Intel® Pentium® III Processor – Low-Power Module Thermal Design Guide

Application Note

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Contents

1.0 Introduction 5

2.0 Importance of Thermal Management 5

3.0 Low-Power Module Thermal Specifications 6

- 3.1 Thermal Diode Temperature Sensor 6

4.0 Thermal Characterization Data 7

5.0 Determining Thermal Solution Design Parameters 11

- 5.1 Measuring Ambient Temperature 11
- 5.2 Measuring Case Temperature 11
- 5.3 Calculating Case-to-Ambient Thermal Resistance 12
- 5.4 Measuring Airflow 12

6.0 Thermal Solution Design Considerations 13

- 6.1 CompactPCI Component Height Requirements 13
- 6.2 Heatsink Solutions 13
  - 6.2.1 Theory of Heatsink Operation 13
  - 6.2.2 Considerations for Implementing a Heatsink Thermal Solution 14
- 6.3 Fan Solutions 14
  - 6.3.1 Theory of Fan Operation 14
  - 6.3.2 Considerations for Implementing a Fan Thermal Solution 14
- 6.4 Heatpipe Solutions 14
  - 6.4.1 Theory of Heatpipe Operation 15
  - 6.4.2 Considerations for Implementing a Heatpipe Thermal Solution 15
- 6.5 Interface Material 16
- 6.6 Attach Method 16
  - 6.6.1 Thermal Transfer Plate (TTP) 16

7.0 Related Documents 17

8.0 Vendor List 17

Figures

1 Heat Pipe Thermal Resistance vs. Airflow 8
2 Passive Heatsink Thermal Resistance vs. Airflow 9
3 Fan Heatsink Thermal Resistance vs. Airflow 10
4 Mounting the Thermocouple 11
5 Compact PCI Height Requirements 13
6 Location of the Thermal Solution for Development/Design Purposes 16

Tables

1 Thermal Design Power and Case Temperature Specification 6
2 SMBUS Interface Signals.. 7
3 Thermal Sensor SMBus Address Table... 7
4 Thermal Resistance vs. System Airflow for Various Thermal Reference Designs 8
5 Related Documents.. 17
6 Vendor List 17

1.0 Introduction

The Pentium® III Processor – Low-Power Module is a small, highly integrated assembly containing the following components:

- Intel® Pentium III processor available at 500 MHz core speeds - 100 MHz processor side bus
- 82443BX Host Bridge/Controller (Northbridge)
- 256-Kbyte on-die L2 cache
- Voltage regulator
- SMBus thermal sensor

The Low-Power Module interfaces to the system via a high density 400-pin BGA connector. Interfaces such as the PCI, DRAM, and AGP buses along with some host bridge sideband signals are bonded out through this connector.

A thermal transfer plate (TTP), which is physically mounted to the Low-Power Module, is provided as an attachment method for a thermal solution. The TTP consists of two M2 screw standoffs for attaching the thermal solution. The TTP thermal resistance measured between the processor core and the top of the TTP is less than 1° C/ W.

As the performance thresholds rise it becomes increasingly important to develop and manage effective thermal solutions.

This application note:

- Introduces the targeted thermal requirements of the Low-Power Module
- Discusses attachment methods for thermal solutions
- Defines targeted thermal parameters and clarifies terminology
- Identifies the concepts and airflow calculations for the design of thermal solutions. Sample calculations are also provided.
- Identifies the z-height constraints of a thermal solution for a single slot CompactPCI (CPCI) Low-Power Module design
- Discusses theory of operation and implementation considerations for various thermal solutions
- Provides a list of thermal solution vendors for the Low-Power Module

2.0 Importance of Thermal Management

The objective of thermal management is to ensure that the temperature of each component is maintained within specified functional limits. The functional temperature limit is the range within which the electrical circuits can be expected to meet their specified performance requirements. Operation outside the functional limit can degrade system performance and cause reliability problems.

The case temperature is the surface temperature of the package at its hottest point, typically at the geographical center of the chip. Temperatures exceeding the case temperature limit over a length of time can cause physical destruction or may result in irreversible changes in operating characteristics.

3.0 Low-Power Module Thermal Specifications

The thermal design power (TDP) for the Low Power Module is shown in Table 1. The processor core dissipates the majority of the thermal power. A thermal solution should be designed to ensure that the maximum case temperature of the TTP (85° C) is not exceeded.

TDP is a specification of the total power dissipation of the processor, 82443BX Host Bridge/ Controller, L2 cache, and voltage regulator while executing an application under normal operating conditions at nominal voltages.

