



# *Low Voltage Intel<sup>®</sup> Xeon<sup>™</sup> Processor for Embedded Applications*

**Thermal Design Guide**

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*September 2003*

Order Number: **273764-003**



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## Revision History

Date	Revision	Description
September 2003	003	Update to include LV Intel® Xeon 2.4 GHz data.
April 2003	002	Update to include LV Intel® Xeon 2.0 GHz data.
August 2002	001	Initial release of this document.

## 1.0 Introduction

This document describes thermal design guidelines for the Low Voltage Intel® Xeon™ processor in the Flip Chip Micro-Pin Grid Array (FC-μPGA2) package. Detailed mechanical and thermal specifications for these processors may be found in the processor datasheet.

The information provided in this document is for reference only and additional validation must be performed prior to implementing the thermal designs into final production. The intent of this document is to assist each original equipment manufacturer (OEM) with the development of thermal solutions for their individual designs. The final thermal solution, including the heat sink, attachment method, and thermal interface material (TIM) must comply with the mechanical design, environmental, and reliability requirements delineated in the processor datasheet. It is the responsibility of each OEM to validate the thermal solution design with their specific applications.

### 1.1 Document Goals

The goal of this document is to describe the thermal characteristics of the Low Voltage Intel Xeon processors and provide guidelines for meeting the thermal requirements imposed on single and dual processor systems. The thermal solutions presented in this document are specifically designed for embedded computing applications, including the 1U Server and double slot compact PCI\* form factors.

### 1.2 Document Scope

This document discusses the thermal management techniques for the Low Voltage Intel Xeon processor, specifically in embedded computing applications. The physical dimensions and power numbers used in this document are for reference only. Please refer to the processor's datasheet for the product dimensions, thermal power dissipation, and maximum case temperature. In case of conflict, the datasheet supersedes any data in this document.

### 1.3 References

- *Low Voltage Intel® Xeon™ Processor Datasheet* (order number 273766)
- *Intel® Xeon™ Processor MP Thermal Design Guidelines* (order number 298650)
- *Intel® Xeon™ Processor Thermal Design Guidelines* (order number 298348)
- *Intel® Xeon™ Processor Thermal Solution Functional Specifications Application Note* (order number 249673)
- *Intel® Xeon™ Processor with 512 KB L2 Cache Datasheet at 1.80 GHz to 3.0 GHz* (order number 298642)
- *Intel® Xeon™ Processor with 533 MHz Front Side Bus at 2 GHz to 3.06 GHz Datasheet* (order number 252135)



## 1.4 Definition of Terms

Term	Definition
$T_{LA}$ ( $T_{Local-Ambient}$ )	The measured ambient temperature locally surrounding the processor. The ambient temperature should be measured just of a passive heat sink, or at the fan inlet of an active heat sink.
$T_{case-max}$	The maximum case temperature of the processor, as specified in the processor datasheet.
$T_{case}$	The measured case temperature of the processor.
Thermal Interface Material (TIM)	The thermally conductive compound between the heat sink and processor case. This material fills air gaps and voids, and enhances spreading of the heat from the case to the heat sink.
$\Psi_{CS}$	The case to sink thermal resistance, which is dependent on the thermal interface material. Also referred to as $\theta_{TIM}$ .
$\Psi_{CA}$	The thermal resistance between the processor's case and the ambient air. This is defined and controlled by the system thermal solution.
604-Pin Socket	The surface mount Zero Insertion Force (ZIF) socket designed to accept the Low Voltage Intel Xeon processor.
Bypass/no-bypass	Bypass is the area between a heat sink and any object that may act to form a duct. For this example it may be expressed as the distance from the outermost fin to the nearest duct surface.
Thermal Design Power (TDP)	A specification of the processor. OEMs must design thermal solutions that meet or exceed the TDP as specified by the processor's datasheet.
U	A unit of measure used to define server rack spacing height. 1U is equal to 1.75 inches, 2U equals 3.50 inches, etc.
LFM	Linear feet per minute
CFM	Cubic feet per minute
MP	Multi processor

## 2.0 Design Guidelines

The thermal solutions presented in this document were designed to fit within the maximum component height allowed by certain embedded form factor specifications, including the 1U server and double-slot compact PCI form factors. The thermal solutions may be valid for other form factors; however, individual applications must be modeled, prototyped, and verified.

In some cases, prototype parts have been fabricated for verification tests. It is important to note that the thermal verification information described in this document is not adequate for statistical purposes. The intent of testing was only to verify that the thermal components were performing within reasonable expectations, based on computer modeling and component specifications.

