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Intel® Pentium® M Processor on 90 nm process with 2-MB L2 Cache for Embedded Applications

Thermal Design Guide

February 2006

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Revision History

Date	Revision	Description
June 2004	001	Initial public release of this document
August 2004	002	Added support for Low Voltage Intel® Pentium® M processor.
February 2006	003	Changed these names: • ECC-0060-01 to EEPN41ES-02 and EEB-N42ES-02 • ECC-00061-01 to EEP-N41CS-01 and EEB-N41CS-01 • ECC-00076-01 to EEP-N41SS-01 and EEB-N41SS-01

1.0   Introduction

This document describes thermal design guidelines for the Intel® Pentium® M Processor on 90 nm Process with 2 MB L2 Cache and 400 MHz Front Side Bus in the Micro Flip Chip Ball Grid Array (micro-FCBGA) package and the Micro Flip Chip Pin Grid Array (micro-FCBGA) package. Detailed mechanical and thermal specifications for this processor may be found in the Intel® Pentium® M Processor *on 90 nm Process with 2 MB L2 Cache Datasheet*.

The information provided in this document is for reference only and additional validation must be performed prior to implementing the thermal designs into final production. The intent of this document is to assist 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 Processor and provides guidelines for meeting the thermal requirements imposed on uni-processor 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 the thermal management techniques for the Intel® Pentium® M Processor, specifically in embedded computing applications. The physical dimensions and power numbers used in this document are for reference only. Please refer to the processor's datasheet for the product dimensions, thermal power dissipation, and maximum 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

Title	Number
Intel® Pentium® M Processor on 90 nm Process with 2 Mb L2 Cache Datasheet	302189
Intel Mobile Processor Micro-FCPGA Socket (mPGA479M) Design Guidelines	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
Ψ_{JA}	The thermal resistance between the processor's junction and the ambient air. This is defined and controlled by the system thermal solution.
Ψ_{JS}	The junction to sink thermal resistance, which is dependent on the thermal interface material. Also referred to as Ψ_{TIM}.
$T_{junction}$	The measured junction temperature of the processor. Also referred to as T_j.
$T_{junction-max}$	The maximum junction temperature of the processor, as specified in the processor datasheet. Also referred to as T_{j-max}.
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 Guidelines

The thermal solutions presented in this document were designed to fit within the maximum component height allowed by certain embedded form factor specifications, including the 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 Processor is 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-FCBGA) package technology. Detailed mechanical specifications for the processor may be obtained from the processor datasheet.

Figure 1, Figure 2 and Figure 3 show different views of the micro-FCBGA package; dimensions are provided in Table 3. Figure 4, Figure 5 and Figure 6 show different views of the micro-FCPGA package; dimensions in Table 4. Refer to the Intel® Pentium® M Processor *on 90 nm Process with 2-MB L2 Cache Datasheet* for detailed information.

The micro-FCBGA package may have capacitors placed in the area surrounding the die. Since 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

PACKAGE KEEPOUT

CAPACITOR AREA

LABEL   DIE

TOP VIEW   BOTTOM VIEW
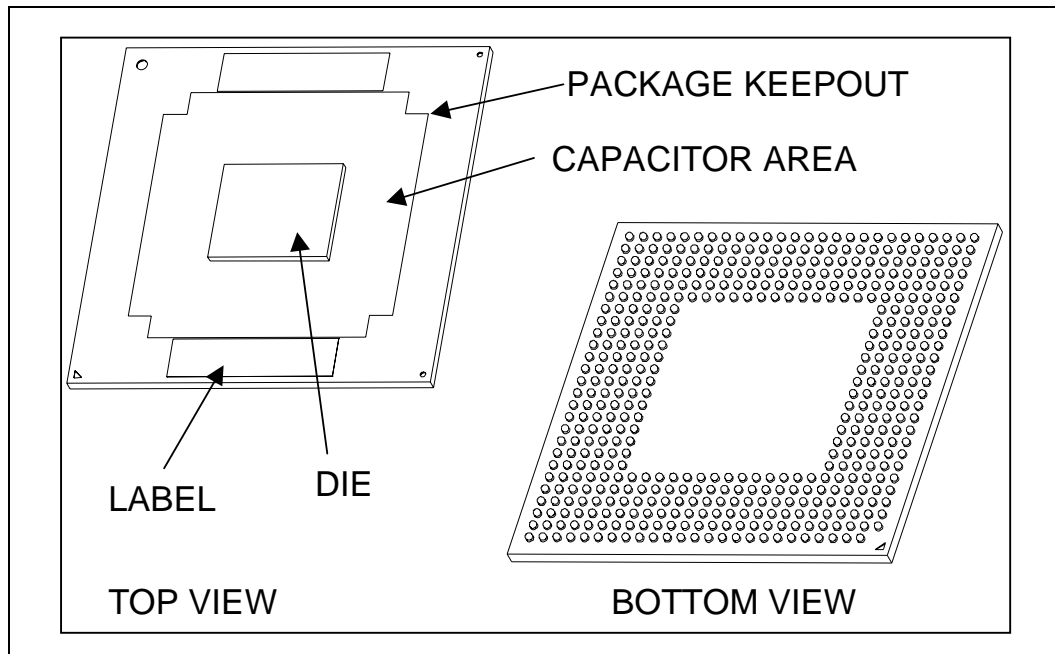
Figure 2.   Micro-FCBGA Package Top and Side View

7 (K1)
8 places

5 (K)
4 places

SUBSTRATE KEEPOUT ZONE
DO NOT CONTACT PACKAGE
INSIDE THIS LINE

0.20

A

A2

D1

35 (D)

Ø 0.78 (b)
479 places

E1

K2

35 (E)

PIN A1 CORNER

NOTE: All dimensions in millimeters. The die is entered on the package. Values shown for reference only.
Refer to Table 3 for details.
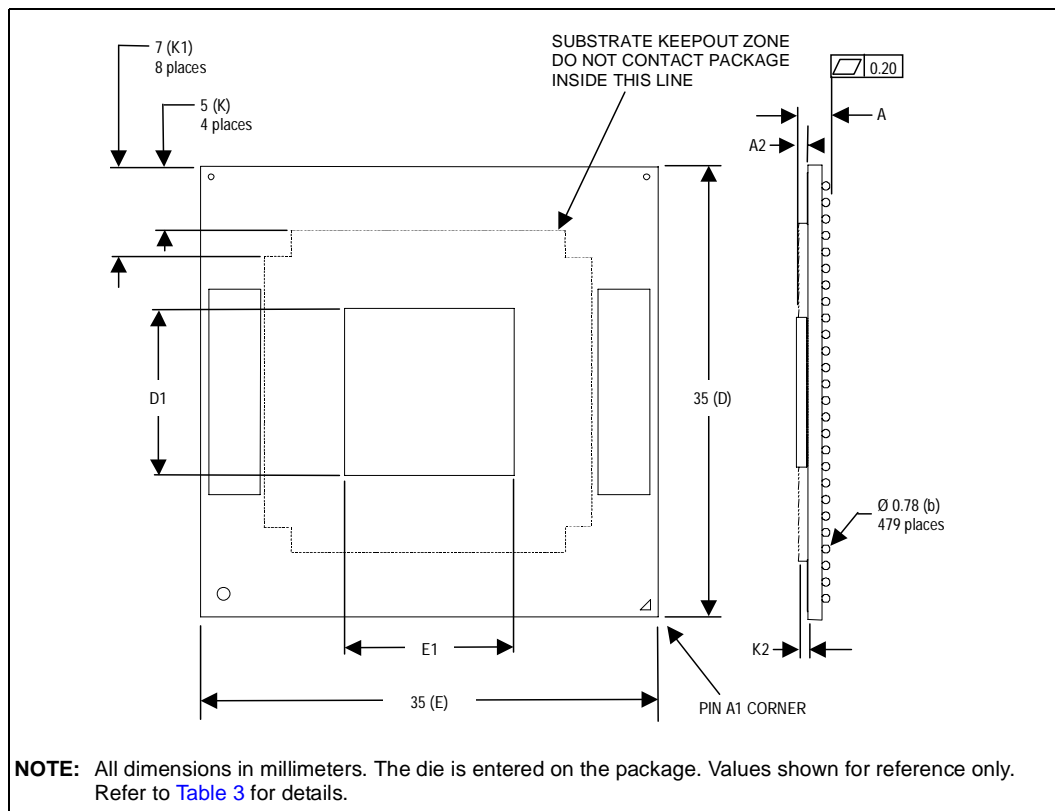
Table 3.   Micro-FCBGA Package Dimensions

Symbol	Parameter	Min	Max	Unit
A	Overall height, as delivered (Refer to Note 1.)	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	12.54		mm
E1	Die width	6.99		mm
e	Ball pitch	1.27		mm
K	Package edge keep-out	5		mm
K1	Package corner keep-out	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 co-planarity	0.2		mm
Pdie	Allowable pressure on the die for thermal solution	-	689	kPa
W	Package weight	4.5		g

NOTE:
1. 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

NOTE: All dimensions in millimeters. Values shown for reference only. Refer to Table 3 for details.

