AP-907 Pentium® III Processor Thermal Design Guidelines

Application Note

February 1999

Order Number: 245087-001

The Pentium® III processor may contain design defects or errors known as errata which may cause the product to deviate from published specifications. Current characterized errata are available on request.

Contact your local Intel sales office or your distributor to obtain the latest specifications and before placing your product order.

Copies of documents which have an ordering number and are referenced in this document, or other Intel literature may be obtained by calling 1-800-548-4725 or by visiting Intel's website at http://www.intel.com.

Contents

Figures

Tables

1.0 Introduction

In a system environment, the processor's 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 processor and the airflow over the processor(s) as well as the physical constraints at and above the processor(s). The processor temperature, measured at various points, depends on the component power dissipation, cartridge size and material (effective thermal conductivity), the type of interconnection to the substrate, the presence of a thermal cooling solution, the thermal conductivity, and the power density of the substrate.

All these parameters are aggravated by the continued push of technology to increase performance levels (higher operating speeds) and packaging density (more transistors). As operating frequencies increase and packaging sizes decrease, the power density increases and the thermal cooling solution space and airflow become more constrained. The result is an increased importance on system design to ensure that thermal design requirements are met for each component in the system.

The Single Edge Contact Cartridge (S.E.C.C.) and Single Edge Contact Cartridge 2 (S.E.C.C.2) packaged processors introduce new temperature constraint specifications and new thermal parameters to manage. Depending on the type of system and the chassis characteristics, new designs are required to provide adequate cooling for the processor. The goal of this document is to provide an understanding of these new thermal characteristics and discuss guidelines for meeting the thermal requirements imposed on single and multiple processor systems.

Note: This document discusses techniques in thermal management only for S.E.C.C. and S.E.C.C.2 processors primarily intended for the performance desktop. The Single Edge Plastic Package (SEPP) is not covered.

1.1 Related Documents

The following related documents are available from the Intel web site at http://developer.intel.com.

Table 1. Related Resources

Document Title	Order Number
Pentium® III Processor datasheet	244452
Pentium® II Processor Developer's Manual	243502
Pentium® II Processor at 350 MHz, 400 MHz and 450 MHz datasheet	243657
AP-588 Mechanical Assembly and Customer Manufacturing Technology for S.E.C. Cartridge Processors	243333
Pentium® III Processor Specification Update	244453
Max1617EV Temperature Evaluation Kit	see http://www.maxim-ic.com

1.2 Terms Used in this Document

Table 2 contains definitions for terms used throughout this document.

Table 2. Definition of Terms

Term	Definition
$T_{ambient\text{-}local}$	The measured ambient temperature locally surrounding the processor. Measure the ambient temperature just “upstream” of a passive heat sink, or at the fan inlet for an active heat sink.
$T_{ambient\text{-}OEM}$	The target worst-case ambient temperature at a given **external** system location as defined by the system designer (OEM).
$T_{ambient\text{-}external}$	The measured ambient temperature at the OEM defined **external** system location defined by the system designer (OEM).
$T_{ambient\text{-}max}$	The target worst-case local ambient temperature. This can be determined by placing the system in maximum external temperature conditions and measuring the ambient temperature locally surrounding the processor. Under these conditions $T_{ambient\text{-}local} = T_{ambient\text{-}max}$. This can also be determined by simultaneously measuring the $T_{ambient\text{-}external}$, $T_{ambient\text{-}local}$ and $T_{junction\_HIPWR30}$ with the following equation: $T_{ambient\text{-}max} = T_{ambient\text{-}OEM} - T_{ambient\text{-}external} + T_{ambient\text{-}local}$ (This equation assumes a thermally linear system; i.e., no temperature controlled fans.)
$T_{junction\text{-}max}$	The maximum core junction temperature of the processor, as specified in the processor datasheet.
$T_{junction\text{-}HIPWR30}$	The measured core junction temperature of the processor while running the High Power Application software (HIPWR30.EXE).
$T_{junction\text{-}proj}$	The projected thermal junction temperature at the maximum processor power dissipation for the system under analysis.
$T_{junction\text{-}offset}$	The worst-case difference between the thermal reading from the on-die thermal diode and the hottest location in the processor’s core, as specified in the processor datasheet.
$T_{sensor\text{-}offset}$	The measurement error for a diode connected to the Max1617 from Maxim Integrated Products, as specified in the Max1617 Temperature Sensor datasheet.
$T_{case\text{-}BSRAM\text{-}max}$	The maximum case temperature of the L2 cache BSRAM, as specified in the processor datasheet.
$T_{case\text{-}BSRAM}$	The measured case temperature of the L2 cache BSRAM, while running the HIPWR30.EXE /L utility.
T_{cover}	The maximum cover temperature of the S.E.C.C.2 cartridge, as specified in the processor datasheet.
$\theta_{junction\text{-}ambient}$	The thermal resistance between the processor’s core junction and the ambient air. This is defined and controlled by the system thermal solution.
P_{max}	The maximum processor power, as specified in the processor’s datasheet.
$P_{HIPWR30}$	The processor power running the High Power Application software (HIPWR30.EXE).
Intel SC242	Slot Connector 242 (242 contacts): Formerly referred to as “Slot 1,” this is the connector on a baseboard where the processor is installed.
Intel SC242 processor	Any Intel processor which plugs into the Intel SC242, including the Pentium® II processor.

2.0 Importance of Thermal Management

The objective of thermal management is to ensure that the temperature of all components in a system is maintained within functional limits. The functional temperature limit is the range within which the electrical circuits can be expected to meet their specified performance requirements. Operation outside the functional limit can degrade system performance, 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.

3.0 S.E.C.C. and S.E.C.C.2 Processor Packaging Technology

This processor is delivered in a variety of packaging technologies. The following sections provide an overview of each type.

3.1 Single Edge Contact Cartridge

The Intel® Pentium® II processor introduced a new packaging technology known as a Single Edge Contact cartridge (S.E.C. cartridge, or S.E.C.C.). The S.E.C.C. contains the microprocessor and the second level cache (referred to as “L2”). The cartridge consists of a plastic cover and an aluminum thermal plate. The thermal plate is designed for attaching a heatsink using the techniques described in the application note, *AP-588 Mechanical Assembly and Customer Manufacturing Technology for S.E.C. Cartridge Processors*. The S.E.C.C. connects to the motherboard through an edge connector called the Intel SC242 (Slot Connector 242).

3.2 Single Edge Contact Cartridge 2

Further developments have produced a second generation S.E.C.C., simply referred to as S.E.C.C.2. This cartridge no longer requires the aluminum thermal plate.

The substrate used in this cartridge uses the Organic Line Grid Array (OLGA) packaged processor core and up to two BSRAM components for the L2 cache. This processor type is referred to in this document as S.E.C.C.2-OLGA.

4.0 Thermal Specifications

Power dissipation is described in the applicable Pentium III processor datasheet. Refer to the datasheet to verify the actual thermal specifications for a particular processor. While the processor core dissipates the majority of the thermal power, system designers should also be aware of the thermal power dissipated by the second level cache. Systems should be designed to handle the highest possible thermal power, even if a processor with a lower power requirement is planned, so that the design can accept either processor.

4.1 Assumptions

For the purposes of this application note, the following assumptions have been made about the requirements for proper operation and reliability of the processor:

- Considering the power dissipation levels and typical system ambient environments of 35 °C to 45 °C, the processor's temperatures cannot be maintained at or below the specified guidelines without additional thermal enhancement to dissipate the heat generated.
- The thermal characterization data described in later sections indicates that both a thermal-cooling device and system airflow are needed. The size and type (passive or active) of thermal cooling device and the amount of system airflow are interrelated and can be traded off against each other to meet specific system design constraints. In typical systems, board layout, spacing, and component placement limit the thermal solution size. Airflow is determined by the size and number of fans 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 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 to account for the thermal requirements of each component.

4.2 Cartridge Cover Temperature

The cover temperature is a function of the local ambient temperature, the internal temperature of the processor, and the various components internal to the processor. The local ambient temperature is the temperature found within the system chassis surrounding the cartridge. This is discussed in the temperature measurement process found in "Local Ambient Temperature Measurement Guidelines" on page 30. "Cartridge Cover Measurement Guidelines" on page 30 discusses proper guidelines for measuring the cover temperature.

4.3 Thermal Plate Temperature

The thermal plate provides a common interface for multiple types of thermal solutions and is the attach location for all thermal solutions onto an S.E.C.C.. These solutions can be active or passive. Active solutions incorporate a fan in the heatsink and may be smaller than a passive heatsink. Considerations in heatsink design include:

- Local ambient temperature at the heatsink
- Surface area of the heatsink
- Volume of airflow over the surface area
- Power being dissipated by the processor
- Other physical volume constraints placed by the system

Note: Processors packaged in the S.E.C.C.2 do not have a thermal plate. Techniques for measuring thermal plate temperatures are provided in "Thermal Plate Measurements" on page 32.

4.4 Thermal Junction Temperature

The introduction of the S.E.C.C.2 package with OLGA core eliminates the thermal plate, which in turn requires a new technique for measuring a thermal solution's effectiveness. The core thermal junction temperature reading is used to evaluate the system's thermal solution. The measurement of the core junction temperature of a live processor using S.E.C.C.2 packaging technology and OLGA processor core is critical to validate an OEM chassis and heat sink thermal designs. A thermal diode is independently routed off the processor core to the Intel SC242 connector to assist in evaluating the junction temperature. This diode has been used by DMI client software to monitor processor temperature since the introduction of the Intel SC242 processor. For more information on the thermal diode, refer to the processor datasheet. Techniques for measuring thermal junction temperatures are provided in "Thermal Junction Measurement Techniques" on page 35.

4.5 Thermal Case Temperature

S.E.C.C.2 packaged processors also require a measurement of thermal case temperature. The L2 cache (BSRAM) components are probed with this method in the S.E.C.C.2-OLGA package.

4.5.1 BSRAM

The introduction of the S.E.C.C.2 package eliminates the thermal plate, which requires the system designer to test the core processor temperature and the L2 cache BSRAM components. The BSRAM case temperature reading is used to evaluate the effectiveness of the system thermal solutions. This parameter should be tested in the S.E.C.C.2-OLGA solution when BSRAMs are present. Techniques for measuring BSRAM temperatures are provided in “BSRAM Case Temperature Measurement” on page 45.

4.6 Power

The processor core dissipates the majority of the thermal power. The system designer should also be aware of the thermal power dissipated by the second level cache. Systems should be designed to handle the highest possible thermal power. The combination of the processor core and the second level cache dissipating heat through the thermal plate is the thermal plate power in S.E.C.C. packaged processors. In S.E.C.C.2 packages, this heat is dissipated through the component case (processor, BSRAM, resistors). The processor power is the total of heat dissipated through all paths.

Note: The overall system thermal design must comprehend the processor power. The cooling solution should be designed to dissipate the processor core and L2 cache power.

5.0 Designing for Thermal Performance

In designing for thermal performance, the goal is to keep the processor(s) within the operational thermal specifications. The inability to do so will shorten the life of the processor(s). It is the goal and requirement of the thermal design to ensure these operational thermal specifications are maintained. The heat generated by components within the chassis must be removed to provide an adequate operating environment for both the processor and other system components. To do so requires moving air through the chassis to transport the heat generated by the processor for both the processor and other system components.