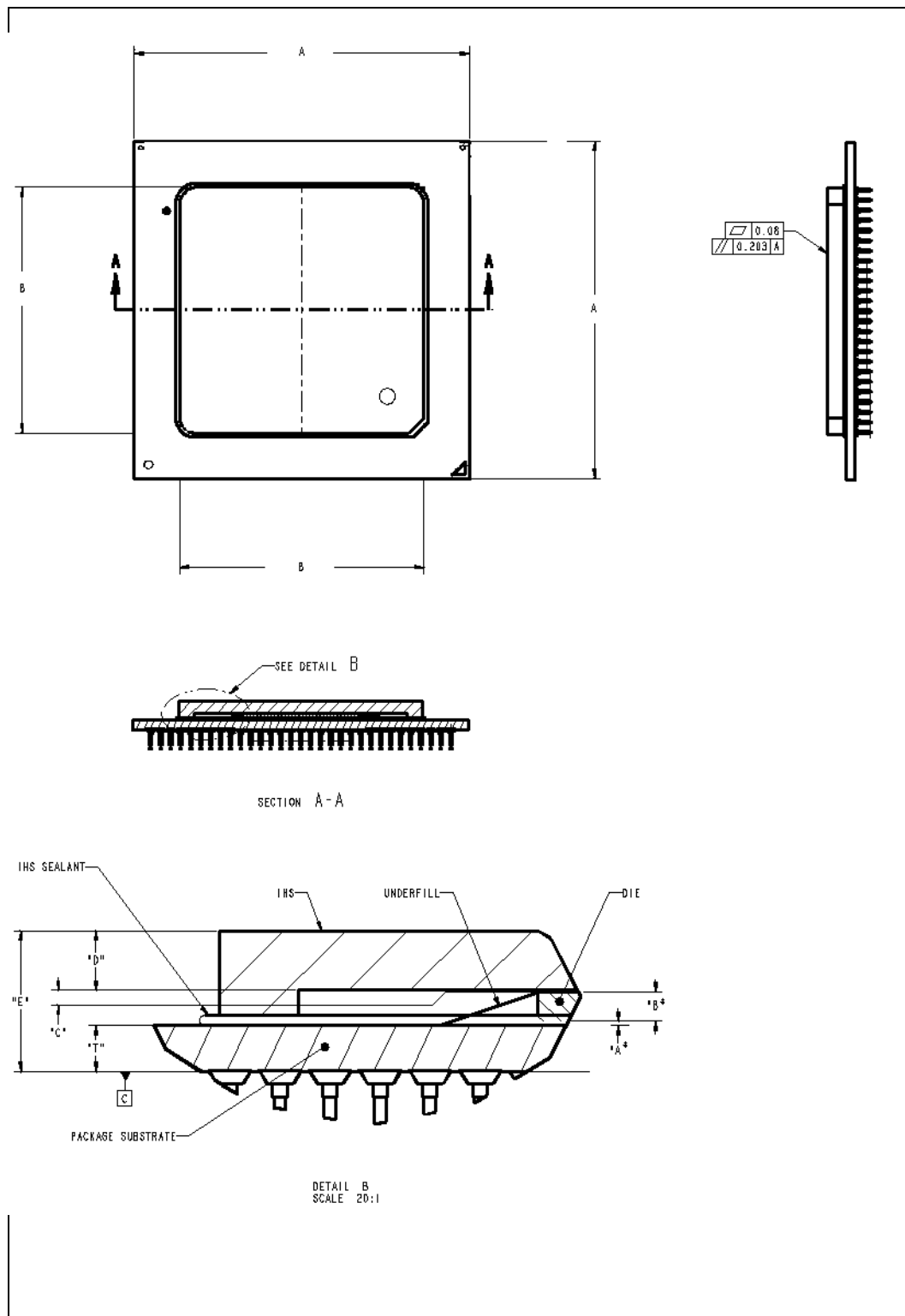
## 2.1 Mechanical Guidelines

### 2.1.1 Processor Package

The processor uses the Flip Chip Micro-Pin Grid Array (FC- $\mu$ PGA2) package technology with an integrated heat spreader (IHS) mounted directly to the package containing the processor die and pinned substrate. The IHS is designed to improve package thermal performance and is the interface for attaching a heat sink. The processor connects to the motherboard through a Zero Insertion Force (ZIF) socket. Detailed mechanical specifications for the processor may be obtained from the processor datasheets.

[Figure 1](#) illustrates the geometry of the FC- $\mu$ PGA2 package with dimensions provided in [Table 1](#). Refer to the processor datasheet for detailed information.

Figure 1. FC-μPGA2 Package Geometry





**Table 1. FC-μPGA2 Mechanical Dimensions**

Symbol	Nominal	Tolerance (±)	Unit
A	42.5	0.100	mm
B	31.0	0.100	mm
C	0.038	0.012	mm
D	1.5	0.050	mm
E	3.548	0.197	mm
T	1.17	0.070	mm
A†	0.1	0.025	mm
B†	0.74	0.025	mm

† In the event of conflict, dimensions provided in the processor datasheet supersedes this data.

### 2.1.2 .Keep-In/Keep-Out Zones

The keep-in zone reserved for the processor package, heat sink, and heat sink attachment method for the baseboard is shown in Figures 2 through 4. These are the typical keep-in/keep-out zones for the FC-μPGA2 package and 604-pin socket. Please refer to the Low Voltage Intel® Xeon™ processor and socket 604 datasheets for detailed information.