A thermal solution should be designed to ensure the junction temperature (T_J) never exceeds the specifications. If no closed loop thermal fail-safe mechanism (processor throttling) is present to maintain T_J within specification, the thermal solution should be designed to cool the maximum power condition. If a thermal fail-safe mechanism is present, the thermal solution could possibly be designed to a typical Thermal Design Power (TDP_{TYP}). TDP_{TYP} is a thermal design power recommendation based on the power dissipation of the processor while executing publicly available software under normal operating conditions at nominal voltages. TDP_{TYP} power is lower than TDP_{MAX}. Contact your Intel Field Sales Representative for further information.

Table 1. Thermal Design Power and Case Temperature Specification

Low Power Module Frequency	Thermal Design Power (TDP_{MAX}), Case Temp of TTP = 85° C[1,2]
500 MHz	15.0 W

NOTES:

1. The case temperature value assumes a 1° C thermal resistance for the TTP, which results in a temperature rise of 15° C at max power dissipation. Thus, the case temperature on the top surface of the TTP would be $T_{C,module} \sim T_{j,\ processor} - T_{ttp,rise} = 100° C - 15° C = 85° C$.
2. Not 100% tested. Specified by design/characterization.

3.1 Thermal Diode Temperature Sensor

The Pentium III Processor – Low Power incorporates an on-die thermal diode that can be used to monitor the die temperature (T_J). A thermal sensor located on the Low-Power Module monitors the die temperature of the processor for thermal management or instrumentation purposes.

The reading of the thermal sensor will not necessarily reflect the temperature of the hottest location on the die. This is due to inaccuracies in the thermal sensor, on-die temperature gradients between the location of the thermal diode and the hottest location on the die at a given point in time, and time based variations in the die temperature measurement. Time based variations can occur when the sampling rate of the thermal diode (by the thermal sensor) is slower than the rate at which the T_J temperature can change.

On the Low-Power Module, the thermal sensor is controlled using two signals on the SMBUS. The SM_CLK and SM_DATA signals refer to the two-wire serial SMBus interface. Although this interface is currently used on the Low-Power Module only for the digital thermal sensor, the SMBus contains reserved serial addresses for future use. These signals are described in Table 2. For more information about using the module's thermal sensor, see the *Mobile Pentium® II Processor and Pentium® II Processor Mobile Module Thermal Sensor Interface Specifications* application note.

Table 2. SMBUS Interface Signals

Name	Type[†]	Voltage	Description
SM_CLK	I/O D CMOS	V_3	**Serial Clock:** This clock signal is used on the SMBus interface to the digital thermal sensor.
SM_DATA	I/O D CMOS	V_3	**Serial Data:** Open-drain data signal on the SMBus interface to the digital thermal sensor.

† Refer to the datasheet for the Type descriptions.

Table 3 identifies the address allocated for the SMBus thermal sensor used on the module.

Table 3. Thermal Sensor SMBus Address Table

Function	Fixed Address AD Bits (6:4)	Selectable Address AD Bits (3:0)
Thermal Sensor	100	1110
Reserved	010	1010
Reserved	010	1011

NOTE: The thermal sensor used is compliant with SMBus addressing. Please refer to the *Mobile Pentium® II Processor and Pentium® II Processor Mobile Module Thermal Sensor Interface Specifications*.

4.0 Thermal Characterization Data

Thermal solutions vendors have developed reference designs for the Low-Power Module. Refer to Section 8.0 for a list of vendors for each type of solution. Three types of thermal solutions are available to accommodate various system design requirements:

- Heatsink
- Fan heatsink
- Heatpipe with a cooling device

The thermal characterization data described in Table 4 illustrates that a thermal solution may be needed depending on the system's operating ambient temperature and the system airflow that can be provided. The size of the heatsink and the amount of airflow are interrelated and can be optimized for a given system. For example, an increase in heatsink size decreases the amount of airflow required. In a typical system, heatsink size is limited by board layout, spacing, and component placement. Airflow is limited by the size and number of system fans and their placement in relation to the components and the airflow channels. Acoustic noise and life-expectancy constraints may also limit the size or types of fans used in the system.

Note: The inclusion of these reference designs by third-party thermal solution vendors should not be considered a recommendation or product endorsement by Intel Corporation.