Figure 4.   Micro-FCPGA Package Top and Bottom Isometric View

PACKAGE KEEPOUT

CAPACITOR AREA

DIE

LABEL

TOP VIEW
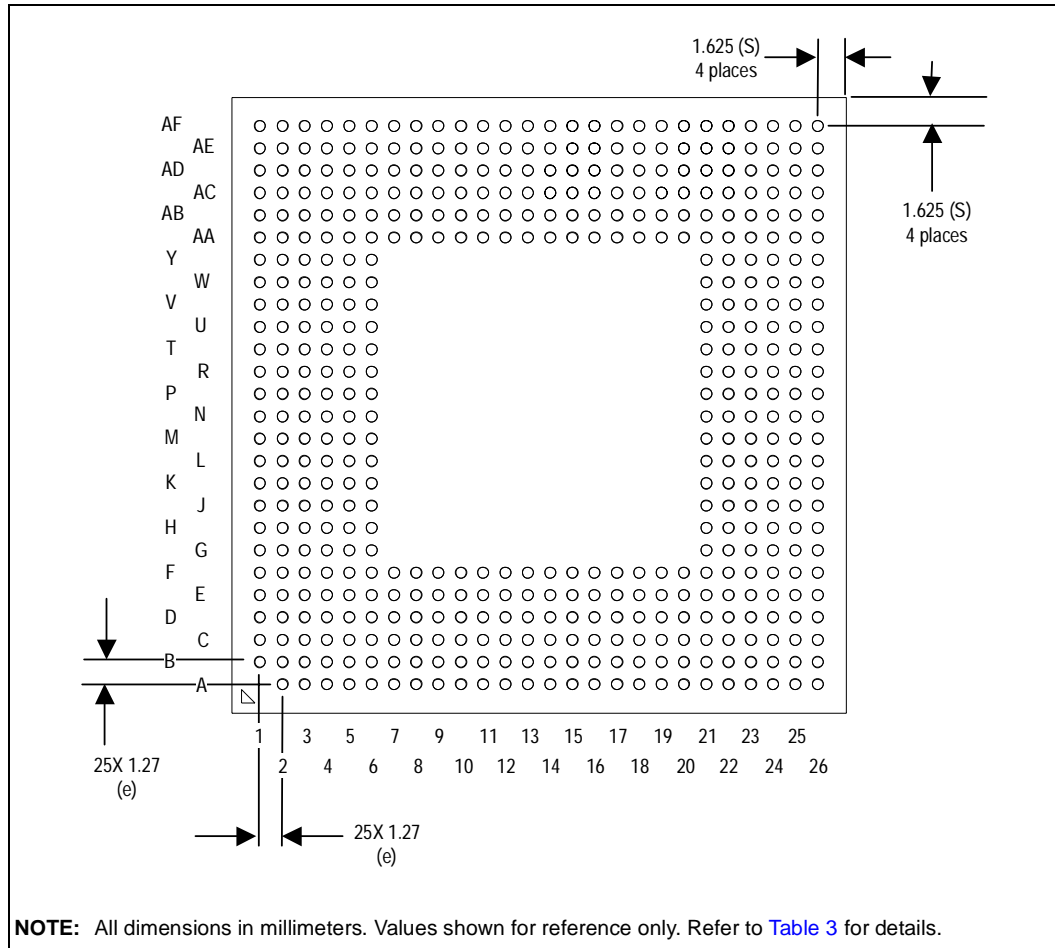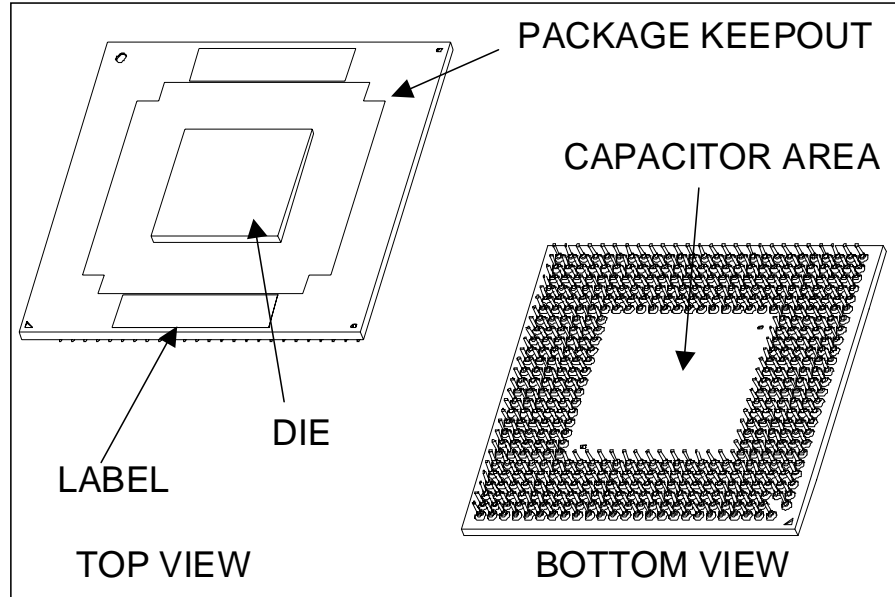
BOTTOM VIEW

Figure 5.   Micro-FCPGA Package - Bottom View

NOTE: All dimensions are in millimeters. Values shown for reference only. Refer to Table 4 for details.
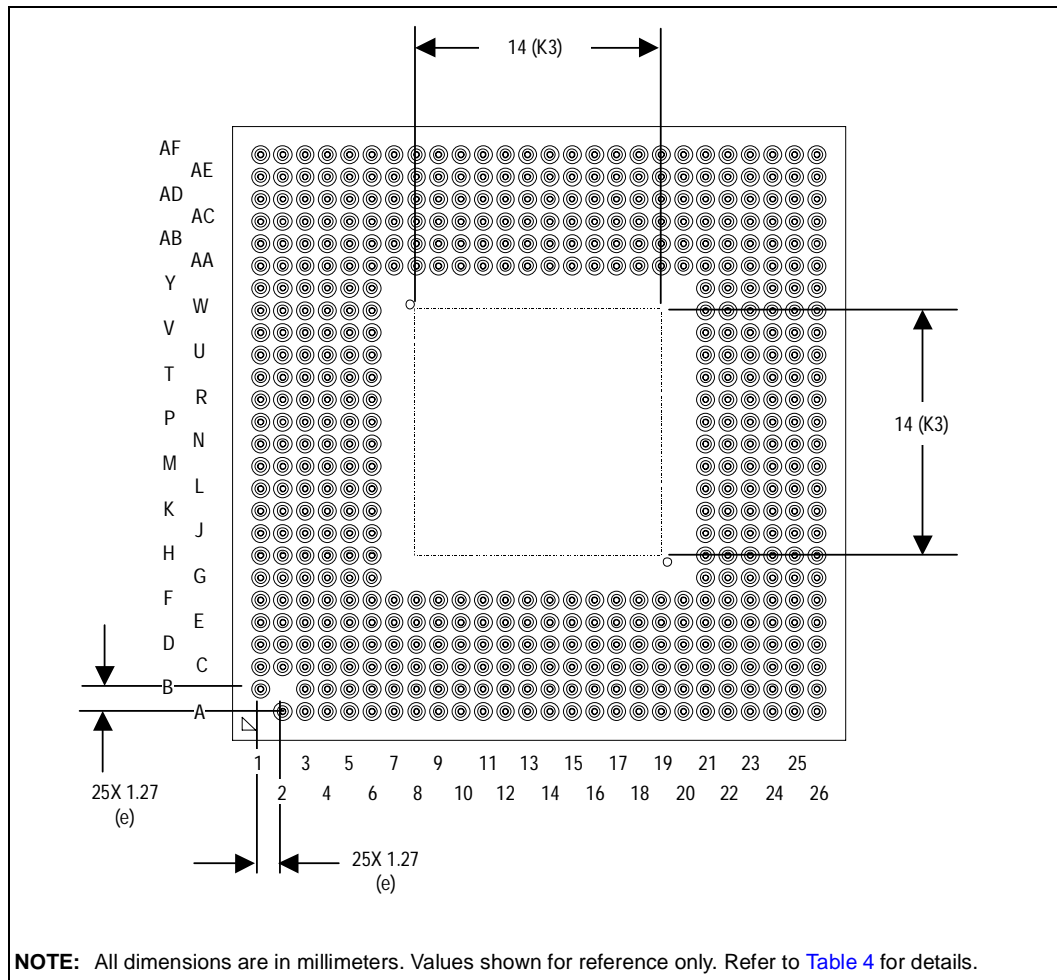
Figure 6.   Micro-FCPGA Package - Top and Side View

NOTE: All dimensions are in millimeters. The die is centered on the package. Values shown for reference only. Refer to Table 4 for details.
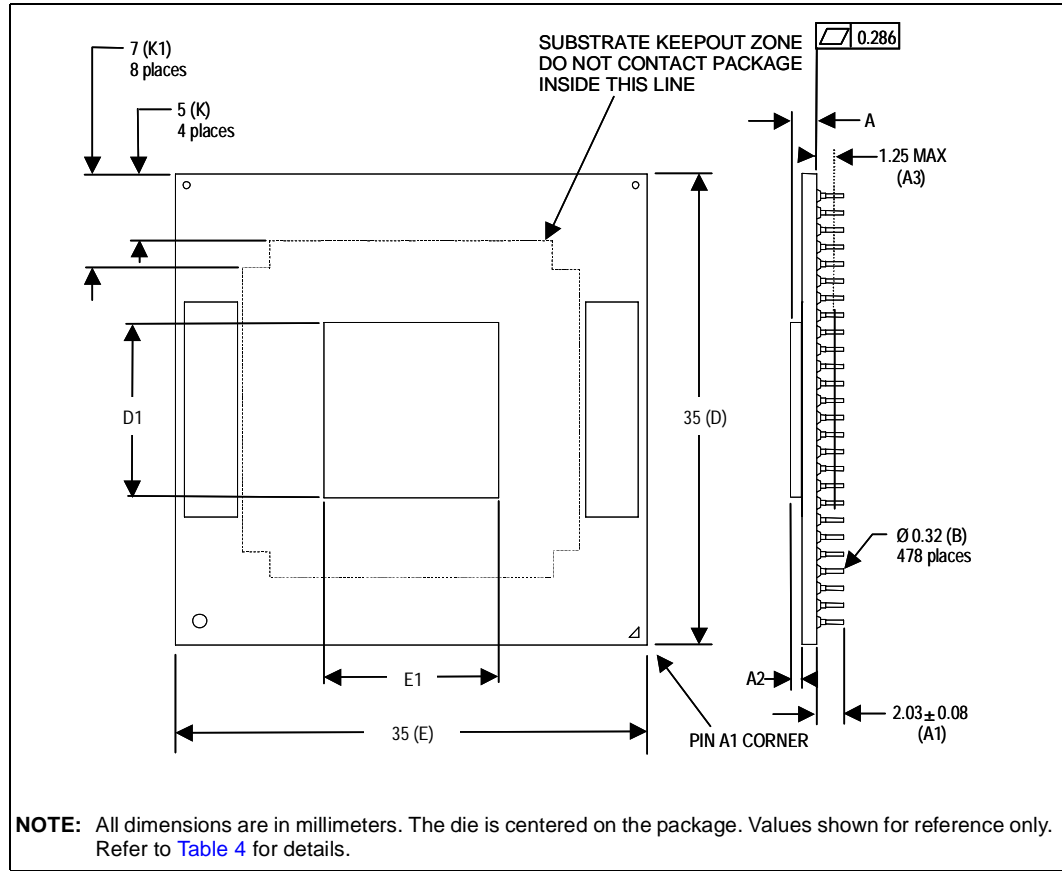
Table 4.   Micro-FCPGA Package Dimensions

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 (Refer to Note 1.)	4.74	5.16	mm
A1	Pin length	1.95	2.11	mm
A2	Die height	0.820		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	12.54		mm
E1	Die width	6.99		mm
e	Pin pitch	1.27		mm
K	Package edge keep-out	5		mm
K1	Package corner keep-out	7		mm
K3	Pin-side capacitor boundary	14		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

NOTE:
1. 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.

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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 7, Figure 8 and Figure 9. There are multiple zones depending on which processor is being used:

- Low Voltage Intel® Pentium® M Processor
- Intel® Pentium® M Processor processor in the micro-FCBGA package
- Intel® Pentium® M Processor in the micro-FCPGA package

The volumetric constraint zone for the Intel® Pentium® M Processor for the third-party vendor enabled heatsinks are shown in Figure 26 through Figure 27. Figure 10 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 11 shows the Intel® Pentium® M Processor in the micro-FCPGA package in a single-slot CompactPCI* form factor. Figure 12 shows the mechanical stack-up in the 1U form factor.

