Intel® IXP45X and Intel® IXP46X Product Line of Network Processors

Thermal Design Application Note

May 2006

Order Number: 308073-002US

Contents

Figures

Tables

Revision History

Date	Revision	Description
May 2006	002	Edited text for customer usability, alphabetized Terminology list, and clarified information regarding consequences of exceeding $T_{CASE\ MAX}$. Updated with new branding requirements (logo, font, color, etc.) See change bars for specific updates.
June 2005	001	Initial public release of document.

1.0 Introduction

This document describes the thermal characteristics for the Intel® IXP45X and Intel® IXP46X Product Line of Network Processors. This document is used to properly design a thermal solution for systems implementing the following IXP45X/IXP46X product line parts:

- Intel XScale® Processor frequency 667 MHz (Intel® IXP465 Network Processor only).
- Intel XScale® Processor frequency 533 MHz.

Properly designed solutions must provide adequate cooling to maintain the IXP45X/IXP46X product line case temperature (T_{CASE}) at or below the values listed in Table 1 on page 7. Ideally, this is accomplished by providing a low local ambient temperature and creating a minimal thermal resistance to that local ambient temperature. Heat sinks may be required if case temperatures exceed those listed in Table 1 on page 7.

By maintaining the case temperature at or below the values recommended in this document, the IXP45X/IXP46X product line will function properly and reliably.

1.1 About This Document

This document contains the following sections:

- Section 2.0 Thermal Specifications — IXP45X/IXP46X product line case temperature specifications and where to find power requirements and thermal packaging techniques.
- Section 3.0 Thermal Attributes — IXP45X/IXP46X product line thermal characteristic data, package mechanical attributes, and package thermal characteristic data. Use this section to determine your thermal solution requirements.
- Section 4.0 Thermal Enhancement Requirements (667 MHz Processors only) — Heat sink attachment methods, heat sink interfacing, and heat sink reliability.
- Section 5.0 Measurements for Thermal Specifications — Guidelines for measuring the IXP45X/IXP46X product line's case temperature with and without a heat sink.
- Section 6.0 Conclusion.
- Appendix A Heat Sink and Attachment Suppliers.
- Appendix B PCB Guidelines.

1.1.1 Intended Audience

The intended audience for this document is system design engineers using the IXP45X/IXP46X product line. System designers are required to address component and system-level thermal challenges as the market continues to adopt products with higher speeds and port densities. Depending on the type of system and target operating environment, different chassis designs may be required to provide better cooling solutions for silicon devices.

1.1.2 Acronyms and Terminology

Packaging acronyms and terminology used in this document include:

- Ambient — The local ambient temperature of the bulk air approaching the component. It can be measured by placing a thermocouple approximately 1 in. upstream from the component edge.

- Heat Spreader — A thermal enhancing solution that is an integral part of the package which increases thermal performance. When an additional heat sink is used, the heat spreader — which is part of the component package — also provides a better thermal junction between the component and a heat sink.
- Heat Spreader Ball Grid Array (HSBGA) — A surface-mounted package whose PCB-interconnect method consists of eutectic or lead-free solder ball array on the interconnecting side of the package. An integrated heat spreader is used to enhance thermal performance.
- HSBGA — Heat Spreader Ball Grid Array.
- Junction — Refers to the P-N junction in the silicon. In this document, the term is used as a temperature reference point.
- Lands — Pads on the PCB to which BGA balls are soldered.
- LFM — Linear Feet per Minute (unit of measurement for air flow).
- PCB — Printed Circuit Board.
- Printed Circuit Assembly (PCA) — An assembled PCB.
- T_{CASE} — Case Temperature, °C.
- $T_{CASE\text{-}HS}$ — Case Temperature with Heat Sink, °C.
- $T_{CASE\text{-}NO\ HS}$ — Case Temperature with No Heat Sink, °C.
- TDP — Thermal Design Power. The estimated maximum power generated by a component in a realistic application. Use maximum power requirement numbers from Table 1 on page 7.
- $T_{J\ MAX}$ — Maximum junction temperature, °C.
- Θ_{JA} — Parameter specifying the Junction-to-Ambient thermal resistance, °C/W.
- Ψ_{JT} — Parameter specifying the Junction-to-Package-Top thermal resistance, °C/W. Please do not confuse this parameter with the Junction-to-Case thermal resistance.

1.1.3 Reference Documents and Information Sources

Document Name	Number	Available From
Integrated Circuit Thermal Measurement Method - Electrical Test Method (Single Semiconductor Device)	JESD51-1	http://www.jedec.org
Integrated Circuits Thermal Test Method Environmental Conditions - Natural Convection (Still Air)	JESD51-2	http://www.jedec.org

1.2 Product Package Thermal Specification

The thermal parameters defined in Table 1 are based on simulated results of packages assembled on standard multi-layer, 2s2p, 1.0-oz., copper-layer boards in a natural-convection environment.