Figure 2. Keep-In Zone for the 604-Pin Socket

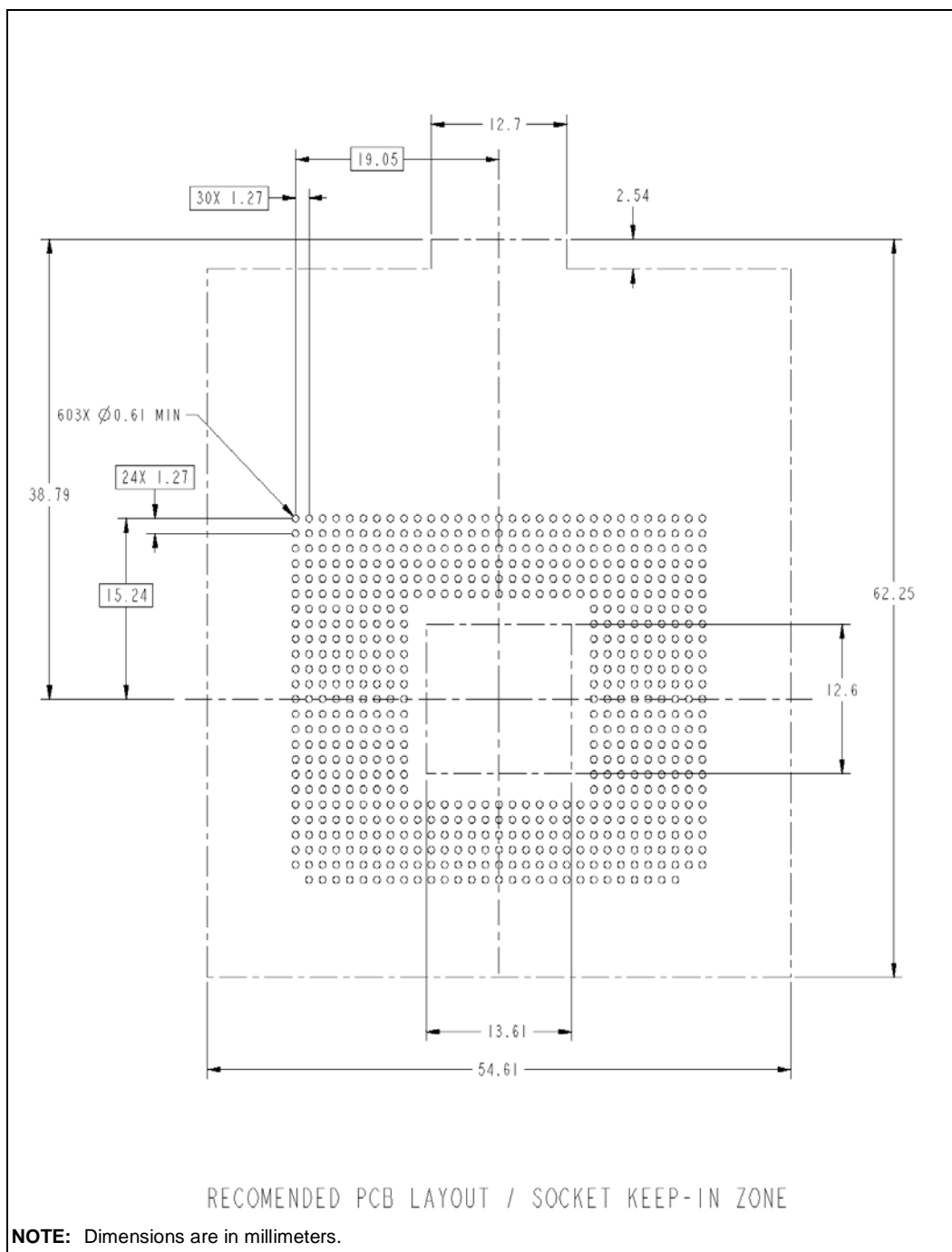


Figure 3. Retention Mechanism Keep-Out Zone

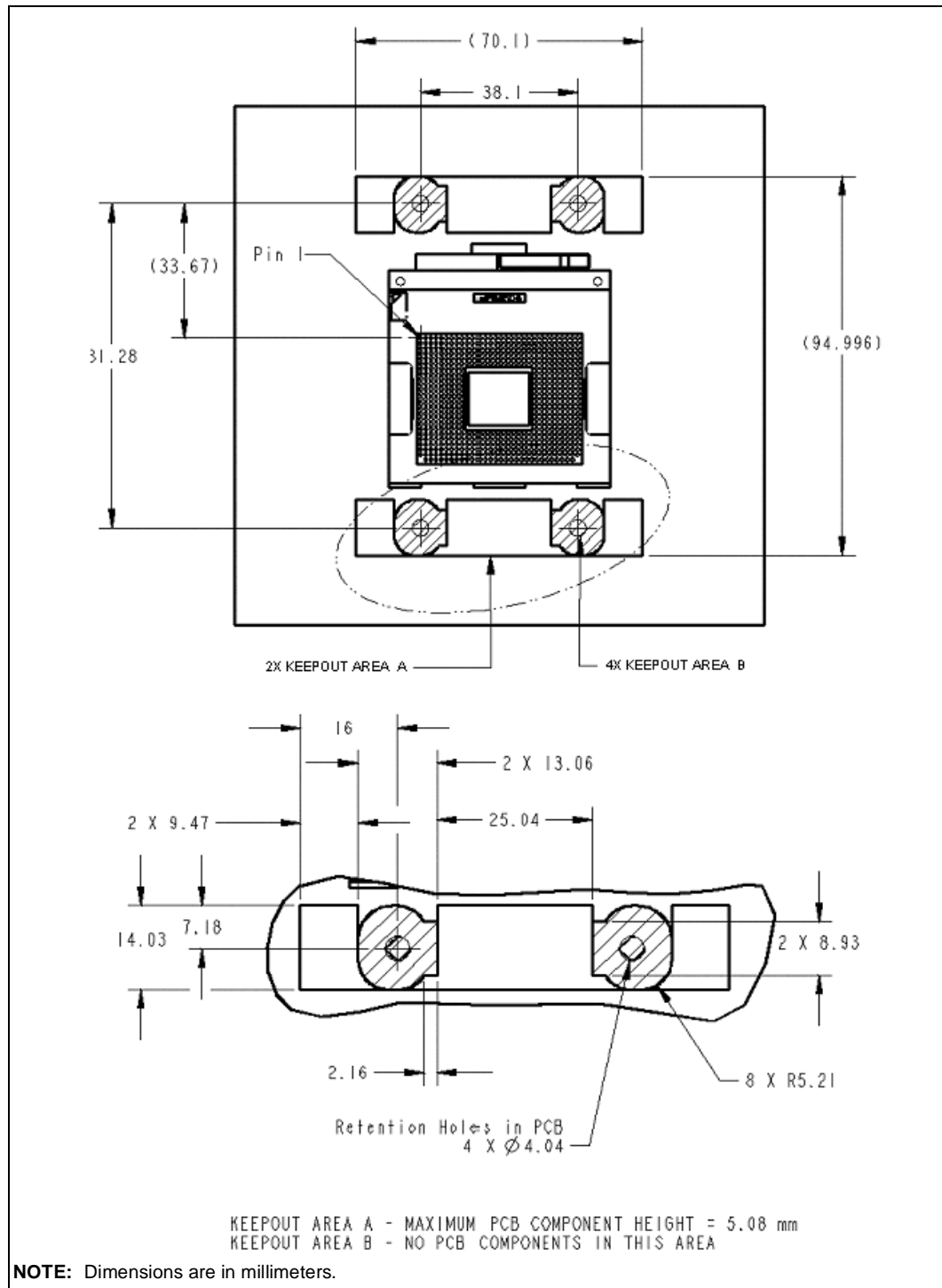
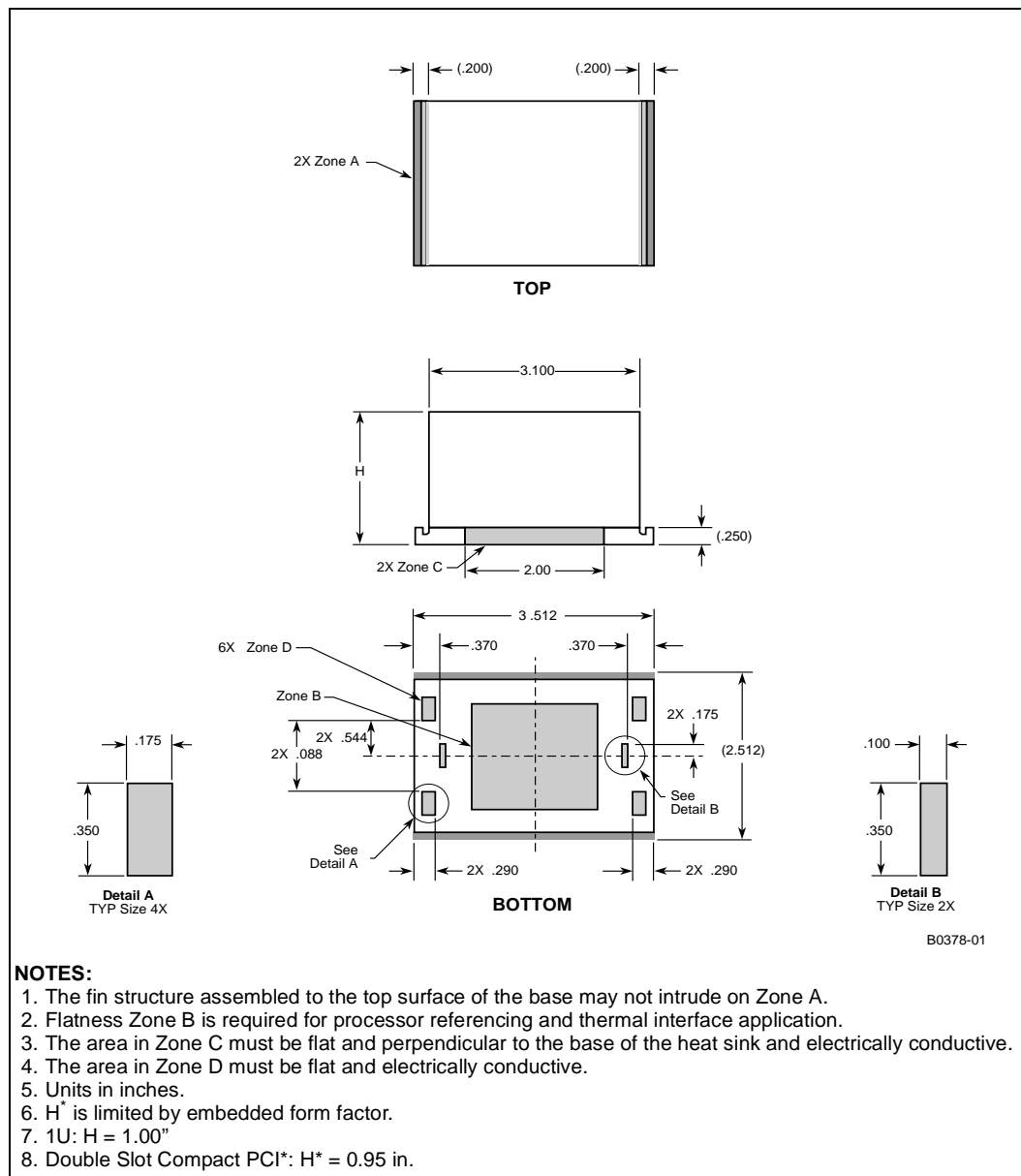


Figure 4. Heat Sink Keep-In Zone



## 2.2 Thermal Guidelines

This document presents thermal solutions for the Low Voltage Intel Xeon processor. The required performance of the thermal solution is dependant on many parameters including the processor's thermal design power (TDP), maximum case temperature ( $T_{case-max}$ ), the operating ambient temperature, and system airflow. The guidelines and recommendations presented in this document are based on specific parameters. It is the responsibility of each product design team to verify that thermal solutions are suitable for their specific use.

The thermal metrology for the Intel Xeon processor in the FC-μPGA2 package should be followed to evaluate the thermal performance of proposed cooling solutions. The thermal metrology is contained in the *Intel® Xeon™ Processor MP Thermal Design Guidelines*.

To develop a reliable thermal solution, all of the appropriate variables must be considered. Thermal simulations and characterizations must be carried out with all system parameters accounted for. The solutions presented in this document must be validated as specified in their final intended system.

Thermal data for the Low Voltage Intel Xeon processor is presented in [Table 2](#). The data is provided for informational purposes only. Please refer to the processor’s datasheet for the most current data. In the event of conflict, the processor’s datasheet supersedes information provided in this document.

