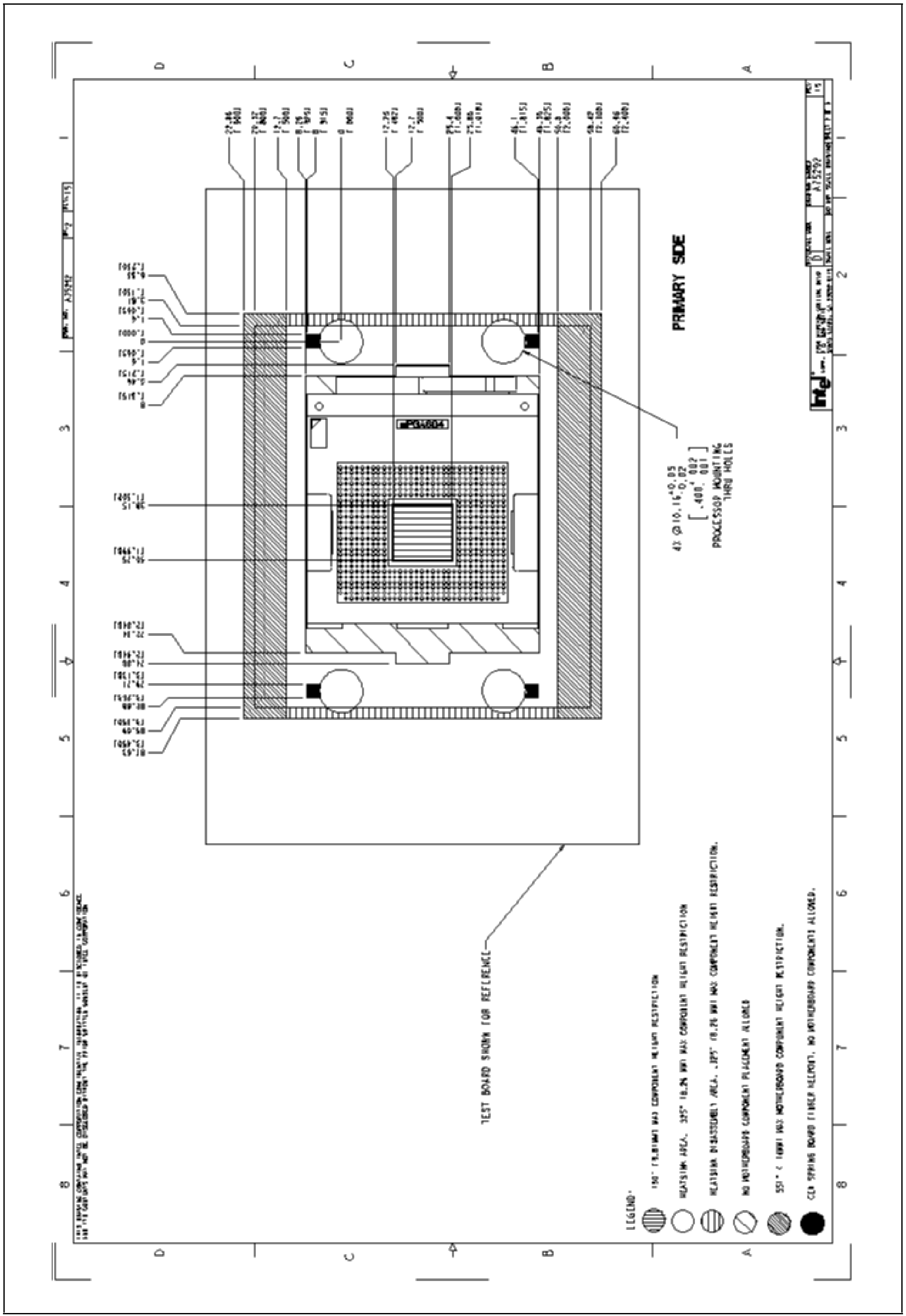


Figure A-10. Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 3 of 6)

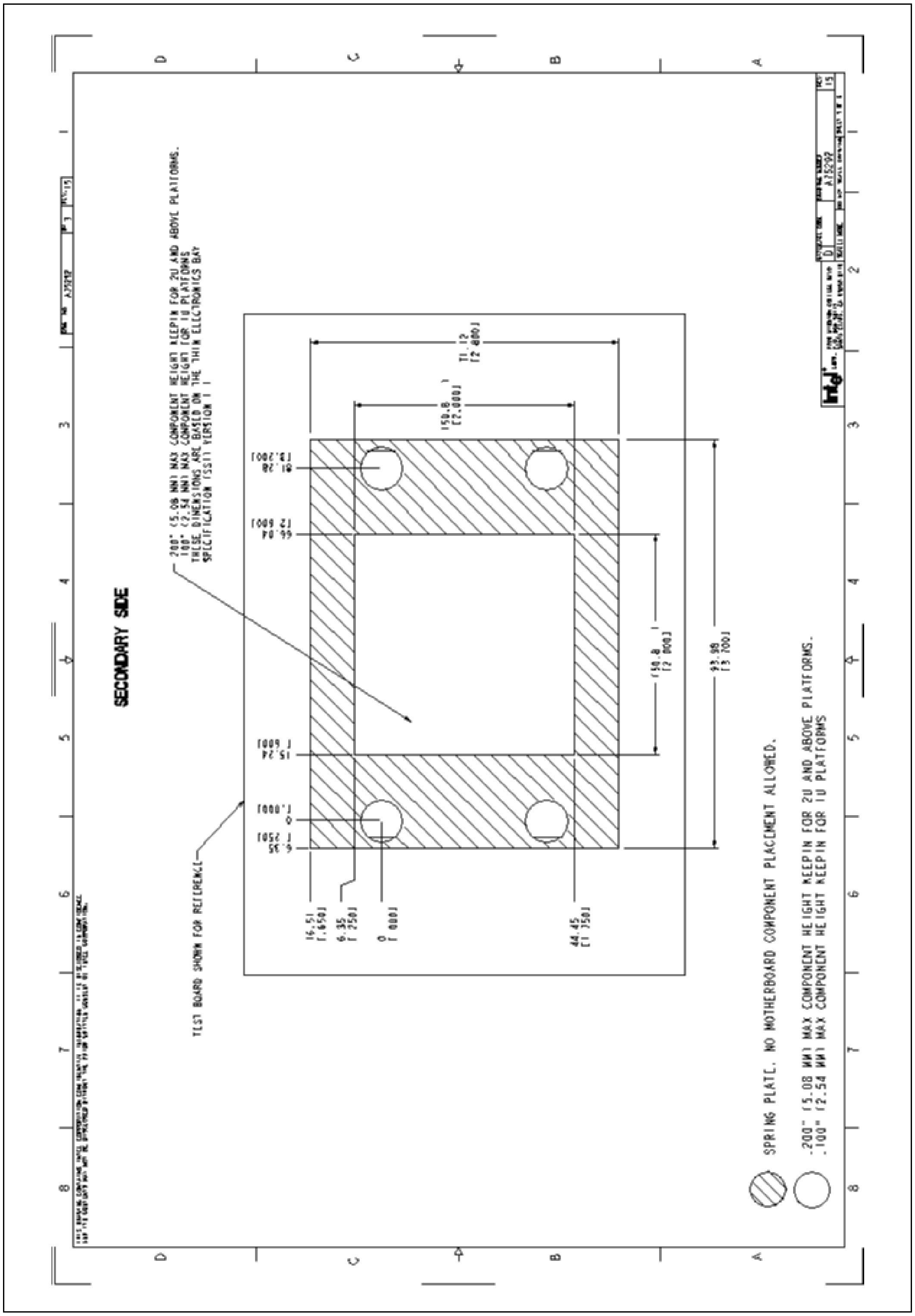


Figure A-11. Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 4 of 6)