The maximum case temperature is defined as:

$$T_{CASE\ MAX} = T_{J\ MAX} - (\Psi_{JT} \times \text{Power Dissipation})$$

If the case temperature exceeds the specified $T_{CASE\ MAX}$, thermal enhancements such as heat sinks or forced air will be required.

Table 1. Package Thermal Characteristics in Standard JEDEC Environment

Package Type	Target Product	Est. Power (TDP)	Θ_{JA}	Ψ_{JT}	$T_{CASE\ MAX}$ †
35-mm HSBGA	533 MHz	3.2 W	12.4° C/W	1.4° C/W	115° C
35-mm HSBGA	667 MHz	4.0 W	12.4° C/W	1.4° C/W	114° C
† The maximum case temperature **cannot** be exceeded. This is not the normal operating temperature.					

1.3 Thermal Conditions

This document provides a method for determining the junction temperature of the IXP45X/IXP46X product line in a specific system, based on sampling T_{CASE} (Case Temperature).

T_{CASE} is a function of the local ambient and internal temperatures of the component. This document specifies a maximum allowable case temperature $T_{CASE\ MAX}$ for the IXP45X/IXP46X product line.

1.4 Thermal Considerations

Component temperature in a system environment is a function of the component, board, and system thermal characteristics. Some board/system-level thermal constraints consist of the following:

- Local ambient temperature near the component.
- Air flow over the component and surrounding board.
- Physical constraints at, above, and surrounding the component that may limit the size of a thermal enhancement.

The component die temperature depends on the following:

- Component power dissipation.
- Component size.
- Packaging materials (effective thermal conductivity).
- Type of interconnection to the substrate and motherboard.
- Presence of a thermal cooling solution.
- Thermal conductivity.
- Power density of the substrate/package, nearby components, and circuit board to which it is attached.

Technology trends continue to push these parameters toward increased performance levels (higher operating speeds), I/O density (smaller packages), and silicon density (more transistors). Power-density increases and thermal-cooling solution space and air flow become more constrained as operating frequencies increase and packaging sizes decrease. These issues result in an increased emphasis on the following:

- Package and thermal enhancement technology to remove heat from the device.
- System design to reduce local ambient temperatures and ensure that thermal design requirements are met for each component in the system.

1.5 Importance of Thermal Management

The thermal management objective is to ensure that all system component temperatures are maintained within functional limits. The functional temperature limit is the range within which the electrical circuits are expected to meet specified performance requirements. Operation outside the functional limit can degrade system performance, cause logic errors, or cause component permanent damage. Case temperature exceeding $T_{CASE\ MAX}$ may result in irreversible changes in the component operating characteristics.

2.0 Thermal Specifications

The thermal solution must maintain a case temperature below the values specified in Table 2 and Table 3 to ensure proper operation and reliability of the IXP45X/IXP46X product line.

System or component-level thermal enhancements are required to dissipate generated heat when case temperature exceeds the maximum temperatures.

- For processors operating at 667 MHz — See Table 2 on page 8.
- For processors operating at 533 MHz — See Table 3 on page 8.

Good system air flow is critical to dissipate the highest possible thermal power. It is very important that if your design requires fans, vents, and/or ducts, their placement in relation to nearby components is carefully assigned. Air flow channels must be clear of obstruction to maximize heat transfer. Acoustic noise constraints may limit the size and types of fans, vents, and ducts that can be used in a particular design.

To develop a reliable, cost-effective thermal solution, all of the system variables must be considered. Use system-level thermal characteristics and simulations to account for individual component thermal requirements.

Table 2. IXP46X product line Preliminary Thermal Absolute Maximum Rating (667 MHz Processor)

Parameter	Maximum
$T_{CASE\text{-}HS}$ [1]	105° C
$T_{CASE\text{-}NO\ HS}$ [2]	114° C

Notes:
1. $T_{CASE\text{-}HS}$ is defined as the maximum case temperature with the default enhanced thermal solution (heat sink) attached.
2. $T_{CASE\text{-}NO\ HS}$ is defined as the maximum case temperature without any thermal enhancement (heat sink) attached to the package.

Table 3. IXP45X/IXP46X product line Preliminary Thermal Absolute Maximum Rating (533, 400, 266 MHz Processor)

Parameter	Maximum
$T_{CASE\text{-}NO\ HS}$ [1]	115° C

Note:
1. $T_{CASE\text{-}NO\ HS}$ is defined as the maximum case temperature without any thermal enhancement (heat sink) attached to the package.

