



# Intel<sup>®</sup> Pentium<sup>®</sup> M Processor and Celeron<sup>®</sup> M Processor for Embedded Applications

Thermal Design Guide

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*February 2006*

Order Number: [273885-003](#)





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# Contents

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- 1.0 Introduction**..... 8
  - 1.1 Document Goals ..... 8
  - 1.2 Document Scope ..... 8
  - 1.3 Document References ..... 8
  - 1.4 Definition of Terms..... 9
- 2.0 Design Guideline** ..... 10
  - 2.1 Mechanical Guidelines..... 10
    - 2.1.1 Processor Package..... 10
    - 2.1.2 Volumetric Constraint Zones ..... 18
  - 2.2 Thermal Guidelines..... 21
    - 2.2.1 Processor Power ..... 22
    - 2.2.2 Thermal Diode ..... 22
    - 2.2.3 Thermal Monitor..... 22
    - 2.2.4 Power Density and Non-Uniform Heating ..... 24
    - 2.2.5 Thermal Solution Requirements ..... 24
    - 2.2.6 Recommended Heatsink Designs..... 26
      - 2.2.6.1 Intel® Pentium® M and Celeron® M Processors in the Micro-FCBGA Package—Copper Base, Aluminum Snap Fin Heatsink #1..... 26
      - 2.2.6.2 Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package—Copper Base, Aluminum Snap Fin Heatsink #2..... 27
      - 2.2.6.3 Low Voltage Intel Pentium M Processor in the Micro-FCBGA Package—Extruded Aluminum Heatsink #1 ..... 27
      - 2.2.6.4 Low Voltage Intel Pentium M Processor—Extruded Aluminum Heatsink #2 ..... 28
      - 2.2.6.5 Heatsink Orientation Relative to Airflow ..... 29
    - 2.2.7 Recommended Thermal Interface Material (TIM) ..... 30
    - 2.2.8 Recommended Thermal Solution Attachment Method ..... 31
    - 2.2.9 Intel® Pentium® M and Celeron® M Processor Thermal Test Vehicle ..... 31
- 3.0 Third-Party Vendor Enabled Active Heatsinks** ..... 32
  - 3.1 Applications ..... 32
    - 3.1.1 ECU-PNA1C-35..... 32
      - 3.1.1.1 Thermal Performance ..... 32
      - 3.1.1.2 Mechanical Retention and Volumetric Constraint Zones ..... 33
    - 3.1.2 ECC-00060-01 ..... 33
      - 3.1.2.1 Thermal Performance ..... 34
      - 3.1.2.2 Mechanical Retention and Volumetric Constraint Zones ..... 34
    - 3.1.3 ECC-00061-01 ..... 34
      - 3.1.3.1 Thermal Performance ..... 35
      - 3.1.3.2 Mechanical Retention and Volumetric Constraint Zones ..... 35
    - 3.1.4 ECC-00076-01 ..... 36
      - 3.1.4.1 Thermal Performance ..... 36
      - 3.1.4.2 Mechanical Retention and Volumetric Constraint Zones ..... 36
  - 3.2 Thermal Interface Material and Considerations ..... 37

**4.0 Vendor Data** ..... 38

**A Heatsink Mechanical Drawings** ..... 40

## Figures

1 Micro-FCBGA Package Top and Bottom Isometric View ..... 11

2 Micro-FCBGA Package Top and Side View ..... 11

3 Micro-FCBGA Package Bottom View ..... 13

4 Processor Die Offset ..... 14

5 Micro-FCPGA Package Top and Bottom Isometric View ..... 14

6 Micro-FCPGA Package - Bottom View ..... 15

7 Micro-FCPGA Package - Top and Side View ..... 16

8 Recommended PCB Volumetric Constraint Zone for Low Voltage Intel® Pentium® M Processors in the Single-Slot CompactPCI\* Form Factor ..... 18

9 Single-Slot CompactPCI\* Form Factor Recommended PCB Volumetric Constraint Zone for the Intel® Pentium® M and Celeron® M Processors in the Micro-FCBGA Package ..... 19

10 Single-Slot CompactPCI\* Form Factor Recommended PCB Volumetric Constraint Zone for the Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package ..... 20

11 Intel® Pentium® M and Celeron® M Processors in the Micro-FCBGA Package Mechanical Stack-Up in the Single-Slot CompactPCI\* Form Factor ..... 20

12 Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package Mechanical Stack-Up in the Single-Slot CompactPCI\* Form Factor ..... 21

13 Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package Mechanical Stack-Up in the 1U Form Factor ..... 21

14 Thermal Resistance Values for the Intel® Pentium® M Processor at 1.6 GHz at Various Local Ambient Operating Temperatures ..... 25

15 Copper Base, Aluminum Snap Fin Heatsink #1 Thermal Performance Curve ..... 26

16 Copper Base, Aluminum Snap Fin Heatsink #2 Thermal Performance Curve ..... 27

17 Low Voltage Intel® Pentium® M Processor Extruded Aluminum Heatsink #1 Thermal Performance Curve ..... 28

18 Low Voltage Intel® Pentium® M Processor—Extruded Aluminum Heatsink #2 Performance Curve ..... 29

19 Heatsink Orientation Relative to Airflow Direction ..... 30

20 Third-Party Vendor 1U Active Heatsink ..... 32

21 Active Aluminum Heatsink, ECC-00060-01 ..... 33

22 Active Copper Heatsink, ECC-00061-01 ..... 35

23 Copper Active Heatsink, ECC-00076-01 ..... 36

24 Intel® Pentium® M and Celeron® M Processors in the Micro-FCBGA Package—Copper Base, Aluminum Snap Fin Heatsink #1 ..... 41

25 Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package—Copper Base, Aluminum Snap Fin Heatsink #2 ..... 42

26 Low Voltage Intel® Pentium® M Processor—Extruded Aluminum Heatsink #1 ..... 43

27 Low Voltage Intel® Pentium® M Processor—Extruded Aluminum Heatsink #2 ..... 44

28 Page One (of Two) of the Volumetric Constraint Zone for the 1U Active Heatsink, ECU-PNA1C-35 ..... 45

29 Page Two (of Two) of the Volumetric Constraint Zone for the 1U Active Heatsink, ECU-PNA1C-35 ..... 46

30 Overall Thermal Solution Volumetric Constraint Zone for the 1U Active Heatsink,

ECU-PNA1C-35.....	47
31 Active Heatsink Volumetric Constraint (Primary Side).....	48
32 Active Heatsink Volumetric Constraint Zone (Secondary Side).....	49
33 Fastener (Used by Permission of Pencom*, Inc.).....	50

## Tables

1	Document References.....	8
2	Definitions of Terms.....	9
3	Micro-FCBGA Package Dimensions .....	12
4	Micro-FCPGA Package Dimensions .....	17
5	Intel® Pentium® M and Celeron® M Processors Thermal Specifications .....	22
6	1U Active Heatsink Thermal Performance .....	32
7	Aluminum Active Heatsink Thermal Performance .....	34
8	Active Copper Heatsink Thermal Performance .....	35
9	Copper Active Heatsink Thermal Performance .....	36
10	Vendor Contact Information.....	38

## Revision History

Date	Revision	Description
February 2006	003	Updated document references.
February 2004	002	Added information about the Celeron <sup>®</sup> M processor.
April 2003	001	Initial release of this document.

## 1.0 Introduction

This document describes thermal design guidelines for the Intel® Pentium® M and Celeron® M processors in the Micro Flip Chip Ball Grid Array (micro-FCBGA) package and the Micro Flip Chip Pin Grid Array (micro-FCPGA) package. Detailed mechanical and thermal specifications for this processor can be found in the following documents:

- *Intel® Pentium® M Processor Datasheet*, order number 252612.
- *Intel® Celeron® M Processor Datasheet*, order number 300302.

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 OEMs with the development of thermal solutions for their individual designs. It is the responsibility of each OEM to validate the thermal solution design, including the heatsink, attachment method, and thermal interface material (TIM) with their specific applications.

## 1.1 Document Goals

This document describes the thermal characteristics of the Intel Pentium M and Celeron M processors and provides guidelines for meeting the thermal requirements imposed on uniprocessor systems. The thermal solutions presented in this document are specifically designed for applied computing applications in the single-slot CompactPCI\* and larger form factors.

## 1.2 Document Scope

This document discusses thermal management techniques for the Intel Pentium M and Celeron M processors 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 junction temperature. In case of conflict, the data in the datasheet supersedes any data in this document.

## 1.3 Document References

**Table 1. Document References**

Document Title	Order Number
<i>Intel® Pentium® M Processor Datasheet</i>	252612
<i>Intel® Celeron® M Processor Datasheet</i>	300302
<i>Intel® Mobile Processor Micro-FCPGA Socket (mPGA479M) Design Guidelines</i>	298520



## 1.4 Definition of Terms

**Table 2. Definitions of Terms**

Term	Definition
CFM	Cubic Feet per Minute
LFM	Linear Feet per Minute
PCB	Printed Circuit Board
$\Psi_{JA}$	The thermal resistance between the processor's junction and the ambient air. This is defined and controlled by the system thermal solution.
$\Psi_{JS}$	The junction to sink thermal resistance, which is dependent on the thermal interface material. Also referred to as $\Psi_{TIM}$ .
$T_{junction}$	The measured junction temperature of the processor.
$T_{junction-max}$	The maximum junction temperature of the processor, as specified in the processor datasheet.
$T_{LA}$ ( $T_{Local-Ambient}$ )	The measured ambient temperature locally surrounding the processor. The ambient temperature should be measured approximately one inch (25.4 mm) upstream of a passive heatsink, or at the fan inlet of an active heatsink
Thermal Design Power (TDP)	A design point for the processor. OEMs must design thermal solutions that meet TDP and $T_{junction}$ specifications as specified in the processor's datasheet.
Thermal Interface Material (TIM)	The thermally conductive compound between the heatsink and processor die. This material fills air gaps and voids, and improves the spread of heat from the die to the heatsink.
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.

## 2.0 Design Guideline

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 single-slot CompactPCI\* form factor. 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 testing. 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 Intel® Pentium® M and Celeron® M processors are available in the 479-Ball Micro-Flip Chip Ball Grid Array (micro-FCBGA) package and the 478-pin Micro-Flip Chip Pin Grid Array (micro-FCPGA) package technology. Detailed mechanical specifications for these processors can be obtained from the processor datasheets.

Figure 1 through Figure 3 show different views of the micro-FCBGA package; dimensions are provided in Table 3. The dies of the Intel Pentium M and Celeron M processors are not centered on the package; therefore, they have a die offset. The die offsets for the Intel Pentium M and Celeron M processors are shown in Figure 4. Figure 5 through Figure 7 show different views of the micro-FCPGA package; dimensions are in Table 4. Refer to the processor datasheets for detailed information.

The micro-FCBGA package may have capacitors placed in the area surrounding the die. Because die-side capacitors are electrically conductive, and only slightly shorter than the die height, care should be taken to avoid contacting the capacitors with electrically conductive materials. Doing so may short-circuit the capacitors and possibly damage the device or render it inactive. The use of an insulating material between the capacitors and any thermal solution should be considered to prevent capacitor shorting.

Figure 1. Micro-FCBGA Package Top and Bottom Isometric View

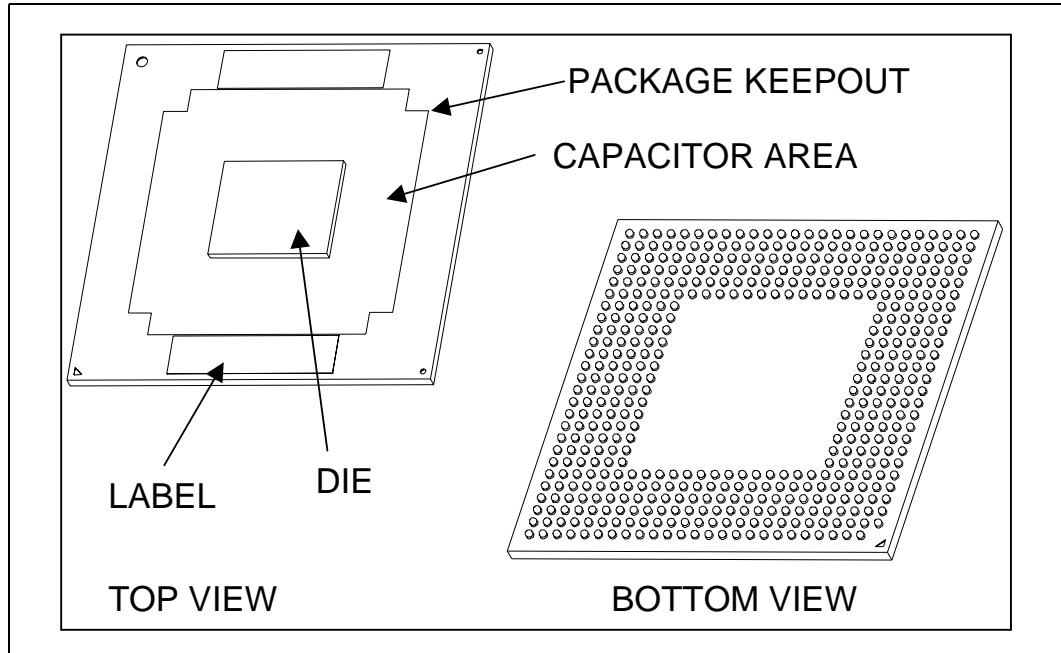


Figure 2. Micro-FCBGA Package Top and Side View

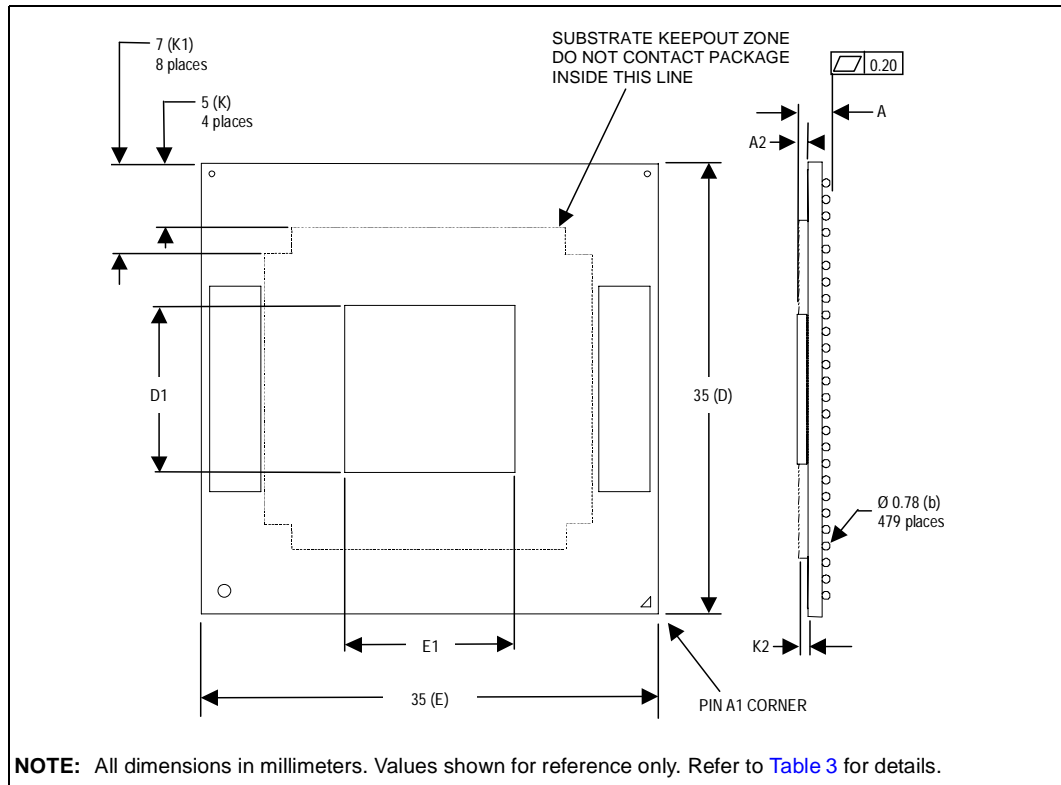


Table 3. Micro-FCBGA Package Dimensions

Symbol	Parameter	Min	Max	Unit
A	Overall height, as delivered <sup>†</sup>	2.60	2.85	mm
A2	Die height	0.82		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	10.56		mm
E1	Die width	7.84		mm
F	To package substrate center	17.5		mm
G	Die offset from package center	1.133		mm
e	Ball pitch	1.27		mm
K	Package edge volumetric constraint zone	5		mm
K1	Package corner volumetric constraint zone	7		mm
K2	Die-side capacitor height	-	0.7	mm
S	Package edge to first ball center	1.625		mm
N	Ball count	479		each
-	Solder ball coplanarity	0.2		mm
Pdie	Allowable pressure on the die for thermal solution	-	689	kPa
W	Package weight	4.5		g

<sup>†</sup> Overall height as delivered. Values are based on design specifications and tolerances. This dimension is subject to change based on OEM motherboard design or OEM SMT process.

