Intel740™ Graphics Accelerator

Application Note 653: Thermal Design Considerations

April 1998

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1.0 Introduction

In a system environment, the chipset temperature 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 surrounding board as well as the physical constraints at, above, and surrounding the component. The component's case temperature depends on the component power dissipation, size, packaging materials (effective thermal conductivity), the type of interconnection to the substrate and motherboard, the presence of a thermal cooling solution, the thermal conductivity and the power density of the substrate, nearby components, and motherboard.

All of these parameters are pushed by the continued trend of technology to increase performance levels (higher operating speeds, MHz) and packaging density (more transistors). As operating frequencies increase and 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 to ensure that thermal design requirements are met for each component in the system.

1.1 Document Goals

The Intel740™ graphics accelerator is the newest addition to the growing market of fast, 3D graphics accelerators. Previous generations of graphics accelerators generated insufficient heat to require an enhanced cooling solution in order to meet the case temperature specifications in system designs. As the market transition to higher-speeds with enhanced features, the heat generated by these advanced graphics accelerators 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 graphics accelerators. The goal of this document is to provide an understanding of the thermal characteristics of the Intel740 graphics accelerator and discuss guidelines for meeting the thermal requirements imposed on systems.

1.2 Importance of Thermal Management

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

1.3 Intel740™ Graphics Accelerator Packaging Terminology

BGA	Ball Grid Array. A package type defined by a resin-fiber substrate on 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.
Lands	Pads on the PCB where BGA Balls are soldered.
Mold-Cap	The black encapsulating molding compound. The top of this is where maximum case temperatures are taken and where heat sinks are attached.
PCB	Printed Circuit Board.
STBGA	Super Thermal BGA. A Ball Grid Array Package enhanced to improve its thermal characteristics. The Intel740 graphics accelerator uses this type of BGA packaging.
Thermal Balls	Typically, this refers to an array of balls in the center of the larger array of balls which serve to channel heat into the PCB as well as ground connections.

2.0 Thermal Specifications

The Intel740™ graphics accelerator power dissipation can be found in the Intel740™ Graphics Accelerator Datasheet and Intel740™ Graphics Accelerator Specification Updates. Please refer to these documents to verify the actual thermal specifications for the Intel740 graphics accelerator. In general, systems should be designed to dissipate the highest possible thermal power.

To ensure proper operation and reliability of the Intel740 graphics accelerator, the thermal solution must maintain the case temperature at or below its specified value (Table 1). Considering the power dissipation levels and typical system ambient environments of 45°C to 55°C, if the Intel740 graphics accelerator case temperature exceeds the maximum case temperature listed in Table 1, system or component level thermal enhancements will be required to dissipate the heat generated.

The thermal characterization data described in later sections illustrates that good system airflow is critical. In typical systems the thermal solution is limited by board layout, spacing and component placement. Airflow is determined by the size and number of fans and vents along with 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 types of fans and vents 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 carried out at the entire system level accounting for the thermal requirements of each component.

Table 1. Intel740 Graphics Accelerator Preliminary Thermal Absolute Maximum Rating

Parameter	Maximum
$T_{case-nhs}$1	109°C
$T_{case-hs}$2	96°C

NOTES:
1. $T_{case-nhs}$ is defined as the maximum case temperature without a Heat Sink attached.
2. $T_{case-hs}$ is defined as the maximum case temperature with a Heat Sink attached (see Section 4.2, “Thermal Enhancements” on page 10).

2.1 Case Temperature

The case temperature is a function of the local ambient temperature and the internal temperature of the Intel740graphics accelerator. As a local ambient temperature is not specified for the Intel740, the only restriction is that the maximum case temperature (T_{case}) is not exceeded. Section 5.1, “Case Temperature Measurements” on page 19 discusses proper guidelines for measuring the case temperature.

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

2.2 Power

In previous generations of graphics accelerators where Quad Flat Pack (QFP) packages have been the primary package type, the majority of power dissipation has been through the plastic case of the package into the surrounding air. With the advent of Ball Grid Array (BGA) packaging for graphics accelerators, the majority of the thermal power dissipated by the chipset typically flows into the motherboard where it is mounted. The remaining thermal power is dissipated by the package itself. The STBGA used for the Intel740 graphics accelerator continues this trend by further enhancing the package's ability to channel heat into the motherboard.

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 motherboard design. The following should be taken into account by system designers when developing new systems:

- How well the thermal balls are connected to the inner planes of the motherboard. It is recommended that:
  - One via per ground ball be used.
  - Minimum width of the trace connecting the motherboard ground pad to the via be 10 mil.
  - Plated Via Size for ground balls be 14 to 16 mil in diameter on a 24 to 27 mil pad. A larger via is more efficient in channeling heat.
  - Do not use Thermal Relief Patterns on the inner plane connections of the thermal balls.
- How well the inner planes conduct heat away from the package. Good ground paths to other areas of the board will distribute heat more efficiently.
- The size of the motherboard, number of copper layers and the thickness of those layers.

3.0 Designing for Thermal Performance

In designing for thermal performance, the goal is to keep the component within the operational thermal specifications. The heat generated by the components within the chassis must be removed to provide an adequate operating environment for all of the system components. To do so requires moving air through the chassis to transport the heat generated out of the chassis.

