Intel® 840 Chipset Thermal Design Considerations

Application Note

July 2000

Order Number: 298027-002

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Revision History

Rev.	Description	Date
-001	• Initial Release	December 1998
-002	• Removed references to SDRAM	July 2000

1. Overview

In a system environment, the temperature of a component is a function of both the system and component thermal characteristics. The system-level thermal constraints consist of the local ambient temperature at the component, the airflow over the component and the surrounding board as well as the physical constraints at, above, and surrounding the component that may limit the size of a thermal enhancement. The component's case temperature depends on the component power dissipation, the size, the packaging materials (effective thermal conductivity), the type of interconnection to the substrate and motherboard, the presence of a thermal cooling solution, and the thermal conductivity. It also depends on the power density of the substrate, nearby components, and motherboard.

All of these parameters are driven by the continuing trend of technology to increase performance levels (i.e., higher operating speeds, in MHz) and packaging density (i.e., more transistors). As the operating frequencies increase and the packaging size decreases, the power density increases and the thermal cooling solution space and airflow become more constrained. The result is an increased emphasis on system design, in order to ensure that the thermal design requirements are met for each component in the system.

1.1. Document Goals

The Intel® 840 chipset is the newest addition to Intel's line of Pentium® III processor chipsets. Some previous generations of Pentium® III processor chipsets generated insufficient heat to require an enhanced cooling solution, in order to meet the case temperature specifications in system designs. As the market transitions to higher speeds and higher bandwidths with enhanced features, the heat generated by these devices will introduce new thermal challenges for system designers. Depending on the type of system and the chassis characteristics, new designs may be required to provide better cooling solutions for these devices. The goals of this document are to facilitate the understanding of the thermal characteristics of the Intel® 840 chipset and to discuss the guidelines for satisfying the thermal requirements imposed on systems.

1.2. Importance of Thermal Management

The objective of thermal management is to ensure that the temperatures of all components in a system are maintained within functional limits. The functional temperature limits are the range within which an electrical circuit can be expected to meet specified performance requirements. Operation outside the functional limits can degrade system performance, cause logic errors or cause component and/or system damage. Temperatures exceeding the maximum operating limit may result in irreversible changes in the operating characteristics of the component.

1.3. Intel® 840 Chipset Packaging Terminology

Term	Definition
BGA	Ball Grid Array : A package type defined by a resin-fiber substrate onto which a die is mounted, bonded and encapsulated in molding compound. The primary electrical interface is an array of solder balls attached to the substrate opposite the die and molding compound.
Junction	A p-n junction on the silicon itself. In this document, it is used as a temperature reference point (e.g., Θ_{JA} refers to the “junction” to ambient temperature).
Lands	The pads on the PCB to which the BGA balls are soldered
MBGA	Mini Ball Grid Array: An Intel BGA with a 1.27-mm ball pitch
Mold-cap	The black encapsulating molding compound, at the top of which maximum case temperatures are taken and heat sinks are attached
PCB	Printed Circuit Board
RIMM*	RDRAM* In-line Memory Module
TDP	Thermal Design Power: The estimated maximum possible expected power generated in a component by a realistic application. It is based on extrapolations of both hardware and software technologies over the life of the product. It DOES NOT represent the expected power generated by a power virus.
Thermal balls	Typically, an array of balls at the center of the larger array of balls, which serve to channel heat into the PCB as well as to ground connections

1.4. Reference Documents

Document Name or Information Source	Available from
Intel® 840 Chipset Design Guide	On FDBL
Intel® 840 Chipset Design Guide Update	On FDBL
Intel® 840 Chipset: 82840 Memory Controller Hub (MCH) Datasheet	On FDBL
ICH Specification Update	On FDBL
Intel® 82803AA Memory Repeater Hub for RDRAM (MRH-R) Datasheet	On FDBL
Intel® 82806AA PCI 64 Hub (P64H) Datasheet	On FDBL
MEC Design Guide	On FDBL
MEC Reference Schematics	
Intel® 840 Chipset Thermal Model Guide	On FDBL: (User Guide and password)
Intel® 840 Chipset Thermal Model Files	On FDBL
Intel ATX Power Supply Design Guide	http://www.teleport.com/~atx/spec/index.htm
WTX System Design Guide	http://www.wtx.org/spec/index.htm
Pentium® III Processor Thermal Design Guidelines, Application Note	order number: 245087
Pentium® III Processor EMI Design Guidelines, Application Note	order number: 243334
Integrated Circuit Thermal Measurement Method: Electrical Test Method	EIA/JESD51-1
Integrated Circuits Thermal Test Method: Environmental Conditions – Natural Convection (Still Air)	EIAJESD51-2

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2. Thermal Specifications

Thermal Design Powers (TDPs) for components can be found in their respective datasheets. Refer to these documents to verify the actual thermal specifications for the Intel® 840 chipset. In general, systems should be designed to dissipate the highest possible thermal power.

To ensure the proper operation and reliability of the Intel® 840 chipset, the thermal solution must maintain the case temperature at or below the values specified in Tables 1 through 4 (chipset) and Table 5 (RIMM). Considering the power dissipation levels and the typical system ambient environments of 45 °C to 55 °C, if the case temperatures exceed the maximum case temperatures listed in these tables, system- or component-level thermal enhancements will be required to dissipate the generated heat.

To dissipate the highest possible thermal power, good system airflow is critical. Airflow is determined by the size and number of fans, vents, and ducts, as well as their placement in relation to the components and the airflow channels within the system. In addition, acoustic noise constraints may limit the size and/or type of fans, vents and ducts that can be used in a particular design.

To develop a reliable, cost-effective thermal solution, all of the above variables must be considered. Thermal characterization and simulation should be performed at the overall system level, accounting for the thermal requirements of each component.

Table 1. MCH Preliminary Thermal Absolute Maximum Rating

Parameter	Maximum
$T_{case\text{-}nhs}$ (1)	110 °C
$T_{case\text{-}hs}$ (2)	97 °C

Table 2. MRH-R Preliminary Thermal Absolute Maximum Rating

Parameter	Maximum
$T_{case\text{-}nhs}$ (1)	110 °C
$T_{case\text{-}hs}$ (2)	97 °C

Table 3. P64H Preliminary Thermal Absolute Maximum Rating

Parameter	Maximum
$T_{case\text{-}nhs}$ (1)	93 °C
$T_{case\text{-}hs}$ (2)	80 °C

Table 4. ICH Preliminary Thermal Absolute Maximum Rating

Parameter	Maximum
$T_{case\text{-}nhs}$ (1)	100 °C

Table 5. RDRAM*/RIMM* Reference Design Preliminary Thermal Absolute Maximum Rating

Parameter	Maximum
T_{plate} (3,4)	93 °C

- $T_{case-nhs}$ is defined as the maximum case temperature without any thermal enhancement of the package.
- $T_{case-hs}$ is defined as the maximum case temperature with the default thermal solution attached (see Section 4.2).
- T_{plate} is defined as the maximum temperature of the thermal plate attached to the RIMM. (See the RIMM power software documentation for the proper thermocouple placement during a test.)
- Based on the RDRAM power specifications from RAMBUS* Corp. Because RIMM implementations and RDRAM power specifications may vary, Intel strongly recommends that customers check with their RIMM manufacturer for the updated values.

2.1. Case Temperature

The case temperature is a function of the local ambient temperature and the internal temperature of the component under evaluation. Since a local ambient temperature is not specified for the components of the Intel® 840 chipset, the only restriction is that the maximum case temperature (T_{case}) must not be exceeded. Section 5.1 discusses the proper guidelines for measuring the case temperature. Note that increasing the heat flow through the case (mold-cap) increases the difference in temperature between the junction and case, thereby reducing the maximum allowable case temperature. For the default thermal solution, see the adjusted values listed in Table 1 through Table .

2.2. Power

In previous generations of chipsets in which quad flat pack (QFP) packages may have been the primary package type, most power dissipation was through the plastic case of the package and into the surrounding air. With the advent of ball grid array (BGA) packaging for chipsets, most thermal power dissipated by the chipset typically flows into the motherboard on which it is mounted (when thermal or center balls are present). The remaining thermal power is dissipated into the ambient environment by the package itself (with or without thermal enhancement). The MBGA packages used in the Intel® 840 chipset continue this trend.

The amount of thermal power dissipated either into the board or by the package varies depending on how well the motherboard conducts heat away from the package and whether the package uses thermal enhancements. While package thermal enhancements typically serve to improve heat flow through the case via a heat sink, how well the motherboard conducts heat away from the package is strictly a function of the motherboard design.

The following recommendations ensure good thermal conductivity between the thermal balls and the inner planes of the motherboard:

- Good mechanical connection
- At least one via per ground ball
- Minimum width of the trace connecting the motherboard ground pads to their respective vias: 10 mil
- Plated via size for ground balls: 14-to-16-mil diameter on a 24-to-27-mil pad. A larger via channels heat more efficiently.
- Do not use thermal relief patterns to connect the via to the inner power and ground planes.

The following recommendations ensure that the motherboard's inner planes effectively conduct heat away from the area beneath the package:

- Good ground paths to areas of the board away from the BGA will distribute heat more efficiently.
- The size of the motherboard, the number of copper layers, and the thickness of those layers. In some cases, the use of "2-ounce copper" on the ground plane has been successful in improving the thermal conduction by reducing the case temperatures.

All points should be taken into consideration by system and board designers, when developing new systems.

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3. Designing for Thermal Performance

The general design considerations for all chassis will be discussed next. Specific design considerations for ATX and WTX chassis may be found at the following URLs:

http://www.teleport.com/~atx/

http://www.wtx.org/

3.1. System Cooling

The first step in defining an acceptable cooling solution is to estimate the total airflow required to cool the entire system (not just the processor). Using ideas from the First Law of Thermodynamics (i.e., the conservation of energy) for a steady-state steady flow process, it becomes possible to study the relationship among the volumetric airflow, the heat load (i.e., the measured DC power), and the temperature rise of the system. To obtain this simplified model, it must be assumed that there is zero change in the airflow's kinetic and potential energies and that no work is performed by the system.

For a zero-airflow restriction inside the computer, the relationship is as follows:

$$V = f(\text{Power / Temperature rise})$$

Where

V :	Volumetric airflow
Power :	Actual power dissipated by the power supply (DC power)
Temperature rise :	System temperature rise

Note: As the DC power increases, airflow must increase for NO change in system temperature.

In other words, more volumetric airflow is needed to minimize the system temperature rise. Note that this holds under ideal conditions. In reality, the airflow is restricted from 30% to 50%. For a well designed chassis, an airflow increase of approximately 25% is typical to account for the system impedance. If possible, use the measured DC power of the system for the Power variable. The AC power can be an approximation, but the inefficiency of the power supply makes this measurement larger than the actual power dissipated.

3.2. System Fans

Fans implement the forced-convection approach to cooling. Stated simply, the greater the air velocity over the surface of a component, the greater the heat transfer from that component. Fans can be used to blow air into (pressurize) or out of (evacuate) the chassis, depending on the direction in which they are installed.

