Low Voltage Intel® Pentium® III Processor 512K

Thermal Design Guide

September 2002

Order Number: 273675-002

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Revision History

Date	Revision	Description
September 2002	-002	Second release of this document.
March 2002	-001	Initial release of this document.

1.0 Introduction

This document describes the thermal design guidelines for the Low Voltage Intel® Pentium® III processor 512K in the surface mount, 479-pin, micro FC-BGA package. Detailed mechanical and thermal specifications for this processor may be found in the *Low Voltage Intel® Pentium® III Processor 512K Datasheet* (order number 273673).

The information provided in this document is for reference only and additional validation must be performed prior to implementing the thermal solution designs into final production. The intent of this document is to assist customers with the development of thermal solutions for their individual designs. The final thermal solutions, including the heat sink, attachment method, and thermal interface material (TIM) must comply with the mechanical design, environmental, and reliability requirements specified in the processor datasheet. It is the responsibility of the original equipment manufacturer (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 for the Low Voltage Intel® Pentium® III processor 512K and provide guidelines for meeting the thermal requirements for single and dual processor systems. The thermal solutions presented in this document are specifically designed for embedded applications, including the Compact PCI* form factors.

1.2 Document Scope

This document discusses the thermal management techniques for the Low Voltage Intel® Pentium® III processor 512K, specifically in embedded computing applications. The physical dimensions and power values used in this document are for reference only. Please refer to the processor's datasheet for the most up to date information. In the event of conflict, the data in the datasheet supersedes any data in this document.

1.3 Definition of Terms

Δ	delta, difference, change between two states
θ	thermal resistance
θ max	maximum allowable thermal resistance
BGA	ball grid array
°C	degrees in Celsius
CFD	computational fluid dynamics
CFM	cubic feet per minute
DP	dual processing capability
in.	inches
LFM	liner feet per minute
LP	low power
PCB	printed circuit board
Ta	ambient temperature of air measured approximately one inch upstream of processor
TDPmax	maximum thermal design power
TIM	thermal interface material
Tj	junction temperature
Tj max	maximum allowable junction temperature
W	Watt

2.0 Design Guideline

The thermal solutions presented in this document were designed to fit within the maximum component height allowed by the Compact PCI* specification. The heat sink designs were optimized for the Compact PCI form factor and with airflow equivalent to 200 LFM at one inch upstream of the processor. The thermal solutions may be valid for other form factors, however individual applications must be modeled, prototyped, and verified.

Prototype parts have been fabricated for verification tests. It is important to note that the thermal verification tests described in this document are 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

In order to maintain compatibility with the micro-FCPGA package, Intel recommends adhering to the specification for the keep-out zone, and mounting hole pattern as described in the *Intel® Mobile Processor Micro-FCPGA Socket (mPGA479M) Design Guidelines* (order number 298520). The keep-out zone and mounting hole pattern suggested in this document is intended to follow the guidelines specified in the aforementioned document. However, to accommodate an existing heat sink attachment method, the diameter of the mounting holes is different in this specification.

Figure 1 illustrates the geometry of the micro FC-BGA package with dimensions provided in Table 1. Refer to the processor data sheet for detailed information.