3.1 Airflow Management

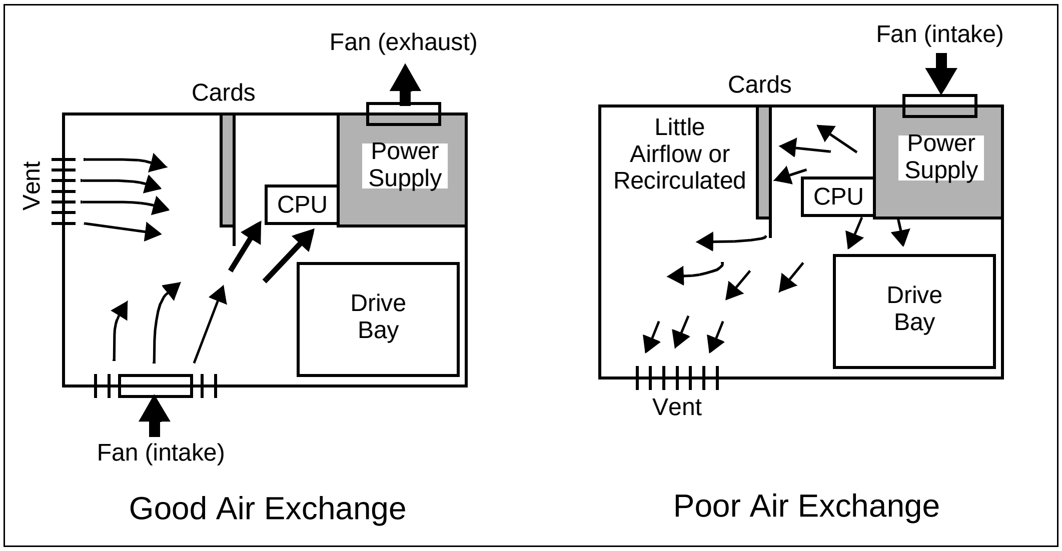
It is important to manage the air flow path and amount of air that flows through the system to maximize the amount of air that will flow over the Intel740 graphics accelerator and AGP Card. System air flow can be increased by adding one or more fans to the system, by vents and fans in combination, by increasing the output (faster speed) or size of an existing system's fan(s). Local air flow can also be increased by managing the local flow direction using baffles or ducts. An important consideration in airflow management is the temperature of the air flowing over the graphics processor. Heating effects from add-in boards, memory, other accelerators and disk drives greatly reduce the cooling efficiency of this air, as does re-circulation of warm interior air. Care must be taken to minimize the heating effects of other system components and to eliminate excessive warm air re-circulation.

For example, a clear air path from the external system vents to the system fan(s) will enable the warm air from the Intel740 graphics accelerator and AGP Card to be efficiently removed from the system. If no air path exists across the them, the warm air ambient to the Intel740 graphics accelerator and AGP Card will not be removed from the system, resulting in localized heating ("hot spots") at and around the graphics processor requiring the addition of a thermal cooling device. Figure 1 shows two examples of air exchange through a PC-ATX style chassis. The system on the left is an example of good air exchange incorporating both the power supply fan, an additional system fan and good venting. The system on the right shows a system with only a power supply fan (blowing into the box) and minimal venting resulting in poor air flow past the AGP card.

Re-circulation of internal warm air is most common between the system fan and chassis, between the system fan intake and the drive bays behind the front bezel and in the card area. These paths may be eliminated by mounting the fan flush to the chassis, thereby obstructing the flow between the drive bays and fan inlet, and by providing generous intake vents in both the chassis and the front bezel.

Note: Note that these are recommendations. With careful engineering, modeling and testing, other solutions may work equally well in cooling the system.

Figure 1. Example of air exchange through a PC chassis



4.0 Cooling Solutions

Numerous alternatives for cooling solutions exist for the Intel740 graphics accelerator. This section will explore system cooling solutions as well as package heat-sinks. Due to their varying attributes, each of these solutions may be appropriate for a particular system implementation.

4.1 System Fans

Fans are needed to move the air through the chassis. The airflow rate of a fan is a function of the system's impedance to airflow and the capability of the fan itself. Maximum acceptable noise levels may limit the fan output or the number of fans selected for a system. It is appropriate at this time to reiterate Section 2.2, "Power" on page 4. The majority of the thermal power dissipated by the Intel740 graphics accelerator typically flows into the motherboard to which it is mounted. Cooling the motherboard will cool the component by increasing the efficiency of heat transfer from the device to the motherboard.

4.1.1 Fan Placement

Proper placement of the fans can ensure that the Intel740 graphics accelerator is properly cooled. Because of the difficulty in building, measuring and modifying a mechanical assembly, models are typically developed and used to simulate a proposed prototype for thermal effectiveness to determine the optimum location for fans and vents within a chassis. Prototype assemblies can also be built and tested to verify if thermal specifications for the system components are met.

An air fan is typically in the power supply exhausting air through the power supply vents. A second system fan is added to improve airflow to the chipset and other system components. The second fan can improve component cooling up to 15% depending on airflow management within the system, obstructions and thermal enhancements. Figure 2 and Figure 3 show recommended fan placements for an ATX form factor layout and a NLX form factor, respectively. Again, note that these are recommendations, with careful engineering, modeling and testing, other solutions may work equally well in cooling the graphics processor.