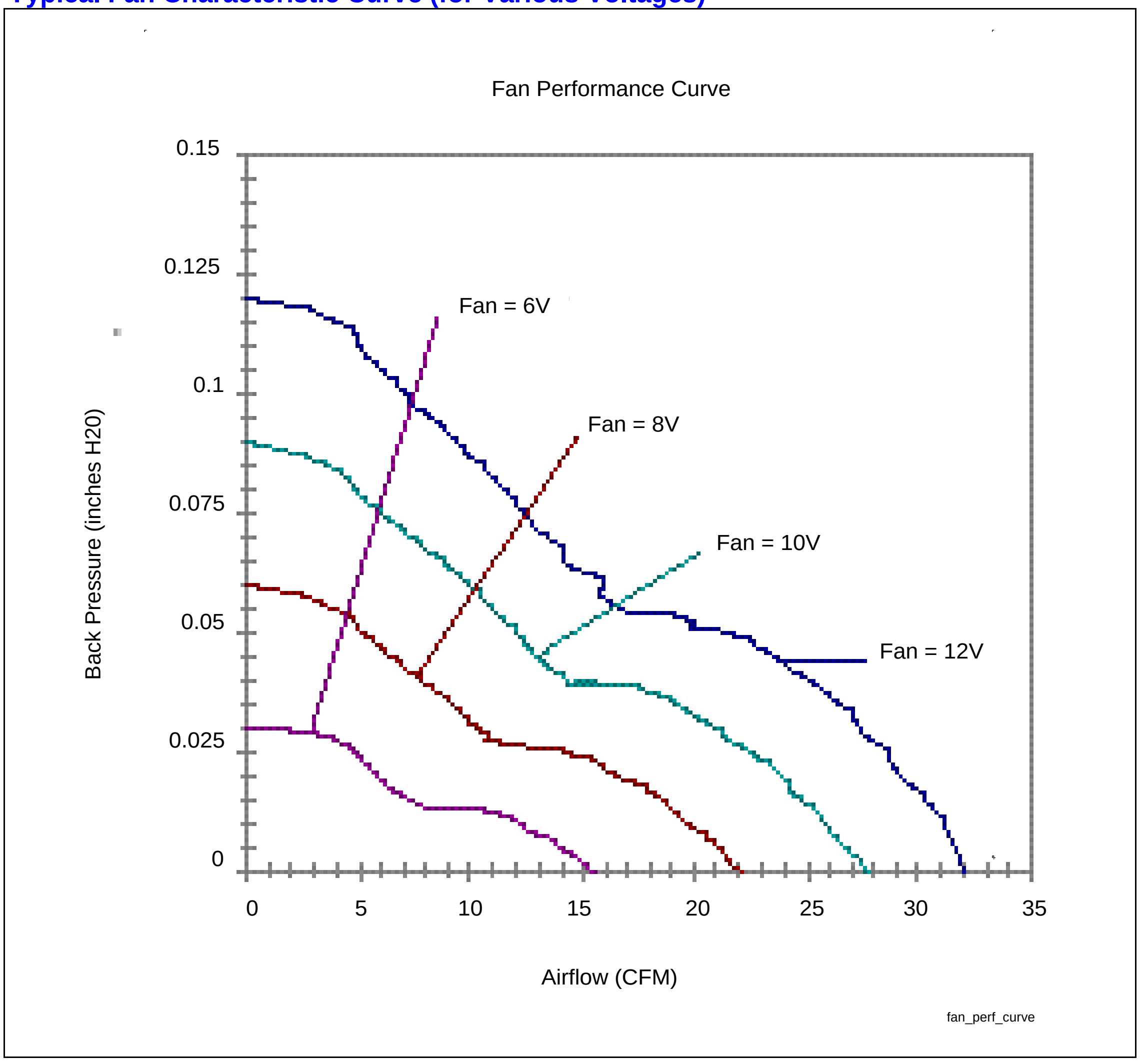
Pressurizing the chassis with a fan delivers cool, room-temperature ambient air onto any location where it is needed to enhance heat transfer.

Evacuation induces a negative pressure (relative to room ambient) inside the chassis, which draws air in through the vents. This inflowing air is pulled through the chassis across hot components and is exhausted out the fan. Fans may differ in their characteristics. Therefore, a prudent choice of fans can optimize both airflow and acoustics.

3.3. Fan Types

Although there are several types of fans to consider for system cooling, this discussion will focus on two types: tube axial and radial (centrifugal - blower). Tube axial is the most commonly used type throughout the computer industry. Axial fans typically cost less and generally push more air, at a given back-pressure. Radial fans, however, are much less susceptible to variations in back-pressure and often have restricted openings that can focus needed cooling air directly toward hot components. When power dissipation is highly concentrated, a blower may be a reasonable option. The following figure shows a typical axial fan characteristic curve and the effect of running the fan at different speeds (or voltage levels).

Figure 1. Typical Fan Characteristic Curve (for Various Voltages)



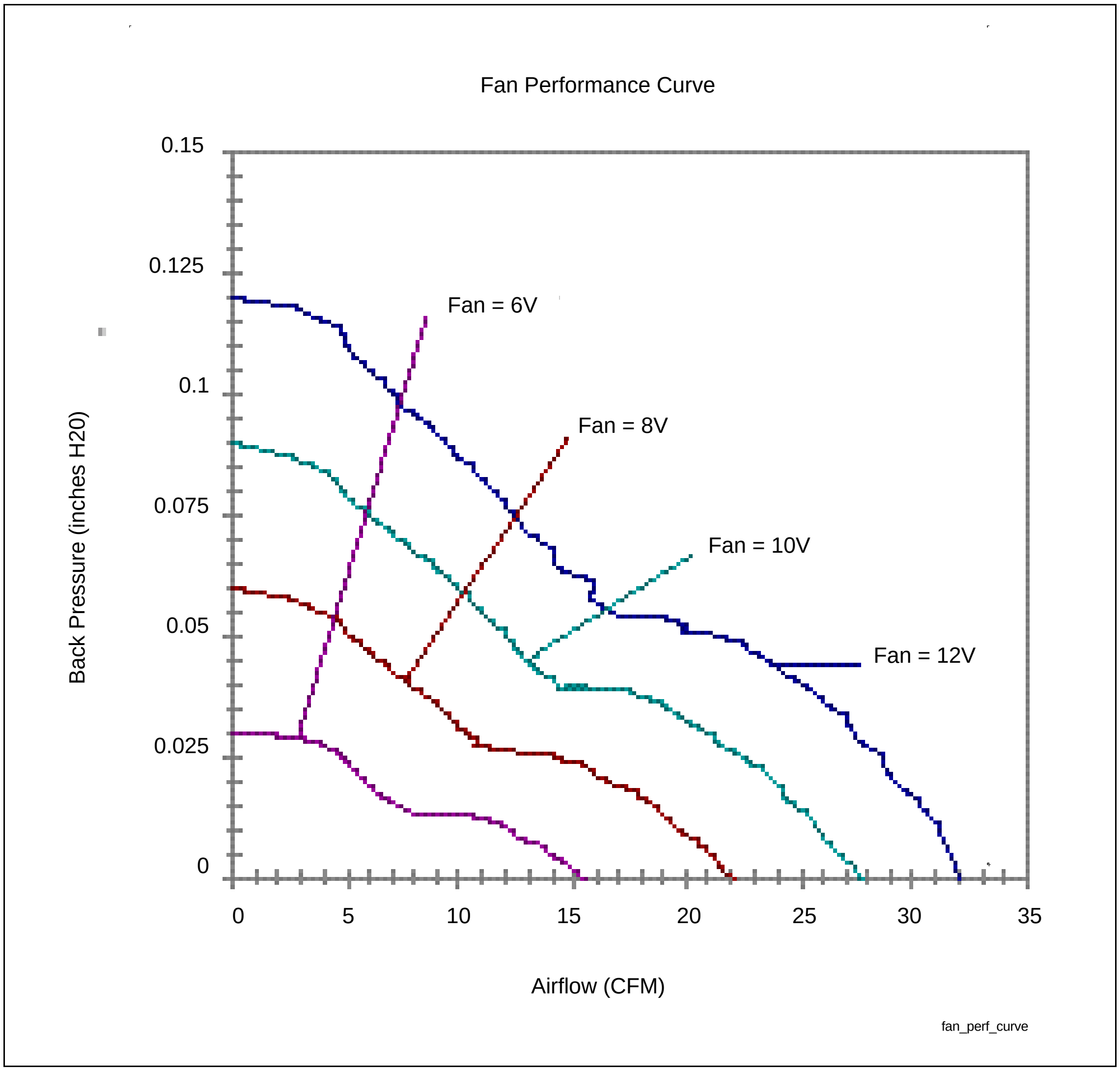
3.3.1. Parallel and Series Fan Combinations

Multiple fans can be utilized in two combinations: parallel and series.

- Two identical fans in parallel double the airflow, so the total airflow equals the airflow of fan 1 plus the airflow of fan 2, at zero back-pressure. An example of a parallel fan combination is a system fan and a power supply fan, both either pressurizing or evacuating a chassis.
- Two identical fans in series double the system's ability to overcome back-pressure, so the total pressure is equal to the pressure of fan 1 plus the pressure of fan 2, at zero airflow. An example of a series fan combination is a system fan blowing air into the chassis and a power supply fan exhausting air from the chassis.

In actual implementations, however, venting, leakage, and design compromises necessitate the use of multiple fans in a combination series-parallel configuration. The following figure shows the effect of employing series-parallel fan configurations.

Figure 2. Performance Curves for Series and Parallel Fan Combinations



The use of multiple (identical) fans in a system does provide marginally increased airflow. The exact amount depends on many factors, including the fan speed and configuration as well as the chassis airflow impedance. If the fans are not identical, then the figures will change slightly, but the trends will be the similar. **The general rules are as follows: If the chassis has high system impedance, place the fans in series. If the chassis has low system impedance, place the fans in parallel.**

3.3.2. Fan Relationships

Fan variables such as airflow, pressure, RPMs, and power can be generalized for a tube axial two-fan combination with constant diameter.

- Airflow increases linearly with speed.
- Pressure increases with the square of the speed.
- Power increases with the cube of the speed.

Keep in mind that increasing the fan speed to increase the airflow results in a much larger increase in pressure. If increased airflow is desired, consider increasing the fan diameter from 80 mm to 92 mm, instead of increasing the speed. Cost must be considered because 92-mm fans generally are more expensive than 80-mm fans. However, a 92-mm fan operating at the same flow rate as an 80-mm fan is approximately 6 dBA quieter.

3.3.3. Fan Speed Control

The idea of a fan speed control circuit has been around for some time, but such circuits generally have been avoided because of their added cost and the system complexity. Computers are now incorporating hotter processors and peripherals, which require greater airflow. At the same time, customers are requesting quieter systems. These competing design constraints have led to a resurgence of fan speed control options. Fan speed control allows a system to vary its airflow according to changes in load and/or temperature. Fan noise increases with fan speed and is a major contributor to total system noise. For systems that incorporate fan speed control, proper speed regulation is important since it is desirable to achieve low acoustic levels without overheating components. The design of a fan speed control circuit should be such that the circuit monitors the temperature at a component (or several components) and adjusts the fan speed as necessary in order to maintain the required thermal margin. Three distinct design options should be considered, as follows:

3.3.3.1. Discrete Digital Switches

If the airflow requirements can be confined to a discrete number of fan speeds, this option is the cheapest and easiest to implement.