Figure 1. Micro FC-BGA Package Geometry

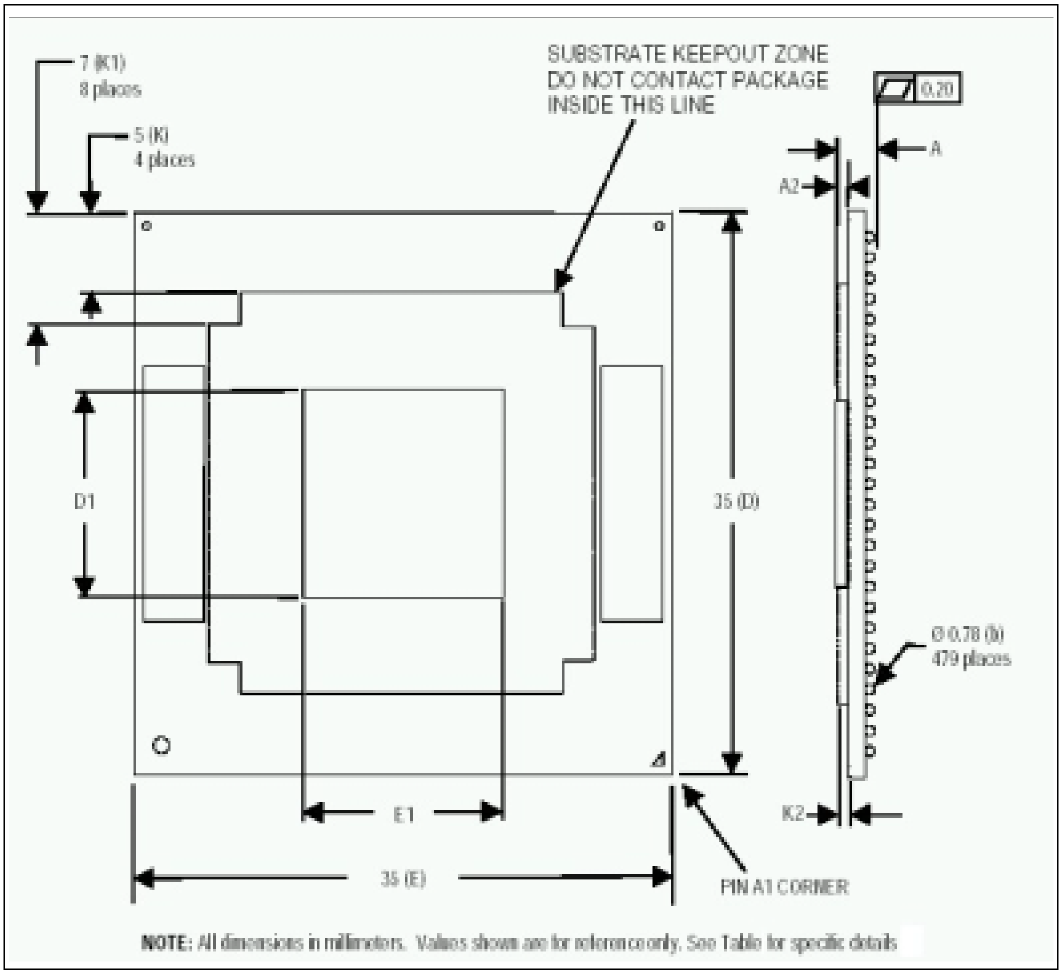


Table 1. Micro FC-BGA Mechanical Specifications

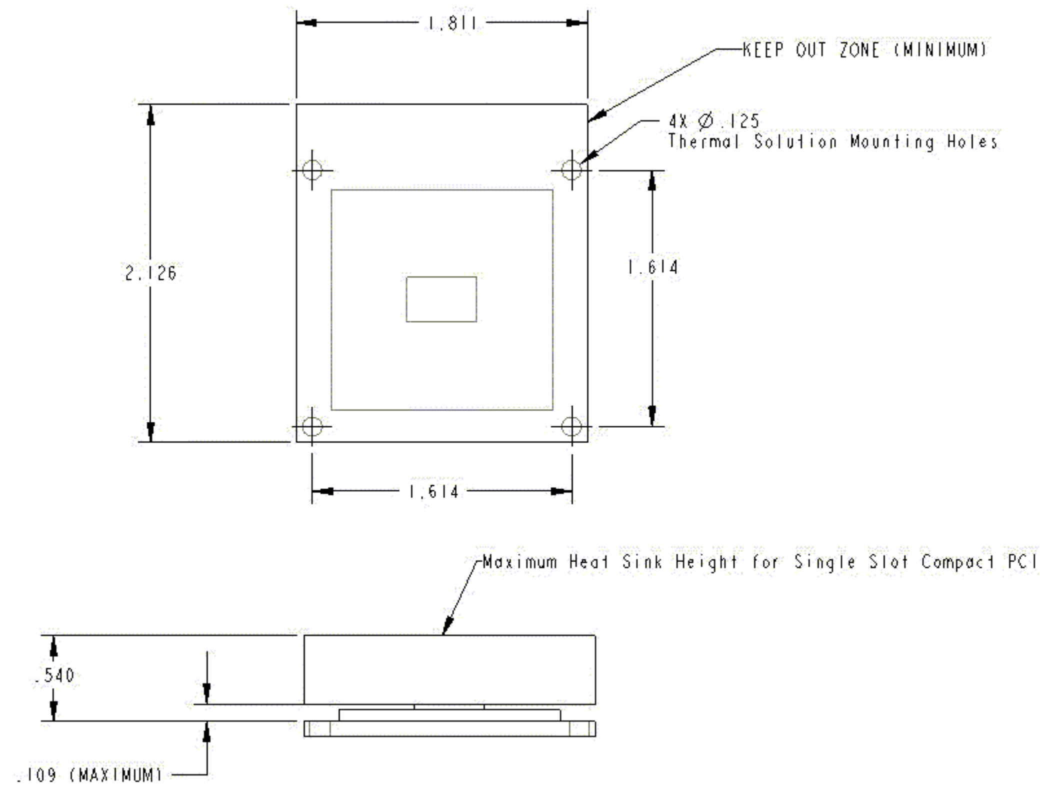
Symbol	Parameter	Min[3, 4]	Max[3, 4]	Unit
A	Overall height as delivered[2]	2.27	2.77	mm
A2	Die height	0.854		mm
b	Ball diameter	0.78		mm
D	Package substrate length	34.9	35.1	mm
E	Package substrate width	34.9	35.1	mm
D1	Die length	11.18		mm
E1	Die width	7.19		mm
e	Ball pitch	1.27		mm
N	Ball count	479		each
K	Keep-out outline from edge of package	5		mm
K1	Keep-out outline at corner of package	7		mm
K2	Capacitor keep-out height	–	0.7	mm
S	Package edge to first ball center	1.625		mm
–	Solder ball coplanarity	0.2		mm
Pdie	Allowable pressure on the die for thermal solution	–	689	kPa
W	Package weight	4.5		g

NOTES:
1. Overall height as delivered. Values were based on design specifications and tolerances. Final height after surface mount depends on the OEM motherboard design and SMT process.
2. All dimensions are subject to change.
3. All dimensions are in millimeters.
4. In the event of conflict, dimensions provided in the processor datasheet supersede this data.

2.1.2 Keep-In/Keep-Out Zones and Mounting Holes

The keep-in zone reserved for the processor package, heat sink, and heat sink attachment method for the baseboard is shown in Figure 2. This is the typical keep-out zone for the micro FC-PGA package with the exception of the mounting hole diameter. The recommended mounting hole diameter has been increased from 0.09 to 0.125 inches. This allows the use of a readily available and proven mounting fastener. Please refer to the *Low Voltage Intel® Pentium® III Processor 512K Datasheet* (order number 273673) for detailed information.

Figure 2. Baseboard Keep-Out Zone for the Micro FC-BGA Package-Primary Side



NOTE: All dimensions are in inches.

2.2 Thermal Guidelines

This document presents thermal solutions for the Low Voltage Intel® Pentium® III processor 512K in the micro FC-BGA package. The required performance of the thermal solution is dependant on many parameters including the processor's thermal design power (TDP), maximum junction temperature (Tj 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 this processor should be followed to evaluate the thermal performance of proposed cooling solutions. The thermal metrology is contained in the *Intel® Pentium® III Processor Thermal Design Guidelines* (order number 245087).

