# *Thermal Design Guideline for Intel Processors in the BGA2 and Micro FC-BGA Packages for Embedded Applications*

***April 2002***

Order Number: 273716-001

Information in this document is provided in connection with Intel® products. No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted by this document. Except as provided in Intel's Terms and Conditions of Sale for such products, Intel assumes no liability whatsoever, and Intel disclaims any express or implied warranty, relating to sale and/or use of Intel products including liability or warranties relating to fitness for a particular purpose, merchantability, or infringement of any patent, copyright or other intellectual property right. Intel products are not intended for use in medical, life saving, or life sustaining applications.

Intel may make changes to specifications and product descriptions at any time, without notice.

Contact your local Intel sales office or your distributor to obtain the latest specifications and before placing your product order.

Copies of documents which have an ordering number and are referenced in this document, or other Intel literature may be obtained by calling 1-800-548-4725 or by visiting Intel's website at http://www.intel.com.

AlertVIEW, i960, AnyPoint, AppChoice, BoardWatch, BunnyPeople, CablePort, Celeron, Chips, Commerce Cart, CT Connect, CT Media, Dialogic, DM3, EtherExpress, ETOX, FlashFile, GatherRound, i386, i486, iCat, iCOMP, Insight960, InstantIP, Intel, Intel logo, Intel386, Intel486, Intel740, IntelDX2, IntelDX4, IntelSX2, Intel ChatPad, Intel Create&Share, Intel Dot.Station, Intel GigaBlade, Intel InBusiness, Intel Inside, Intel Inside logo, Intel NetBurst, Intel NetStructure, Intel Play, Intel Play logo, Intel Pocket Concert, Intel SingleDriver, Intel SpeedStep, Intel StrataFlash, Intel TeamStation, Intel WebOutfitter, Intel Xeon, Intel XScale, Itanium, JobAnalyst, LANDesk, LanRover, MCS, MMX, MMX logo, NetPort, NetportExpress, Optimizer logo, OverDrive, Paragon, PC Dads, PC Parents, Pentium, Pentium II Xeon, Pentium III Xeon, Performance at Your Command, ProShare, RemoteExpress, Screamline, Shiva, SmartDie, Solutions960, Sound Mark, StorageExpress, The Computer Inside, The Journey Inside, This Way In, TokenExpress, Trillium, Vivonic, and VTune are trademarks or registered trademarks of Intel Corporation or its subsidiaries in the United States and other countries.

Copyright © Intel Corporation, 2002

*Other names and brands may be claimed as the property of others.

# Contents

## Figures

# Tables

# Revision History

| Date | Revision | Description |
|---|---|---|
| April 2002 | 001 | First release of document. |

# 1.0 Introduction

This document describes the thermal design guidelines for Intel processors in the BGA2 495 Pin and micro FC-BGA 479 Pin packages for use in embedded applications. This guideline is intended for processors specified at the Embedded Intel Architecture web site, http://developer.intel.com/design/intarch/. The detailed mechanical and thermal specifications for these processors can be obtained from their appropriate datasheets. The processor datasheets are available at http://developer.intel.com.

The contents of this guideline are provided as reference only. It is the responsibility of the user to validate the solutions for final use. The intent of this document is to assist OEMs with the development of thermal solutions for their individual designs. The final heat sink solution, including the heat sink, attachment method, and thermal interface material (TIM) must comply with the mechanical design, environmental, and reliability requirements as delineated in the appropriate processor specification datasheet. It is the responsibility of each integrator 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 Intel processors offered by the Embedded Intel Architecture Division (EID) 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 Compact PCI* form factors.

## 1.2 Document Scope

This document discusses the thermal management techniques for Intel EID processors, specifically in embedded computing applications. The physical dimensions and power numbers used in this document are for reference only. Please refer to the processors' datasheet for the product dimensions, thermal power dissipation, and maximum junction temperature. In case of conflict, the processor datasheets supersede this document.

## 1.3 References

- *Intel® Mobile Processor Micro-FCPGA Package and Socket Manufacturing and Mechanical User's Guide*
- *Mobile Pentium® III-M Processor Datasheet*
- *Mobile Pentium® III Processor in BGA2 and Micro FCPGA2 Packages Datasheet*

## 1.4 Definition of Terms

| Term | Definition |
|---|---|
| $T_{LA}$ ($T_{Local\text{-}Ambient}$) | The measured ambient temperature locally surrounding the processor. The ambient temperature should be measured just upstream of a passive heat sink, or at the fan inlet of an active heat sink. |
| $T_{case\text{-}max}$ | 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. |
| $\theta_{JS}$ | The junction to sink thermal resistance, which is dependent on the thermal interface material. Also referred to as $\theta_{TIM}$. |
| $\theta_{JA}$ | The thermal resistance between the processor’s junction 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 Xeon™ processor. |
| Bypass/no–bypass | Bypass is the area between a heat sink and any object that can act to form a duct. For this example it can 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. |

# 2.0 Design Guideline

The thermal solutions presented in this document were designed to fit within the maximum component height allowed by the single slot CompactPCI specification. The heat sink designs were optimized for the CompactPCI 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 and airflow rates, however other 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

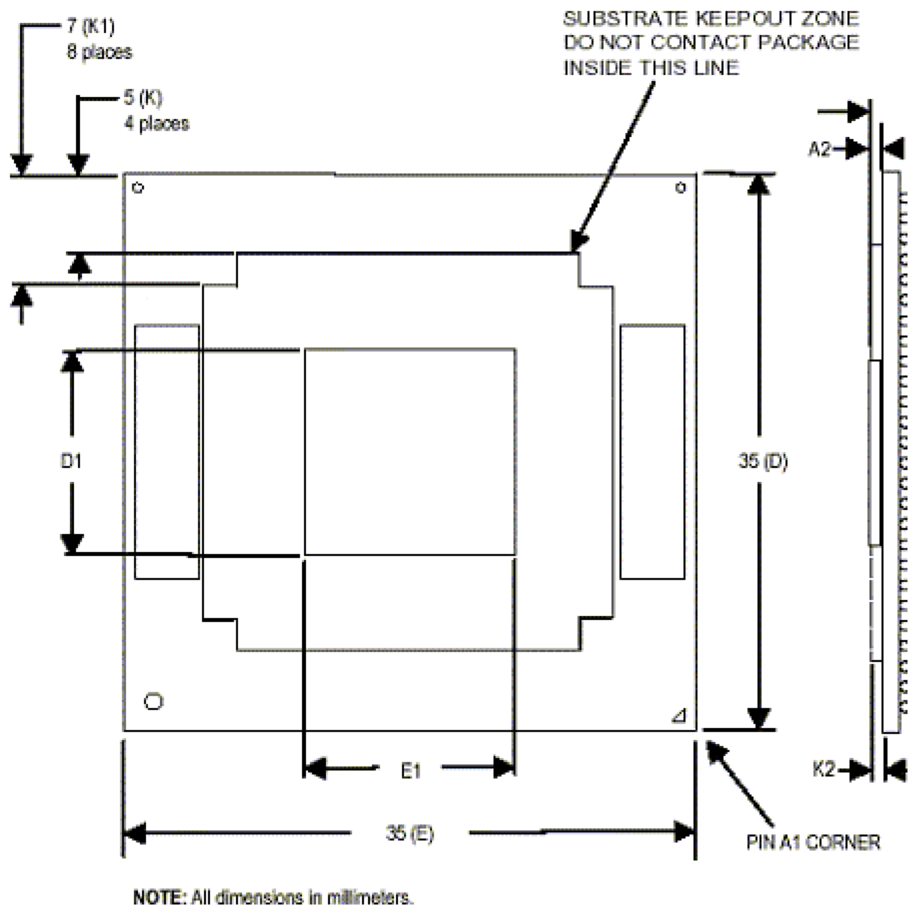
### 2.1.1 Processors with the Micro FC-BGA Package

For processors packaged in the micro FC-BGA package, the mechanical specifications for the surface-mount package are provided in Figure 1 and Table 1. Refer to each processor datasheet for detailed information. In the event of conflict, information in these datasheets are the most accurate. Note that the substrate may only be contacted within the shaded region between the keepout outline and the edge of the substrate. The motherboard keepout zone and mounting hole pattern suggested in this document are not necessarily the same as described in the processors' datasheets.