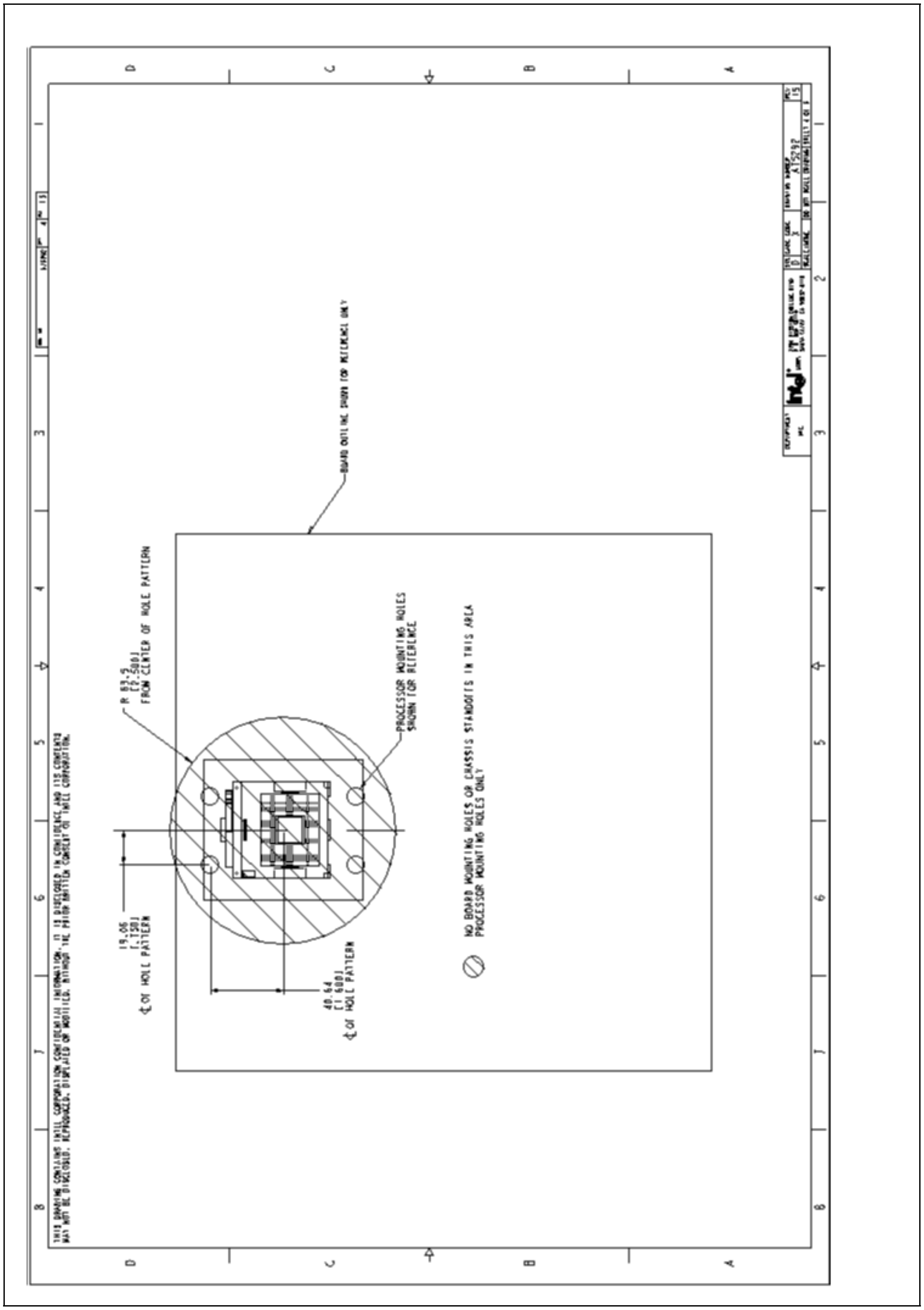


Figure A-12. Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 5 of 6)

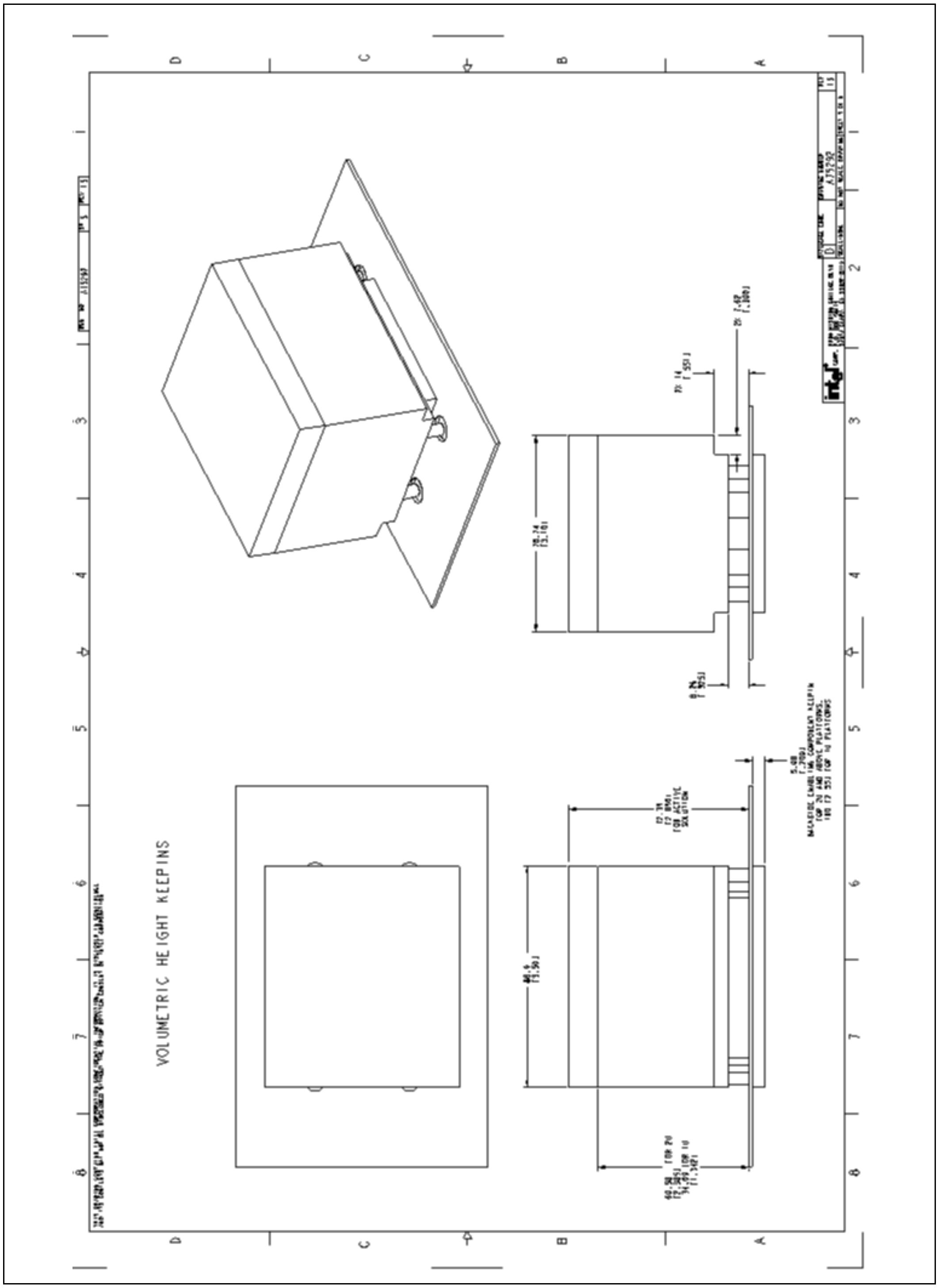


Figure A-13. Baseboard Keepout Footprint Definition and Height Restrictions for Enabling Components (Sheet 6 of 6)

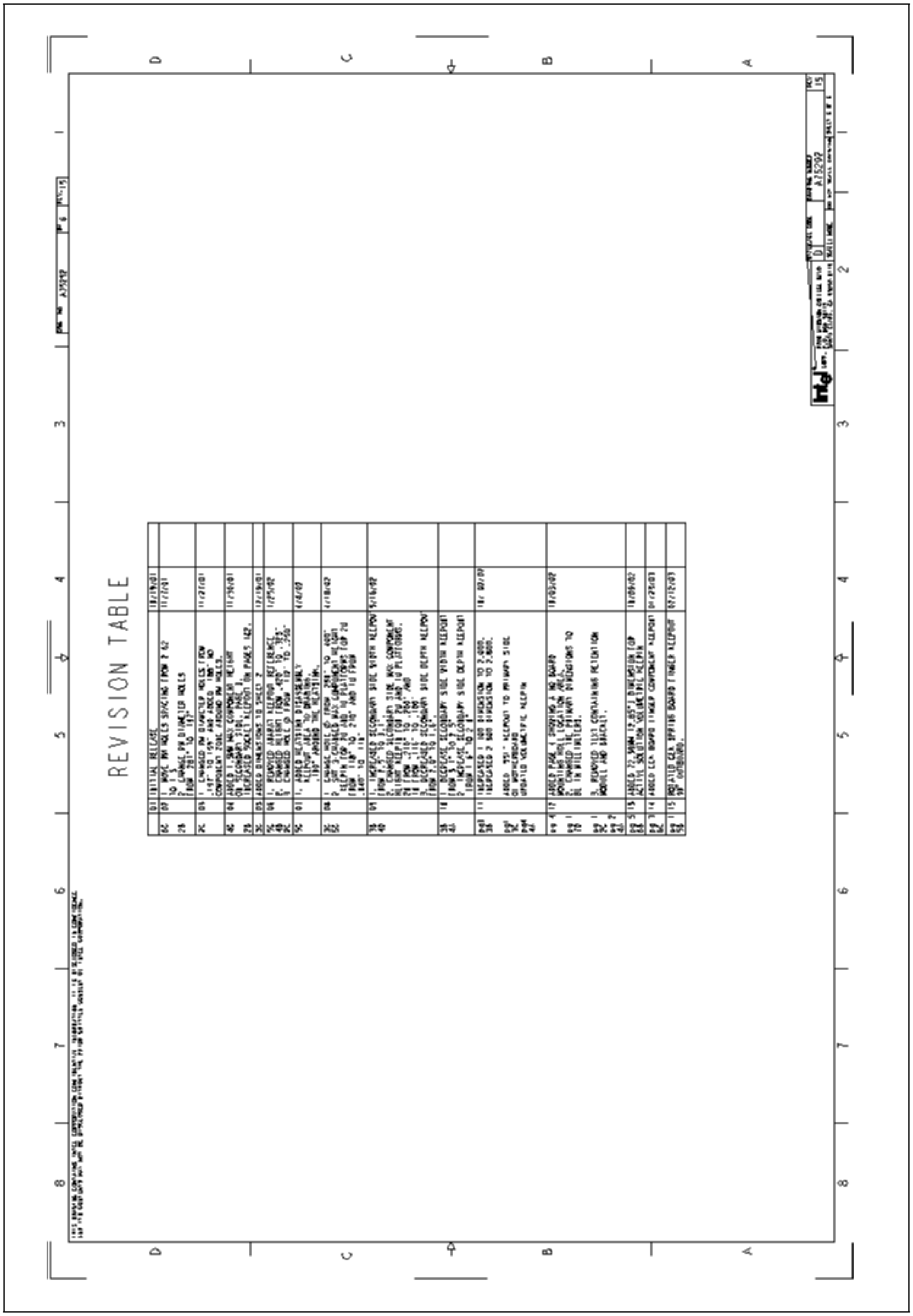


Figure A-14. 1U CEK Heatsink (Sheet 1 of 4)