Thermal data for the processor is presented in Table 2. The data is provided for informational purposes only and is subject to change. Please refer to the processor's data sheet for the most up to date information.

Table 2. Low Voltage Intel® Pentium® III Processor 512K Thermal Data

Core Frequency (MHz)	Maximum Power (W)	Minimum T junction (ºC)	Maximum T junction (ºC)
800	11.2	0	100
933	12.2	0	100

2.2.1 Processor Junction Temperature

The processor's bare die is exposed in the micro FC-BGA package, providing the common interface and attachment location for all processor thermal solutions. Techniques for measuring the junction temperature are provided in Section 7.3 of the *Intel® Pentium® III Processor Thermal Design Guidelines* (order number 245087). The limits for the junction temperature may be found in the processor's datasheet.

2.2.2 Processor Power

The processor's power specifications are documented by the maximum thermal design power, or TDPmax. The maximum power may be approached by running code specifically written to draw the most current, such as the maximum power test application. The most up to date TDP values may be found in the processors datasheet.

2.3 Thermal Solution Requirements

The thermal solutions recommended in this document were designed based on the processor thermal specifications as outlined in the *Low Voltage Intel® Pentium® III Processor 512K Datasheet* (order number 273673). In addition, the operating ambient temperature was specified as 50 °C with a minimum system airflow of 200 LFM. The ambient temperature and airflow are based on a measurement approximately one inch upstream from the processor.

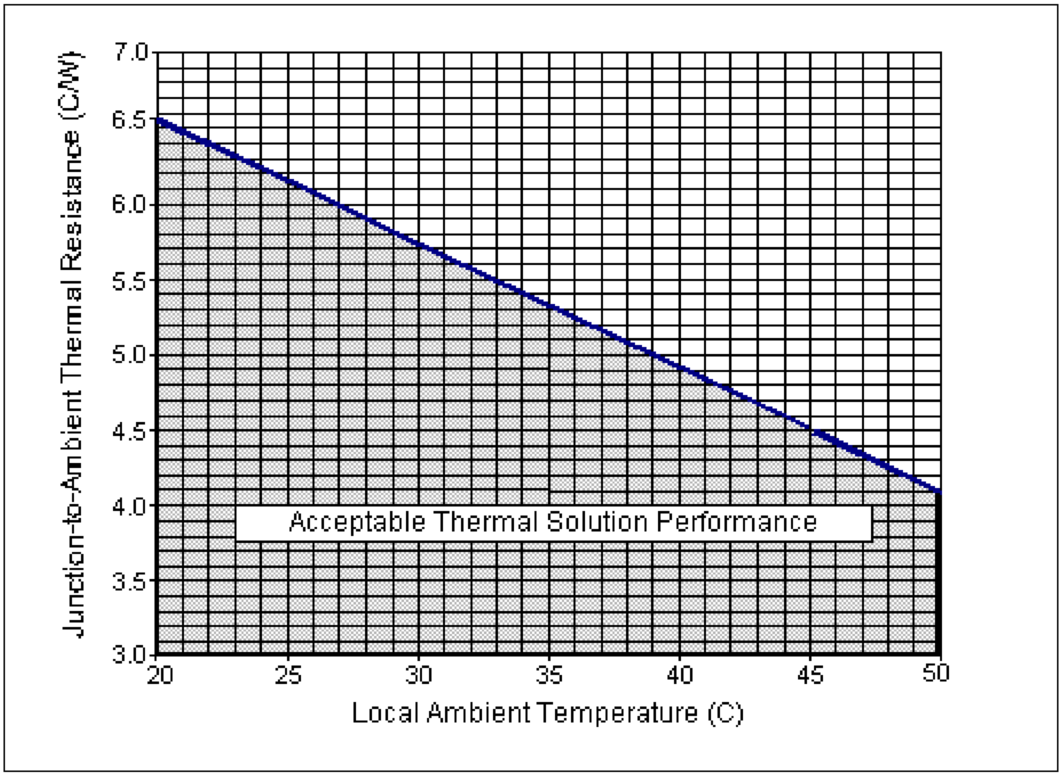
The thermal requirement of the heat sink is determined by calculating the junction-to-ambient thermal resistance, θ_{ja}. This is a basic thermal engineering parameter that may be used to evaluate and compare different thermal solutions. For this particular processor, θ_{ja} is calculated as shown in Equation 1.

Equation 1. Junction-to-Ambient Thermal Resistance

$$\theta_{max} = \frac{T_{jmax}{}^{\circ}C - T_a{}^{\circ}C}{TDP_{max}(W)} = \frac{100^{\circ}C - 50^{\circ}C}{12.2W} = 4.1\frac{^{\circ}C}{W}$$

Figure 3 further illustrates the required thermal performance for the processor at different operating ambient temperatures. The thermal solution used to cool the processor must have a junction-to-ambient thermal resistance less than, or equal to the value shown for a given ambient temperature. For illustrative purposes, data is shown for the 933 MHz processor (worst case).

Figure 3. Thermal Resistance Values for Various Operating Temperatures



2.3.1 Recommended Heat Sink Design

Two heat sinks have been designed that meet the required thermal performance for a minimum ambient temperature of 50 °C. The heat sink designs are Intel intellectual property and are intended for customer use with appropriate consent. The heat sinks shown in Figure 4 and Figure 7 were optimized using computational fluid dynamic (CFD) and thermal modeling software. The heat sink designs are optimized for a minimum airflow of 200 LFM, as measured one inch upstream from the processor. The airflow must be unobstructed up to and beyond the processor.

The geometry is also optimized for high volume manufacturing. All designs may be manufactured using extrusion and folded fin heat sink manufacturing technologies. A list of enabled heat sink vendors is provided in Section 4.0, "Vendor List" on page 19. The information provided in this document is for reference only and additional validation must be performed prior to implementing the designs into final production.