2.1 Case Temperature

The IXP45X/IXP46X product line is designed to operate reliably as long as the thermal and electrical specifications provided in the datasheet are not violated.

Note: $T_{CASE\ MAX}$ must never be exceeded.

Proper guidelines for measuring the case temperature are discussed in Section 5.1, “Case Temperature Measurements” on page 21.

2.2 Designing for Thermal Performance

The PCB and system-design recommendations required for the IXP45X/IXP46X product line to achieve the thermal performance are documented in Appendix B, “PCB Guidelines” on Page 24.

3.0 Thermal Attributes

3.1 Key Notes to Remember

Since system environments and applications vary, note the following when referring to the data presented in this document.

- The evaluation board used to perform simulations is a four-layer, 4-by-4-inch PCB.
- All data is preliminary and not validated using physical samples.
- Your system design may differ significantly.
- A larger board or additional layers will increase copper area, and may improve heat dissipation and overall thermal performance.

3.2 Mechanical Characteristics

The Intel® IXP45X and Intel® IXP46X Product Line of Network Processors is packaged in a 544 pin 35 mm HSBGA. The mechanical drawings for the top and bottom view are shown in Figure 1 and Figure 2.

Figure 1. IXP45X/IXP46X product line 544-HSBGA, 35-mm—Bottom View (Reference Only)