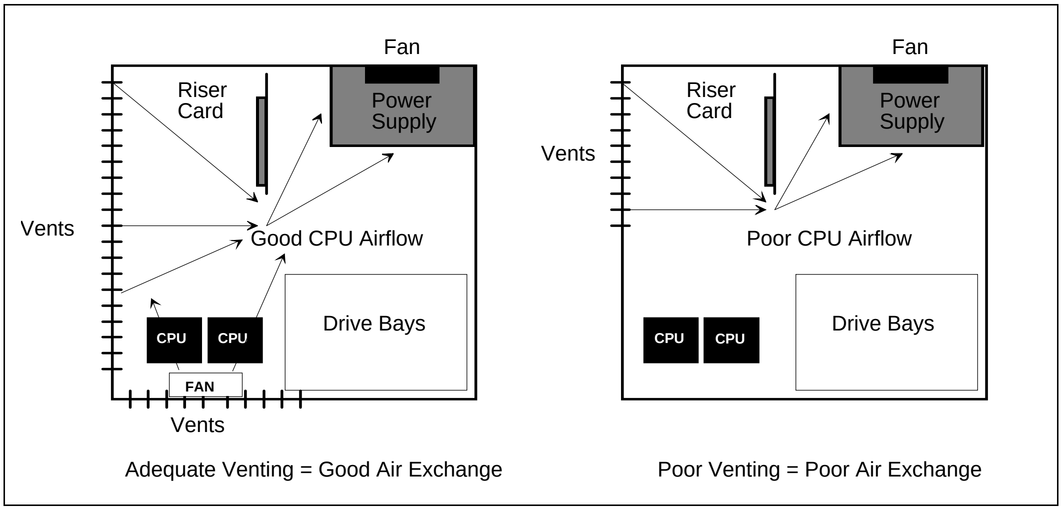
5.1 Airflow Management

It is important to manage the amount of air that flows within the system (and how it flows) to maximize the amount of air that flows over the processor. System air flow can be increased by adding one or more fans to the system or by increasing the output (faster speed) 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 processor(s). Heating effects from add-in boards, DRAM, and disk drives greatly reduce the cooling efficiency of this air, as does recirculation of warm interior air through the system fan. Care must be taken to minimize the heating effects of other system components, and to eliminate warm air circulation.

For example, a clear air path from the external system vents to the system fan(s) enables the warm air from the processors to be efficiently pulled out of the system. If no air path exists across the processors, the warm air from the Intel SC242 processors will not be removed from the system, resulting in localized heating ("hot spots") around the processors. Heatsink fin designs should be aligned with the direction of the airflow. When the airflow is horizontal the fins should be horizontally extruded, and when the airflow is vertical the fins should be vertically extruded.

Figure 1 shows two examples of air exchange through a PC-style chassis. The system on the left is an example of good air exchange. The thermal design incorporates the power supply fan and an additional system fan. The system on the right shows a poorly vented system. This design uses only the power supply fan to move the air; this results in inadequate air flow. Recirculation of warm air is most common between the system fan and chassis, and between the system fan intake and the drive bays behind the front bezel. 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.

Figure 1. Example of Air Exchange Through a PC Chassis



5.2 Extruded Heatsink Solutions

One method used to improve thermal performance is to increase the surface area of the device by attaching a metallic heatsink. Heatsinks are generally extruded from blocks of metal, usually aluminum (due to its low price/performance ratio). To maximize the heat transfer, the thermal resistance from the heatsink to the air can be reduced by maximizing the airflow through the heatsink fins and by maximizing the surface area of the heatsink itself.

5.2.1 Heatsink Design

Though each designer may have mechanical volume restrictions or implementation requirements, the following diagrams illustrate “generic” system form factors that are likely to be compatible with a given type of chassis design.

5.2.2 Example ATX Compatible Heatsinks

Figure 2 and Figure 3 (thermal plate and side view, respectively) indicate the space available for the physical outline for a heatsink in an ATX style chassis.

Figure 2. Thermal Plate View of Example ATX-Style Heatsink

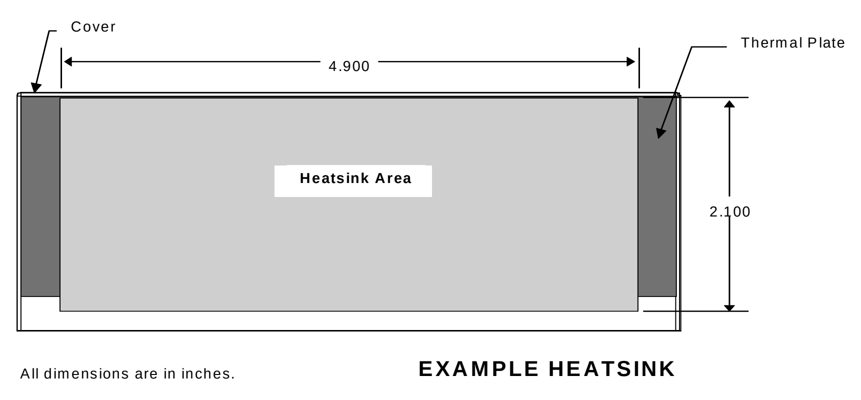
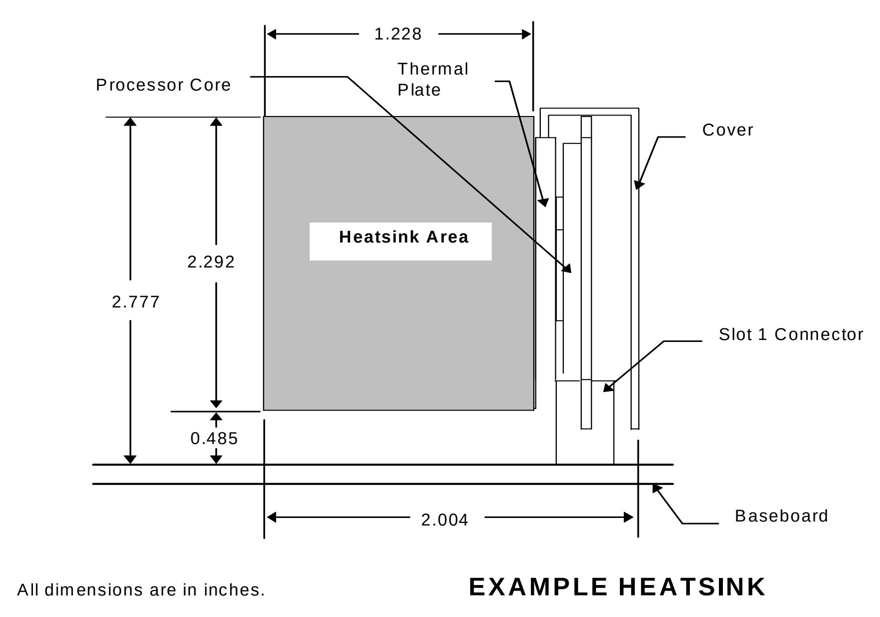


Figure 3. Side View of Example ATX Style Heatsink



5.2.3 Example Low Profile (LPX) Compatible Heatsinks

Figure 4 and Figure 5 shows the front and side view, respectively, indicating the space available for the physical outline for the heatsink in a low profile (LPX) style chassis.

Figure 4. Front View of Example LPX Style Heatsink

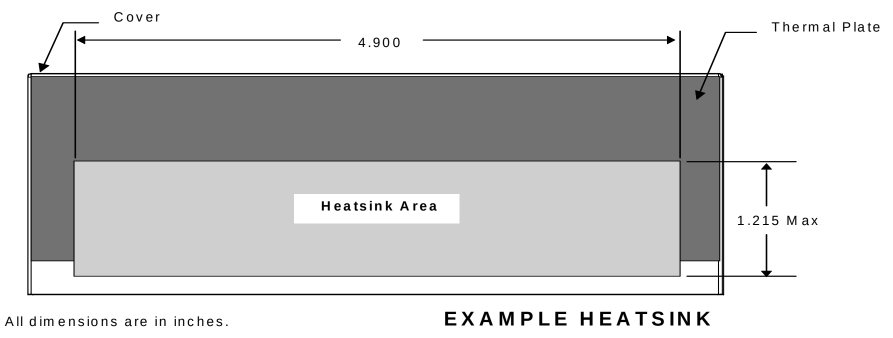
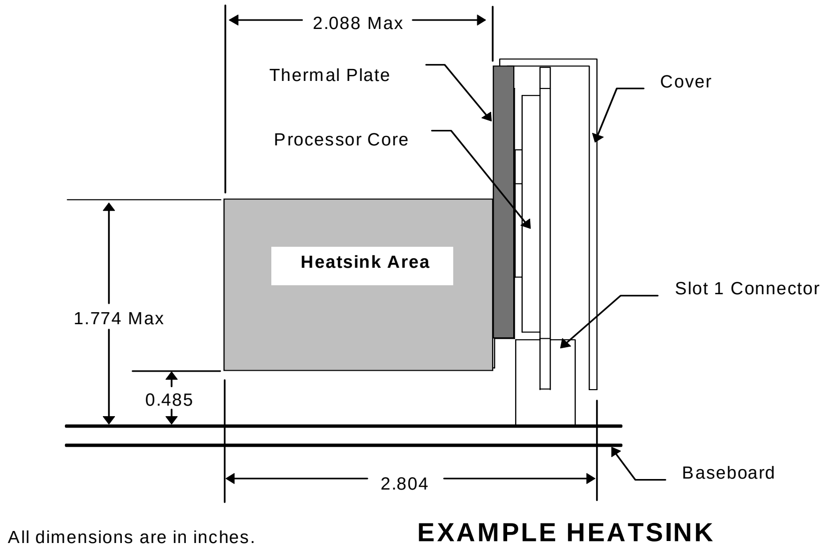


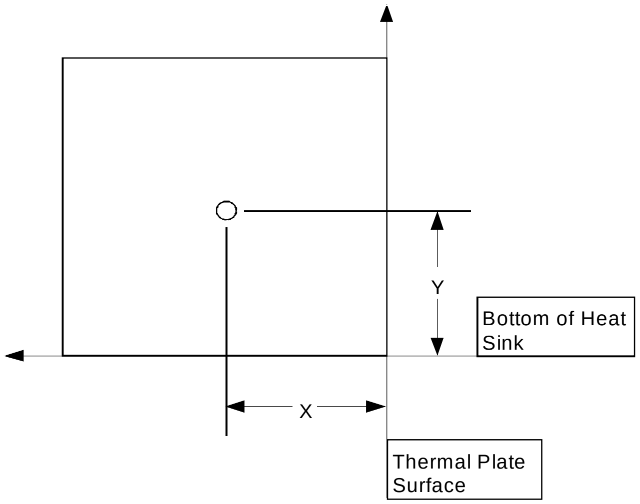
Figure 5. Side View of Example LPX Style Heatsink



5.2.4 Heatsink Weight

The maximum weight of the heatsink and attachment mechanisms should not exceed 250 grams. This limit is based on the ability of the processor retention mechanism and heatsink support to withstand mechanical shock and vibration as a full assembly with heatsink attached. Figure 6 provides the maximum distances for the center of gravity for a heatsink to be used with the S.E.C.C. and S.E.C.C.2. Heatsink designers should try to maintain the center of mass within the "safe" area. This is the shaded area shown in the figures below.

Figure 6. Maximum Distances for Center of Gravity for Heatsink Types



Chassis Type	X Cg	Y Cg
ATX	1.2"	1.0"
LPX	1.4"	0.7"

5.2.4.1 Center of Gravity Calculations

Although commonly calculated through solid modeling programs, the center of gravity can be calculated through straightforward computations described in this section. The center of gravity of an object with a uniform density is the geometrical center of volume of the object. The center of gravity can most easily be determined by dividing the object into smaller objects and averaging each individual centroid with respect to the volumes as shown in the following equations:

$$\sum_{n=1}^{n=m} Xcg_n * volume_n / total\ volume$$

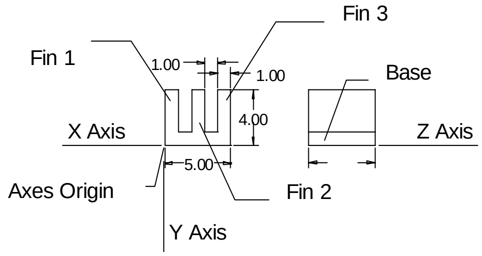
$$\sum_{n=1}^{n=m} Ycg_n * volume_n / total\ volume$$

$$\sum_{n=1}^{n=m} Zcg_n * volume_n / total\ volume$$

Where m = number of smaller objects

Each individual center of gravity (cg) must be related to a single point of origin. After the individual cgs are calculated, multiply the individual cg by the individual volume and sum up each of these individual products. A computational example is shown in Figure 7.