3.3.3.2. Analog Linear Control between Two Guard Bands

For the fans used in most systems, the speed usually can be controlled by varying the voltage level at the fan’s power terminals. (Many power supplies/fans come equipped with this feature.) An example operating voltage range for an 80-mm, 30-cfm, 0.14-amp fan might be 8 V to 12 V DC, which correspond to 1650 rpm and 2500 rpm, respectively.

3.3.3.3. Pulse Width Modulation Schemes

This is a digital variation on the second option. Consider this option if the fan must be varied from some minimum speed (presumably set for the system sleep state) to some maximum speed (needed for a fully loaded active state).

3.3.3.4. Summary

No matter which fan speed control method is chosen, the following issues should also be noted:

- The temperature monitoring location is important. (Sensing critical component case temperatures is recommended.)
- A driver circuit for the fan must be included.
- Some fans need a minimum starting voltage. (See the fan specification.)
- Fan noise increases with fan speed (operating voltage). The minimum fan noise occurs at the maximum fan power efficiency. (See the fan specification.)
- If the fan speed is uncontrolled, at what speed (voltage level) is it operating? In this case, since it is not possible to vary the fan speed, choose the lowest-rated fan speed that will cool the system under the worst-case loading/temperature conditions.

If fan speed control is implemented, the thermal design should account for various load and temperature combinations. Component temperatures should be verified to ensure that the thermal design conforms with the specification under these load and temperature combinations.

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4. System Design

4.1. Chassis and Bezel Venting

Proper venting is a key element in any good thermal design. A balanced vent configuration is a critical factor in this design. With insufficient venting, not enough air in allowed into the system for adequate cooling. With excessive venting, the air velocity across system components can decrease, resulting in less heat transfer through forced convection. To increase the airflow through the system, all system accessory components (cables, wires, sheet metal, etc.) should present the lowest-possible air impedance. To eliminate possible electromagnetic compliance issues, both the maximum vertical and maximum horizontal dimensions of the ventilation apertures, I/O ports, and open areas along chassis seams must be less than 1/20th of the wavelength of the highest harmonic frequency of interest. See the applicable agency requirements (Sections 1.1.1. EMC & 1.1.2 Acoustics Sound Pressure).

Key considerations:

- *Power supply* : The air flow from the power supply fan is less important when the front system fan delivers the majority of the airflow.
- *Front bezel venting* : The bezel vent area should be as large as possible because it serves as the main air inlet for the system. It also provides the main airflow source for the core logic components. Ensure that the plastic bezel vent pattern allows air to enter freely, so that it does not overly restrict the airflow into the system.
- *Riser cards* : Some venting at the front and back of any riser cards is necessary to allow for chassis evacuation and airflow over the add-in cards.
- *Side chassis venting* : This is desirable if there are nearby cards with components that require cooling.
- *Rear chassis venting* : This adds to the airflow capability of the chassis.
- *Peripheral bay venting* : This cools peripherals. Minimal venting, if any, should produce adequate results. Implementing too much venting may cause lower airflow in other areas of the chassis.

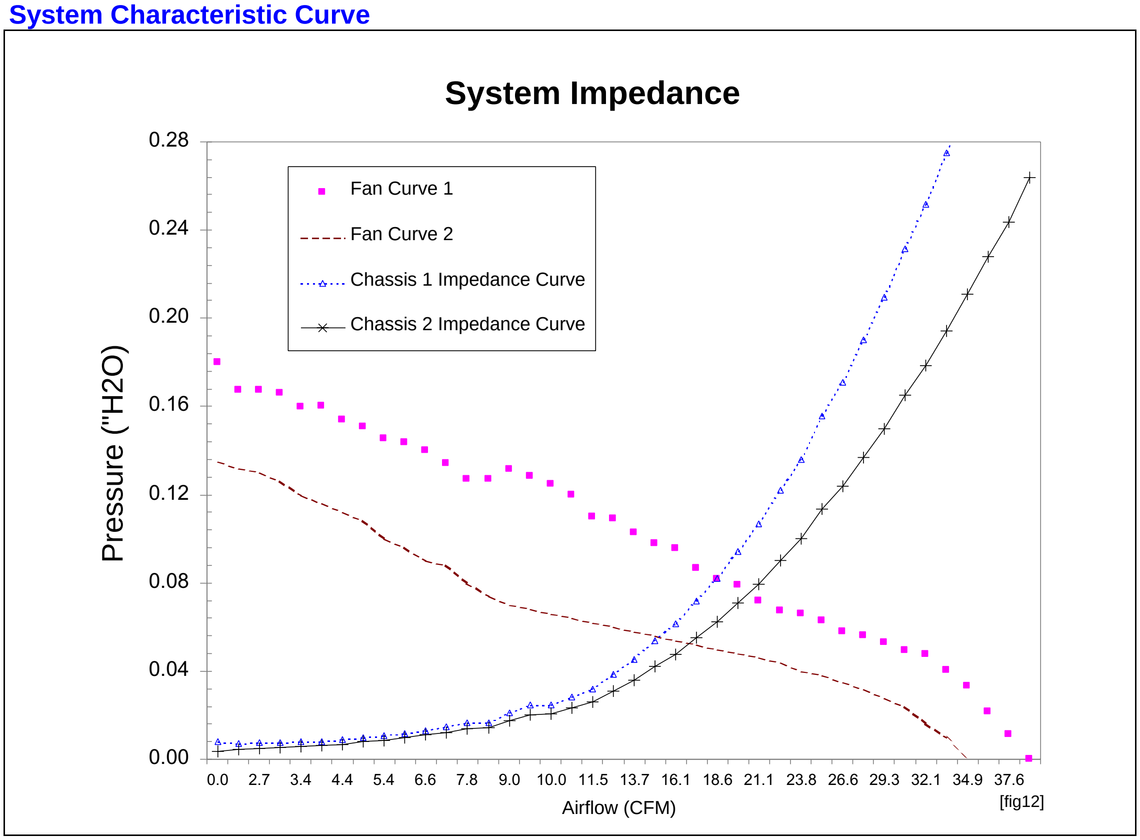
4.2. Airflow Impedance

The air flowing through a computer chassis encounters frictional resistance, known as airflow impedance. This impedance creates a chassis pressure drop that varies with the square of the velocity. The relationship is shown by plotting the pressure loss versus the volumetric flow rate, which yields the system characteristic curve. This behavior allows the system's overall performance to be predicted, if one data point on the curve is known. When the system characteristic curve is superimposed on the fan performance curve, the operating point of the system becomes evident. The concept is demonstrated in the following figure, in which different power supplies are compared with different chassis.

Other guidelines to consider when assessing system airflow issues are as follows:

- To avoid pressure and volume fluctuations, the selected operating point should be just to the right of the intersection of the fan curve and the chassis impedance curve.
- Choose a fan with a steep characteristic curve, in order to maintain constant volumetric flow even with variable system impedance.
- Avoid obstructions near the inlet and exhaust of the fans, because these tend to decrease the airflow and increase the system noise. Objects near the inlet can contribute to system noise.
- Use fan speed control whenever possible. This yields an adequate thermal margin and provides a significant acoustic advantage.
- Power supply cables and drive signal cables should be kept short and should be folded properly.

Figure 3. System Characteristic Curve



4.3. Power Supply Airflow Characteristics

The power supply is the most influential component in the cooling system design. Even if the chassis venting scheme is well designed, if the correct power supply is not selected, the system will not cool the processor, chipset, memory, and/or peripherals. The power supply and any system fans must provide enough airflow to reduce the system heat load, as represented by the equation in Section 3.1.

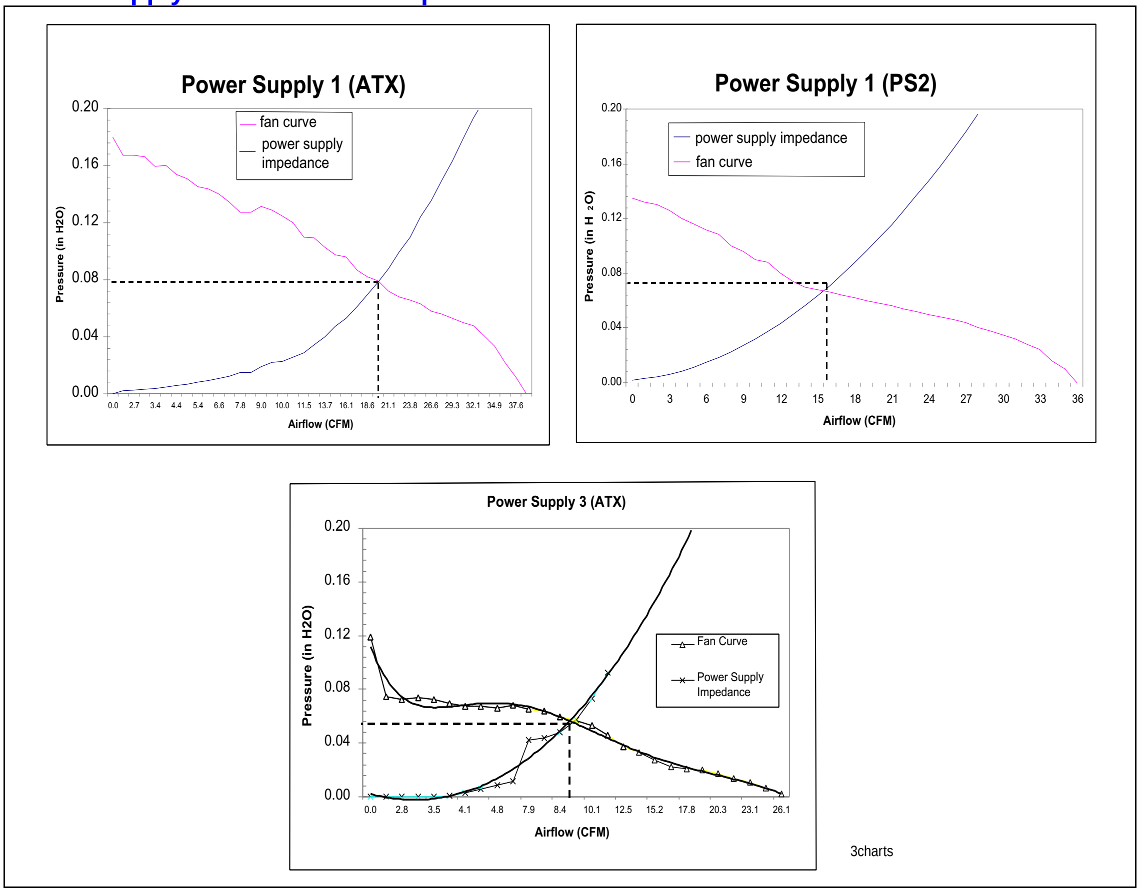
Key considerations when selecting/designing a power supply:

- Rather than pressurize the chassis, evacuate it with the power supply fan. The advantage of evacuating the chassis is that cool, ambient room air can be delivered (via vents) to any location where it is needed to enhance the heat transfer. Evaluation has shown that evacuation produces greater cooling than pressurization, using the same fan and with proper implementation.
- All vents should have a minimum free area ratio of 60%. In order to ensure that vent designs comply with all applicable regulations, consult the *Intel ATX Power Supply Design Guide*, which is located on the WWW at

  http://www.teleport.com/~atx/spec/index.htm
- Implement a wire fan grille rather than the common stamped sheet metal designs, because the airflow impedance is reduced.
- When designing a power supply, minimize component heights in order to keep their profiles low and streamlined. This reduces the overall airflow impedance while maintaining effective power supply cooling.
- Keep power supply cables short in order to reduce their airflow obstruction.
- Select a power supply with the highest possible airflow. A well designed power supply has low airflow impedance, which allows a smaller, quieter fan for cooling. Because it has greater airflow impedance, a poorly designed supply requires a larger, louder fan in order to maintain the same airflow.