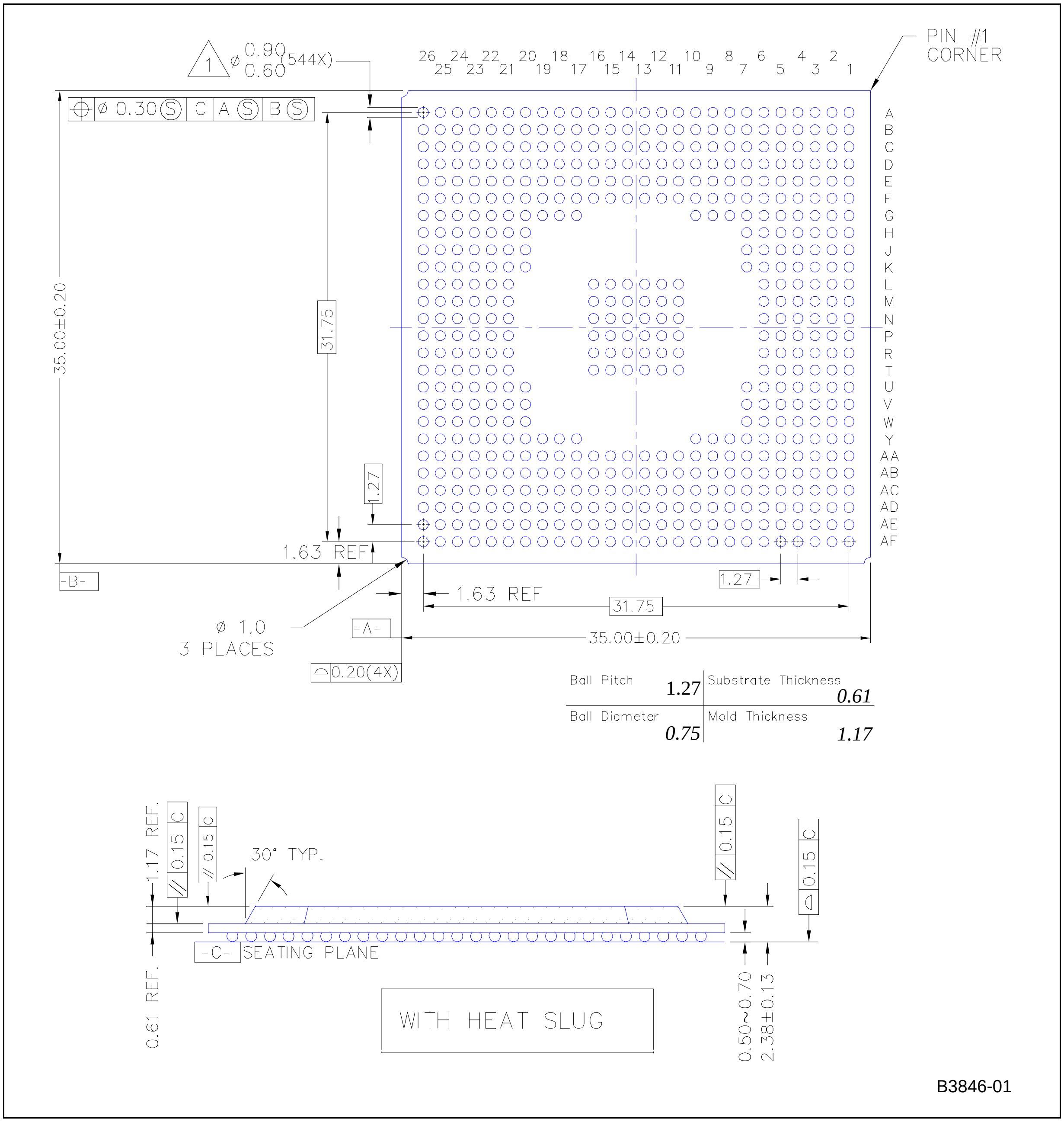
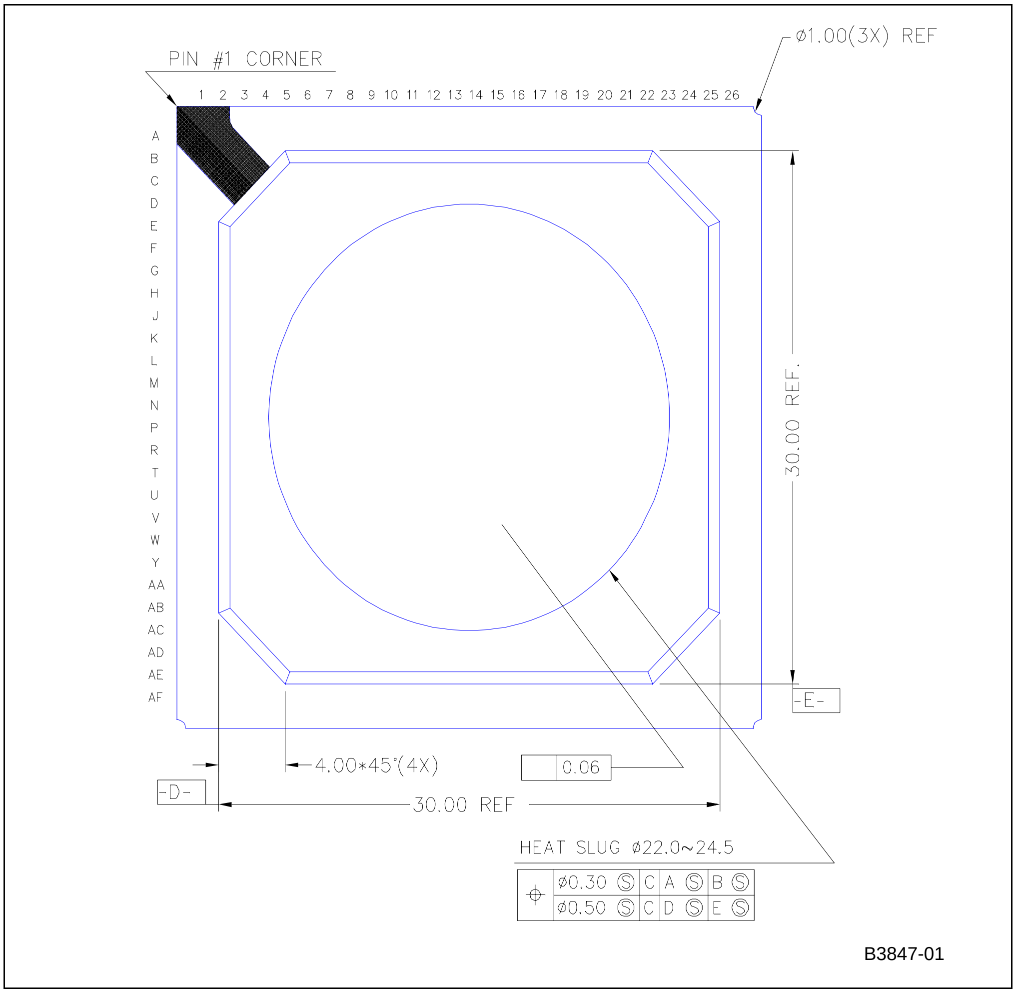


Figure 2. IXP45X/IXP46X product line 544-HSBGA, 35-mm—Top View (Reference Only)



3.3 Thermal Attributes

Thermal attributes for the Intel® IXP45X and Intel® IXP46X Product Line of Network Processors are dependent on the processor speed, as described in the following sections.

3.3.1 Thermal Characteristics at 667 MHz

The graphs and tables in this section are based on simulations. The intent here is to show thermal performance obtained at different airflows with respect to ambient temperature, and provide an estimated case temperature under the conditions shown in Table 4 and Table 5.

Case temperature **must not** exceed $T_{CASE\ MAX}$. Exceeding this value will violate the operating temperature specification, resulting in catastrophic hardware failure and possible permanent damage.