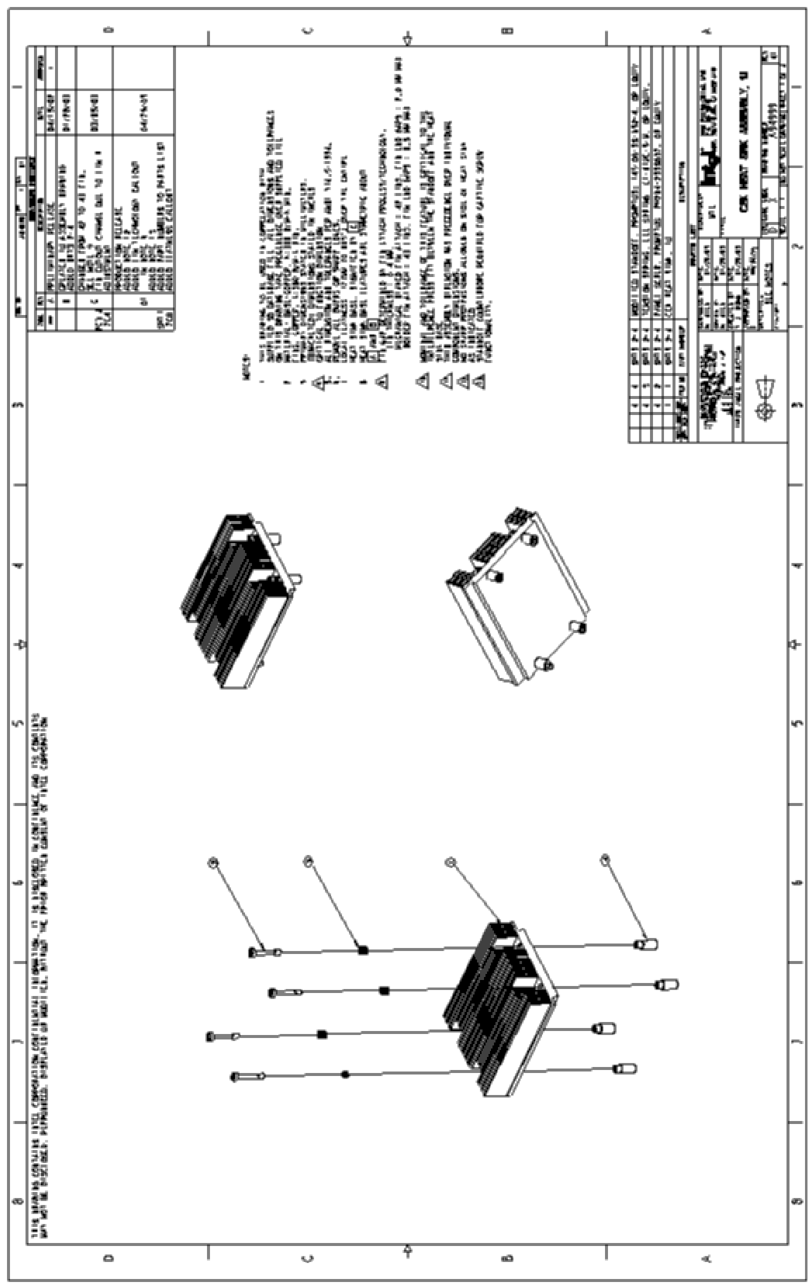


Figure A-15. 1U CEK Heatsink (Sheet 2 of 4)

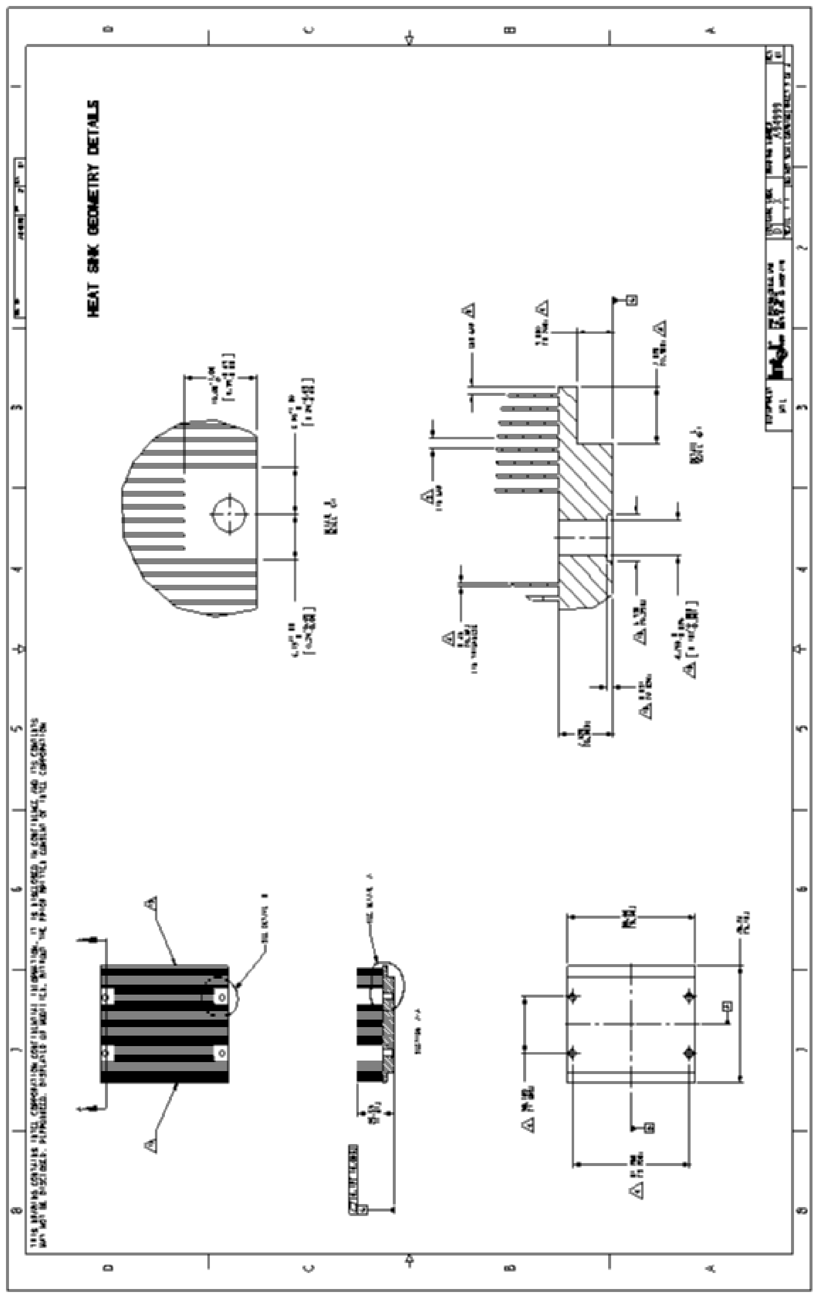


Figure A-16. 1U CEK Heatsink (Sheet 3 of 4)