Figure 3. Micro-FCBGA Package Bottom View

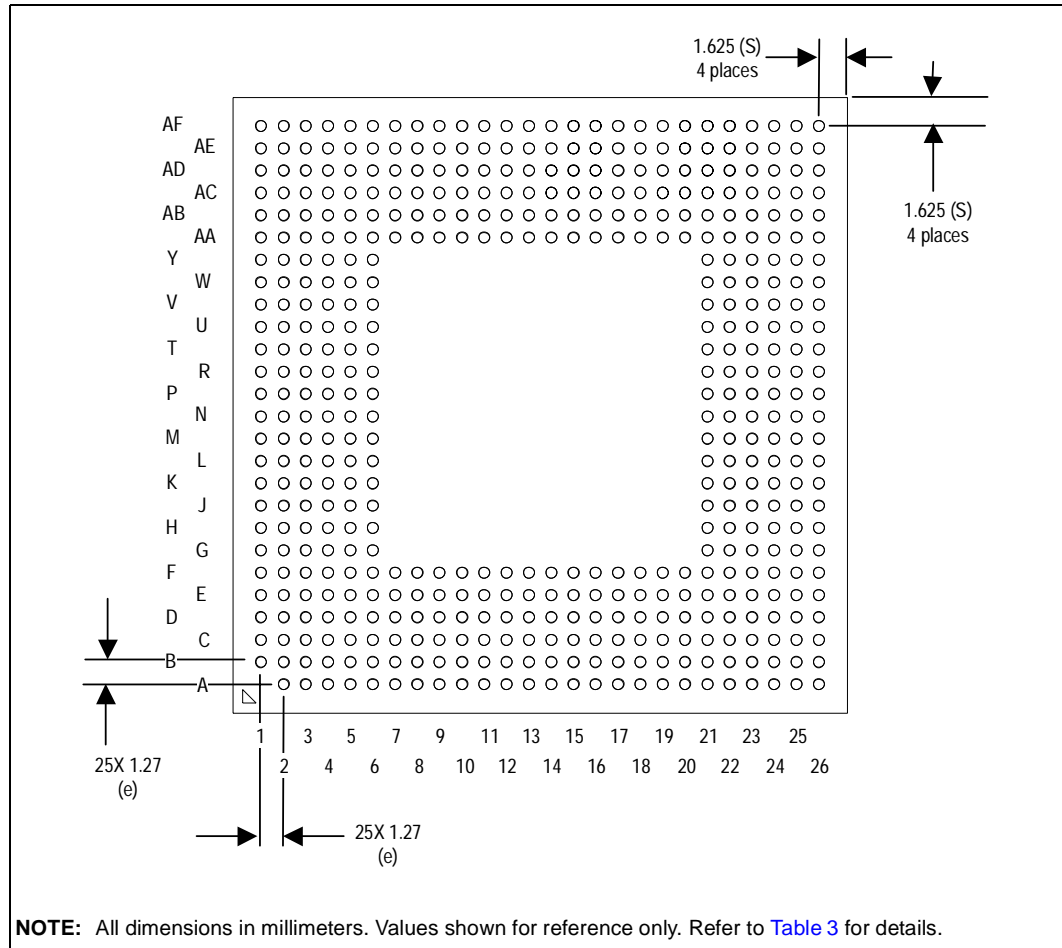


Figure 4. Processor Die Offset

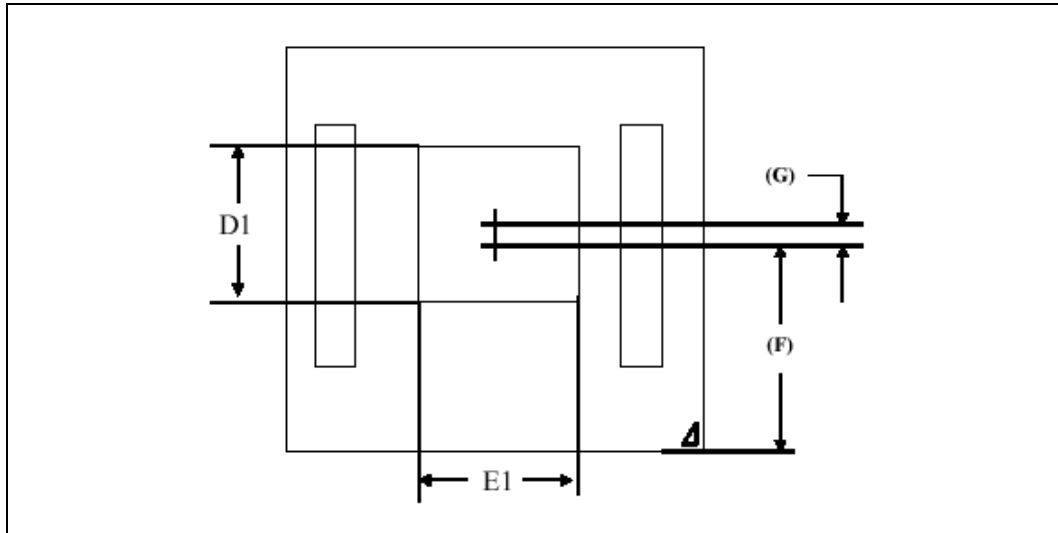


Figure 5. Micro-FCPGA Package Top and Bottom Isometric View

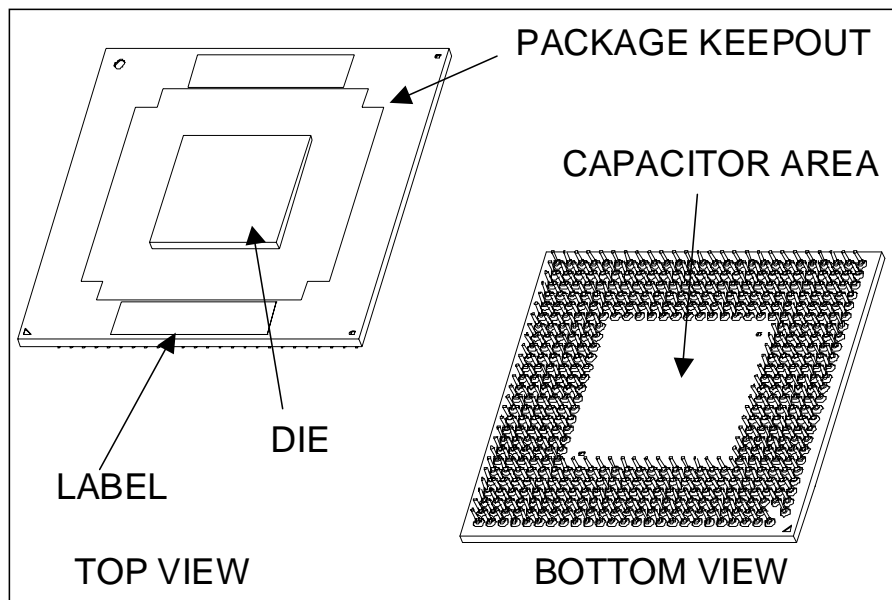


Figure 6. Micro-FCPGA Package - Bottom View

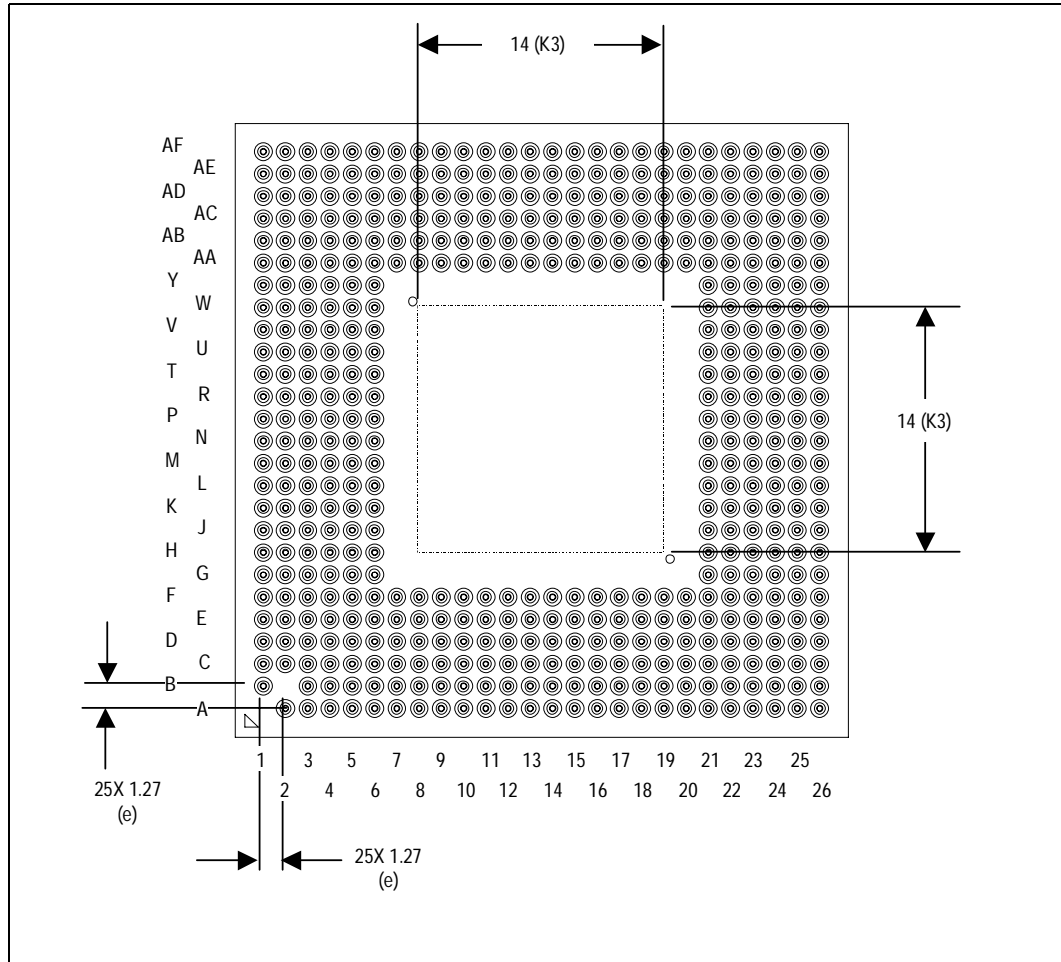
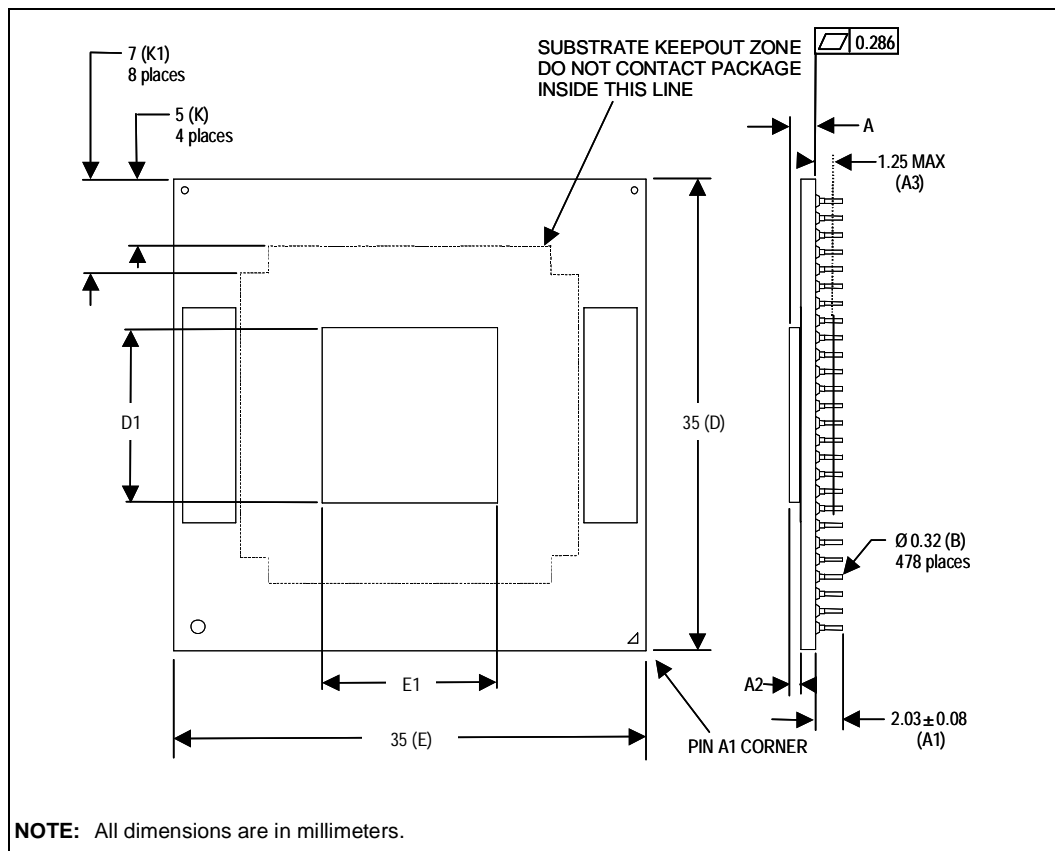


Figure 7. Micro-FCPGA Package - Top and Side View





**Table 4. Micro-FCPGA Package Dimensions**

Symbol	Parameter	Min	Max	Unit
A	Overall height, top of die to package seating plane	1.88	2.02	mm
-	Overall height, top of die to PCB surface, including socket <sup>†</sup>	4.74	5.16	mm
A1	Pin length	1.95	2.11	mm
A2	Die height	0.82		mm
A3	Pin-side capacitor height	-	1.25	mm
B	Pin diameter	0.28	0.36	mm
D	Package substrate length	34.9	35.1	mm
E	Package substrate width	34.9	35.1	mm
D1	Die length	10.56		mm
E1	Die width	7.84		mm
F	To package substrate center	17.5		mm
G	Die offset from package center	1.133		mm
e	Pin pitch	1.27		mm
K	Package edge volumetric constraint zone	5		mm
K1	Package corner volumetric constraint zone	7		mm
K3	Pin-side capacitor boundary	14		mm
-	Pin tip radial true position	<=0.254		mm
N	Pin count	478		each
Pdie	Allowable pressure on the die for thermal solution	-	689	kPa
W	Package weight	4.5		g
	Package surface flatness	0.286		mm

<sup>†</sup> Overall height with socket is based on design dimensions of the Micro-FCPGA package with no thermal solution attached. Values are based on design specifications and tolerances. This dimension is subject to change based on socket design, OEM motherboard design or OEM SMT process.