Figure 3 on page 12 shows the local ambient temperature versus air flow for a typical 667 MHz IXP46X network processor with and without heatsink. The red graph represents the simulation done when the processor has a heatsink. The blue graph represents the simulation done when no heat sink is attached to the processor. Notice how the ambient temperature for the heatsink scenario can be higher at the same airflow as the experiment done without a heatsink. (For a typical system definition, see Section 3.1, "Key Notes to Remember" on page 9.).

Table 4 and Table 5 show T_{CASE} as a function of air flow and ambient temperature at the TDP for a typical 667 MHz IXP46X network processor system. Use the data in these tables to determine the optimum air flow and heatsink combination required to maintain T_{CASE} below $T_{CASE\ MAX}$.

Note: Your system design may vary considerably from the typical system board environment used to generate Table 4 and Table 5.

Figure 3. Maximum Allowable Ambient Temperature Versus Air Flow (667 MHz only)

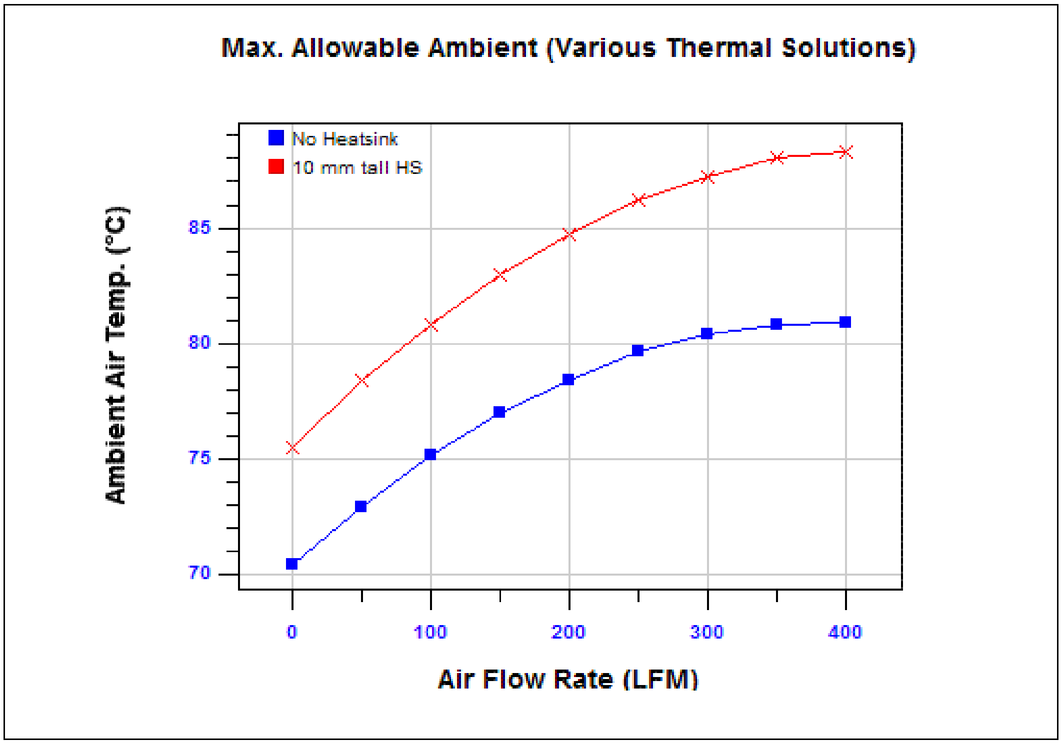


Table 4. Expected T_{CASE} for No Heat Sink Attached at TDP = 4.0 W (667 MHz only) (Sheet 1 of 2)

No Heat Sink Attached						$T_{CASE\ MAX}$ = 114 °C			
Airflow (LFM)	0	50	100	150	200	250	300	350	400
85 °C ambient	129	126	124	122	120	118	117	116	116
80 °C ambient	124	121	119	117	115	113	112	111	111
75 °C ambient	119	116	114	112	110	108	107	106	106
70 °C ambient	114	111	109	107	105	103	102	101	101

Note: The red-colored value(s), if any, indicate air flow/local ambient combinations that exceed the allowable case temperature for the 667 MHz IXP46X network processor. See Section 3.1, "Key Notes to Remember" on page 9 for system assumptions.