Figure 2. Fan Placement and Layout of an ATX Form Factor Chassis - Top View

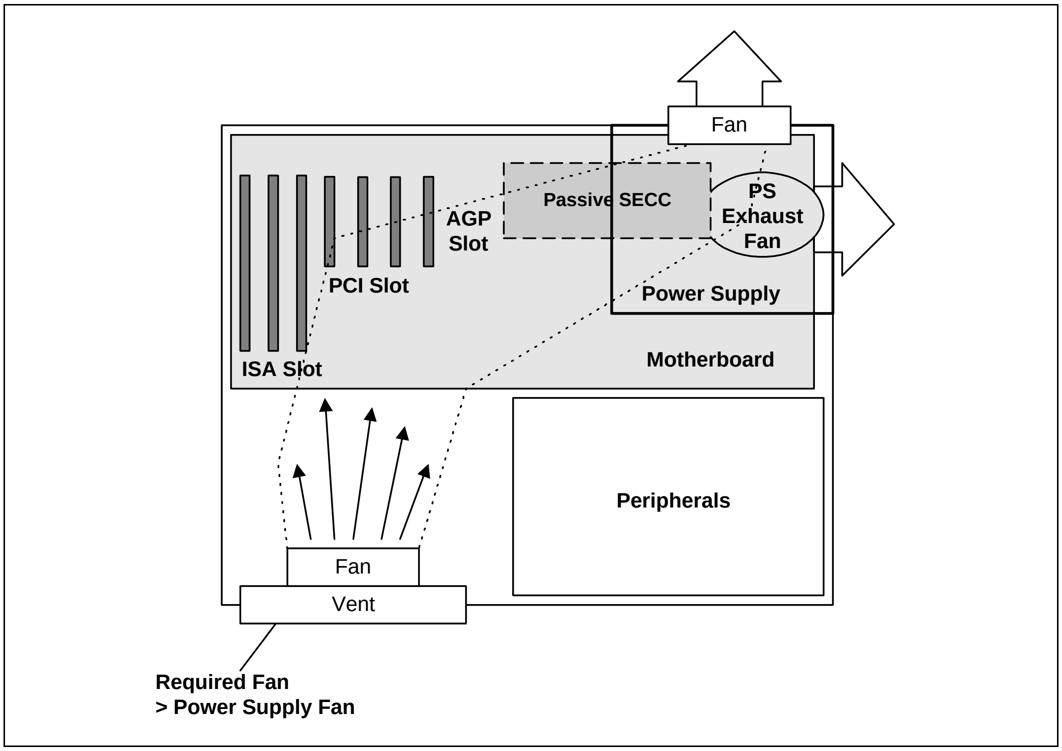
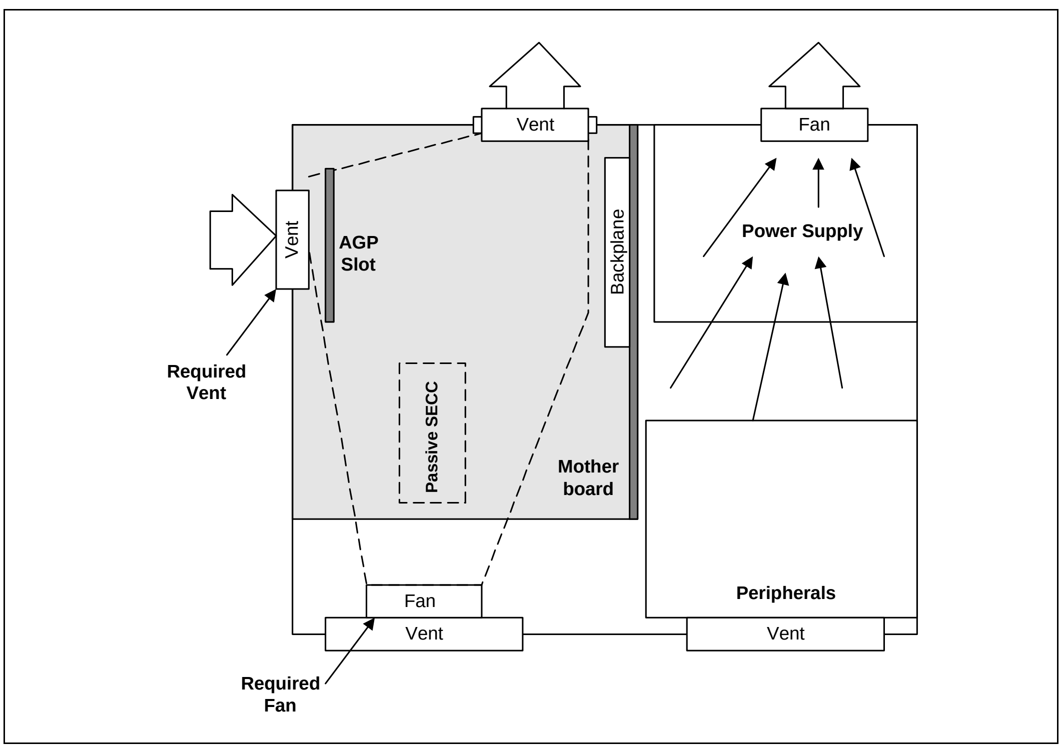


Figure 3. Fan Placement and Layout of an NLX Form Factor Chassis - Top View



4.1.2 Fan Direction

If the fan(s) are not moving air across the graphics processor and the card then little cooling can occur. Hence, the Intel740 graphics accelerator may exceed it's absolute maximum thermal ratings. Note the recommended fan airflow directions in Figure 2 and Figure 3.

The direction of the air flow can also be modified with baffles or ducts to direct the air flow over the graphics processor. This will increase the local flow over the device and card and may eliminate the need for a larger or higher speed fan.

4.1.3 Size and Quantity

A larger fan does not always increase cooling efficiency. A small blower using ducting might direct more air over the graphics card than a larger fan blowing non-directed air. The following provides some recommendations for the size and quantity of the fans in AGP systems.

- The fan should be a minimum of 80 mm (3.150") square, with a minimum airflow of approximately 40 CFM (cubic feet per minute), or approximately 400 LFM (linear feet per minute). As shown in Figure 2 and Figure 3, two fans are used. The intake air fan blows cooler external air into the chassis, while the second fan (most likely in the power supply) exhausts the air out of the system.
- As an example, in a lab test system, graphics card ambient temperatures were reduced by an average of roughly 10% in an ATX design and 15% in an NLX design by simply adding a front system fan. In general, the use of two fans benefits the entire system by reducing internal ambient temperatures. However, as system configurations vary, testing the target configuration to verify the benefit is recommended.

4.1.4 Fan Venting

As shown in Figure 2 and Figure 3, intake venting should be placed at the front (user side) of the system. Location should take into consideration cooling of the microprocessor and peripherals as well as the Intel740 graphics accelerator. A good starting point would be the lower 50% of the Front Panel (Bezel). Intake venting directly in front of the intake fan is the most optimal location.

4.1.5 Vent Placement

In most cases, exhaust venting in conjunction with an exhaust fan in the power supply is sufficient. However, depending on the number, location and types of add-in cards, intake or exhaust venting may be necessary near the cards as well. This is particularly important for the graphics card in NLX designs as it aids in eliminating dead air space near the AGP Slot (see Figure 3).

Vent placements should be modeled or prototyped for the optimum thermal potential. Hence, a system should be modeled for the worst case (i.e., all expansion slots should be occupied with typical add-in options).