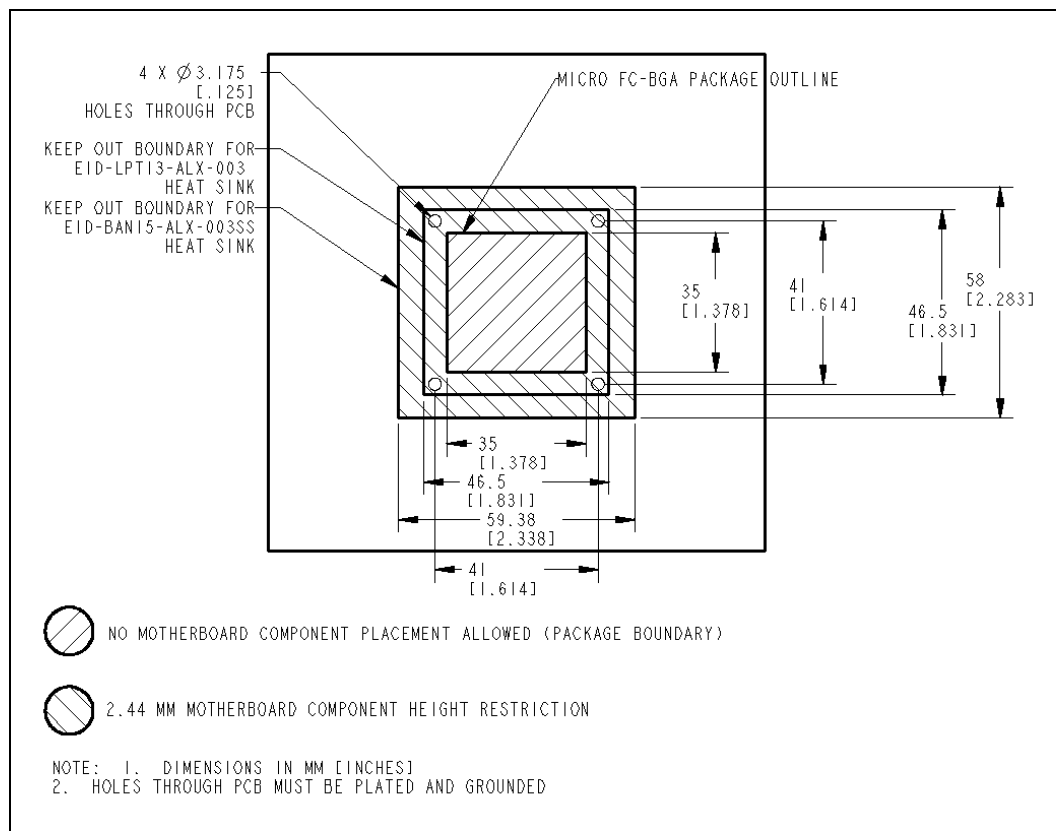
## 2.1.2 Volumetric Constraint Zones

The volumetric constraint zone reserved for the processor package, heatsink, and heatsink attachment method for the baseboard is shown in Figure 8, Figure 9, and Figure 10. There are multiple volumetric constraint zones depending on which processor is being used:

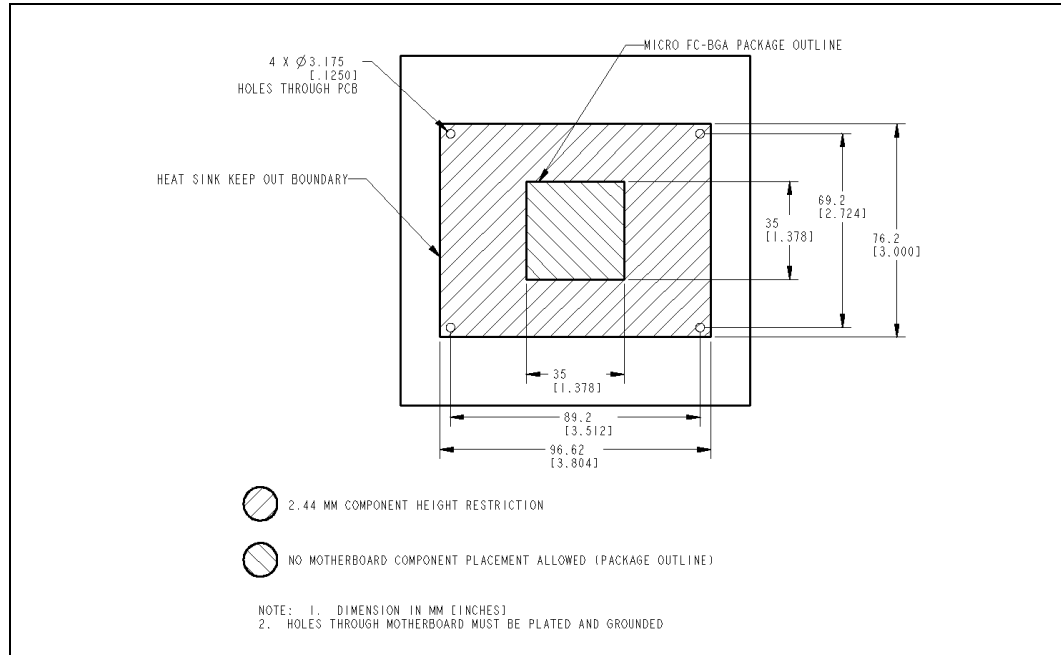
- Low Voltage Intel Pentium M processors.
- Intel Pentium M and Celeron M processors in the micro-FCBGA package.
- Intel Pentium M and Celeron M processors in the micro-FCPGA package.

The volumetric constraint zones for the Intel Pentium M and Celeron M processors for the third-party vendor enabled fansinks are shown in Figure 28 through Figure 33. Figure 11 shows the micro-FCBGA processor package mechanical stack-up in a single-slot CompactPCI\* form factor and the allowable z-height for the thermal solution. Figure 12 shows the Intel Pentium M and Celeron M processors in the micro-FCPGA package in a single-slot CompactPCI\* form factor. Figure 13 shows the Intel Pentium M and Celeron M processors in the micro-FCBGA package mechanical stack-up in the 1U form factor.

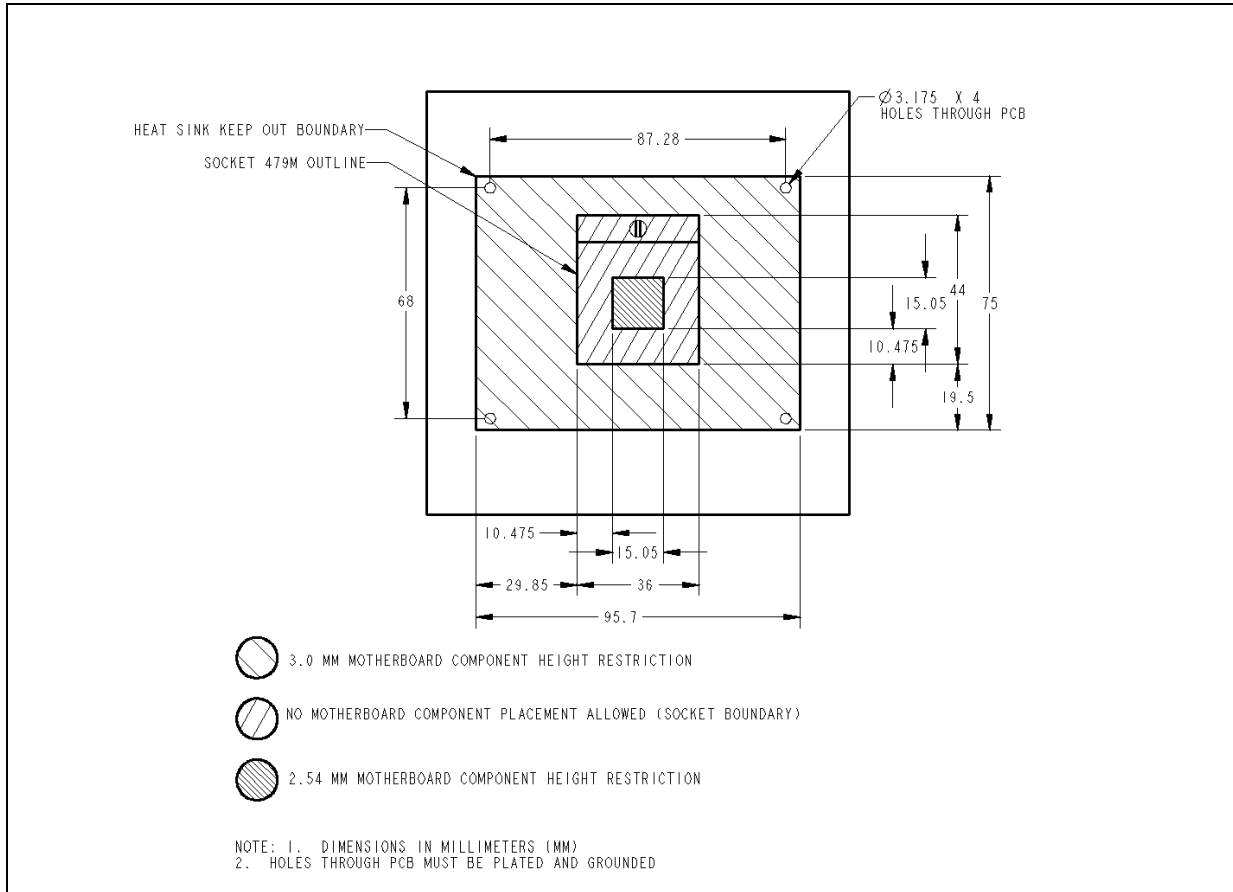
**Figure 8. Recommended PCB Volumetric Constraint Zone for Low Voltage Intel® Pentium® M Processors in the Single-Slot CompactPCI\* Form Factor**



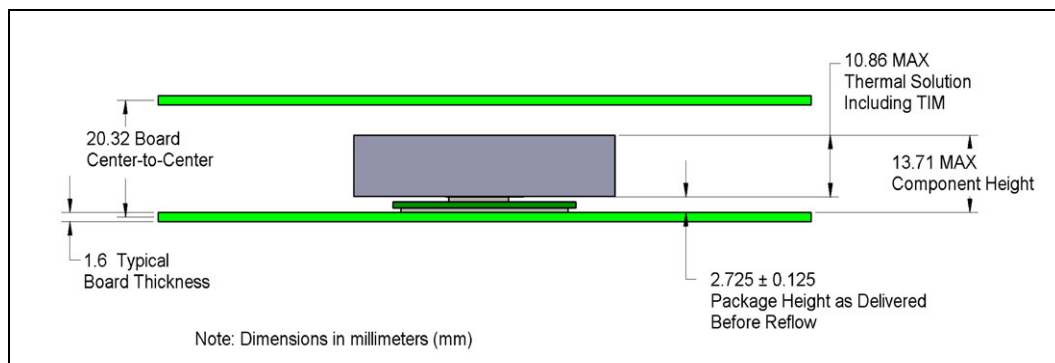
**Figure 9. Single-Slot CompactPCI\* Form Factor Recommended PCB Volumetric Constraint Zone for the Intel® Pentium® M and Celeron® M Processors in the Micro-FCBGA Package**



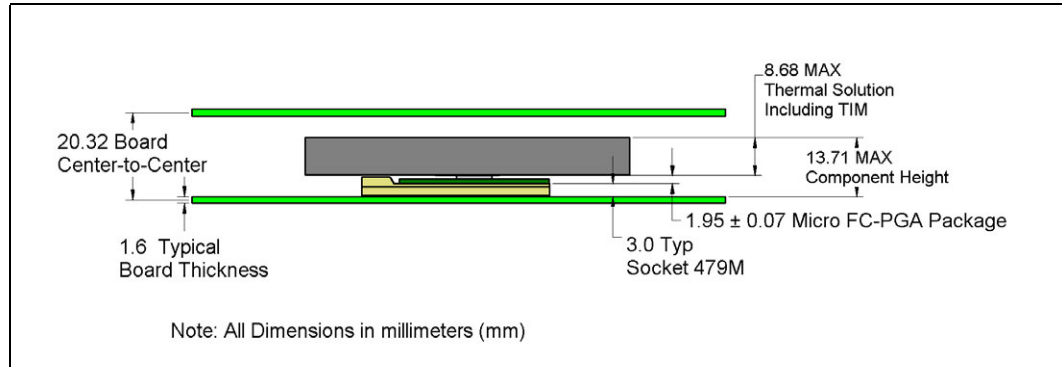
**Figure 10. Single-Slot CompactPCI\* Form Factor Recommended PCB Volumetric Constraint Zone for the Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package**



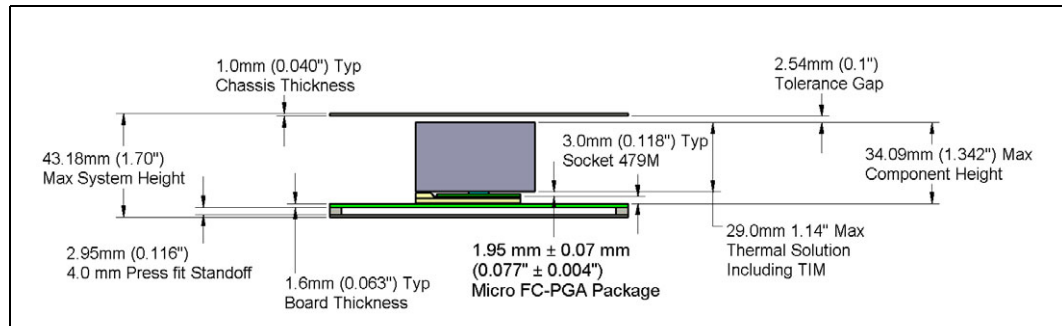
**Figure 11. Intel® Pentium® M and Celeron® M Processors in the Micro-FCBGA Package Mechanical Stack-Up in the Single-Slot CompactPCI\* Form Factor**



**Figure 12. Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package Mechanical Stack-Up in the Single-Slot CompactPCI\* Form Factor**



**Figure 13. Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package Mechanical Stack-Up in the 1U Form Factor**



## 2.2 Thermal Guidelines

The performance of a thermal solution depends on many parameters, including the processor's:

- Thermal design power (TDP)
- Maximum junction temperature ( $T_{\text{junction-max}}$ )
- Operating ambient temperature
- 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.

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

Thermal data for the Intel Pentium M and Celeron M processors is presented in [Table 5](#). 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 5. Intel® Pentium® M and Celeron® M Processors Thermal Specifications

Processor	Core Frequency (GHz)	Thermal Design Power (W)	Minimum Tjunction (°C)	Maximum Tjunction (°C)
Pentium M	1.6	24.5	0	100
Low Voltage Pentium M	1.1	12	0	100
Celeron M	1.3	24.5	0	100

### 2.2.1 Processor Power

The processor's power is specified as Thermal Design Power (TDP) for thermal solution design. TDP is defined as the worst-case power dissipated by the processor while executing publicly available software under normal operating conditions, at nominal voltages that meet the load line specifications. The TDP definition is synonymous with the Thermal Design Power (typical) specification referred to in previous Intel datasheets. The Intel TDP specification is a recommended design point and is not representative of the absolute maximum power the processor may dissipate under worst case conditions. 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.

### 2.2.2 Thermal Diode

The Intel Pentium M and Celeron M processors incorporate two methods of monitoring die temperature, the Intel Thermal Monitor and the thermal diode. The Intel Thermal Monitor must be used to determine when the maximum specified processor junction temperature has been reached. The second method, the thermal diode, can be read by an off-die analog/digital converter (a thermal sensor) located on the motherboard, or a stand-alone measurement kit. The thermal diode may be used to monitor the die temperature of the processor for thermal management or instrumentation purposes but cannot be used to indicate that the maximum  $T_j$  of the processor has been reached. The Thermal Diode can only be used for long-term, steady-state measurement of die temperature. It is not suitable for real-time thermal management. For more information, refer to the *Intel® Pentium® M Processor Datasheet* and the *Intel® Celeron® M Processor Datasheet*.

### 2.2.3 Thermal Monitor

The Intel Thermal Monitor is a feature of the Intel Pentium M and Celeron M processors that allows system designers to lower the cost of thermal solutions without compromising system integrity. The Intel Thermal Monitor automatic mode must be enabled for the processor to operate within specifications. By using a factory-tuned on-die temperature sensor and a fast-acting thermal control circuit (TCC), the processor, without the aid of any additional software or hardware, can restrict its die temperature to remain within factory specifications under typical real-world operating conditions. The Intel Thermal Monitor thus 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 processor maximum power envelope.

The Intel Thermal Monitor controls the processor temperature by activating the TCC when the processor silicon reaches its maximum operating temperature. The temperature at which the Intel Thermal Monitor activates the thermal control circuit is not user configurable and is not software visible. Bus traffic is snooped in the normal manner, and interrupt requests are latched (and serviced during the time that the clocks are on) while the TCC is active.

The Intel Thermal Monitor controls the processor temperature by modulating (starting and stopping) the processor core clocks or by initiating an Enhanced Intel SpeedStep® technology transition when the processor silicon reaches its maximum operating temperature. The Intel Thermal Monitor uses two modes to activate the TCC: automatic mode and on-demand mode. If both modes are activated, automatic mode takes precedence. There are two automatic modes called Intel Thermal Monitor 1 and Intel Thermal Monitor 2. Select these modes by writing values to the Model Specific Registers (MSRs) of the processor.

Automatic mode is required for the processor to operate within specifications and must first be enabled through BIOS. After automatic mode is enabled, the TCC activates only when the internal die temperature reaches the maximum allowed value for operation.

Likewise, when Intel Thermal Monitor 2 is enabled and a high temperature situation exists, the processor performs an Enhanced Intel SpeedStep technology transition to a lower operating point. When the processor temperature drops below the critical level, the processor will make an Enhanced Intel SpeedStep technology transition to the last requested operating point. Intel Thermal Monitor 2 is the recommended mode on Intel Pentium M processors.