In order to maintain compatibility with the micro FC-PGA socket type package, it is recommended that the specification for the keepout zone, mounting hole pattern, and EMI shielding (if required) as described in the *Intel® Mobile Processor Micro-FCPGA Package and Socket Manufacturing and Mechanical User's Guide* be adhered to. However, the motherboard keepout zone and mounting hole pattern suggested in this document are not necessarily the same as described in the processors' datasheets and socket user's guide. The keepout zone and mounting hole patterns described in this document are intended to accommodate the specific heat sink and attachment methods developed for the embedded form factors.

Figure 1 illustrates the geometry of the micro-FCBGA package. Refer to the processor datasheet for detailed information.

**Figure 1. Micro-FCBGA Package Geometry**



**NOTE:** All dimensions in millimeters.

**Table 1. Micro-FCBGA Mechanical Specifications**

| Symbol | Parameter | Min | Max | Unit |
|---|---|---|---|---|
| A | Overall height as delivered (1) | 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 | + | | mm |
| E1 | Die width | + | | mm |
| e | Ball pitch | 1.27 | | mm |
| N | Ball count | 479 | | each |
| K | Keepout outline from edge of package | 5 | | mm |
| K1 | Keepout outline at corner of package | 7 | | mm |
| K2 | Capacitor keepout 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 |

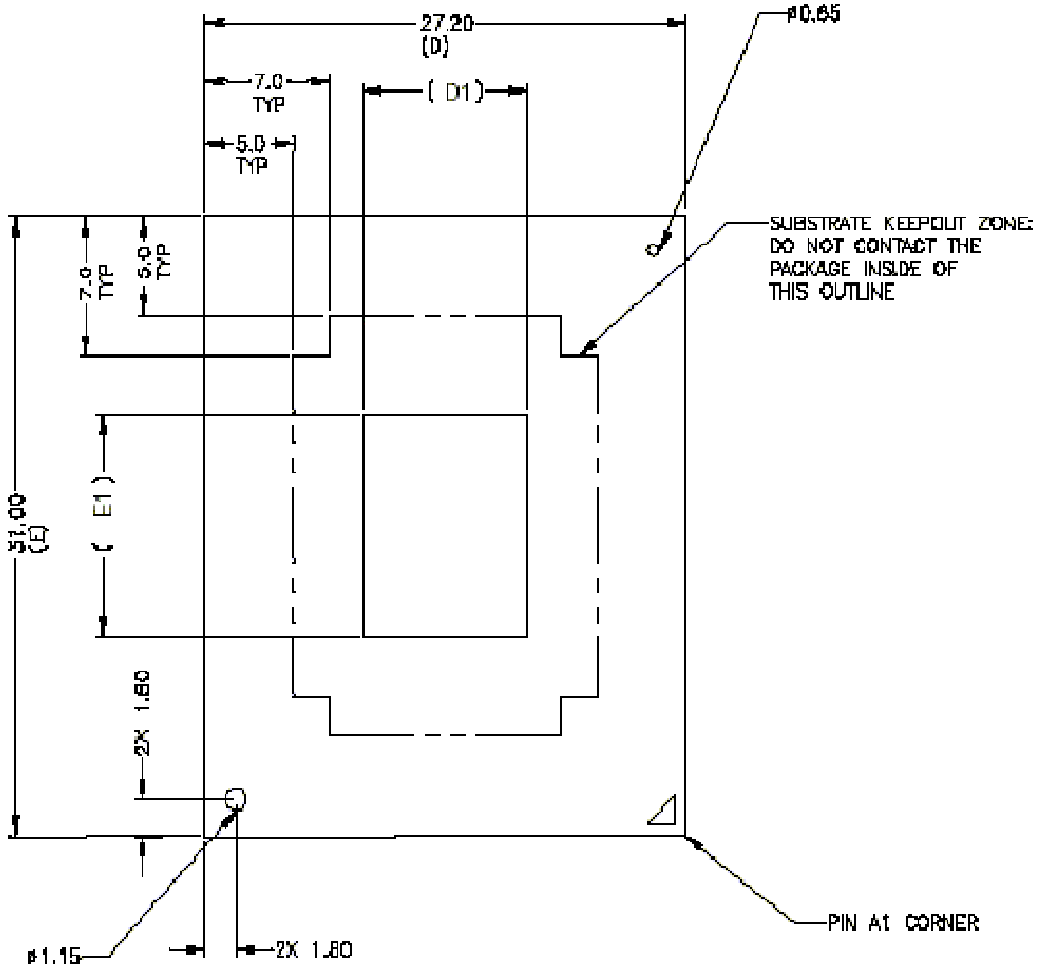
**NOTES:**

1. Overall height as delivered. Values were based on design specifications and tolerances. Final height after surface mount depends on OEM motherboard design and SMT process.
2. All dimensions are in millimeters.
3. Values shown are for reference only.
4. + This value is dependent on the processor. Refer to the processor datasheet for details.
5. The dimensions shown are for the Pentium III-M processor. Refer to each specific processor datasheet for details on other processors.

### 2.1.2 Processors with the BGA2 Package

For processors packaged in the PBGA-B495 package (referred to as BGA2), the mechanical specifications for the surface-mount package are provided in Figure 2 and Table 2. Refer to each processor datasheet for detailed information. In the event of conflict, information in the datasheets is the most accurate. Note that the substrate may only be contacted within the shaded region between the keepout outline and the edge of the substrate. The motherboard keepout zone and mounting hole pattern suggested in this document are not necessarily the same as described in the processors’ datasheets. The keepout zone and mounting hole patterns described in this document are intended to accommodate the specific heat sink and attachment methods developed for the embedded form factors.

**Figure 2. BGA2 Package Geometry**



**NOTE**: All dimensions are in millimeters. Dimensions in figure are for reference only.

**Table 2. BGA2 Mechanical Specifications (Sheet 1 of 2)**

| Symbol | Parameter | Min | Max | Unit |
|---|---|---|---|---|
| A | Overall height as delivered (1) | 2.29 | 2.79 | mm |
| A1 | Substrate height, as delivered | 1.50 REF | | mm |
| A2 | Die height | 0.854 REF | | mm |
| b | Ball diameter | 0.78 REF | | mm |
| D | Package width | 27.05 | 27.35 | mm |
| D1 | Die width | + | | mm |
| E | Package length | 30.85 | 31.15 | mm |
| e | Ball pitch | 1.27 | | mm |

**Table 2. BGA2 Mechanical Specifications (Sheet 2 of 2)**

| Symbol | Parameter | Min | Max | Unit |
|---|---|---|---|---|
| E1 | Die length | + | | mm |
| N | Ball count | 495 | | each |
| S1 | Outer ball center to short edge of substrate | 0.895 REF | | mm |
| S2 | Outer ball center to long edge of substrate | 0.900 REF | | mm |
| Pdie | Allowable pressure on the die for thermal solution | - | 689 | kPa |
| W | Package weight | | 4.5 REF | g |

**NOTES:**
1. Overall height as delivered. Values were based on design specifications and tolerances. Final height after surface mount depends on OEM motherboard design and SMT process.
2. All dimensions are in millimeters.
3. Values shown are for reference only.
4. + This value is dependent on the processor. Refer to the processor datasheet for details.
5. The dimensions shown are for the Pentium III-M processor. Refer to each specific processor datasheet for details on other processors.