Table 4. Thermal Resistance vs. System Airflow for Various Thermal Reference Designs

Reference Designs	**θ_{ca} [°C/W]**				
	600 lfm	**400 lfm**	**200 lfm**	**100 lfm**	**0 lfm**
Aavid extruded heatsink (4” x 2.55” x 0.73”)	1.76	1.88	2.40	3.15	5.19
Sumitomo corrugated heatsink (4” x 2.55” x 0.65”)	1.73	1.80	2.20	3.05	5.25
Sumitomo corrugated heatsink (4” x 2.55” x 0.4”)	2.03	2.32	3.17	4.83	7.60
Fujikura Heatpipe		2.54	3.53	4.40	5.20
Thermacore Heatpipe		2.85	3.46	4.09	4.40
Sanyo Denki Fan Heatsink		2.80	3.00	3.15	3.30
Panasonic Fan Heatsink		2.13	2.25	2.40	2.52

Figure 1. Heat Pipe Thermal Resistance vs. Airflow

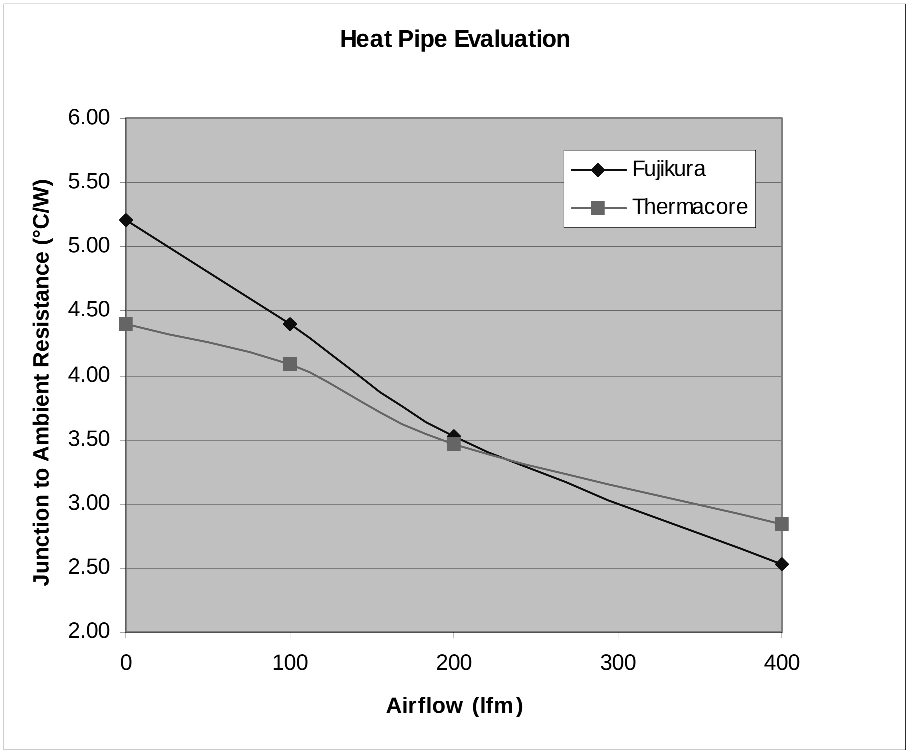


Figure 2. Passive Heatsink Thermal Resistance vs. Airflow

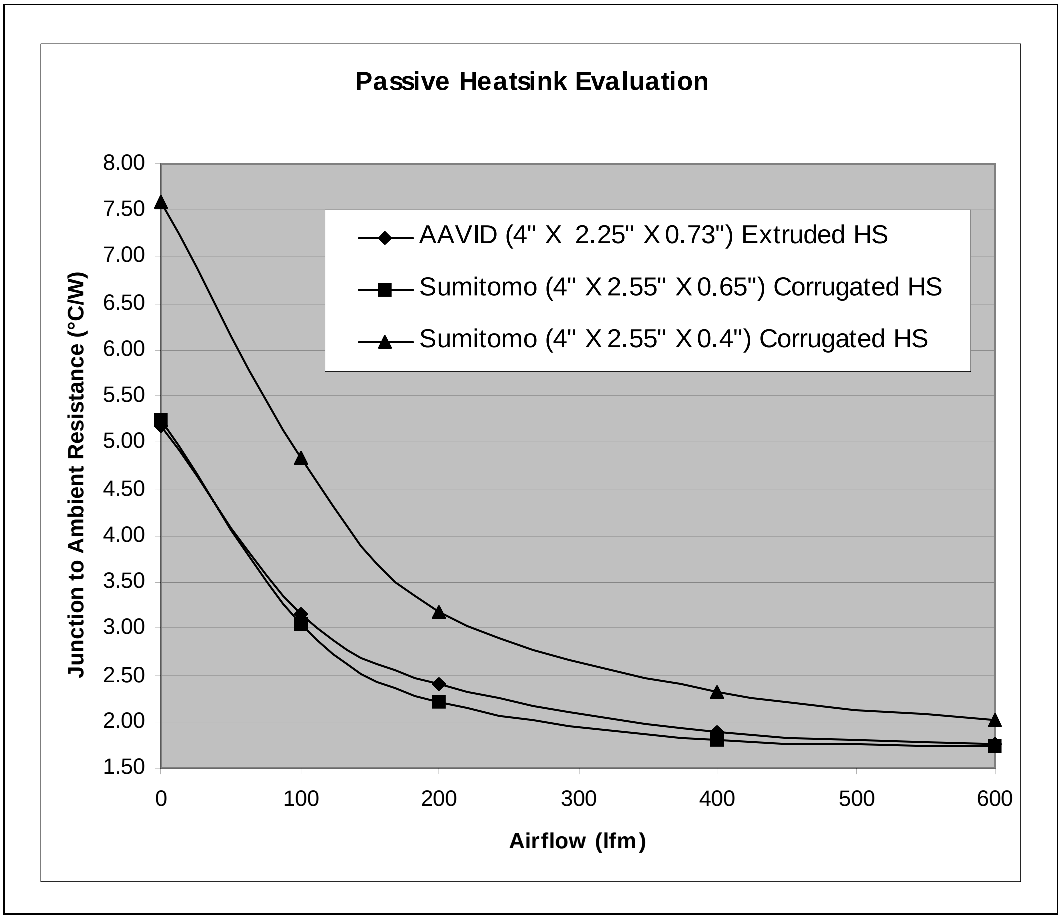
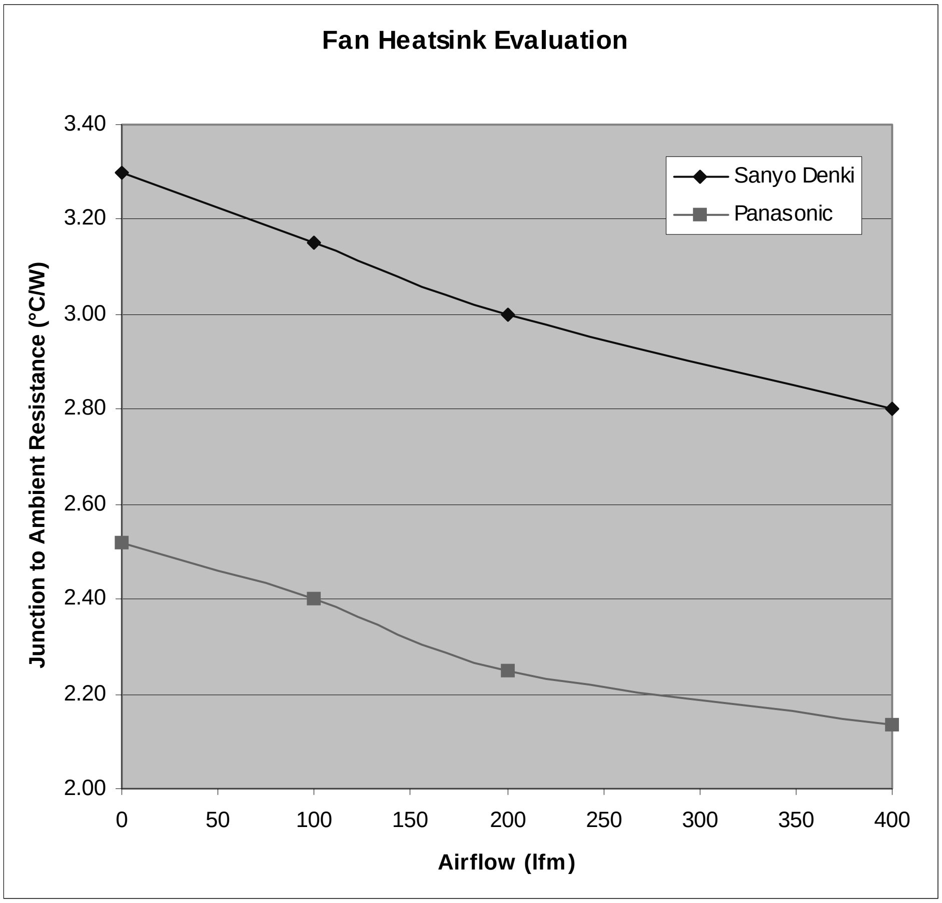


Figure 3. Fan Heatsink Thermal Resistance vs. Airflow



5.0 Determining Thermal Solution Design Parameters

5.1 Measuring Ambient Temperature

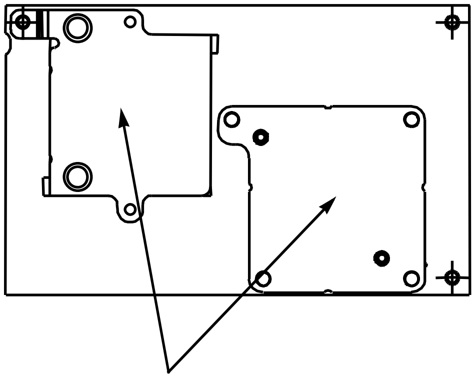
Ambient temperature (T_A) is the temperature of the undistributed air surrounding the module. Ambient temperature is usually measured at a specified distance from the module. In a system environment, ambient temperature is the temperature of the air upstream to the module and in its close vicinity. In a typical laboratory test environment, ambient temperature is measured 12 inches (or as close to 12 inches as possible) upstream from the module to represent the ambient temperature with air flowing past the system. When natural convection is used in a system, the ambient temperature is measured directly underneath the board module. In an active cooling system, the ambient temperature is the inlet air to the active cooling device.