**Note:** Only the Pentium M family of processors features Thermal Monitor 2 and Enhanced Intel Speedstep Technology. Celeron M processors do not have these features and support only Thermal Monitor 1.

If a processor load-based Enhanced Intel SpeedStep technology transition through MSR write is initiated when an Intel Thermal Monitor 2 period is active, there are two possible results:

1. If the processor load-based Enhanced Intel SpeedStep technology transition target frequency is higher than the Intel Thermal Monitor 2 transition-based target frequency, the processor load-based transition will be deferred until the Intel Thermal Monitor 2 event has been completed.
2. If the processor load-based Enhanced Intel SpeedStep technology transition target frequency is lower than the Intel Thermal Monitor 2 transition-based target frequency, the processor will transition to the processor load-based Enhanced Intel SpeedStep technology target frequency point.

When Intel Thermal Monitor 1 is enabled and a high temperature situation exists, the clocks will be modulated by alternately turning the clocks off and on at a 50% duty cycle. Cycle times are processor speed dependent and will decrease linearly as processor core frequencies increase. After the temperature has returned to a non-critical level, modulation ceases and TCC goes inactive. A small amount of hysteresis has been included to prevent rapid active/inactive transitions of the TCC when the processor temperature is near the trip point. 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. Processor performance is decreased by the same amount as the duty cycle when the TCC is active; however, with a properly designed and characterized thermal solution, the TCC most likely will never be activated, or only will be activated briefly during the most power intensive applications.

The TCC may also be activated via on-demand mode. If bit 4 of the ACPI Intel Thermal Monitor Control Register is written to a “1”, the TCC is 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 via bits 3:1 of the same ACPI Intel Thermal Monitor Control Register. In automatic mode, the duty cycle is fixed at 50% on, 50% off, but in on-demand mode, the duty cycle can be programmed from 12.5% on/87.5% off, to 87.5% on/12.5% off, in 12.5% increments. On-demand mode can be used at the same time Automatic mode is enabled; however, if the system tries to enable the TCC through on-demand mode at the same time automatic mode is enabled and a high temperature condition exists, automatic mode takes precedence.

An external signal, PROCHOT# (processor hot) is asserted when the processor detects that its temperature is above the thermal trip point. Bus snooping and interrupt latching are also active while the TCC is active.

**Note:** PROCHOT# will not be asserted when the processor is in the Stop Grant, Sleep, Deep Sleep and Deeper Sleep low power states (internal clocks stopped), hence the thermal diode reading must be used as a safeguard to maintain the processor junction temperature within the 100° C (maximum) specification. If the platform thermal solution is not able to maintain the processor junction temperature within the maximum specification, the system must initiate an orderly shutdown to prevent damage. If the processor enters one of the above low-power states with PROCHOT# already asserted, PROCHOT# remains asserted until the processor exits the low power state and the processor junction temperature drops below the thermal trip point.

If automatic mode is disabled, the processor is operating out of specification. Whether the automatic or on-demand modes are reenabled or not, in the event of a catastrophic cooling failure, the processor automatically shuts down when the silicon has reached a temperature of approximately 125° C. At this point, the system bus signal THERMTRIP# will go active. THERMTRIP# activation is independent of processor activity and does not generate any bus cycles. When THERMTRIP# is asserted, the processor core voltage must be shut down within the time specified in the *Intel® Pentium® M Processor Datasheet* and the *Intel® Celeron® M Processor Datasheet*.

## 2.2.4 Power Density and Non-Uniform Heating

The Intel Pentium M and Celeron M processor dies do not exhibit even power distribution over their surface areas. Non-uniform power distributions can adversely affect the overall thermal solution performance. The thermal interface material, which functions as the first layer of heat spreading above the die, will be most susceptible to non-uniform die power characteristics.

The processor density factor for the Intel Pentium M and Celeron M processors is higher than on previous processors. Processor thermal solution designers must account for the increase in expected thermal impedance, or resistance, from the thermal interface material when it is attached to the processor die. Processor heatsink performance will not be affected to the same degree as the TIM and is dependent on many factors, including heatsink size, base thickness, and material used. It is the responsibility of the OEM thermal solution designer to validate overall thermal solution performance.

## 2.2.5 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 (e.g., Intel Pentium M processor at 1.6 GHz), hence the solutions are suitable for lower frequencies of the processor. In addition, the processor local ambient temperature was specified as 50° C for Intel Pentium M and Celeron M processors, except for the Intel Pentium M and Celeron M processors in the micro-FCPGA package in the single-slot CompactPCI\* form factor, which is 45° C. The ambient temperature and airflow are based on a measurement approximately one inch (25.4 mm) upstream from the processor.

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

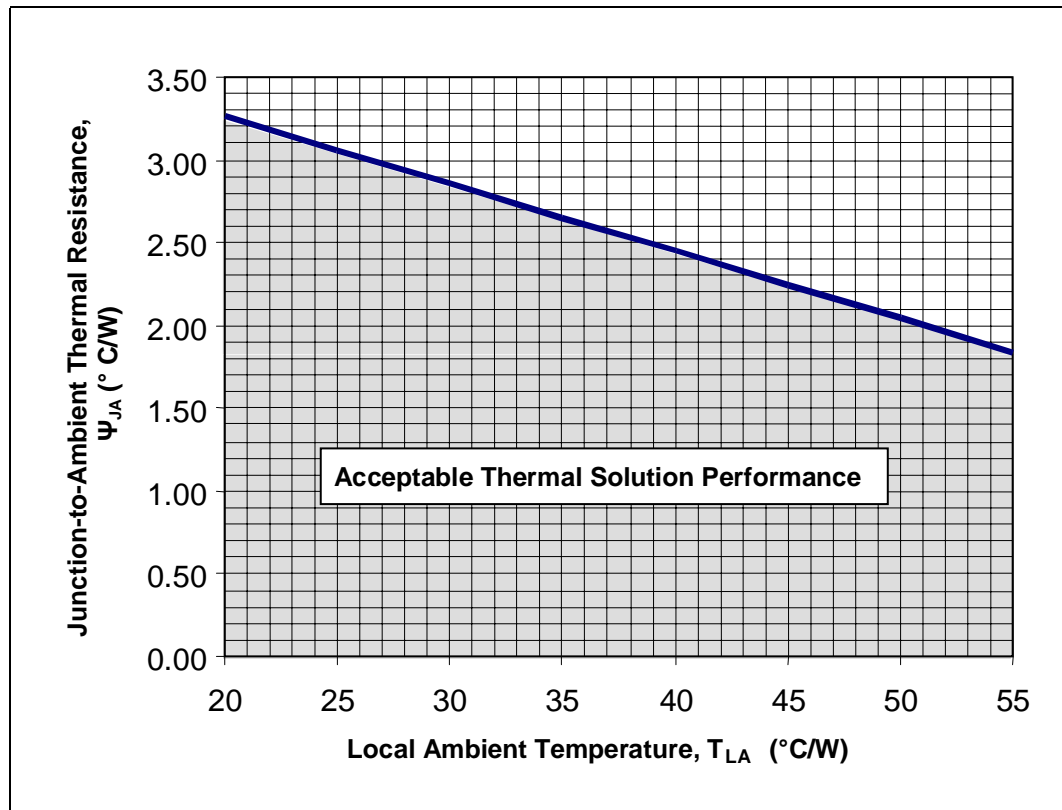


Equation 1.

$$\Psi_{JAmax} = \frac{T_{Jmax}^{\circ C} - T_{LA}^{\circ C}}{TDP(W)} = \frac{100^{\circ C} - 50^{\circ C}}{24.5W} = 2.04 \frac{^{\circ}C}{W}$$

Figure 14 further illustrates the required thermal performance for the Intel® Pentium® M processor at 1.6 GHz 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 values shown for the given local ambient temperature.

**Figure 14. Thermal Resistance Values for the Intel® Pentium® M Processor at 1.6 GHz at Various Local Ambient Operating Temperatures**



## 2.2.6 Recommended Heatsink Designs

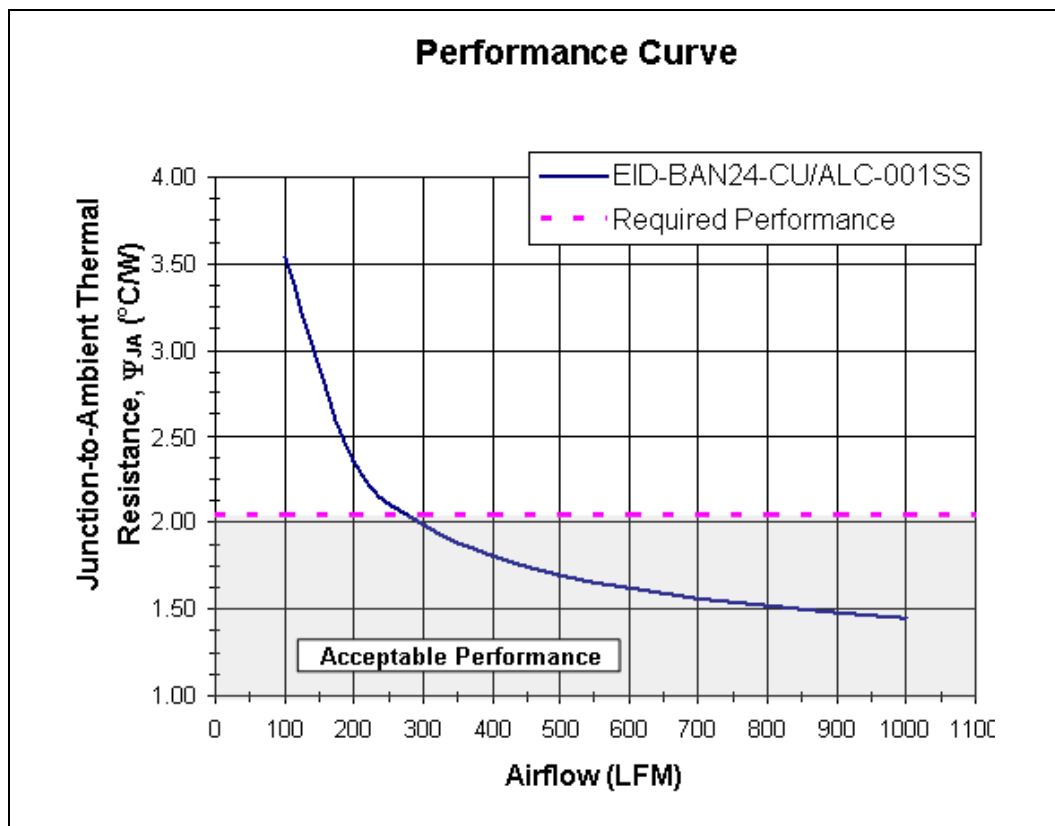
### 2.2.6.1 Intel® Pentium® M and Celeron® M Processors in the Micro-FCBGA Package—Copper Base, Aluminum Snap Fin Heatsink #1

This heatsink was designed to meet the required thermal performance for a maximum local ambient temperature of 50° C and a TDP of 24.5 W. This design is Intel intellectual property and intended for customer use with appropriate consent. The heatsink shown in Figure 24 was optimized using computational fluid dynamic (CFD) and thermal modeling software. The heatsink is optimized for a non-ducted airflow, as measured approximately one inch upstream from the processor.

Figure 15 shows the thermal performance for the copper/aluminum heatsink in a non-ducted configuration.

Thermal modeling and lab verification tests indicate that this heatsink has a junction-to-ambient thermal resistance of 2.0 °C/W with 300 LFM of system airflow, thus meeting the requirements for the performance Intel Pentium M and Celeron M processors.

Figure 15. Copper Base, Aluminum Snap Fin Heatsink #1 Thermal Performance Curve



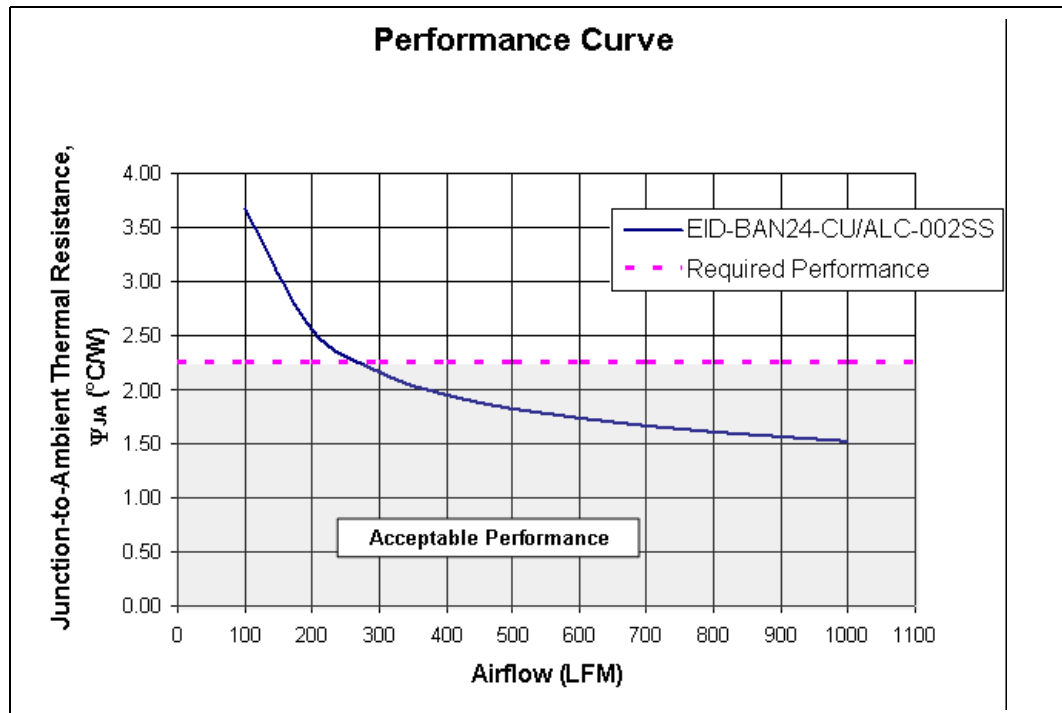
### 2.2.6.2 Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package—Copper Base, Aluminum Snap Fin Heatsink #2

This heatsink was designed to meet the required thermal performance for a maximum local ambient temperature of 45° C and a TDP of 24.5 W. This design is Intel intellectual property and intended for customer use with appropriate consent. The heatsink shown in Figure 25 was optimized using computational fluid dynamic (CFD) and thermal modeling software. The heatsink is optimized for a non-ducted airflow, as measured approximately one inch upstream from the processor.

Figure 16 shows the thermal performance for the copper/aluminum heatsink in non-ducted configuration.

Thermal modeling and lab verification tests indicate that this heatsink has a junction-to-ambient thermal resistance of 2.16° C/W with 300 LFM of system airflow, thus meeting the requirements for the Intel Pentium M and Celeron M processors.

Figure 16. Copper Base, Aluminum Snap Fin Heatsink #2 Thermal Performance Curve



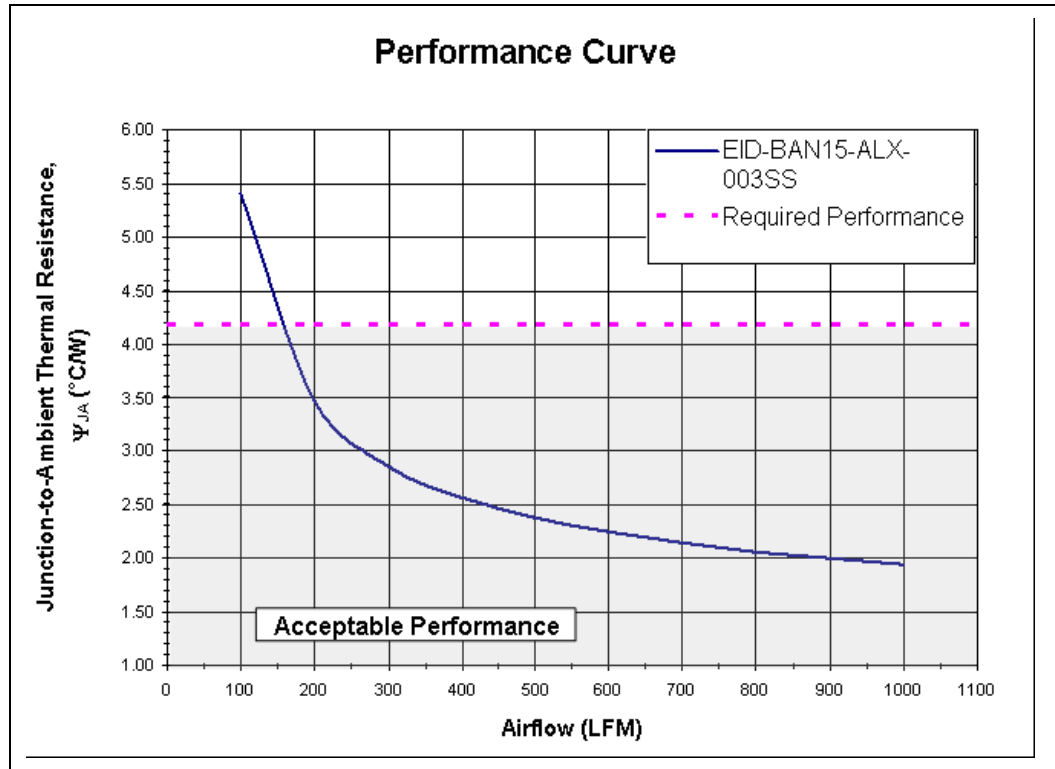
### 2.2.6.3 Low Voltage Intel Pentium M Processor in the Micro-FCBGA Package—Extruded Aluminum Heatsink #1

This heatsink was designed to meet the required thermal performance for a maximum local ambient temperature of 50° C and a TDP of 12 W. This design is Intel intellectual property and intended for customer use with appropriate consent. The heatsink shown in Figure 26 was optimized using computational fluid dynamic (CFD) and thermal modeling software. The heatsink is optimized for a non-ducted airflow, as measured approximately one inch upstream from the processor.