Table 4. Expected T_{CASE} for No Heat Sink Attached at TDP = 4.0 W (667 MHz only) (Sheet 2 of 2)

No Heat Sink Attached					$T_{CASE\ MAX}$ = 114 °C				
Airflow (LFM)	**0**	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**
65 °C ambient	109	106	104	102	100	98	97	96	96
60 °C ambient	104	101	99	97	95	93	92	91	91
55 °C ambient	99	96	94	92	90	88	87	86	86
50 °C ambient	94	91	89	87	85	83	82	81	81
45 °C ambient	89	86	84	82	80	78	77	76	76

Note: The red-colored value(s), if any, indicate air flow/local ambient combinations that exceed the allowable case temperature for the 667 MHz IXP46X network processor. See Section 3.1, “Key Notes to Remember” on page 9 for system assumptions.

Table 5. Expected T_{CASE} for Heat Sink Attached at TDP = 4.0 W (667 MHz only)

Heat Sink Attached					$T_{CASE\ MAX}$ = 105 °C				
Airflow (LFM)	**0**	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**
85 °C ambient	115	112	108	105	103	101	99	98	97
80 °C ambient	110	107	103	100	98	96	94	93	92
75 °C ambient	105	102	98	95	93	91	89	88	87
70 °C ambient	100	97	93	90	88	86	84	83	82
65 °C ambient	95	92	88	85	83	81	79	78	77
60 °C ambient	90	87	83	80	78	76	74	73	72
55 °C ambient	85	82	78	75	73	71	69	68	67
50 °C ambient	80	77	73	70	68	66	64	63	62
45 °C ambient	75	72	68	65	63	61	59	58	57

Note: The red-colored value(s), if any, indicate air flow/local ambient combinations that exceed the allowable case temperature for the 667 MHz IXP46X network processor. See Section 3.1, “Key Notes to Remember” on page 9 for system assumptions.

3.3.2 Thermal Characteristics for 533 MHz Processors

The graphs and tables in this section are based on simulations. The intent here is to show thermal performance obtained at different airflows with respect to ambient temperature, and provide an estimated case temperature under the conditions shown in Table 6.

Case temperature **must not** exceed $T_{CASE\ MAX}$. Exceeding this value will violate the operating temperature specification, resulting in catastrophic hardware failure and possible permanent damage.

The simulations created for this section were performed at 533 MHz clock speed. Note that if the processor is configured to operate at a lower speed such as 400 or 266 MHz, the thermal characteristics will be lower than those shown in Figure 4 and Table 6. Under normal operation, temperature will be different at all four speeds: the lower the core speed selected, then the lower the operational temperature. This becomes a tradeoff between temperature and core speed. In other words, temperature will increase or decrease depending on the operational core speed.

Figure 4 shows the local ambient temperature versus air flow for a typical IXP45X/46X network processor with no heatsink. The blue graph represents the simulation done when no heat sink is attached to the processor. (For a typical system definition, see Section 3.1, "Key Notes to Remember" on page 9.)

Table 6 shows T_{CASE} as a function of air flow and ambient temperature at the TDP for a typical IXP45X/46X network processor system. Use the data in the table to determine the optimum air flow required to maintain T_{CASE} below $T_{CASE\ MAX}$.

Note: Your system design may vary considerably from the typical system board environment used to generate Table 6.

Figure 4. Maximum Allowable Ambient Temperature Versus Air Flow (533 MHz)