5.2 Measuring Case Temperature

To verify that the proper case temperature (T_C) is maintained for the Low-Power Module, it should be measured at the top surface of the TTP, centered above the processor package. To minimize any measurement errors, the following techniques and materials are recommended:

- Use 36 AWG or finer diameter K, T, or J type thermocouples. Intel’s laboratory testing was performed using a thermocouple offered by Omega Engineering, Inc. (part number: 5TC-TTK-36-36).
- Attach the thermocouple bead or junction to the center and top surface of the package using a cement or glue that is highly thermally conductive. Intel’s laboratory testing was performed using Omega Bond* (Part number: OB-101).
- Attach the thermocouple at a 0° angle on the center of the top surface of the TTP above the processor and chipset packages, as shown in Figure 4.

Figure 4. Mounting the Thermocouple



Measure case temperature at center of thermal transfer plates above the processor and chipset

5.3 Calculating Case-to-Ambient Thermal Resistance

The case-to-ambient thermal resistance determines the performance of the thermal solution and can be calculated using the following equation:

Equation 1. $\theta_{CA} = (T_C - T_A)/P$

where:

θ_{CA} = case-to-ambient thermal resistance (°C/W)
T_A = ambient temperature (°C)
T_C = case temperature (°C)
P = device power dissipation (Watts)

The lower the thermal resistance between the case and the ambient air, the more efficient the thermal solution.

The thermal resistance values depend on the material, thermal conductivity, thermal interface material, and geometry of the thermal cooling solution and airflow rates.

Example 1. Assuming worst case conditions

Case temperature of TTP = 85° C
Ambient temperature = 50° C
Power = 15.0 W @ 500 MHz

The case-to-ambient thermal resistance is calculated to be 2.3° C/W. Referring to Figures 1 through 3 and Table 4 on page 8, the estimated worst-case system airflow for the following thermal solutions is:

- Passive heatsinks require 200 to 400 LFM, depending on solution chosen
- Passive heatpipes with attached heatsinks require up to 500 LFM
- Active fan heatsinks require up to 150 LFM (only the Panasonic fan meets requirements)

Note: Solutions can be optimized to reduce system airflow. The samples characterized were not optimized.

5.4 Measuring Airflow

The airflow, or air velocity flowing across the components, can be measured using a portable air velocity meter (anemometer). The meter contains two temperature sensing elements. The first element is used to track the air stream temperature and the second element is heated by an electrical current to maintain a constant temperature above the air stream temperature. As the air stream takes heat energy away from the heated element, more current is required to maintain the temperature differential. The required electrical current is proportional to the air mass velocity displayed on the meter. This meter is available from Kurz Instruments. Refer to the vendor list in Section 8.0 for vendor information.

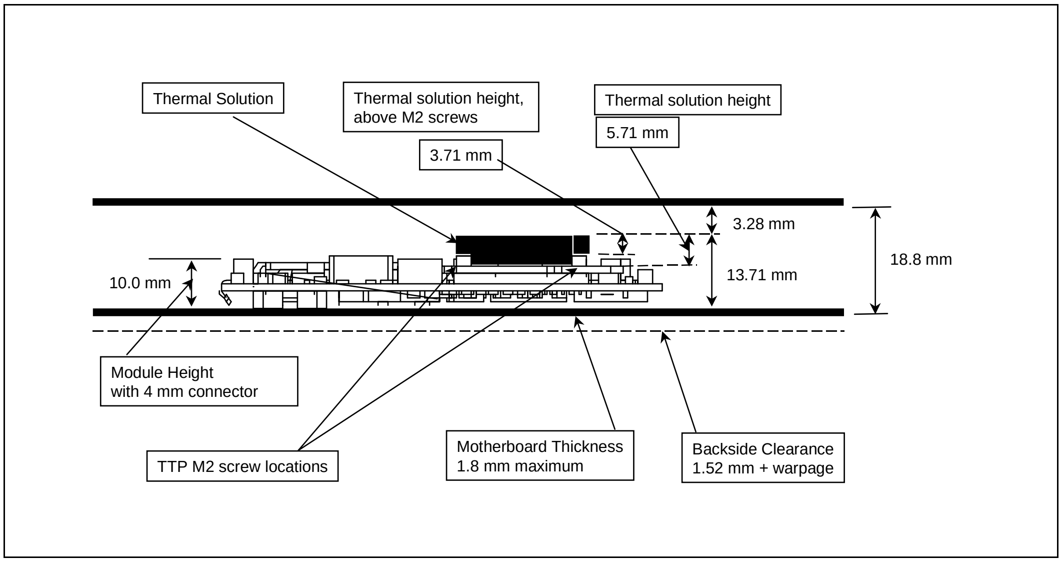
6.0 Thermal Solution Design Considerations