4.1.5.1 Vent Area/Size

The area and/or size of the intake vents should consider the size and shape of the fan(s). Adequate air volume must be obtained and this will require appropriately sized vents. Intake vents should be located in front of the intake fan(s) and adjacent to the drive bays. Venting should be approximately 50% to 60% open in the EMI containment area due to EMI constraints. Outside the EMI containment area, the open percentage can be greater if needed for aesthetic appeal (i.e., bezel/cosmetics). For more information concerning EMI constraints and Pentium II processor based system design, see the *Pentium II Processor EMI Design Guidelines* Application Note.

4.1.5.2 Vent Shape

Round, staggered pattern openings are best for EMI containment, acoustics and airflow balance. For material related to EMI considerations please see the *Pentium II Processor EMI Design Guidelines* Application Note.

4.1.6 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 could be channeled directly over the Intel740 graphics accelerator and card or split into multiple paths to cool multiple components.

4.1.6.1 Ducting Placement

When ducting is to be used, it should direct the airflow evenly from the fan across the entire component and surrounding motherboard. The ducting should be accomplished, if possible, with smooth, gradual turns as this will enhance the airflow characteristics. Sharp turns in ducting should be avoided. Sharp turns increase friction and drag and will greatly reduce the volume of air reaching the Intel740 graphics accelerator and card.

4.2 Thermal Enhancements

One method used to improve thermal performance is to increase the surface area of the device by attaching a metallic heat sink to the mold cap. To maximize the heat transfer, the thermal resistance from the heat sink to the air can be reduced by maximizing the surface area of the heat sink itself.

For users whose ambient environments exceed 55°C, a Fan Heat Sink is strongly recommended to effectively cool the Intel740 graphics accelerator (discussed in Section 4.2.2, “Low Profile Fan Heat Sink” on page 11).

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

4.2.1 Clearance

Though each design may have unique mechanical volume and height restrictions or implementation requirements, the constraints typically placed on the Intel740 graphics accelerator by an adjacent PCI Card is 0.450” clearance between the Intel740 graphics accelerator mold cap and the back of the adjacent PCI Card.

Note: If the heat sink selected is larger than 35 mm x 35 mm, the maximum component height under the portion of the heat sink overhaning the board is 0.09 inches.

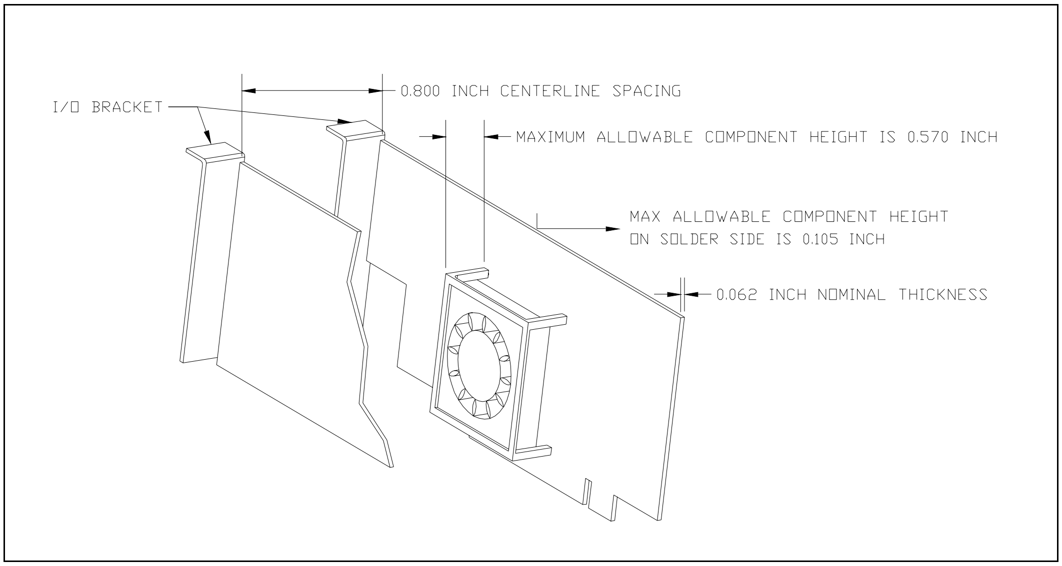
4.2.2 Low Profile Fan Heat Sink

A generic drawing for this Fan Heat Sink is shown in Figure 4. Recommended sources for the Low Profile Fan Heat Sink are discussed in Appendix A, “Sources”.

The thermal performance of the Fan Heat Sink and Thermal Interface Material (combined) must be sufficient to maintain a case temperature at or below $T_{case\text{-}hs}$ (See Table 1) in a worst case system environment (defined as: zero airflow, 55°C ambient temperature).

Note: The weight of the Fan Heat Sink must not exceed 55 gm.

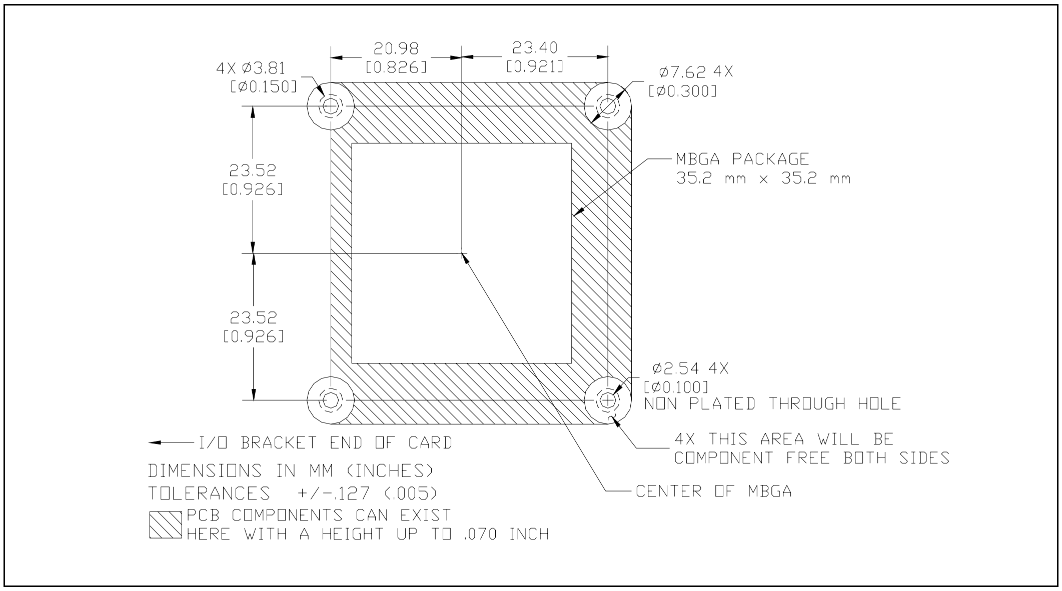
Figure 4. Low Profile Fan Heat Sink Drawing