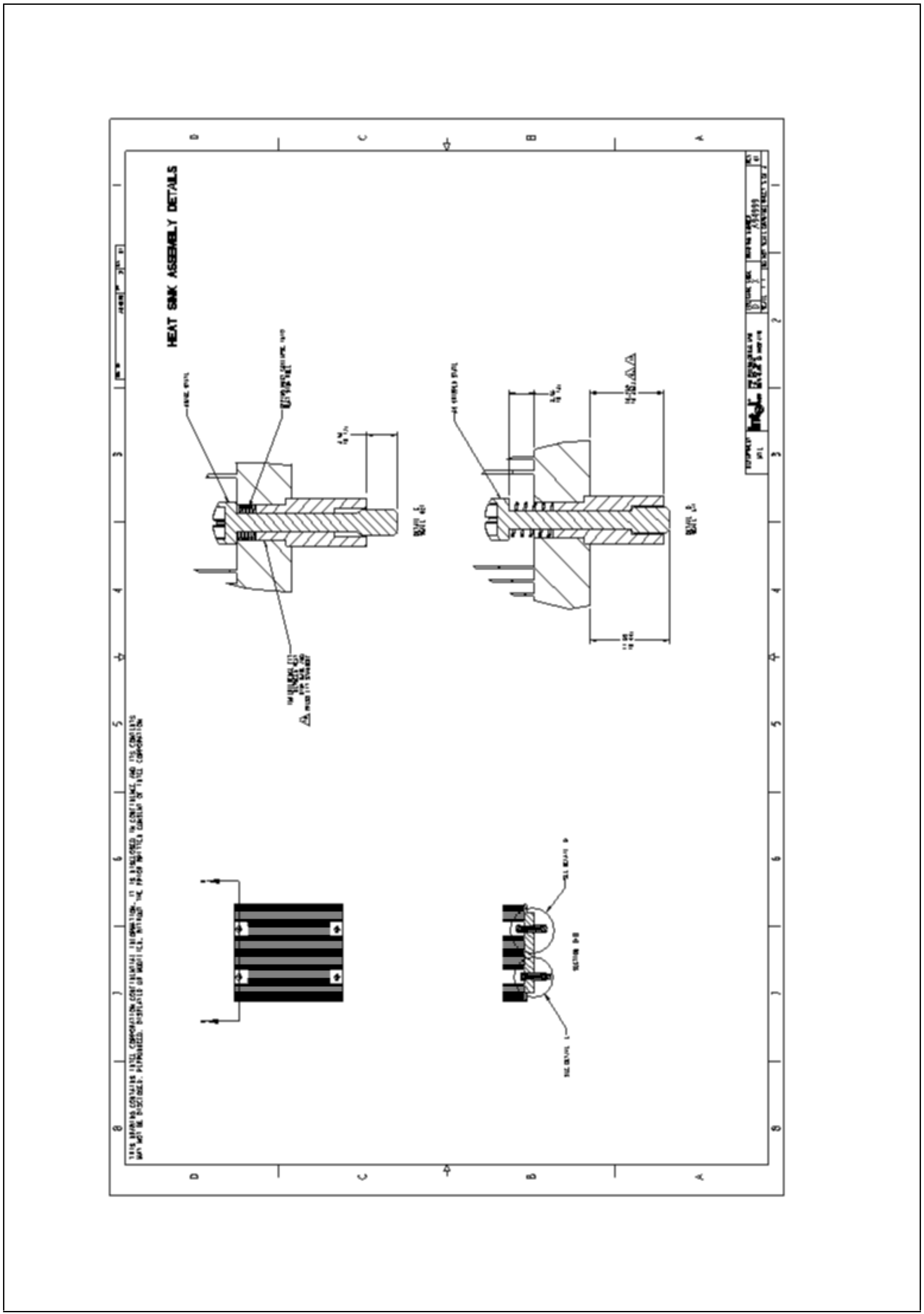


Figure A-17. 1U CEK Heatsink (Sheet 4 of 4)

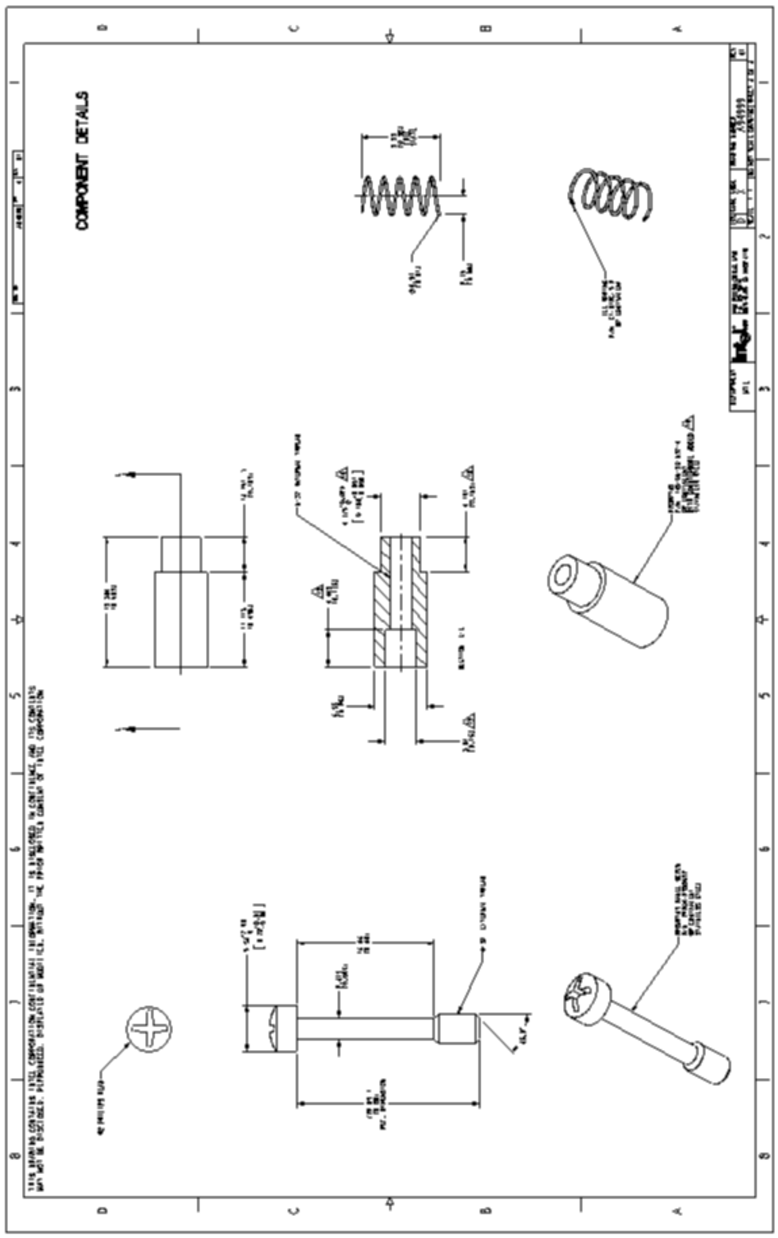


Figure A-18. 4-Pin Fan Cable Connector (for active CEK Heatsink)

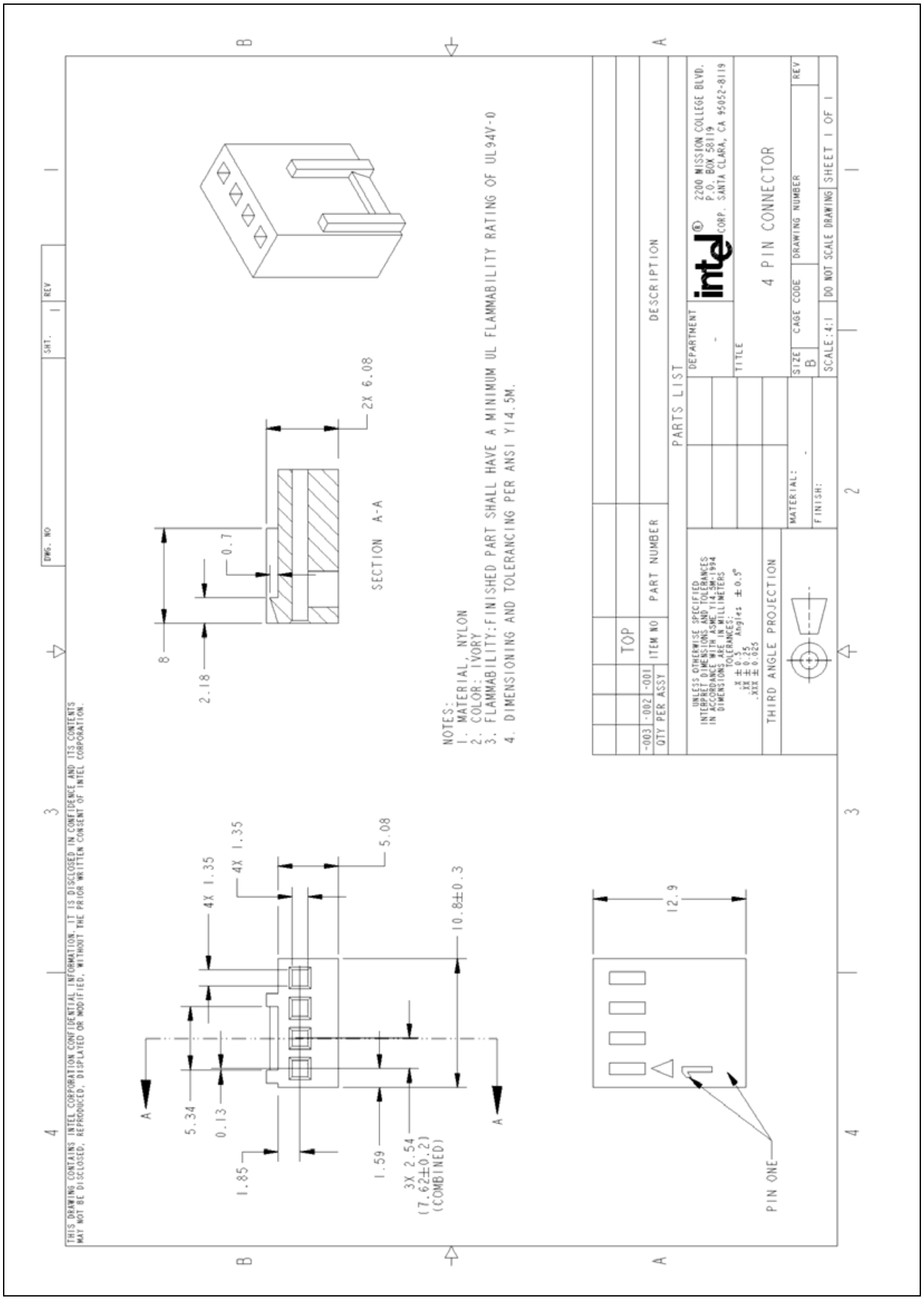
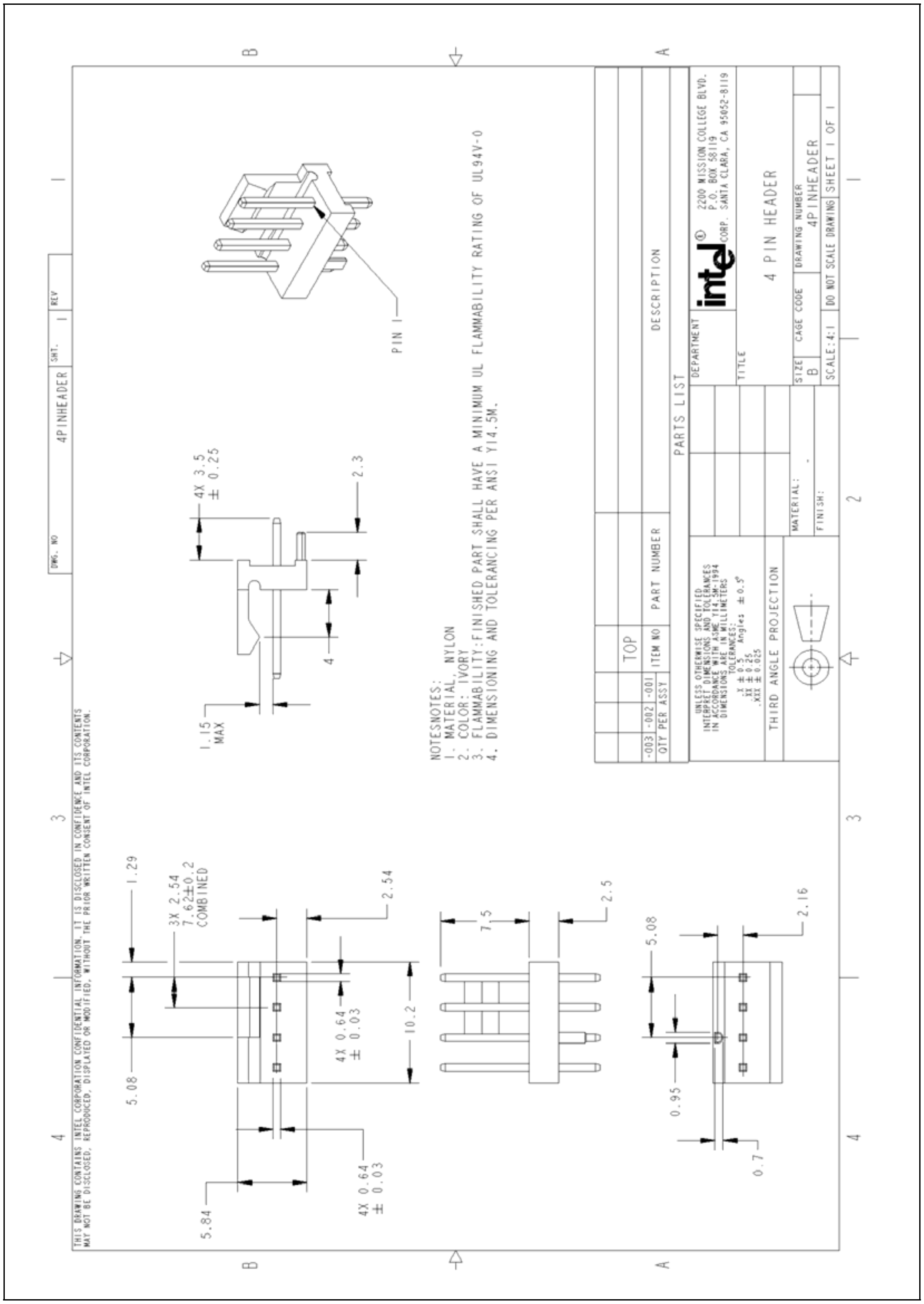