Figure 17 shows the thermal performance for the extruded aluminum heatsink in non-ducted configuration.

Thermal modeling and lab verification tests indicate that this heatsink has a junction-to-ambient thermal resistance of 3.48 °C/W with 200 LFM of system airflow, thus meeting the requirements for the Low Voltage Intel® Pentium® M processor.

**Figure 17. Low Voltage Intel® Pentium® M Processor Extruded Aluminum Heatsink #1 Thermal Performance Curve**



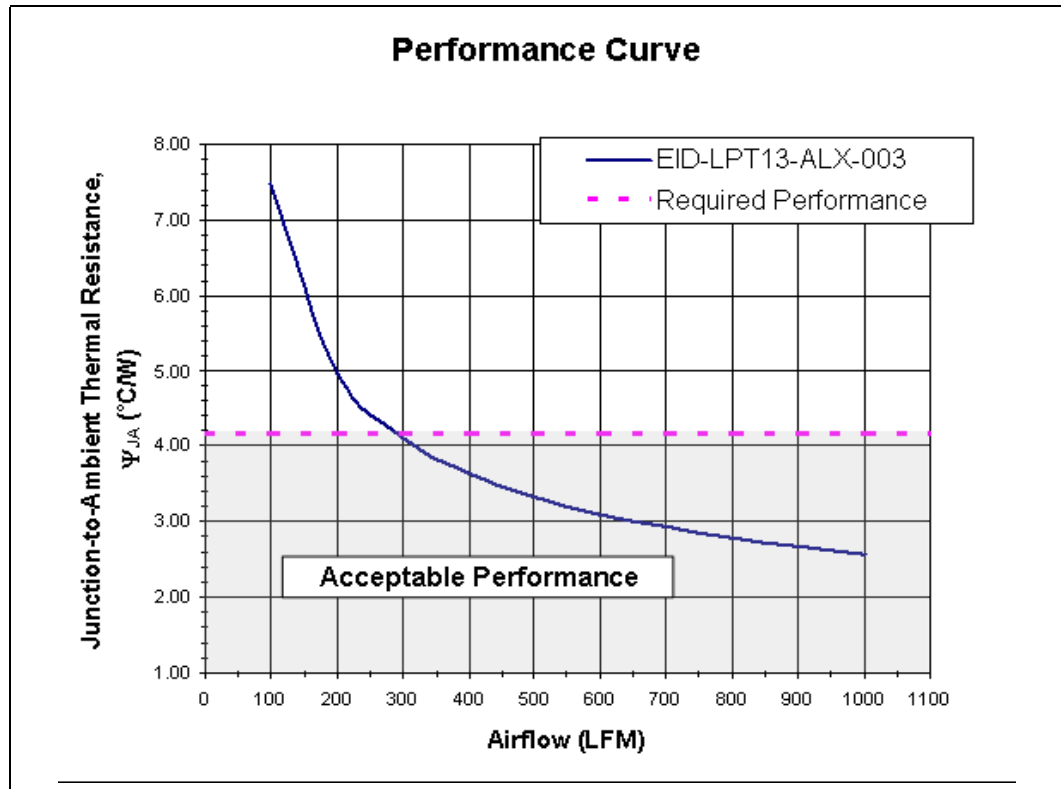
#### 2.2.6.4 Low Voltage Intel Pentium M Processor—Extruded Aluminum Heatsink #2

This heatsink was designed to meet the required thermal performance for a maximum local ambient temperature of 50° C and a TDP of 12 W. This design is Intel intellectual property and intended for customer use with appropriate consent. The heatsink shown in Figure 27 was optimized using computational fluid dynamic (CFD) and thermal modeling software. The heatsink is optimized for a non-ducted airflow, as measured approximately one inch upstream from the processor.

Figure 18 shows the thermal performance for the extruded aluminum heatsink in non-ducted configuration.

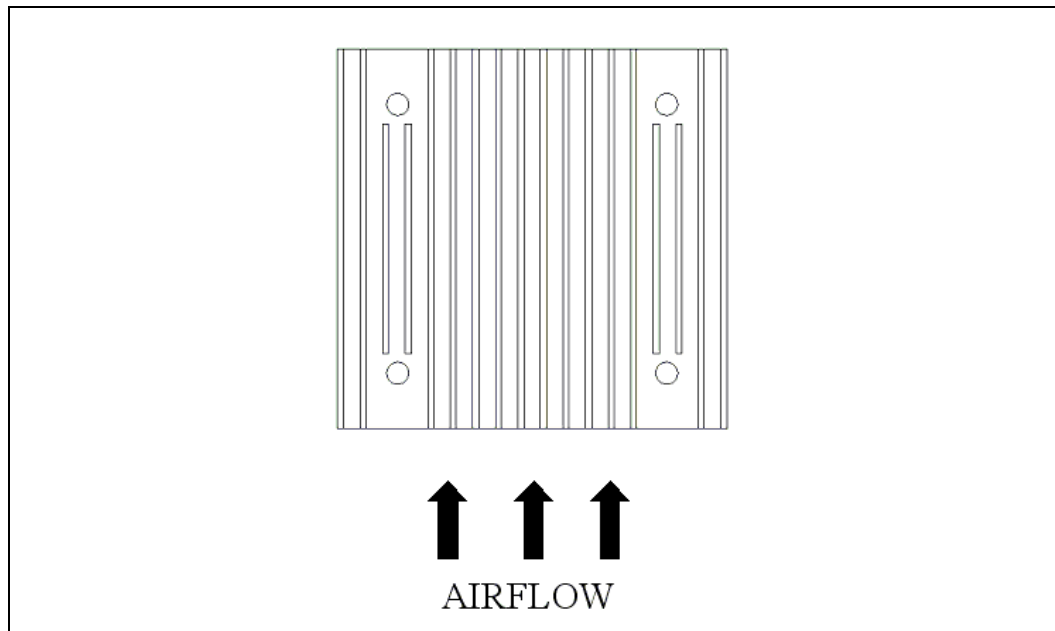
Thermal modeling and lab verification tests indicate that this heatsink has a junction-to-ambient thermal resistance of 4.11 °C/W with 300 LFM of system airflow, thus meeting the requirements for the Low Voltage Intel Pentium M processor.

Figure 18. Low Voltage Intel® Pentium® M Processor—Extruded Aluminum Heatsink #2 Performance Curve



### 2.2.6.5 Heatsink Orientation Relative to Airflow

The heatsinks were designed to maximize the available space within the volumetric constraint zone. These heatsinks must be oriented in a specific direction relative to the processor volumetric constraint zone and airflow. In this design, the processor must be placed on the PCB in an orientation so the heatsink fins will be parallel to the airflow. Figure 19 illustrates this orientation. A top view of the heatsink assembly is shown.

**Figure 19. Heatsink Orientation Relative to Airflow Direction**

### 2.2.7 Recommended Thermal Interface Material (TIM)

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

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

The heatsink solution was optimized using a high-performance grease TIM with low thermal impedance. The heatsinks were designed using ShinEtsu\* G751 thermal grease. Vendor information for this material is provided in [Section 4.0, “Vendor Data” on page 38](#). Alternative materials can be used at the user’s discretion. The entire heatsink assembly, including the heatsink, attach method, and TIM, must be validated together for specific applications.

### 2.2.8 Recommended Thermal Solution Attachment Method

The thermal solution can be attached to the motherboard in a number of ways. The thermal solutions have been designed with mounting holes in the heatsink base. A plastic rivet is available that can be used to fasten smaller heatsinks, such as the Low Voltage Intel® Pentium® M processor heatsink. Depending on the system, it may or may not conform to secondary side CompactPCI\* height requirements. This fastener is shown in [Figure 33](#).

For larger and heavier heatsinks, such as the Intel Pentium M processor heatsink, a fastening system consisting of screws and springs, and secured with a fastener, should be used. Designs used in a CompactPCI\* system must conform to maximum component height specifications on both the primary and secondary sides of the PCB. The entire heatsink assembly must be validated together for specific applications, including the heatsink, attach method, and thermal interface material.

### 2.2.9 Intel® Pentium® M and Celeron® M Processor Thermal Test Vehicle

To aid in thermal design and verification, Intel has developed a Thermal Test Vehicle (TTV) for the Intel Pentium M and Celeron M processors. For more information, contact your Intel field representative.

## 3.0 Third-Party Vendor Enabled Active Heatsinks

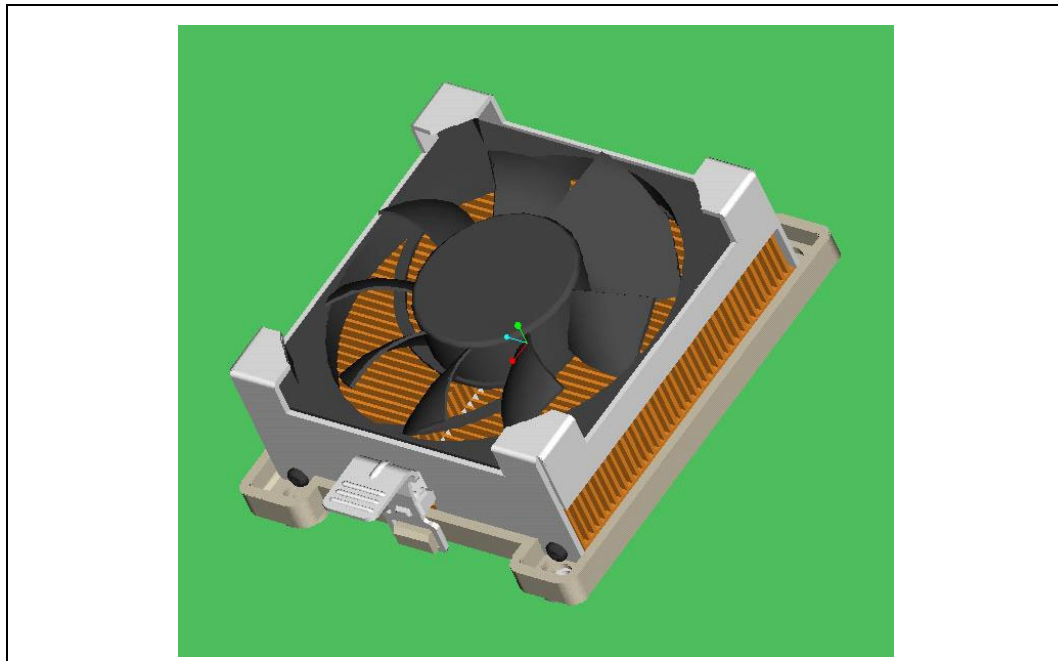
### 3.1 Applications

CoolerMaster\* has developed a number of active fan heatsinks that can be used to provide cooling for the Intel® Pentium® M and Celeron® M processors for Embedded Applications. These heatsinks are a good fit for platforms requiring an active thermal solution (integrated fan heatsink) if z-height allows for 1U or greater of clearance. The following sections provide details on the different active fansinks.

#### 3.1.1 ECU-PNA1C-35

This active fansink is a copper heatsink designed to meet the form factor constraints of a 1U server system.

Figure 20. Third-Party Vendor 1U Active Heatsink



##### 3.1.1.1 Thermal Performance

Thermal performance for this heatsink was verified with the Pentium M Thermal Test Vehicle (TTV). The heatsink is capable of cooling a Pentium M and Celeron M processor at 24.5 W with local ambient temperatures up to  $T_{LA} = 57^{\circ}\text{C}$ . The performance of the thermal solution is a verification test only to ensure that the heatsink is performing within expectations. This test does not imply any statistical significance; it is up to system integrator to perform validation in the final intended system, including the heatsink, attach method, and thermal interface material.

Table 6. 1U Active Heatsink Thermal Performance

Thermal Performance ( $^{\circ}\text{C/W}$ )	$\Psi_{JA} = 1.73^{\circ}\text{C/W}$
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### 3.1.1.2 Mechanical Retention and Volumetric Constraint Zones

The 1U active heatsink is attached to the motherboard using a retention mechanism. This retention mechanism is attached using four screws and a backplate, which will be flush against the backside of the motherboard. The backplate will limit placement of any components on the underside of the board opposite the volumetric constraint zone.

The active heatsink attaches to the retention mechanism using a thumb-actuated clip that latches on to two extrusions on the retention mechanism.

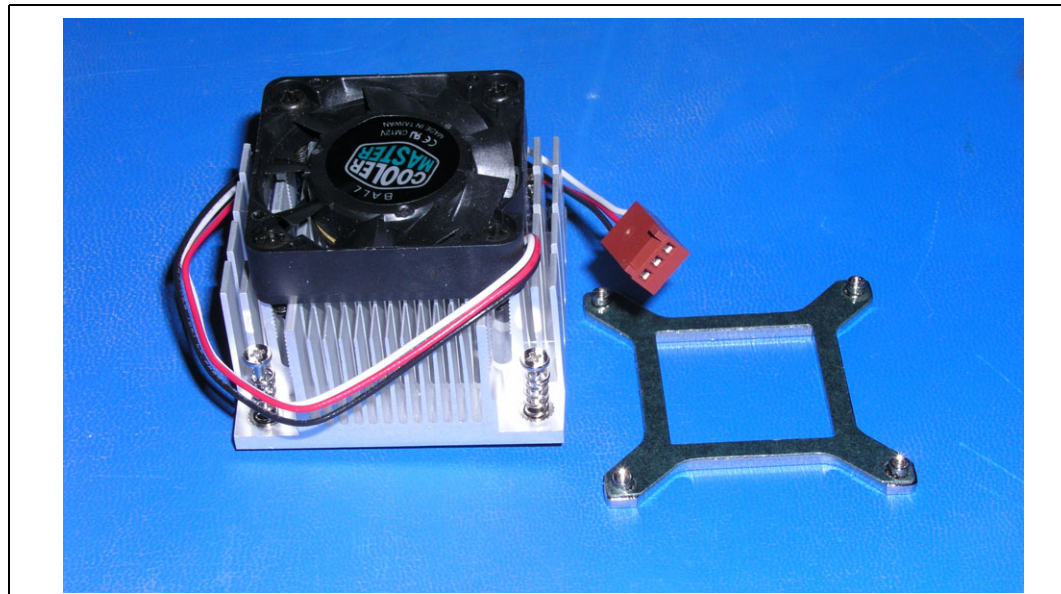
The volumetric constraint zone reserved for the processor package, 1U heatsink, and retention mechanism for the baseboard are shown in [Figure 28, “Page One \(of Two\) of the Volumetric Constraint Zone for the 1U Active Heatsink, ECU-PNA1C-35”](#) on page 45, [Figure 29, “Page Two \(of Two\) of the Volumetric Constraint Zone for the 1U Active Heatsink, ECU-PNA1C-35”](#) on page 46, and [Figure 30, “Overall Thermal Solution Volumetric Constraint Zone for the 1U Active Heatsink, ECU-PNA1C-35”](#) on page 47.

**Note:** The backside of the motherboard directly under the volumetric constraint zones defined below does not allow for any surface-mount components due to the backplate.