2.3.1.1 Heat Sink Design Option 1

Heat sink design option 1 has been designed to maximize the available space within the keep-out zone. The geometry of the heat sink is shown in Figure 4. Thermal modeling and verification tests indicate that this heat sink has a junction-to-ambient thermal resistance of 3.2 °C/W at 200 LFM. The thermal resistance at other airflow rates is shown in Figure 5.

This heat sink 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 are parallel to the airflow. Figure 6 illustrates a top-view orientation of the heat sink relative to the processor, keep-out zone, and airflow.

Figure 4. Heat Sink Design Option 1

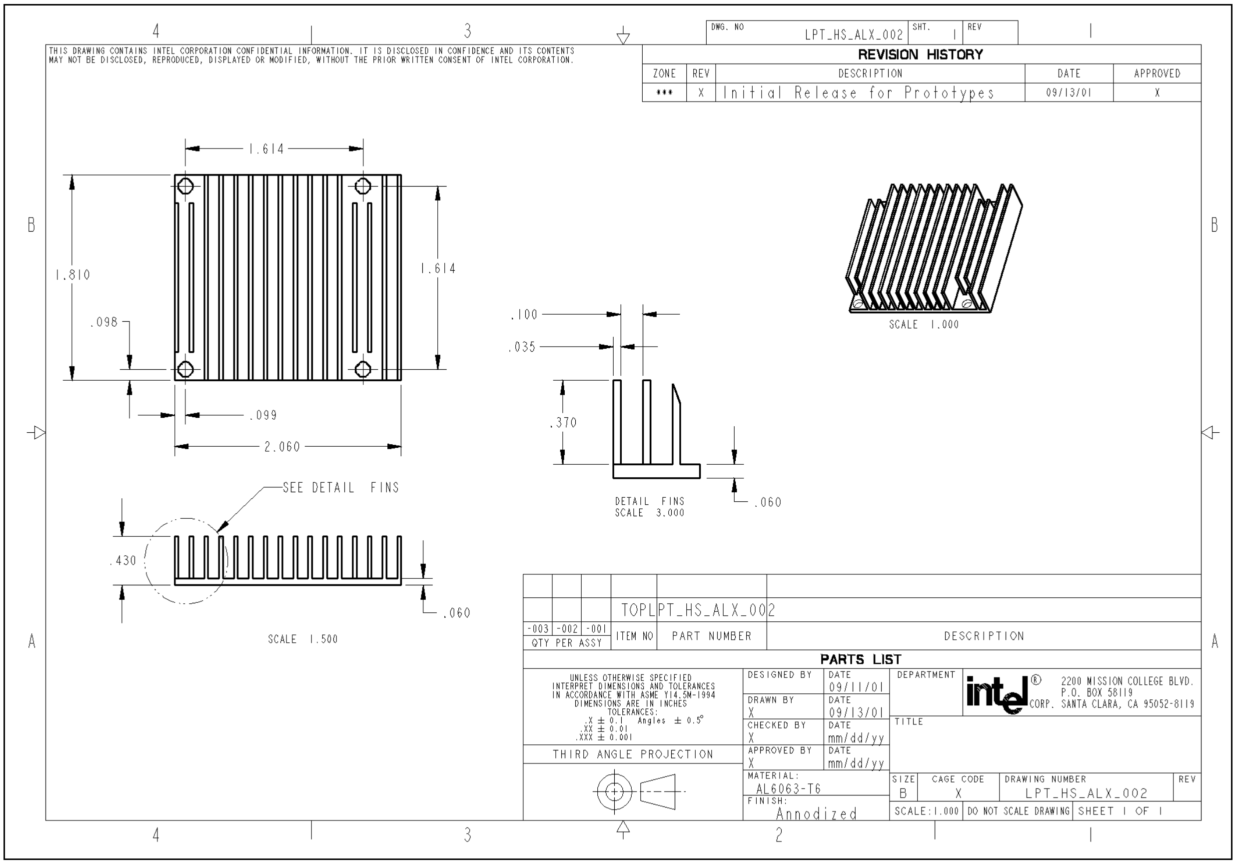


Figure 5. Heat Sink Option 1 Thermal Performance Curve

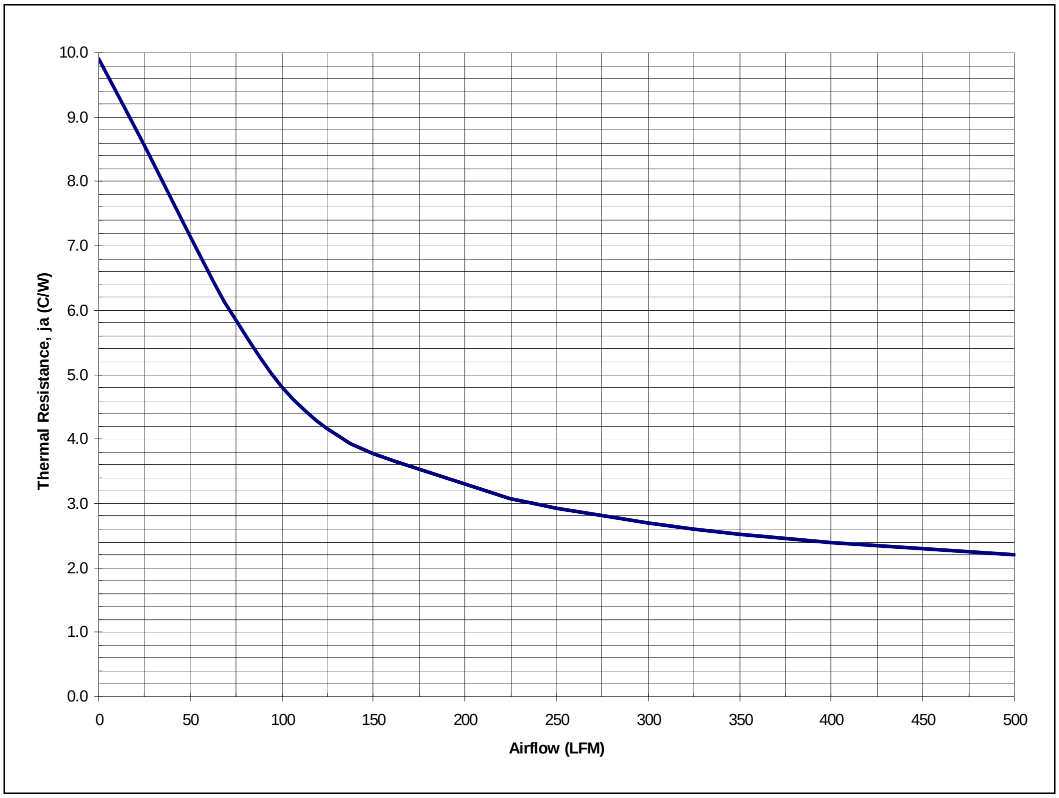
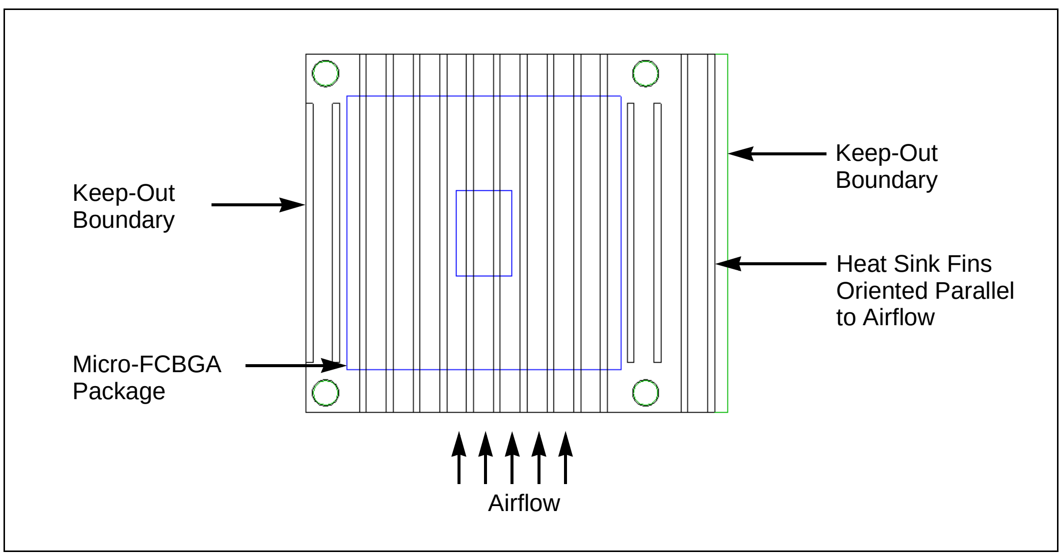


Figure 6. Heat Sink Option 1 Acceptable Orientation to the Processor and Airflow-Top View



2.3.1.2 Heat Sink Design Option 2

Heat sink design option 2 has been optimized to be the smallest size possible within the keep-out zone and using the standard mounting hole pattern. The geometry of the heat sink is shown in Figure 7. Thermal modeling and verification tests indicate that this heat sink has a junction-to-ambient thermal resistance of 3.9 °C/W at 200 LFM. The thermal resistance at other airflow rates is shown in Figure 8. This heat sink is symmetric and may be placed in any orientation relative to the processor. However, extreme care must be taken to make sure that the heat sink is assembled to the PCB with the fins parallel to the airflow. Figure 9 illustrates a top-view orientation of the heat sink relative to the processor, keep-out zone, and airflow.