The following figure shows the power supply impedance curve and the associated fan curve for three different power supplies. The operating point is the point where the fan curve intersects the power supply impedance curve. Power supplies 1 and 2 (ATX and PS2 styles, respectively) flow approximately twice as much as power supply 3 (ATX style). Note that power supply 3 has a smaller fan *and* a higher airflow impedance, resulting in a lower airflow.

Figure 4. Power Supply Performance Comparison



4.4. Ducting

Ducts can be designed to isolate components from the effects of system heating and to maximize the thermal budget. Air provided by a fan or blower can be either channeled directly over the components to be cooled or split into multiple paths in order to cool multiple components.

4.4.1. Ducting Placement

When ducting is used, it should direct the airflow evenly from the fan and across the entire component and the surrounding motherboard. If possible, ducting should be implemented with smooth, gradual turns, because this will enhance the airflow characteristics. Sharp turns in ducting should be avoided, because they will increase friction and drag and will greatly reduce the volume of air reaching the Intel® 840 chipset and motherboard.

While there are many ducting options, an excellent source of ducting alternatives can be found at the following website:

http://developer.intel.com/ial/sdt/fanduct.htm intel®

4.5. Intel® 82840 MCH Thermal Attributes

The 82840 MCH is packaged in a 35-mm, 4-layer MBGA. See the *82840 Memory Controller Hub (MCH) Datasheet* for details.

4.5.1. MCH Package Thermal Characteristics

The following tables are provided to facilitate the determination of the optimum airflow and heat sink combination for the MCH. These tables show Tcase as a function of the airflow and the ambient temperature, at the thermal design power. They can be used by the customer to evaluate the system solution.

NOTES (The following notes apply to Table 4 and Table 5):

1. The **unshaded** values indicate the airflow/ambient combinations that will exceed the allowable case temperature for the MCH. The shaded values do not.
2. The heat sink case assumes the default thermal solution.
3. With no heat sink, Tcase max. is 110 ºC. With a heat sink, Tcase max. is 97 ºC.
4. Data is based on Flotherm* simulations of a motherboard environment (Appendix B).
5. All data is preliminary and has not been validated against physical samples.
6. Zero air flow is defined as a natural convection environment.

Table 4. No Heat Sink Attached (Tcase Spec ºC = 110)

Amb °C	No Heatsink Tcase(°C) table at TDP						
60	121	117	113	111	**109**	**108**	**106**
55	116	112	**108**	**106**	**104**	**103**	**101**
50	111	**107**	**103**	**101**	**99**	**98**	**96**
45	**106**	**102**	**98**	**96**	**94**	**93**	**91**
40	**101**	**97**	**93**	**91**	**89**	**88**	**86**
35	**96**	**92**	**88**	**86**	**84**	**83**	**81**
LFM ->	0	50	100	150	200	250	300

Table 5. Heat Sink Attached (Tcase Spec ºC = 97)

Amb °C	Heatsink Tcase(°C) table at TDP						
60	103	98	**95**	**93**	**91**	**89**	**87**
55	98	**93**	**90**	**88**	**86**	**84**	**82**
50	**93**	**88**	**85**	**83**	**81**	**79**	**77**
45	**88**	**83**	**80**	**78**	**76**	**74**	**72**
40	**83**	**78**	**75**	**73**	**71**	**69**	**67**
35	**78**	**73**	**70**	**68**	**66**	**64**	**62**
LFM ->	0	50	100	150	200	250	300

4.6. Intel® 82803AA MRH-R Thermal Attributes

The Intel® 82806AA PCI 64 Hub (P64H) is packaged in a 27-mm, 4-layer MBGA. See the *Intel® 82803AA Memory Repeater Hub for RDRAM (MRH-R) Datasheet* for details.

4.6.1. MRH-R Package Thermal Characteristics

The thermal solution required for MRH-R is a no-heat-sink solution.

4.7. Intel® 82806AA P64H Thermal Attributes

The P64H is packaged in a 23-mm, 4-layer MBGA. See the *Intel® 82806AA PCI 64 Hub (P64H) Datasheet* for details.

4.7.1. P64H Package Thermal Characteristics

As aids in determining the optimum airflow and heat sink combination for the P64H, the following tables show the case temperature as a function of the airflow and the ambient temperature, at the thermal design power. They are provided to enable the customer to evaluate their system solution.

NOTES (The following notes apply to Table 6 and Table 7):

1. The unshaded values indicate the airflow/ambient combinations that will exceed the allowable case temperature for the P64H. The shaded values do not.
2. The heat sink case assumes the default thermal solution.
3. With no heat sink, Tcase max. is 93 ºC. With a heat sink, Tcase max. is 80 ºC.
4. Data is based on Flotherm simulations of a motherboard environment (Appendix B).
5. All data is preliminary and has not been validated against physical samples.
6. Zero airflow is defined as a natural convection environment.

Table 6. Heat Sink Attached (Tcase Spec ºC = 80)

Amb °C	Heatsink Tcase(°C) table at TDP						
60	96	91	88	86	84	83	82
55	91	86	83	81	**79**	**78**	**77**
50	86	81	**78**	**76**	**74**	**73**	**72**
45	81	**76**	**73**	**71**	**69**	**68**	**67**
40	**76**	**71**	**68**	**66**	**64**	**63**	**62**
35	**71**	**66**	**63**	**61**	**59**	**58**	**57**
LFM ->	0	50	100	150	200	250	300

Table 7. No Heat Sink Attached (Tcase Spec ºC = 93)

Amb °C	No Heatsink Tcase(°C) table at TDP						
60	118	114	112	110	108	107	106
55	113	109	107	105	103	102	101
50	108	104	102	100	98	97	96
45	103	99	97	95	**93**	**92**	**91**
40	98	94	**92**	**90**	**88**	**87**	**86**
35	**93**	**89**	**87**	**85**	**83**	**82**	**81**
LFM ->	0	50	100	150	200	250	300

4.8. RIMM Thermal Attributes

4.8.1. RIMM Mechanical Attributes (Reference Design Only)

The heat-spreader attach material and the heat spreader type used in a RIMM vary with the manufacturer. It is beyond the scope of this document to exhaustively list the performance of each RIMM available. As a result, this section will focus on a reference design.

Note: The RIMM design referenced in this document and its thermal performance are based on the RDRAM power, as specified by RAMBUS Corp**. Customers are strongly encouraged to validate the power and thermal limits with their respective RIMM suppliers.**

Figure 5. Exploded Diagram (Reference RIMM)

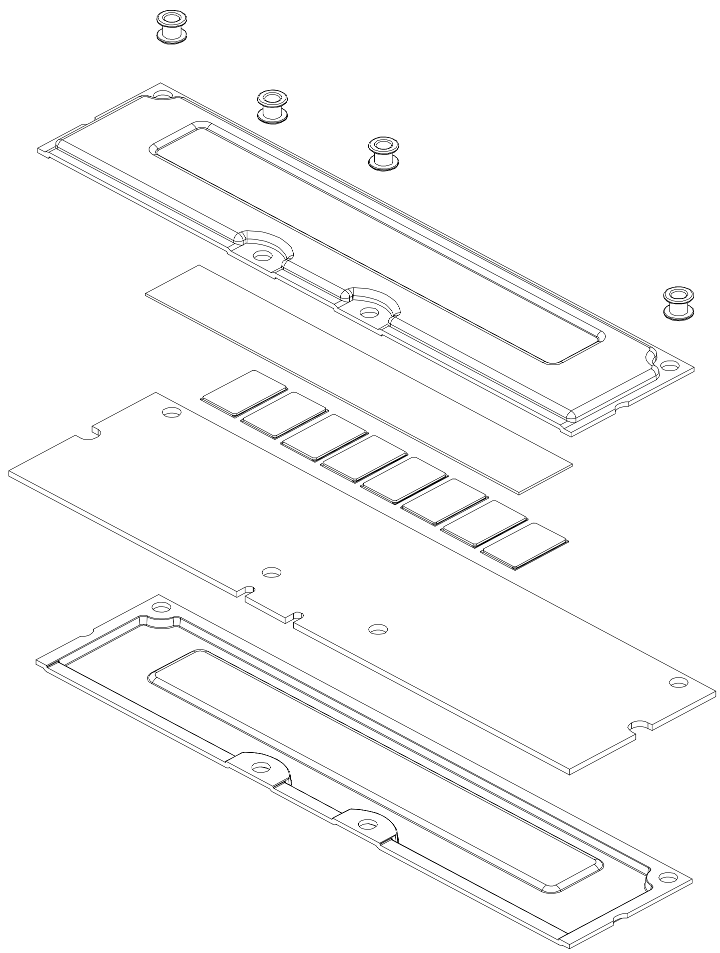
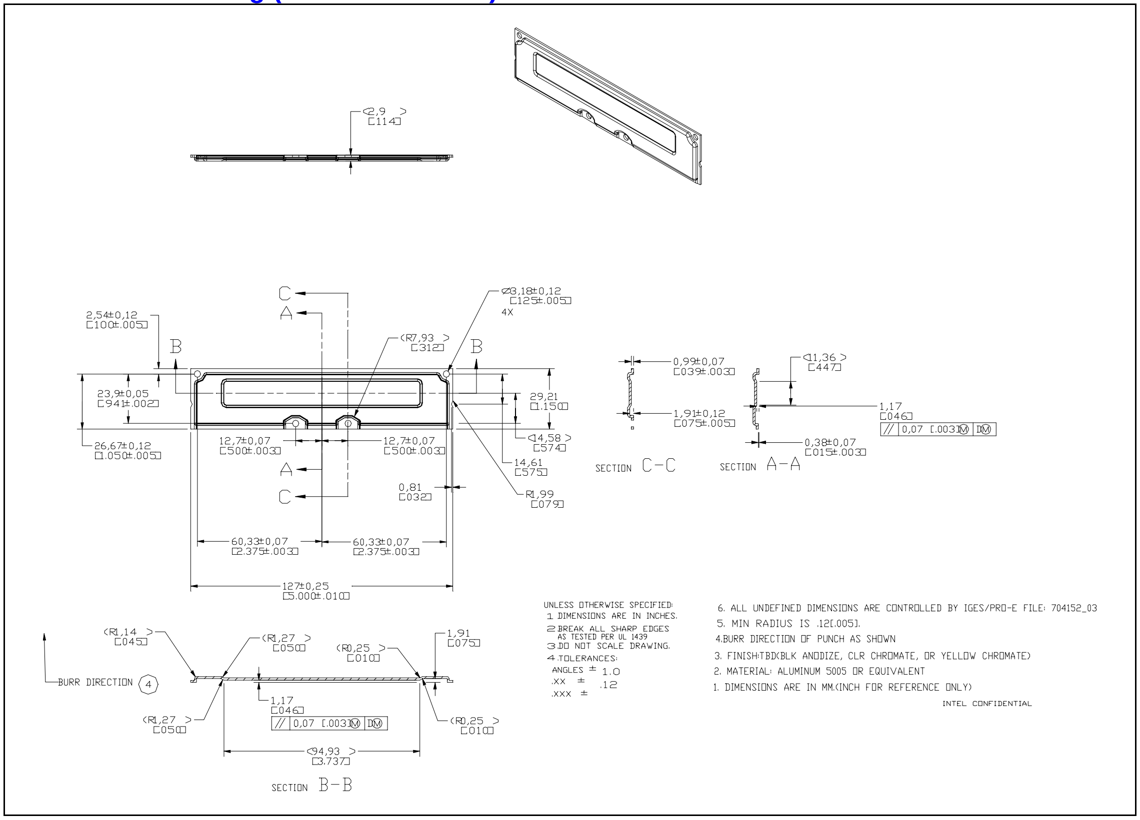