Figure 7.   Recommended PCB Volumetric Constraint Zone for Low Voltage Intel® Pentium® M Processor in the Single-slot CompactPCI* Form Factor

Figure 8. **Single-slot CompactPCI* Form Factor Recommended PCB Volumetric Constraint Zone for the Intel® Pentium® M Processor in the micro-FCBGA Package**
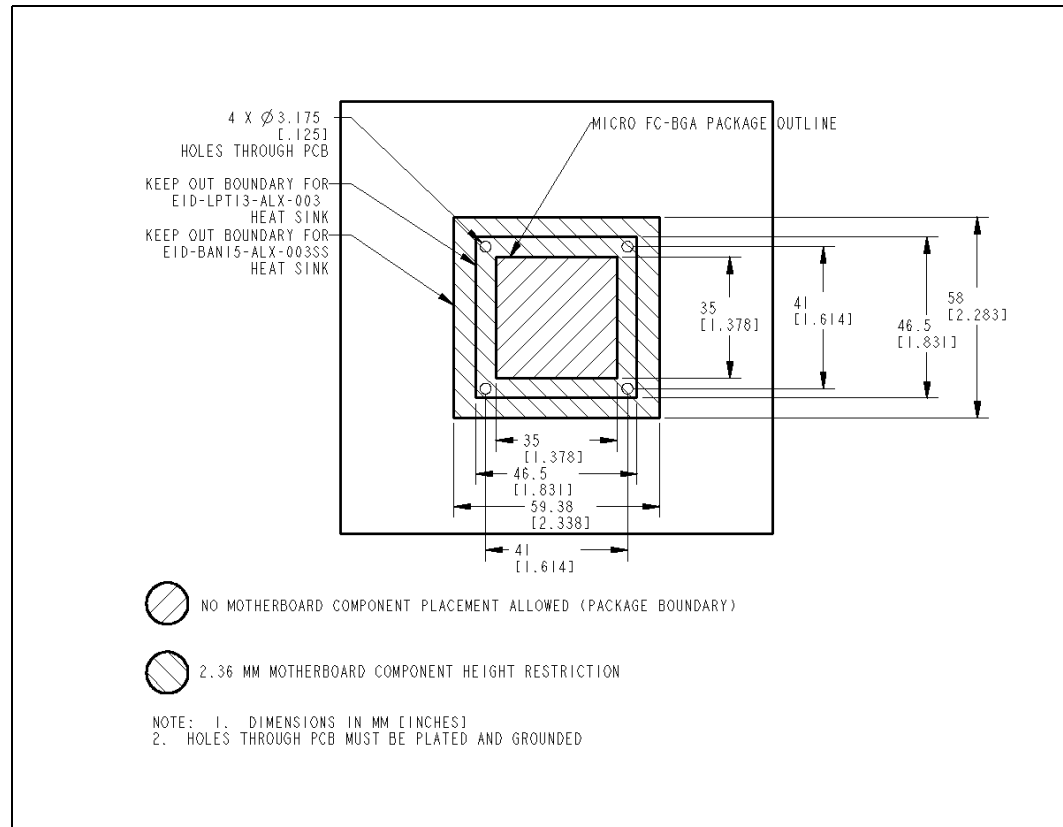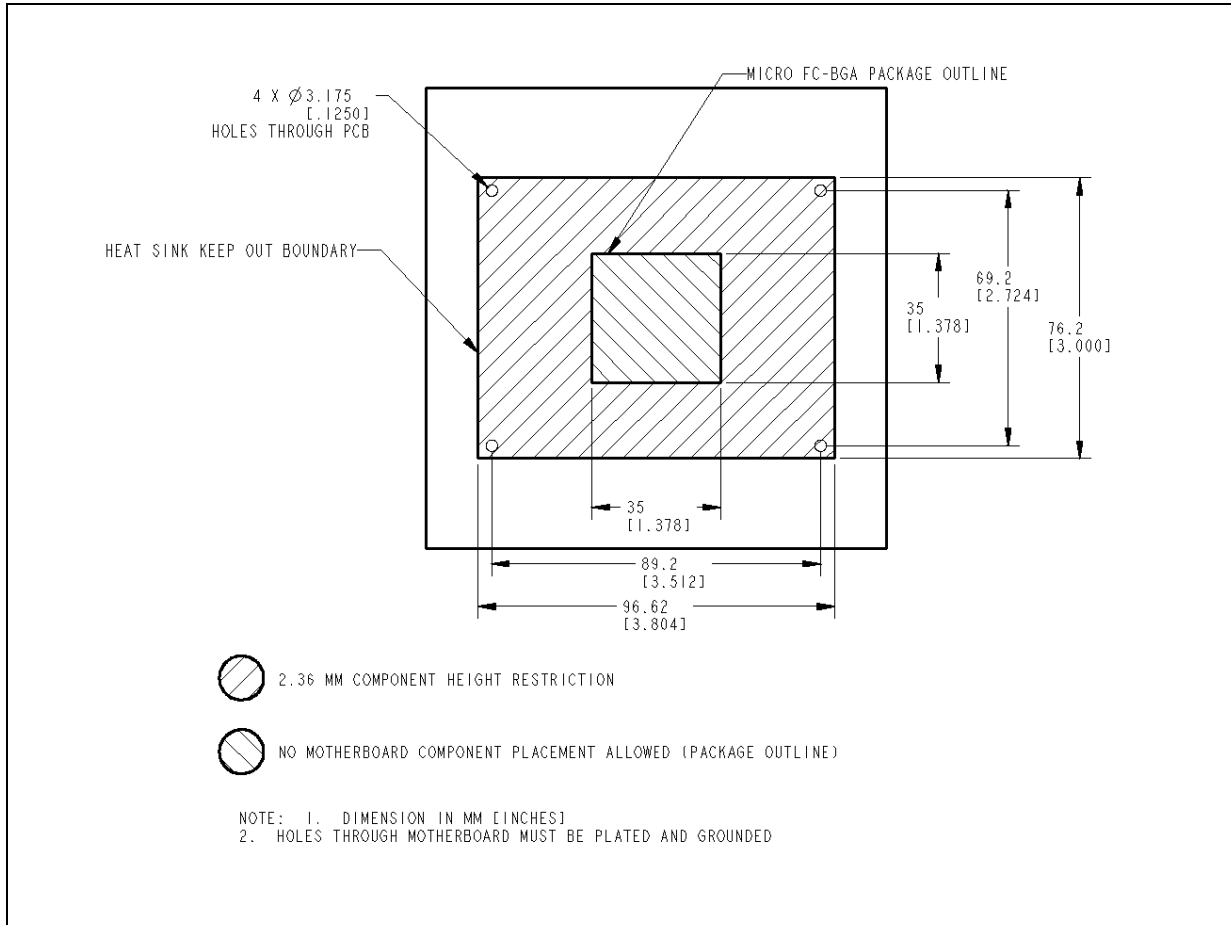
Figure 9.   Single-slot CompactPCI* Form Factor Recommended PCB Volumetric Constraint Zone for the Intel® Pentium® M Processor in the micro-FCPGA Package
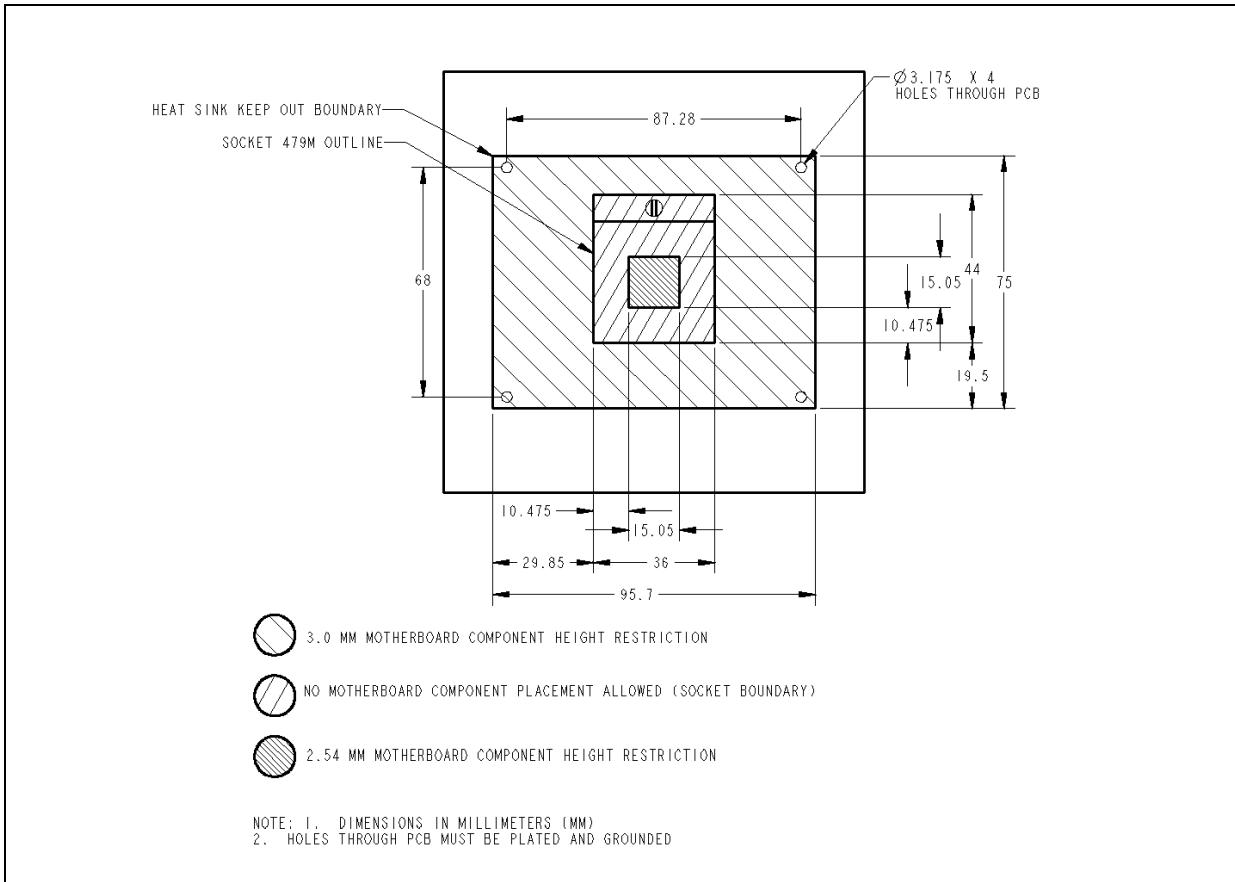
Figure 10.   Intel® Pentium® M Processor in the micro-FCBGA Package Mechanical Stack-up in the Single-Slot CompactPCI* Form Factor
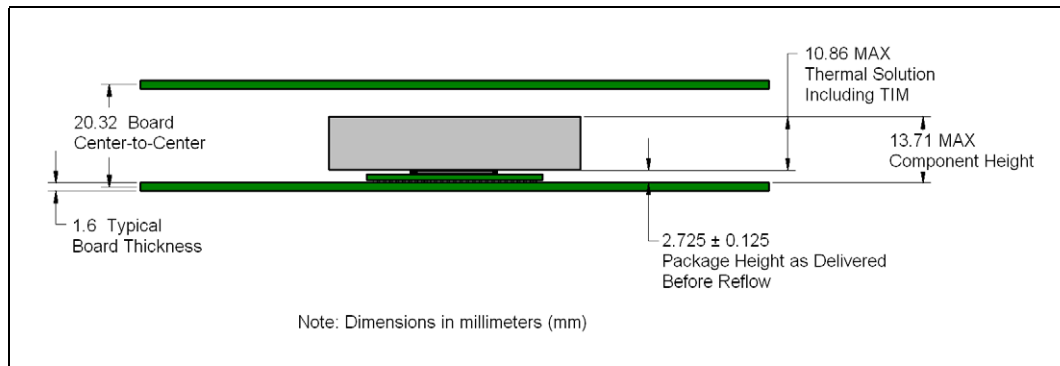
Figure 11. **Intel® Pentium® M Processor in the micro-FCPGA Package Mechanical Stack-up in the Single-Slot CompactPCI* Form Factor**
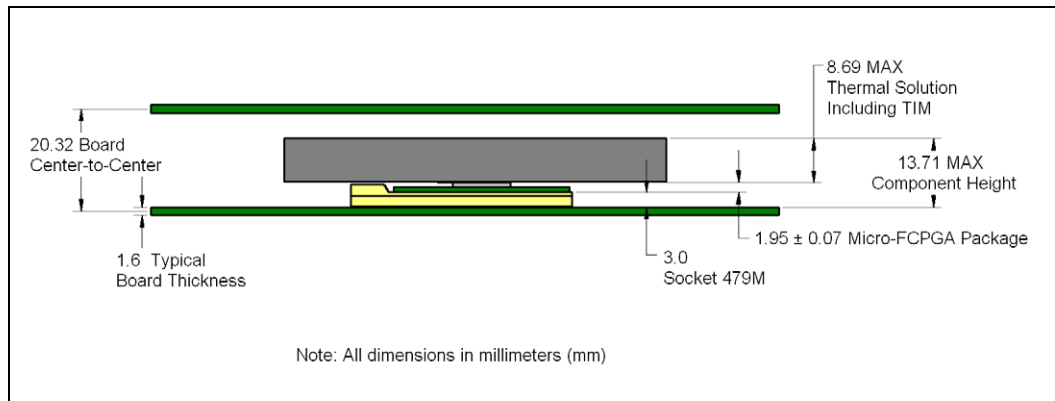
Figure 12. **Intel® Pentium® M Processor in the micro-FCPGA Package Mechanical Stack-up in the 1U Form Factor**
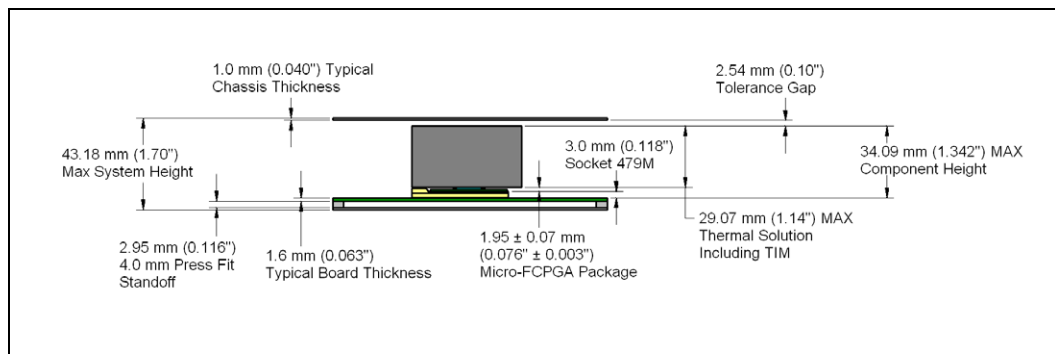
2.2 Thermal Guidelines