### 3.1.2 ECC-00060-01

The following active heatsink was developed to minimize footprint on the motherboard while still providing an effective means to dissipate heat from processors in the micro-FCPGA and micro-FCBGA packages. This is an aluminum heatsink that has approximate dimensions of 50 mm x 50 mm x 35.5 mm. This heatsink is too tall for 1U server applications but is a good fit for form factors that have the available height.

**Figure 21. Active Aluminum Heatsink, ECC-00060-01**



### 3.1.2.1 Thermal Performance

Thermal performance for the heatsink was verified with the Pentium M TTV. The heatsink is capable of cooling a Pentium M and Celeron M processor at 24.5 W with local ambient temperatures up to  $T_{LA} = 60\text{ }^{\circ}\text{C}$ . The performance of the thermal solution is a verification test only to ensure that the heatsink is performing within expectations. This test does not imply any statistical significance; it is up to system integrator to perform validation in the final intended system, including the heatsink, attach method, and thermal interface material.

**Table 7. Aluminum Active Heatsink Thermal Performance**

Thermal Performance ( $^{\circ}\text{C/W}$ )	$\Psi_{JA} = 1.62^{\circ}\text{C/W}$
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### 3.1.2.2 Mechanical Retention and Volumetric Constraint Zones

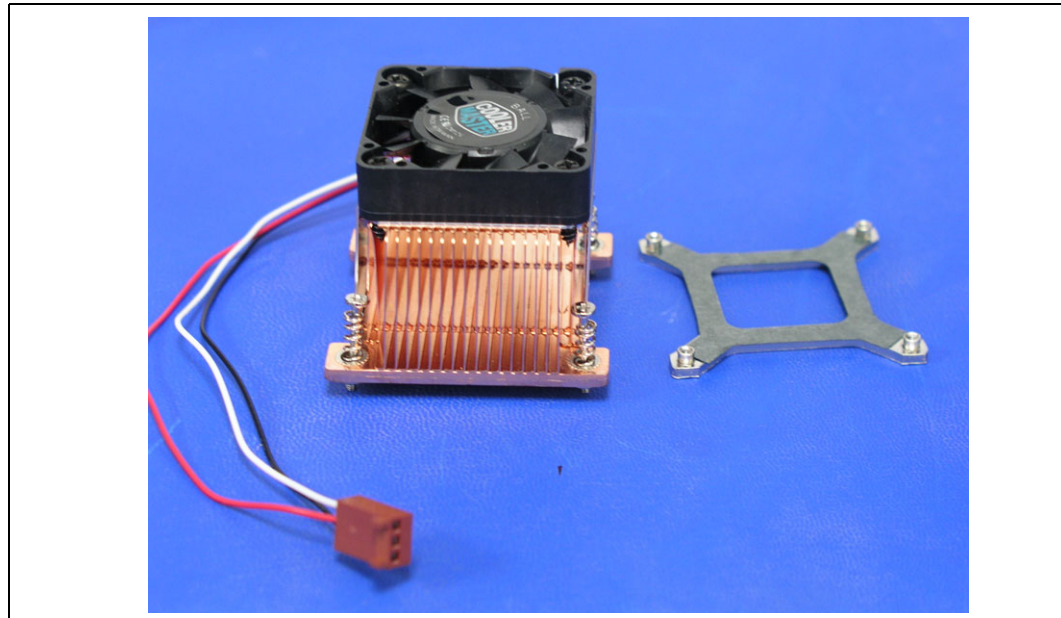
The active heatsink is attached to the motherboard using a backplate that is fastened to the motherboard by four screws. This attach method uses spring-loaded fasteners to apply an even load on the processor die. The backplate, when assembled, will be flush against the backside of the motherboard.

The volumetric constraint zone for this heatsink is shown in [Figure 31, “Active Heatsink Volumetric Constraint \(Primary Side\)”](#) on page 48 and [Figure 32, “Active Heatsink Volumetric Constraint Zone \(Secondary Side\)”](#) on page 49. [Figure 31](#) shows the primary side volumetric constraint for processors in the micro-FCPGA and micro-FCBGA packages. This drawing is based on the standard mobile Intel processor hole mounting pattern of 41 mm x 41 mm. [Figure 32](#) shows the secondary side volumetric constraint zone for backplate assembly. It is important to adhere to both the primary and secondary side volumetric constraint zones so that there will be no interference with the assembly of the heatsink onto the motherboard.

### 3.1.3 ECC-00061-01

The following active heatsink was developed to minimize footprint on the motherboard while still providing an effective means to dissipate heat from processors in the micro-FCPGA and micro-FCBGA packages. This is a copper heatsink that has approximate dimensions of 50 mm x 50 mm x 40.5 mm. This heatsink is too tall for 1U server applications but is a good fit for form factors that have the available height.

Figure 22. Active Copper Heatsink, ECC-00061-01



### 3.1.3.1 Thermal Performance

Thermal performance for the heatsink was verified with the Pentium M TTV. The heatsink is capable of cooling a Pentium M and Celeron M processor at 24.5 W with local ambient temperatures up to  $T_{LA} = 67^{\circ}\text{C}$ . The performance of the thermal solution is a verification test only to ensure that the heatsink is performing within expectations. This test does not imply any statistical significance; it is up to system integrator to perform validation in the final intended system, including the heatsink, attach method, and thermal interface material.

Table 8. Active Copper Heatsink Thermal Performance

Thermal Performance ( $^{\circ}\text{C/W}$ )	$\Psi_{JA} = 1.35^{\circ}\text{C/W}$
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### 3.1.3.2 Mechanical Retention and Volumetric Constraint Zones

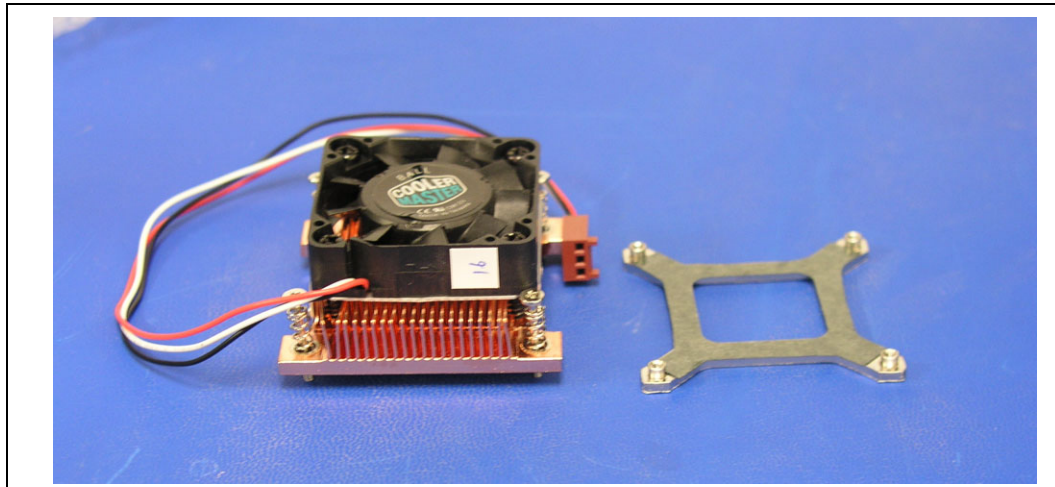
The active heatsink is attached to the motherboard using a backplate that is fastened to the motherboard by four screws. This attach method uses spring-loaded fasteners to apply an even load on the processor die. The backplate, when assembled, will be flush against the backside of the motherboard.

The volumetric constraint zone for this heatsink is shown in [Figure 31, “Active Heatsink Volumetric Constraint \(Primary Side\)”](#) on page 48 and [Figure 32, “Active Heatsink Volumetric Constraint Zone \(Secondary Side\)”](#) on page 49. [Figure 31](#) shows the primary side volumetric constraint zone, including processors in the micro-FCPGA and micro-FCBGA packages. This drawing is based on the standard mobile Intel processor hole mounting pattern of 41 mm x 41 mm. [Figure 32](#) shows the secondary side volumetric constraint zone for backplate assembly. It is important to adhere to both the primary and secondary side volumetric constraint zones so that there will be no interference with the assembly of the heatsink onto the motherboard.

### 3.1.4 ECC-00076-01

The following active heatsink was developed to minimize footprint on the motherboard while still providing an effective means to dissipate heat from processors in the micro-FCPGA and micro-FCBGA packages. This is a copper heatsink that has approximate dimensions of 50 mm x 50 mm x 23 mm. This heatsink is ideal for 1U or larger form factors that require the use of an active fansink.

Figure 23. Copper Active Heatsink, ECC-00076-01



#### 3.1.4.1 Thermal Performance

Thermal performance for the heatsink was verified with the Pentium M TTV. The heatsink is capable of cooling a Pentium M and Celeron M processor at 24.5 W with local ambient temperatures up to  $T_{LA} = 59^{\circ}\text{C}$ . The performance of the thermal solution is a verification test only to ensure that the heatsink is performing within expectations. This test does not imply any statistical significance; it is up to system integrator to perform validation in the final intended system, including the heatsink, attach method, and thermal interface material.

Table 9. Copper Active Heatsink Thermal Performance

Thermal Performance ( $^{\circ}\text{C/W}$ )	$\Psi_{JA} = 1.67^{\circ}\text{C/W}$
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#### 3.1.4.2 Mechanical Retention and Volumetric Constraint Zones

The active heatsink is attached to the motherboard using a backplate that is fastened to the motherboard by four screws. This attach method uses spring loaded fasteners to apply an even load on the processor die. The backplate, when assembled, will be flush against the backside of the motherboard.

The volumetric constraint zone for this heatsink is shown in [Figure 31, “Active Heatsink Volumetric Constraint \(Primary Side\)”](#) on page 48 and [Figure 32, “Active Heatsink Volumetric Constraint Zone \(Secondary Side\)”](#) on page 49. [Figure 31](#) shows the primary side volumetric constraint zone, including processors in the micro-FCPGA and micro-FCBGA packages. This drawing is based on the standard mobile Intel processor hole mounting pattern of 41 mm x 41 mm. [Figure 32](#) shows the secondary side volumetric constraint zone for backplate assembly. It is important to adhere to both the primary and secondary side volumetric constraint zones so that there will be no interference with the assembly of the heatsink onto the motherboard.

## 3.2 Thermal Interface Material and Considerations

The CoolerMaster active heatsinks are delivered with preapplied thermal interface material. This material, Powerstrate\* 51, manufactured by Power Devices, Inc., is a phase-change thermal interface material. This implies the material will change properties at elevated temperatures to increase thermal performance. This phase change must be accounted for when testing the CoolerMaster active heatsink. At low temperatures, the heatsink performance will be significantly degraded, but at elevated junction temperatures, the material will change phase and improve in performance. For more information, see the Power Devices website at: <http://www.powerdevices.com>.

## 4.0 Vendor Data

The following table lists the vendors and contact information for the parts referenced in this document.

**Table 10. Vendor Contact Information**

Supplier	Contact	Phone	Email	Components
Cooler Master 9F., No. 786, Chung-Cheng Rd. Chung Ho City Taipei Hsien, Taiwan, R.O.C	Wendy Lin	886-2-3234-0050 ext. 333	<a href="mailto:wendy@coolermaster.com">wendy@coolermaster.com</a>	<ul style="list-style-type: none"> <li>Extruded Aluminum Heat Sink, Reference No. EID-BAN15-ALX-003SS and EID-LPT13-ALX-003</li> <li>Copper Base, Aluminum Snap Fin Heat Sink, Reference No. EID-BAN24-CU/ALC-001SS and EID-BAN24-CU/ALC-002SS</li> <li>Active Heatsink, Part Number: ECU-PNA1C-35, ECC-00060-01, ECC-00061-01, ECC-00076-01</li> </ul>
Pencom Engineering Solutions 1300 Pioneer St., Suite E Brea, CA 92821	Steve Blank	562-694-4477	<a href="mailto:steve@pencomsf.com">steve@pencomsf.com</a>	<ul style="list-style-type: none"> <li>Extruded Aluminum Heat Sink, Reference No. EID-BAN15-ALX-003SS and EID-LPT13-ALX-003</li> <li>Heatsink Mounting Fasteners (Pencom P/N PL1664-65)</li> </ul>
Fujikura America Inc. 3001 Oakmead Village Dr. Santa Clara, CA 95051-0811	Ash Ooe	408-748-6991	<a href="mailto:a_ooe@fujikura.com">a_ooe@fujikura.com</a>	<ul style="list-style-type: none"> <li>Extruded Aluminum Heat Sink, Reference No. EID-BAN15-ALX-003SS and EID-LPT13-ALX-003</li> <li>Copper Base, Aluminum Snap Fin Heat Sink, Reference No. EID-BAN24-CU/ALC-001SS and EID-BAN24-CU/ALC-002SS</li> </ul>
Shin-Etsu Micro Si, Inc. 10028 S. 51st St. Phoenix, AZ 85044		(480) 893-8898	<a href="http://www.microsi.com">http://www.microsi.com</a>	Thermal Interface Material (ShinEtsu PN G751)
Power Devices Inc. 26941 Cabot Rd., Bldg. 124 Laguna Hills, CA 92653		(949) 582-6712	<a href="http://www.powerdevices.com">http://www.powerdevices.com</a>	Thermal Interface Material (Powerstrate® 51)



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## **Appendix A Heatsink Mechanical Drawings**

*Note:* Mechanical drawings are shown on the following pages.



Figure 24. Intel® Pentium® M and Celeron® M Processors in the Micro-FCBGA Package—Copper Base, Aluminum Snap Fin Heatsink #1

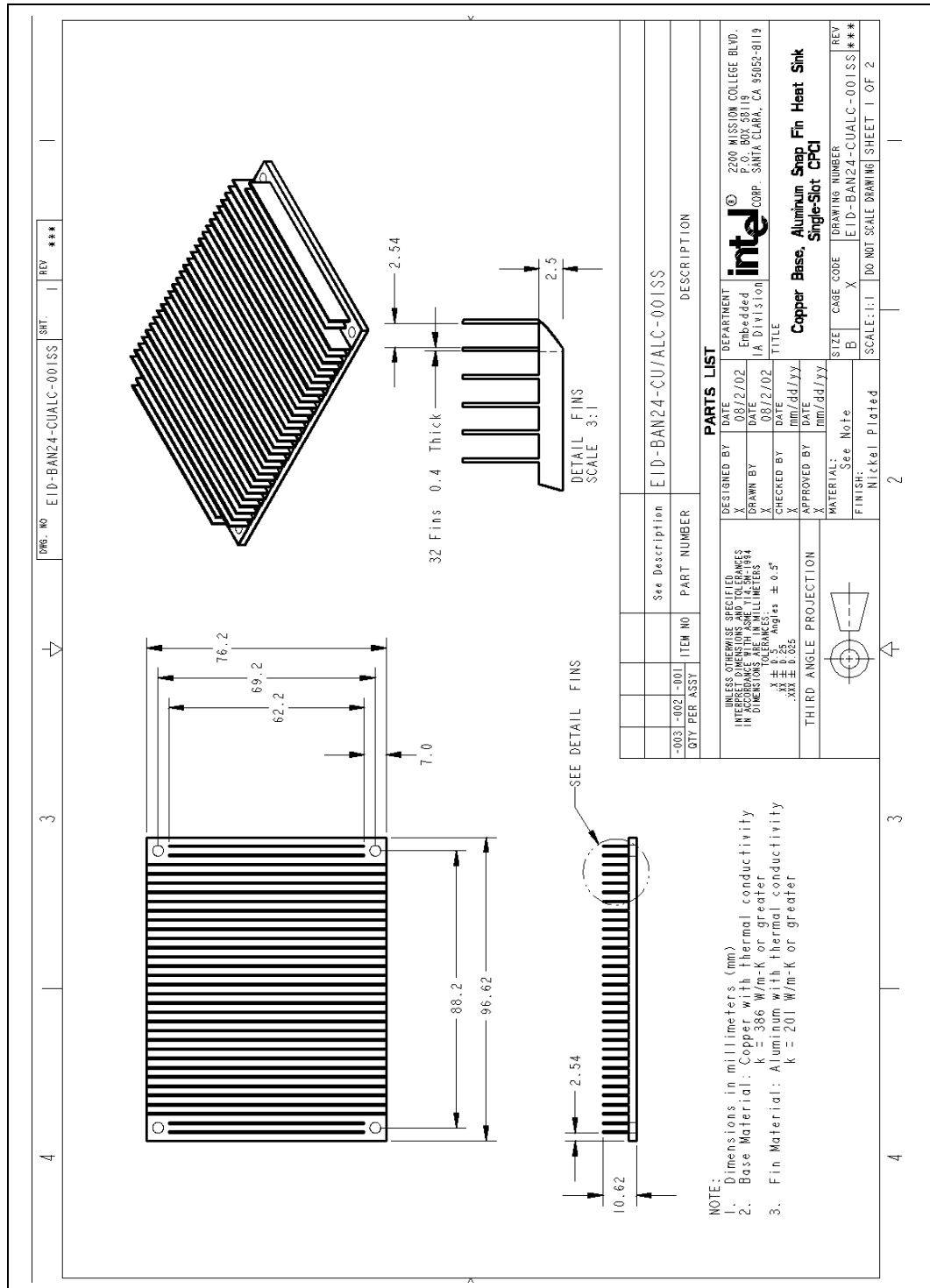


Figure 25. Intel® Pentium® M and Celeron® M Processors in the Micro-FCPGA Package—Copper Base, Aluminum Snap Fin Heatsink #2