6.1 CompactPCI Component Height Requirements

Hybrid heatpipe solutions have been developed to meet the single slot CompactPCI z-height constraints. Standard heatsinks or fans may be used for designs with relaxed z-height constraints or for dual slot CPCI solutions.

Figure 5 illustrates the height restrictions faced by a single-slot CPCI application. The minimum z-height for the Low-Power Module, including the mated connectors, is 10.00 mm. For a single slot CPCI solution, the maximum z-height of the Low-Power Module, connector, and thermal solution should be 13.71 mm. The remaining height for the thermal solution is 3.71 mm, measured from the top of the screw hole stand-offs of the thermal transfer plate (TTP). Vendors have 5.71 mm from the top of the TTP except at the mounting hole location for mounting of the thermal solution.

Figure 5. Compact PCI Height Requirements



6.2 Heatsink Solutions

6.2.1 Theory of Heatsink Operation

A heatsink is simply a metal surface with pins or fins rising up off the surface. Heatsinks are used to cool electronic devices by expanding the surface area of the part to which it is attached, increasing the amount of heat that can be cooled by the ambient air. A main characteristic of heatsinks is thermal resistance (θ), measured in ° C/W. For example, if a design has a heatsink with a thermal resistance θ = 2° C/W, then for every watt of heat it dissipates its temperature increases by 2° C.

6.2.2 Considerations for Implementing a Heatsink Thermal Solution

The following points should be considered when evaluating heatsink thermal solutions:

- **Cost.** Heatsink solutions typically are cheaper than the fan and heatpipe solutions.
- **Flexibility in x, y and z dimensions.** Based on the amount of airflow available in the system, a design may require a larger block of heatsink to dissipate a specified amount of heat. System designers may need to be flexible in at least one or two dimensions.
- **System airflow.** It is desirable to have some system airflow to allow heat to be removed from the heatsink.

6.3 Fan Solutions

Passive-active fan heatsink solutions provide airflow and require little or no system airflow. Active fan heatsink solutions incorporate a fan that is attached to the solution. They can handle a load of up to 160 W.

6.3.1 Theory of Fan Operation

The typical fan involves a motor and a propeller. The motor can be either an AC induction motor or a brushless DC motor. The air movement that a fan produces blows parallel to the fan's blade axis. These fans can be made to blow a significant amount of air, but they work against low pressure. Fans can be used alone to blow cool intake air through the processor, pushing warm air out. They can also be used in passive thermal solutions to blow hot air off heatsinks.

6.3.2 Considerations for Implementing a Fan Thermal Solution

The following points should be considered when evaluating fan thermal solutions:

- **Performance at a moderate cost.** Fan solutions typically cost more than heatsink solutions but less than heatpipe solutions.
- **System airflow.** When there is no system airflow, a fan solution provides an excellent source of dedicated airflow, which can be critical in ensuring removal of heat from the heat source.
- **Flexibility in x, y or z dimensions.** The size of the required fan solution can vary according to the amount of heat that must be dissipated, the availability of system airflow, and other factors. To achieve certain thermal requirements, a system designer may need to be flexible with one or more dimensions of the design.
- **Reliability.** Fans are reliable and typically have a life of 100,000 hours depending on the fan design and the manufacturer's standards.

6.4 Heatpipe Solutions

Another type of thermal solution is the phase change recirculating system. This solution uses heatpipes that either contain a wick or are helped by gravity. This solution can handle loads of approximately up to 150 W.

6.4.1 Theory of Heatpipe Operation

A heatpipe, in its simplest sense, is a heat moving or spreading device; it acquires heat from a source, such as the embedded module, and moves or spreads it to a region where it can be more readily rejected.

A typical heatpipe is a sealed and evacuated tube, a porous wick structure and a very small amount of working fluid on the inside (typically water is used). A porous wick structure, such as sintered powder metal, lines the internal diameter of the tube. The center core of the tube is left open to permit vapor flow. The heatpipe has three sections: evaporator, adiabatic, and condenser. As heat enters the evaporator section, it is absorbed by the vaporization of the working fluid. The generated vapor travels down the center of the tube through the adiabatic section to the condenser section where the vapor condenses, giving up its latent heat of fusion. The condensed fluid is returned to the evaporator section by gravity or by capillary pumping in the porous wick structure. Heatpipe operation is completely passive and continuous. The heatpipe moves this heat with very little drop in temperature.

