Intel® Pentium® 4 Processor-M for Applied Computing

Thermal Design Guide

October 2002

Order Number: 273729-003

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Revision History

Date	Revision	Description
May 2002	1.0	First release of this document
June 2002	1.1	Technical edit, Processor Name Change incorporated, “mobile” references removed, new part numbers, set for public viewing
September 2002	1.2	Added Cooler Master active heatsink design as additional option. Added support for µPGA479M (mobile) socket.

1.0 Introduction

This document describes thermal design guidelines for embedded applications using the Intel Pentium 4 Processor - M in the Micro Flip Chip Pin Grid Array (µFCPGA) package on the 0.13 micron process. More detailed mechanical and thermal specifications for this processor can be found in the *Mobile Intel Pentium 4 Processor - M Datasheet* (order number 250686) available on http://developer.intel.com/design/mobile/pentium4p-m/p4p-m.htm.

Note: This design guide only covers the Intel Pentium 4 Processor - M for platform implementations described in the *Intel Pentium 4 Processor and Intel 845E Chipset Platform Design Guide Addendum for Embedded Applications*.

The information provided in this document is for reference only and additional validation must be performed prior to implementing the designs into final production. The intent of this document is to assist OEMs with the development of thermal solutions for individual designs. The final heat sink solution, including the heat sink, attachment method, and thermal interface material (TIM) must comply with the mechanical design, environmental, and reliability requirements found in the documents located at http://developer.intel.com/design/Pentium4/guides/, under the section titled *Intel Pentium 4 Processor in the 478-pin Package*. It is the responsibility of each OEM to validate the thermal solution design with their specific applications.

1.1 Document Purpose

The purpose of this document is to describe the thermal characteristics of the Intel Pentium 4 Processor - M and provide guidelines for meeting its thermal requirements. The thermal solutions presented in this document are specifically designed for embedded computing applications.

1.2 Document Scope

This document discusses the thermal management techniques for the Intel Pentium 4 Processor - M in embedded computing applications.

Note: This design guide only covers the Intel Pentium 4 Processor – M for platform implementations described in the *Intel Pentium 4 Processor and Intel 845E Chipset Platform Design Guide Addendum for Embedded Applications*. That document contains guidelines for transitioning the Intel Pentium 4 Processor-M to high-frequency performance mode (MPM) running at 1.3 V.

The physical dimensions and power numbers used in this document are for reference only. Please refer to the *Intel Pentium 4 Processor – M Datasheet* for the current product dimensions, thermal power dissipation, and maximum junction temperature.

For details on Intel 845 chipset thermal enabling, please see design guides section of http://developer.intel.com/design/chipsets/845/.

1.3 References

Unless otherwise noted, the following documents are available on http://developer.intel.com:

- *Mobile Intel® Pentium® 4 Processor - M Datasheet* (order number 250686)
- *Mechanical Enabling for the Intel® Pentium® 4 Processor in the 478-Pin Package* (order number 290728)
- *Intel® Pentium® 4 Processor in the 478-pin Package Thermal Design Guidelines* (order number 249889)
- *Intel® Pentium® 4 Processor 478-Pin Socket (mPGA478) Design Guidelines* (order number 249890)
- *Intel® Pentium® 4 Processor in the 478-pin Package at 1.40 GHz, 1.50 GHz, 1.60 GHz, 1.70 GHz, 1.80 GHz, 1.90 GHz, and 2 GHz Datasheet* (order number 249887)

1.4 Definition of Terms

T_{LA} ($T_{Local-Ambient}$)	The measured ambient temperature locally surrounding the processor. This temperature should be measured just upstream of a passive heat sink or at the fan inlet of an active heat sink.
T_{jmax}	The maximum processor junction temperature, as specified in the processor datasheet. This is measured at the hottest point of the die.
T_j	The measured junction temperature of the processor, located at the hottest point of the die.
Thermal Interface Material (TIM)	The thermally conductive compound between the heat sink and processor case. This material fills air gaps and voids, and enhances spreading of the heat from the case to the heat sink.
θ_{js}	The junction to sink thermal resistance, which measures the performance of the thermal interface material. Also referred to as θ_{TIM}.
θ_{ja}	The thermal resistance between the processor junction and the ambient air. This is defined and controlled by the system and component thermal solution.
µPGA478B, µPGA479M	A surface mount zero insertion force (ZIF) socket designed to accept the Intel Pentium 4 Processor - M.
Thermal Design Power (TDP)	A design point for thermal solution enabling specified by using real applications.
U	A unit of measure used to define server rack spacing height. 1U is equal to 1.75 inches, 2U equals 3.50 inches, etc.
LFM	Linear feet-per-minute.
CFM	Cubic feet-per-minute.

2.0 Design Guideline

The thermal solutions presented in this document fit within the maximum component height allowed by 1U and double-slot CompactPCI embedded form factor specifications. These solutions may be valid for other form factors, however individual applications must be modeled, prototyped and verified.

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

It is the responsibility of the designer to thoroughly test, verify and validate all thermal solutions to ensure all guidelines and specifications contained in this design guide are fully met.

3.0 Mechanical Guidelines

3.1 Processor Package

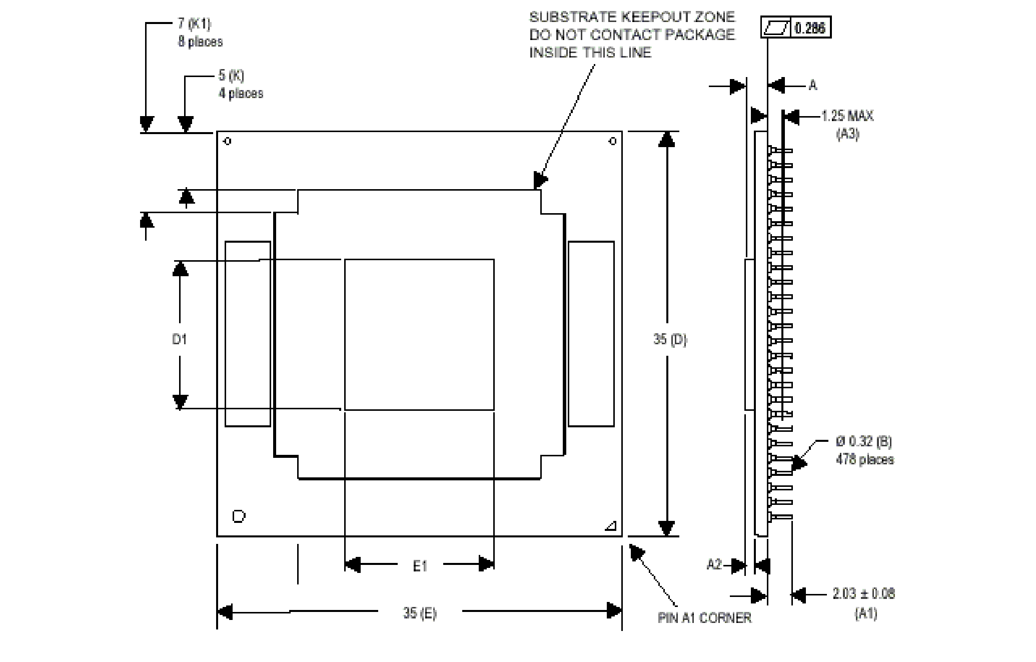
The Intel Pentium 4 Processor - M is packaged in a Micro Flip-Chip Pin Grid Array (µFCPGA) package technology.

The Intel Pentium 4 Processor - M package **DOES NOT** include an integrated heat spreader (IHS). The IHS is a copper heat-spreading device that is mounted atop the processor die. The IHS package is used on the Intel Pentium 4 processor and is referenced in the *Intel Pentium 4 Processor in the 478-Pin Package Datasheet* (order number 249887). See Figure 1 for exposed die mechanical dimension information for the Intel Pentium 4 Processor - M.

The processor connects to the motherboard through a zero insertion force (ZIF) surface mount socket. It is important to note that the Intel Pentium 4 processor and the Intel Pentium 4 Processor - M can both share the same socket, the µPGA478B. This socket is the recommended version for embedded applications, and is compatible with the Intel reference thermal solution. This is the general desktop socket used with the Intel Pentium 4 processor in the 478 pin package. A description of the socket and processor can be found in the *Intel Pentium 4 Processor in the 478-Pin Socket (µPGA478B) Design Guidelines* (order number 249890).

Figure 1, Figure 2 and Table 1 describe the geometry of the µFCPGA package used for the Intel Pentium 4 Processor - M. Please refer to the *Mobile Intel Pentium® 4 Processor - M Datasheet* for more detailed geometry and specifications information.