Figure 7. Center of Gravity Calculation Example



The heatsink has a fin thickness of 1 and a square base of 5 by 5. First the heatsink must be split into four different volumes: three fin blocks (1x3x5 each) and one base block (5x1x5). The individual center of gravity with respect to the axis origin is:

Fin 1: Xcg1 = 0.5, Ycg = 2.5, Zcg = 2.5
Fin 1 Volume = 15

Fin 2: Xcg2 = 2.5, Ycg = 2.5, Zcg = 2.5
Fin 2 Volume = 15

Fin 3: Xcg3 = 4.5, Ycg = 2.5, Zcg = 2.5
Fin 3 Volume = 15

Base: Xcgb = 2.5, Ycg = 0.5, Zcg = 2.5
Base Volume = 25

Total Volume = 70

Now that the individual block centroids have been calculated, the average of the centroids with respect to the volumes as described earlier is:

Xcg = ((0.5*15)+(2.5*15)+(4.5*15)+(2.5*25)/70
Xcg = 2.5

Ycg = ((2.5*15)+(2.5*15)+(2.5*15)+(0.5*25)/70
Ycg = 1.8

Zcg = ((2.5*15)+(2.5*15)+(2.5*15)+(2.5*25)/70
Zcg = 2.5

5.3 Example S.E.C.C.2 Passive Heatsink

Intel designed a passive heatsink for the S.E.C.C.2 package. This heatsink was designed assuming a $T_{ambient}$ of 45 ºC, 200 Linear Feet per Minute (LFM) airflow and a maximum processor power of 28 watts. Information on this device can be located on Intel’s web site at http://developer.intel.com/ (search for “SECC2 packaging”).

5.4 Thermal Interface Management

To optimize the heatsink design for the Intel SC242 processor, it is important to understand the impact of factors related to the interface between the processor and the heatsink base. Specifically, the bond line thickness, interface material area and interface material thermal conductivity should be managed to realize the most effective thermal solution. For more information on this subject refer to *Single Edge Contact Connector 2 (S.E.C.C.2) Thermal Interface Material Functional Requirements* (order number 244458).

5.4.1 Bond Line Management

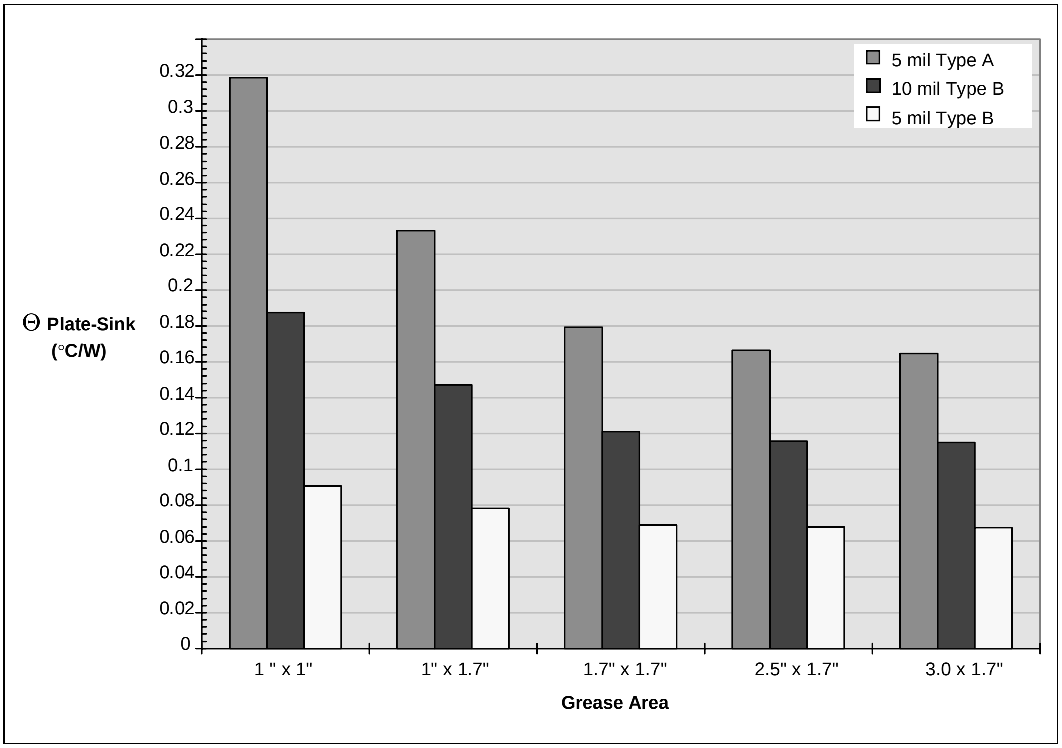
The gap between the processor and the heatsink base impacts thermal solution performance. The larger the gap between the two surfaces, the greater the thermal resistance. The thickness of the gap is determined by the flatness of both the heatsink base and the thermal plate, plus the thickness of the thermal interface material (i.e., thermal grease) used between these two surfaces.

The worst case flatness of the thermal plate will be 0.005” over the entire thermal plate surface. The attach area on the thermal plate will have the flatness specified as no greater than 0.001” per inch. The flatter the heatsink base, the thinner the resultant bond line that can be achieved. In addition, the attachment mechanism for the heatsink must be able to supply sufficient clamping force to spread the interface material out to form the thinnest film possible.

5.4.2 Interface Material Area

The size of the contact area between the processor and the heatsink base impacts the thermal resistance. There is, however, a point of diminishing returns. Unrestrained incremental increases in thermal grease area do not translate to a measurable improvement in thermal performance. Figure 8 illustrates the results of empirical measurements of two different types of grease based on thermal conductivity. The bulk thermal conductivity of type A grease is 0.5 to 1.5 W/mK and type B grease is 2 to 3 W/mK. In addition to the diminishing returns seen with larger grease areas, the overall flatness that can be achieved tends to decrease. The decrease in flatness would have a negative impact of potentially increasing the resistance across the interface between the processor and the heatsink.

Figure 8. Impact of Contact Area and Thermal Interface Properties of the Interface Material



5.4.3 Interface Material Performance

Two factors impact the performance of the interface material between the processor and the heatsink 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, under the load applied by the heatsink attach mechanism, to spread and fill the gap between the processor and the heatsink. Since air is an extremely poor thermal conductor, the more completely the interface material fills the gaps, the lower is the temperature drop across the interface. In this case, grease area size also becomes significant, as the larger the desired grease area size, the higher the force required to spread the thermal interface material.

Thermal pads are available from various vendors and may provide an adequate thermal interface solution. Also, some vendors can supply their heatsinks with pre-applied thermal grease to reduce the handling, assembly time and assembly steps for attaching a thermal solution.

5.5 Fans

Fans are needed to move the air through the chassis. The airflow rate of a fan is usually directly related to the acoustic noise level of the fan and system. Maximum acceptable noise levels may limit the fan output or the number of fans selected for a system. Fan/heatsink assemblies are one type of advanced solution that can be used to cool the processor. Intel has worked with fan/heatsink vendors and computer manufacturers to make fan/heatsink cooling solutions available in the industry. Please consult such a vendor to acquire the proper solution for your needs.

5.5.1 Placement

Proper fan placement can ensure that the processor is being 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, and to determine the optimum location for fans and vents within a chassis. Prototype assemblies can also be built and tested to verify that the system components and processor thermal specifications are met.

Ideally, an intake air fan is centered vertically and placed along one axis with respect to the Intel SC242 processor with a heatsink. The fan should also be approximately two inches from the leading edge of the Intel SC242 processor and heatsink. Figure 9 and Figure 10 show the recommended fan placement for an ATX form factor layout and a LPX form factor, respectively.

Figure 9. Fan Placement and Layout of an ATX Form Factor Chassis – Top View

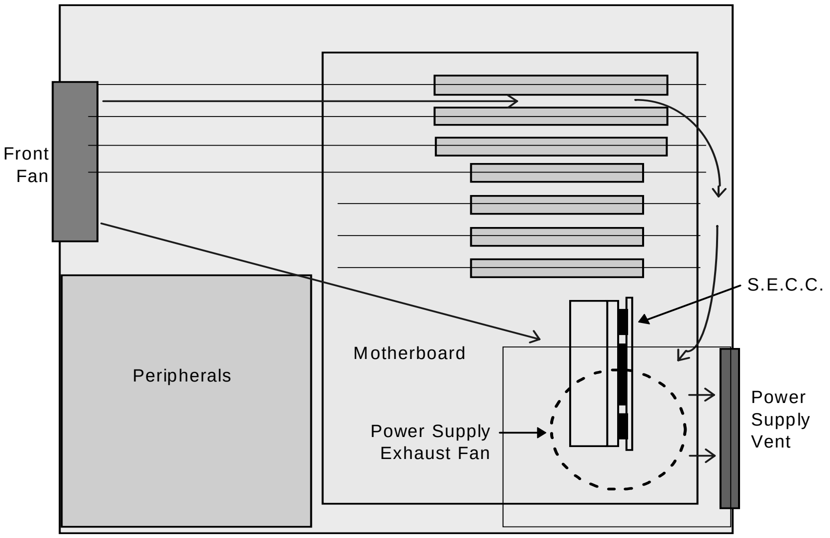
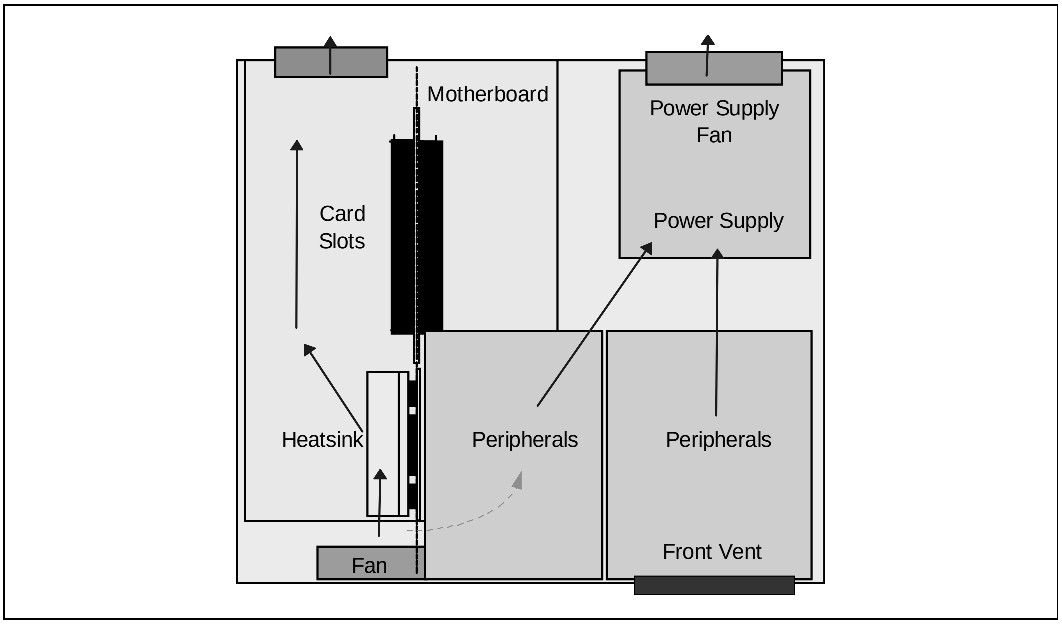


Figure 10. Fan Placement and Layout of an LPX Form Factor Chassis – Top View



5.5.2 Direction

If the fan(s) are not moving air across the heatsink, minimal cooling can occur. This may cause the processor to operate above the recommended specification values. Two possibilities exist for blowing air across the heatsink of a Intel SC242 processor. Air can be blown down vertically or horizontally across the heatsink. This may depend on the layout of other components on the board or within the chassis. The intake fan should blow through the S.E.C.C. heatsink lengthwise. The heatsink fins can be shorter in this case. For a vertically extruded heatsink the fins might need to be longer. Both of these factors are considerations when laying out components on the board and in the chassis.