Figure A-19. 4-Pin Baseboard for Header (for active CEK Heatsink)



Test Setup Methodology B

B.1 Thermal Metrology

B.1.1 Processor Thermal Solution Performance Assessment

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

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

Once the thermal solution is designed and validated with the TTV, Intel recommends OEMs use this tool in conjunction with other design and verification methods to verify their cooling solution meets the specifications outlined in the product datasheet. A tool, by itself, should not be used to determine compliance of a thermal design to the processor's thermal specifications.

B.1.1.1 TTV Correction Factor for Intel® Xeon™ Processor with 800 MHz System Bus

Thermal characterization parameter measurements made with a TTV must be corrected for the non-uniform power dissipation of actual processors. Table B-2 provides correction factor for using an Intel® Xeon™ processor with 512 KB L2 cache TTV to assess the thermal characterization parameter of Intel Xeon Processor with 800 MHz System Bus heatsinks. The value of a thermal characterization parameter is derived from the value measured on the TTV and the corresponding correction offset according to equation:

Equation B-1. {Processor Ψ_{CA}} = {TTV Ψ_{CA}} + Correction offset

The correction factor should be applied to a mean + 3sigma value when testing with a statistical sample size.

Table B-2. Intel® Xeon™ Processor with 800 MHz System Bus Thermal Characterization Parameter CorrectionOffset for TTV

Thermal Characterization Parameter (°C/W)	Correction Offset Intel Xeon Processor with 512-KB L2 cache TTV (°C/W)
Ψ_{CA}	0.02

B.1.2 Thermocouple Attachment, Air Temperature and Velocity Measurements

Hysol Epoxy-Patch #309* or equivalent may be used for bonding thermocouples to the heat sources. A good thermal bond between the thermocouple and the device being measured is essential. However, excessive bonding material can affect the measurement for small devices particularly if the bonding material has a significantly different thermal conductivity compared to the device being tested. The standard thermocouple mounting location will be at the top, geometric center of the component unless otherwise noted.

Velocity probes will be placed using hot glue with the face of the probe set perpendicular to the primary flow direction. To support these probes in the air stream, toothpicks or paper clips may be attached to the probes for stability. It is important to note that velocity readings represent a single point in space and should not be used to calculate the volumetric airflow entering a given region. To calculate an approximate volumetric airflow, several measurements should be averaged to capture the velocity gradient in that region. Nevertheless, single velocity measurements are useful in making relative qualitative comparisons between regions. If the probe is close to the flow source (i.e. fans, blowers, etc.), a wide range of readings may be measured and result in the need for multiple velocity measurements.

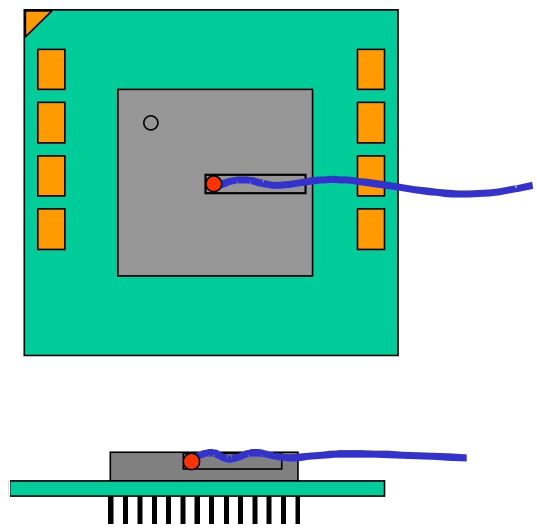
Note: Special attention should be made when mounting air velocity probes. The probe readings are extremely sensitive to alignment with the flow and any misalignment will compromise the measurement result.

B.1.2.1 Processor Thermocouple Placement

Processor cooling performance is determined by measuring the processor case temperature using a 30-36 AWG thermocouple. For processor case temperature measurements, the 0° attachment method is recommended for mounting a thermocouple (see Figure B-20). This method consists of milling a slot into the top of the processor IHS. For a 36 AWG thermocouple, the recommended depth and width of the channel are 0.4 mm and 0.8 mm, respectively. If larger gauge thermocouple wires are used, *the milled slot should only be large enough so that the thermocouple bead and wire do not protrude above the plane of the IHS.* The thermocouple is then placed in the milled channel with the tip bonded to the surface to be measured. The milled channel and thermocouple placement are carefully examined to ensure that the IHS surface is not compromised by any burrs or epoxy. To ensure direct contact of the thermocouple bead with the IHS channel surface, the engineer should test for continuity between the thermocouple wire and the heat spreader.

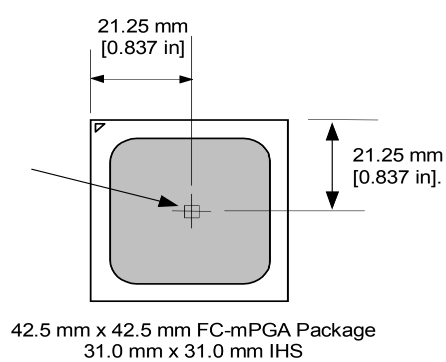
Note: The processor and TTV are extremely fragile components. To avoid damage, it is very important that special attention be given when milling a channel into the IHS.

Figure B-20. 0° Attachment Method



For illustration, the measurement location for a 42.5 mm x 42.5 mm [1.673 in. x 1.673 in.] flip-chip micro pin grid array 4 (FC-mPGA4) package with 31 mm x 31 mm [1.22 in. x 1.22 in.] IHS is shown in Figure B-21. In case of conflict, the package dimensions in the *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet* supersede dimensions provided in this document.