Figure 1. µFCPGA Package Geometry – Top and Side Views



NOTE: Refer to Table 1 for dimensional information

Figure 2. µFCPGA Package Geometry – Bottom View

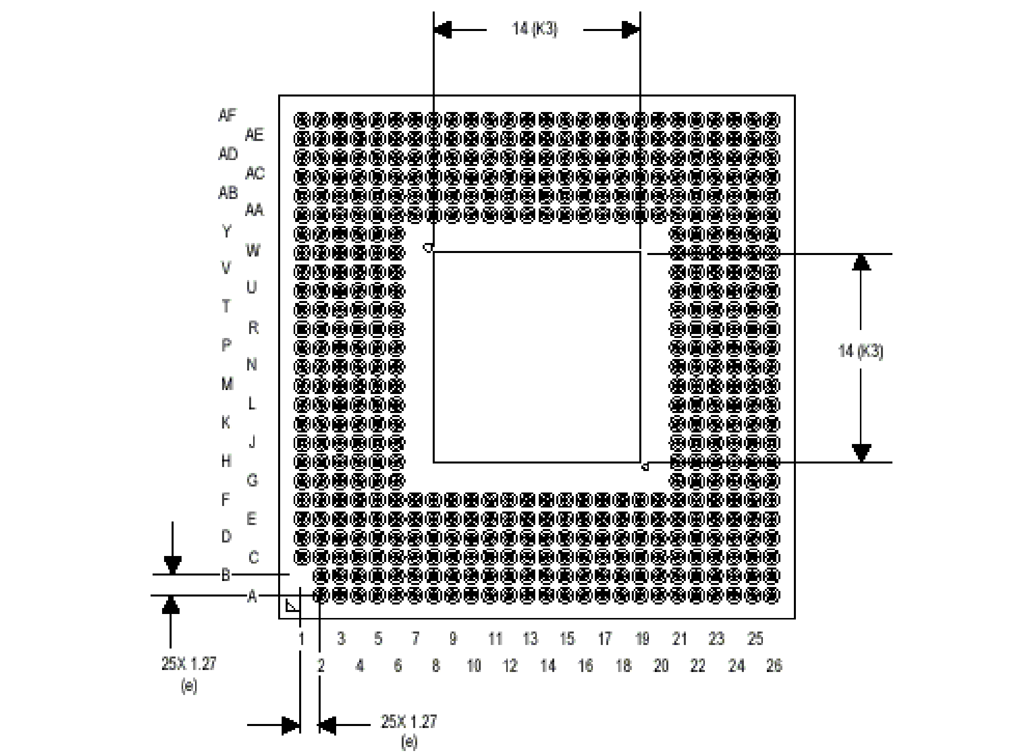


Table 1. µFCPGA Mechanical Dimensions

Symbol	Parameter	Min		Max	Unit
A	Overall height, top of die to package seating plane	1.81		2.03	mm
A1	Pin length	1.95		2.11	mm
A2	Die height		0.854		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		12.24		mm
E1	Die width		11.93		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
-	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

NOTES:
1. All Dimensions are Preliminary and subject to change. Values shown are for reference only.

The overall height of the package from the top of the die to the PCB surface (including socket but with no thermal solution attached) is 5.92 mm ±0.31 mm. This dimension assumes the use of the µPGA478B socket as described in Section 3.2, Socket Information.

For the µPGA479M socket, the overall height of the package from the top of the die to the PCB is 4.92 mm ±0.23 mm.

3.2 Socket Information

Two sockets are available for the Intel Pentium 4 Processor - M, the µPGA478B and the µPGA479M. Either socket will accept the processor. The µPGA479M requires a flat-head screwdriver for actuation, while the µPGA478B requires no tools and is operable with an actuation arm mechanism. The µPGA479M is also 1 mm shorter than the µPGA478B. For simplicity of actuation and compatibility with the Intel Pentium 4 processor, the µPGA478B socket is recommended for Intel embedded thermal enabling with the Sanyo-Denki heat sink referred to in Section 4.6.1.

Note: The Sanyo-Denki reference design described in Section 4.6 has been thermally verified only with the Intel Pentium 4 Processor – M in the µPGA478B socket. Other socket configurations must be verified and validated by the OEM thermal designer. The CoolerMaster* design described in Section 4.6.2 has been thermally verified in both the µPGA478B and the µPGA479M sockets.

Figure 3. µPGA478B Socket Dimensional Drawing

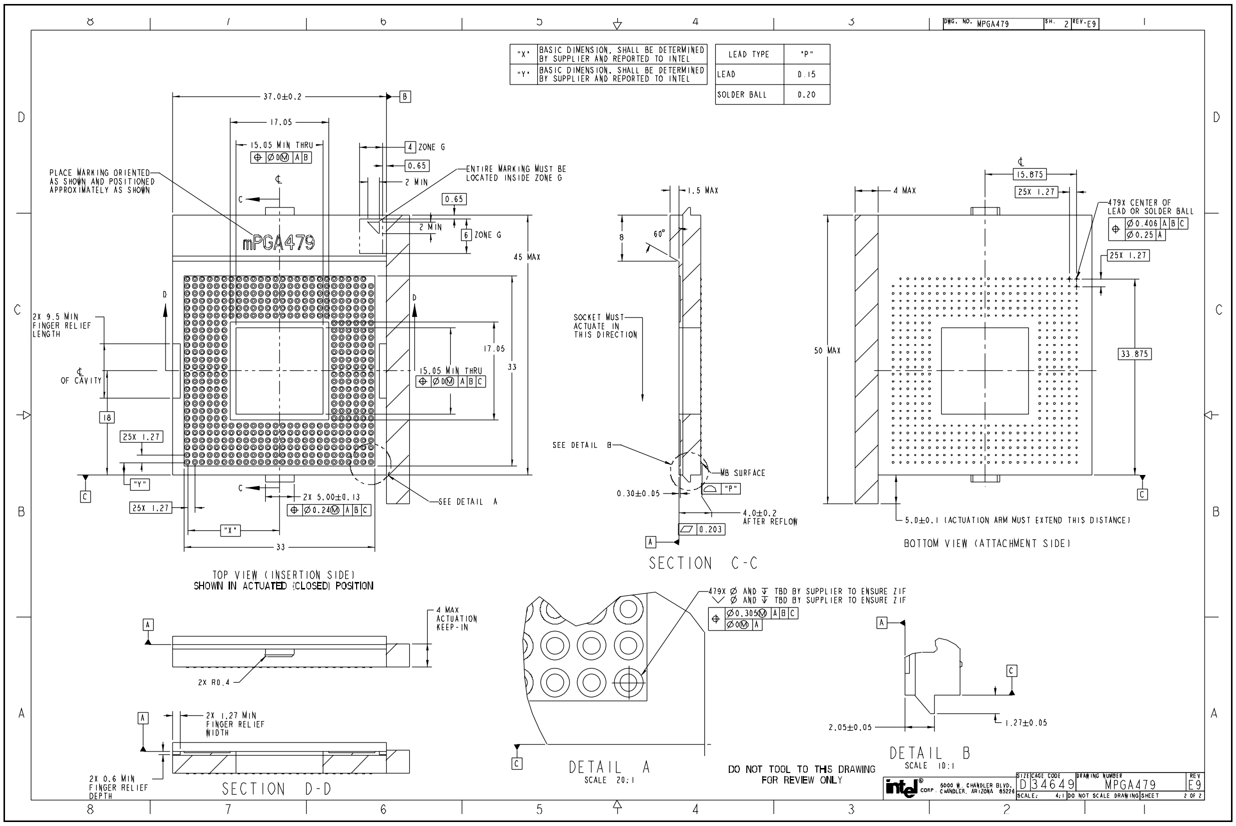
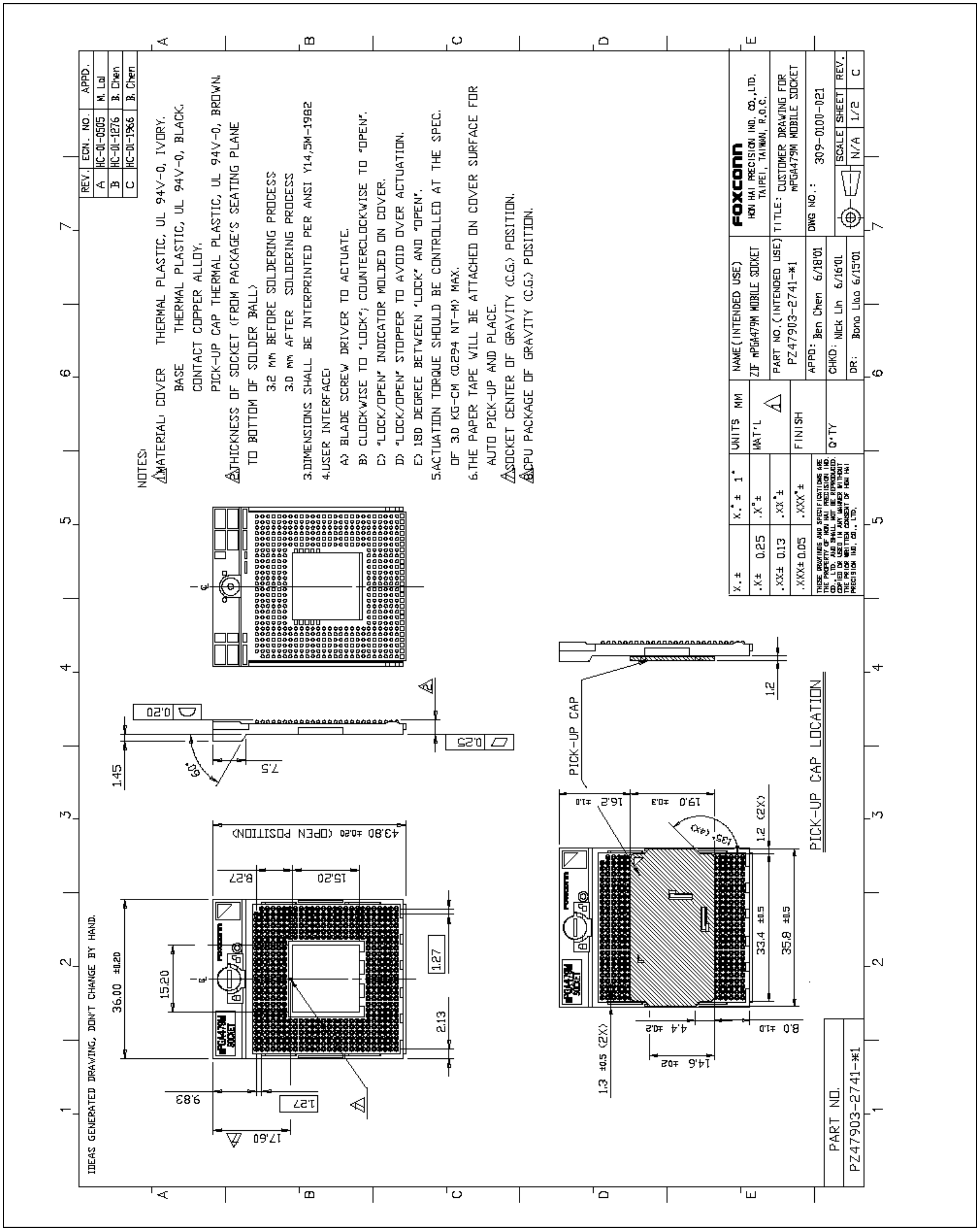