**Table 2. Low Voltage Intel Xeon Processor Thermal Data**

Core Frequency (GHz)	Thermal Design Power (W)	Minimum T case (°C)	Maximum T case (°C)
1.6	30	5	81
2.0	35	5	83
2.4	40	5	81

### 2.2.1 Processor Case Temperature

The Integrated Heat Spreader (IHS) provides a common interface and attach location for all processor thermal solutions. The IHS may improve thermal solution performance by spreading the concentrated heat from the core to a larger surface area. Techniques for measuring the case temperature are provided in Section 7 of the *Intel® Xeon™ Processor Thermal Design Guidelines*. The maximum case temperature values for the Low Voltage Intel Xeon processors may be found in the *Low Voltage Intel® Xeon® Processor Datasheet*.

### 2.2.2 Processor Power

The processor’s power specification is specified by the thermal design power (TDP). Maximum power may be attained while running code specifically written to draw the most current, such as the maximum power test application. While running typical applications, maximum power is not usually reached, especially for a significant amount of time. As a result, the TDP is provided as the thermal design target for systems. This power specification is derived from profiling multiple workstation and server applications. For any excursions beyond TDP, the thermal monitor feature is available to maintain the processor thermal specifications. Refer to the processor datasheet for details regarding the thermal design power specifications and the thermal monitor.

### 2.2.3 Thermal Solution Requirements

The thermal solutions recommended in this document were designed based on the processor thermal specifications as outlined in the processor’s datasheet for the worst case conditions, hence the solutions are suitable for all frequencies of the Low Voltage Intel Xeon processor. Airflow is based on a measurement approximately one inch upstream from the processor.

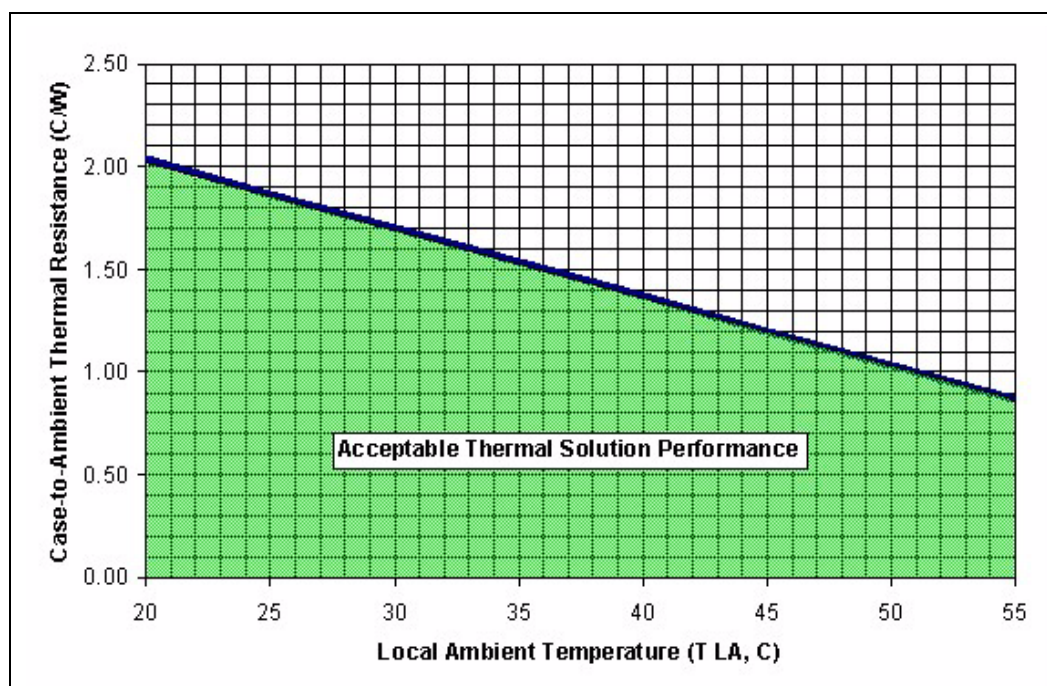
The thermal performance required for the heat sink is determined by calculating the case-to-ambient thermal resistance,  $\Psi_{ca}$ . This is a basic thermal engineering parameter that may be used to evaluate and compare different thermal solutions. For this particular processor,  $\Psi_{ca}$  is calculated as shown in [Equation 1](#).

### Equation 1. Case-to-Ambient Thermal Resistance

$$\Psi_{CAmax} = \frac{T_{cmax}^{\circ C} - T_{LA}^{\circ C}}{TDP(W)} = \frac{81^{\circ C} - 50^{\circ C}}{30W} = 1.03 \frac{^{\circ C}}{W}$$

As an example, Figure 5 further illustrates the required thermal performance for the Intel Low Voltage Intel Xeon Processor at 1.6 GHz at different operating ambient temperatures. The thermal solution used to cool the processor must have a case-to-ambient thermal resistance less than or equal to the values shown for the given local ambient temperature.

Figure 5. Thermal Resistance Values for Various Operating Temperatures



## 2.2.4 Recommended Heat Sink Designs

### 2.2.4.1 Aluminum Extruded Heat Sink Design

This heat sink was designed to meet the required thermal performance for LV Intel Xeon processors. This design is Intel intellectual property and intended for customer use with appropriate consent. The heat sink shown in Figure 6 was optimized using computational fluid dynamic (CFD) and thermal modeling software. The heat sink is optimized for a non-ducted airflow, as measured approximately one inch upstream from the processor.

Thermal modeling and verification tests indicate that this heat sink has a case-to-ambient thermal resistance of 0.95° C/W without the duct at 300 LFM, thus meeting the requirements for the 1.6 GHz Low Voltage Intel Xeon processor. Figure 7 shows the thermal performance for the aluminum extruded heat sink with non-ducted airflow.

The geometry of the heat sink is optimized for high volume manufacturing methods including extrusion, folded fin, and other heat sink manufacturing technologies. A list of enabled vendors is provided in Section 3.0.