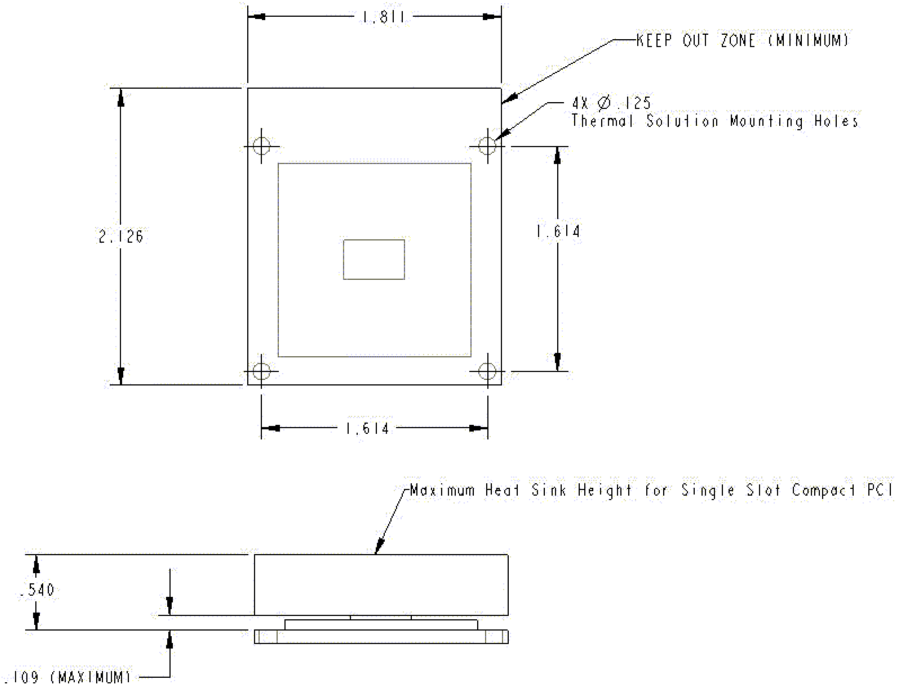
## 2.1.3 Keepout Zone and Mounting Holes

The keepout zone reserved for the processor package, heat sink, and heat sink retention mechanism for the baseboard should adhere to the guidelines designated by the appropriate processor datasheet. However, the heat sink designs shown in this design guide may differ. The changes have been made to accommodate the required heat sink dimensions needed to cool the processors in embedded form factors. The user should make certain the appropriate keepout zone and mounting hole pattern is selected for the heat sink. The required keepout and mounting hole pattern for the heat sink must be incorporated early in the motherboard design. The orientation of the heat sink on the motherboard relative to the airflow is also critical. In all cases, the heat sink fins must be placed so that the fins are parallel to the airflow direction.

### 2.1.3.1 Processors with the Micro FC-BGA Package

Figure 3 illustrates the typical keepout zone for the Micro-FCPGA package with the exception of the mounting hole diameter. The recommended mounting hole diameter has been increased from 0.09 inches to 0.125 inches. This allows the use of a readily available and proven mounting fastener, shown in Figure 18. Refer to the *Intel® Mobile Processor Micro-FCPGA Package and Socket Manufacturing and Mechanical User's Guide* for more details on the keepout zone specifications.

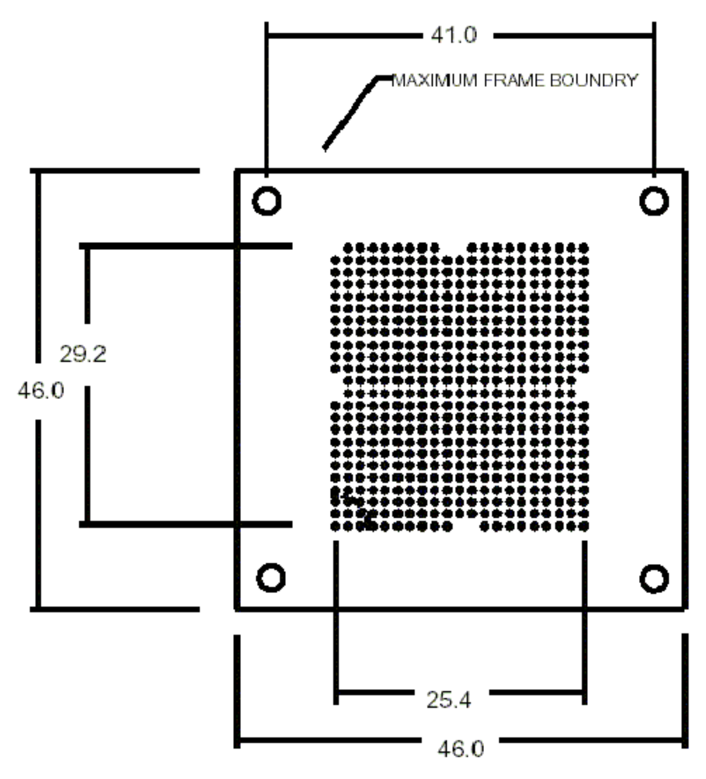
**Figure 3. Baseboard Keepout Zone for the Micro-BGA Package, Primary Side**



### 2.1.3.2 Processors in the BGA2 Package Keepout and Mounting Holes

Figure 4 illustrates the typical keepout zone for the BGA2 package with the exception of the mounting hole diameter. The recommended mounting hole diameter has been increased to 0.125 inches. This allows the use of a readily available and proven mounting fastener shown in Figure 18. Please refer to the processor datasheet for more details on the keepout zone specifications.

**Figure 4. BGA2 Package Keepout/In Zone and Mounting Hole Pattern**



## 2.2 Thermal Guidelines

This document presents several thermal solutions for Intel processors in the BGA2 and micro FC-BGA packages in embedded form factors. 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 user to verify that thermal solutions are suitable for their specific use.

### 2.2.1 Thermal Solution Requirements

The thermal solutions recommended in this document were designed based on the processor thermal specifications as outlined in the processor datasheets. In addition, the operating ambient temperature was specified as 50° C with minimum system airflow of 200 LFM. The ambient temperature and airflow are based on a measurement approximately 1 inch upstream from the processor.

The thermal requirement of the heat sink is determined by calculating the junction-to-ambient thermal resistance, $\theta_{ja}$. This is a basic thermal engineering parameter that can be used to evaluate and compare different thermal solutions. Equation 1 should be used to determine the thermal resistance required for a thermal solution to work properly for each specific processor and operating condition. Equation 1 shows an example of the heat sink thermal performance needed to cool the 700 MHz Pentium® III processor in the 495 Pin BGA package. From this example, it is evident that the thermal solution designed for this processor must have a junction-to-ambient thermal resistance less than 3.1° C/W. Similar calculations can be made for the various processors and different ambient temperatures. Table 3 summarizes the thermal data for the current processors available from the Embedded Intel Architecture Division.

**Table 3. Thermal Data for Current Embedded IA Division Processors**

| Product | Core Speed (MHz) | L2 Cache | External Bus Speed (MHz) | Thermal Design Power (MAX) | Voltage | $T_{junction}$ (MAX) | Package |
|---|---|---|---|---|---|---|---|
| Low Voltage Pentium® III | 800 | 512 K | 133 | 11.2 W | 1.15 V | 0-100C | 479 ìFCBGA |
| Low Power Pentium® III | 700 | 256 K | 100 | 16.12 W | 1.35 V | 0-100C | 495 FCBGA |
| Low Power Pentium® III | 500 | 256 K | 100 | 12.2 W | 1.35 V | 0-100C | 495 FCBGA |
| Low Power Pentium® III | 400 | 256 K | 100 | 10.1W | 1.35 V | 0-100C | 495 FCBGA |
| Low Power Celeron® III | 400A | 128 K | 100 | 10.1W | 1.35 V | 0-100C | 495 FCBGA |
| Low Power Celeron® III | 300 | 128 K | 100 | 5.7 W | 1.1 V | 0-100C | 495 FCBGA |

**Equation 1. Junction-to-Ambient Thermal Resistance**

$$\theta_{\max} = \frac{T_{j\max}{}^{\circ}C - T_a{}^{\circ}C}{TDP_{\max}(W)} = \frac{100^{\circ}C - 50^{\circ}C}{16.1W} = 3.1\frac{^{\circ}C}{W}$$

## 2.2.2 Recommended Heat Sink Designs

Several 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 intended for customer use with appropriate consent. The heat sinks shown in Figure 6 through Figure 16 in the appendix were optimized using computational fluid dynamic (CFD) and thermal modeling software. The heat sinks are optimized for a minimum airflow of 200 LFM, as measured 1 inch upstream from the processor. The airflow must be unobstructed up to and beyond the processor.