Figure 6. Mechanical Drawing (Reference RIMM)



4.8.2. RIMM Clearances

Each RIMM supplier may have unique mechanical volume and height restrictions or implementation requirements. The drawing above is for reference only. Customers are encouraged to refer to their supplier's mechanical specification document for a clearer definition.

4.8.3. RIMM Thermal Characteristics

As listed in Table 5, T_{plate} for the RIMM (reference design) is 93 ^{o}C. T_{plate} is defined as the maximum temperature of the thermal plate attached to the RIMM. (See the RIMM power software documentation for the proper thermocouple placement during test.) T_{plate} is based on the RDRAM power specifications from RAMBUS Corp. (Check with your company's RIMM manufacturer for updates.)

To achieve the thermal performance mentioned previously, the following thermal interface and heat spreader materials were used:

Table 8. Reference RIMM Design Thermal Materials List

Material	Source	Part Number
Thermal interface	Bergquist*	GapPad* 2000, 15 mils thick
Thermal interface	Thermagon*	T-ply, 15 mils thick
Heat spreader	Accrafab*	TBD

4.8.4. Integrated Thermal Management

Each RIMM is expected to incorporate a thermal sensor. For usage details, refer to the *Intel® 82840 MCH (Memory Controller Hub) Datasheet*.

4.9. Intel® 82801AA ICH Thermal Attributes

The ICH is packaged in a 23-mm, 2-layer MBGA. Refer to the Intel® 82801AA (ICH) and Intel® 82801AB (ICH0) I/O Controller Hub for details.

4.9.1. ICH Package Thermal Characteristics

The thermal solution required for the ICH is a no-heat-sink solution.

4.10. Thermal Enhancements

If sufficient airflow cannot be supplied to the component and motherboard, the thermal performance can be improved by increasing the surface area of the component by attaching a metallic heat sink to the mold-cap. To maximize the heat transfer, maximizing the surface area of the heat sink itself can reduce the thermal resistance from the heat sink to the air.

Note: Increasing the heat flow through the case increases the difference in temperature between the junction and case, reducing the maximum allowable case temperature.

4.10.1. Clearances

Although each design may have unique mechanical volume and height restrictions or implementation requirements, the height, width and depth constraints typically placed on the Intel® 840 chipset components are shown in the following three figures.

When using heat sinks that extend beyond the component, the motherboard component height under the Intel® 840 chipset components is limited to 0.090”.

Figure 7. Heat Sink Volume Restrictions for the MCH

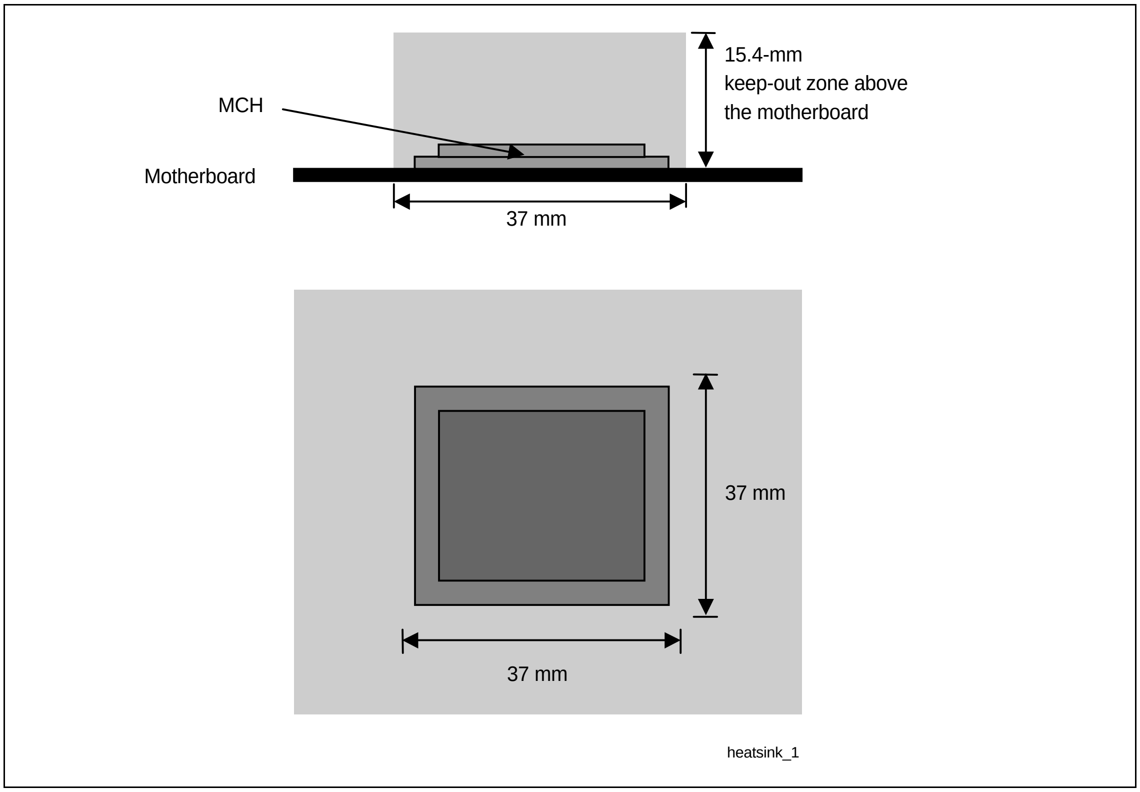
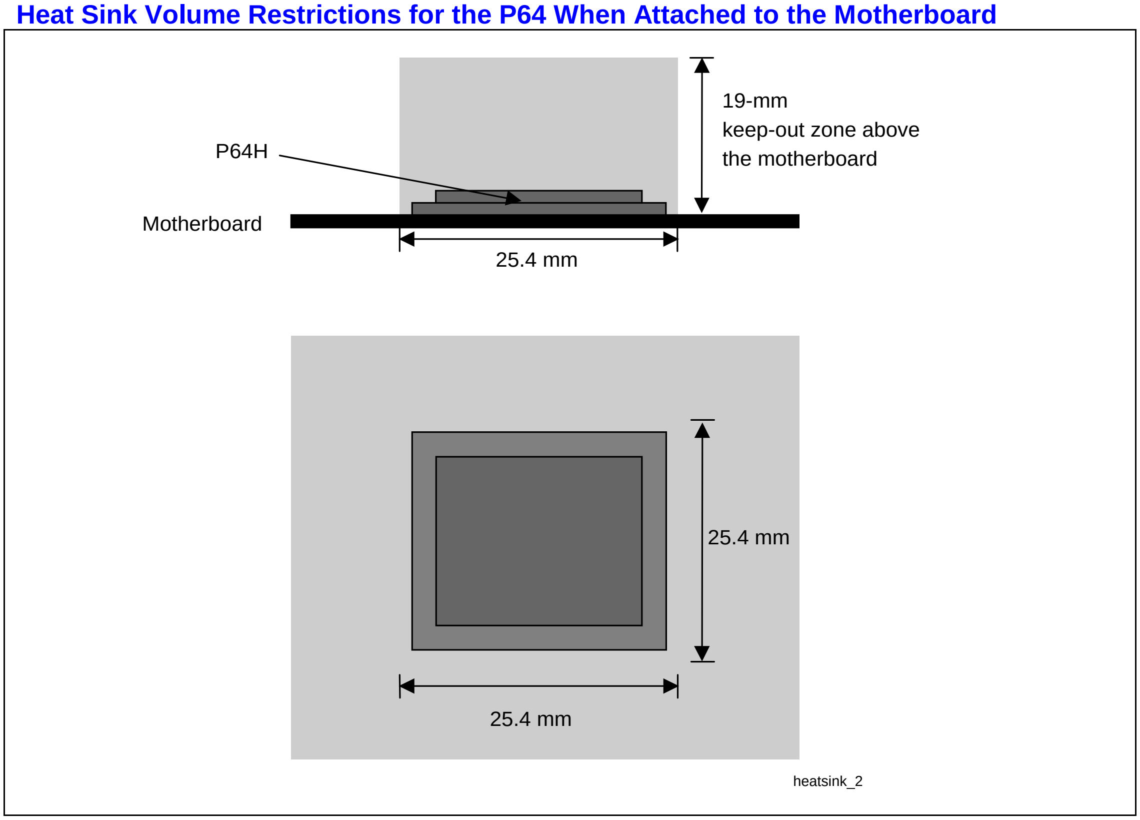


Figure 8. Heat Sink Volume Restrictions for the P64 When Attached to the Motherboard



4.10.2. Default Thermal Solutions

For users who have no control over their end-user's thermal environment or for those who wish to bypass the thermal modeling and evaluation process, Intel has developed a default thermal solution for the MCH, MRH-R, and P64H (see the following section). The default thermal solution replicates the performance defined in Tables 8, and 10, at the thermal design power. **If, after the default thermal solution is implemented, the case temperature still exceeds the appropriate value listed in Tables 1 to 4, additional cooling is needed. This is achieved by improving the airflow either to the component or to the motherboard surrounding the component.**

4.10.3. Extruded Heat Sinks

Extruded heat sinks are the default thermal solutions for the Intel® 840 chipset if airflow improvements are not implemented. The following two figures show the drawings for these heat sinks. The extruded heat sink's sources are discussed in Appendix A.