Figure 6. Aluminum Extruded Heat Sink Drawing

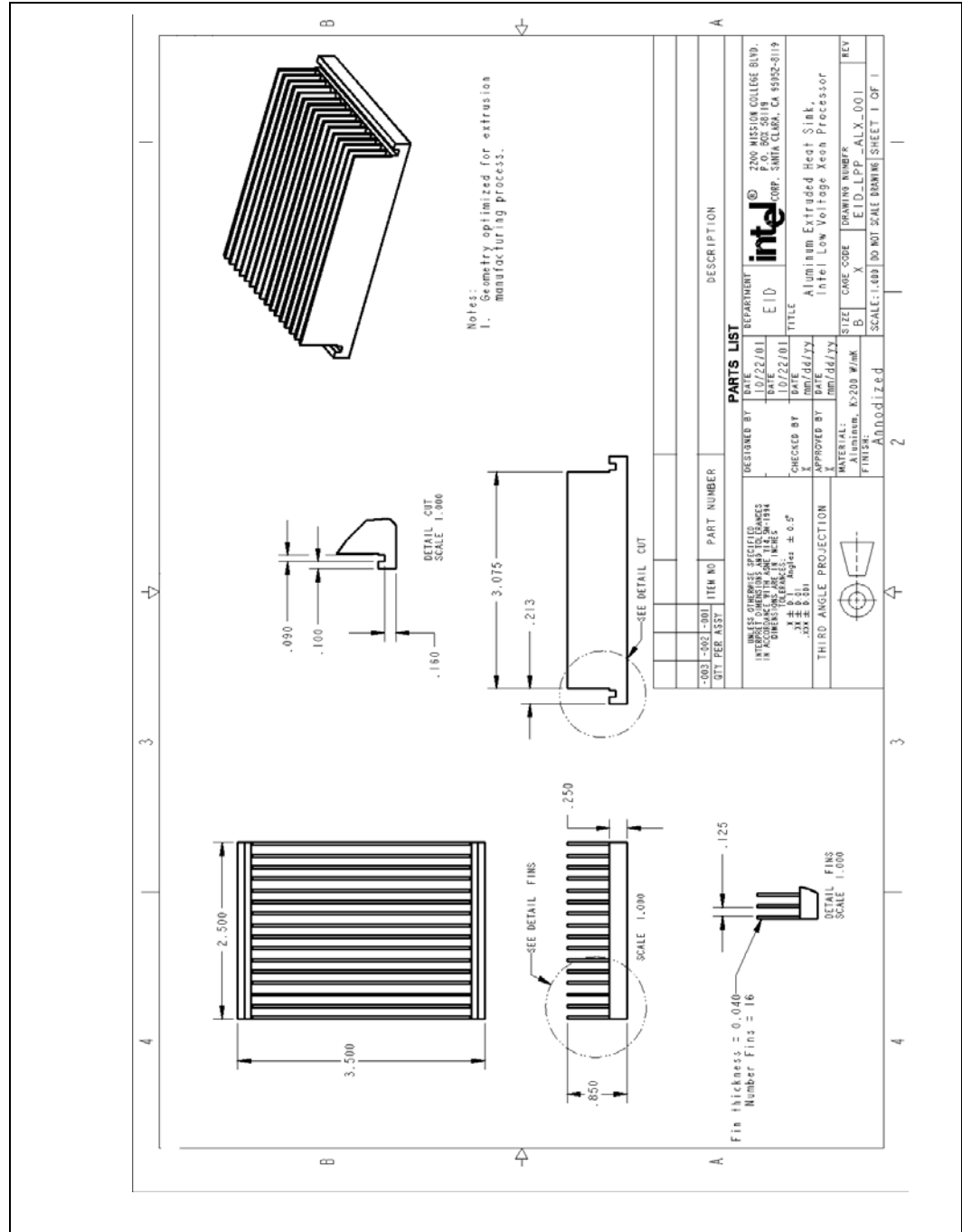
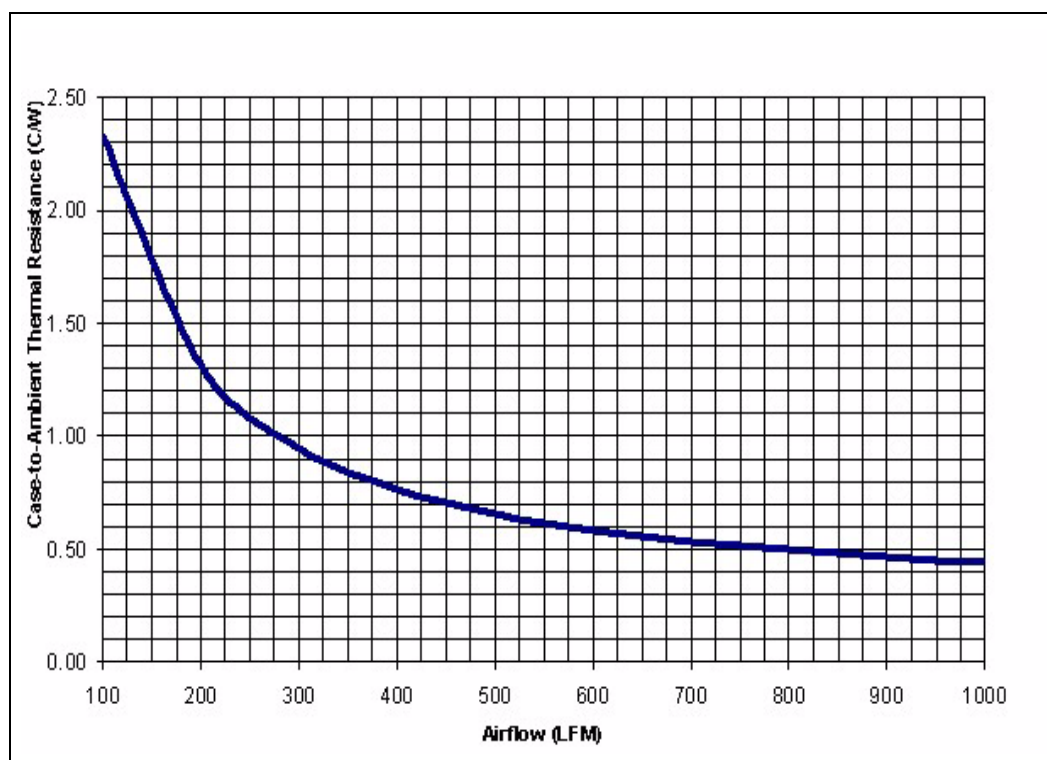


Figure 7. Aluminum Extruded Heat Sink Thermal Performance Curve



#### 2.2.4.2 Aluminum Crimped Fin Heat Sink Design

This heat sink was designed to meet the required thermal performance for the LV Intel Xeon processor. The heat sink design is Intel intellectual property and intended for customer use with appropriate consent. The heat sink shown in [Figure 8](#) was optimized using computational fluid dynamic (CFD) and thermal modeling software. The heat sink is optimized for ducted airflow, as measured one inch upstream from the processor. Due to pressure loss with this heat sink design, ducted airflow is required.

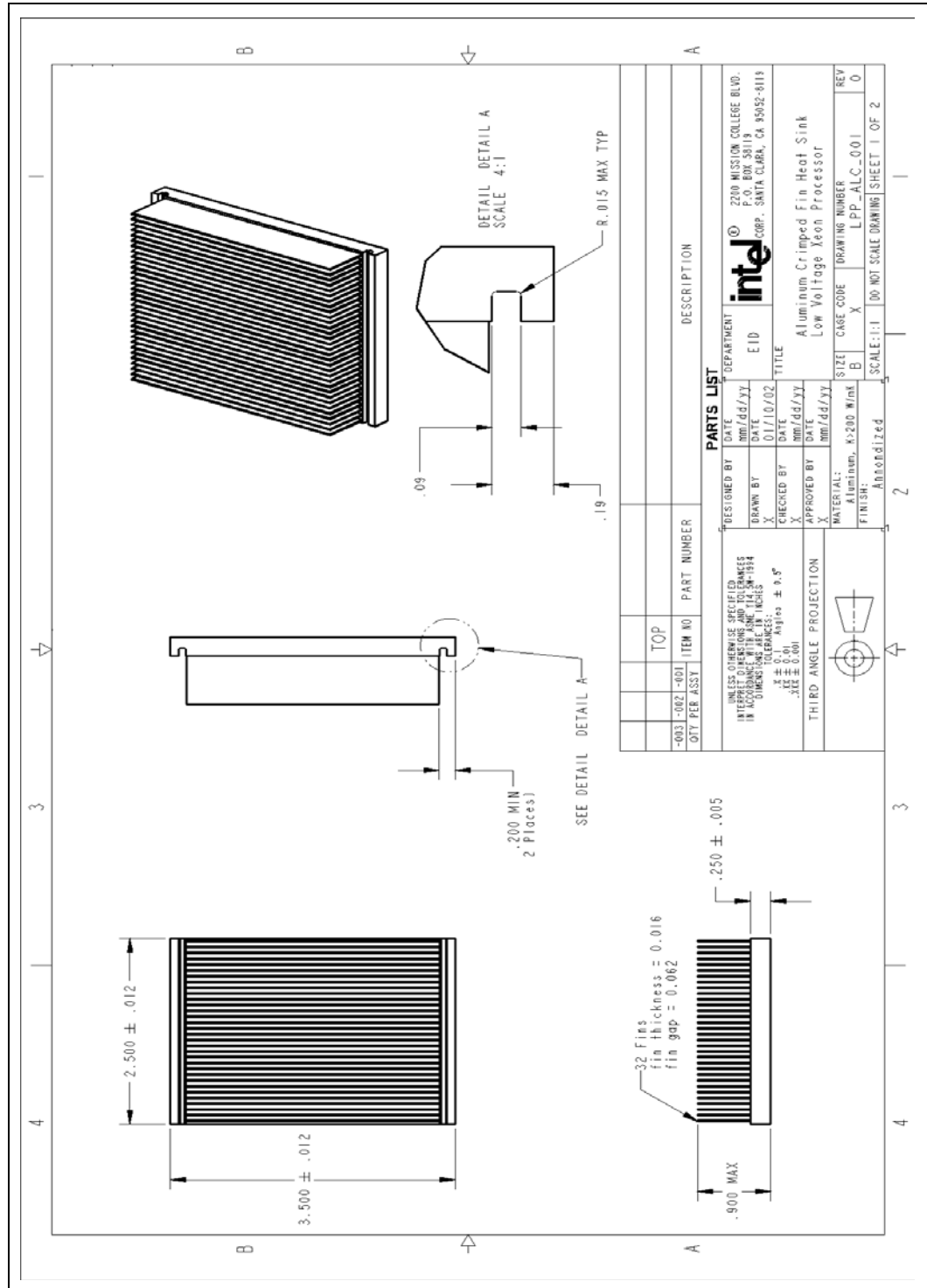
Based on computer modeling and experience, an optimum duct may have a bypass less than 0.2 inch on both sides and no bypass at the top of the heat sink. [Figure 9](#) illustrates heat sink thermal performance when using a duct with a 0.2 inch bypass. It is important to note that the duct must be connected directly to the fan, or blower, supplying the airflow. Simply providing air from a system airflow source and placing a duct over the heat sink may not improve the heat sink's performance.