Table 4 summarizes the six heat sink designs recommended for use with the processors in Table 3. The six different heat sinks can accommodate processors with TDP values from 12.8 W up to 18.1 W. The user should select the heat sink that best suits their need based on the processor used, system airflow, and ambient temperature.

The geometry is also optimized for high volume manufacturing. All designs can be manufactured using extrusion and folded fin heat sink manufacturing technologies. A list of enabled heat sink vendors is provided in Section 3.0. In addition to using the vendors listed in Table 6, the user can select to have these heat sink designs manufactured by the vendor of their choice. Please contact your Intel Field Service Engineer to obtain drawing files. The information provided in this document is for reference only and additional validation must be performed prior to implementing the designs into final production.

Figures 7 through 17 illustrate the thermal performance for the aluminum extruded heat sinks for airflow from 0 LFM to 500 LFM.

### 2.2.3 Required Heat Sink Orientation

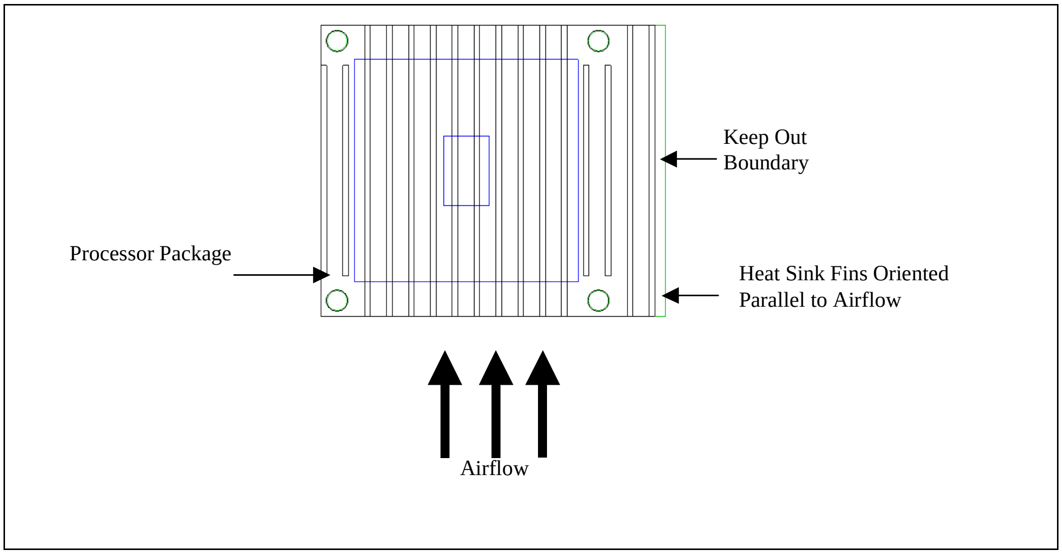
The heat sinks must be oriented in a specific direction relative to the system airflow. To use these designs, the processor must be placed on the PCB in an orientation so the heat sink fins will be parallel to the airflow. Figure 9 illustrates the orientation of the heat sink relative to the processor and airflow. A top view of the heat sink on the processor assembly is shown.

**Table 4. Summary of Heat Sink Designs**

| Heat Sink Design | Size (W x L) | # Fins | Θ ja @ 200 LFM | Maximum Power[1] (W) |
|---|---|---|---|---|
| EID-LPT-ALX-001[2] | 2.25” x 2.25” | 14 | 3.55 | 14.1 |
| EID-LPT-ALX-001B[2] | 2.25” x 2.25” | 18 | 3.10 | 16.1 |
| EID-LPT-ALX-002 | 2.06” x 1.81” | 16 | 3.20 | 15.6 |
| EID-LPT-ALX-003 | 1.81” x 1.81” | 10 | 3.90 | 12.8 |
| EID-LPT-ALX-004[2] | 2.8” x 2.25” | 22 | 2.79 | 17.9 |
| EID-LPP3-ALX-001[2,3] | 2.0” x 2.0” | 22 | 2.76 | 18.1 |

**NOTES:**
1. Maximum power is determined using Tj max = 100 C, and $T_{LA}$ = 50 C.
2. These heat sinks use a non-standard mounting hole pattern. Refer to the drawings in the Appendix for detailed hole pattern dimensions.
3. This heat sink has a height of 0.57”, which is too large to comply with the single slot CompactPCI form factor.

**Figure 5. Required Heat Sink Orientation to the Processor and Airflow**



### 2.2.4 Recommended Thermal Interface Material

It is important to understand and consider the impact that 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 critical 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 will yield a greater thermal resistance. The thickness of the gap is determined by the flatness of both the heat sink base and the processor package, 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 solutions were optimized using a high performance phase change TIM with low thermal impedance. The heat sinks were prototyped and verified using the Chomerics* T725 Phase Change Interface Pad. Alternative materials can be used at the user’s discretion. The entire heat sink assembly must be validated together for specific applications, including the heat sink, attachment method, and thermal interface material.

Other thermal interface material with similar characteristics include Thermagon* T-PCM27-94 phase change material and ShinEtsu* G749 thermal grease. Properties for these materials are summarized in Table 5. The values are provided for reference only. Refer to the manufacturer’s datasheet for details.

**Table 5. Thermal Interface Material Properties**

| Material | Type | Thermal Resistivity (°C $cm^2$/W) |
|---|---|---|
| Chomerics* T725 | Phase Change Pad | 0.19 |
| Thermagon* T-PCM27-94 | Phase Change Pad | 0.11 |
| ShinEtsu G749* | Thermal Grease | 0.11 |

### 2.2.5 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. For optimum thermal performance, the spring-loaded fastener applies between 20 and 100 PSI of total pressure on the surface of the processor die chip. Figure 18 in the Appendix shows an example of a spring-loaded fastener developed by Peninsula Components* (PENCOM*) that meets the pressure requirements. These fasteners (four) apply a nominal pressure of 53.75 PSI. PENCOM has a mounting fastener available that interfaces with both a 0.063 and 0.093 inch thick PCB.

The heat sink designs were prototyped and verified using the PENCOM fastener for the 0.093 inch thick PCB. Vendor information for this fastener is provided in Section 3.0.

# 3.0 Vendor List

Table 6 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 6. Vendor List**

| **Aluminum Extruded Heat Sinks** | |
|---|---|
| Peninsula Components (PENCOM)<br>1300 Pioneer Street, Suite E<br>Brea, CA 92821 | Contact: Steve Blank (562) 964-4477 |
| **Heat Sink Mounting Fasteners (PENCOM* P/N: PL1664-65)** | |
| Peninsula Components (PENCOM)<br>1300 Pioneer Street, Suite E<br>Brea, CA 92821 | Contact: Steve Blank (562) 964-4477 |
| **Thermal Interface Material (Chomerics Material No. Thermflow* T725)** | |
| Parker Hannifin Corporation (Chomerics Division)<br>842 E. Fairway Drive<br>Orange, CA 92866 | Contact: John Kefeyan (714) 639-6079 |
| **Thermal Interface Material (ShinEtsu* G749)** | |
| ShinEtsu Micro Si, Inc.<br>10028 S. 51st St.<br>Phoenix, AZ 85044 | Contact: (480) 893-8898 |
| **Thermal Interface Material (Thermagon* T-PCM27-94)** | |
| Thermagon Inc.<br>4707 Detroit Ave.<br>Cleveland, OH 44102-2216 | Contact: (888) 246-9050 |