4.2.2.1 Low Profile Fan Heat Sink PCB Layout Guidelines

As the Low Profile Fan Heat Sink uses a mechanical attach, mounting holes must be provided in the PCB to accommodate the clips necessary in attaching the Fan Heat Sink. PCB Guidelines for the Fan Heat Sink mounting hole layout are provided in Figure 5. The mounting holes must be non-plated, but each must have a grounding pad on the solder side of the board surrounding the hole. It must be designed in such a way to ensure that the mechanical attachment clip is in solid contact with this pad. The mechanical assembly should only contact the PCB within the four 0.300 inch diameter component keep-out zones as shown in Figure 5. The outline of the Fan Heat Sink should be silk-screened onto the PCB to facilitate placement of the Fan Heat Sink on to the package.

Figure 5. PCB Layout Guidelines for Mounting Holes



4.2.2.2 Low Profile Fan Heat Sink Electrical Requirements

The Fan Heat Sink's total maximum power usage should not exceed 1 Watt and should start and operate within ±10% of rated voltage.

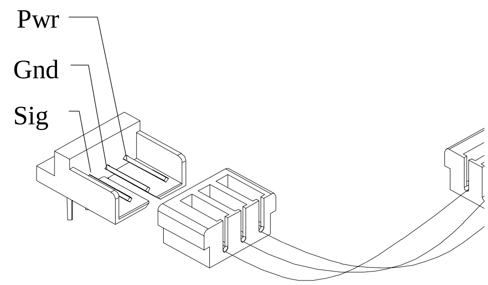
The Fan Heat Sink may use a connector which incorporates 2 separate connections: 12 Volt power, ground and signal (tachometer function). The fan connector may mate with a receptacle attached to a power cable that will be installed by the graphics card manufacturer. See Figure 5.

The Fan Heat Sink assembly, when installed in at least one typical host application, should not cause an increase in emissions above that measured from the host application before the assembly was installed.

The signal pin on fan header may supply an open collector rotor lock output signal:

- Operating: Output is asserted by pulling the output low
- Locked Rotor: Output is de-asserted, allowing output to float high using a pull up resistor on the graphics card.

Figure 6. Fan Heat Sink Connector Design



4.2.2.3 Low Profile Fan Heat Sink Attach

The Low Profile Fan Heat Sink uses a mechanical attach to the card in conjunction with a thermal interface material. The recommended process flow for attaching the Low Profile Fan Heat Sink is shown as follows:

1. Ensure that the surface of the component and heat sink are free from contamination. Use a clean, lint-free wipe, proper safety precautions and Isopropyl Alcohol to ensure cleanliness.
2. Apply the Thermal Interface Material to the moldcap.
3. Place the Fan Heat Sink onto the moldcap within the confines of the silkscreened markings on the board.
4. Apply the mechanical attachment clip.

To repeat, the Thermal Performance of the Fan Heat Sink and Attach (combined) must be a maximum of 4.0°C per Watt at 80% of nominal fan RPM in a worst case system environment (defined as: zero airflow, 55°C internal ambient temperature).

4.2.2.4 Low Profile Fan Heat Sink Reliability

As every motherboard, system, heat sink and attach-process combination may introduce variance in attach strength and the use of a fan heat sink adds the need for fan-lifetime evaluation, it is generally recommended that the user carefully evaluate the reliability of the completed assembly prior to use in high volume. Some Test recommendations can be seen in Table 2.

Table 2. Default Thermal Solution Reliability Validation

Test[1]	Requirement	Pass/Fail Criteria
Mechanical Shock	50G 11 msec, 3 shocks/direction	Visual Check [3] RPM Check [4]
Random Vibration	7.3 G 45 minutes/axis, 50 to 2000 Hz	Visual Check RPM Check
Temperature Life	85 °C, 2000 hours total, checkpoints occur at 168, 500, 1000 and 2000 hours	Visual Check RPM Check
Thermal Cycling	-5 °C to +70 °C 500 Cycles	Visual Check RPM Check

Table 2. Default Thermal Solution Reliability Validation

Humidity	85% relative humidity 55 °C, 1000 hours	Visual Check RPM Check
Power Cycling	7,500 on/off cycles with each cycle specified as 3 minutes on, 2 minutes off 70 °C	Visual Check RPM Check

NOTES:
1. The above tests should be performed on a sample size of at least 12 Fan Heat Sink units from 3 assembly lots.
2. Visual Check: Labels, housing and connections all intact.
3. RPM Check: No fan RPM changes before and after test of greater than 20%.
4. The Fan Heat Sink's thermal performance should meet the minimum specified requirements at an altitude of 1 to 10,000 feet.
5. Additional Pass/Fail Criteria may be added at the discretion of the user.

4.2.3 Low Profile Passive Heat Sink

A Passive, Extruded Heat Sink may be attached using Clips and Thermal Interface (tape, grease, etc.), Epoxy or Tape Adhesives. Suggested suppliers and part numbers for a passive heat sink are listed in Section A, "Sources" on page 23.