The air flow direction can be modified with baffles or ducts to direct the air flow over the processor. This increases the local flow over the processor and may eliminate the need for a second fan, a larger fan, or a higher-speed fan.

5.5.3 Size and Quantity

It is not always true that the larger the fan the more air it moves. A small blower using ducting might direct more air over the heatsink than a large fan blowing non-directed air over the heatsink. The following provide some guidelines for size and quantity of the fan(s).

The fan should be a minimum of 80 mm (3.150”) square, with a minimum airflow of approximately 200 LFM (linear feet per minute). Ideally two fans should be used. The intake air fan would blow directly into the S.E.C.C. with heatsink, while a second fan (most likely in the power supply) would exhaust the air out of the system.

5.5.4 Venting

Intake vents should be placed at the front (user side) of the system. They should be located to optimize cooling of the processor and peripherals (drives and add-in cards). A good starting point would be the lower 50% of the front panel (bezel). Intake vents directly in front of the intake fan is the optimal location. The ideal design provides airflow directly over the processor heatsink.

5.5.4.1 Placement

In most cases, an exhaust fan and vent located at the power supply is sufficient. However, depending on the number, location and types of add-in cards, exhaust vents may be necessary near the cards. This should be modeled or prototyped for the optimum thermal dissipation potential. A system should be modeled for the worst case; i.e., all expansion slots should be occupied with typical add-in options.

5.5.4.2 Area and Size

The area and size of the intake vents should be designed with the size and shape of the fan(s) in mind. Adequate air volume requires appropriately sized vents. Intake vents should be located in front of the intake fan(s) and adjacent to the drive bays. Vents 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 Intel SC242 processor-based system design, see the *Slot 1 Processor EMI Overview* application note (order number 243334).

5.5.4.3 Vent Shape

Round, staggered pattern openings are best for EMI containment, acoustics and airflow balance.

6.0 Alternative Cooling Solutions

In addition to extruded heatsink and system fans, other solutions exist for cooling integrated circuit devices. For example, ducted blowers, heat pipes and liquid cooling are all capable of dissipating heat. Due to their varying attributes, each of these solutions may be appropriate for a particular system implementation. More information on this topic can be located on Intel’s web site at http://developer.intel.com/.

6.1 Ducting

Ducts can be designed to isolate the processor(s) from the effects of system heating (such as add-in cards), and to maximize the processor cooling temperature budget. Air provided by a fan or blower can be channeled directly over the processor and heatsink, or split into multiple paths to cool multiple processors. This method can also be employed to provide some level of redundancy in a system requiring redundant capabilities for fault tolerance. This is accomplished by channeling air from two or more fans through the same path across a processor. Each fan, or each set of fans, must be designed to provide sufficient cooling in the event that the other has failed.

6.1.1 Duct Placement

When ducting is to be used, it should direct the airflow evenly from the fan through the length of the heatsink. The duct design should use smooth, gradual turns to enhance the airflow characteristics. Sharp turns in ducting should be avoided. Sharp turns increase friction and drag and greatly reduce the volume of air reaching the processor heatsink.

6.2 Fan Heatsink

An active fan heatsink can be employed as an alternative mechanism for cooling the Intel SC242 processor. This is the acceptable solution for most chassis. Adequate clearance must be provided around the fan heatsink to ensure unimpeded air flow for proper cooling. The Intel boxed processor uses this implementation and is shown here as an example of a fan heatsink implementation. The space requirements and dimensions for the fan heatsink on the Intel boxed processor are shown in Figure 11 (front view), Figure 12 (side view) and Figure 13 (top view). All dimensions are in inches.

Figure 11. Space Requirements for the Fan Heatsink (Front View)

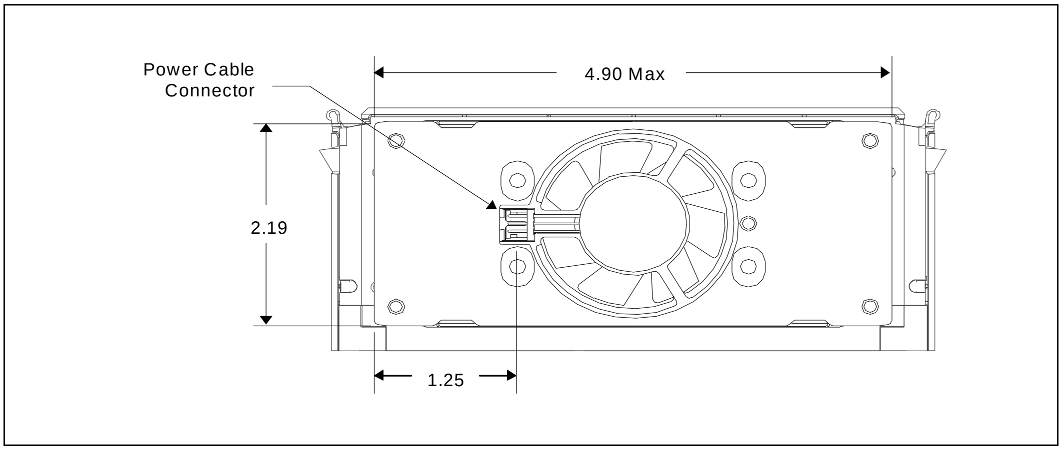


Figure 12. Space Requirements for the Fan Heatsink (Side View, Supports Not Shown)

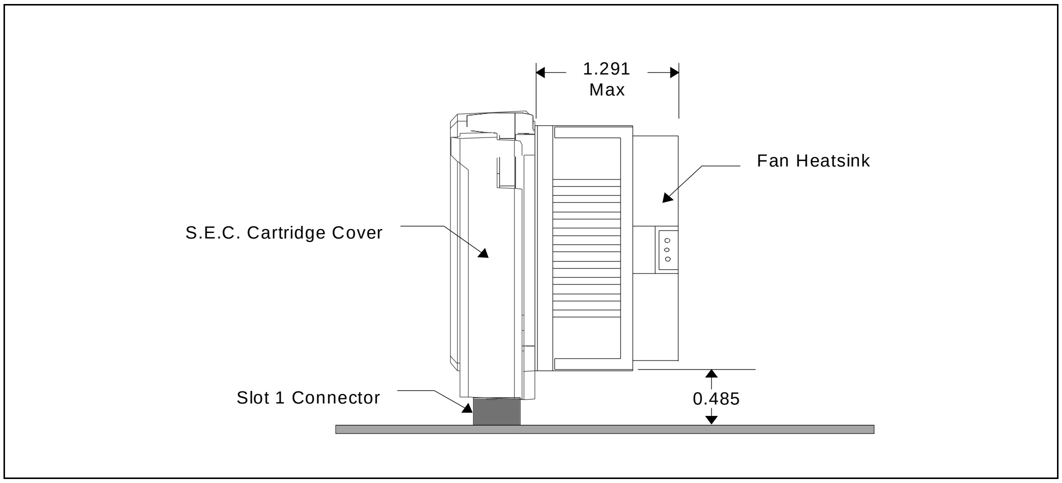
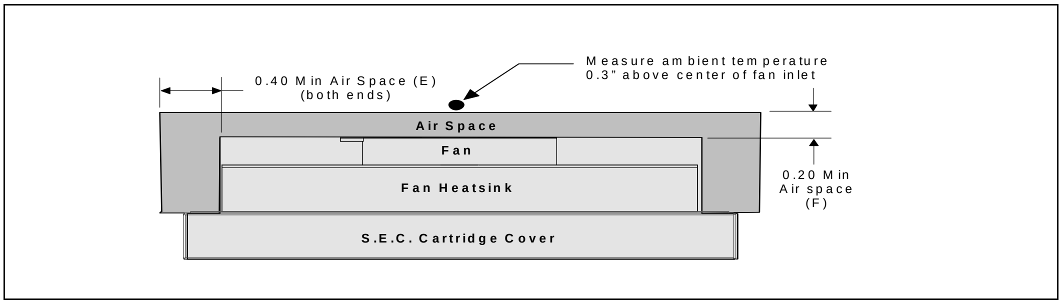


Figure 13. Space Requirements for the Fan Heatsink (Top View)



6.3 Fan Heatsink Measurements

A fan heatsink must be able to keep the processor temperature, T_{plate} or $T_{junction}$, within the specifications. This requires that the airflow through the fan heatsink be unimpeded and that the air temperature entering the fan be below 45 °C; see Figure 13 for the measurement location. Airspace is required around the fan to ensure that the airflow through the fan heatsink is not blocked. Blocking the airflow to the fan heatsink reduces the cooling efficiency and decreases fan life. Figure 13 illustrates an acceptable airspace clearance for the fan heatsink.

6.4 System Components

6.4.1 Placement

Peripherals such as CD-ROMs, floppy drives, and hard drives, can be placed to take advantage of the fan's movement of ambient air (i.e., near intake or exhaust fans or vents). Some add-in cards often have a low tolerance for temperature rise. These components should be placed near additional vents if they are downstream of the S.E.C.C. to minimize temperature rise.

6.4.2 Power

Some types of drives, such as a floppy drive, do not dissipate much heat, while others (read/write CD-ROM, SCSI drives) dissipate a great deal of heat. These hotter components should be placed near fans or vents whenever possible. The same can be said for some types of add-in cards. Some PCI cards are very low wattage (5 W) while others can be as high as 25 watts, per the PCI specification. Great care should be taken to ensure that these cards have sufficient cooling.

7.0 Thermal Metrology

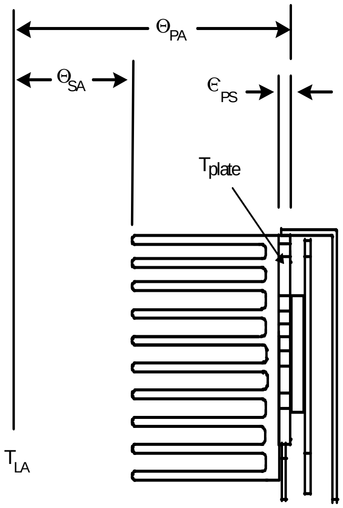
The following sections discuss the techniques for testing thermal solutions under the two package types: S.E.C.C., and S.E.C.C.2-OLGA. It should be noted that determining if a processor is sufficiently cooled is not as simple as it may seem. Carefully read the following instructions and interpretation steps to validate your cooling solution. “S.E.C.C. Metrology” on page 32 describes the steps necessary to test S.E.C.C. thermal plate temperature. “S.E.C.C.2-OLGA Metrology” on page 33 describes the steps for testing an S.E.C.C.2-OLGA cartridge processor temperature. The next section describes the steps common to all packages.

7.1 Common Metrology for Intel Processors Using the SC242

7.1.1 Thermal Resistance

The thermal resistance value for the plate-to-ambient (Θ_{PA}) in S.E.C.C. packages and core-to-ambient (Θ_{JA}) in S.E.C.C.2 packages is used as a measure of the cooling solution’s thermal performance. Thermal resistance is measured in units of °C/W. The thermal resistance of the plate-to-local ambient, Θ_{PA}, includes the plate-to-sink thermal resistance (Θ_{PS}) and the sink-to-local ambient thermal resistance (Θ_{SA}). Θ_{PS} is a measure of the thermal resistance along the heat flow path from the top of the processor cartridge to the bottom of the thermal cooling solution. The thermal resistance of the core-to-ambient, Θ_{JA}, includes the processor core (OLGA) thermal resistance and the sink-to-local ambient thermal resistance (Θ_{SA}). This value is strongly dependent on the thermal conductivity and thickness of the material used for the interface between the heatsink and the surface of the processor. Θ_{SA} is a measure of the thermal resistance from the bottom of the cooling solution to the local ambient air. Θ_{SA} is dependent on the heatsink’s material, thermal conductivity, and geometry, and is strongly dependent on the air velocity through the fins of the heatsink.