Most electronic cooling applications use a copper heatpipe with water as the working fluid.

6.4.2 Considerations for Implementing a Heatpipe Thermal Solution

The following points should be considered when evaluating heatpipe solutions:

- **Limited to single slot CPCI z-height.** In some applications, the height over the embedded module does not provide sufficient space to provide direct cooling at this location. A heatpipe in this situation can be used to move the heat to a location where it can be effectively dissipated by natural or forced convection.
- **Power Consumption.** Cooling with a fan requires electricity. A heatpipe allows the developer to acquire additional surface area for heat rejection by natural convection, thus eliminating the need for a fan. If a natural convection cooling solution is needed, a heatpipe to a miniature fan or heatsink might be more economical than a large system fan solution.
- **No noise (or noise reduction).** Cooling by natural convection eliminates fan noise. If volume constraints limit the use of a natural convection cooling solution, a heatpipe to a miniature fan/sink will result in less noise than a large system fan solution.
- **High Reliability.** All electro-mechanical devices such as fans have finite life. A heatpipe thermal solution has no moving parts to fail; consequently, product maintenance requirements are eliminated or reduced.
- **Sealed enclosure cooling.** In some applications, the Low-Power Module may be in a sealed enclosure to protect it from the environment. An example is an industrial PC located in an unclean environment. In this situation, the heat needs to be evacuated to the outside of the sealed enclosure. The heatpipe provides a thermal path to the enclosure wall.
- **No system airflow is available.**
- **Extended ambient temperatures.** Requires a heatpipe solution to have a thermal solution with the lowest thermal resistance (1-2° C/W).

6.5 Interface Material

Heat generated by a semiconductor device must be removed to the ambient environment to ensure reliable operation of the device. Unless space is available to provide sufficient forced convection cooling, this requires a series of physical interfaces to provide a thermally conductive path. These interfaces must offer minimum resistance to heat flow and often must provide electrical isolation. Such requirements can be met by using thermal interface materials. Thermal interface materials can reduce contact resistance by conforming to two mating surfaces and eliminating air gaps.

The optimal material for interfacing the TTP surface to the thermal solution surface must be determined for each application. An available interface material is the Thermagon T-Pli 210 thermally conductive dielectric elastomeric material. The thickness is approximately 5-10 mils for the processor and 10-40 mils for the BX chipset. This elastomer has a θ_{jp} value of approximately 0.76° C/W. Shin-Etsu grease may also be an option. The θ_{jp} for Shin-Etsu grease is 0.46° C/W.

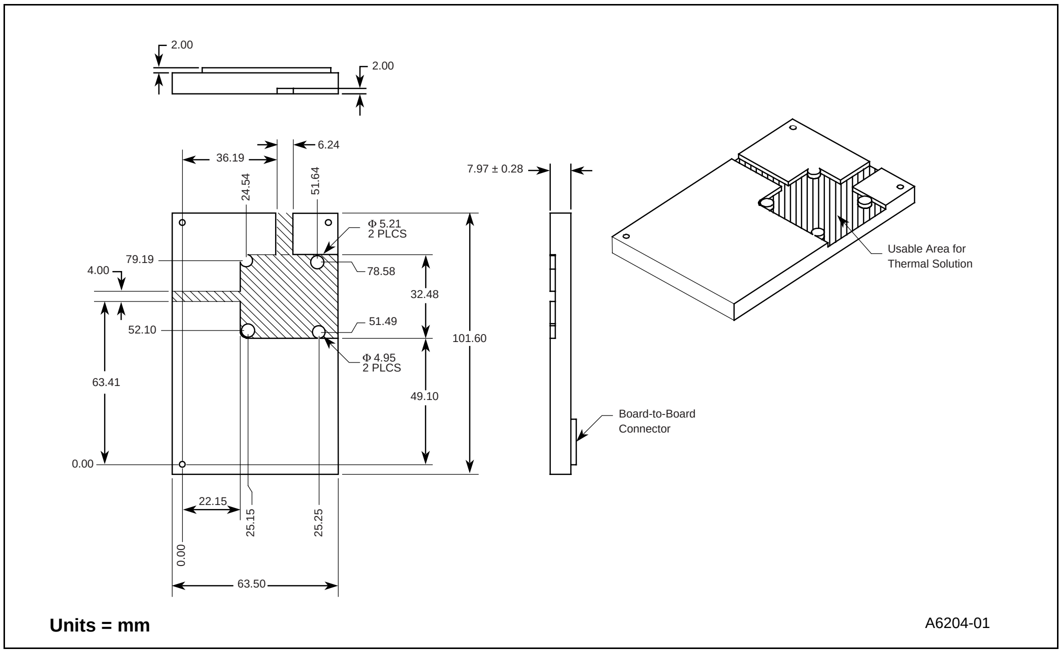
Note: Mention of specific brand-name interface materials should not be considered a recommendation or product endorsement by Intel Corporation.