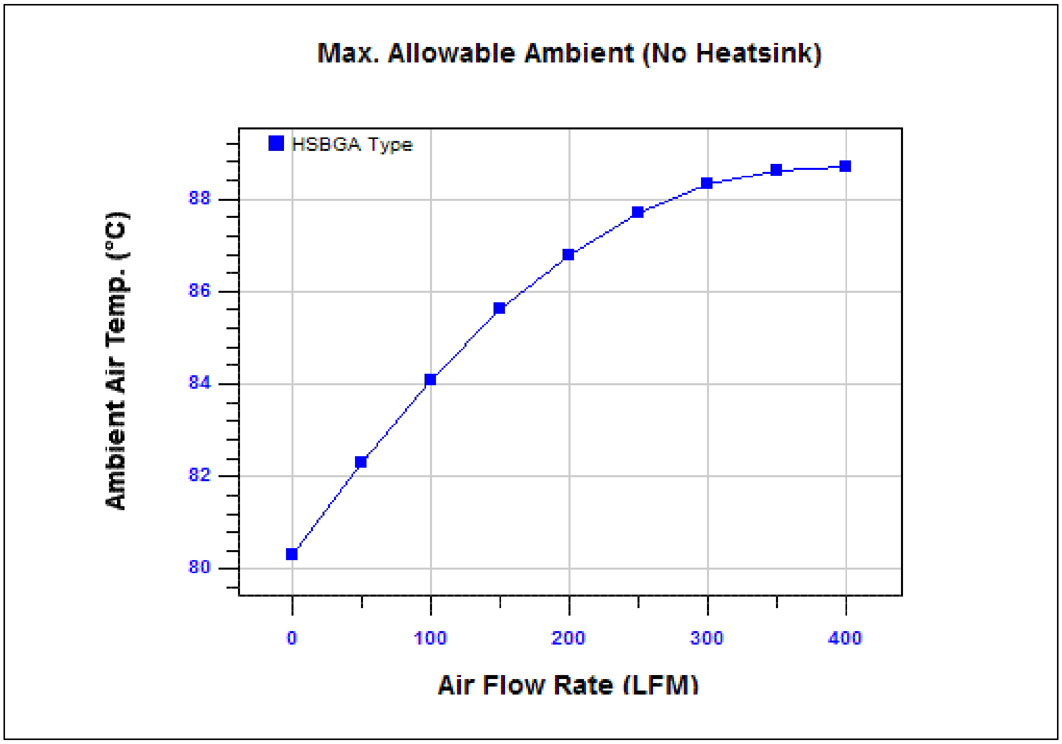


Table 6. Expected T_{CASE} for No Heat Sink Attached at TDP = 3.2 W (533 MHz)

No Heat Sink Attached					$T_{CASE\ MAX}$ = 115 °C				
Airflow (LFM)	**0**	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**
85 °C ambient	120	118	116	114	113	111	110	110	110
80 °C ambient	115	113	111	109	108	106	105	105	105
75 °C ambient	110	108	106	104	103	101	100	100	100
70 °C ambient	105	103	101	99	98	96	95	95	95
65 °C ambient	100	98	96	94	93	91	90	90	90
60 °C ambient	95	93	91	89	88	86	85	85	85

Note: The red-colored value(s), indicate air flow/local ambient combinations that exceed the allowable case temperature for the IXP45X/IXP46X product line. See Section 3.1, "Key Notes to Remember" on page 9 for system assumptions.

Table 6. Expected T_{CASE} for No Heat Sink Attached at TDP = 3.2 W (533 MHz)

No Heat Sink Attached					$T_{CASE\ MAX}$ = 115 °C				
Airflow (LFM)	**0**	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**
55 °C ambient	90	88	86	84	83	81	80	80	80
50 °C ambient	85	83	81	79	78	76	75	75	75
45 °C ambient	80	78	76	74	73	71	70	70	70

Note: The red-colored value(s), indicate air flow/local ambient combinations that exceed the allowable case temperature for the IXP45X/IXP46X product line. See Section 3.1, "Key Notes to Remember" on page 9 for system assumptions.

4.0 Thermal Enhancement Requirements (667 MHz Processors only)

This section is generally only applicable to 667 MHz speed options of the IXP46X network processor. The 533/400/266 MHz versions of the product generally will be able to operate within specified conditions in most environments without using a heat sink. Please verify that the maximum specified conditions are not violated for any speed grades of the product used.

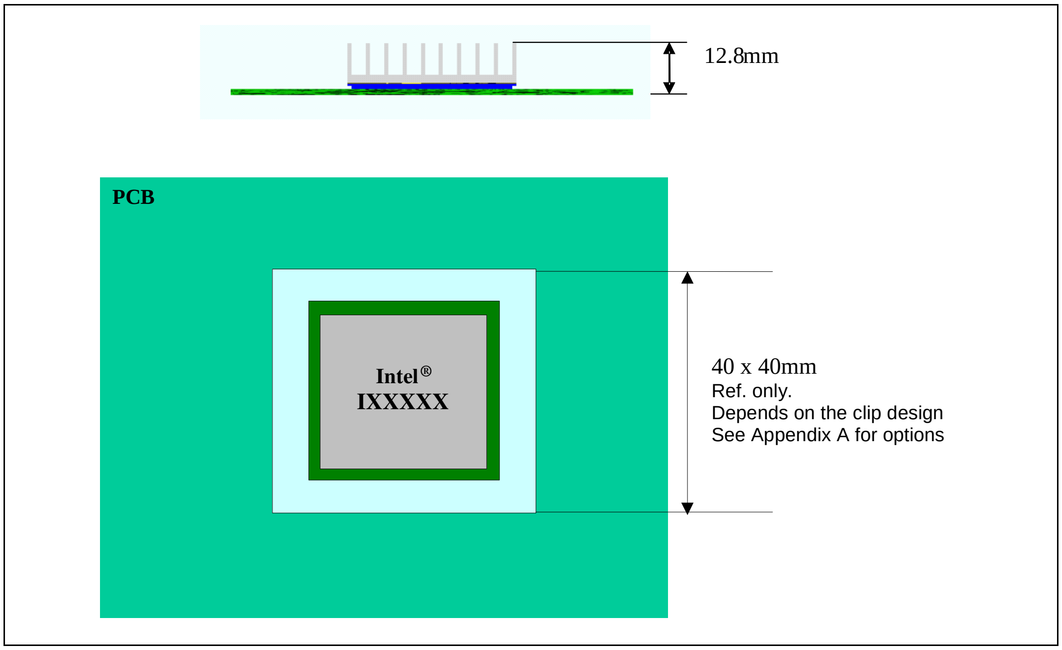
This verification can be done through thermal simulations. Simulation models can be provided upon request.