Figure B-21. 0° Processor Case Temperature Measurement Location

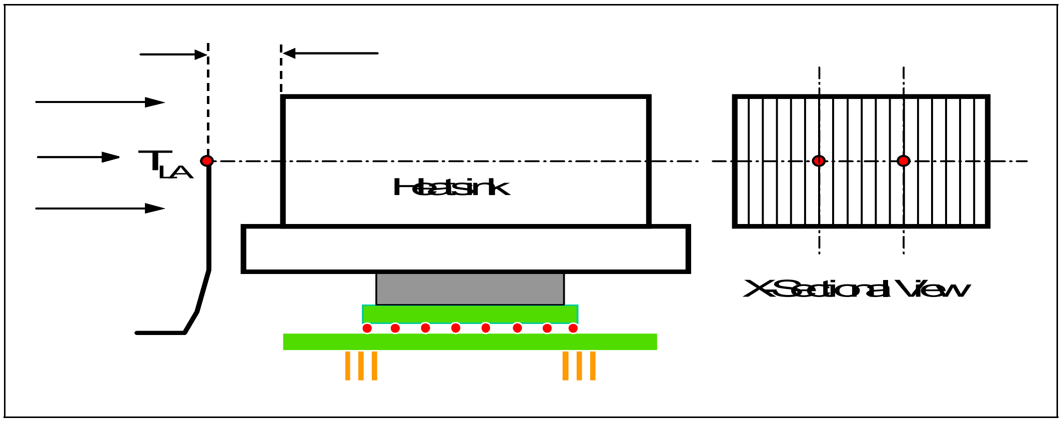


NOTE: Measure from edge of processor.

B.1.2.2 Processor Local Air Thermocouple Placement

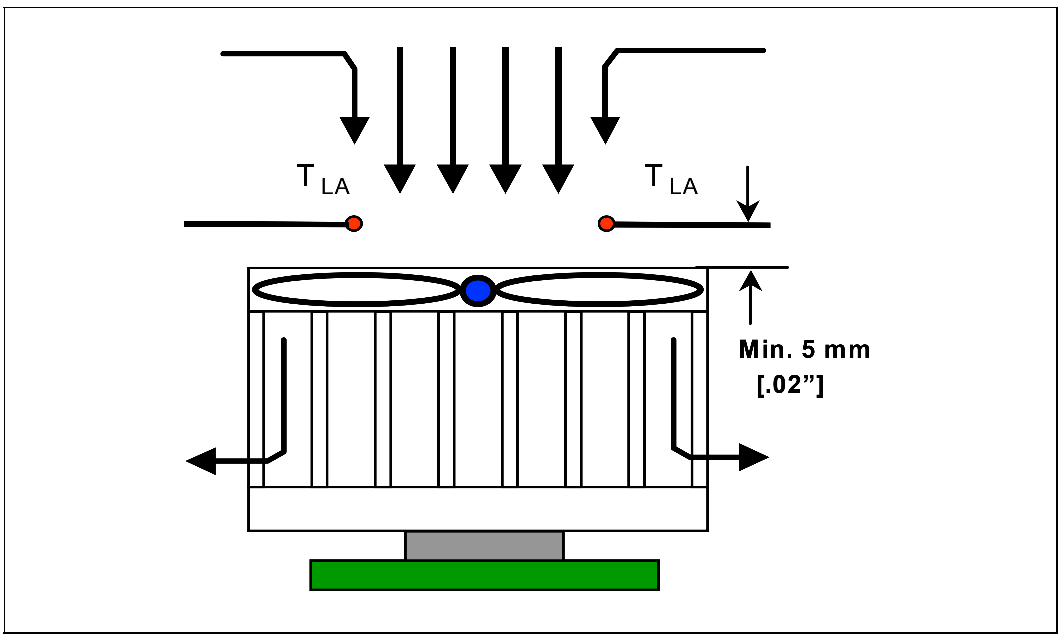
For passive heatsinks, two thermocouples will be placed 10 mm upstream of the processor heatsink. The thermocouples will be centered with respect to the height of the heatsink fins and evenly across the width of the heatsink as shown in Figure B-22.

Figure B-22. Local Air Thermocouple Placement for Passive Heatsinks



For active heatsinks, four thermocouples will be placed on the fan inlet as shown Figure B-23. These thermocouples will be mounted between 5mm and 10mm above the fan. The average of these measurements will be used to represent the local inlet temperature to the active heatsink.

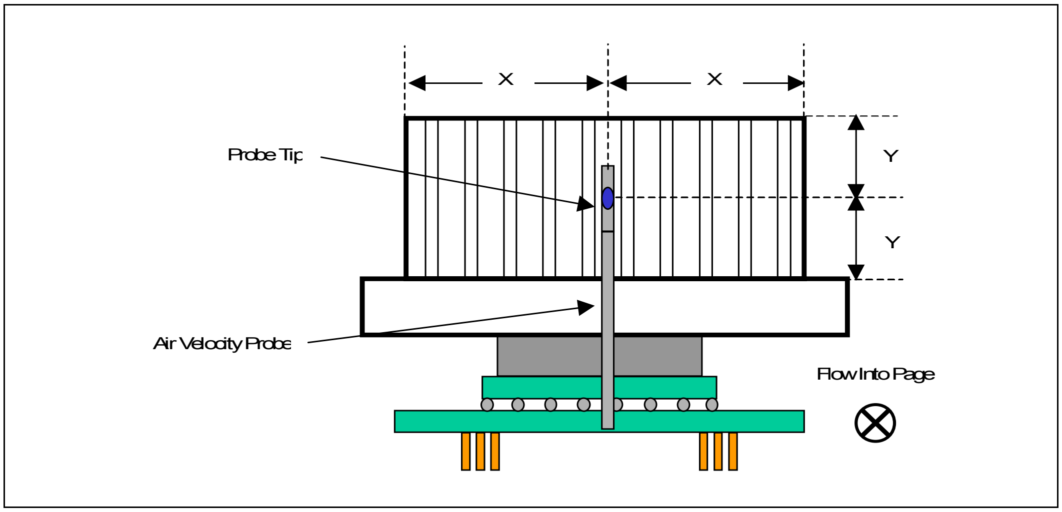
Figure B-23. Local Air Thermocouple Placement for Active Heatsinks (Side View)



B.1.2.3 Processor Local Air Velocity

In the case where measurement of the local air velocity is desired, a single airflow probe will be placed no closer than 10mm upstream of the processor heatsink. The probe will be centered with respect to the cross-section of the heatsink and the tip perpendicular to the direction of flow (see Figure B-24). The recommended air velocity probe can be used to measure both local air temperature and air velocity. Utilizing the dual capability of the probe is highly recommended as this minimizes the number of measurement devices that may disrupt flow to the processor heatsink.

Figure B-24. Local Air Thermocouple Placement for Passive Heatsinks



§

Safety Requirements C

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

- UL Recognition-approved for flammability at the system level. All mechanical and thermal enabling components must be a minimum UL94V-2 approved.
- ESA Certification. All mechanical and thermal enabling components must have CSA certification.
- Heatsink fins must meet the test requirements of UL1439 for sharp edges.

§

Quality and Reliability Requirements D

D.1 Intel Verification Criteria for the Reference Designs

D.1.1 Reference Heatsink Thermal Verification

The Intel reference heatsinks will be verified within specific boundary conditions based on the methodology described in Appendix B.1, and using a TTV.

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

D.1.2 Environmental Reliability Testing

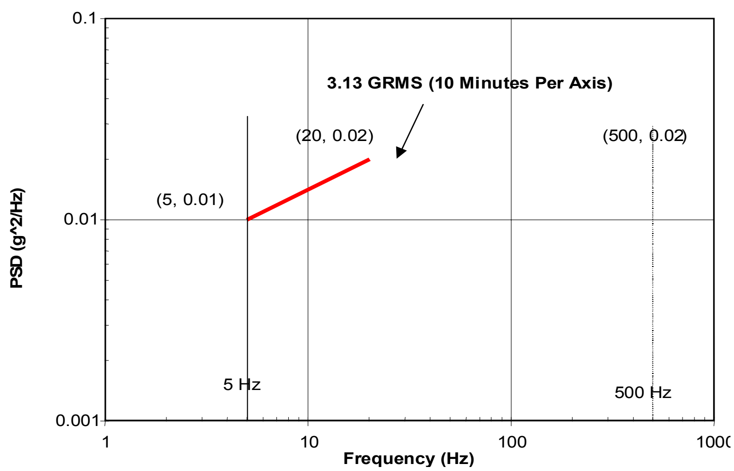
D.1.2.1 Structural Reliability Testing

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

D.1.2.2 Random Vibration Test Procedure

- Duration: 10 min/axis, 3 axes
- Frequency Range: 5 Hz to 500 Hz
- Power Spectral Density (PSD) Profile: 3.13 G RMS (refer to Figure D-25)

Figure D-25. Random Vibration PSD

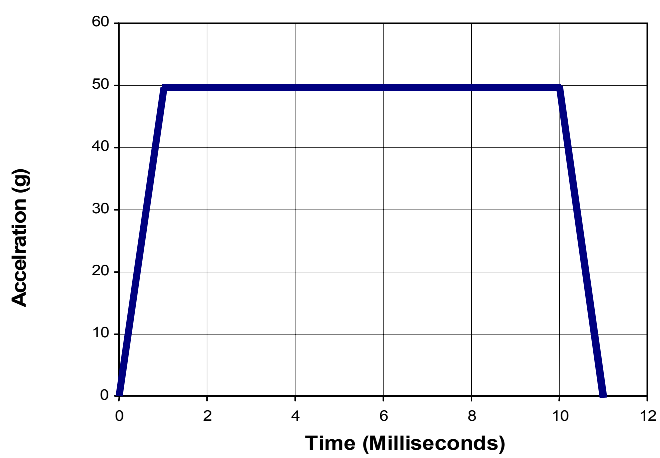


D.1.2.3 Shock Test Procedure

Recommended performance requirement for a baseboard:

- Quantity: 3 drops for + and – directions in each of 3 perpendicular axes (i.e. total 18 drops).
- Profile: 50 G trapezoidal waveform, 11 ms duration, 4.32 m/sec minimum velocity change.
- Setup: Mount sample board on test fixture.