Thermal modeling and verification tests indicate that this heat sink has a case-to-ambient thermal resistance of  $0.63^{\circ}\text{C/W}$  at 500 LFM and  $0.88^{\circ}\text{C/W}$  at 300 LFM, both ducted airflow.

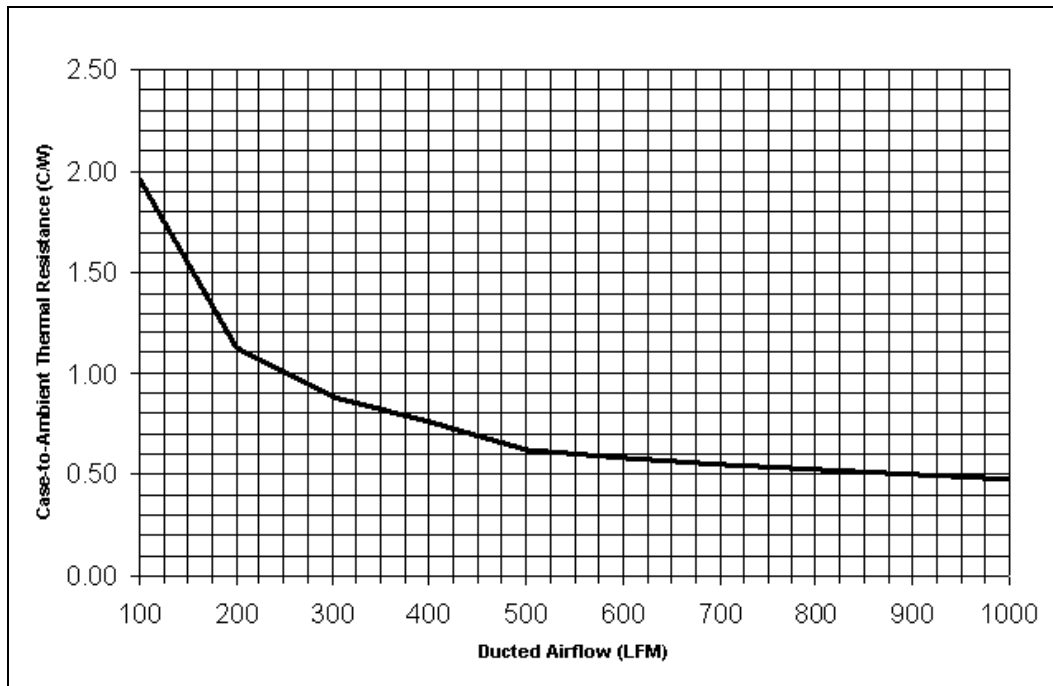
The geometry of the heat sink is optimized for the high volume crimped fin heat sink manufacturing technology. A list of enabled vendors is provided in [Section 3.0](#).



Figure 8. Aluminum Crimped Fin Heat Sink Drawing



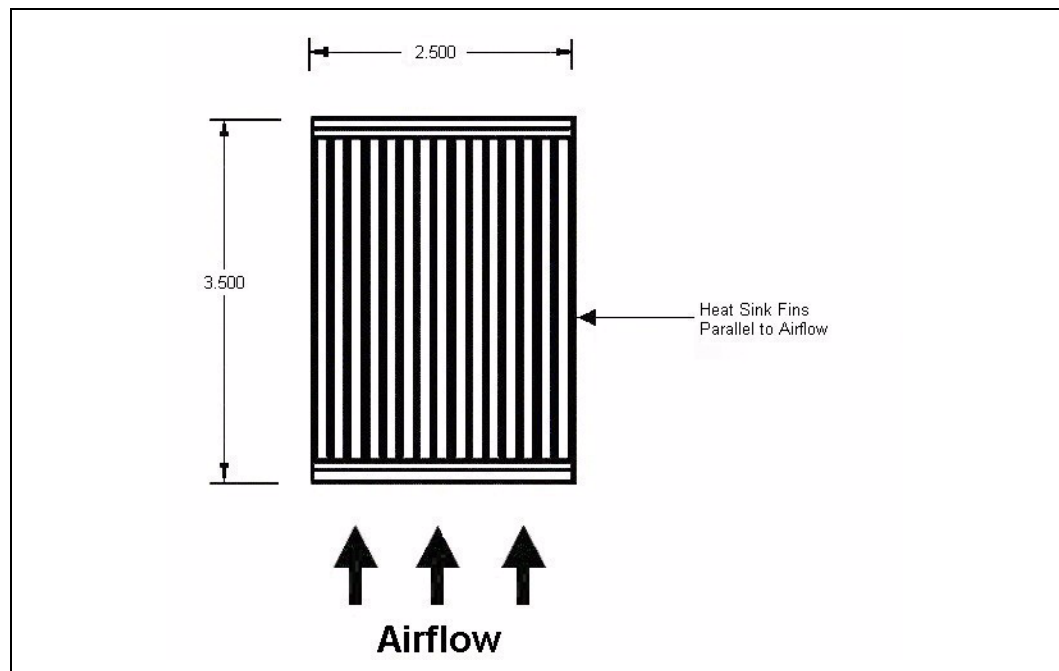
**Figure 9. Aluminum Crimped Fin Heat Sink Thermal Performance**



### 2.2.4.3 Heat Sink Orientation Relative to Airflow

The heat sinks in [Figure 6](#) and [Figure 8](#) were designed to maximize the available space within the volumetric keep out zone. These heat sinks must be oriented in a specific direction relative to the processor keep out zone and airflow. In order to use this design, the processor must be placed on the PCB in an orientation so the heat sink fins may be parallel to the airflow. [Figure 10](#) illustrates this orientation. A top view of the heat sink assembly is shown.

