Pentium® II Processor Mobile Module: Embedded Module Connector-2 Thermal Design Guide

Application Note

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Order Number: 273216-001

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1.0 Introduction

The Pentium® II Processor Mobile Module: Embedded Module Connector II (EMC-2) is a small, highly integrated assembly containing an Intel® Pentium II processor @ 266 MHz core, the 443BX Northbridge, 512 Kbytes L2 cache, a voltage regulator, and an SMBus thermal sensor. The EMC-2 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 EMC-2 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 EMC-2 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) EMC-2 design
- Discusses theory of operation and implementation considerations for various thermal solutions
- Provides a list of thermal solution vendors for the EMC-2 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 EMC-2 Thermal Specifications

3.1 Targeted Thermal Performance Parameters

The Pentium II processor at 266 MHz with the 443BX chipset, L2 cache, and voltage regulator (VR) dissipates a thermal design power maximum (TDP max) of 13.4 W when a case temperature of approximately 86° C is maintained. 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 is never exceeded. The specified maximum ambient temperature for module operation is 55 °C. However, the thermal solutions are targeted for operation in the ambient temperature range of 50-70 °C. The criteria is subject to change after thermal validation.

All thermal solutions for the EMC-2 module must be designed to meet the thermal specifications indicated in Table 1.

Table 1. EMC-2 Targeted Thermal Requirements

Parameter	Criteria
EMC2 Module Requirements	
Case Temperature, TTP (T_C)†	86 °C
Case Temperature, processor ($T_{C\ processor}$)	100 °C
Ambient temperature	50 - 70 °C
System Airflow for fan/heatpipe solution	0 to 200 LFM
System Airflow for heat sink solution	300 LFM
EMC-2 Board form factor	63.50 mm X 101.6 mm X 10.0 mm
Fan Tachometer	required
Typical Power @ 266 MHz	9.3 W
Max. Thermal Design Power @ 266 MHz	13.4 W

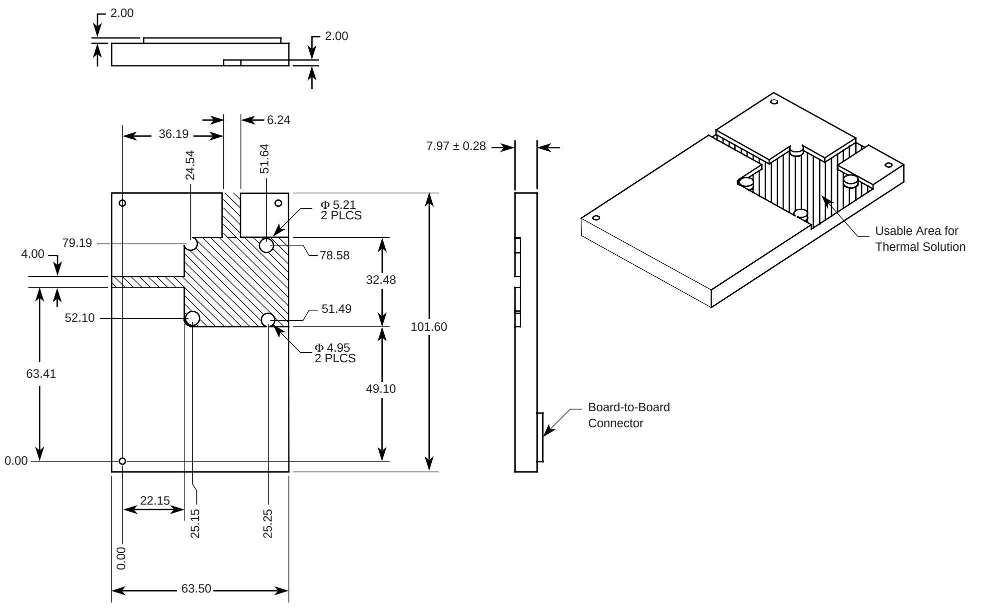
† The case temperature values assume 1 °C/W for the TTP, a temperature rise of 13.4 °C for maximum power dissipation. Thus the case temperature on top of the TTP would be $T_{C\ module} \sim T_j - T_{C\ processor,}$ ttp = 100 -13.4, C = 86.6 °C (top of TTP surface).