Figure 9. Extruded Heat Sink Drawing for the MCH

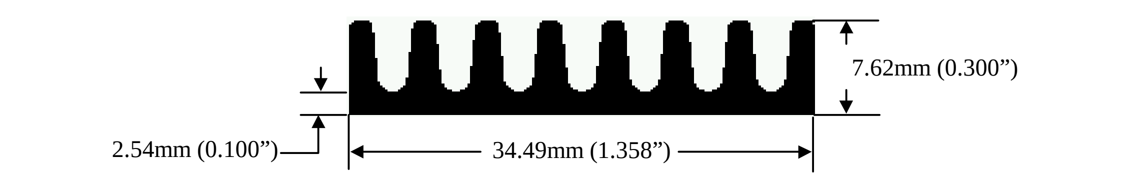
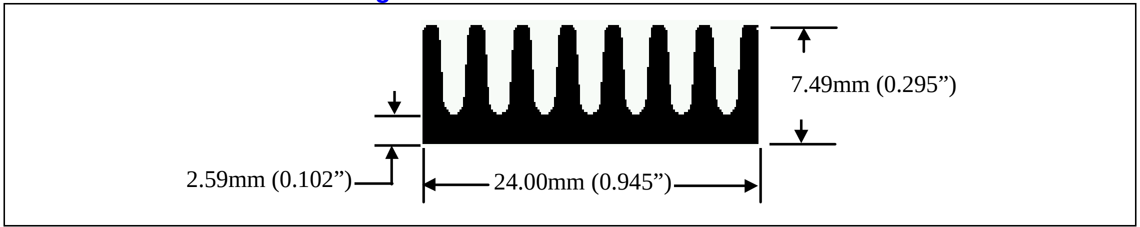


Figure 10. Extruded Heat Sink Drawing for the P64H



4.10.4. Attaching the Extruded Heat Sink

The extruded heat sink may be attached using clips and a thermal interface (e.g., tape, grease, phase-change), epoxy or tape adhesive.

4.10.4.1. Clips

A well designed clip, in conjunction with a thermal interface material (e.g., tape, grease) solution, may offer the best combination of mechanical stability and reworkability. The use of a clip requires considerable advance planning, because mounting holes are required in the PCB. The mounting holes should be non-plated, but each must have a grounded annular ring on the solder side of the board surrounding the hole. For a typical low-cost clip, this annular ring should have an inner diameter of 150 mils and an outer diameter of 300 mils. This ring should contain at least 8 ground connections. The solder mask opening for these holes should have a radius of 300 mils.

As clip designs are generally unique to a specific system and board layout, no procedural comments are provided.

4.10.4.2. Epoxy

Some users may prefer to implement epoxy attaches for their thermal solution. For these users, the products known to be compatible with the mold-cap material are listed in Appendix A. Epoxy users should plan their process carefully, because once it is attached, the heat sink may be difficult or impossible to remove without damaging the component.

For the epoxies described in Appendix A, the manufacturer's recommended attach procedure is as follows:

1. Ensure that the surface of the component and heat sink are free from contamination. To ensure cleanliness, use a clean, lint-free wipe, proper safety precautions, and isopropyl alcohol.
2. Use the applicator provided by the epoxy manufacturer to apply the epoxy activator to the mold-cap.
3. After the activator solvent evaporates, the active ingredients will appear "wet" and will remain active for a maximum of two hours after application. **Contamination of the surface during this pre-bonding interval must be avoided.**
4. Apply the adhesive to the heat sink. Only apply the amount necessary to fill the bond and provide a small fillet (see Section 4.12.1).
5. Join and secure the assembly, while centering the heat sink on the component using a maximum pressure of 30 psi. Wait for the adhesive to set (approximately 5 min.) before any further handling. The adhesive cures fully within 4-24 hours. **When applying pressure during attach, keep the motherboard flat, because bending or flexing the motherboard during application of the thermal solution may damage the solder joints of the Intel® 840 chipset. Excessive bending/flexing will create open joints.**

Note: The successful application of this product depends on accurate dispensing onto the parts being bonded. The manufacturer (Appendix A) offers equipment engineers to assist customers in selecting and implementing the appropriate dispensing equipment for various applications.

Note: To remove the heat sink after the epoxy has set, the manufacturer recommends applying heat (70 ºC – 93 ºC) to the assembly. Within this temperature range, the heat sink can be removed safely from the component without damaging it.

4.10.4.3. Tape (WP110, Single-Layer)

For users who prefer to attach by means of tape, refer to Appendix A for the suggested manufacturer and part number. To maximize heat transfer from the chipset part to the heat sink, Intel recommends using a single-layer phase-change tape.

Figure 11. Phase-Change Tape

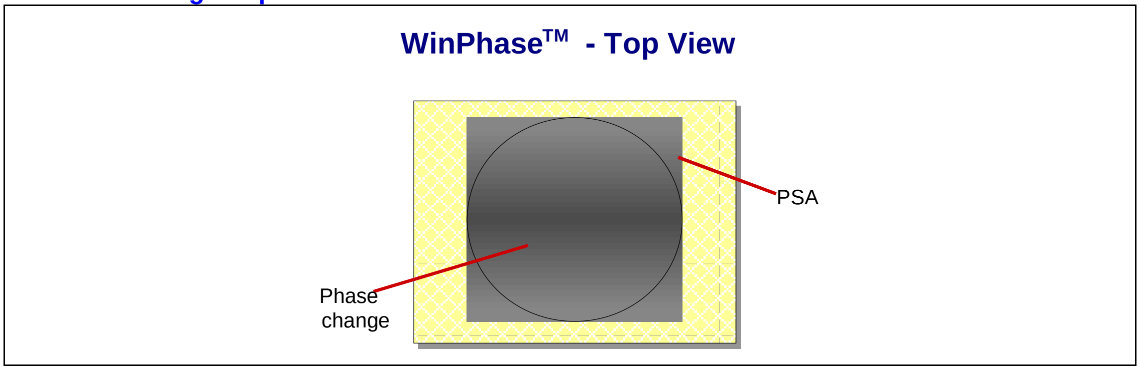
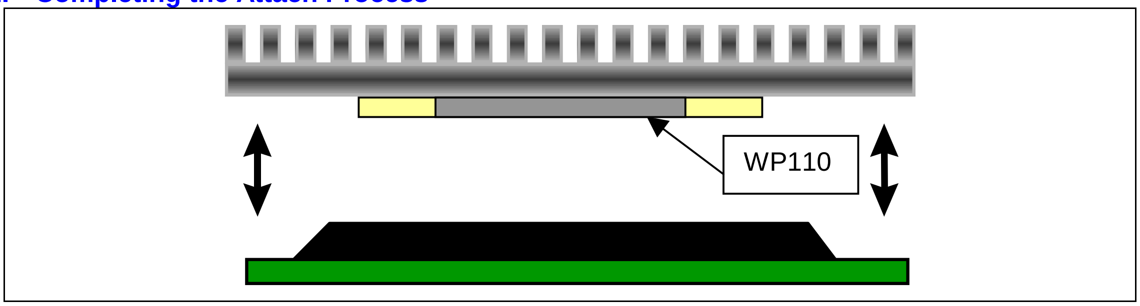


Figure 12. Completing the Attach Process



Note: Because each motherboard-system-heat sink combination may introduce variation in the attach strength, it is generally recommended that the user carefully evaluate the reliability of tape attaches prior to their high-volume use.

For the single-layer phase-change tape described in Appendix A, the recommended attach procedure is as follows:

1. Ensure that the surface of the component and the heat sink are free from contamination. To ensure cleanliness, use a clean, lint-free wipe, proper safety precautions, and isopropyl alcohol.
2. Remove the opaque foil-side backing (i.e., the side which is easier to remove) from the WPXXX tape. Apply the tape to the center of the heat sink, and smooth over the entire surface using moderate pressure. **There should be no air bubbles under the tape.**
3. Remove the other paperback liner from the tape just attached to heat sink.
4. Center the heat sink over the component and apply about 15 psi for a few seconds. **When applying pressure during attach, keep the motherboard flat, because bending or flexing the motherboard during application of the thermal solution may damage the solder joints of the Intel® 840 chipset. Excessive bending/flexing will create open joints.**

Note: Approximately 50% of the ultimate adhesion bond strength is achieved with the initial application. Once the phase-change tape has heated above 50 °C and cooled to the solid state (i.e., room temperature), the WP-110 adhesion is approximately double the initial value.

4.10.4.4. Tape (T-410, 2-Layer)

If T-410 is preferred, in order to maximize the bond line contact area and improve adhesion, Intel recommends using two pieces of tape: one attached to the heat sink and one attached to the mold-cap, as shown in the following three figures. The recommended attach procedure is discussed at the end of this section.

Figure 13. Tape Layers (Exploded Diagram)