Figure 7. Heat Sink Design Option 2

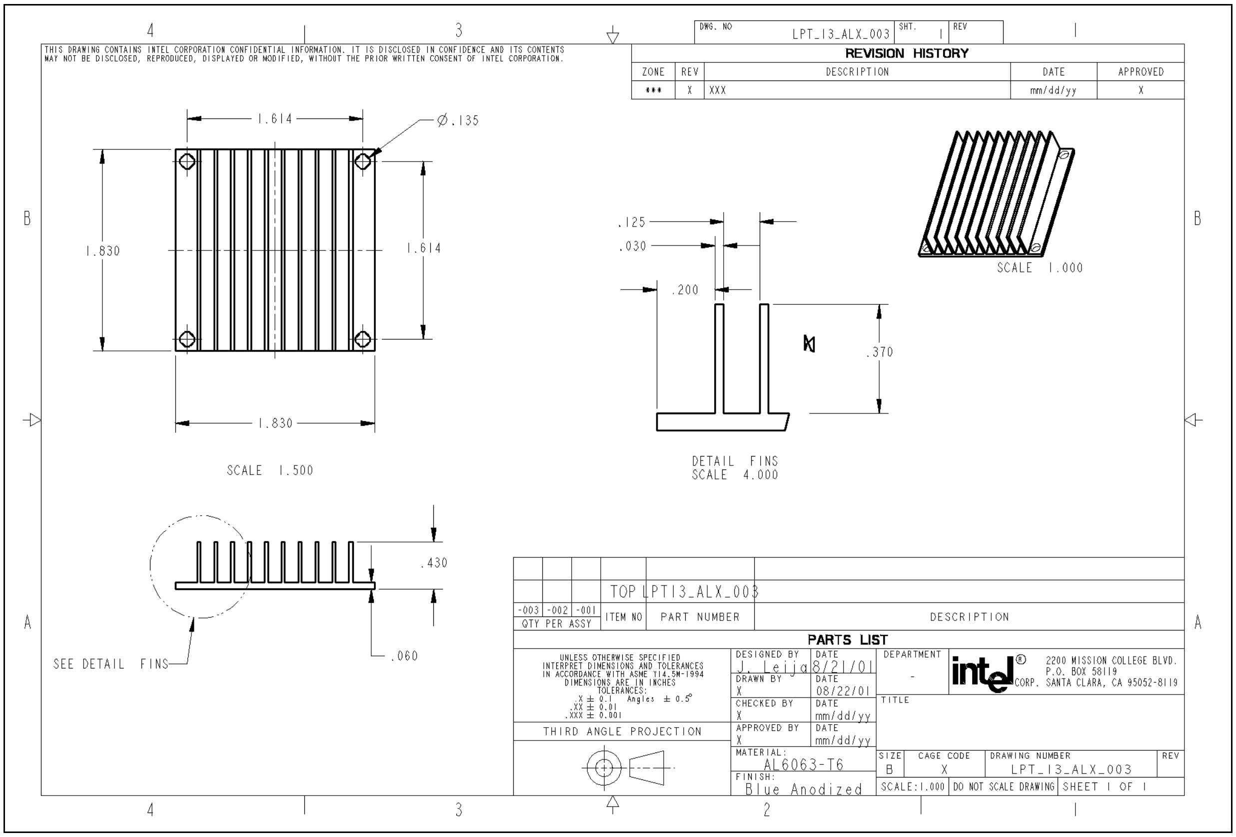


Figure 8. Heat Sink Option 2 Thermal Performance Curve

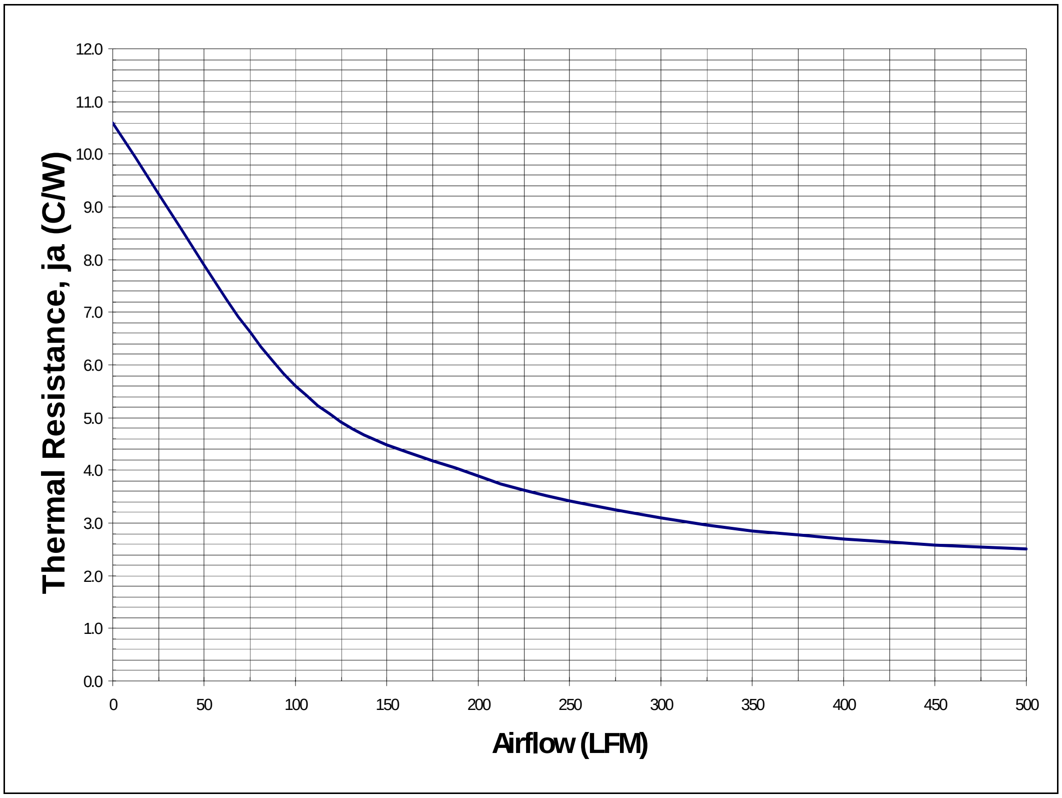
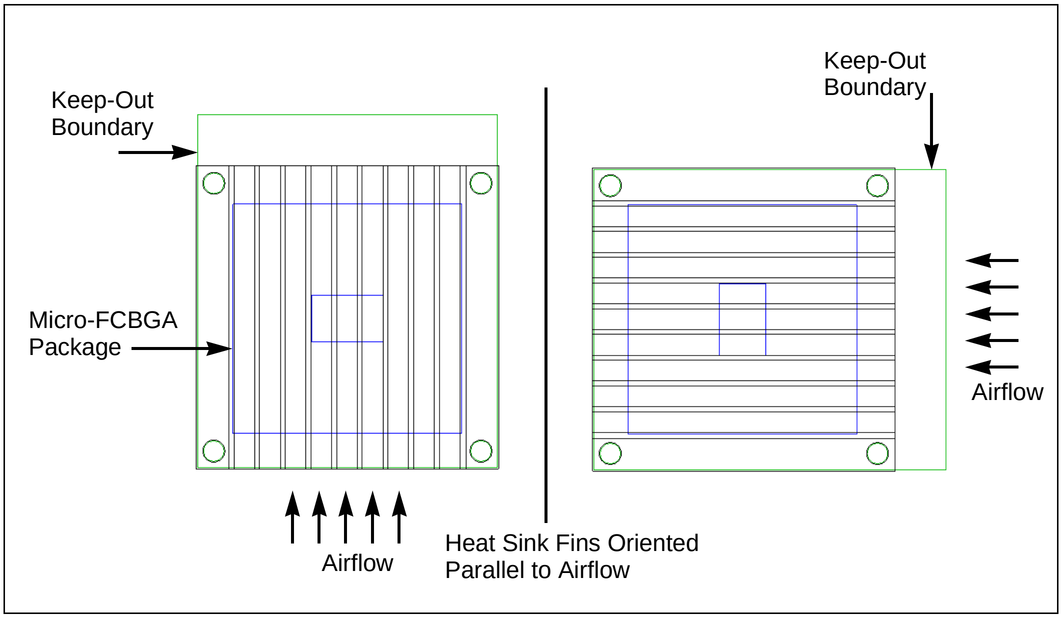