3.2 Attach Method

3.2.1 Thermal Transfer Plate (TTP)

The EMC-2 module contains a thermal transfer plate (TTP). Figure 1 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 EMC-2 and may be different for other generations of Intel mobile modules.

Figure 1. Placement of Thermal Solution on TTP



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3.2.2 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 using interface materials or 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. The proposed 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 ºC/W.

4.0 Thermal Parameters

4.1 Ambient Temperature

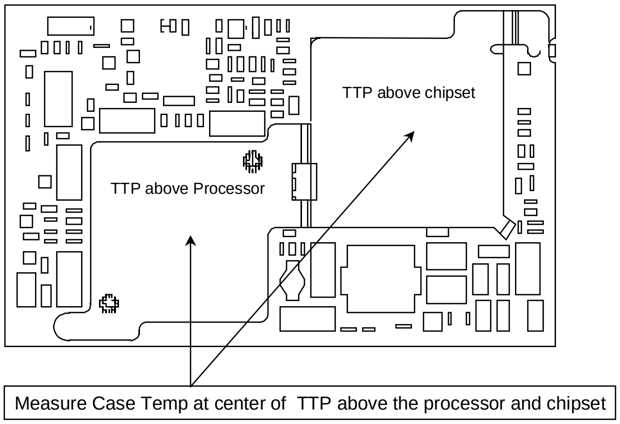
Ambient temperature (T_A) is the temperature of the undistributed air surrounding the module. Ambient temperature is usually measured at a specified distance from the module. In a system environment, ambient temperature is the temperature of the air upstream to the module and in its close vicinity. In 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.

4.2 Measuring Case Temperature

To verify that the proper case temperature (T_C) is maintained for the EMC-2, 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 2.

Figure 2. Mounting the Thermocouple



4.3 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.

For example, assuming worst case conditions:

- the case temperature at the surface of the TTP is 86 °C (with max power dissipation and thermal resistance of 1 °C/W)
- the ambient temperature is 55 °C
- the TDP max dissipated by the EMC-2 module is 13.4 W

then the case-to-ambient thermal resistance (θ_{CA}) = 2.31 °C/W.

Knowing the θ_{CA} value allows the system designer to estimate the airflow required to keep the TTP case temperature at 86° C and to determine the best orientation of the board to satisfy the minimum airflow requirement.

4.4 Airflow Measurement

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. One 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 7.0 for vendor information.

5.0 Thermal Solution Options for the EMC-2

Thermal solutions vendors have developed reference designs for the EMC-2 module. Refer to Section 7.0 for a list of vendors for each type of solution. Three types of thermal solutions are available to accommodate various system design requirements:

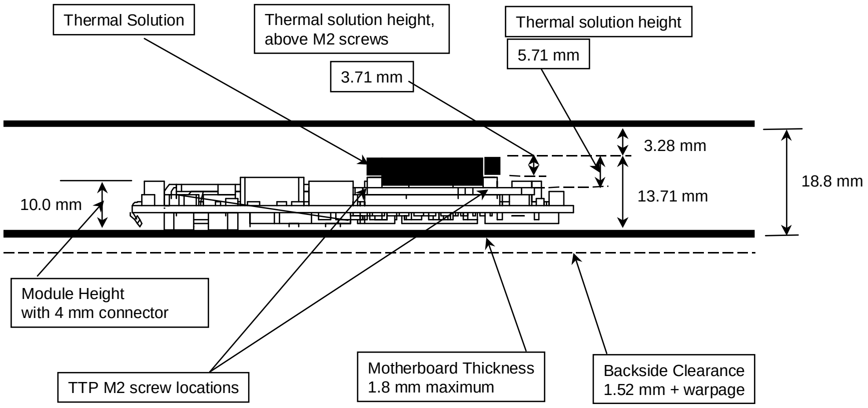
- heat sink
- fan heat sink
- heatpipe with a cooling device

5.1 CompactPCI Component Height Requirements (for Heatpipe Solution Only)

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 3 illustrates the height restrictions faced by a single-slot CPCI application. The minimum z-height for an EMC-2 module, including the mated connectors, is 10.00 mm. For a single slot CPCI solution, the maximum z-height of the EMC-2 module, connector, and thermal solution should be 13.71 mm. Thus, 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 3. CompactPCI Height Requirements



5.2 Heatsink Solutions

5.2.1 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 heatsink with a thermal resistance $\theta = 2$ °C/W, then for every watt of heat it dissipates its temperature increases by 2 °C. The larger the heatsink, i.e., the more surface area it has, the better its thermal resistance. A simple (rough) formula for calculating the area needed for a heatsink is:

$$A = \left[\frac{50}{C / W} \right]$$ where the area A is expressed in cm^2.