Figure 10. Heat Sink Orientation to the Processor and Airflow



### 2.2.5 Recommended Thermal Interface Material

It is important to understand and consider the impact the interface between the processor and heat sink base has on the overall thermal solution. Specifically, the bond line thickness, interface material area, and interface material thermal conductivity must be managed to optimize the thermal solution.

It is important to minimize the thickness of the thermal interface material, commonly referred to as the bond line thickness. A large gap between the heat sink base and processor case may yield a greater thermal resistance. The thickness of the gap is determined by the flatness of both the heat sink base and the IHS, plus the thickness of the thermal interface material (i.e., thermal grease), and the clamping force applied by the heat sink attachment clips. To ensure proper and consistent thermal performance, the TIM and application process must be properly designed.

The heat sink solution was optimized using a high performance phase change thermal interface material (TIM) with low thermal impedance. The heat sinks were prototyped and verified using ShinEtsu\* G749 thermal grease. Vendor information for this material is provided in [Section 3.0](#). Alternative materials may be used at the user's discretion. The entire heat sink assembly must be validated together for specific applications, including the heat sink, clip, and thermal interface material.

### 2.2.6 Recommended Heat Sink Attachment Method

The heat sink is secured to the processor assembly with two pressure-loaded clips. The clips apply force to the heat sink base to maintain a desired pressure on the thermal interface material between the IHS and heat sink, and to hold the heat sink in place during dynamic loading. The reference design heat sink clip attaches to the heat sink base through the grooves at each end of the base, as

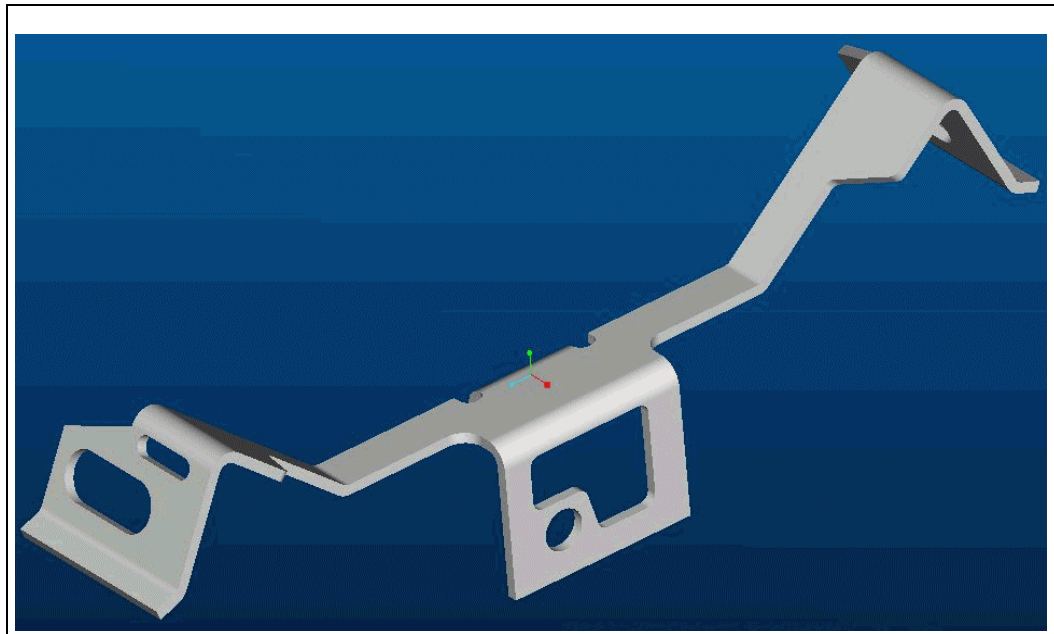
shown in [Figure 11](#) and [Figure 12](#). The clips are latched to the reference design retention mechanism (RM) clip tabs, which are located at each end of the RM. Two clips and RMs are required per heat sink assembly.

### 2.2.6.1 Heat Sink Clip

The reference design clip, Intel part number A74694, is shown in [Figure 11](#). The clips may be susceptible to deformation during any rework or upgrade procedure that requires the heat sink assembly to be disassembled. The system integrator should exercise caution in re-using clips that have experienced multiple assembly-disassembly cycles.

Caution must also be taken to make sure the proper clip is being used, since there are a variety of similar clips available for other processor packages. The system integrator must be certain that the proper clip is used to ensure adequate thermal performance. A list of enabled vendors is available in [Section 3.0](#).

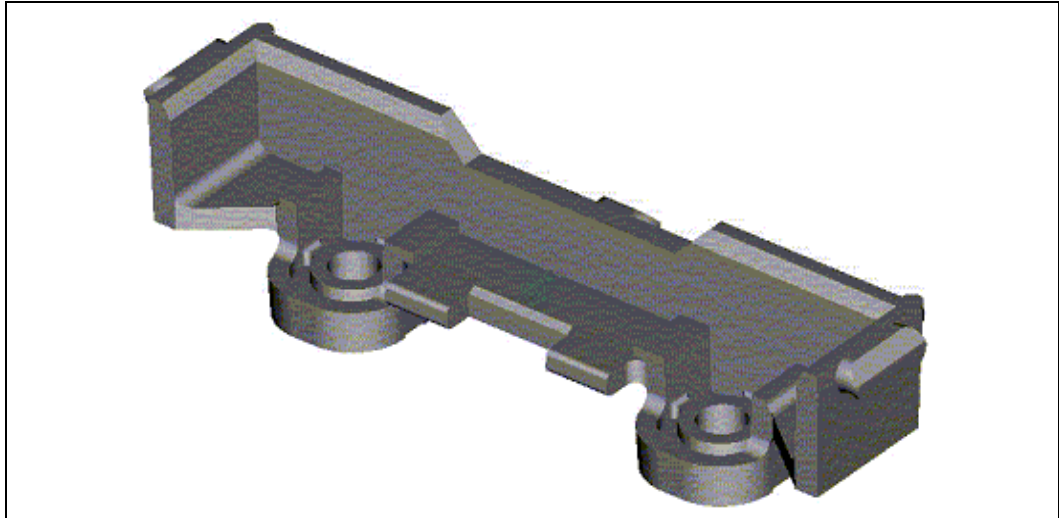
**Figure 11. Heat Sink Clip Intel Part Number A74694 for the FC- $\mu$ PGA2P Package**



### 2.2.6.2 Retention Mechanism

The reference design retention mechanism, Intel part number A346844, is shown in [Figure 12](#). This is the same retention mechanism used for the 423 pin Intel® Pentium® 4 processor. A list of enabled vendors is available in [Section 3.0](#).