# 4.0 Appendix

**Figure 6. EID-LPT-ALX-001 Heat Sink Drawing**

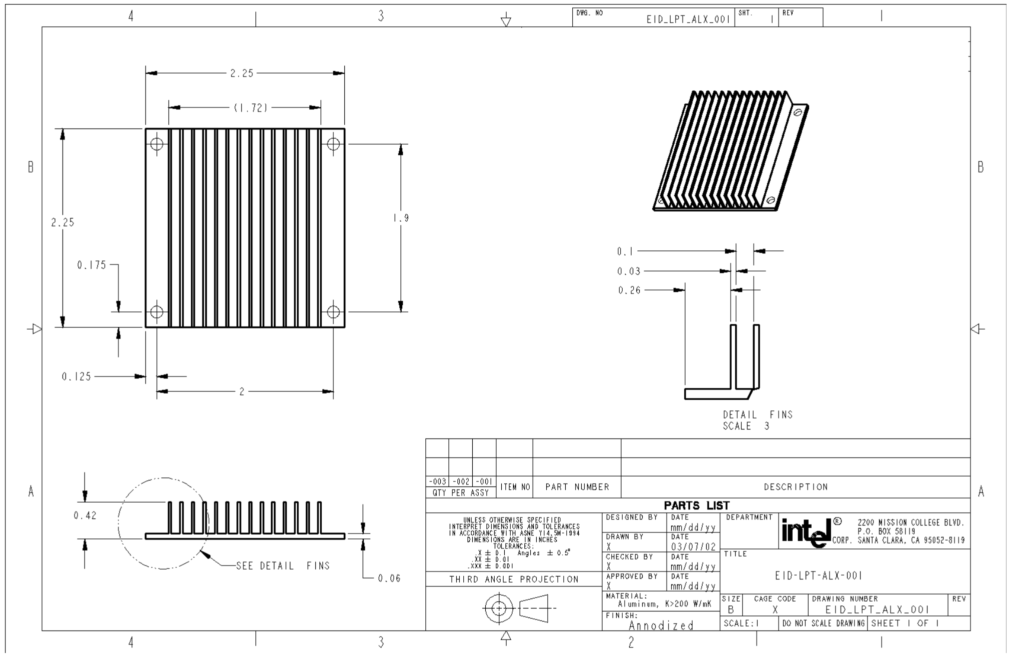


**Figure 7. EID-LPT-ALX-001 Heat Sink Thermal Performance Curve**

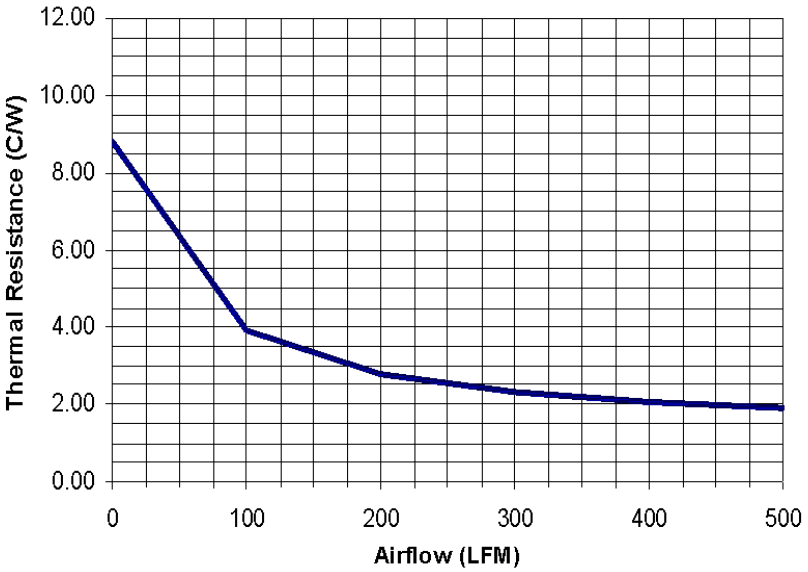


**Figure 8. EID-LPT-ALX-001B Heat Sink Drawing**

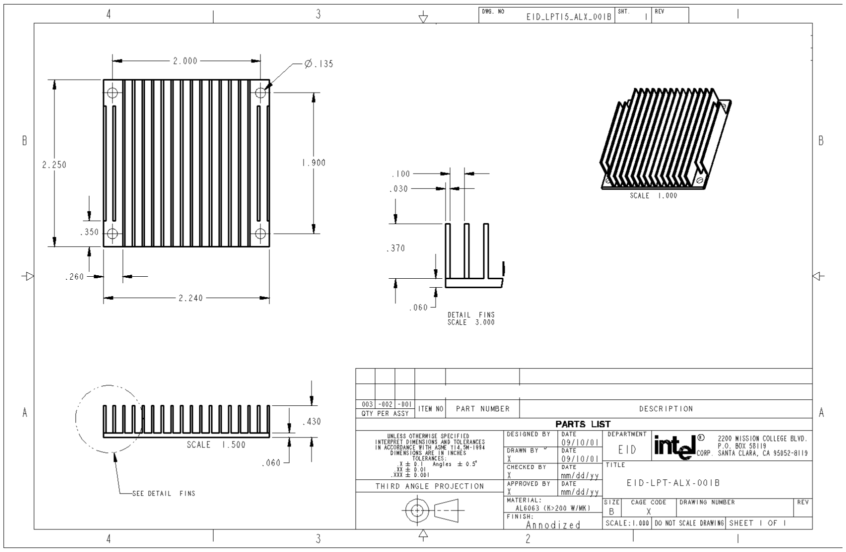
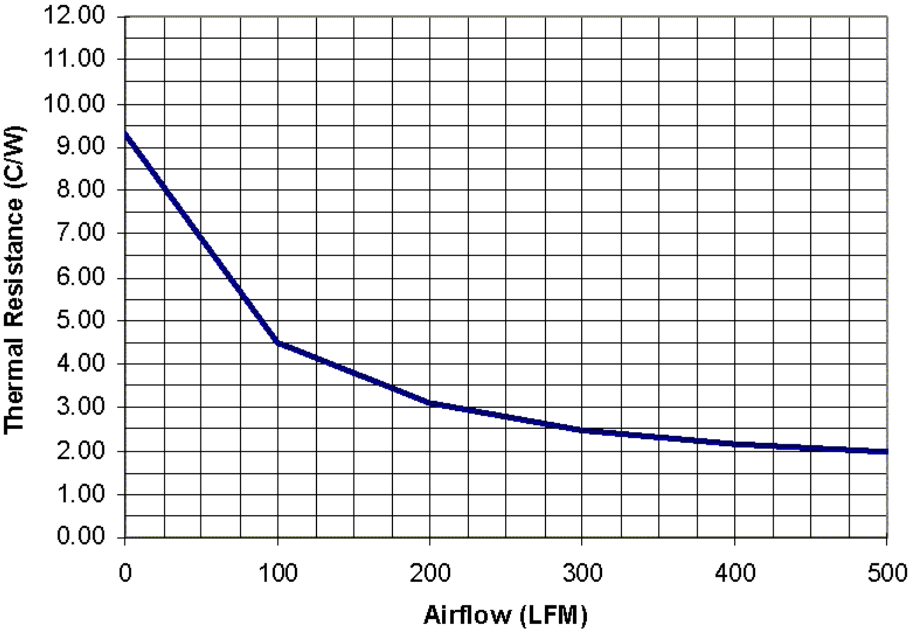
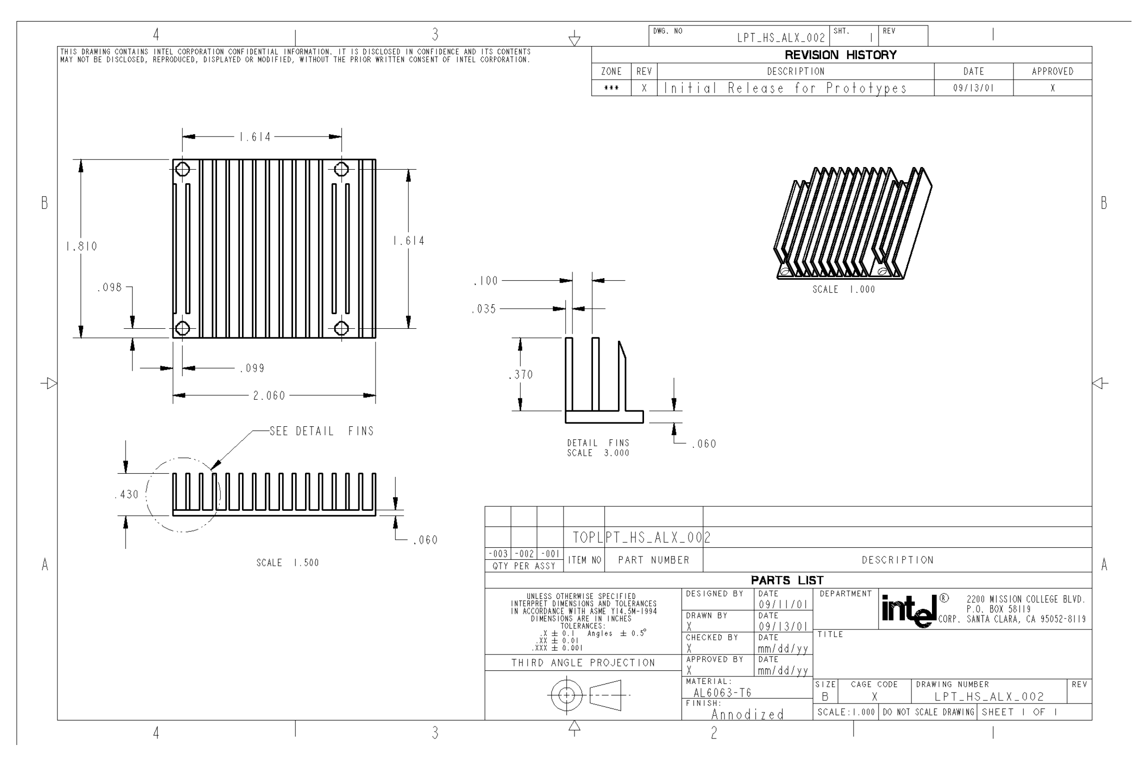