Figure 4. µPGA479M Socket Dimensional Drawing



3.3 Keep-In/Keep-Out Zones

The Keep-In/Keep-Out Zone reserved for the processor package, heat sink, and retention mechanism for the baseboard is shown in Figures 4 through 6.

Figure 5. Keep-Out Zone Using Reference Intel Retention Mechanism — Part 1 of 2

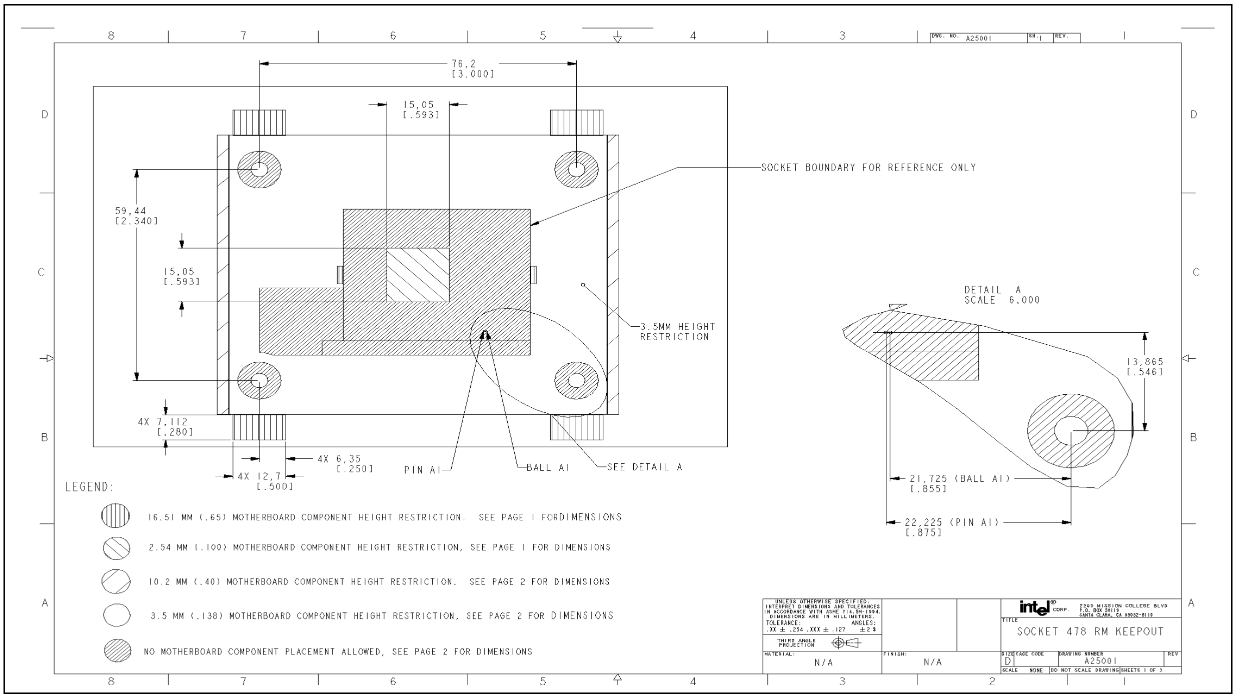


Figure 6. Keep-Out Zone with Sizings, Dimensions and Architecture — Part 2 of 2

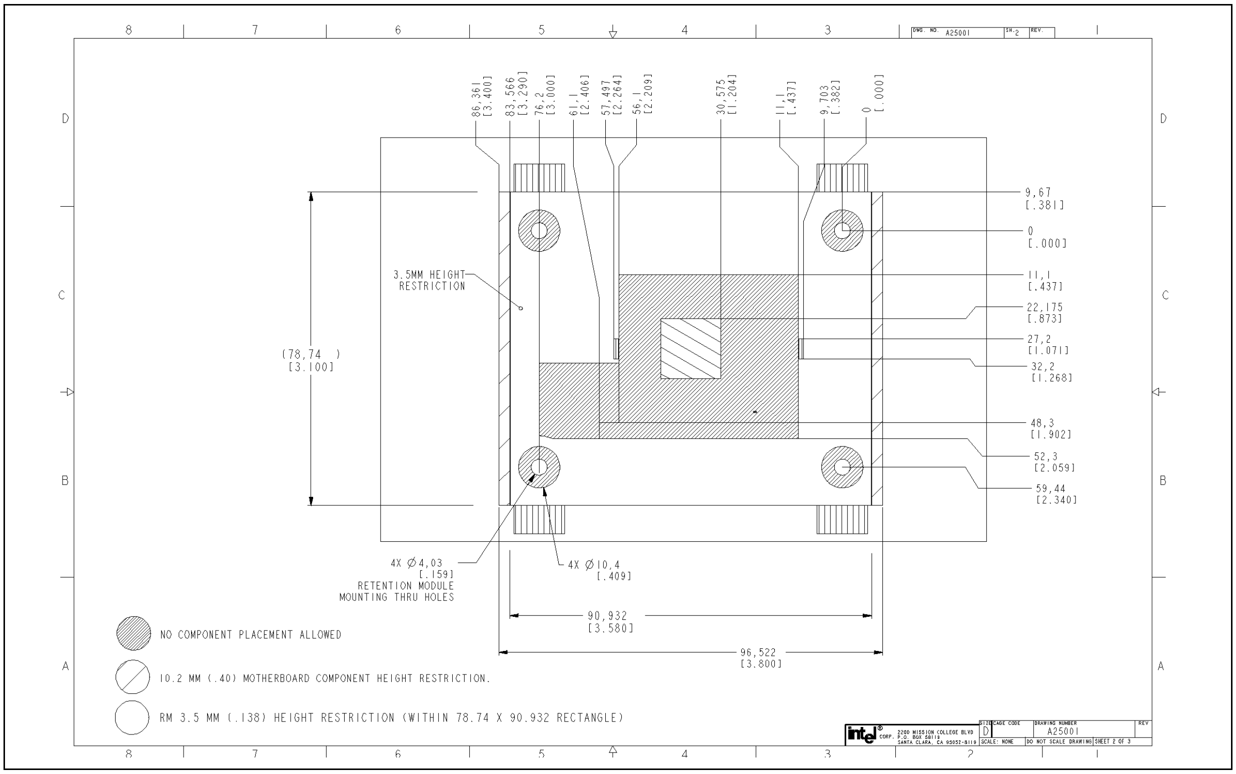
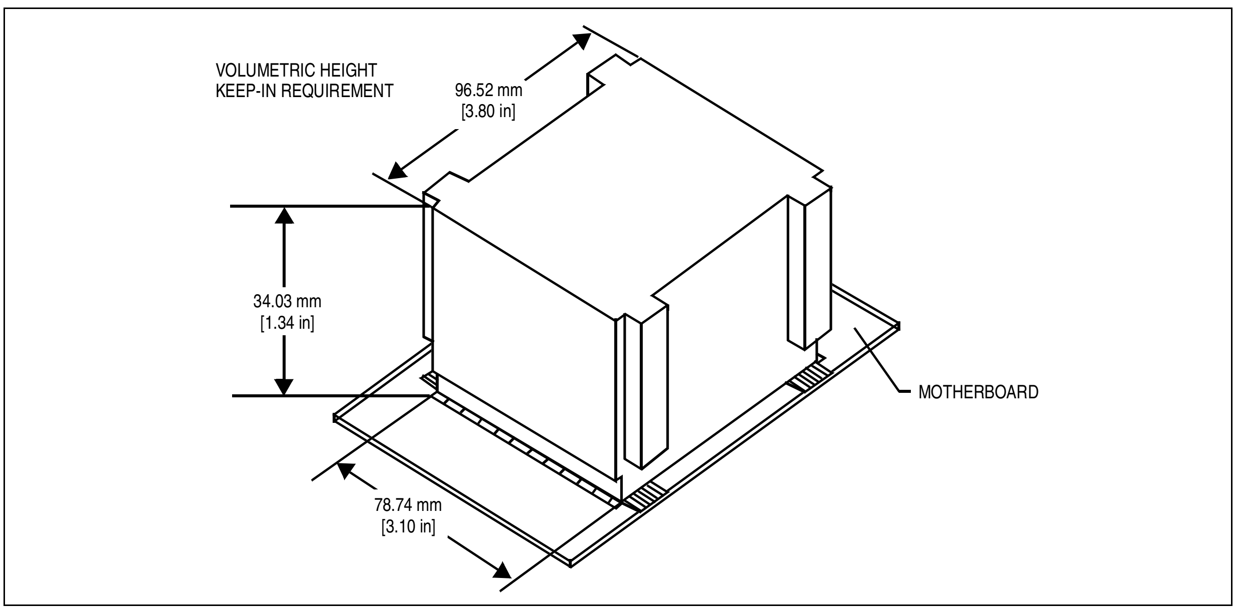