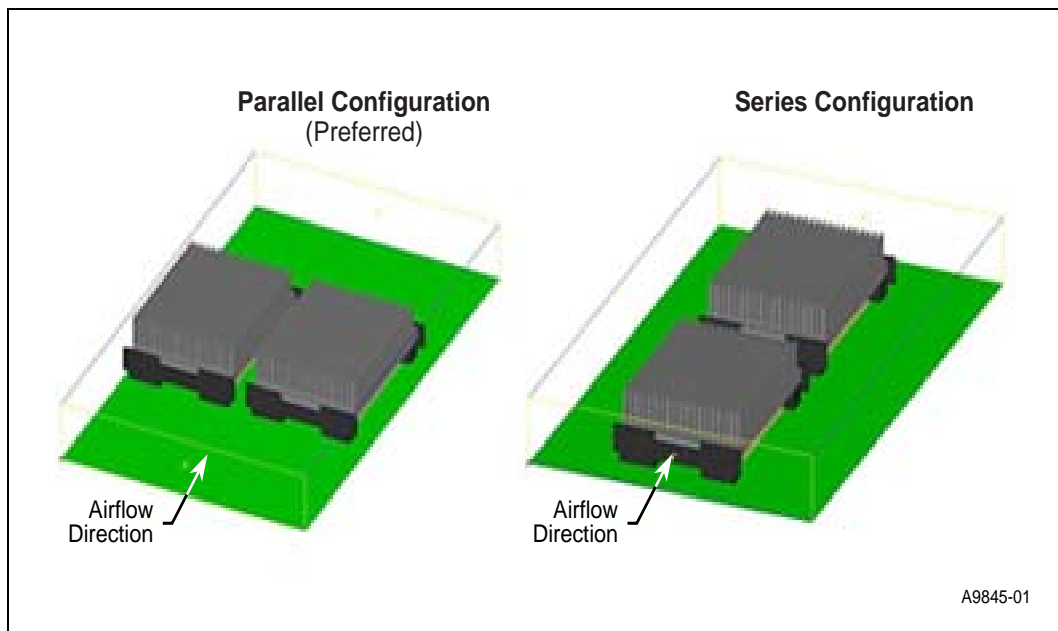
Figure 12. Retention Mechanism Intel Part Number A346844



### 2.2.7 Dual Processor Considerations

The heat sink designs presented are suitable for use in multi-processor configurations. However additional precautions must be taken with the orientation of the processors on the baseboard. The results of computer modeling and testing indicate that processors placed in series, meaning that one processor placed directly behind the other relative to the airflow, may have a higher CPU temperature when compared to processors placed in parallel (side-by-side relative to the airflow). As a result, it is strongly recommended that the processors be placed in the parallel orientation for optimized thermal performance. For a better understanding, Figure 13 illustrates the preferred orientation.

Figure 13. Orientation of Multi-Processor Configuration



A9845-01

## 2.3 Thermal Monitor

Thermal Monitor is a feature of the Low Voltage Intel Xeon processor that allows system designers to lower the cost of thermal solutions without compromising system integrity, or reliability. The processor, without the aid of any additional software or hardware, may control the die temperature within factory specifications under typical real-world operating conditions by using a factory-tuned, precision on-die temperature sensor and a fast acting thermal control circuit (TCC). Thermal Monitor allows the processor and system thermal solutions to be designed much closer to the power envelopes of real applications, instead of being designed to the much higher maximum processor power envelopes.

Thermal Monitor controls the processor temperature by modulating (starting and stopping) the internal processor core clocks. The processor clocks are modulated when the thermal control circuit is activated. Thermal Monitor uses two modes to activate TCC: Automatic and On-Demand Modes. Automatic mode must be enabled through BIOS, which is required for the processor to operate within specification.

Once automatic mode is enabled, the TCC may activate only when the internal die temperature is very near the temperature limits of the processor. When the TCC is enabled and a high temperature situation exists (i.e., TCC is active), the clocks may be modulated by maintaining a duty cycle between the ranges of 30% to 50%. Clocks may not be off or on for more than 3.0 ms when the TCC is active. Cycle times are processor-speed dependent and may decrease as processor core frequency increases. An amount of hysteresis has been included to prevent rapid active/inactive transitions of the TCC when the processor temperature is near the trip point. Once the temperature has returned to a non-critical level and the hysteresis timer has expired, modulation ceases and the TCC goes inactive. Processor performance may be decreased by approximately 50% when the TCC is active (assuming a duty cycle in the range of 30% to 50%). However, with a properly designed and characterized thermal solution the TCC most likely may only be activated briefly during the most power intensive applications.

For automatic mode, the duty cycle is factory configured and cannot be modified. Also, automatic mode does not require any additional hardware, software drivers, or interrupt handling routines.

The TCC may also be activated through On-Demand mode. When bit 4 of the ACPI Thermal Monitor Control Register is written to a 1 the TCC may be activated immediately, independent of the processor temperature. When using On-Demand mode to activate the TCC, the duty cycle of the clock modulation is programmable through bits 3:1 of the same ACPI Thermal Monitor Control Register. In automatic mode, the duty cycle is fixed anywhere between the range of 30% to 50%. In On-Demand mode the duty cycle may be programmed from 12.5% on/ 87.5% off to 87.5% on/ 12.5% off in 12.5% increments. On-Demand mode may be used at the same time Automatic mode is enabled. However, when the TCC is enabled through On-Demand and Automatic mode, **AND** a high temperature condition exists, the fixed duty cycle of the Automatic mode may override the duty cycle selected by the On-Demand mode.

An external signal, PROCHOT# (processor hot) is asserted at any time the TCC is active (either in Automatic or On Demand mode). Bus snooping and interrupt latching are also active while the TCC is active. The temperature at which the TCC activates is not user configurable and is not software visible. In an MP system, Thermal Monitor must be configured for each processor. All processors in a system must be programmed identically.

Besides the thermal sensor and TCC, the Thermal Monitor feature also includes one ACPI register, one performance counter register, three model specific registers, and on I/O pin (PROCHOT#). All are available to monitor and control the state of the Thermal Monitor feature. Thermal Monitor may be configured to generate an interrupt upon the assertion or de-assertion of PROCHOT# (i.e., upon the activation/deactivation of TCC).

**Note:** When Automatic mode is disabled, the processor may be operating out of specification and reliable results cannot be ensured.

In the event of a catastrophic cooling failure the processor may automatically shut down when the silicon has reached a temperature of approximately 135° C, regardless if Automatic or On-Demand modes are enabled. At this point the system bus signal THERMTRIP# may go active and stay active until the processor has cooled down and RESET# has been initiated. THERMTRIP# activation is independent of processor activity and does not generate any bus cycles. When THERMTRIP# is asserted, processor core voltage (Vcc) must be removed within the time frame specified by the processor datasheet.

### **2.3.1 Thermal Diode**

The Low Voltage Intel Xeon processor incorporates an on-die thermal diode. This sensor located on the processor may be used to monitor the die temperature for long term thermal management and die temperature change purposes. This thermal diode is separate from the Thermal Monitor's thermal sensor and cannot be used to predict the behavior of the Thermal Monitor.



### 3.0 Vendor List

Table 3 provides a vendor list as a service to our customers for reference only. The inclusion of this list should not be considered a recommendation or product endorsement by Intel Corporation.

**Table 3. Vendor List**

<b>Aluminum Extruded Heat Sink (Reference No. EID-LPP38-ALX-001)</b>	
Peninsula Components (PENCOM) 1300 Pioneer Street, Suite E Brea, CA 92821	Contact: Steve Blank (562) 964-4477
<b>Aluminum Crimped Fin Heat Sink (Reference No. EID-LPP-ALC-001)</b>	
Computer Memory Disk (Furukawa) 2380 Qume Dr., Unit D San Jose, CA 95131	Contact: Katsu Mizushima (408) 232-9300
<b>Heat Sink Clips (Intel part number A74694)</b>	
Foxconn 1699 Richard Ave. Santa Clara, CA 95050	Contact: Julia Jiang (408) 916-6178
<b>Retention Mechanism (Intel part number A346844)</b>	
Foxconn 1699 Richard Ave. Santa Clara, CA 95050	Contact: Julia Jiang (408) 916-6178
<b>Thermal Interface Material (ShinEtsu G749)</b>	
Shin-Etsu Micro Si, Inc. 10028 S. 51 <sup>st</sup> St. Phoenix, AZ 85044	Contact: (480) 893-8898