**Figure 9. EID-LPT-ALX-001B Heat Sink Thermal Performance Curve**



### Figure 10. EID-LPT-ALX-002 Heat Sink Drawing



### Figure 11. EID-LPT-ALX-002 Heat Sink Thermal Performance Curve

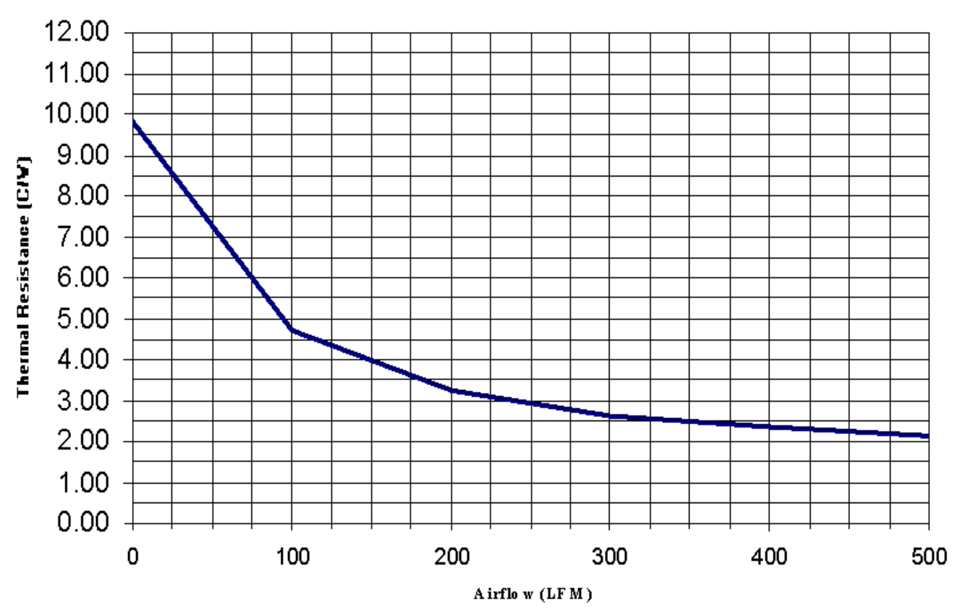


Figure 12. EID-LPT-ALX-003 Heat Sink Drawing

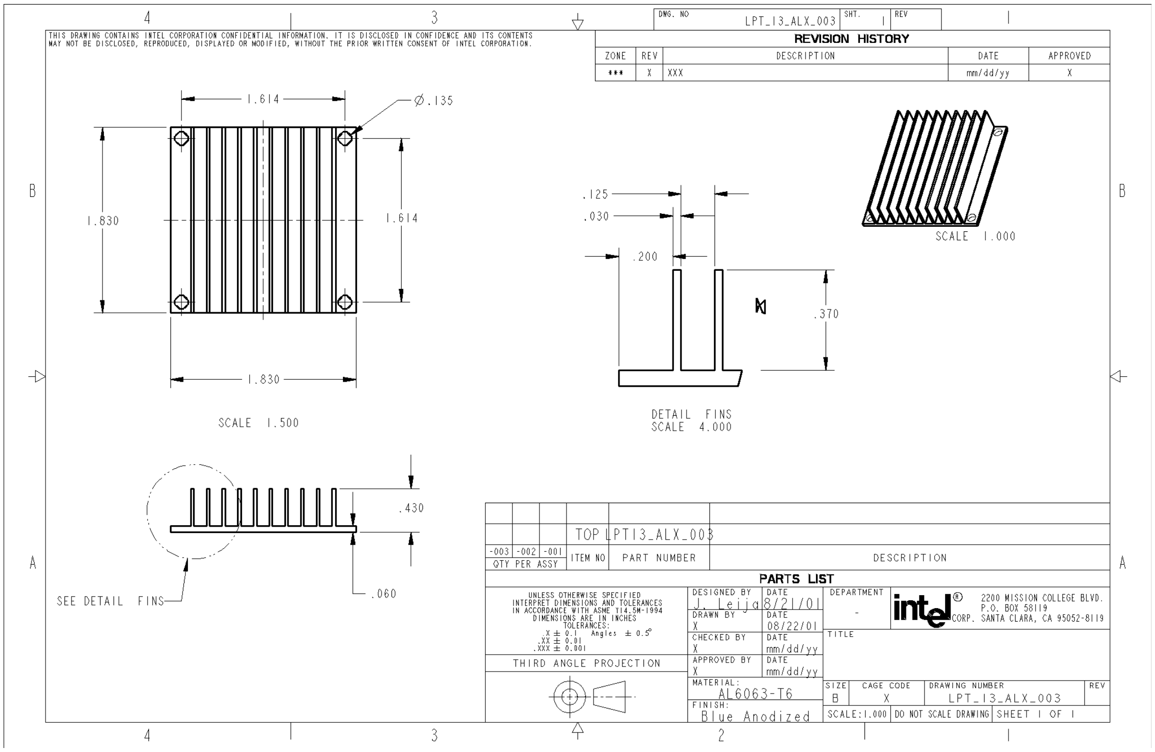
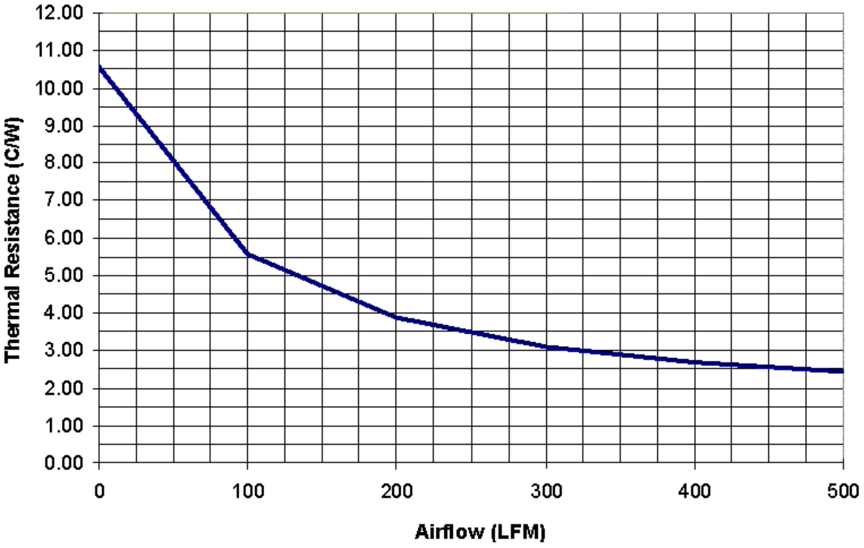
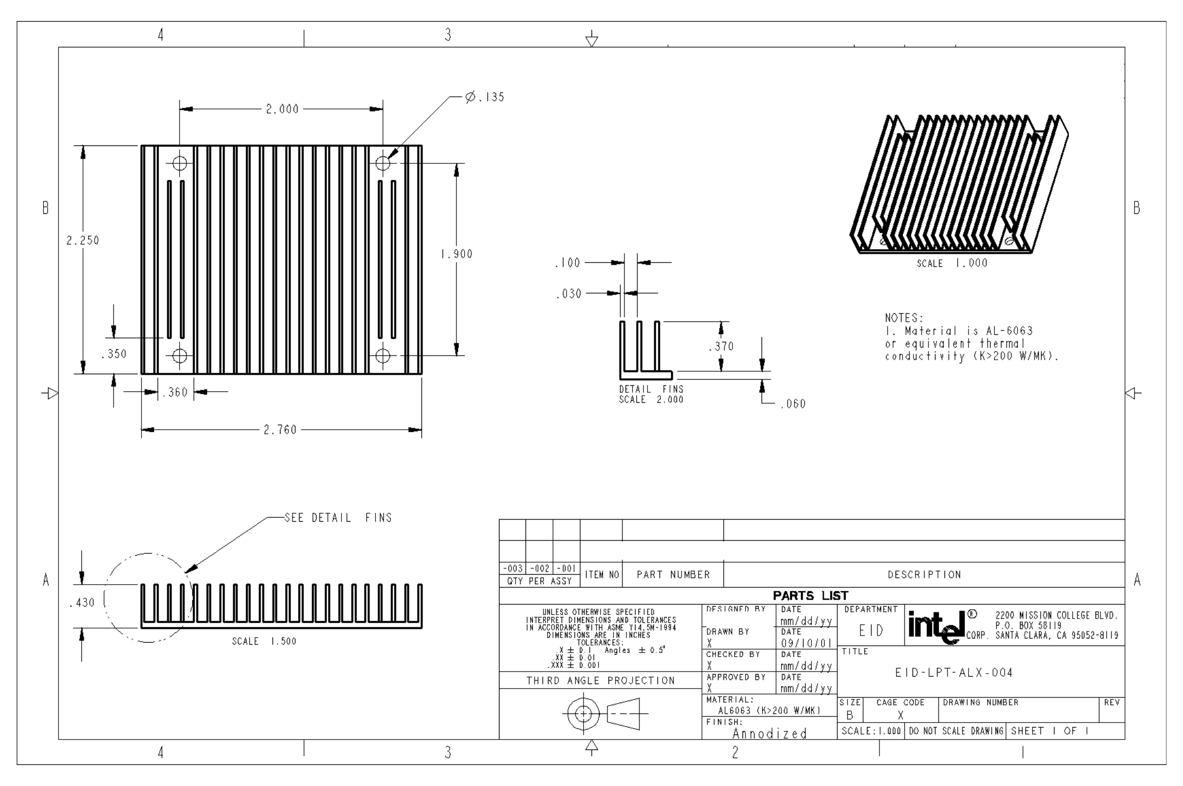