Figure 7. Keep-In Zone for 1U and Double Slot CompactPCI Form Factors



Note: The maximum z-height dimension indicated in this drawing is from the top of the motherboard to the top of the heat sink, including the processor package.

3.4 Motherboard Interface: Clip and Retention Mechanism

3.4.1 Retention Mechanism

If a retention mechanism other than the Intel reference design is developed, it should comply with the following guidelines:

1. Symmetrical design allowing installation in either orientation
2. Installation force on the motherboard lower than 10 lbf
3. Motherboard interface complies with motherboard keepouts, as defined in Figure 5 and Figure 6, including:
    - Hole pattern information
    - Hole size
    - Board thickness: 0.062 – 0.093 inches (design-specific)

Figure 8. Intel® Reference Retention Mechanism – Final Assembly

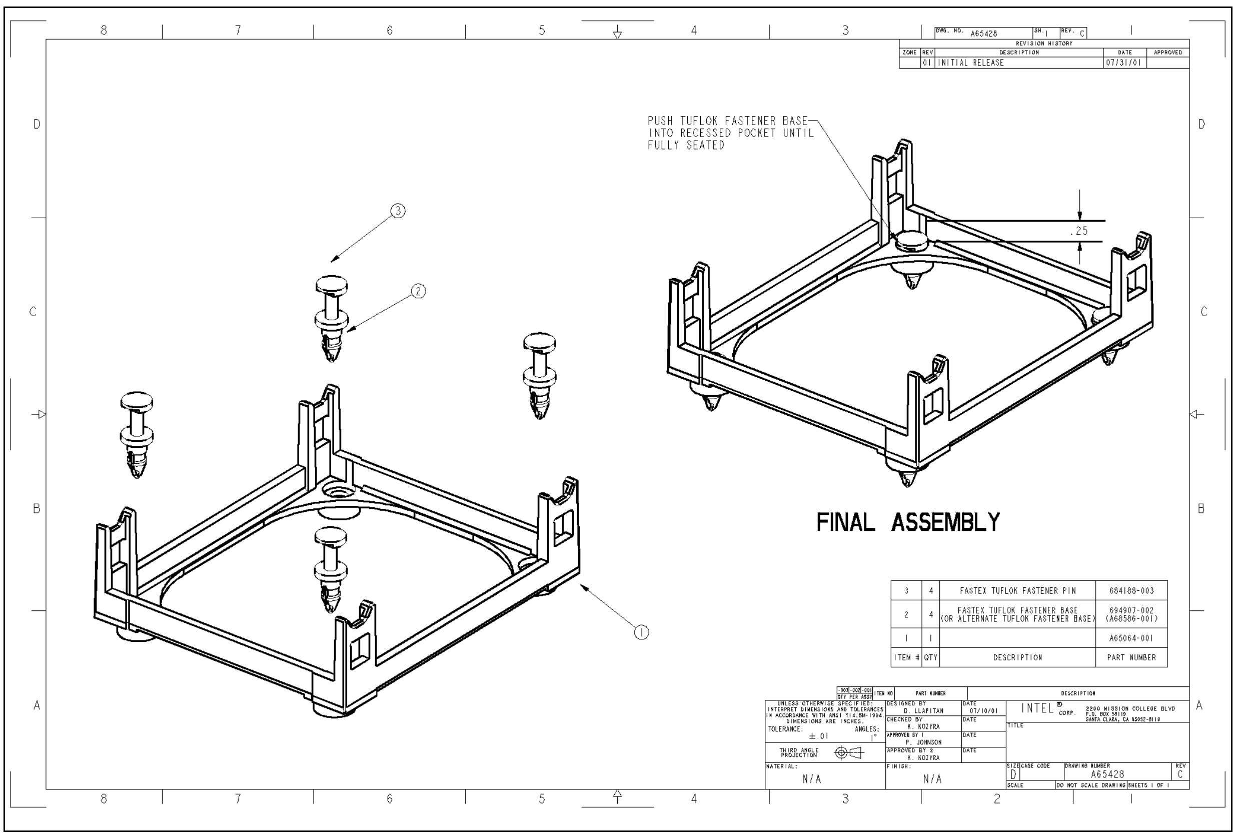
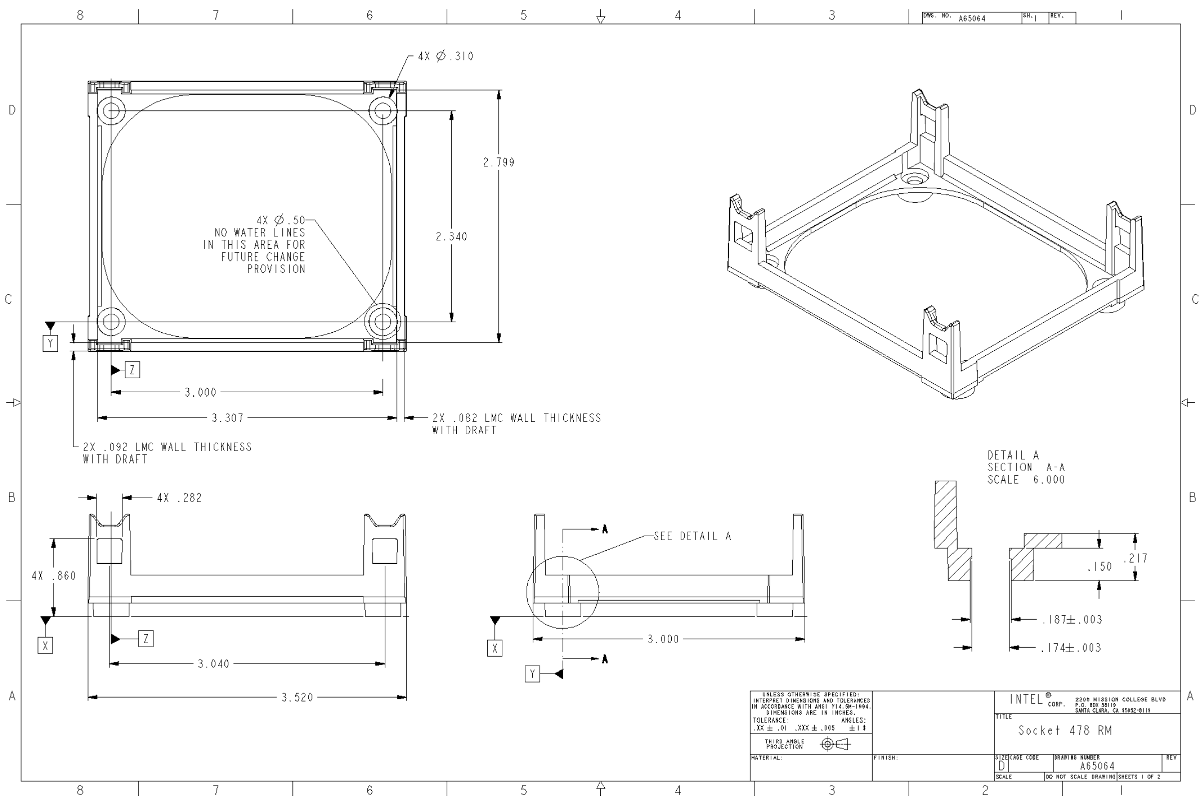


Figure 9. Intel® Reference Retention Mechanism with Sizings, Dimensions and Architecture



NOTES:

1. Interpret dimensions and tolerances in accordance with ANSI Y14.5M-1994.
2. This drawing to be used in correlation with supplied 3D database file. All dimensions and tolerances on this drawing take precedence over supplied file.
3. Material:
   - Type: General Electric Corp. Lexan# 3412R
   - Color: Blk GE Ref 7101
   - Regrind: 25% Permissible
4. Flammability: Finished part shall have a minimum UL Flammability rating of 94V2.
5. Degate: +.000/-.015
6. Flash:.005 Max
7. Sink:.005 Max
8. Ejector Marks: Flush to -.015
9. Parting line mismatch not to exceed.002
10. All dimensions shown are critical to function dimensions. All other dimensions for part construction should be taken from supplied 3-D CAD Model and held to a +/-.01 inch.
11. Tool design to be submitted to and approved by Intel Engineering prior to construction of the tools.