6.6 Attach Method

6.6.1 Thermal Transfer Plate (TTP)

The Low-Power Module contains a thermal transfer plate (TTP). Figure 6 shows the area (dashed lines) where the thermal solution should be mounted and the dimensions the thermal solution designer can work within. The TTP thermal resistance as measured between the processor core and the thermal interface (the thermal attach point on top of the TTP) is less than or equal to 1° C/W. The thermal transfer plate is physically mounted to the Low-Power Module and may be different for other generations of Intel modules.

Figure 6. Location of the Thermal Solution for Development/Design Purposes



7.0 Related Documents

These documents are available for download from Intel’s World Wide Web site at http://www.intel.com.

Table 5. Related Documents

Document	Order Number
Intel Pentium® III Processor Low-Power Module datasheet	273299
Mobile Pentium® II Processor and Pentium® II Processor Mobile Module Thermal Sensor Interface Specifications	243724
Intel Packaging Handbook	240800

8.0 Vendor List

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

Table 6. Vendor List (Sheet 1 of 2)

Heat Sink Vendors	
Aavid Thermal Products, Inc. 143 N. Main St., Ste. 206 Concord, NH 03301 Phone: 603 224-9988 Fax: 603-223-1738 E-mail: chapman@aavid.com http://www.aavid.com	**Sumitomo Precision Products Co., LTD.** C/O Sumitronics, Inc. 2900 Patrick Henry Dr. Santa Clara, CA 95054-1833 Phone: 408-980-0811 Fax: 408-980-1409 http://www.sumitronics.com *Japan*: E-mail: heatsink@spp.co.jp Phone:81-6-6489-5832 Fax: 81-6-6489-5879
Fan Heatsink Vendors[†]	
Panasonic Fan Heatsink: *North America:* **Panasonic Industrial Co.** 15075 SW Koll Parkway Suite B Beaverton, OR 97006 Phone: 503-641-8743 Fax: 503-643-8933 http://www.panasonic.com *Japan:* **Kyushu Matsushita Electric** 2111 UEDA OITA, 879-04 Japan Phone: (0978)37-1991 Fax: (0978)37-3502	**Sanyo Denki America, Inc.** 468 Amapola Ave. Torrance, CA 90501-1474 Phone: 888-616-7987 Fax: 310-212-6545 http://www.sanyo-denki.com

[†] For all other areas, please contact your local Panasonic Sales Office.

Table 6. Vendor List (Sheet 2 of 2)

Heat Pipe and Heat Exchanger Vendors	
Fujikura America, Inc. 3001 Oakmead Village Drive Santa Clara, CA 95051-0811 Phone: 408-988-7408 or 408-988-7415 Fax: 408-727-3515 http://www.fujikura.com/product/htm	**Thermacore, Inc.** 780 Eden Road Lancaster, PA 17601 Phone: 717-569-6551 Fax: 717-569-4797 http://www.thermacore.com
Furukawa Electric North America, Inc. **(A division of Fitel Technologies, Inc.)** 200 Westpark Dr., Ste. 190 Peachtree City, GA 30269 Phone: 770-487-1234 Fax: 770-487-9910 http://www.furukawa-usa.com	
Interface Material Vendors	
MicroSi (Thermal Grease) 10028 S. 51st St. Phoenix, AZ 85044 Phone: 480-893-8898 Fax: 480-893-8637 http://www.microsi.com	**Thermagon, Inc.** (Elastomer) 3256 W. 25th St. Cleveland, OH 44109-1668 Phone: 888-246-9050 Fax: 216-741-3943 http://www.thermagon.com
Air Velocity Meter Supplier	
Kurz Instruments, Inc. 2411 Garden Road Monterey, CA 93940 Phone: 800-424-7356 Fax: 831/646-8901 http://www.kurz-instruments.com	
Copper Heat Spreader Supplier	
Chomerics 77 Dragon Court Woburn, MA 01888-4014 Phone: 781-935-4850 Fax: 781-933-4318 http://www.chomerics.com	
CompactPCI Specification	
Rogers Communications, Inc. 401 Edgewater Place, Suite 500 Wakefield, MA 01880-6212 Phone: 781-224-1100 Fax: 781-224-1239 http://rogers.com	
Temperature Measurement Suppliers	
Omega Engineering, Inc. One Omega Drive P.O. Box 4047 Stamford, CT 06907 Phone: 1-800-622-2378 http://www.omega.com	

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