Figure 14. Thermal Resistance Relationships—S.E.C.C.



The thermal parameters for the S.E.C.C. are related by the following equations:

$\Theta_{PA} = (T_{plate} - T_{LA})/P_D$
$\Theta_{PA} = \Theta_{PS} + \Theta_{SA}$

Where:

Θ_{PA} = Thermal resistance from plate-to-local ambient (°C/W)
T_{plate} = Processor thermal plate temperature (°C)
T_{LA} = Local ambient temperature in chassis around processor (°C)
P_D = Device power dissipation (W; assume no power goes to the other side)
Θ_{PS} = Thermal resistance from plate-to-sink (°C/W)
Θ_{SA} = Thermal resistance from heatsink-to-local ambient (°C/W)

The thermal parameters for the S.E.C.C.2 are related by the following equations:

$\Theta_{JA} = (T_{junction} - T_{LA})/P_D$
$\Theta_{JA} = \Theta_{JS} + \Theta_{SA}$

Where:

Θ_{JA} = Thermal resistance from junction-to-local ambient (°C/W)
$T_{junction}$ = Processor thermal plate temperature (°C)
T_{LA} = Local ambient temperature in chassis around processor (°C)
P_D = Device power dissipation (W; assume no power goes to the other side)
Θ_{JS} = Thermal resistance from junction-to-sink (°C/W)
Θ_{SA} = Thermal resistance from heatsink-to-local ambient (°C/W)

7.1.2 Thermal Solution Performance

All processor thermal solutions should attach to the processor cartridge. The thermal solution must adequately control the processor and the local ambient air around the processor ($\Theta_{\text{thermal plate to local ambient}}$). The lower the thermal resistance between the processor and the local ambient air, the more efficient the thermal solution. The required $\Theta_{\text{thermal plate to local ambient}}$ depends on the maximum allowed processor temperature ($T_{\text{cartridge}}$), the local ambient temperature (T_{LA}) and the processor power ($P_{\text{cartridge}}$). This can be expressed in the following equation:

$$\Theta_{PA} = (T_{\text{cartridge}} - T_{LA}) / P_{\text{cartridge}}$$

T_{LA} is a function of the system design. Table 3 and Table 4 provide the resultant thermal solution performance for Intel SC242 processor at different local ambient air temperatures around the processor.

Table 3. Thermal Solution Performance for Sample S.E.C.C. Packaged Processors

T_{ambient}	Intel SC242 Processor Θ_{PA} (°C/W)	
	Thermal Plate Power of 41.4 Watts	Thermal Plate Power of 26.4 Watts
35° C	0.85	1.33
40° C	0.99	1.52
45° C	1.11	1.70

NOTE: See applicable processor datasheet for required power specifications

Table 4. Thermal Solution Performance for an S.E.C.C.2 Processor at Processor Core Power of 28 Watts

T_{ambient}	Intel SC242 Processor Θ_{JA} (°C/W) at 28 W Processor Core Power
35° C	1.25
40° C	1.42
45° C	1.61

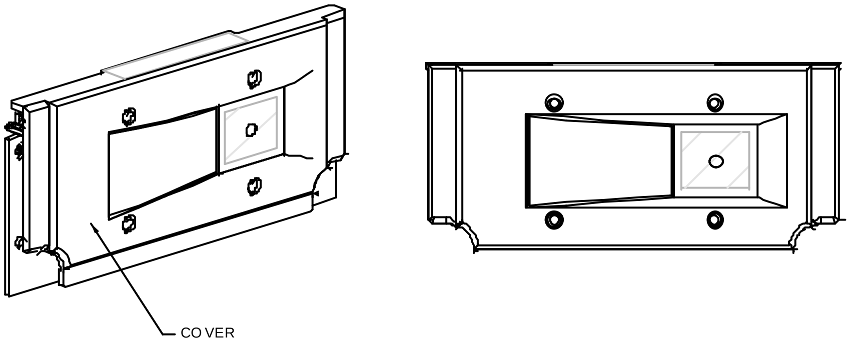
NOTE: See applicable processor datasheet for required power specifications

The Θ_{PA} value is made up of two primary components: the thermal resistance between the processor and heatsink (Θ_{PS}) and the thermal resistance between the heatsink and the local ambient air around the processor (Θ_{SA}). A critical but controllable factor is to decrease the resultant value of Θ_{PS} between the processor and the heatsink. Thermal interfaces are addressed in Section 4.0. The other controllable factor (Θ_{SA}) is determined by the design of the heatsink and the airflow around the heatsink. Heatsink design constraints are discussed in Section 5.0.

7.1.3 Cartridge Cover Measurement Guidelines

The cartridge cover temperature specification is a maximum of 75 °C. There are several components on the substrate that comprise the Intel SC242 processor. Each of these components generates heat and since some components may reside on the opposite side of the substrate from the processor core, the cover must also meet a specified temperature for proper operation. Techniques similar to those presented in “Thermal Plate Measurements” on page 32 for measuring thermal plate temperature can be used for the cover measurements. The HIPWR30.EXE application should be running when the T_{cover} measurement is made. Refer to “About the HIPOWER Application” on page 34 for information on the HIPWR30.EXE application. Please contact your local Intel Field Sales representative to receive a copy.

Figure 15. Example Processor Cover



7.1.4 Local Ambient Temperature Measurement Guidelines

Local ambient temperature, T_{LA}, is the temperature of the ambient air surrounding the cartridge. In a system environment, ambient temperature is the temperature of the air upstream of the cartridge and in its close vicinity; or in an active cooling system, it is the inlet air to the active cooling device.

Note: An ambient temperature is not specified for the Intel SC242 processor. The only restriction is that T_{cover} (cover temperature) and T_{plate} (thermal plate temperature) requirements be met.

It is worthwhile to determine the local ambient temperature in the chassis around the processor to better understand the effect it may have on the thermal plate temperature and the cover temperature. To determine the T_{LA} values, the following equation may be used:

$$T_{cover} = T_{LA} + (P_D * \Theta_{CA})$$

Where:

T_{LA} = Local ambient temperature (°C)

T_{cover} = Cover temperature of the device under test (°C)

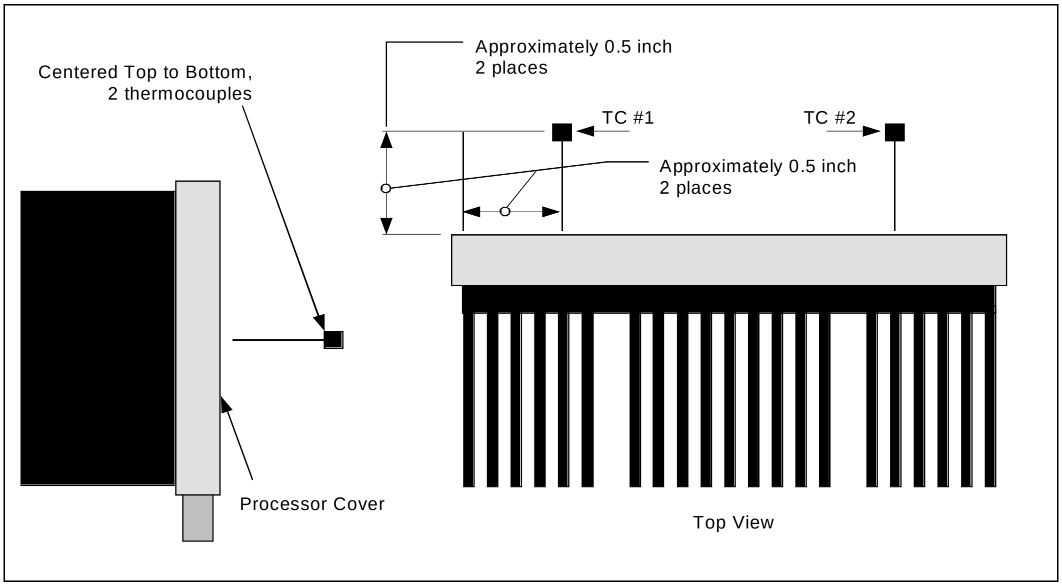
P_D = Total power dissipated by the Intel SC242 processor (W)

Θ_{CA} = Cover-to-local ambient thermal resistance (°C/W)

The following guidelines are meant to alleviate the non-uniform measurements found in typical systems. The local ambient temperature is best measured as an average of the localized air surrounding the processor. The following guidelines are meant to enable accurate determination of the localized air temperature around the processor during system thermal testing. These guidelines are meant as a reasonable expectation to ensure the product specifications are met.

- During system thermal testing, a minimum of two thermocouples should be placed approximately 0.5” away from the cartridge cover and heatsink as shown in Figure 16. This placement guideline is meant to minimize localized hot spots due to the processor, heatsink, or other system components.
- The thermocouples should be placed approximately two inches above the baseboard. This placement guideline is meant to minimize localized hot spots from baseboard components.
- The T_{LA} should be the average of the thermocouple measurements during system thermal testing.

Figure 16. Guideline Locations for Local Ambient Temperature



7.2 S.E.C.C. Metrology

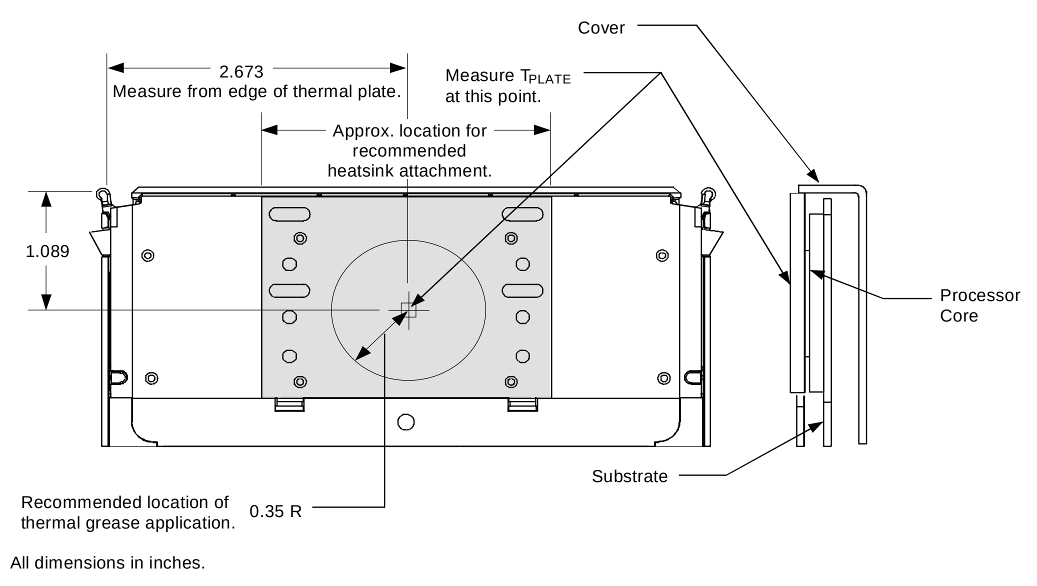
7.2.1 Measurements for Thermal Specifications

To appropriately determine the thermal properties of the system, measurements must be made. Guidelines have been established for proper techniques for measuring processor temperatures. The following sections describe these guidelines for measurement.

7.2.1.1 Thermal Plate Measurements

To ensure functionality and reliability, the Intel SC242 processor is specified for proper operation when T_{plate} (thermal plate temperature) is maintained at or below 75 °C. The surface temperature of the thermal plate directly above the center of the processor core is measured. Figure 17 shows the location for T_{plate} measurement.