Note: Vendor information for the retention mechanism may be found in Section 6.0.

3.4.2 Requirements for Solutions Using Intel® Retention Mechanism

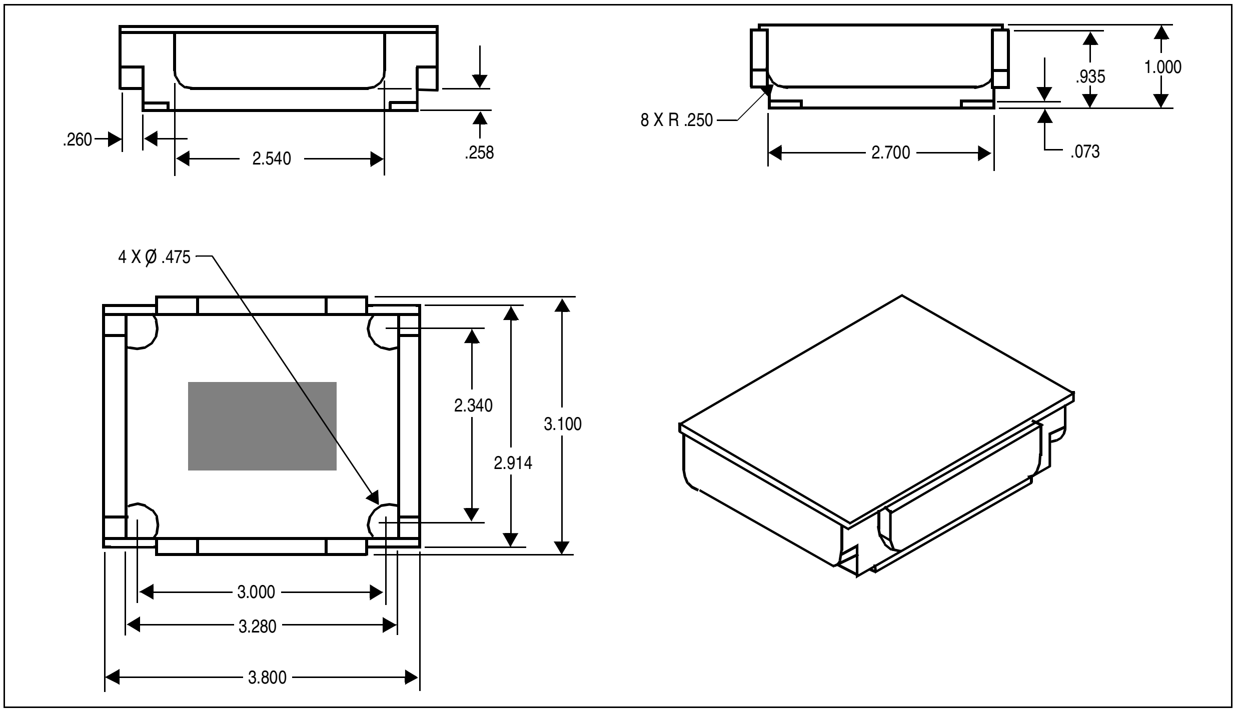
This section defines the mechanical requirements for the interface between a processor heat sink/fan/shroud assembly and the Intel reference retention mechanism. These requirements are intended to support interface control in the design of a custom thermal solution, other than the Sanyo-Denki reference design presented in this document.

1. **Requirement:** Heat sink/fan/shroud assembly must stay within the volumetric keep-in defined in Section 3.3, Keep-In/Keep-Out Zones, and attach to the Intel Reference Retention Mechanism defined in Figure 8 and Figure 9.
   a. Guideline: Rectangular heat sink base dimensions and tolerances:
      - X-dimension = 2.70 ±0.010 inch
      - Y-dimension = 3.28 ±0.010 inch
      - Z-dimension: Inset in bottom surface of heat sink base in each of four corners should hold a z-dimension of 0.073 ±0.010 inch.

   These dimensions are recommended to limit heat sink movement (rocking and sliding) during lateral shock (x and y directions).
2. **Requirement:** Maximum mass and center of gravity (CG)
   a. The maximum combined mass of the heat sink/fan/shroud assembly is 370 grams.
3. **Requirement**: Base Thickening: When using the Intel reference retention mechanism described in Section 3.4.1, the base must be thickened to reach the processor die. The thickened area of the heat sink must fit through the open area of the retention mechanism. The amount of base thickening depends on the socket used:
   - µPGA478B socket – Base msut be thickened by a minimum of 0.071 inches (1.88 mm)
   - µPGA479M socket – Base must be thickened by a minimum of 0.107 inches (2.72 mm)

Note: The combined center of gravity of the heat sink/fan/shroud assembly must be no greater than 0.85 inch above the motherboard.

Figure 10. Intel® Retention Mechanism Volumetric Keep-in (1U & Double-Slot CompactPCI Form Factor)



Note: The shaded area of the bottom left view shows the base location that must be thickened to reach the processor die. The maximum x-y dimension of the thickened region is governed by the Intel reference retention mechanism. See Section 3.4.1 and Section 3.4.2 for more information.

3.4.3 Heat Sink Clip Requirements

3.4.3.1 Heat Sink Attach Clip Usage

The heat sink attach clip holds the heat sink in place under dynamic loading and applies force to the heat sink base to:

- Maintain desired pressure on the thermal interface material for thermal performance
- Ensure that the package does not disengage from the socket during mechanical shock and vibration events (also known as package pullout)
- Protect solder joints of surface mount component damage during mechanical shock events if no other motherboard stiffening device is used

When using the Intel reference retention mechanism, the heat sink chip(s) are to be attached to the tab features located at each corner (see Section 3.4.1, Retention Mechanism).

3.4.3.2 Clip Structural Considerations

The heat sink attach clip should be able to support the mass of its corresponding heat sink during mechanical stress-testing (see Section 3.6). The clip must remain engaged with the retention mechanism tab features and continue to provide adequate force to the heat sink base after mechanical stress testing for the thermal interface material to perform as expected. Maximum load is constrained by the package load capability, as described in Table 1, “µFCPGA Mechanical Dimensions” on page 9.

The clip should be designed in a way that makes it easy and ergonomic to engage with the retention mechanism tabs without the use of special tools. The force required to install the clip (during clip engagement to the retention mechanism tabs) should not exceed 15 lbf. Clips that take more than 15 lbf to install may require a tool to make installation ergonomically possible.

3.5 Fan Requirements for Active Heat Sinks

3.5.1 Electrical Requirements

- Minimum: 9 volts
- Typical: 12 volts
- Maximum: 13.8 volts
- Maximum startup and steady state fan current draw (IC): 740 mA
- The fan must start and operate at the minimum rated voltage and operating temperature.
- The motor must be:
    a. Polarity protected: Fan must not be damaged if the power and ground connections are switched
    b. Locked rotor protected: Fan must not be damaged if the fan is stopped during operation
    c. Sense frequency: Two pulses per revolution
    d. Open collector: Motherboard must pull this pin up to VCC 5.0 V with a 10 KΩ resistor

3.5.2 Variable Speed Fan

If a thermostat is used to monitor fan temperature at the inlet (T_{LA}), it must conform to the following requirements:

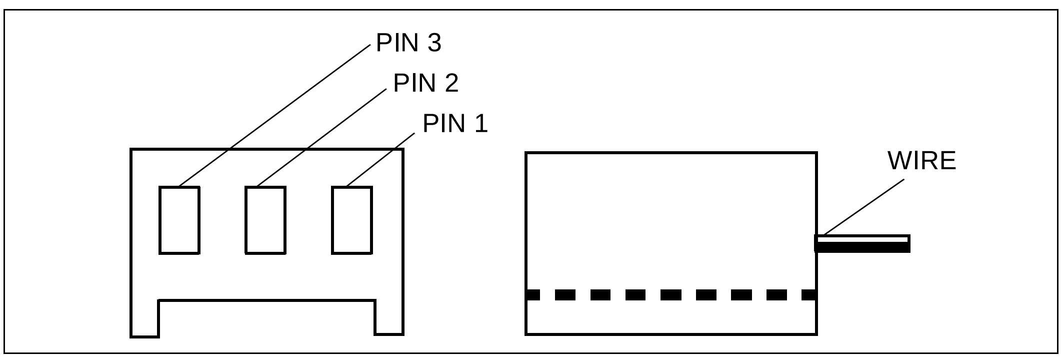
- The maximum thermal performance, achieved at fan maximum speed (RPM) set point temperature is: 45° C.
- The minimum set point temperature (minimum fan speed) should be set at 32° C. The fan speed will be sufficient for the fan heat sink to meet processor thermal specifications at this T_{LA}. This minimizes noise at lower ambient temperatures.
- The transition from minimum to maximum RPM is linear.
- Fail-safe: The fan must run at the high set point RPM if the thermister becomes damaged, sheared off, or otherwise disabled.