Figure 9. Heat Sink Option 2 Acceptable Orientations to the Processor and Airflow-Top View



2.3.1.3 Alternative Heat Sink Designs

Additional thermal solutions are available for the Low Voltage Intel® Pentium® III processor 512K for other form factors. A summary of thermal solutions may be obtained in the *Thermal Design Guide for Intel® Processors in the BGA2 and Micro FC-BGA Packages for Embedded Application*s (order number 273716).

In addition, an active heat sink with a fan mounted directly on top is available from Tyco Electronics Corporation. The active heat sink uses the same mounting hole pattern shown in Figure 2. The active heat sink design is suitable for laboratory testing, or other applications where system airflow is not available. The Tyco* part number is PN 8-1542007-5.

2.3.2 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 area, and interface material thermal conductivity must be managed to optimize the thermal solution.

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

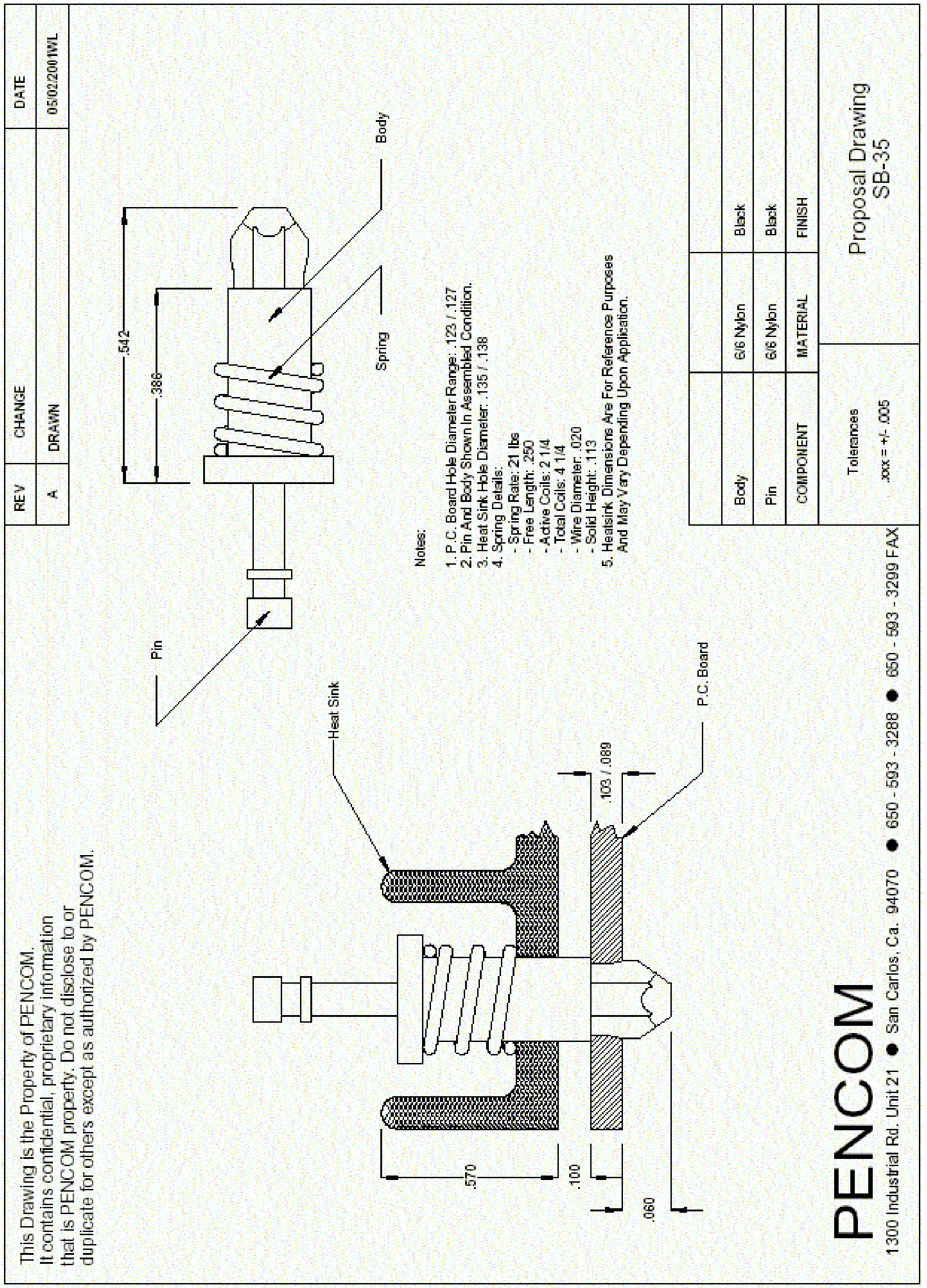
The heat sink solutions were optimized using a high performance phase change TIM with low thermal impedance. The heat sinks were prototyped and verified using Chomerics T725* phase change interface pads. Vendor information for this material is provided in Section 4.0, “Vendor List” on page 19. Alternative materials may be used at the user’s discretion. The entire heat sink assembly including the heat sink, attachment mechanisms, and interface material must be validated together for specific applications.