Figure D-26. Shock Acceleration Curve



D.1.2.4 Recommended Test Sequence

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

The test sequence should always start with a visual inspection after assembly, and BIOS/Processor/memory test. The stress test should be then followed by a visual inspection and then BIOS/Processor/memory test.

D.1.2.5 Post-Test Pass Criteria

The post-test pass criteria are:

1. No significant physical damage to the heatsink and retention hardware.
2. Heatsink remains seated and its bottom remains mated flatly against the IHS surface. No visible gap between the heatsink base and processor IHS. No visible tilt of the heatsink with respect to the retention hardware.
3. No signs of physical damage on baseboard surface due to impact of heatsink.
4. No visible physical damage to the processor package.
5. Successful BIOS/Processor/memory test of post-test samples.
6. Thermal compliance testing to demonstrate that the case temperature specification can be met.

D.1.2.6 Recommended BIOS/Processor/Memory Test Procedures

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

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

- Appropriate system baseboard.
- Processor and memory.
- All enabling components, including socket and thermal solution parts.

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

D.1.3 Material and Recycling Requirements

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

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

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

§

Enabled Suppliers Information E

Table E-3. Enabled Suppliers

Component	Description	Development Suppliers	Supplier Contact Info
CEK Heatsink	Copper Fin, Copper Base	Fujikura* (stacked fin) CNDA 36187 Furukawa* (crimped fin) CNDA 65755	Mechatronics* Steve Carlson 800-453-4569 x205 steve@mechatronics.com Furukawa America* Katsu Mizushima (408) 232-9306 katsumizushima@mindspring.com
Thermal Interface Material	Grease	Shin-Etsu* G751 CNDA 75610	Donna Hartigan (480) 893-8898
CEK Spring	Stainless Steel 301, Kapton* Tape on Spring Fingers	ITW Fastex* CNDA 78538 AVC* CNDA 2085011 Foxconn* CNDA 11251	Ron Schmidt (847) 299-2222 rschmidt@itwfastex.com Felicia Lee 886-2-22996390 x144 felicia@avc.com.tw

§

Processor Thermal Management Logic and Thermal Monitor Features F

F.1 Thermal Management Logic and Thermal Monitor Feature

F.1.1 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 Intel Xeon Processor with 800 MHz System Bus. It provides a thermal management approach to support the continued increases in processor frequency and performance. By using a highly accurate on-die temperature sensing circuit and a fast acting temperature control circuit, the processor can rapidly initiate thermal management control. The Thermal Monitor can reduce cooling solution cost, by allowing designs to target TDP instead of maximum processor power.

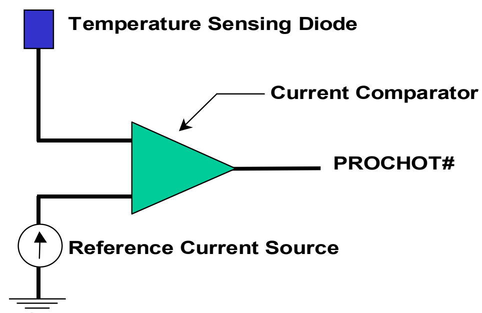
F.1.2 Thermal Monitor Implementation

On the Intel Xeon Processor with 800 MHz System Bus, the Thermal Monitor is integrated into the processor silicon. The Thermal Monitor includes:

- An on-die temperature sensing circuit.
- An external output signal (PROCHOT#) that indicates the processor has reached its maximum operating temperature.
- An external input signal (FORCEPR#) that allows the platform to force a power reduction by the processor by activating the TCC.
- A TCC that can reduce processor temperature by rapidly reducing power consumption when the on-die temperature sensor indicates that it has reached the maximum operating point.
- Registers to determine the processor thermal status.

The processor temperature is determined through an analog thermal sensor circuit comprised of a temperature sensing diode, a factory calibrated reference current source, and a current comparator (see Figure F-27). A voltage applied across the diode induces a current flow that varies with temperature. By comparing this current with the reference current, the processor temperature can be determined. The reference current source corresponds to the diode current when at the maximum permissible processor operating temperature. Processors are calibrated during manufacturing on a small sample set. Once configured, the processor temperature at which the PROCHOT# signal is asserted (trip point) is not re-configurable.

Figure F-27. Thermal Sensor Circuit

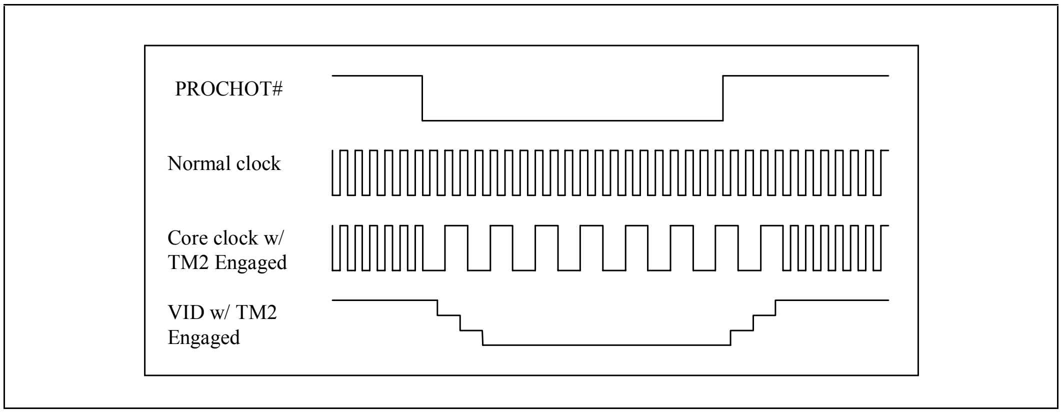


The PROCHOT# signal is available internally to the processor as well as externally. External indication of the processor temperature status is provided through the bus signal PROCHOT#. When the processor temperature reaches the trip point, PROCHOT# is asserted. When the processor temperature is below the trip point, PROCHOT# is de-asserted. Assertion of the PROCHOT# signal is independent of any register settings within the processor. It is asserted any time the processor die temperature reaches the trip point. The point where the TCC activates is set to the same temperature at which the processor is tested and at which PROCHOT# asserts.

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. 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 s, and is frequency dependent. Higher frequency processors will disable the internal clocks for a shorter time period. Figure F-28 illustrates the relationship between the internal processor clocks and PROCHOT#.

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

Figure F-28. Concept for Clocks under Thermal Monitor Control



F.1.3 Operation and Configuration

To maintain compatibility with previous generations of processors, which have no integrated thermal logic, the TCC portion of Thermal Monitor is disabled by default. During the boot process, the BIOS must enable the TCC; or a software driver may do this after the operating system has booted. **Thermal Monitor or Thermal Monitor 2 feature must be enabled for the processor to remain within specification.**

The TCC feature can be configured and monitored in a number of ways. OEMs are expected to enable the TCC while using various registers and outputs to monitor the processor thermal status. The TCC is enabled by the BIOS setting a bit in an MSR (model specific register). Enabling the TCC allows the processor to maintain a safe operating temperature without the need for special software drivers or interrupt handling routines. When the TCC 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 TCC 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 consistently indicate the thermal status of the processor.

The TCC can also be manually activated using an on-demand mode.

F.1.4 Thermal Monitor 2

The Intel Xeon Processor with 800 MHz System Bus also supports an enhanced TCC that works in conjunction with the existing Thermal Monitor logic. This capability is known as Thermal Monitor 2. This improved TCC provides a more efficient means for limiting the processor temperature by reducing the power consumption within the processor.