Figure 17. Processor Thermal Plate Temperature Measurement Location



Special care is required when measuring the T_{plate} temperature to ensure an accurate temperature measurement. Thermocouples are often used to measure T_{plate}. 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 thermal plate, or due to heat loss by radiation, convection, conduction through thermocouple leads, or contact between the thermocouple cement and the heatsink base. To minimize these measurement errors, the following approach is recommended:

- Use 36 gauge or finer diameter K, T, or J type thermocouples.
- Ensure that the thermocouple has been properly calibrated.
- Attach the thermocouple bead or junction to the top surface of the thermal plate at the location specified in Figure 17 using high thermal conductivity cements.
- The thermocouple should be attached at a 0° angle if there is no heatsink interference with the thermocouple attach location or leads.
- The thermocouple should be attached at a 90° angle if a heatsink is attached to the thermal plate and the heatsink covers the location specified for T_{plate} measurement.
- The hole size through the heatsink 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 heatsink base. Contact will affect the thermocouple reading.

7.3 S.E.C.C.2-OLGA Metrology

This section describes the procedure for measuring the core junction temperature for Intel SC242 processors in the Single Edge Contact Cartridge 2 (S.E.C.C.2) package with OLGA core packaging technology. The metrology involves use of the High Power Application software (HIPWR30.EXE) to perform system level analysis of cooling solutions. Using the methodologies described in this section, a system designer will be able to validate system cooling solutions for compatibility with the specified processor worst-case power consumption. Two specific measurements are involved, the processor core temperature utilizing the on-die thermal diode (described in this section) and the L2 cache BSRAM using a temperature probe on the BSRAM case (described in “BSRAM Case Temperature Measurement” on page 45).

Currently the only reliable and accurate method of measuring $T_{junction}$ for the OLGA is with the Maxim tool (see Table 1, “Related Resources” on page 7). While it is tempting to place a measurement device on the top of the OLGA package the results can not be correlated to $T_{junction}$. Extensive experiments were conducted by Intel using a top of the OLGA package measurement method, but the results were very inconsistent and highly variable.

7.3.1 About the HIPOWER Application

The High Power Application software (HIPWR30.EXE) is intended for thermal evaluation purposes only. This software is not a general purpose application. The software does not generate the absolute worst-case thermal power dissipation as defined in the processor's datasheet. Differences between the observed thermal power measurements and the maximum power dissipation indicated in the datasheet can be attributed to process variation, manufacturing tester guardbands, system configuration differences and potential High Power Application software optimizations. This software does provide system designers with an application nearing worst-case power consumption for the analysis and validation of system cooling solutions.

All systems should be designed with the ability to dissipate the worst case thermal power indicated in the datasheet. The High Power Application software, utilizing the methodologies presented in this document, can enable system designers to design and validate robust cooling solutions that can adequately cool the processor at the maximum specifications.

The High Power Application software maximizes the current consumption of the processor core. All execution stages and various functional units of the core and L1 cache are fully utilized. The software performs minimal system bus accesses, with minimal L2 cache utilization. This mode of operation produces a large amount of thermal power from the processor.

A newer High Power Application ("HIPWR30.EXE") incorporates the functionality of the "HIPWR30.EXE" utility and a L2 cache exerciser. "HIPWR30.EXE" can be run in two modes, one in which it only exercises the processor's core power and another in which it only runs L2 cache utilization code. The mode that concentrates on the processor's core is the same application as HIPWR30.EXE and can be run by executing "HIPWR30 **/P**" at the DOS command window. For the purpose of this document and the procedures that involve the use of a High Power Application "HIPWR30.EXE" is equivalent to using "HIPWR30 /P". For all references to "HIPWR30.EXE", "HIPWR30 /P" can be used alternatively.

The "HIPWR30.EXE" utility also has a mode for L2 cache utilization that can be used to produce a large amount of thermal power from the L2 cache BSRAMS. To execute this utility in the L2 cache mode execute "HIPWR30 **/L**" at the DOS command window.

7.3.2 Executing the High Power Application Software

The High Power Application software is a 32 bit Windows* NT or Windows* 95/98 application. The application should be executed from a DOS window command prompt from within the Windows NT or Windows 95/98 environment, and not from a DOS only environment. The High Power Application software puts the processor into an infinite loop and locks the command prompt environment. The HIPWR30.EXE utility has an on-screen message with version number information and usage help. To halt execution of the application, use the Windows NT Task Manager* or Windows 95/98 Task Bar* to stop execution of the command prompt environment. For maximum processor power consumption, the software should be the only application executing on the system under evaluation. It is recommended that the Windows NT or Windows 95/98 operating environment be configured to the default OS settings.

7.3.3 Thermal Measurements

The High Power Application software can be used to design and validate cooling solutions compatible with the maximum power dissipation values specified in the processor's datasheet. Two methodologies are presented for validating worst-case processor compliance using this software. "Simplified Validation Method" on page 40 presents a simplified approach that system designers can use to check for worst-case processor power dissipation compatibility. For those designs that do not prove compatible or appear to be marginal using the simplified approach, "Detailed Validation Method" on page 43 provides a more detailed, accurate methodology for validating worst-case power compliance. The detailed approach does require a significant increase in effort over the simplified approach, but provides a more accurate measurement method using specific characteristics of the processor under analysis.

7.3.3.1 Thermal Junction Measurement Techniques

Purpose

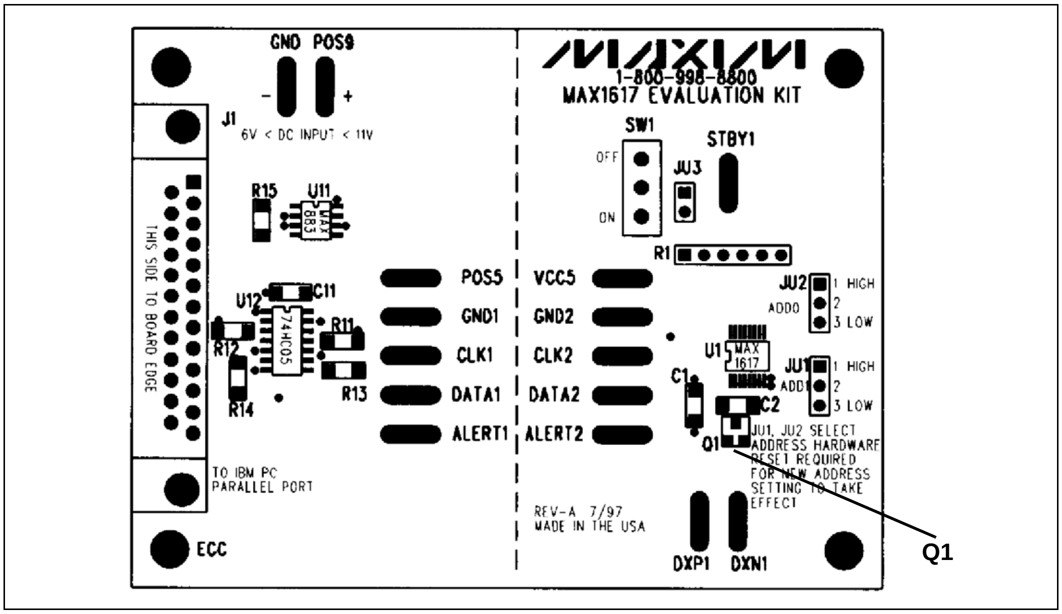
The purpose of this procedure is to explain how to take junction (die) level temperature measurements on live Intel SC242 processors in the S.E.C.C.2 package technology with an OLGA processor core package using the Max1617EV kit. All electrical connections and software keystrokes needed to take no-power and power-on temperature measurements are included.

Background

The measurement of the junction temperature of a live processor using S.E.C.C.2 packaging technology and OLGA processor core is critical to validate an OEM chassis and heat sink thermal design. A thermal diode is independently routed off the processor core to the SC242 connector to assist in evaluating the junction temperature. In order to simplify the measurement of the diode temperature, it is recommended to use the Max1617EV kit. The advantage of using the kit is that it requires no calibration of the diode.

The Max1617EV Temperature Sensor Evaluation Kit is a tool provided by Maxim Integrated Products which includes the Max1617 temperature sensor IC and all the additional circuitry and software needed to take temperature measurements with the Max1617 and a typical PC (see Figure 18 for layout of the EV kit). The Max1617 is essentially an 8-bit A/D converter and integrated controller which measures the difference between the voltage drop across a diode using two exciting currents to derive a junction temperature. The 8-bit temperature data is accessed by external applications via the 2-wire SMBus. The EV kit conditions the output from the Max1617 to be read by a standard 25-pin parallel port terminal on a PC. Software is included with the EV kit to display temperature measurements on a PC running Windows 3.1 or Windows 95/98 OS. See the Max1617 and Max1617EV kit datasheets for more detailed information on the measurement tools.

Figure 18. Layout of Max1617EV Kit



Equipment Needed

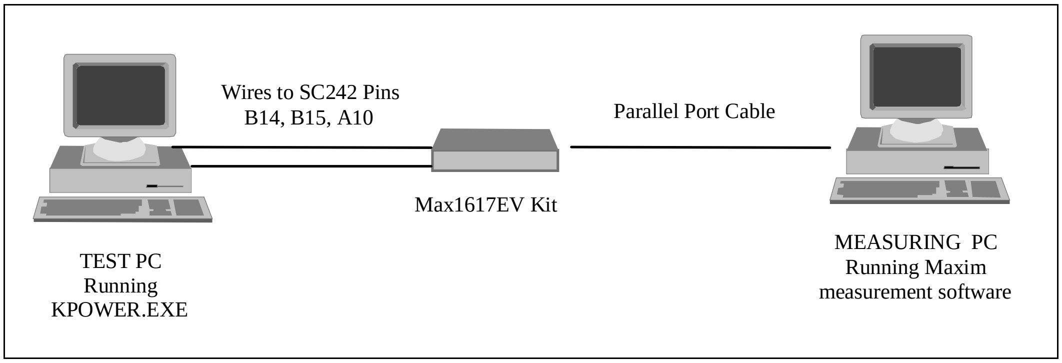
- A Max1617EV Temperature Sensor Evaluation Kit (with software) from Maxim Integrated Products (www.maxim-ic.com)
- A 9 V off-the-shelf battery
- A 9 V battery connector with extension wires
- A Pentium class PC with available parallel port and Windows 3.1 or Windows 95/98 OS to take temperature measurements (measuring PC)
- A parallel port cable with straight-through 25 pin connector, male-to-female type
- A twisted, shielded pair cable, up to 56” long, 24 gauge stranded copper
- An insulated wire, 24 gauge stranded copper, same length as the shielded pair cable (up to 56” long)
- An alligator clip wire (only to make room temperature measurements)
- A soldering iron
- A live chassis with processor diode to be evaluated (test PC)

7.3.3.2 Measurement Procedure

Electrical Hookups

This section outlines the electrical connectivity for the Max1617EV kit to measure the on-die diode. Figure 19 is a diagram of the test setup. For details on locating SC242 pins refer to Figure 8 of the *SC242 Connector Design Guidelines* (order number 243397).

Figure 19. Measurement Setup



1. Remove motherboard from test PC.
2. Strip insulation off ends of insulated wire and twisted, shielded pairs, and tin wire tips.
3. Solder the 56” insulated wire to the SC242 connector ground pin A10 (V_{SS}).
4. Ensure that any motherboard thermal sensor is disconnected from the processor. If the motherboard provides zero ohm resistors for this purpose, remove them, otherwise cut the traces going to pin B14 and B15.
5. Solder 1 wire of 56” twisted, shielded pair to SC242 connector pin B14/THERMDP (diode anode).
6. Solder the other wire of 56” twisted, shielded pair to SC242 connector pin B15/THERMDN (diode cathode).
7. For reduced noise conditions it is recommended to solder the shield of the twisted pair to ground on the processor side. An alternate V_{SS} pin on the SC242 connector, such as A18, can be chosen.
8. Tape the ground wire and twisted, shielded pair wires to the backside of the motherboard to relieve stress on the solder joints. Route wires out to the edge of motherboard which has enough clearance to allow wires to pass through.
9. Replace motherboard in chassis (you may wish to take room temperature measurements on processor before replacing all chassis components to verify good solder joints).
10. Route the wires out of the chassis through a PCI slot (or other convenient hole in chassis), taking care to ensure that the wires do not obstruct any critical airflow paths.
11. Solder the ground wire (pin A10) to GND1 pad on the Max1617EV kit substrate (see Figure 18 on page 36).
12. Solder the diode anode wire (pinB14) to DXP1 pad on the Max1617EV kit substrate (see Figure 18).
13. Solder the diode cathode wire (pin B15) to DXN1 pad on the Max1617EV kit substrate (see Figure 18).