Figure 13. EID-LPT-ALX-003 Heat Sink Thermal Performance Curve



### Figure 14. EID-LPT-ALX-004 Heat Sink Drawing



### Figure 15. EID-LPT-ALX-004 Heat Sink Thermal Performance Curve

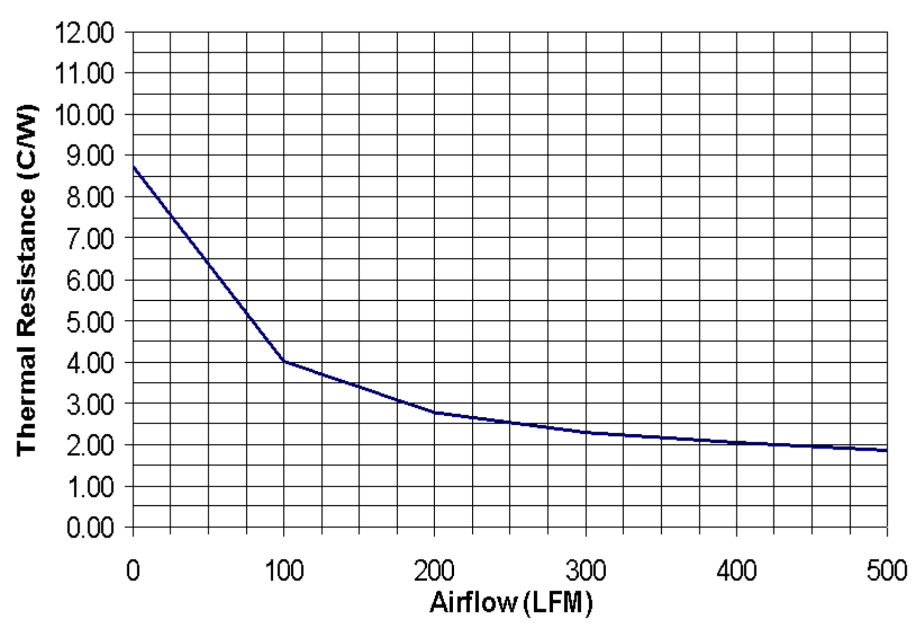


**Figure 16. EID-LPP3-ALX-001 Heat Sink Drawing**

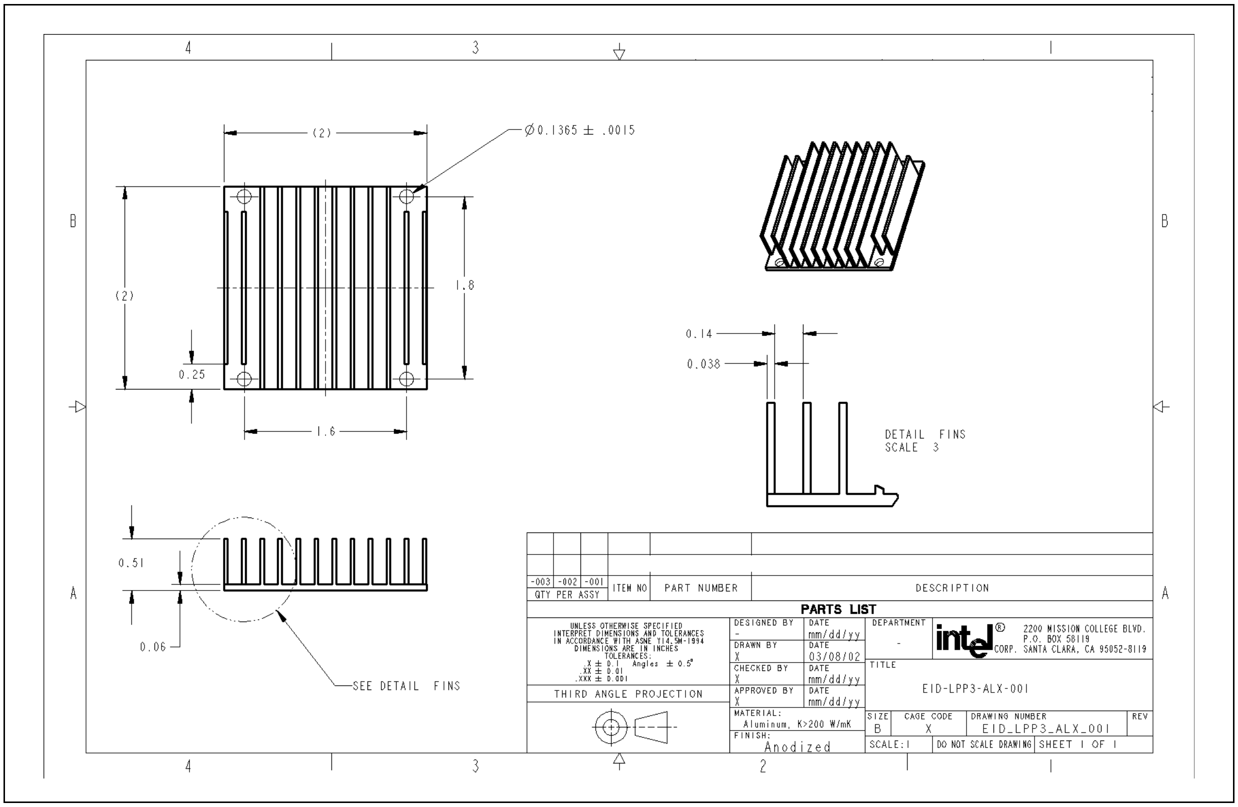


**Figure 17. EID-LPP3-ALX-001 Heat Sink Thermal Performance Curve**

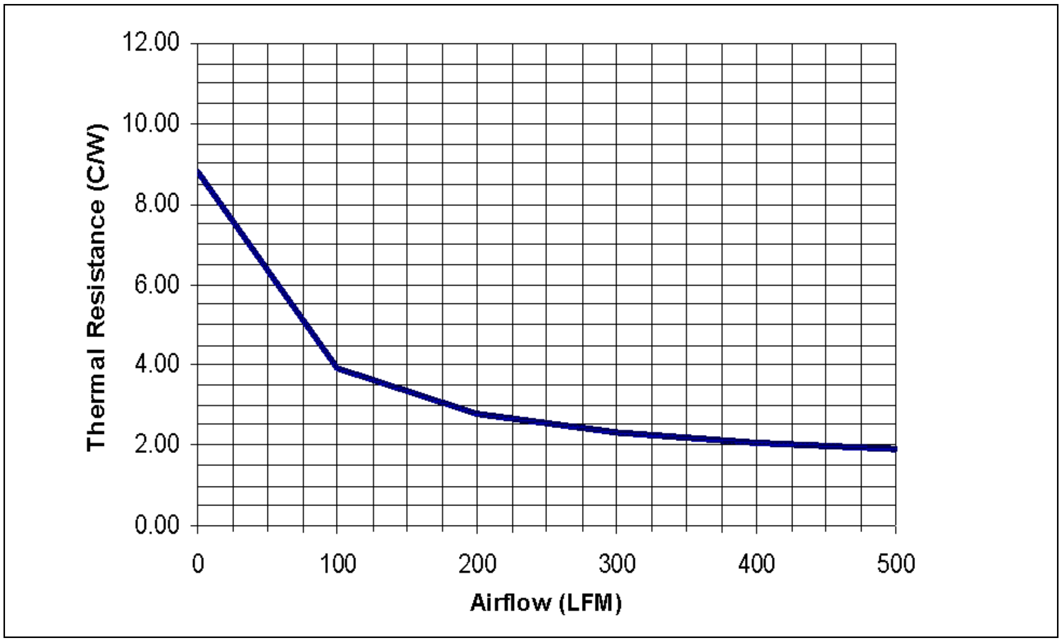
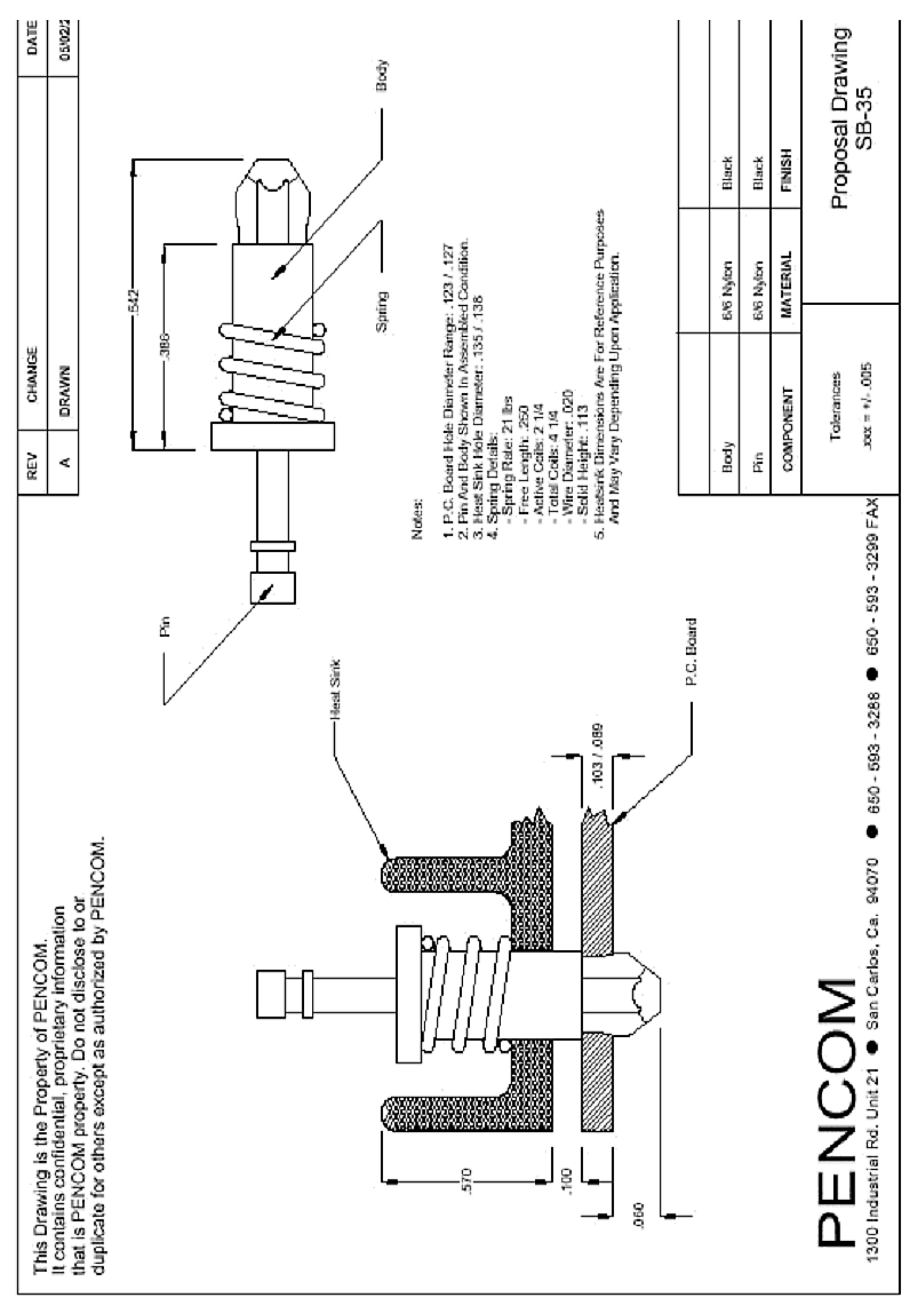


**Figure 18. Heat Sink Mounting Fastener Drawing**



Notes:

1. P.C. Board Hole Diameter Range: .123 / .127
2. Pin And Body Shown In Assembled Condition.
3. Heat Sink Hole Diameter: .135 / .138
4. Spring Details:
   - Spring Rate: 21 lbs
   - Free Length: .250
   - Active Coils: 2 1/4
   - Total Coils: 4 1/4
   - Wire Diameter: .020
   - Solid Height: .113
5. Heatsink Dimensions Are For Reference Purposes And May Vary Depending Upon Application.

| COMPONENT | MATERIAL | FINISH |
|---|---|---|
| Body | 6/6 Nylon | Black |
| Pin | 6/6 Nylon | Black |