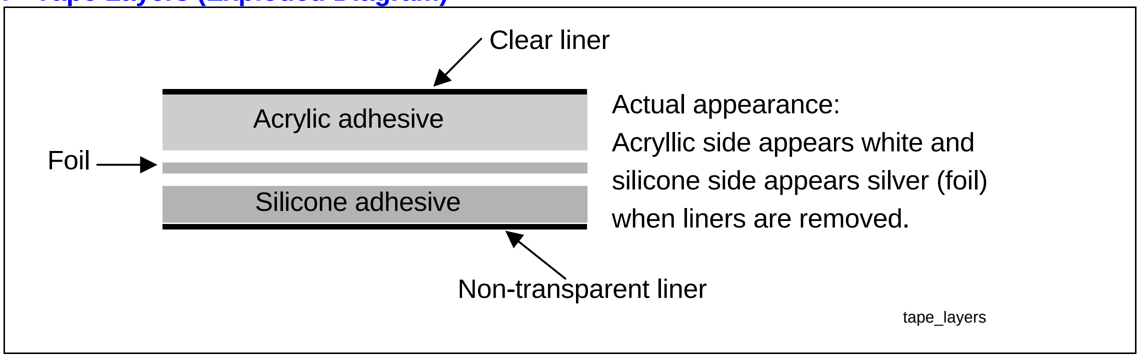


Figure 14. Attaching the Tape to the Package and Heat Sink

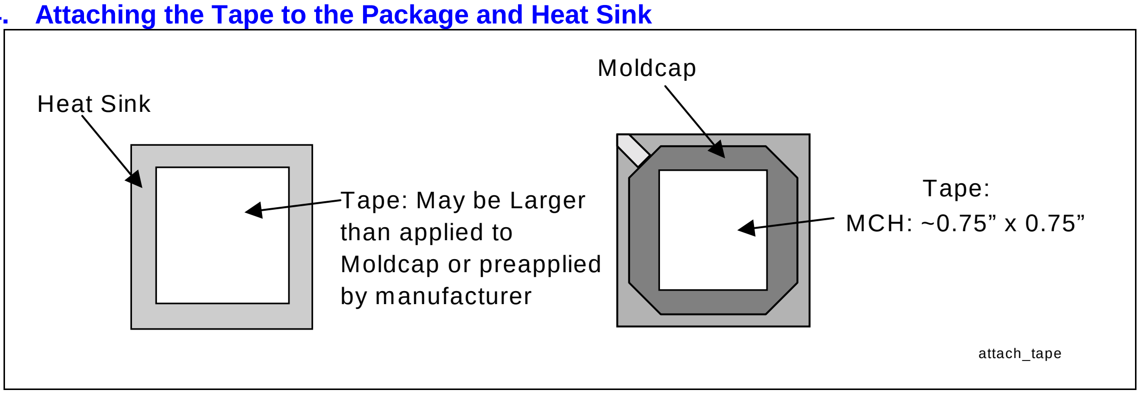
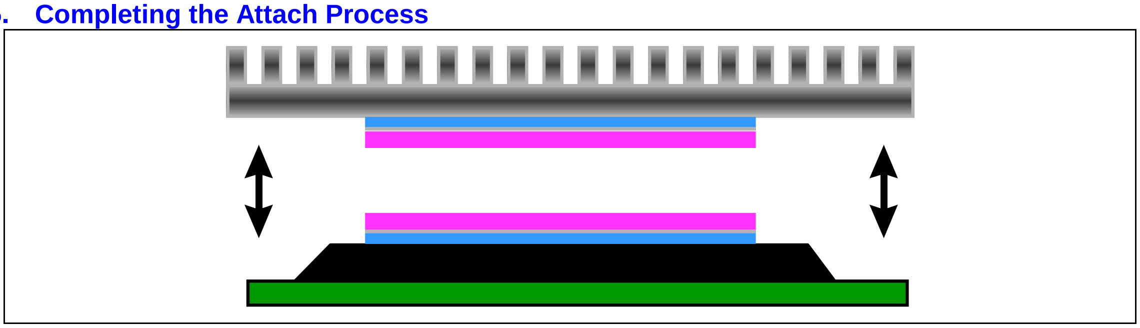


Figure 15. Completing the Attach Process



Note: The silicone adhesive always joins to either the heat sink or the mold-cap. The acrylic adhesive sides must join to each other (Figure 15)

Note: Because each motherboard-system-heat sink combination may introduce variation in the attach strength, it is generally recommended that the user carefully evaluate the reliability of tape attaches prior to high-volume use.

For the tape described in Appendix A, the recommended two-piece attach procedure is as follows:

1. Ensure that the surface of the component and the heat sink are free from contamination. To ensure cleanliness, use a clean, lint-free wipe, proper safety precautions, and isopropyl alcohol.
2. Cut the tape to size. Suggestions for the appropriate size are provided in Figure 14.
3. Heat sink side: Remove the non-transparent liner. Foil is visible underneath (Figure 13). Apply the tape to the center of the heat sink and smooth over the entire surface using moderate pressure. **There should be no air bubbles under the tape.**
4. Component side: Remove the non-transparent liner. Foil is visible underneath (Figure 13). Apply the tape to the center of the mold-cap and smooth over the entire surface using moderate pressure. **There should be no air bubbles under the tape.**
5. Both sides: Remove the clear liners from each side, center the heat sink over the component, and apply using any of the manufacturer's recommended temperature-pressure options listed in the following table. **When applying pressure during attach, keep the motherboard flat, because bending or flexing the motherboard during application of the thermal solution may damage the solder joints of the Intel® 840 chipset. Excessive bending/flexing will create open joints.**

Table 9. Tape Attach Application Temperature/Pressure Options (Not To Be Exceeded)

Pressure (psi (mPa))	Temperature (ºC)	Time (sec.)
10 (0.069)	22	15
30 (0.207)	22	5
10 (0.069)	50-65	5
30 (0.207)	50-65	3

Note: Approximately 70% of the ultimate adhesion bond strength is achieved during the initial application, and 80-90% of the ultimate adhesion bond is achieved within 15 minutes. The ultimate adhesion strength is achieved within 36 hours.

4.10.4.5. Reliability

Because every motherboard-system-heat sink-attach process combination may introduce variation in the attach strength, it is generally recommended that the user carefully evaluate the reliability of the completed assembly prior to high-volume use. Some test recommendations are listed in the following table:

Table 10. Reliability Validation

Test[1]	Requirement	Pass/Fail Criteria[2]
Mechanical shock	50 G, board level 11 msec, 3 shocks/direction	Visual check
Random vibration	7.3 G, board level 45 minutes/axis, 50 to 2000 Hz	Visual check
Temperature life	85 °C, 2000 hours total, checkpoints at 168, 500, 1000, and 2000 hours	Visual check
Thermal cycling	-5 °C to +70 °C 500 cycles	Visual check
Humidity	85% relative humidity 55 °C, 1000 hours	Visual check

NOTES:

1. The above tests should be performed on a sample size of at least 12 assemblies from 3 lots of material.
2. Additional pass/fail criteria may be added, at the discretion of the user.

4.11. Thermal Interface Management for Heat Sink Solutions

For solutions that require a heat sink, in order to optimize the heat sink design for the Intel® 840 chipset, it is important to understand the effects of factors related to the interface between the mold-cap and the heat sink base. Specifically, the bond line thickness, interface material area, and interface material thermal conductivity should be managed to realize the most effective heat sink solution.

4.11.1. Bond Line Management

The gap between the mold-cap and the heat sink base will affect heat sink solution performance. The larger the gap between the two surfaces, the greater the thermal resistance. The thickness of the gap is determined by the flatness of both the heat sink base and the mold-cap, plus the thickness of the thermal interface material (e.g., PSA, thermal grease, epoxy) used between these two surfaces.

The Intel® 840 chipset mold-cap planarity is specified as 0.006 inches maximum.

4.11.2. Interface Material Performance

Two factors affecting the interface material performance between the mold-cap and the heat sink base:

- Thermal resistance of the material
- Wetting/filling characteristics of the material

The thermal resistance indicates how readily a thermal interface material is able to transfer heat from one surface to another. The higher the thermal resistance, the less efficiently an interface transfers heat. The thermal resistance of the interface material has considerable effect on the thermal performance of the overall thermal solution. A high thermal resistance requires a greater temperature drop across the interface, so the thermal solution must be more efficient.

The wetting/filling characteristics of the thermal interface material indicate its ability to fill the gap between the case and the heat sink. Since air is an extremely poor thermal conductor, the more completely the interface material fills the gaps, the lower the temperature drop across the interface.

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5. Measurements for Thermal Specifications

Measurements must be obtained in order to appropriately determine the thermal properties of a system. Guidelines have been established for the proper techniques to be used when measuring the case temperatures of the Intel® 840 chipset. The following subsection provides guidelines regarding how to accurately measure the case temperature of the Intel® 840 chipset. Section 5.2 contains information on running an application program that emulates the anticipated maximum thermal design power. The flowchart in Figure 19 and Section 4.12 offer useful guidelines for performance and evaluation.

5.1. Case Temperature Measurements

To ensure the functionality and reliability of the Intel® 840 chipset, proper operation is obtained when the Tcase (case temperature) is maintained at or below the maximum case temperatures listed in Table 1. The surface temperature of the case is measured at the geometric center of the mold-cap. Special care is required when measuring the Tcase temperature, in order to ensure accurate temperature measurement.

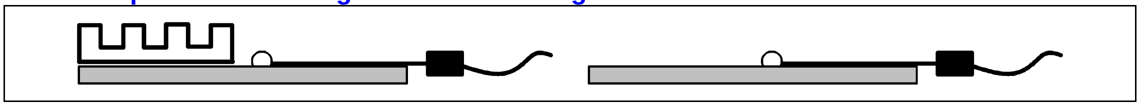
Thermocouples often are used to measure Tcase. Before temperature measurement, the thermocouples must be calibrated.

When measuring the temperature of a surface with a temperature different from that of the local ambient air, measurement errors could be introduced. The measurement errors could be due to poor thermal contact between the thermocouple junction and the surface of the package, heat loss by radiation, convection, conduction through thermocouple leads or contact between the thermocouple cement and the heat sink base, in the case of a solution that implements a heat sink. To minimize these measurement errors, the following approach is recommended:

Attaching the Thermocouple

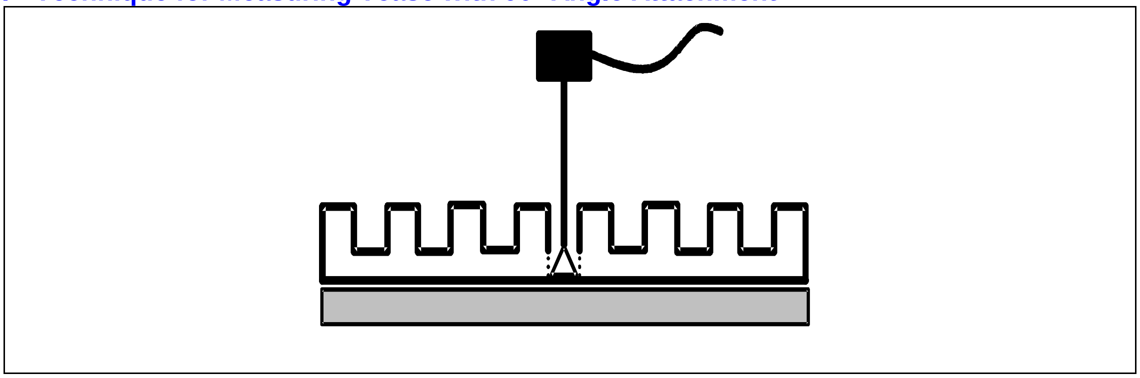
- Use 36-gauge or smaller-diameter K-type thermocouples.
- Ensure that the thermocouple has been calibrated properly.
- Attach the thermocouple bead or junction to the top surface of the package (case) at the center of the mold-cap, using a high-thermal-conductivity cement. An alternative for tape attach users is to use the tape itself to mount the thermocouple. It is *critical* that the entire thermocouple lead be butted tightly against the mold-cap.
- The thermocouple should be attached at a 0° angle, if there is no interference with the thermocouple attach location or leads (see the following figure). This is the preferred method and is recommended for use with both unenhanced packages as well as packages employing thermal enhancements.

Figure 16. Technique for Measuring Tcase with 0° Angle Attachment



- If the thermocouple cannot be attached as shown previously, the thermocouple may be attached at a 90° angle (see the following figure).
- The hole through the heat sink base, which is used to route the thermocouple wires out, should be smaller than 0.150" in diameter.
- Make sure there is no contact between the thermocouple cement and the heat sink base. Such a contact would affect the thermocouple reading.