5.2.2 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.

5.3 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 watts.

5.3.1 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 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 ventilate cool intake air through the processor, pushing warm air out. Or, they can be used in passive thermal solutions to blow hot air off of heatsinks.

5.3.2 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 prompt 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.

5.4 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 watts.

5.4.1 Theory of Heatpipe Operation

A heatpipe, in its simplest sense, is a heat mover or spreader; 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. 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.

5.4.2 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.
- **Low maintenance.** 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 EMC-2 module may be in a sealed enclosure to protect it from the environment. An example is an industrial PC located in an unclean environment. Heat in this situation, needs to be rejected 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).

6.0 Related Documents

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

Table 2. Related Documents

Document	Order Number
Intel Pentium® II Processor Mobile Module: Mobile Module Connector 2 (MMC-2) datasheet	243668
AP-825, Mobile Pentium® II Processor and Pentium II Processor Mobile Module Thermal Sensor Interface Specifications application note	243724
Intel Packaging Handbook	240800

7.0 Vendor List

This vendor list is provided 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 3. Vendor List (Sheet 1 of 2)

Heat Sink Vendors	
Aavid Thermal Products, Inc. 143 N. Main St., Ste. 206 Concord, NH 03301 Phone: 603 223-1700 Fax: 603-223-1738	**SMI Electronic Devices America, Inc.** 4645 S. Lakeshore Drive Suite # 11 Tempe, AZ 85282 Phone: 602-820-9889
Fan Heat Sink Vendors†	
North America: **Sourceline, Inc. (Panasonic)** 2833 Junction Ave. Ste. 110 San Jose, CA 95134 Phone: 800-891-0649 Fax: 408-570-0675	*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 95134 Phone: 800-891-0649 Fax: 408-570-0675	

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

Table 3. Vendor List (Sheet 2 of 2)

Heat Pipe and Heat Exchanger Vendors	
Fujikura America, Inc. 3001 Oakmead Village Drive Santa Clara, CA 95051 Phone: 408-988-7408 or 408-988-7415 Fax: 408-727-3515	**Thermacore, Inc.** 780 Eden Road Lancaster, PA 17601 Phone: 717-569-6551 Fax: 717-569-4797
Furukawa Electric 200 Westpark Dr., Ste. 190 Peachtree City, GA 30269 Phone: 770-487-1234 Fax: 770-487-9910	**Denso Sales California, Inc.** 3900 Via Oro Ave. Long Beach, CA 90810 Fax: 310-513-7319 Phone: 310-513-8544
Interface Material Vendors	
MicroSi (Thermal Grease) 1028 S 51st St. Phoenix, AZ 85044 Phone: 602-893-8898 Fax: 602-893-8637	**Thermagon, Inc.** (Elastomer) 3256 W. 25th St. Cleveland, OH 44109-1668 Phone: 888-246-9050 Fax: 216-741-3943
Air Velocity Meter Supplier	
Kurz Instruments, Inc. 2411 Garden Road Monterrey, CA 93940 Phone: 800-424-7356	
Copper Heat Spreader Supplier	
Chomerics 77 Dragon Court Woburn, MA 01888-4014 Phone: 617-935-4850 Fax: 617-933-4318	
CompactPCI Specification	
Rogers Communication 301 Edgewater Place, Suite 220 Wakefield, MA 01880 Phone: 617-224-1100 Fax: 617-224-1239	
Temperature Measurement Suppliers	
Omega Engineering, Inc. One Omega Drive P.O. Box 4047 Stamford, CT 06906 Phone: 1-800-622-2378	

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