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

- Thermal design power (TDP)
- Maximum junction temperature ($T_{junction-max}$)
- 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 of the 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 intended system.

Thermal data for the Intel® Pentium® M Processor and Low Voltage Intel® Pentium® M Processor 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 Processor and Low Voltage Intel® Pentium® M Processor Thermal Specifications

Processor Number	Core Frequency (GHz)	Thermal Design Power (W)	Minimum Tjunction (°C)	Maximum Tjunction (°C)
745	1.8	21.0	0	100
738	1.4	10	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 operation 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 Processor incorporates 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, may 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. When using a thermal diode, a temperature offset value must be read from a processor Model Specific register and applied. The thermal diode may only be used for long term, steady state measurement of die temperature. It is not suitable of real time thermal management. For more information refer to the Intel® Pentium® M Processor *on 90 nm Process with 2-MB L2 Cache Datasheet*.

Note: The reading of the external thermal sensor (on the motherboard) connected to the processor thermal diode signals will not necessarily reflect the temperature of the hottest location on the die. Inaccuracies can include:

- the external thermal sensor

- on-die temperature gradients between the location of the thermal diode and the hottest location on the die

- time based variations in the die temperature measurement

Time based variations may occur when the sampling rate of the thermal diode (by the thermal sensor) is slower than the rate at which the T_J temperature may change.

2.2.3   Thermal Monitor

The Intel Thermal Monitor is a feature of the Intel® Pentium® M processor that allows system designers to lower the cost of thermal solutions without compromising system integrity.

Note: **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 helps control 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. These modes are selected 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.

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, however 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 via 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.

Besides the thermal sensor and thermal control circuit, the Intel Thermal Monitor feature also includes one ACPI register, one performance counter register, three model specific registers (MSR), and one I/O pin (PROCHOT#). All are available to monitor and control the state of the Intel Thermal Monitor feature. The Intel Thermal Monitor can be configured to generate an interrupt upon the assertion or deassertion of PROCHOT#.

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. Regardless of enabling the automatic or On-Demand modes, 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 FSB 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*.

2.2.4   Power Density and Non-Uniform Heating

The Intel® Pentium® M Processor die does not exhibit an even power distribution over its surface area. Non-uniform power distributions may 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 Processor will be 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 (i.e., Intel® Pentium® M Processor 745), hence the solutions are suitable for other SKUs of the processor with equivalent or lower thermal specifications. In addition, the processor local ambient temperature was specified as 50° C for the Intel® Pentium® M Processor, except for the Intel® Pentium® M Processor 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.
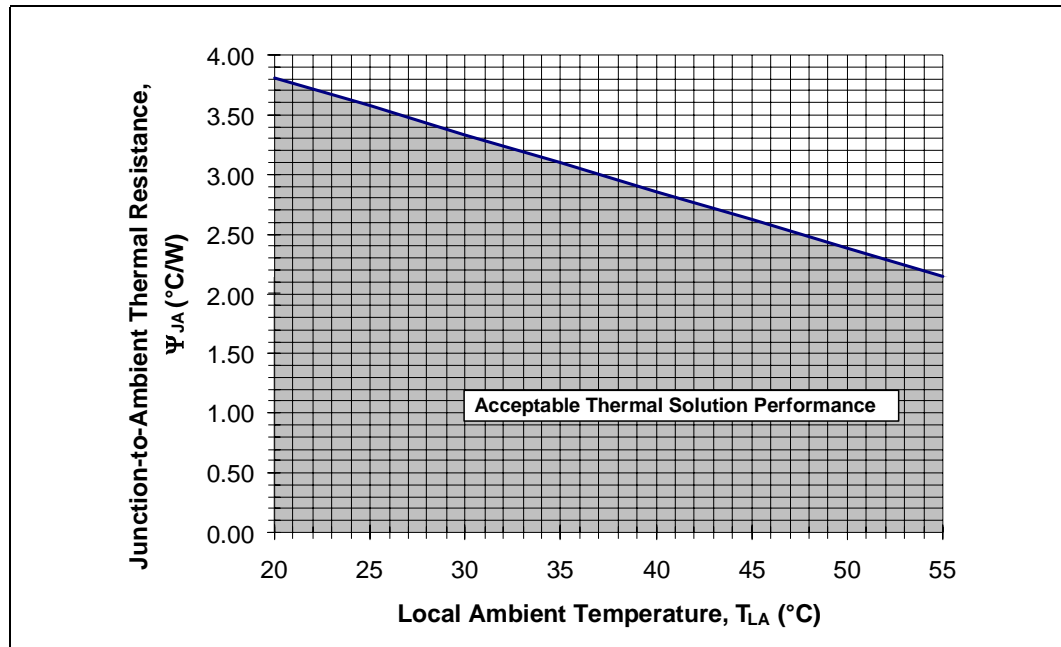
The thermal performance required for the heatsink is determined by calculating the junction-to-ambient thermal characterization parameter, Ψ_{JA}. This is a basic thermal engineering parameter that may be used to evaluate and compare different thermal solutions. For this particular processor, Ψ_{JA} is calculated as shown in Equation 1.

Equation 1. Calculation of Ψ_{JA}

$$\Psi_{JA} = \frac{T_{Jmax}{}^{\circ}C - T_{LA}{}^{\circ}C}{TDP(W)} = \frac{100^{\circ}C - 50^{\circ}C}{21.0W} = 2.38\frac{^{\circ}C}{W}$$

Figure 13 further illustrates the required thermal performance for the Intel® Pentium® M Processor 745 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 13. **Thermal Resistance Values for the Intel® Pentium® M Processor 745 at Various Local Ambient Operating Temperatures**

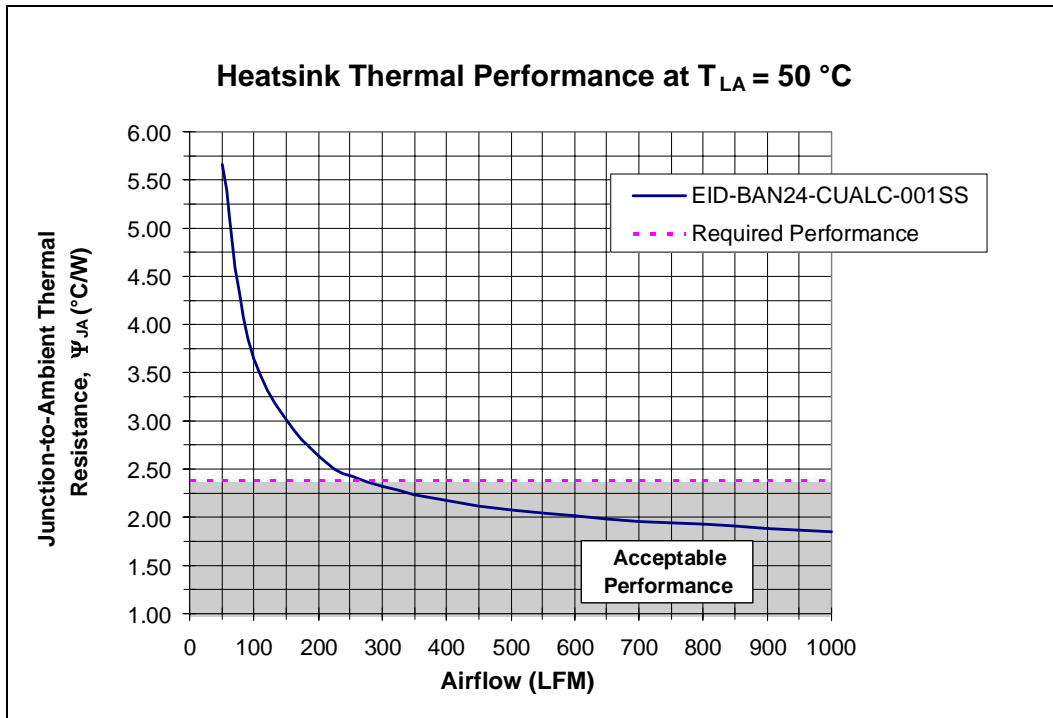## 2.2.6 Recommended Heatsink Designs

2.2.6.1 Intel® Pentium® M Processor in the Micro-FCBGA Package-Copper Base, Aluminum Fin Heatsink #1

This heatsink was designed to meet the required thermal performance for a maximum local ambient temperature of 50° C. The heatsink shown in Figure 22 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 14 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 2.33° C/W with 300 LFM of system airflow, thus meeting the requirements of heatsink thermal performance for the Intel® Pentium® M Processor.