14. Solder 9 V battery connector wires to GND and POS9 pads on the Max1617EV kit substrate, taking care to ensure correct polarity.
15. Use a soldering iron to remove the transistor component Q1 on the Max1617EV kit (just north of DXP1 and DXN1 pads in Figure 18.
16. Using the parallel port cable, connect measuring PC to Max1617EV kit.

Software Installation

This section describes how to install the temperature measurement software.

17. Insert the software disk that comes with the Max1617EV kit into the floppy drive.
18. Start the Windows* Program Manager application.
19. Select the A:\ drive.
20. To install the software on the hard drive, run the INSTALL.EXE application.

    This will automatically set up a program group containing the test software, a help document, and a un-install application. The test software may be run from a floppy disk.

No-Power (Test PC) Measurement

This section is optional and describes how to take no-power (on the test PC) temperature measurements on the processor diode. It is useful to gain confidence in the Max1617EV kit accuracy, however, it requires an extra electrical hookup.

21. Plug the 9 V battery into battery connector.
22. Slide switch, SW1 on EV kit, from “off” to “on”.
23. Using wire with alligator clips ends, short together the wires connected to GND1 (V_{SS}) and DXN1 (diode cathode) on the EV kit.

    This step is needed for room temperature measurements only, as the diode is not properly biased when the test processor is not running.
24. Start the test program from the floppy or hard drive by starting the MAX1617.EXE application.

    A dialog box appears listing three possible parallel port addresses.
25. If the auto-detect routine was successful in finding the EV kit, one of the addresses will automatically be selected. Select “OK”.

    A window containing the temperature measurement and data collection control features will start up. (If there are slave addressing problems, check to make sure that all electrical connections are properly made and that the switch is in the “on” position. If that does not solve the addressing problem, please refer to the Max1617 datasheet to resolve the problem.)

    If none of the addresses are selected, there is probably a problem with the parallel port connection with the EV kit. Close the application and check the connections.
26. Select a measurement rate of 1 Hz.

    Temperature measurements from the processor diode automatically updates in the box labeled “Remote.” The temperatures displayed in the “local” box are measurements taken using the Max1617 on die temperature sensor.

    The temperatures displayed should read ambient temperature (provided the test processor has not been heated up). This is typically around 25 °C.

Power-On (Test PC) Temperature Measurement

This process outlines how to use the processor diode to take temperature measurements while the processor is powered on. This is the procedure that should be used to validate chassis and heat sink thermal designs while running the High Power Application software.

27. Plug the 9 V battery into battery connector.
28. Slide switch SW1 on EV kit from “off” to “on”.
29. *Important:* Remove alligator clips from between GND1 and DXN1 if used for no-power measurement.
30. Start the test program from the floppy or hard drive by starting the MAX1617.EXE application.

    A dialog box appears listing three possible parallel port addresses.
31. If the auto-detect routine was successful in finding the EV kit, one of the addresses will automatically be selected. Select “OK”.

    A window containing the temperature measurement and data collection control features will start up. (If there are slave addressing problems, check to make sure that all electrical connections are properly made and that the switch is in the “on” position. If that does not solve the addressing problem, please refer to the Max1617 data sheet to resolve the problem.)

    If none of the addresses are selected, there is probably a problem with the parallel port connection with the EV kit. Close the application and check the connections.
32. Select a measurement rate of 1 Hz.

    Temperature measurements from the processor diode automatically update in the box labeled “Remote.” The temperatures displayed in the “local” box are measurements taken using the Max1617 on die temperature sensor. Temperatures will be unpredictable at this time as the diode is not properly biased until the test PC is powered up.
33. Turn on the test PC and run the High Power Application software.

    Allow the High Power Application software to run for at least 1 hour to allow all chassis components to come to thermal equilibrium.
34. Note the temperature displayed in “remote” box. This is the test processor $T_{\text{junction-HIPWR30}}$ temperature.

7.3.4 Simplified Validation Method

This section assumes a familiarity with the terms defined in the processor datasheets. These are available at http://developer.intel.com. The technique described here can be used to verify a system under test from T_{ambient} to $T_{\text{ambient-max}}$. Performing a simplified validation of the cooling solution on the junction temperature for maximum specified processor power dissipation values requires the measurement of $T_{\text{junction-HIPWR30}}$ and $T_{\text{ambient-local}}$ temperatures while executing the High Power Application software. The system and processor under analysis should be prepared to gather $T_{\text{junction-HIPWR30}}$ temperature measurement as described in "S.E.C.C.2-OLGA Metrology" on page 33 and the $T_{\text{ambient-local}}$ temperature just "upstream" of a passive heat sink or at the fan inlet for an active heat sink using a thermocouple.

When the system is ready for data collection, the HIPWR30.EXE High Power Application software should be executed. With HIPWR30.EXE executing, after the temperatures have stabilized, gather the $T_{\text{junction-HIPWR30}}$ and $T_{\text{ambient-local}}$ temperature measurements.

The graph shown in Figure 20 on page 41 plots the maximum acceptable. $T_{\text{junction-HIPWR30}}$ temperatures vs. a measured $T_{\text{ambient-local}}$ temperature for a given target $T_{\text{ambient-max}}$ while running the High Power Application software. The junction temperature shown is the maximum temperature value at the given $T_{\text{ambient-local}}$ while running the High Power Application software that ensures compliance with the worst-case power dissipation values specified in the processor's datasheet. If the measured $T_{\text{junction-HIPWR30}}$ is less than or equal to the temperature on the graph at the measured $T_{\text{ambient-local}}$ for a specific target $T_{\text{ambient-max}}$, then the system and cooling solution is compliant for the worst-case specification provided in the datasheet.

For systems with non-linear thermal behavior, like those with thermally controlled fan(s), the system designer should exercise caution to ensure that the processor temperature specifications are met given the dependencies on airflow and different fan activation patterns. The change in airflow effectively changes the $q_{\text{junction-ambient}}$ of the processor's thermal solution. Therefore, the various system conditions should be evaluated when determining the worst-case target $T_{\text{ambient-max}}$, $T_{\text{ambient-local}}$ and $T_{\text{junction-HIPWR30}}$.

If the measured $T_{\text{junction-HIPWR30}}$ temperature for the measured $T_{\text{ambient-local}}$ exceeds the value specified in the graph, then the detailed measurement approach presented in "Detailed Validation Method" on page 43 should be used. The detailed approach incorporates the actual power consumed by the processor while executing the High Power Application software and the effectiveness of the particular cooling solution to eliminate guard-banding added to account for "HIPWR30.EXE" power dissipation variances across processors.

The $T_{\text{junction-HIPWR30}}$ temperatures shown in Figure 20 were derived using empirical worst-case power dissipation values executing the High Power Application and using the Max1617EV kit.

For example, in determining compliance of a 450 MHz processor to the $T_{\text{junction-max}}$ specification as stated in the processor's datasheet:

Stated Conditions:

Processor Core Freq. = 450 MHz

$T_{ambient\text{-}local}$ = 35.0 °C (measured local to the processor running HIPWR30.EXE)

$T_{junction\text{-}HIPWR30}$ = 62.0 °C (measured temperature running HIPWR30.EXE)

$T_{ambient\text{-}OEM}$ = 35.0 °C (maximum target ambient temp. from system designer)

$T_{ambient\text{-}external}$ = 25.0 °C (measured external ambient temperature)

Using the equation from the definition table, we have:

$T_{ambient\text{-}max} = T_{ambient\text{-}OEM} - T_{ambient\text{-}external} + T_{ambient\text{-}local}$

$T_{ambient\text{-}Max}$ = 35.0 °C – 25.0 °C + 35.0 °C

$T_{ambient\text{-}max}$ = 45.0 °C

From the graph in Figure 20, drawing a vertical line from $T_{ambient\text{-}local}$ = 35.0 °C and intersecting $T_{ambient\text{-}max}$ = 45.0 °C we draw a horizontal line to the y-axis to determine the $T_{junction\text{-}HIPWR30}$ of 66.0 °C. Since the measured junction temperature of 62.0 °C while running HIPWR30.EXE is less that the y-axis value of 66.0 °C the cooling solution is compliant with the example processor's maximum junction temperature using the S.E.C.C.2 package.

Figure 20. Intel SC242 Processors in S.E.C.C.2 OLGA Package $T_{junction\text{-}HIPWR30}$ vs. $T_{ambient\text{-}local}$ Executing HIPWR30.EXE

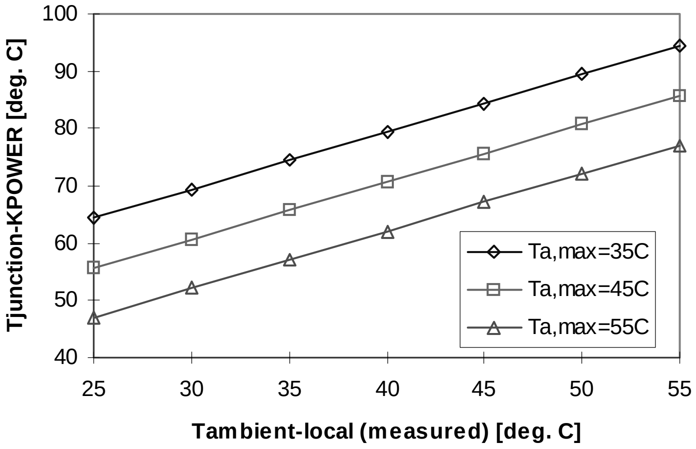
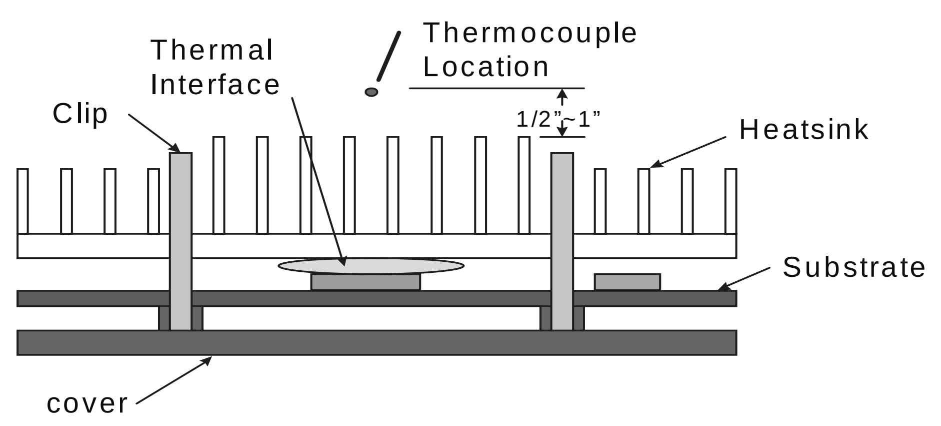


Table 5. Data Points for Graph in Figure 20

$T_{ambient-local}$ (Measured)	$T_{junction-HIPWR30}$ (°C)		
	$T_{ambient-max}$ =35 °C	$T_{ambient-max}$ =45 °C	$T_{ambient-max}$ =55 °C
25	64	56	47
30	69	61	52
35	74	66	57
40	79	71	62
45	84	76	67
50	89	81	72
55	94	86	77

Figure 21. A Typical Example for $T_{ambient-local}$ Measurement Location ½” to 1” Above Center of Heatsink



7.3.5 Detailed Validation Method

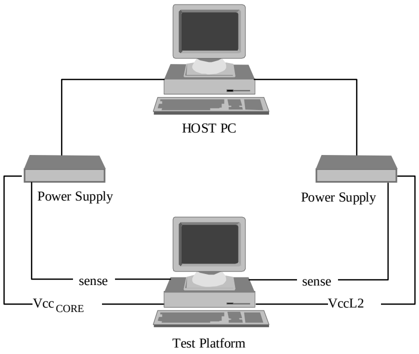
The detailed validation method uses the actual power dissipation values of the processor under test while running the High Power Application software and the effectiveness of the cooling solution to determine a projected $T_{junction\text{-}proj}$ temperature at the worst-case specifications. This projected temperature can then be used to determine worst-case compliance.