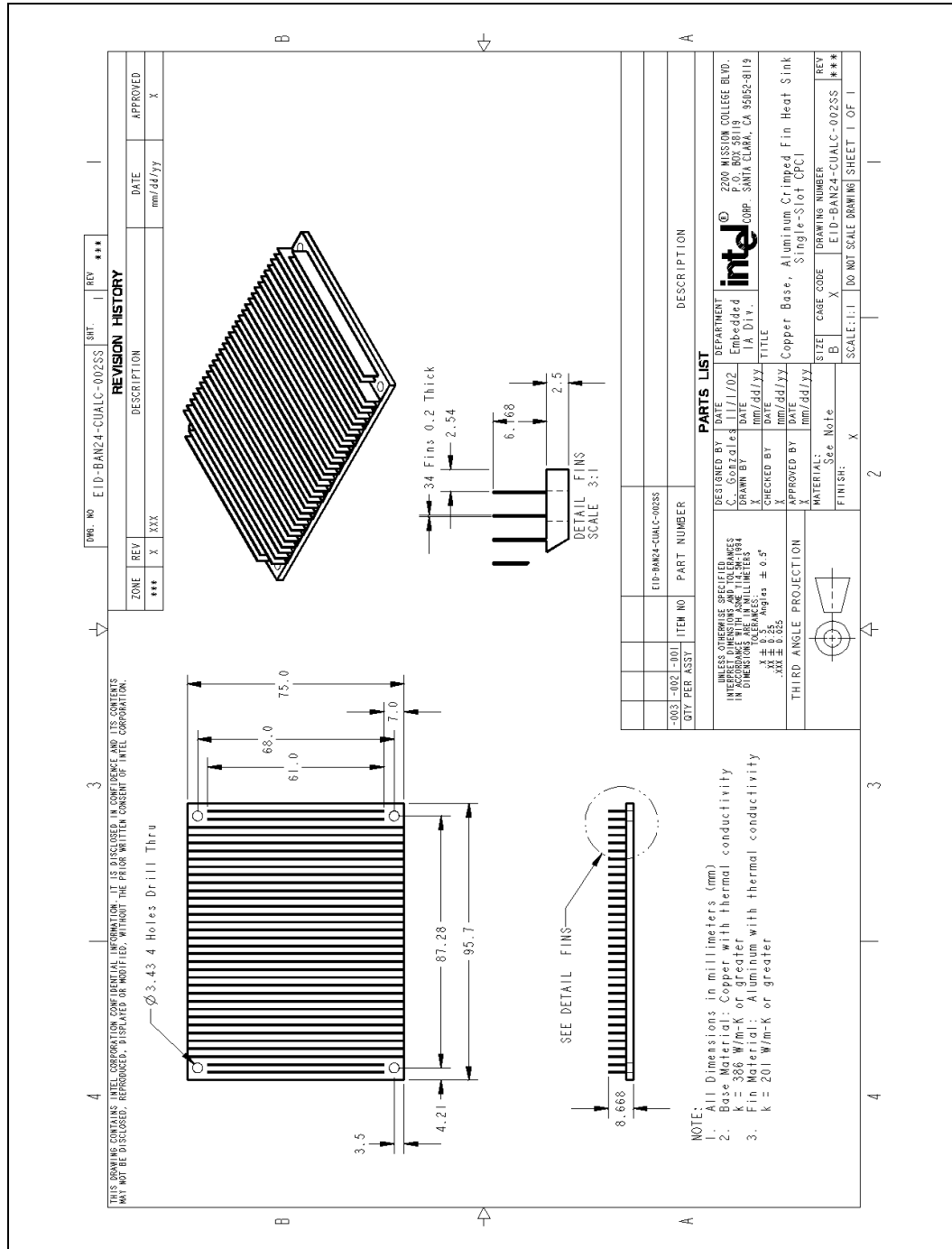


Figure 26. Low Voltage Intel® Pentium® M Processor—Extruded Aluminum Heatsink #1

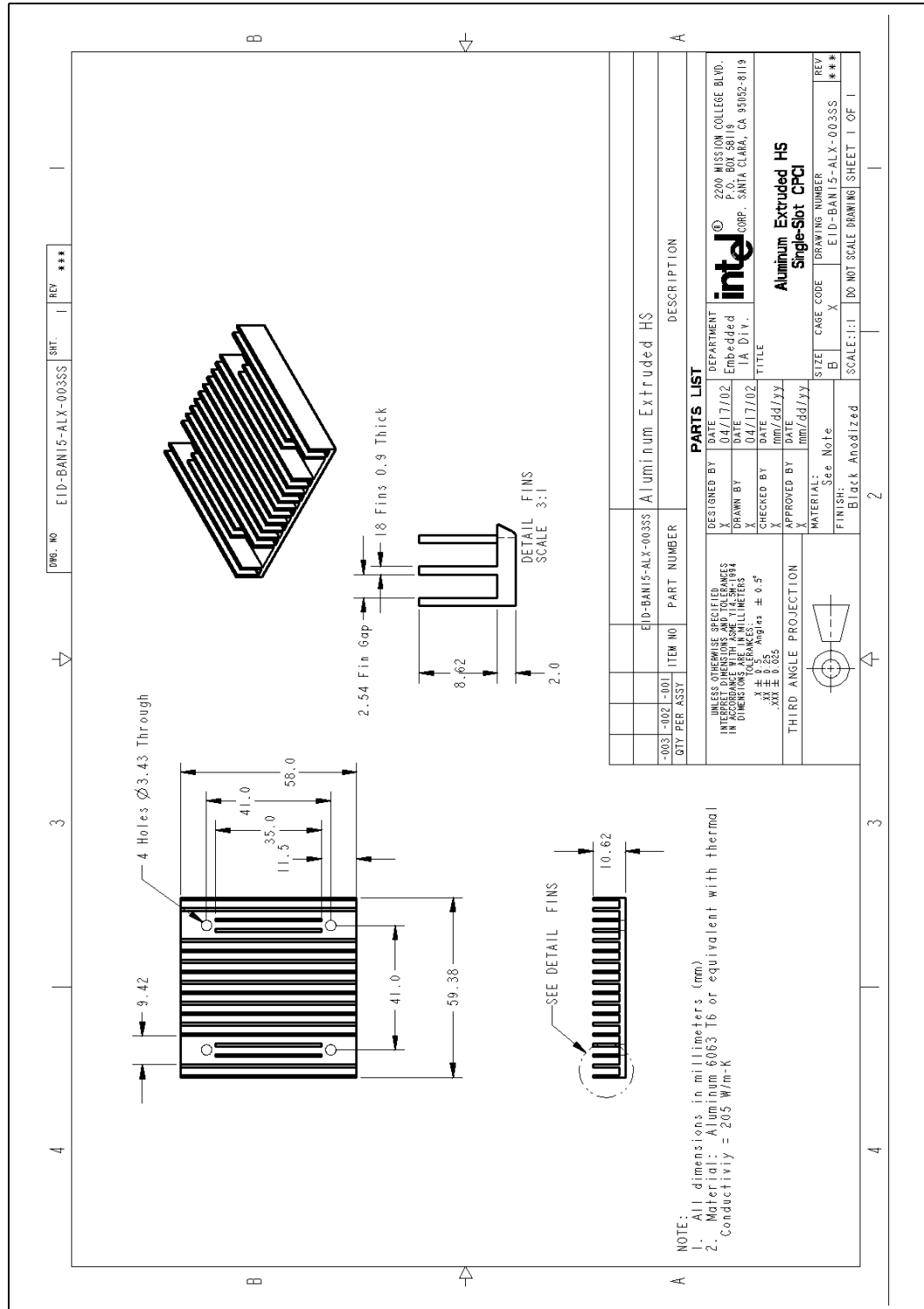


Figure 27. Low Voltage Intel® Pentium® M Processor—Extruded Aluminum Heatsink #2

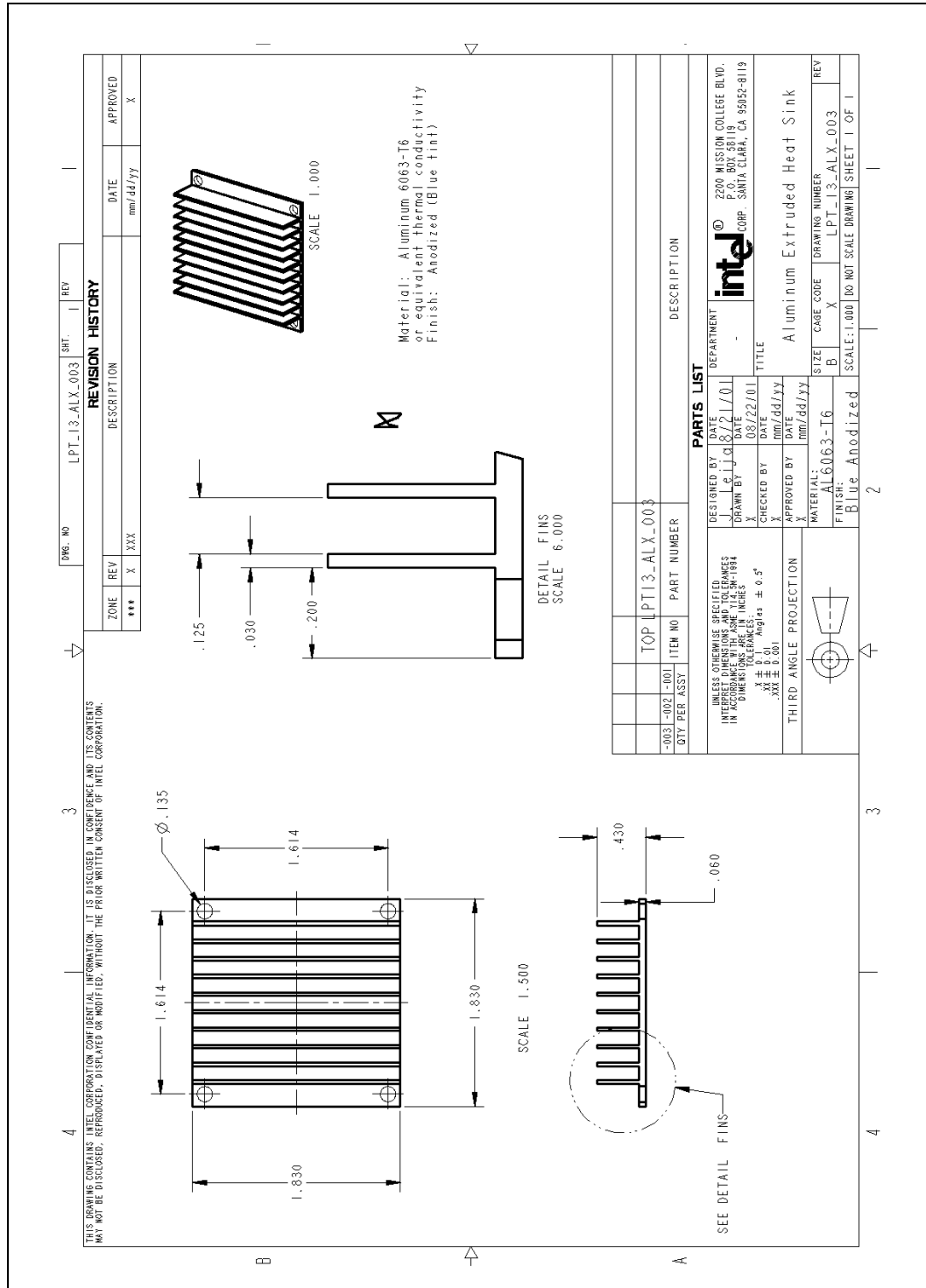


Figure 28. Page One (of Two) of the Volumetric Constraint Zone for the 1U Active Heatsink, ECU-PNA1C-35

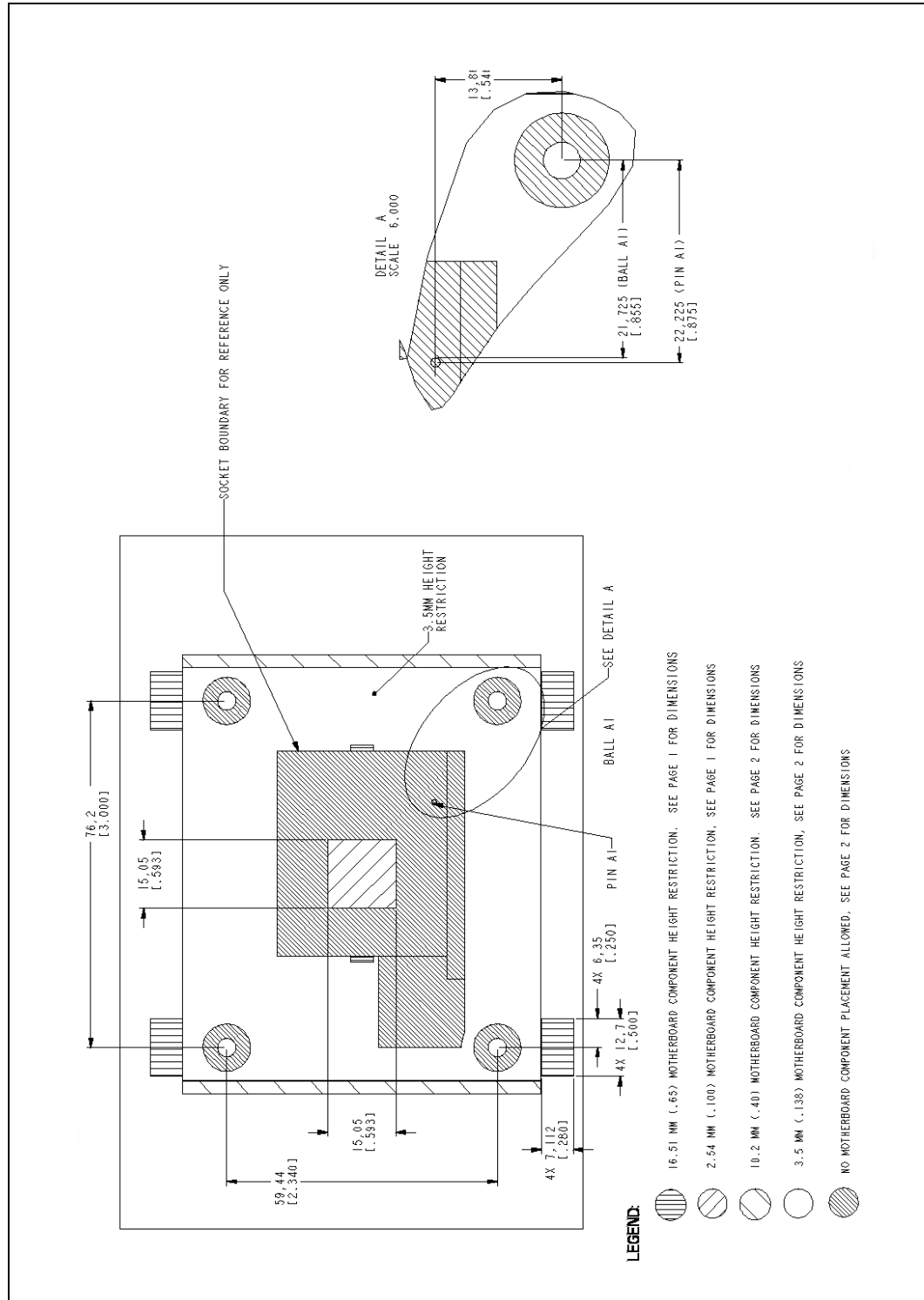


Figure 29. Page Two (of Two) of the Volumetric Constraint Zone for the 1U Active Heatsink, ECU-PNA1C-35