Figure 14. **Intel® Pentium® M Processor Copper Base, Aluminum Fin Heatsink #1 Thermal Performance Curve**
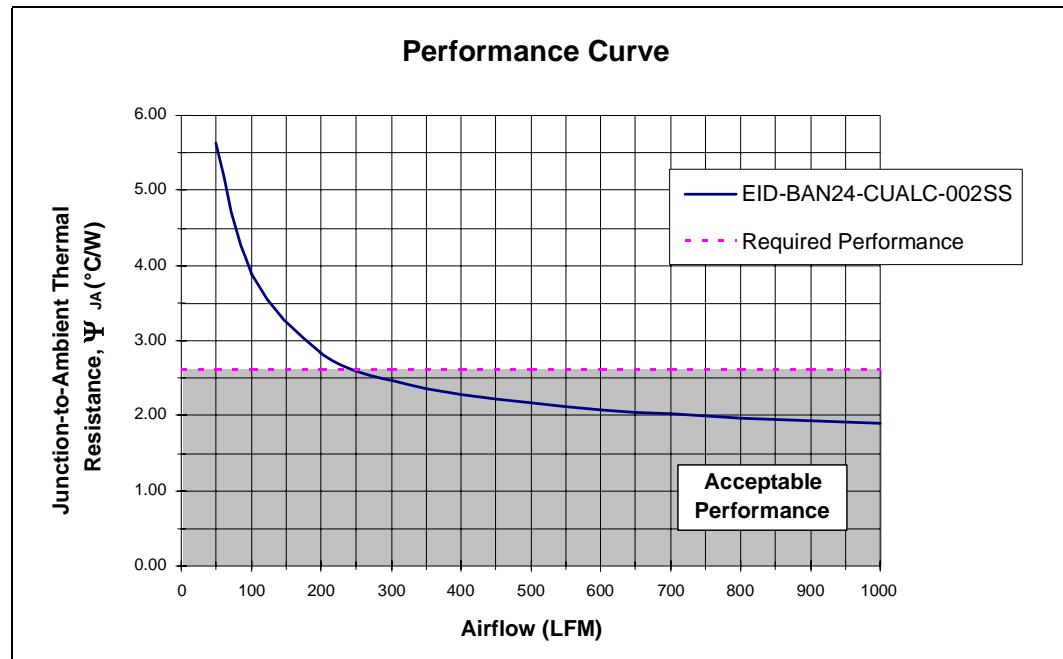
2.2.6.2 Intel® Pentium® M Processor in the Micro-FCPGA Package-Copper Base, Aluminum Fin Heatsink #2

This heatsink was designed to meet the required thermal performance for a maximum local ambient temperature of 45° C. The heatsink shown in Figure 22 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 non-ducted configuration.

Thermal modeling and lab verification tests indicate that this heatsink has a junction-to-ambient thermal resistance of 2.47° C/W with 300 LFM of system airflow, thus meeting the requirements of heatsink thermal performance for the Intel® Pentium® M Processor.

Figure 15.   Copper Base, Aluminum Fin Heatsink #2 Thermal Performance Curve
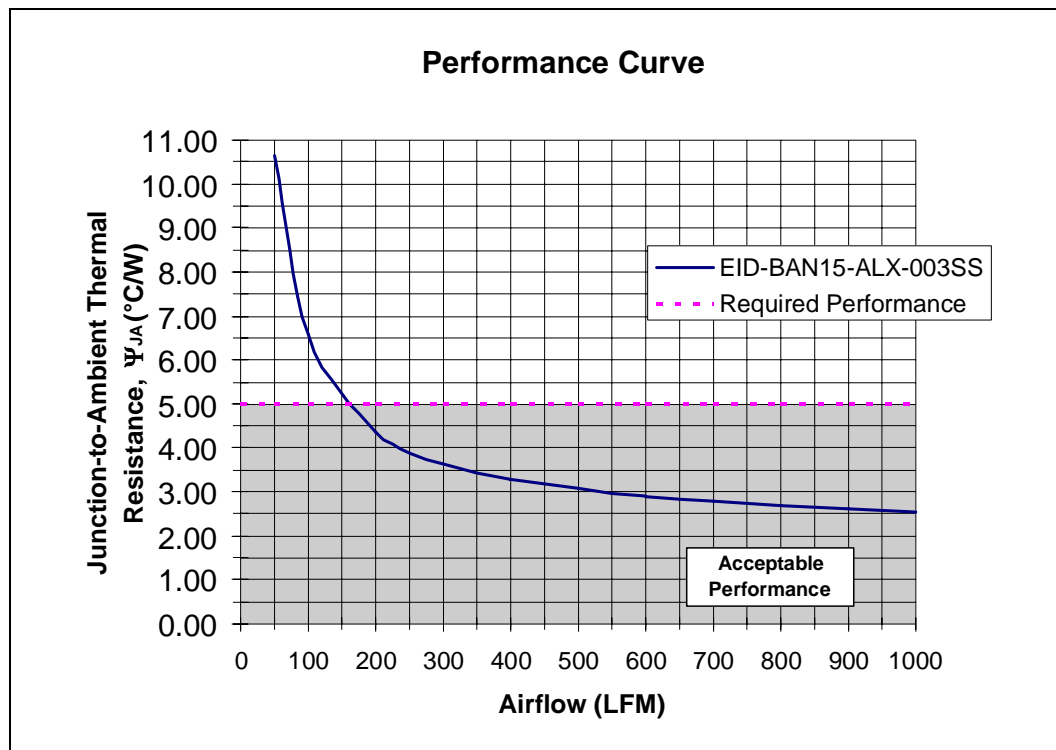
2.2.6.3 Low Voltage Intel® Pentium® M Processor in the Micro-FCBGA Package-Extruded Aluminum Heatsink #1

This heatsink was designed to meet the required thermal performance for a maximum local ambient temperature of 50° C. 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 16 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 4.63° C/W with 200 LFM of system airflow, thus meeting the requirements of heatsink thermal performance for the Low Voltage Intel® Pentium® M Processor.

Figure 16. Low Voltage Intel® Pentium® M Processor Extruded Aluminum Heatsink #1 Thermal Performance Curve

intel®

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. 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 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 4.92° C/W with 300 LFM of system airflow, thus meeting the requirements of heatsink thermal performance for the Low Voltage Intel® Pentium® M Processor.

Figure 17.   Low Voltage Intel® Pentium® M Processor – Extruded Aluminum Heatsink #2 Performance Curve

intel®
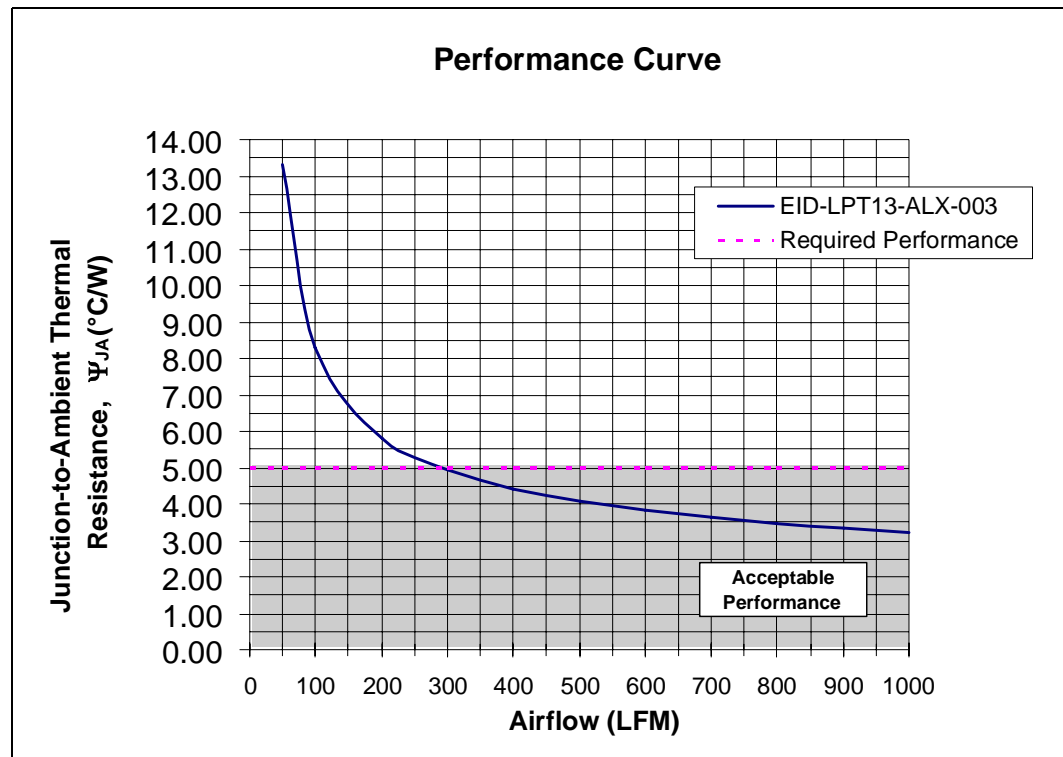
2.2.6.5 Heatsink Orientation Relative to Airflow

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 order to use this design, the processor must be placed on the PCB in an orientation so the heatsink fins will be parallel to the airflow. Figure 18 illustrates this orientation. A top view of the heatsink assembly is shown.