3.5.3 Fan Power Connector

The fan/heat sink assembly must be delivered with an integrated (attached) three-wire fan cable and connector. Figure 10 illustrates the fan connector pin-out location. The following is a summary of the fan electrical connector and wire specifications:

- The fan connector must be a straight square pin, three-pin terminal housing with polarizing ribs and friction locking ramp and it must match with a straight pin, friction lock header on the motherboard. The manufacturer and part numbers (or equivalent) are as follows:
  - — AMP*: Fan connector: 643815-3, header: 640456-3
  - — Walden*/Molex*: Fan connector: 22-01-3037, header: 22-23-2031
- The wire must meet the regulatory requirements outlined in Table 3.5.4, “Reliability Requirements for Active Solutions” on page 20.
- Number of wires and connections: Three
  - — Pin 1: Ground; black wire
  - — Pin 2: Power, +12 V; yellow wire
  - — Pin 3: Signal, Open collector tachometer output signal requirement: Two pulses per revolution; green wire
- Orientation as required to clear the retention mechanism/clip assembly
- Fan cable length:
  - — The fan cable connector must reach a mating motherboard connector at any point within a radius of 110 mm (4.33”) measured from the central datum planes of the enabled assembly.

Figure 11. Fan Connector Electrical Pin Layout



3.5.4 Reliability Requirements for Active Solutions

For active thermal solutions, the fan must demonstrate a functional lifetime of 40,000 hours. In addition, the fan must demonstrate performance to the reliability criteria outlined in Table 2.

Table 2. Fan Performance Recommendation

Test	Requirement	Pass/Fail Criteria
Thermal Cycling	-5° C to +70° C, 500 cycles	Visual check[1] RPM check[2]
Humidity	85% relative humidity/55° C, 1000 hours	Visual check[1] RPM check[2]
Power Cycling	7,500 on/off cycles with each cycle specified as three minutes on, two minutes off at 70° C	Visual check[1] RPM check[2]

Notes: Visual check: Labels, housing and connections are all intact

RPM check: Following testing, no fan RPM changes of greater than 20%

3.6 Mechanical Performance Requirements

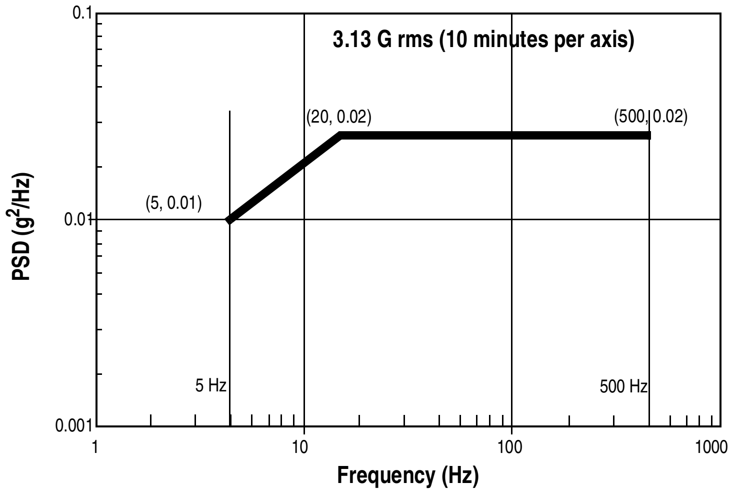
3.6.1 Structural Requirements

Structural reliability tests consist of unpackaged, board-level vibration and shock tests of a given thermal solution in its assembled state. The thermal solution should be capable of sustaining thermal performance after these tests are conducted. However, the conditions of the tests outlined here may differ from your own system requirements.

3.6.1.1 Random Vibration Test

- Duration: 10 min/axis, three axes
- Frequency Range: 5 - 500 Hz
- Power Spectral Density (PSD) Profile: 3.13 G rms

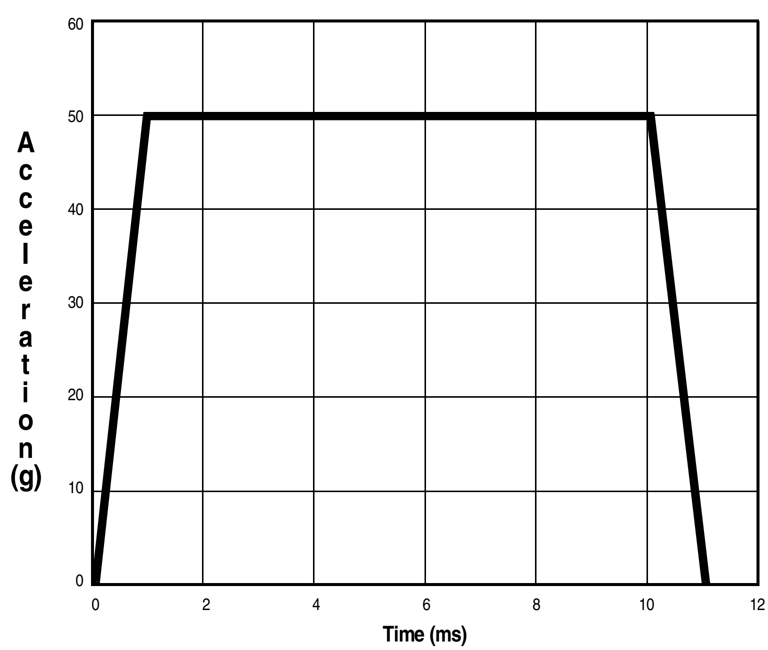
Figure 12. Random Vibration PSD



2.6.1.2 Shock Test

1. The recommended performance requirements for a motherboard are as follows:
   a. Quantity: Three drops for + and - directions in each of three perpendicular axes (a total of 18 drops)
   b. Profile: 50 G trapezoidal waveform, 11 ms duration, 170 in/s minimum velocity change
   c. Setup: Mount sample board on test fixture

Figure 13. Shock Acceleration Curve



3.6.1.2 Post-Test Pass Criteria

The post-test pass criteria include:

- No significant physical damage to the retention mechanism windows, including any indication of shearing or cracks in the retention mechanism body
- Clip must remain latched to the retention mechanism windows
- Heat sink remains seated and its bottom remains mated flatly against processor die surface. **No visible gap between the heat sink base and processor die.** No visible tilt of the heat sink with respect to the retention mechanism.
- No signs of physical damage to the motherboard surface due to impact of heat sink or heat sink attach clip
- No visible physical damage to the processor package
- Successful BIOS/Processor/memory test of post-test samples
- Thermal compliance testing to demonstrate that the case temperature specification can be met

3.7 Miscellaneous Requirements

3.7.1 Material and Recycling Requirements

The material must be resistant to fungal growth. Examples of non-resistant materials include cellulose materials, animal and vegetable based adhesives, grease, oils and many hydrocarbons. Synthetic materials such as PVC formulations, certain polyurethane compositions (e.g., polyester and some polyethers), plastics which contain organic fillers of laminating materials, paints and varnishes are also susceptible to fungal growth. If materials are not fungal growth-resistant, then MIL-STD-810E, Method 508.4 must be performed to determine material performance.

The material used must not have deformation or degradation in a temperature-life test.

Any plastic component exceeding 25 grams must be recyclable per the European Blue Angel recycling standards.

3.7.2 Safety Requirements

The heat sink and attachment assemblies must be consistent with the manufacture of units that meet the following safety standards:

- UL Recognition-approved for flammability at the system level: All mechanical and thermal enabling components must be a minimum UL94V-2 approved
- CSA Certification: All mechanical and thermal enabling components must have CSA certification
- Edging: Heat sink fins must meet the test requirements of UL1439 for sharp edges

4.0 Thermal Guidelines

4.1 Introduction

This section presents thermal design guidelines for the Intel Pentium 4 Processor - M. The required performance of the thermal solution is dependant on many parameters, including the processor's thermal design power (TDP), maximum junction temperature (T_{jmax}), the local ambient temperature (T_{LA}), and system airflow. The guidelines and recommendations presented in this document are based on specific parameters. It is the responsibility of each product design team to verify that thermal solutions are suitable for their specific use.