7.3.5.1 Determining the High Power Application Software Power Consumption

Gathering valid processor power consumption and dissipation data requires isolating the processor power source from the power source of other system components. The isolation requires the use of external supplies to provide power to the processor. Isolation of the processor's power systems can be accomplished by masking the power source edge fingers of the processor from the baseboard power delivery paths. This isolation may be attained via modifications to either the system baseboard or the SC242 connector/baseboard connection.

The external supplies used to source the processor power should be able to provide voltage and current readings at regular intervals during system operation. This data may then be stored and analyzed for maximum and average power consumption figures. Figure 22 illustrates a test setup that may be used to collect power consumption data. External power supplies should be used to source both the V_{CCcore} and V_{CCL2} power to gather data for the processor power consumption measurements. An isolated V_{TT} power supply is not required due to minimal activity of the system bus during execution of the High Power Application software. V_{TT} should be provided to the processor from the system V_{TT} supply.

Figure 22. Test Setup for Power Consumption Measurements



Current and voltage data should be sampled from the external power supplies several times per second over a span of several seconds. Increasing the number of data collection points will improve the precision of test results. While it is impossible to determine the absolute maximum power consumed by the processor using a periodic sampling methodology, average power consumption data can be derived. For the High Power Application software, this maximum power consumption value is an adequate approximation of the maximum thermal power dissipation of the processor.

7.3.5.2 Detailed $T_{junction\text{-}max}$ Validation Approach

Detailed evaluation of the cooling solution to cool $T_{junction\text{-}max}$ uses the power dissipation data along with actual $T_{ambient\text{-}local}$ and $T_{junction\text{-}HIPWR30}$ temperatures while running the High Power Application software to determine the effectiveness of the cooling solution. This effectiveness is characterized by the junction to ambient thermal resistance $\theta_{junction\text{-}ambient}$ and should be calculated using the measured system $T_{ambient\text{-}local}$, $T_{junction\_HIPWR30}$, and $P_{HIPWR30}$, as shown in Equation 1.

Equation 1. Thermal Junction to Ambient Thermal Resistance

$$\theta_{junction\text{-}ambient} = (T_{junction\text{-}HIPWR30} + T_{junction\text{-}offset} + T_{sensor\text{-}offset} - T_{ambient\text{-}local}) / P_{HIPWR30}$$

The following example shows $\theta_{junction\text{-}ambient}$ for an example system. $\theta_{junction\text{-}ambient}$ should be calculated using actual system measurements and processor specifications:

Stated Conditions

Processor Core Freq. = 500 MHz

$T_{ambient\text{-}local}$ = 40.0 °C (measured temperature)

$T_{junction\text{-}HIPWR30}$ = 70.0 °C (measured temperature)

$P_{HIPWR30}$ = 25.0 W (measured power)

P_{max} = 28.0 W (from processor's datasheet)

$T_{junction\text{-}max}$ = 90.0 °C (from processor's datasheet)

$T_{junction\text{-}offset}$ = 4.8 °C (from processor's datasheet)

$T_{sensor\text{-}offset}$ = 3.0 °C (from Max1617 datasheet)

$\theta_{junction\text{-}ambient} = (70.0\ °C + 4.8\ °C + 3.0\ °C - 40.0\ °C) / 25.0\ W = 1.51\ °C/W$

Using the calculated $\theta_{junction\text{-}ambient}$ and measured system $T_{ambient\text{-}local}$, it is now possible to determine the projected processor junction temperature at the maximum specified processor junction power. This is accomplished using Equation 2.

Equation 2. Projected Junction Temperature at Maximum Power

$$T_{junction\text{-}proj} = (\theta_{junction\text{-}ambient} * P_{max}) + T_{ambient\text{-}max}$$

If the calculated $T_{junction\text{-}proj}$ is lower than the specified maximum processor junction temperature, $T_{junction\text{-}max}$, then the system cooling solution is compatible with the maximum processor power specifications for a given core frequency.

Continuing the previous example to determine worst case processor compatibility:

Stated Conditions

$T_{ambient\text{-}max}$ = 45.0 °C (maximum target local ambient temperature from system designer)

$T_{junction\text{-}proj}$ = (1.51 °C/W * 28.0 W) + 45.0 °C

= 87.3 °C < $T_{junction\text{-}max}$

= 87.3 °C < 90.0 °C

Since 87.3 °C is less than the specified maximum junction temperature of 90.0 °C the example cooling solution is compliant with the example processors.

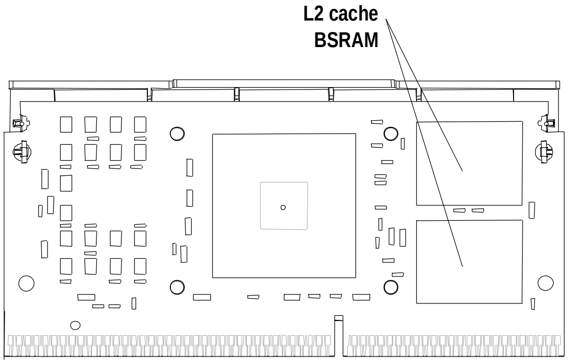
7.3.6 BSRAM Case Temperature Measurement

To ensure functional and reliable operation, the L2 Cache BSRAM case temperature ($T_{case\text{-}BSRAM}$) should be maintained at or below the maximum $T_{case\text{-}BSRAM}$ and at or above the minimum $T_{case\text{-}BSRAM}$ specified in the processor datasheet. Figure 6 shows the location for the $T_{case\text{-}BSRAM}$ measurement, assuming no external heating factors that cause other areas of the BSRAM's case to reach higher temperatures. Before taking the $T_{case\text{-}BSRAM}$ measurement, execute the HIPWR30.EXE utility for approximately an hour to maximize power dissipation of the BSRAM devices and allow for a stable reading. To select the L2 cache power portion of the utility execute with the “/L” switch from a DOS command window: “HIPWR30 /L”.

Thermocouples are used to measure $T_{case\text{-}BSRAM}$. Special care is required to ensure an accurate temperature measurement. Before taking any temperature measurements, the thermocouples must be calibrated. When measuring the temperature of a surface, errors can be introduced in the measurement if not handled properly. Such measurement errors can be due to a poor thermal contact between the thermocouple junction and the surface of the processor's core case, conduction through thermocouple leads, heat loss by radiation and convection, or contact between the thermocouple cement and the heatsink base. To minimize these errors, the following approach is recommended:

- Use 30 gauge or finer diameter K, T, or J type thermocouples.
- Attach the thermocouple bead or junction using high thermal conductivity cements at the center of the top of the BSRAM package. See Figure 6.
- Ensure the thermocouple is attached at a 0° angle if no heat sink makes contact with the BSRAM case. If a heat sink makes contact with the BSRAM case, but the heat sink does not cover the location specified for $T_{case\text{-}BSRAM}$ measurement, the thermocouple should be attached at a 0° angle (refer to Figure 7). The thermocouple should be attached at a 90° angle if a heat sink makes contact with the BSRAM case and the heat sink covers the location specified for $T_{case\text{-}BSRAM}$ measurement (refer to Figure 8).
- Drill a hole through the heat sink base to route the thermocouple wires out. Ensure this hole is 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 23. BSRAM Case Temperature ($T_{case\text{-}BSRAM}$) Measurement Location



7.3.6.1 BSRAM $T_{case\text{-}BSRAM}$ Validation Method

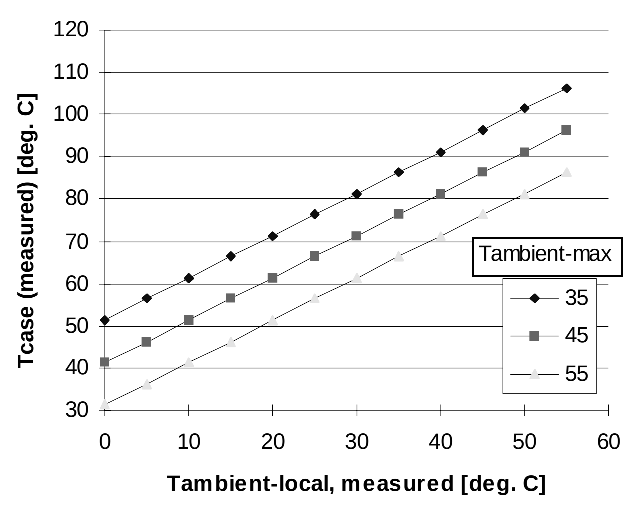
Once the $T_{case\text{-}BSRAM}$ has been obtained, a simple equation can be used to determine compliance to the specified maximum BSRAM case temperature. Equation 3 relates the measured case temperature running the High Power Application software for the L2 cache with the measured ambient temperature for a given target maximum ambient temperature and processor frequency. Figure 9 on page 21 is an example graph and a set of three given target ambient maximum temperatures. Equation 3 is valid for determining compliance to the maximum BSRAM case temperature for processors using the S.E.C.C.2 OLGA package.

Equation 3. BSRAM Case Temperature Limit at Maximum Power

$$T_{case\text{-}BSRAM} \leq 105.56 - 0.0392 * \text{frequency} - (T_{ambient\text{-}max} - T_{ambient\text{-}local})$$

Where frequency is the processor’s operating frequency in MHz. Equation 3 was developed to accommodate different frequencies. The 105.56 in the equation is from empirical data and has nothing to do with the BSRAM case specified maximum temperature.

Figure 24. Example of $T_{case\text{-}BSRAM}$ vs. $T_{ambient\text{-}local}$



In determining compliance of a 450 MHz processor to $T_{case\text{-}BSRAM}$ specification the following example illustrates the use of the simplified equation:

Stated Conditions

Processor Core Freq. = 450 MHz

$T_{ambient\text{-}local}$ = 47.1 °C (measured temperature)

$T_{case\text{-}BSRAM}$ = 80.6 °C (measured temperature running HIPWR30 /L)

$T_{ambient\text{-}max}$ = 45.0 °C (maximum target ambient temperature from system designer)

Using Equation 3, we have:

$T_{case\text{-}BSRAM} \leq 105.56 - 0.0392 * \text{frequency} - (T_{ambient\text{-}max} - T_{ambient\text{-}local})$

$\leq 105.56 - 0.0392 * 450 - (45.0 - 47.1)$

$80.6 \leq 105.56 - 17.64 - (-2.1)$

≤ 90.02

Since the measured $T_{case\text{-}BSRAM}$ of 80.6 °C is less than the calculated maximum case temperature from Equation 3, the cooling solution is compliant with the example processor using the S.E.C.C.2 package.

8.0 Conclusion

As the complexity of today's microprocessors 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 passive heatsinks, fans and/or active cooling devices. Additional solutions can be achieved through the use of ducting solutions.

The simplest and most cost effective method is to use an extruded heatsink and a system fan. The size of the heatsink and the output of the fan can be varied to balance size and space constraints with acoustic noise. This document has presented the conditions and requirements for properly designing a heatsink solution for a Intel SC242 processor based system. Properly designed solutions provide adequate cooling to maintain the Intel SC242 processor. This is accomplished by providing a low local ambient temperature and creating a minimal thermal resistance to that local ambient temperature. Active fan heatsinks or ducting can be used to cool the processor(s) if proper cover and package temperatures cannot be maintained otherwise. By maintaining the processor's cover temperature and processor temperature at the values specified in the processor datasheet, a system can guarantee proper functionality and reliability of these processors.