Figure 18. Heatsink Orientation Relative to Airflow Direction
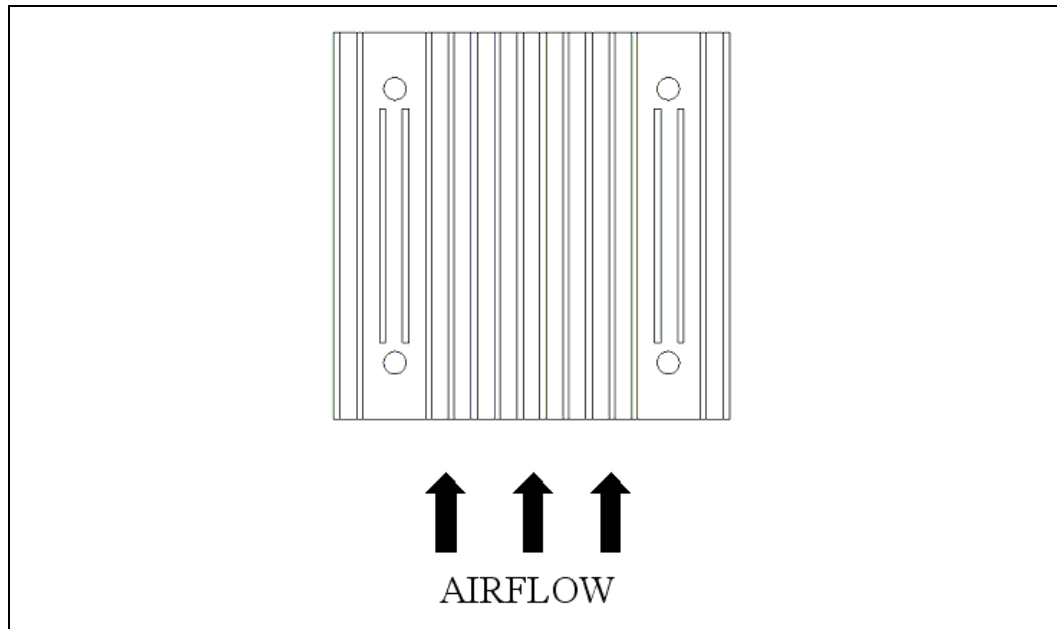
2.2.7 Recommended Thermal Interface Material (TIM)

It is important to understand and consider the impact the interface between the processor and heatsink base has 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, 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, 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 Thermal Interface Material (TIM) with low thermal impedance. The heatsinks were designed using ShinEtsu* G751 thermal grease. Vendor information for this material is provided in "Vendor Information" on page 36. Alternative materials may be used at the user's discretion. The entire heatsink assembly, including the heatsink, attach method, and thermal interface material, must be validated together for specific applications.

2.2.8 Recommended Thermal Solution Attachment Method

The thermal solution may 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 may 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. A fastener is shown in Figure 28.

For larger and heavier heatsinks, such as the Intel® Pentium® M Processor heatsink, a fastening system consisting of screws, springs, and secured with a fastener, should be used. To be used in a CompactPCI* system the system designer 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 Processor Thermal Test Vehicle

To aid in thermal design and verification Intel has developed a Thermal Test Vehicle (TTV) for the Intel® Pentium® M Processor. 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 Processor 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 EEP-N41ES-02 and EEB-N41ES-02

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 19. Active Aluminum Heatsink, EEP-N41ES-02 and EEB-N41ES-02
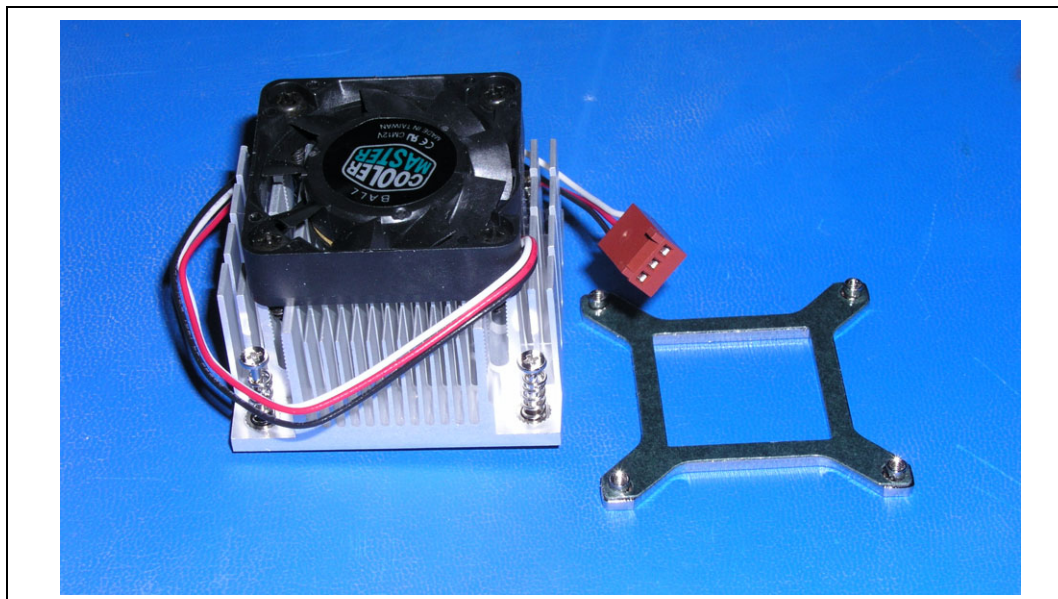
3.1.1.1 Thermal Performance

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 21.0 W with local ambient temperatures up to $T_{LA} = 64$ °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. Aluminum Active Heatsink Thermal Performance

Thermal Performance (° C/W)	$\Psi_{JA} = 1.67$° C/W

## 3.1.1.2   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 26 and Figure 27. Figure 26 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 27 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.

3.1.2   EEP-N41CS-01 and EEB-N41CS-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 20. Active Copper Heatsink, EEP-N41CS-01 and EEB-N41CS-01
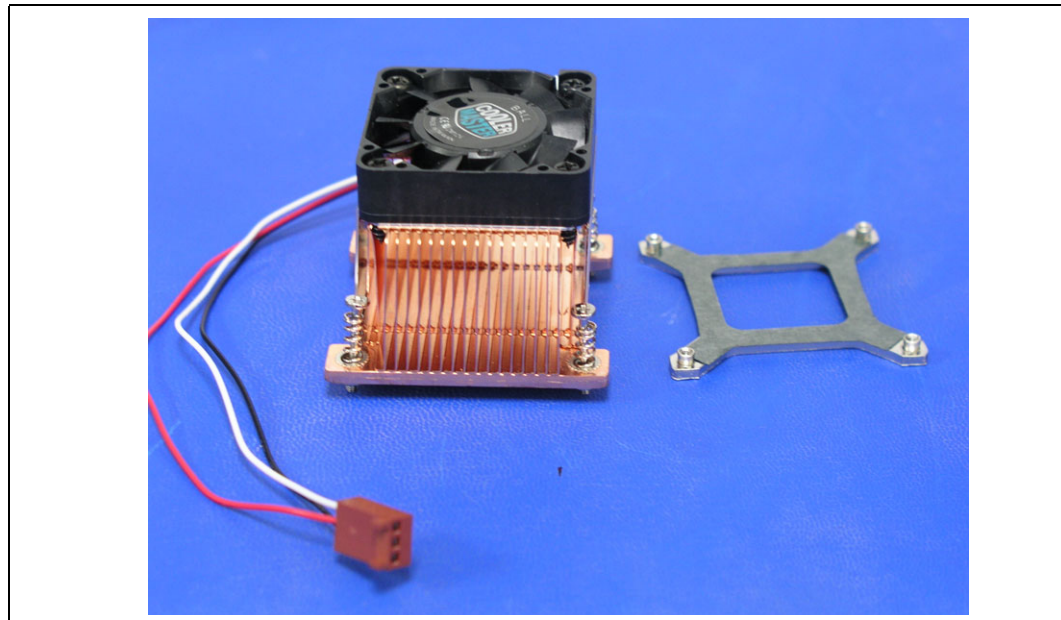
3.1.2.1   Thermal Performance

Thermal performance for the heatsink was verified with the Pentium M TTV. The heatsink is capable of cooling a Intel® Pentium® M processor at 21.0 W with local ambient temperatures up to $T_{LA} = 68$ °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. Active Copper Heatsink Thermal Performance

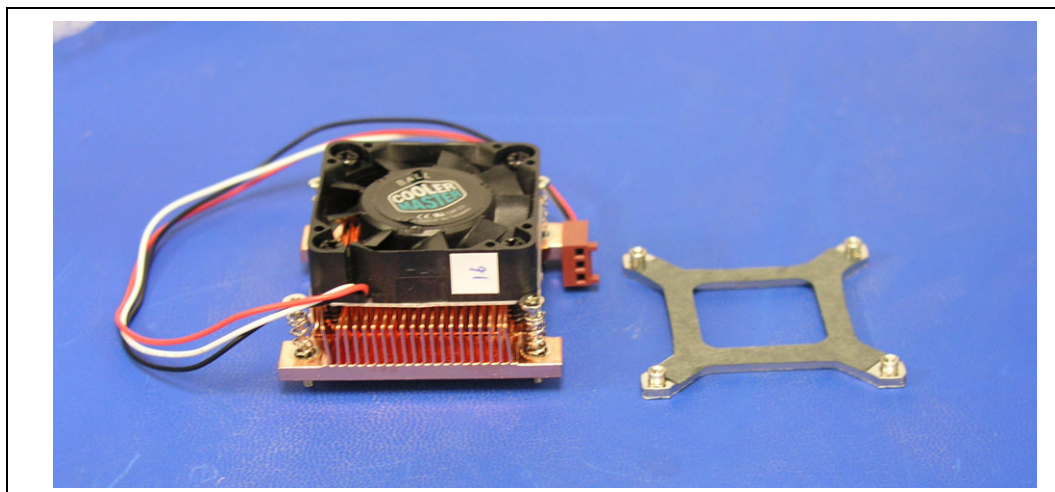| Thermal Performance (° C/W)	Ψ_{JA} = 1.52° C/W

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 26 and Figure 27. Figure 26 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 27 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   EEP-N41SS-01 and EEB-N41SS-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 21. Copper Active Heatsink, EEP-N41SS-01 and EEB-N41SS-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 Intel® Pentium® M processor at 21.0 W with local ambient temperatures up to T_{LA} = 60 °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. Copper Active Heatsink Thermal Performance

Thermal Performance (° C/W)	Ψ_{JA} = 1.885° C/W

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 26 and Figure 27. Figure 26 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 27 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 Information

Table 9. Vendor Contact Information

Supplier	Contact	Phone	Email	Components
Cooler Master 4124 Clipper Ct Fremont, CA 94538 USA	Wendy Lin	(510) 770-8566, x211	wendy@coolermaster.com	• • AdvancedTCA* Reference Thermal Solution (not currently available) • • Active Heatsink, Part Number, Micro-FCPGA Package: EEP-N41ES-02, EEP-N41CS-01, EEP-N41SS-01 • • Active Heatsink, Part Number, Micro-FCBGA Package: EEB-N41ES-02, EEB-N41CS-01, EEB-N41SS-01
Pencom Engineering Solutions 1300 Pioneer St., Suite E Brea, CA 92821	Steve Blank	562-694-4477	steve@pencomsf.com	• Extruded Aluminum Heat Sink, Reference No. EID-BAN15-ALX-003SS and EID-LPT13-ALX-003 • Heatsink Mounting Fasteners (Pencom P/N PL1664-65)
Fujikura America Inc. 3001 Oakmead Village Dr. Santa Clara, CA 95051-0811	Ash Ooe	408-748-6991	a_ooe@fujikura.com	• Extruded Aluminum Heat Sink, Reference No. EID-BAN15-ALX-003SS and EID-LPT13-ALX-003 • Copper Base, Aluminum Snap Fin Heat Sink, Reference No. EID-BAN24-CU/ALC-001SS and EID-BAN24-CU/ALC-002SS
Shin-Etsu Micro Si, Inc. 10028 S. 51st St. Phoenix, AZ 85044		(480) 893-8898	http://www.microsi.com	Thermal Interface Material (ShinEtsu PN G751)
Power Devices Inc. 26941 Cabot Rd.,Bldg. 124 Laguna Hills, CA 92653		(949) 582-6712	http://www.powerdevices.com	Thermal Interface Material (Powerstrate* 51)