2.3.3 Recommended Heat Sink Attachment Method

The heat sinks are designed to secure to the PCB with four spring-loaded fasteners placed at each corner of the base. The spring-loaded fasteners apply force to the heat sink base to maintain a desired pressure on the thermal interface material between the processor and the heat sink, and to hold the heat sink in place during dynamic loading. Figure 10 shows an example of a spring-loaded fastener that meets the pressure requirements of the processor. A mounting fastener is available that interfaces with both a 0.063 and 0.093 inch thick PCB.

The heat sink designs were prototyped and verified using the Peninsula Components (PENCOM*) fastener for the 0.093 inch thick PCB. Vendor information for this fastener is provided in Section 4.0, “Vendor List” on page 19.

Figure 10. PENCOM* Heat Sink Mounting Fastener Assembly

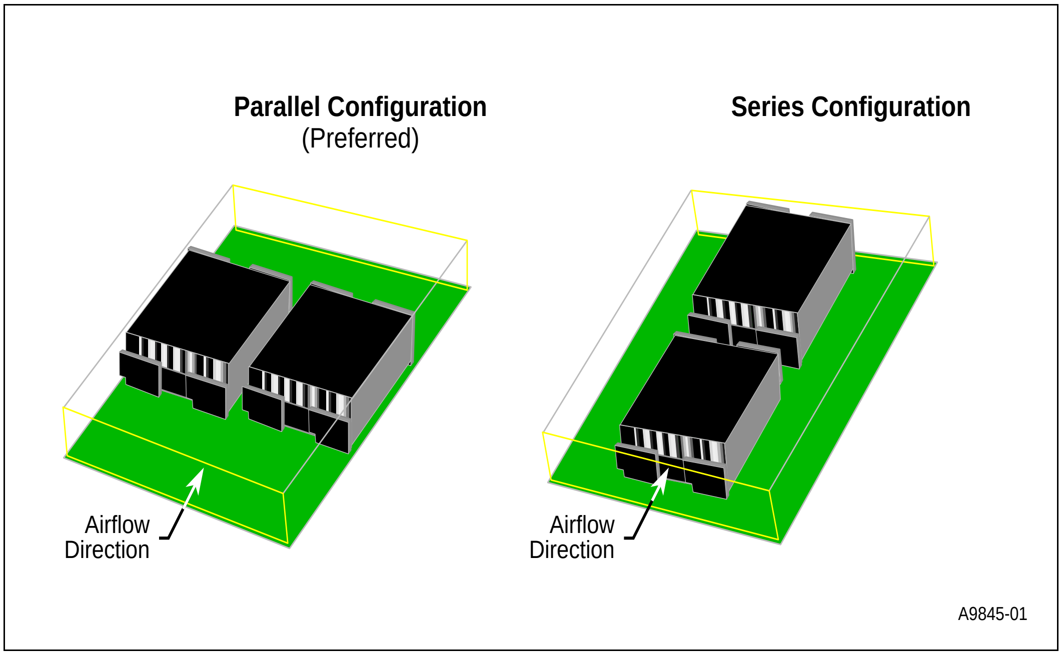


Drawing used with permission from PENCOM.

2.4 Dual Processor Considerations

The two heat sink designs presented are suitable for use in a dual processor configuration. However additional precautions must be taken with the orientation of the processors on the baseboard. The results of computer models indicate that two processors placed in series (one processor placed directly behind the other relative to the airflow) will have higher junction temperatures 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 11 illustrates the two orientations and modeling results.

Figure 11. The Optimum Processor Orientation in Dual Processor Configurations



3.0 Related Documents

Table 3. Related Documents

Document	Order Number
Low Voltage / Ultra Low Voltage Intel® Pentium® III Processor 512K Dual Processor Platform Design Guide	273674
Low Voltage Intel® Pentium® III Processor 512K Datasheet	273673
Low Voltage / Ultra Low Voltage Intel® Pentium® III Processor 512K/815E Chipset Platform Design Guide	273676
Mobile Intel® Pentium® III Processor - M Datasheet	298340
Intel® Mobile Processor Micro-FCPGA Socket (mPGA479M) Design Guidelines	298520
Intel® Pentium® III Processor Thermal Design Guidelines	245087
Thermal Design Guide for Intel® Processors in the BGA2 and Micro FC-BGA Packages for Embedded Applications	273716

4.0 Vendor List

Table 4 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 4. Vendor List

Aluminum Extruded Heat Sink – Option 1 (Reference No. EID-LPT13-ALX-003)	
Peninsula Components (PENCOM*) 1300 Pioneer Street, Suite E Brea, CA 92821	Contact: Steve Blank (562) 964-4477
Aluminum Extruded Heat Sink – Option 2 (Reference No. EID-LPT15-ALX-002)	
Peninsula Components (PENCOM) 1300 Pioneer Street, Suite E Brea, CA 92821	Contact: Steve Blank (562) 694-4477
Heat Sink Mounting Fasteners (PENCOM P/N: PL1664-65)	
Peninsula Components (PENCOM) 1300 Pioneer Street, Suite E Brea, CA 92821	Contact: Steve Blank (562) 964-4477
Thermal Interface Material (Chomerics Material No. Thermflow* T725*)	
Parker Hannifin Corporation (Chomerics Division) 842 E. Fairway Drive Orange, CA 92866	Contact: John Kefeyan (714) 639-6079
Active Fan/Heat Sink (Tyco* P/N: 8-1542007-5)	
Tyco Electronics 101 South 38th Street Harrisburg, PA 17111-2282	(800)552-6752

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