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

Note: Please refer to the processor's datasheet for the most current thermal data. In the event of conflict, the processor's datasheet supersedes information provided in this document.

Table 3. Intel® Pentium 4® Processor – M Thermal Data

Core Frequency (GHz)	Thermal Design Power (W)	T_{jmax}
1.7	30.0	100
1.7 +	see processor datasheet	see processor datasheet

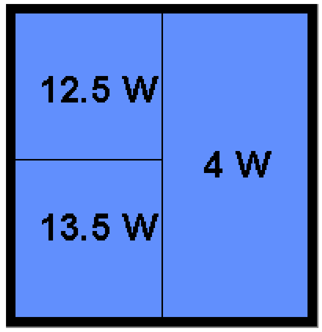
Reminder: This document covers thermal design for the Intel Pentium 4 Processor - M in the maximum performance mode only.

4.2 Processor Junction Temperature and Die Modeling

It is not recommended to use external thermocouples in the laboratory to measure junction temperature on the Intel Pentium 4 Processor - M. Power density on the processor die is non-uniform and the location of the hottest part of the die cannot be determined. Instead, the on-die thermal diode, along with an offset correction factor, must be used to determine T_j. Note that T_j is the temperature of the hottest part of the die. See the Intel Pentium 4 Processor-M Datasheet for more information on how to measure the junction temperature using the offset correction factor.

For CFD modeling, it is recommended that the die be split into four equal regions, as shown in Figure 13. This example shown is for enabling a 30 W processor. Half of the die will dissipate approximately 4 W, one quarter will dissipate approximately 12.5 W, and the last quarter will dissipate approximately 13.5 W. The same ratio is carried over for greater than 30 W-enabling. For example, a 35 W die will be split into three areas of 15.75 W, 14.58 W and 4.67 W respectively.

Figure 14. Processor Die CFD Modeling Technique (30 W Example)



4.3 Processor Thermal Design Power

An electronics cooling solution for the Intel Pentium 4 Processor - M must be designed to adequately dissipate the Thermal Design Power (TDP) while keeping the processor junction temperature (T_j) under its maximum value. The TDP value for the Intel Pentium 4 Processor - M is specified:

- Under normal operating conditions
- While operating at nominal VCC
- At worst case junction temperature (T_j =100° C)
- Based on the average and sustainable peak power dissipation using real applications

This TDP value can be implemented for thermal solution design only if a thermal feedback fail-safe mechanism is incorporated to ensure that product temperature remains below its maximum value (T_{jmax} = 100° C). The Intel Pentium 4 Processor - M incorporates this feature using an on-die Thermal Monitor that prohibits the processor from exceeding both the TDP and the T_{jmax} temperature at the same time. The thermal monitor is required for the processor to operate under specification and must be enabled through the BIOS. For more information on the Thermal Monitor, see Section 5.0 of this design guide, or consult the *Intel Pentium® 4 Processor - M Datasheet*.

4.4 Thermal Solution Requirements

The thermal solutions recommended in this document were designed based on the Intel Pentium 4 Processor - M at a TDP of 35 W. The thermal performance required for the heat sink is determined by calculating the junction-to-ambient thermal resistance, θ_{ja}. This is a basic thermal engineering parameter that can be used to evaluate and compare different thermal solutions. For this particular processor at a local ambient temperature of 50º C, θ_{ja} is calculated as shown in Equation 1.

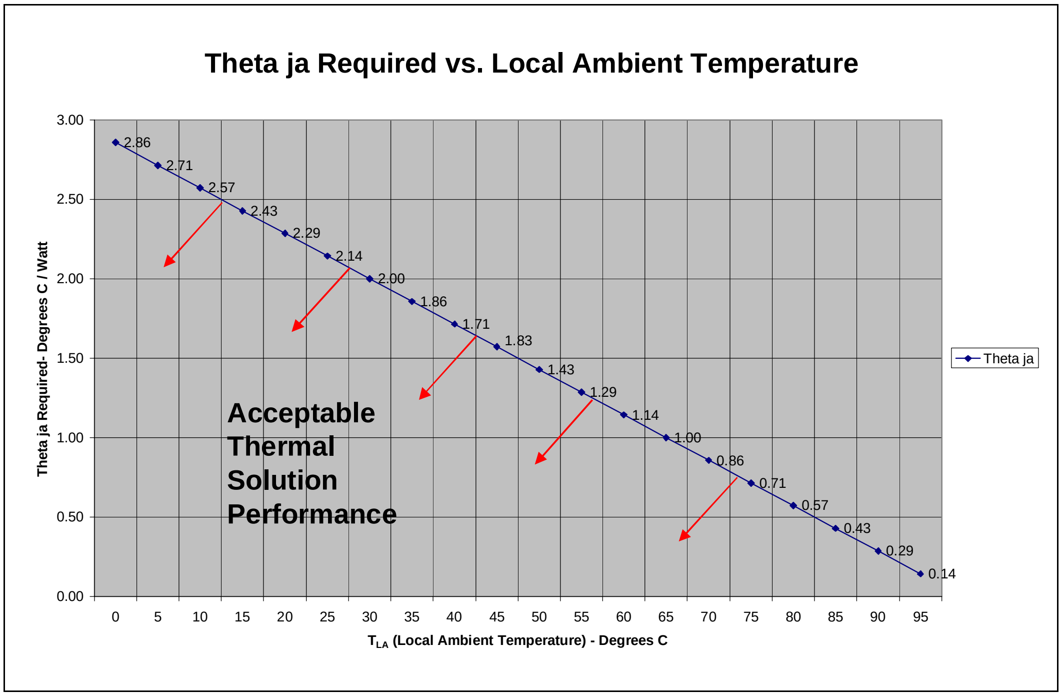
Equation 1. Junction-to-Ambient Thermal Resistance

$$\theta_{JA\max} = \frac{T_{J\max}{}^{\circ}C - T_{LA}{}^{\circ}C}{TDP(W)} = \frac{100^{\circ}C - 50^{\circ}C}{35W} = 1.43\frac{^{\circ}C}{W}$$

Figure 15 further illustrates the required thermal performance for the Intel Pentium 4 Processor - M at different operating local 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.

It is important to note that the junction temperature measurement is taken at the hottest part of the die. Please see the *Intel Pentium 4 Processor-M Datasheet* for more information on how to measure the junction temperature.

Figure 15. θ_{ja} Required vs. Local Ambient Temperature for the Intel® Pentium 4® Processor - M at a TDP of 35 W



4.5 Recommended Thermal Interface Material

It is important to understand and consider the impact the interface between the processor and heat sink base has on the overall thermal solution. Specifically, the bond line thickness, interface material area, and interface material thermal conductivity must be managed to optimize the thermal solution. For the Intel Pentium 4 Processor - M, this factor is especially important since the processor is not packaged with an integrated heat spreader (IHS), which serves to spread heat and create a stable environment on which the thermal interface can rest. The Intel Pentium 4 Processor includes the IHS.

The thickness of the thermal interface material, commonly referred to as the bond line thickness, must be minimized for best overall thermal performance. A large gap between the heat sink base and processor die yields a greater thermal resistance. The thickness of the gap is determined by the flatness of both the heat sink base and the processor die, the thickness of the thermal interface material, and the clamping force applied by the heat sink attachment clips. To ensure proper and consistent thermal performance, the TIM and application process must be properly designed.

The heat sink solution was optimized using a high-performance phase change thermal interface material (TIM) with low thermal impedance. Other materials, such as grease, may be used as long as the entire heat sink thermal is validated in the intended use environment. Vendor information for thermal interface material is provided in Chapter 6.0, “Vendor List”.

The designer must also consider the implications that the small die size and non-uniform power distribution have on the thermal interface material thermal resistance. The entire heat sink assembly must be validated together for specific applications, including the heat sink, clip, and thermal interface material.

4.6 Reference Thermal Solutions

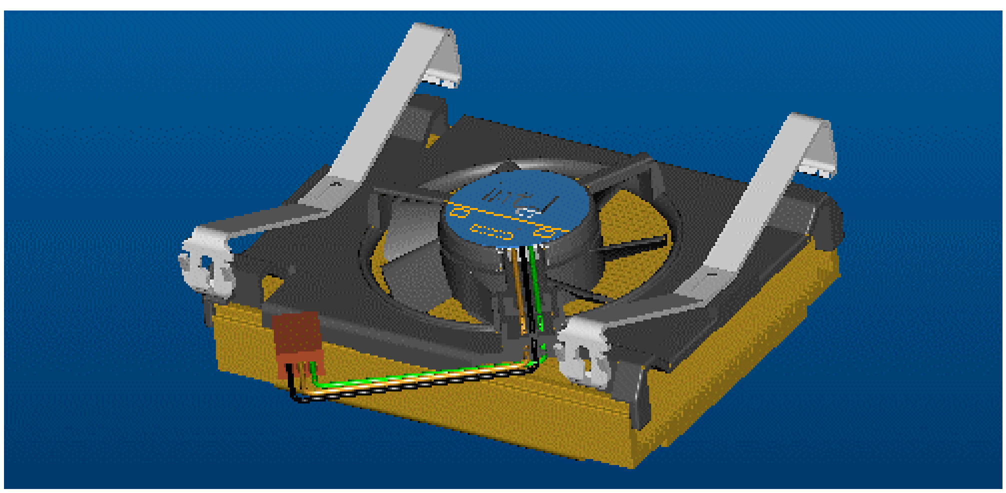
Intel has enabled two different active reference thermal solutions for the Intel Pentium 4 Processor - M. Both solutions fit within the volumetric envelope defined in Figure 7. See Chapter 6.0, “Vendor List” for vendor information.