Appendix A Heatsink Mechanical Drawings

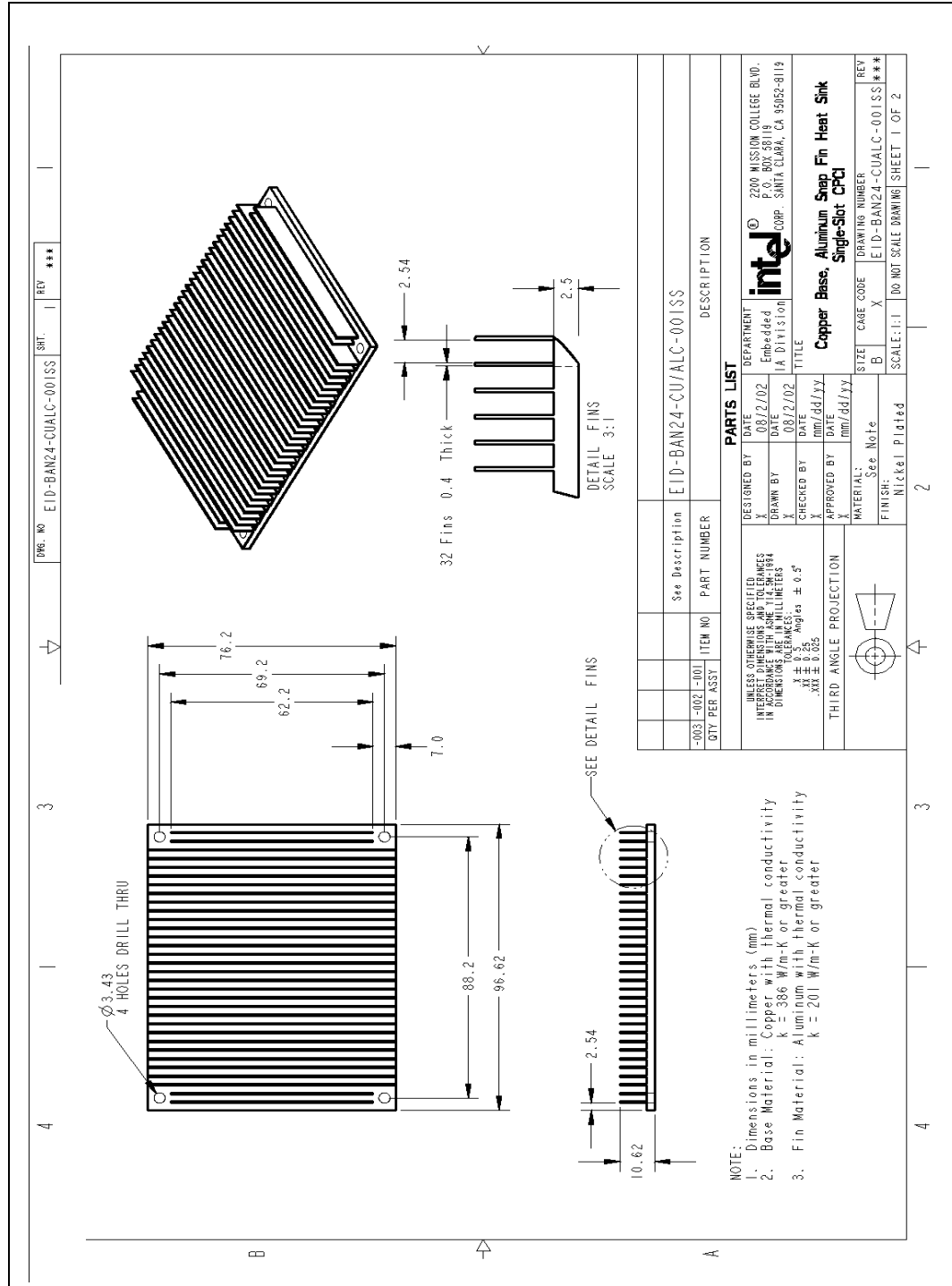**Figure 22. Intel® Pentium® M Processor in the Micro-FCBGA Package Heatsink #1**

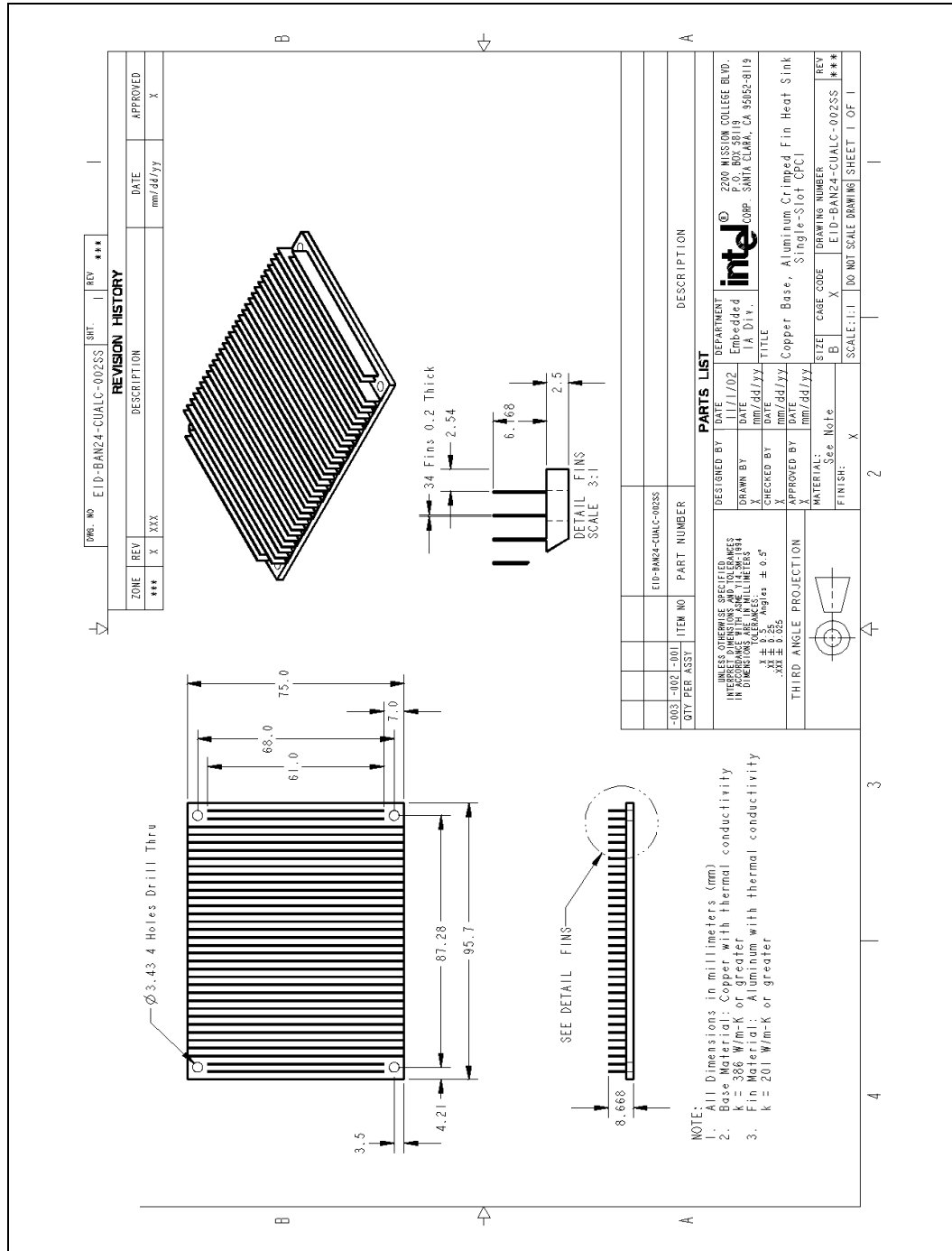**Figure 23.** **Intel® Pentium® M Processor in the Micro-FCPGA Package Heatsink #2**

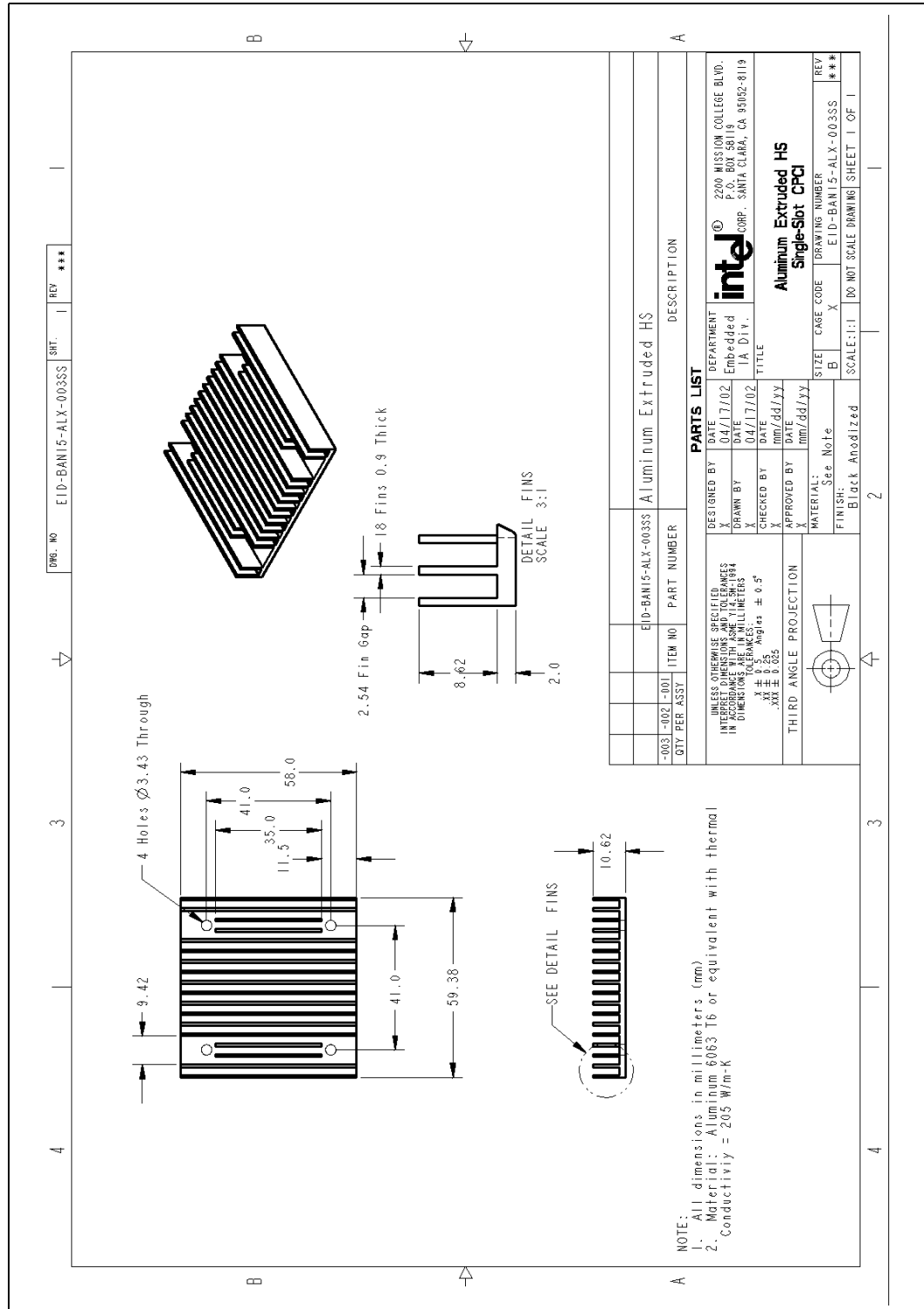**Figure 24. Low Voltage Intel® Pentium® M Processor-Extruded Aluminum Heatsink #1**