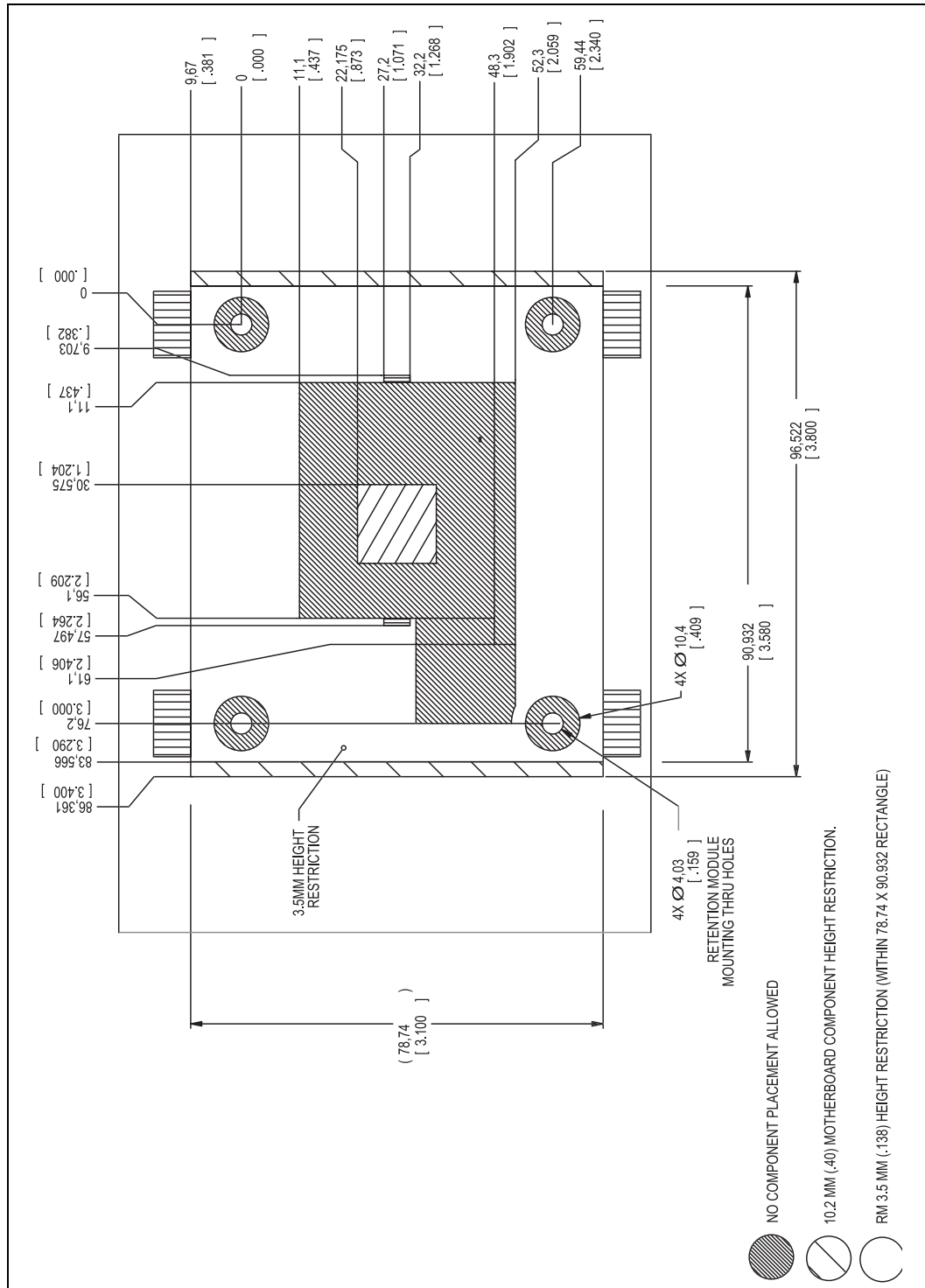


Figure 30. Overall Thermal Solution Volumetric Constraint Zone for the 1U Active Heatsink, ECU-PNA1C-35

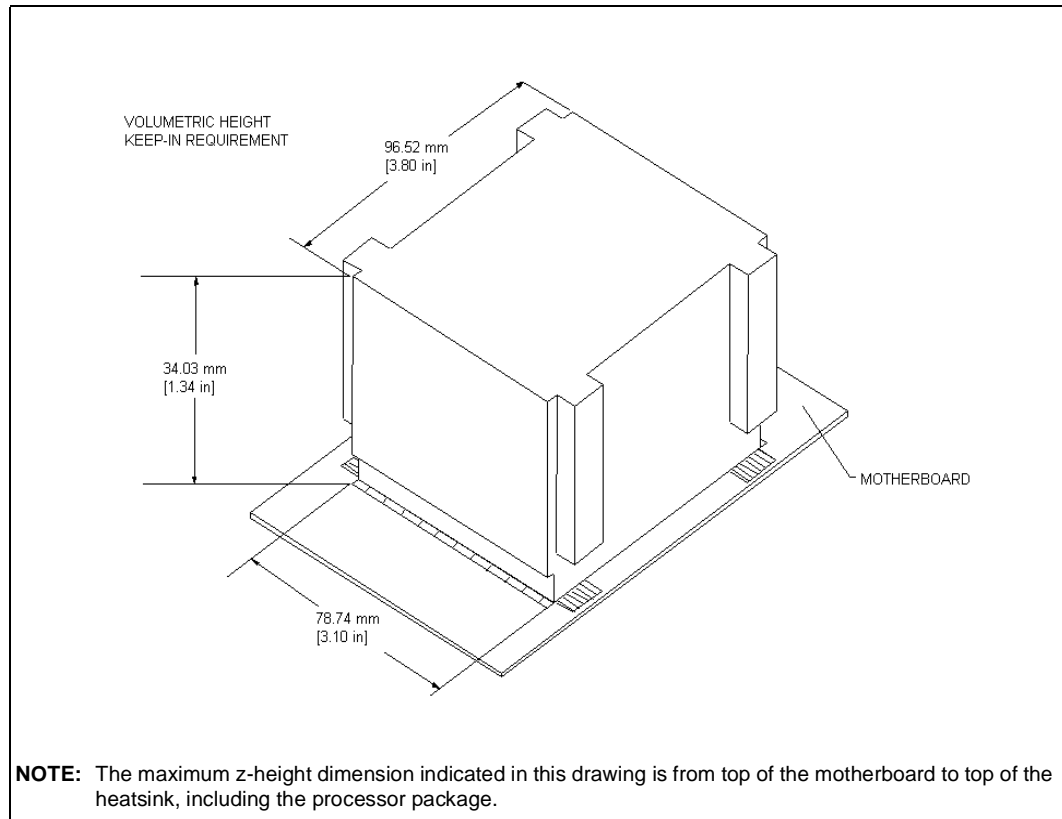


Figure 31. Active Heatsink Volumetric Constraint (Primary Side)

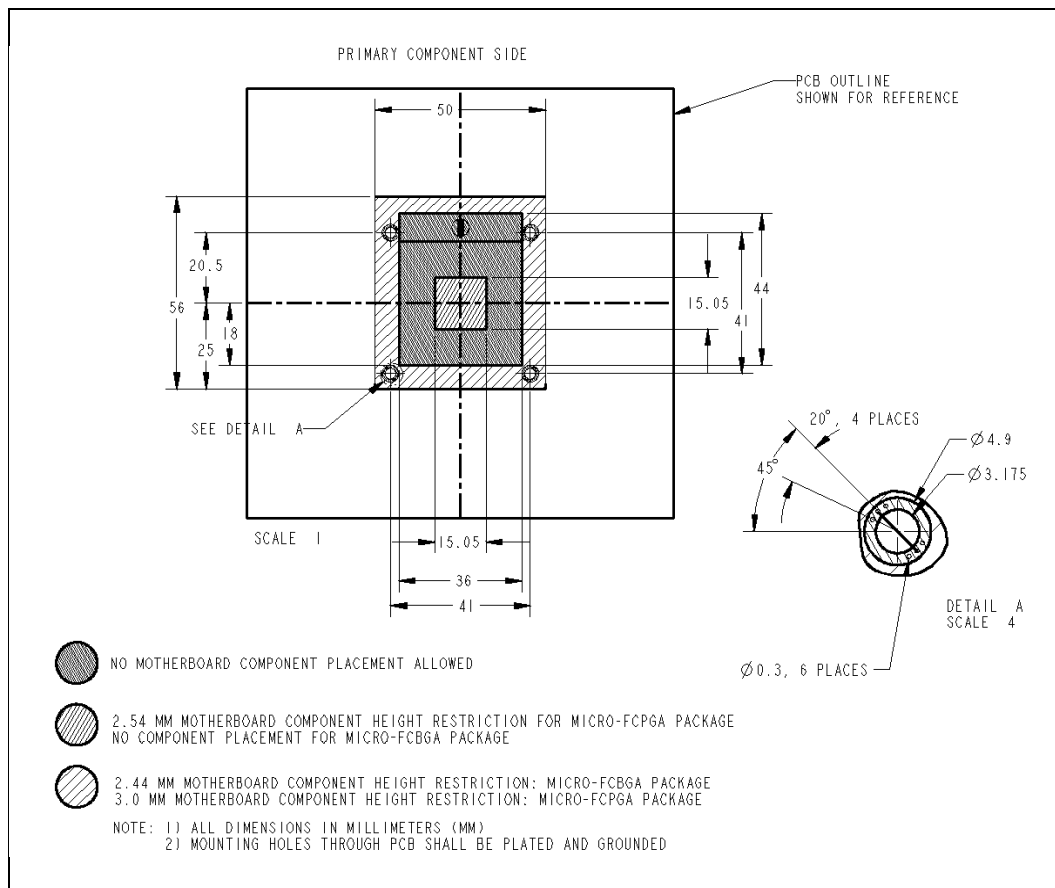




Figure 32. Active Heatsink Volumetric Constraint Zone (Secondary Side)

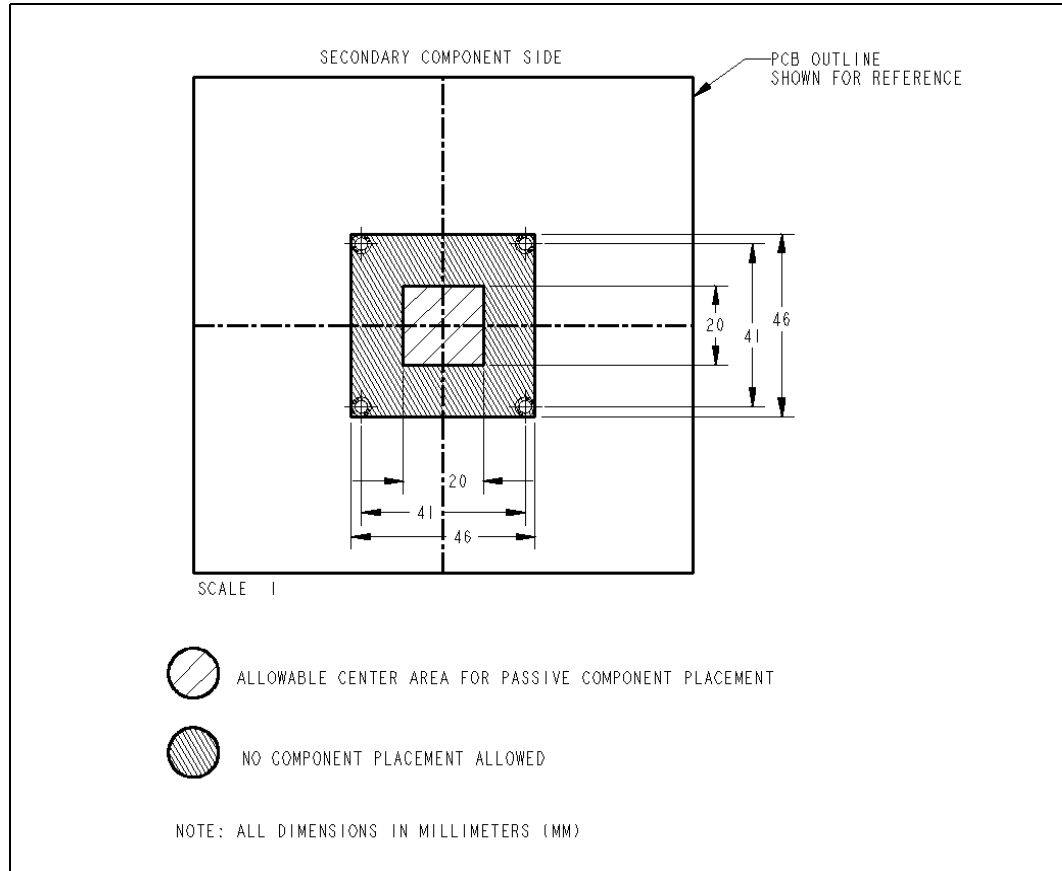
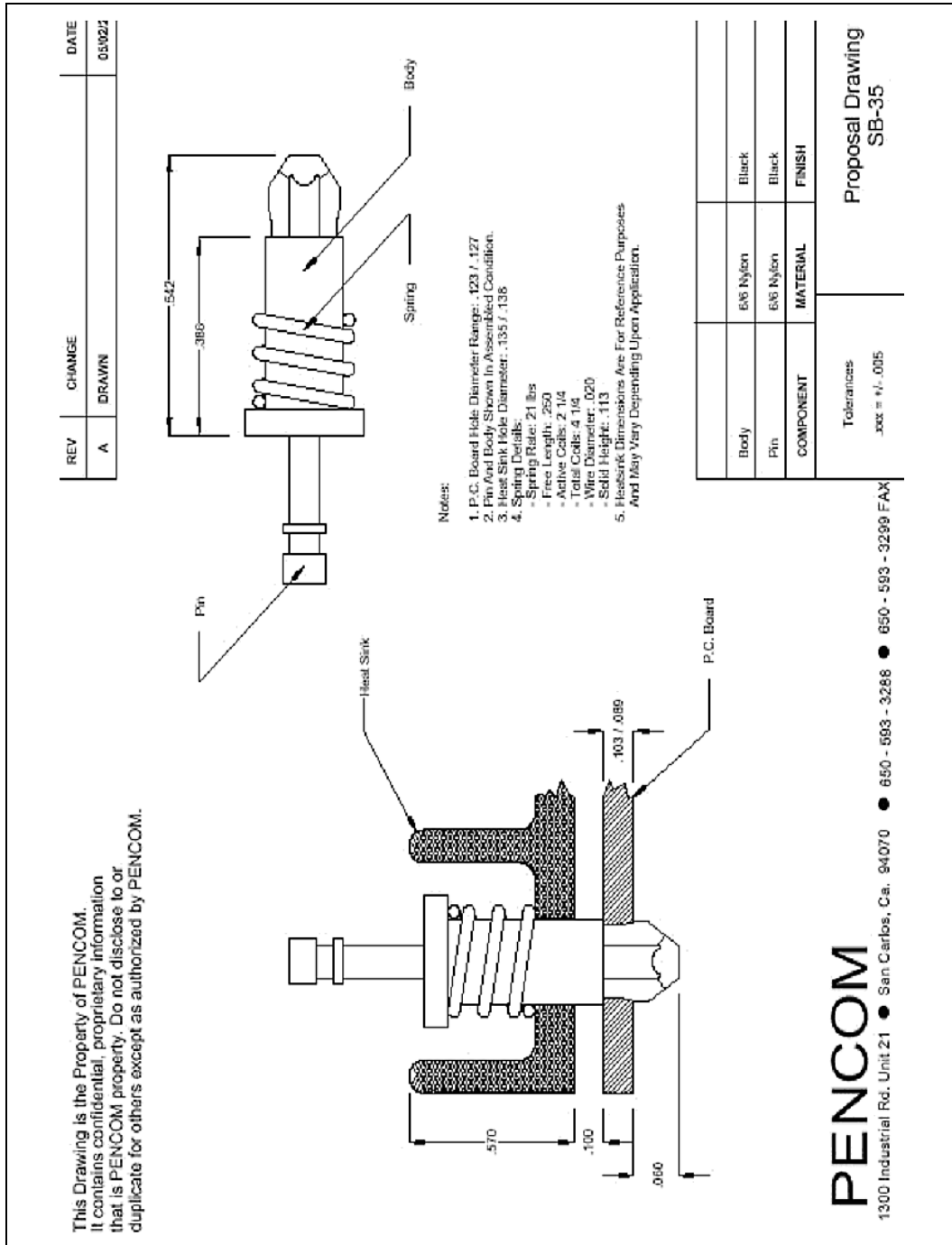


Figure 33. Fastener (Used by Permission of Pencom\*, Inc.)





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