4.2.3.1 Clip Attach

A well designed clip in conjunction with a thermal interface material (tape, grease, etc.) solution may offer the best combination of mechanical stability and reworkability. Use of a clip requires significant advance planning as 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.

4.2.3.2 Epoxy

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

For the Epoxies described in Section A, "Sources" on page 23, the manufacturer's recommended attach procedure is as follows:

1. Ensure that the surface of the component and heat sink are free from contamination. Use a clean, lint-free wipe, proper safety precautions and Isopropyl Alcohol to ensure cleanliness.
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 time prior to bonding must be avoided.**
4. Apply the adhesive to the heat sink. The amount of adhesive applied to the heat sink should be limited to the amount necessary to fill the bond and provide a small fillet (see Section 4.3.1, "Bond Line Management" on page 18).

5. Join and secure the assembly centering the heat sink on the component. Wait for the adhesive to fixture (approximately 5 minutes) before any further handling. Full cure occurs in 4-24 hours.

Note: The successful application of this product depends on accurate dispensing on to the parts being bonded. The manufacturer (Section A, “Sources” on page 23) offers equipment engineers to assist customers in selecting and implementing the appropriate dispensing equipment for various applications.

To remove the heat sink after the epoxy has set, the manufacturer recommends applying heat (70°C - 93°C) to the assembly. When in this temperature range the heat sink can safely be removed from the component without damaging it.

4.2.3.3 Tape Attach

For users who prefer to attach via Tape, please refer to Section A, “Sources” on page 23 for the suggested manufacturer and part number. To maximize the bond line contact area and improve adhesion we recommend using two pieces of tape, one attached to the heat sink and one attached to the moldcap as shown in Figure 7, Figure 8, and Figure 9. The recommended attach procedure is at the end of this section.

Figure 7. Tape Layers

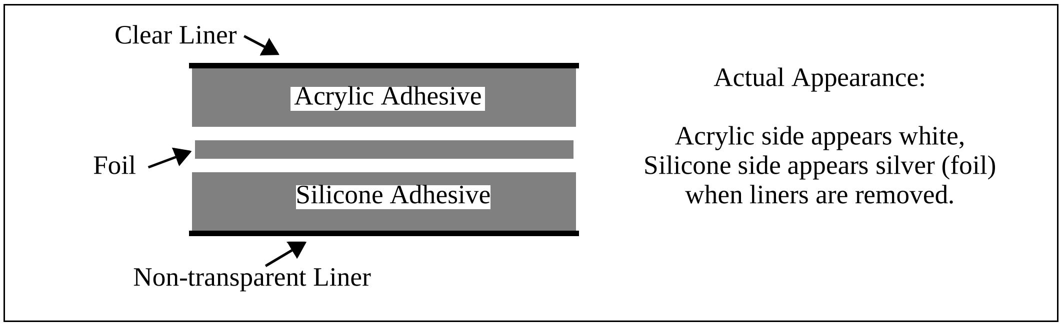


Figure 8. Attaching the Tape to the Package and Heat Sink

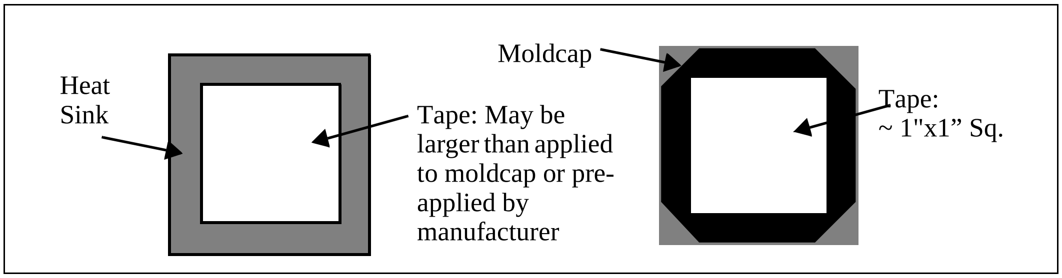
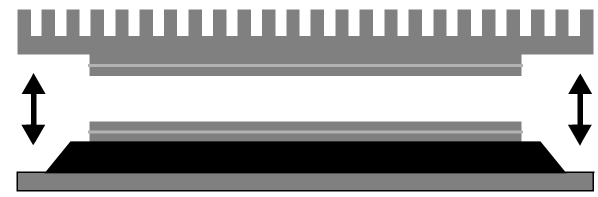


Figure 9. Completing the Attach Process



Note: Silicone Adhesive always joins to either the heat sink or the moldcap, the Acrylic Adhesive sides must join to each other (Figure 9).

Note: As every motherboard, system and heat sink combination may introduce variance in attach strength, it is generally recommended that the user carefully evaluate the reliability of tape attaches prior to using in high volume.

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

1. Ensure that the surface of the component and heat sink are free from contamination. Use a clean, lint-free wipe, proper safety precautions and Isopropyl Alcohol to ensure cleanliness.
2. Cut tape to size. Suggestions for the appropriate size can be seen in Figure 8.
3. Heat Sink Side: Remove the non-transparent liner. You will see foil underneath (Figure 7). 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. You will see foil underneath (Figure 7). 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 one of the manufacturer's recommended temperature/pressure options shown in Table 3.

Table 3. Tape Attach Application Temperature/Pressure Option

Pressure	Temperature	Time
10 psi (0.069 mPa)	22°C	15 seconds
30 psi (0.207 mPa)	22°C	5 seconds
10 psi (0.069 mPa)	50-65°C	5 seconds
30 psi (0.207 mPa)	50-65°C	3 seconds

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

4.2.3.4 Reliability

As every motherboard, system, heat sink and attach-process combination may introduce variance in attach strength, it is generally recommended that the user carefully evaluate the reliability of the completed assembly prior to use in high volume. Some Test recommendations can be shown in Table 4.

Table 4. Reliability Validation

Test[1]	Requirement	Pass/Fail Criteria[2]
Mechanical Shock	50G, 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 occur 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.