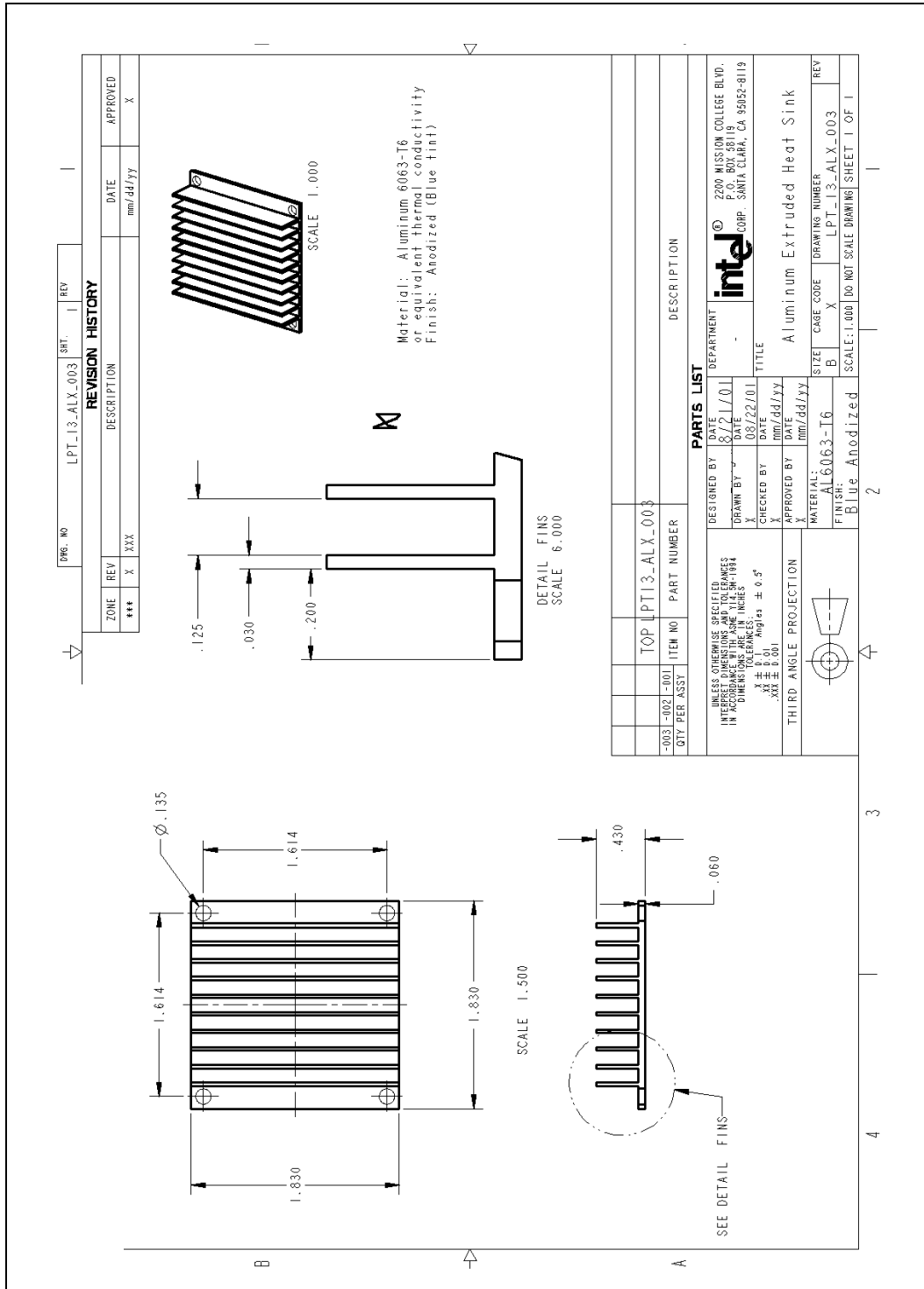**Figure 25.   Low Voltage Intel® Pentium® M Processor-Extruded Aluminum Heatsink #2**

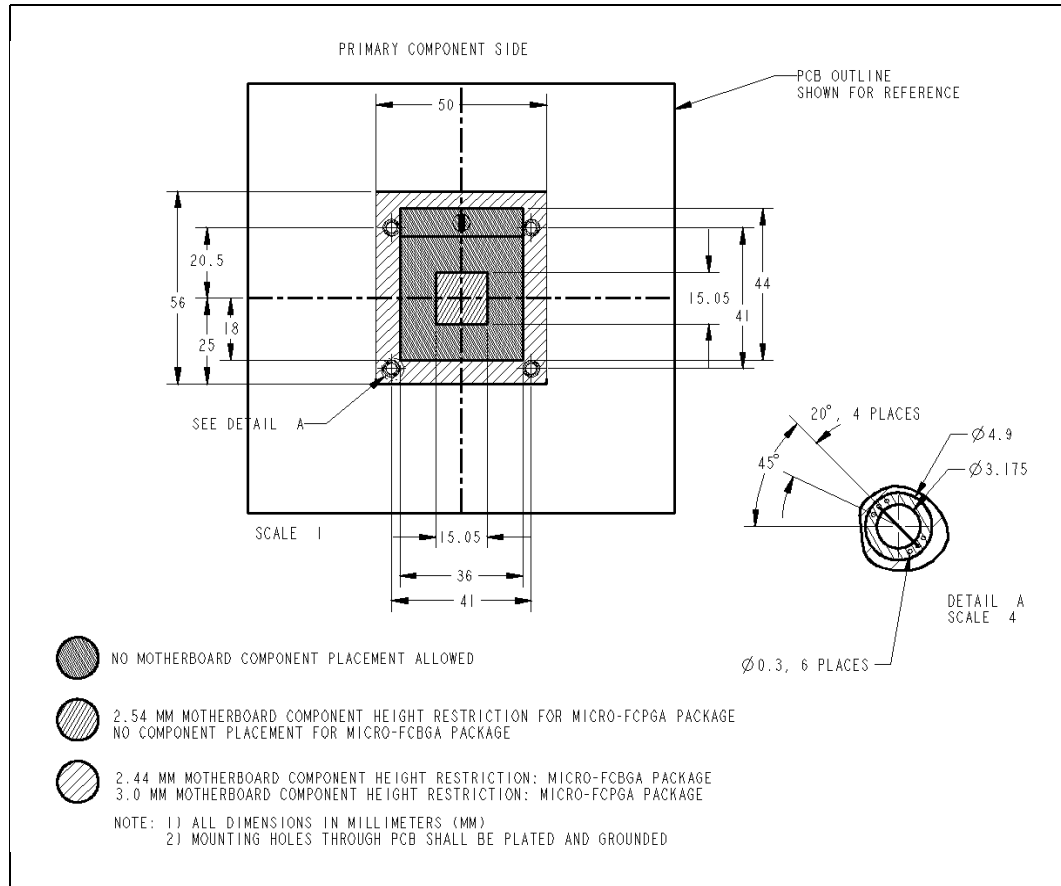**Figure 26. Active Heatsink Volumetric Constraint Zone (Primary Side)**

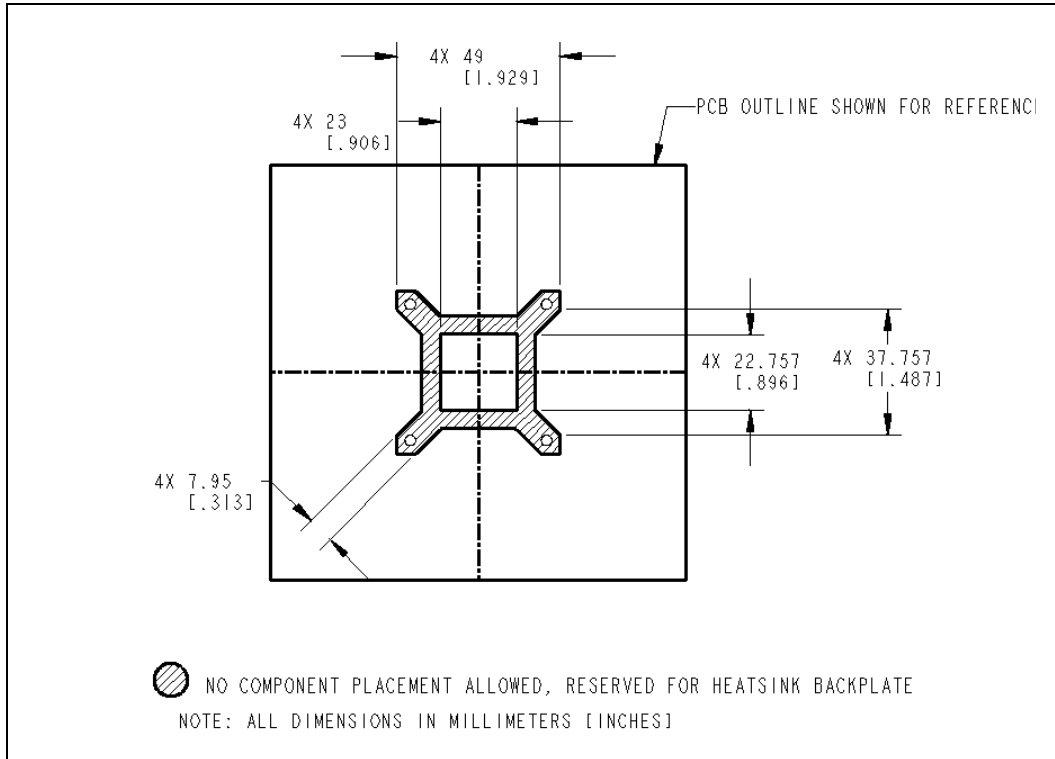**Figure 27. Active Heatsink Volumetric Constraint Zone (Secondary Side)**

Figure 28.   Pencom* Fastener (Used with Permission of Pencom*, Inc.)