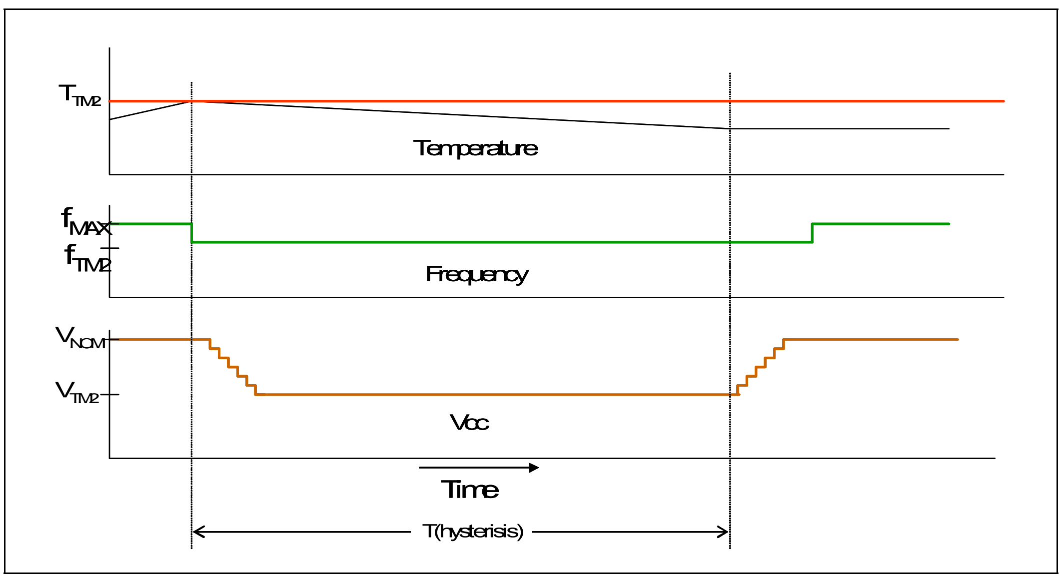
When Thermal Monitor 2 is enabled, and a high temperature situation is detected, the enhanced TCC will be activated. The enhanced TCC causes the processor to adjust its operating frequency (bus-to-core multiplier) and input voltage identification (VID) value. This combination of reduced frequency and the lowering of VID results in a reduction in processor power consumption.

A processor enabled for Thermal Monitor 2 includes two operating points, each consisting of a specific operating frequency and voltage. The first operating point represents the normal operating condition for the processor. The second operating point consists of both a lower operating frequency and voltage.

When the TCC is activated, the processor automatically transitions to the new frequency. This transition occurs very rapidly (on the order of 5 microseconds). During the frequency transition, the processor is unable to service any bus requests, and consequently, all bus traffic is blocked during the frequency transition. Edge-triggered interrupts will be latched and kept pending until the processor resumes operation at the new frequency.

Once the new operating frequency is engaged, the processor will transition to the new core operating voltage by issuing a new VID code to the voltage regulator. The voltage regulator must support dynamic VID changes in order to support Thermal Monitor 2. During the voltage change, it will be necessary to transition through multiple VID codes to reach the target operating voltage. Each step will be one VID table entry (i.e. 12.5 mV steps). The processor continues to execute instructions during the voltage transition. Operation at the lower voltage reduces both the dynamic and leakage power consumption of the processor. Once the processor has sufficiently cooled, and the time based hysteresis period has expired, the operating frequency and voltage transition back to the normal system operating point. Transition of the VID code will occur first, in order to insure proper operation once the processor reaches its normal operating frequency. Refer to Figure F-29 for an illustration of this ordering.

Figure F-29. Thermal Monitor 2 Frequency and Voltage Ordering



F.1.5 System Considerations

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

Note: **Intel requires the TCC to be enabled for all Intel Xeon Processor with 800 MHz System Bus based systems.** At a minimum, the TCC provides an added level of protection against processor thermal solution failure.

A system designed to meet the TDP and T_{CASE} targets published in the processor *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet* greatly reduces the probability of real applications causing the TCC to activate under normal operating conditions. Systems that do not meet these specifications could be subject to more frequent activation of the TCC 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 Appendix F.1.7.2 and to the *Intel® Xeon™ Processor with 800 MHz System Bus at 2.80 GHz and 3.60 GHz Datasheet.*

F.1.6 Operating System and Application Software Considerations

The Thermal Monitor feature and its TCC work seamlessly with ACPI compliant operating systems and those utilizing hardware based timing routines. The Thermal Monitor feature is transparent to application software since the processor bus snooping, ACPI timer, and interrupts are active at all times.

Activation of the TCC during a non-ACPI aware operating system boot process may result in incorrect calibration of operating system software timing loops. This is also the case with operating systems that utilize execution based timing routines. The BIOS must disable the TCC prior to boot and then the operating system or BIOS must enable the TCC after the operating system boot process completes.

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

F.1.7 Legacy Thermal Management Capabilities

In addition to Thermal Monitor, the Intel Xeon Processor with 800 MHz System Bus supports the same thermal management features originally introduced with the Intel® Pentium® III Xeon processor. These features include the on-die thermal diode and THERMTRIP# signal for indicating catastrophic thermal failure.

F.1.7.1 On-Die Thermal Diode

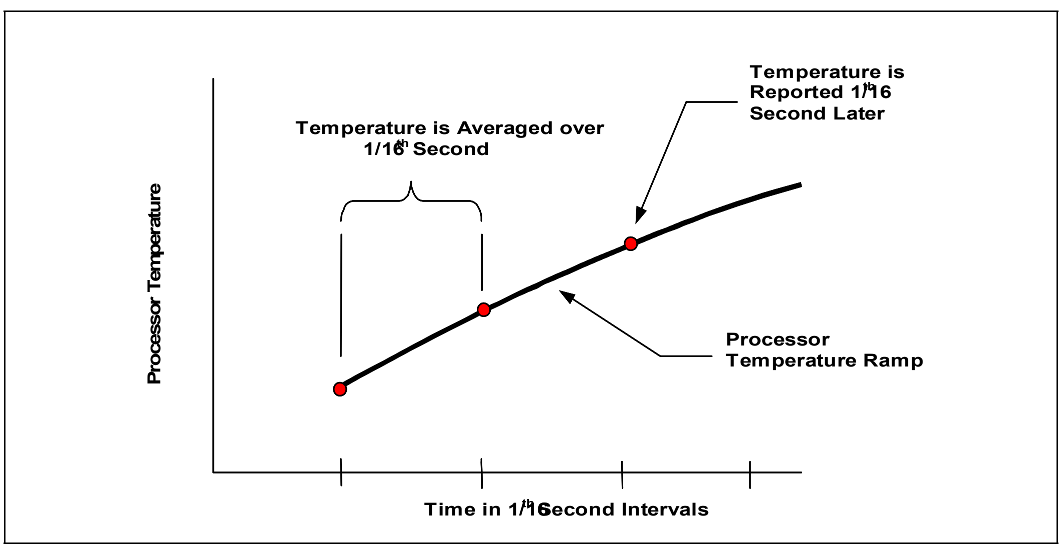
There are two independent thermal diodes in the Intel Xeon Processor with 800 MHz System Bus. One is the on-die thermal diode and the other is in the temperature sensor used for the Thermal Monitor and for THERMTRIP#. The Thermal Monitor's temperature sensor and the on-die thermal diode are independent and isolated devices with no direct correlation to one another. Circuit constraints and performance requirements prevent the Thermal Monitor's temperature sensor and the on-die thermal diode from being located at the same place on the silicon. 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 TCC by monitoring the on-die thermal diode.

System integrators that plan on using the thermal diode for system or component level fan control need to be aware of the potential for rapid changes in processor power consumption as the executing workload changes. Variable performance thermal solutions that fail to react quickly to changing workloads may experience TCC activation or worse yet, result in automatic shutdown via THERMTRIP# (refer to Appendix F.1.7.2 for more information on THERMTRIP). One example of this situation is as follows: A fan control scheme slows the fans such that the processor is operating very near the thermal trip point while executing a relatively low power workload. The start of a higher power application creates a sudden increase in power consumption and elevates the temperature of the processor above the trip point, causing the TCC to activate. The power reduction resulting from TCC activation slows the rate of temperature increase, but is not sufficient to clamp the temperature, due to inadequate thermal solution performance at reduced fan speed. As a result, the temperature continues to slowly increase. The fan is then sped up to compensate for the change in processor workload but reacts too slowly to prevent the processor from shutting down due to THERMTRIP# activation.

High temperature change rates on-die can also limit the ability to accurately measure the on-die thermal diode temperature. As a result, the on-die thermal diode should not be relied upon to warn of processor cooling system failure or predict the onset of the TCC. An illustration of this is as follows. Many thermal diode sensors report temperatures a maximum of 8 times per second. Within the $1/8^{th}$ (0.125 sec.) second time period, the temperature is averaged over $1/16^{th}$ of a second. In a scenario where the silicon temperature ramps at 50°C/sec, or approximately 6°C/ 0.125 sec, the processor will be ~4.5°C above the temperature reported by the thermal sensor. Change in diode temperature averaged over $1/16^{th}$ seconds = ~1.5°C; temperature reported $1/16^{th}$ second later at $1/8^{th}$ second when the actual processor temperature would be 6°C higher (see Figure F-30).

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

Figure F-30. On-Die Thermal Diode Sensor Time Delay



F.1.7.2 THERMTRIP# Signal Pin

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# signal goes active and power must be removed from the processor. THERMTRIP# stays active until RESET# has been initiated. THERMTRIP# activation is independent of processor activity and does not generate any bus cycles.

F.1.7.3 FORCEPR# Signal Pin

The Intel Xeon Processor with 800 MHz System Bus provides a means for system hardware to force activation of the TCC. One possible usage model would be to use this capability to protect the voltage regulator from overheating in order to avoid a catastrophic shutdown. Refer to the appropriate platform design guidelines and voltage regulator design guidelines for implementation details. The use of the FORCEPR# signal pin requires that BIOS code enable the signal's recognition via an MSR.

F.1.8 Cooling System Failure Warning

If desired, the system may be designed to cool the maximum processor power. In this situation, it may be useful to use the PROCHOT# signal as an indication of cooling system failure. Messages could be sent to the system administrator to warn of the cooling failure, while the TCC 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.

§.