4.3 Thermal Interface Management for Heat Sink Solutions

For solutions where a heat sink is preferred, to optimize the heat sink design for Intel740 graphics accelerator, it is important to understand the impact 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.

4.3.1 Bond Line Management

The gap between the mold-cap and the heat sink base will impact 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 Intel740 graphics accelerator mold cap planarity is specified as 0.006 inches maximum (see the Intel740™ Graphics Accelerator Datasheet, order number 290618, for package drawing).

4.3.2 Interface Material Performance

Two factors impact the performance of the interface material between the thermal plate and the heat sink base:

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

Thermal resistance is a description of the ability of the thermal interface material to transfer heat from one surface to another. The higher the thermal resistance, the less efficient an interface is at transferring heat. The thermal resistance of the interface material has a significant impact on the thermal performance of the overall thermal solution. The higher the thermal resistance, the higher the temperature drop across the interface and the more efficient the thermal solution must be.

The wetting/filling of the thermal interface material is 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.

5.0 Measurements for Thermal Specifications

To appropriately determine the thermal properties of the system, measurements must be made. Guidelines have been established for the proper techniques to be used when measuring the Intel740 graphics accelerator case temperatures. Section 5.1, "Case Temperature Measurements" on page 19 provides guidelines on how to accurately measure the case temperature of the Intel740 graphics accelerator. Section 5.2, "Power Simulation Software" on page 20 contains information on running an application program which will emulate anticipated thermal design power. The flowchart in Figure 12 as well as Section 4.2, "Thermal Enhancements" on page 10 offer useful guidelines for performance and evaluation.

5.1 Case Temperature Measurements

To ensure functionality and reliability, the Intel740 graphics accelerator is specified for proper operation when T_{case} (case temperature) is maintained at or below the maximum case temperatures listed in Table 1. The surface temperature of the case in the geometric center of the mold cap is measured. Special care is required when measuring the T_{case} temperature to ensure an accurate temperature measurement.

Thermocouples are often used to measure T_{case}. Before any temperature measurements are made, the thermocouples must be calibrated.

When measuring the temperature of a surface which is at a different temperature from the surrounding local ambient air, errors could be introduced in the measurements. The measurement errors could be due to having a poor thermal contact between the thermocouple junction and the surface of the package, heat loss by radiation, convection, by conduction through thermocouple leads, or by contact between the thermocouple cement and the heat-sink base for those solutions which implement 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 properly calibrated.
- Attach the thermocouple bead or junction to the top surface of the package (case) in the center of the mold-cap using high thermal conductivity cements. An alternative for tape attach users is to use the tape itself to mount the thermocouple. **It is Critical that the thermocouple be intimately attached across the entire moldcap.**
- The thermocouple should be attached at a 0° angle if there is no interference with the thermocouple attach location or leads (refer to Figure 10). This is the preferred method and is recommended for use with both unenhanced packages as well as packages employing Thermal Enhancements.
- For solutions where a heat-sink is preferred, the thermocouple should be attached at a 90° angle if a heat sink is attached to the case and the heat sink covers the location specified for T_{case} measurement (refer to Figure 11).
- The hole size through the heat sink base 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 heat sink base. This contact will affect the thermocouple reading.

Figure 10. Technique for Measuring T_{case} with 0° Angle Attachment

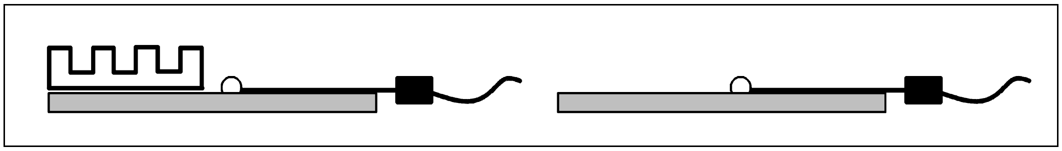
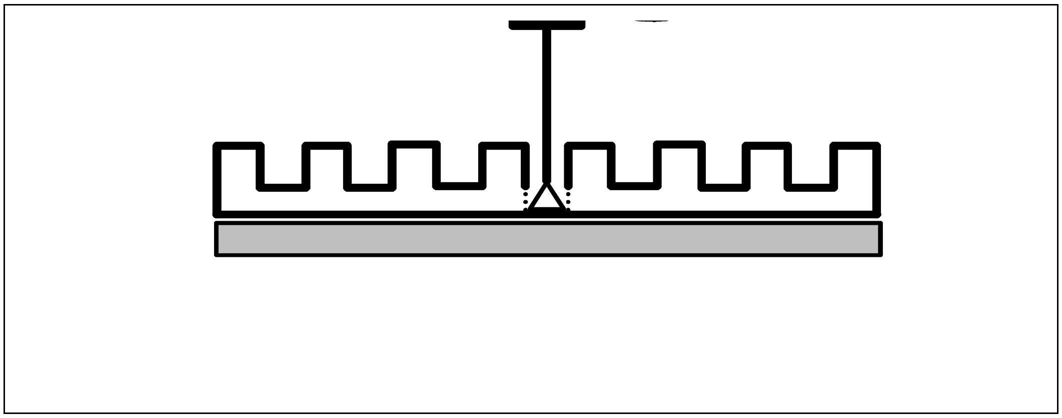