Figure 17. Technique for Measuring Tcase with 90° Angle Attachment

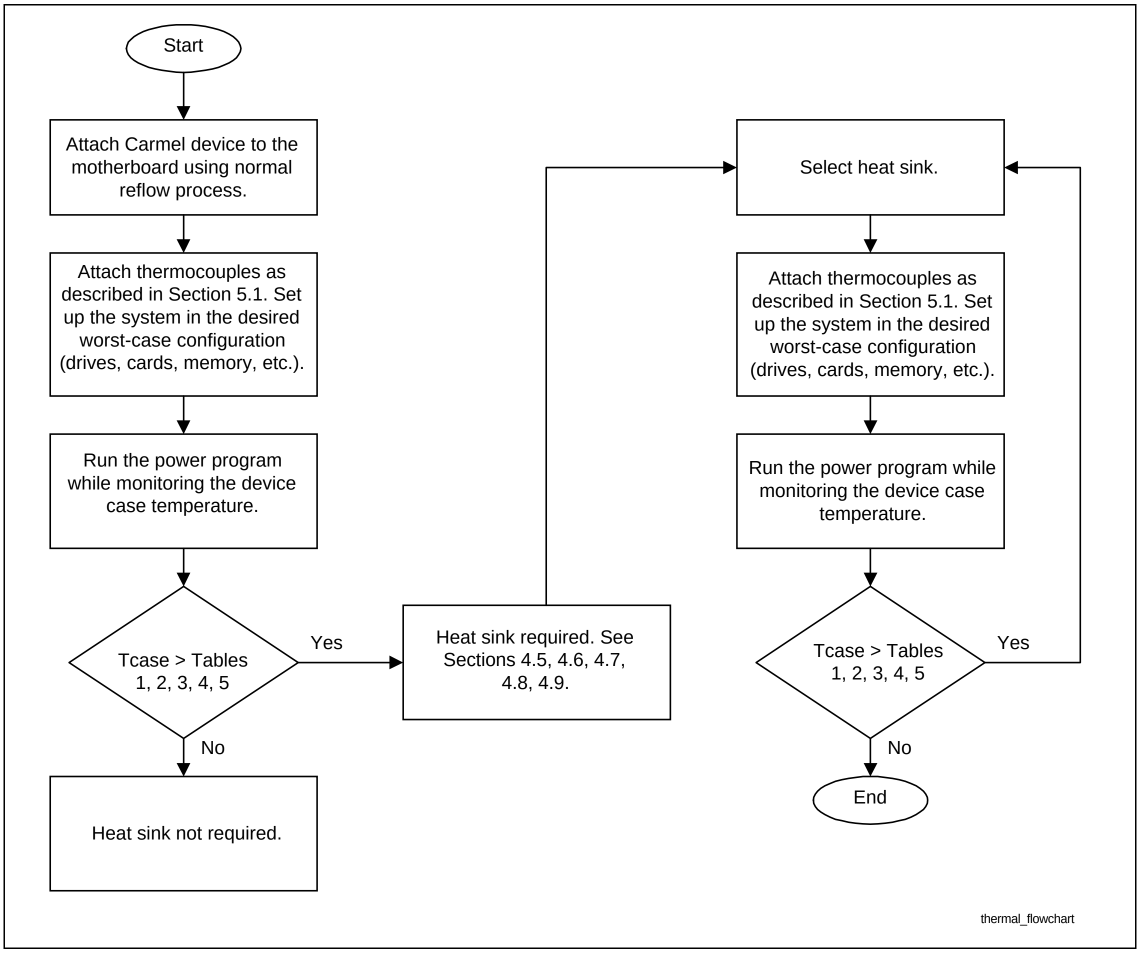


5.2. Power Simulation Software

The Power Simulation Software is a utility designed to test the thermal design power for an Intel® 840 chipset, when used in conjunction with a Pentium® III processor. The combination of the Pentium® III processor and the higher bandwidth capability of the Intel® 840 chipset enables new levels of system performance. To ensure the thermal performance of the Intel® 840 chipset under "worst-case, realistic-application" conditions, Intel has developed a software utility that emulates this anticipated power dissipation.

The Power Simulation Software was developed solely for testing the thermal design power and customer thermal solutions (see the following flowchart). Real future applications may exceed the thermal design power limit for transient time periods. For the power supply current requirements under these transient conditions, refer to each component's datasheet addendum for the I_{CC} (max. power supply current) specification.

Figure 18. Thermal Enhancement Decision Flowchart



6. Conclusion

As today's systems become increasingly complex, so will their power dissipation requirements. Care must be taken to ensure that the additional power is dissipated properly. Heat can be dissipated using improved system cooling, the selective use of ducting, and/or passive heat sinks.

The simplest and most cost-effective method is to improve the inherent system cooling characteristics by means of the careful design and placement of fans, vents, and ducts. When additional cooling is required, thermal enhancements may be implemented in conjunction with enhanced system cooling. The size of the fan or heat sink can be varied to balance size and space constraints with acoustic noise.

This document has presented the conditions and requirements associated with the proper design of a cooling solution for systems implementing the Intel® 840 chipset. Properly designed solutions provide adequate cooling that maintains the Intel® 840 chipset case temperatures at or below those listed in Table 1. This is accomplished by providing a low local ambient temperature and by creating a minimal thermal resistance to that local ambient temperature. If the Intel® 840 chipset case temperature is maintained at or below those recommended in this document, a system will function properly and reliably.

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7. APPENDIX A: Heatsink and Attach Suppliers

Extruded Heat Sink Sales Locations

Thermalloy* : http://www.thermalloy.com

AAVID* : http://www.AAVID.com

Part Numbers

Thermalloy

22368B	P64H
21946B	MCH

AAVID

619953 B 00945	P64H
634553 B 01358	MCH

Attach Sales Locations

For epoxy, go to the following website: http://www.loctite.com. Select a country, and then select "Products for the Electronics Industry."

For tape, go to the following website: http://www.chomerics.com/.

Part Numbers

Loctite* epoxy :	Part number 383 or 384
Chomerics* tape :	T-410
Thermoset* winPhase* tape :	WP110

Package Size (mm^2)	Mold-Cap Dimensions (mm^2)	WP # to Be Used
23	19	WP075
27	24	WP100
31	26	WP100
35	30	WP110

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8. APPENDIX B: System-Based Thermal Assumptions

As mentioned in Section 4.2 and elsewhere, most thermal power dissipated by the chipset typically flows into the motherboard on which it is mounted (when thermal or center balls are present). The size of the board is a key factor in determining the amount of heat that the package can dissipate. When comparing JESD/JEDEC-derived data with data derived from system-level testing, it was determined that the effect of the larger board used for a typical motherboard was profound. To reconcile the differences and provide more realistic data to the customer, Intel has adopted a system-based thermal simulation and test methodology.

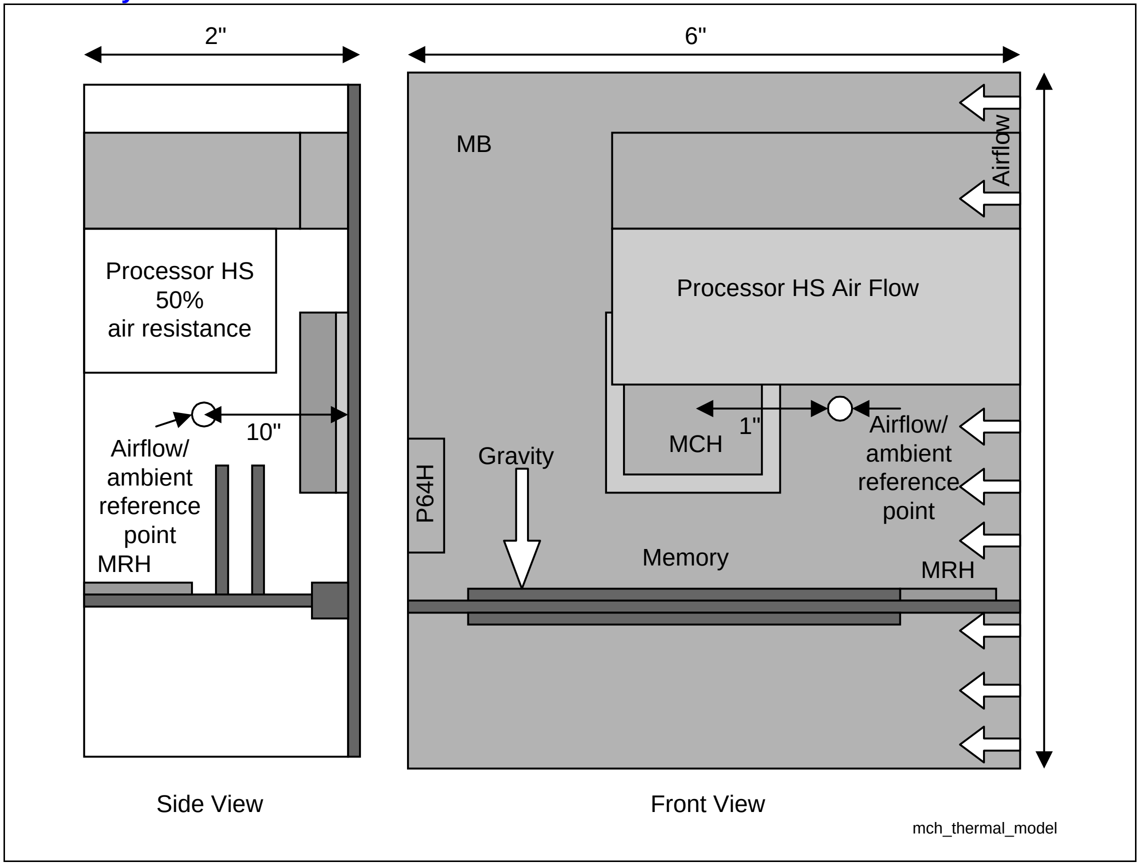
The system-based model for the MCH, P64H, and MRH-S are described in the following subsections and are illustrated in the figures.

8.1. MCH System Model

The assumptions in the system-based model shown in the following figure are as follows:

- A six-layer board is used, and it incorporates 1-oz. copper inner layers.
- The effective thermal dissipation area for the MCH is defined as the 6×6-inch area surrounding the MCH, as shown in the following figure.
- The CPU dissipates 20 W into the ambient environment.
- The CPU does not dissipate thermally significant amounts of heat through the connector.
- Any airflow is parallel to the motherboard.
- Zero airflow is defined as a natural convection environment.
- Airflow is measured at a point one inch above the motherboard and one inch upstream of the MCH’s top dead center.
- The heat sink is defined as a black anodized 35×35×7.5-mm unidirectional type (i.e., “pin fin”).

Figure 19. MCH System-Based Thermal Model



8.2. P64H System Model

The assumptions in the system-based model shown in the following figure are as follows:

- A six-layer board is used, and it incorporates 1-oz. copper inner layers.
- The effective thermal dissipation area for the P64H is defined as a 6×6-inch area, as shown in the following figure.
- The MCH dissipates heat nearby, into the motherboard (see the following figure).
- There is no heat flow from the MEC to the motherboard.
- The MEC is partially modeled for airflow effects.
- Any airflow is parallel to the motherboard.
- Zero airflow is defined as a natural convection environment.
- Airflow is measured at a point one inch above the motherboard and one inch upstream of the MRH-R's top dead center.
- The heat sink is defined as a black anodized 24×24×7.5-mm unidirectional type (i.e., "pin fin").

Figure 20. P64H System-Based Thermal Model