4.6.1 Sanyo-Denki Active Heat Sink with Intel Retention Mechanism

The Sanyo-Denki active heat sink fits the retention mechanism described in Section 3.4.1, Retention Mechanism. This design was thermally verified using the desktop socket (µPGA478B) for the Intel Pentium 4 Processor - M. Use of any other socket has not been thermally verified and is the responsibility of the designer to test and validate. Separate mechanical validation has not been done on this design and is the responsibility of the OEM.

Sanyo-Denki Reference Thermal Solution Verification Results
Thermal Performance • θ_{ja} = 1.024º C/W

Figure 16. Sanyo-Denki Reference Thermal Solution for the Intel® Pentium 4® Processor-M (Utilizes Intel Retention Mechanism)

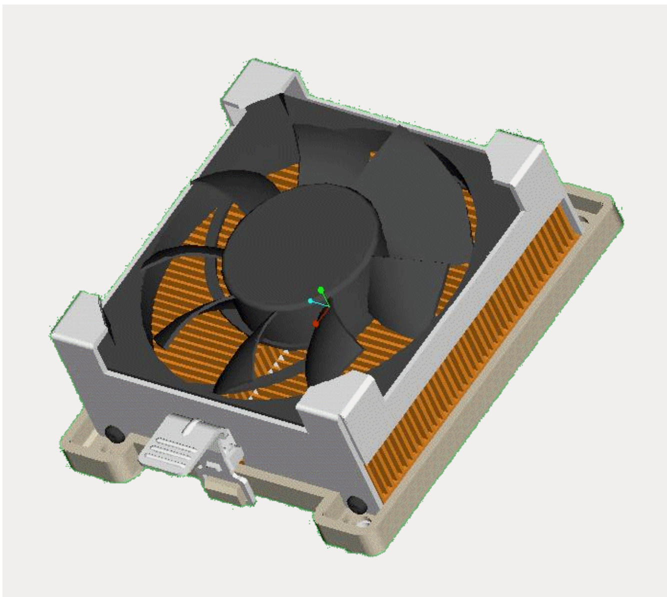


4.6.2 CoolerMaster* Active Heat Sink

The CoolerMaster heat sink was thermally verified using both the desktop (µPGA478B) abd nibuke (µPGA479M) sockets. The retention method is entirely a CoolerMaster design. The keep-out and size of the thermal solution are matched to fit the description set forth in Section 3.3. Separate mechanical validation has not been done on this design and is the responsibility of the OEM.

CoolerMaster* Reference Thermal Solution Verification Results
Thermal Performance • θ_{ja} = 1.132º C/W

Figure 17. CoolerMaster* Reference Thermal Solution for the Intel® Pentium 4® Processor-M (Utilizes a CoolerMaster Designed Mechanical Retention Mechanism)



5.0 On-Die Thermal Management

5.1 Thermal Monitor

The thermal monitor is a feature of the Intel Pentium 4 Processor - M that allows system designers to lower the cost of thermal solutions without compromising system integrity or reliability. The processor, without the aid of any additional software or hardware, can control the die temperature within factory specifications under typical real-world operating conditions via a factory-tuned, precision on-die temperature sensor and a fast-acting thermal control circuit (TCC).

The thermal monitor allows the processor and system thermal solutions to be designed much closer to the power envelopes of real applications, instead of being designed to the much higher maximum processor power envelopes.

The thermal monitor controls the processor temperature by modulating (starting and stopping) the internal processor core clocks. The processor clocks are modulated when the thermal control circuit is activated. The thermal monitor uses two modes to activate TCC; Automatic and On-Demand modes.

Note: Automatic mode must be enabled via the BIOS, which is required for the processor to operate within specification.

Once Automatic mode is enabled, the TCC activates only when T_j = 100° C. When the TCC is enabled and a high-temperature situation exists (i.e., TCC is active), the clocks are modulated by maintaining a duty cycle between the ranges of 30% - 50%. Clocks will not be off or on for more than 3.0 ms when the TCC is active. Cycle times are processor speed-dependent and will decrease as processor core frequency increases. An amount of hysteresis has been included to prevent rapid active/inactive transitions of the TCC when the processor temperature is near the trip-point.

Once the temperature has returned to a non-critical level and the hysteresis timer has expired, modulation ceases and the TCC goes inactive. Processor performance will decrease by approximately 50% when the TCC is active (assuming a duty cycle in the range of 30% - 50%). However, with a properly designed and characterized thermal solution the TCC will most likely only be activated briefly during the most power-intensive applications.

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

The TCC may also be activated via On-Demand mode. When bit 4 of the ACPI Thermal Monitor Control Register is a “1,” the TCC activates 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 Thermal Monitor Control Register. In Automatic mode, the duty cycle is fixed within the range of 30% to 50%. 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 may be used while Automatic mode is enabled. However, if the TCC via On-Demand and Automatic mode is enabled, **AND** a high-temperature condition exists, the fixed duty cycle of the Automatic mode overrides the duty cycle selected by the On-Demand mode.

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

Besides the thermal sensor and TCC, the Thermal Monitor feature also includes one ACPI register, one performance counter register, three model-specific registers, and on I/O pin (PROCHOT#). All are available to monitor and control the state of the Thermal Monitor feature. Thermal Monitor can be configured to generate an interrupt upon the assertion or de-assertion of PROCHOT# (i.e., upon the activation/deactivation of TCC). Refer to the *Intel® NetBurst™ Micro-Architecture BIOS Writer’s Guide* for specific register and programming details.

Caution: If Automatic mode is disabled, the processor will be operating out of specification and cannot be guaranteed to provide reliable results.

5.2 Thermal Diode

The Intel Pentium 4 Processor - M incorporates an on-die thermal diode that can be used to monitor the die temperature (T_j). A thermal sensor located on the motherboard, or a stand-alone measurement kit, may monitor the die temperature of the processor for laboratory thermal measurements. The reading of the thermal sensor connected to the thermal diode will not necessarily reflect the temperature of the hottest location on the die. Please see the document, *Intel Processor Thermal Performance Characterization Test Procedure*, and (contact an Intel Field Representative) for more information on how to use the thermal diode to estimate the temperature at the hottest location on the die.

5.3 Catastrophic Thermal Protection

The Intel Pentium 4 Processor - M supports the THERMTRIP# signal for catastrophic thermal protection. The activation on THERMTRIP# halts all processor clocks and activity at an approximate junction temperature of T_j=135° C (maximum). For more information, see the *Intel Pentium 4 Processor - M Datasheet.*

6.0 Vendor List

Table 4 provides a vendor list as a service to our customers for reference only. The inclusion of this list should not be considered a recommendation or product endorsement by Intel Corporation.

Table 4. Vendor List

Sanyo-Denki Reference Thermal Solution (includes heat sink, fan, and thermal interface material) **Sanyo-Denki Part Number: 109X9412G4046** **Reference Thermal Solution heat sink Clip** **Sanyo-Denki Part Number: 109-1011 (2 clips are required per heat sink assembly)**	
Sanyo-Denki, Inc.*	Contact: Harry Kawasami (310) 783-5430 haruhiko@sanyo-denki.com

CoolerMaster* Thermal Solution (includes heat sink, fan, clip, thermal interface material, retention mechanism, back plate, and four mounting screws) **CoolerMaster Part Number: ECU-PNA1C-35**	
CoolerMaster	Contact: Wendy Lin 886-2-3234-0050 ext. 333 wendy@coolermaster.com.tw

Intel Retention Mechanism (Intel Part Number A65428-001 rev c)	
Foxconn*	Contact: Julia Jiang (408) 919-6178 juliaj@foxconn.com
Thermal Interface Material	
Thermagon, Inc.	Contact: (888) 246-9050
ShinEtsu* Micro-Si	Contact: (480) 893-8898
µPGA478B Socket	
Foxconn (Intel Part Number A16104-006)	Contact: Julia Jiang (408) 919-6178 juliaj@foxconn.com
Tyco/Amp, Inc.* (Intel Part Number A42093-002)	Contact: Ralph Spayd (717) 592-7653 respayd@tycoelectronics.com
µPGA479M Socket	
Foxconn (Vendor Part Number PZ47903-2741-6)	Contact: Julia Jiang (408) 919-6178 juliaj@foxconn.com
Tyco/Amp, Inc.* (Vendor Part Number 2-1473128-1)	Contact: Dave Bender (717) 592-4347 drbender@tycoelectronics.com