Figure 11. Technique for Measuring T_{case} with 90° Angle Attachment



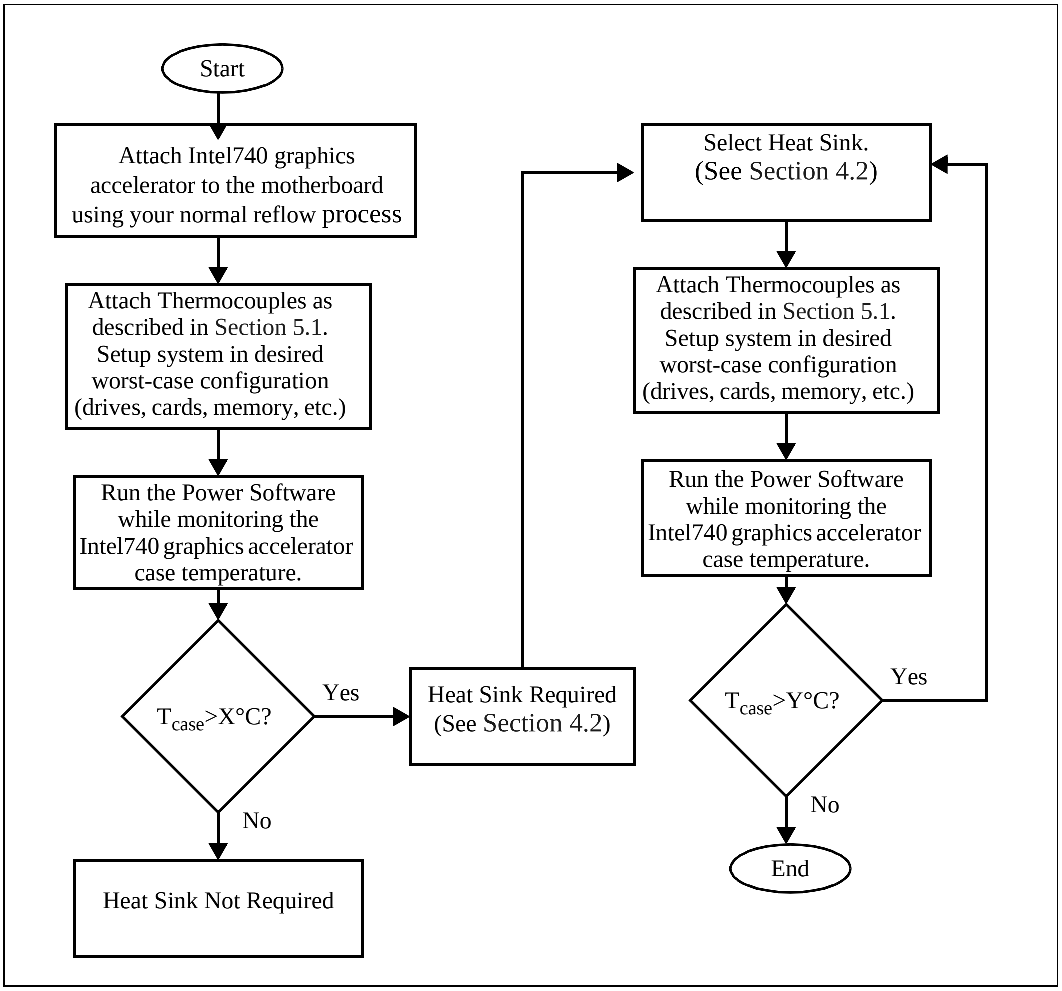
5.2 Power Simulation Software

The power simulation software for the Intel740 graphics accelerator is a utility designed to stress the thermal design power for an Intel740 graphics accelerator when used in conjunction with a Pentium II processor. The combination of the Pentium II processor along with the high bandwidth capability of the new enables new levels of graphics performance which are not utilized in most current software applications. However, it is conceivable that new applications and drivers will be written which take advantage of this increased bandwidth. To ensure the thermal performance of the Intel740 graphics accelerator while running future applications, Intel has developed a software utility which emulates this anticipated power dissipation.

The power simulation software has been developed only for testing Thermal Design Power. Real future applications may exceed the Thermal Design Power limit for transient time periods. For power supply current requirements under these transient conditions, please refer to the *Intel740 Graphics Accelerator Datasheet* for I_{CC-740}, the Power Supply Current (Max) specification.

Note: Please contact your local Intel representative for more information about the Intel740™ Graphics Accelerator Power Simulation Software.

Figure 12.Thermal Enhancement Decision Flowchart



Note: For the latest values of "X°C" and "Y°C", refer to the Power Simulation Software User Guide.

6.0 Conclusion

As the complexity of today's graphics accelerators continues to increase, so do the power dissipation requirements. Care must be taken to ensure that the additional power is properly dissipated. Heat can be dissipated using improved system cooling, selective use of ducting and/or passive heat sinks.

The simplest and most cost effective method is to improve the inherent system cooling characteristics through careful design and placement of fans and ducts. When additional cooling is required, thermal enhancements 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 for properly designing a cooling solution a system implementing the Intel740 graphics accelerator. Properly designed solutions provide adequate cooling to maintain the Intel740 graphics accelerator case temperature at or below those listed in Table 1. This is accomplished by providing a low local ambient temperature and creating a minimal thermal resistance to that local ambient temperature. By maintaining the Intel740 graphics accelerator case temperature at or below those recommended in this document, a system will function properly and reliably.

Appendix A Sources

A.1 Low Profile Fan Heat Sink Sales Locations

Sanyo Denki	Please visit WEB at http://www.sanyodenki.co.jp/profile_e17.html
Future Second Source	Panasonic

Part Numbers

Sanyo Denki	109P4405H9026

A.2 Low Profile Passive Heat Sink Sales Locations

Thermalloy	please visit WEB at: http://www.thermalloy.com
JME	please visit WEB at: http://www.jme.com

Part Numbers

Thermalloy	2522B
JME:	HAA740BBXXB-001 (with 1-layer Chomerics T410)
	HAA740BBXXX-001 (without attach)

A.3 Attach Sales Locations

For Epoxy	please visit WEB: http://www.loctite.com Select the country of your choice and Select Products for the Electronics Industry.
For Tape	please visit WEB: http://www.chomerics.com/locate

Part Numbers

Loctite Epoxy	Part Numbers 383 or 384
Chomerics Tape	T-410

UNITED STATES AND CANADA
Intel Corporation
2200 Mission College Boulevard
P.O. Box 58119
Santa Clara, CA 95052-8119
USA
Tel: 408-765-8080

EUROPE
Intel Corporation (U.K.) Ltd.
Pipers Way
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ASIA PACIFIC
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32/F Two Pacific Place
88 Queensway, Central
Hong Kong
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