One method frequently used to improve thermal performance is to increase the component's surface area by attaching a metallic heat sink to the component top. Increasing the surface area of the heat sink reduces the thermal resistance from the heat sink to the air, increasing heat transfer.

4.1 Clearances

To be effective, a heat sink requires a pocket of air around it, which is free of obstructions. Though each design may have unique mechanical restrictions, the recommended clearance zones for the heat sink for the IXP45X/IXP46X product line are described in Appendix A, "Heat Sink and Attachment Suppliers" on Page 23 and shown in Figure 5.

Figure 5. IXP45X/IXP46X product line Heat Sink Volume Restrictions



4.2 Default Enhanced Thermal Solution

If no control over the end-user's thermal environment is available, or if it is desired to bypass the thermal modeling and evaluation process, the default enhanced thermal solution can be used.

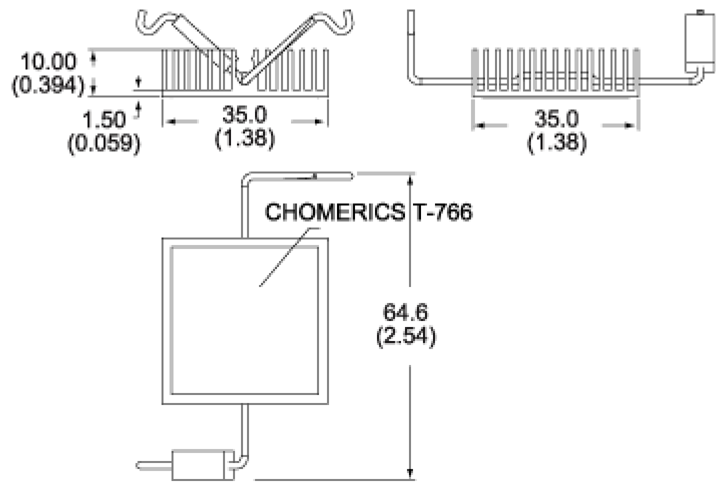
The default enhanced thermal solution replicates the performance defined in Table 4 and Table 5 at the thermal design power. If the case temperature continues to exceed the values listed in Figure 3 on page 12 after the default enhanced thermal solution has been implemented, then additional cooling will be needed.

Additional cooling may be achieved by improving air flow to the component and/or adding additional thermal enhancements.

4.3 Extruded Heat Sinks

If required, an extruded heat sink is the suggested 667 MHz IXP46X network processor thermal solution. Figure 6 shows the suggested heat sink drawing. Other equivalent heat sinks and their sources are provided in Appendix A, “Heat Sink and Attachment Suppliers”.

Figure 6. Extruded Heat Sink for the 667 MHz Intel® IXP46X Product Line



Note: Dimensions are in millimeters and inches (shown in parentheses).

4.4 Attaching the Extruded Heat Sink

The extruded heat sink may be attached using clips with a phase-change, thermal-interface material.

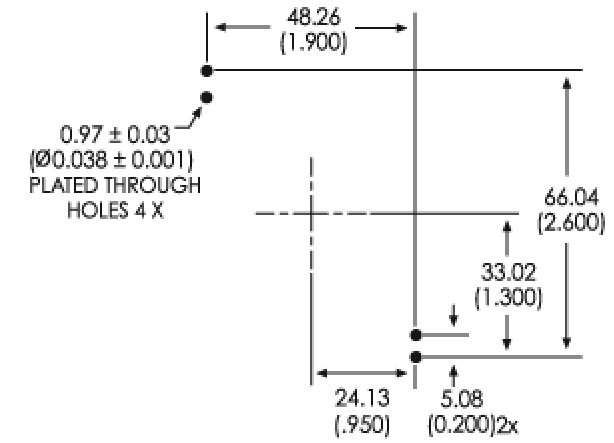
4.4.1 Clips

A well-designed clip, in conjunction with a thermal interface material (such as tape or grease), often offers the best combination of mechanical stability and reworkability.

Use of a clip requires significant advance planning as mounting holes are required in the PCB. Use non-plated mounting with a grounded annular ring on the solder side of the board surrounding the hole. For a typical low-cost clip, set the annular ring inner diameter to 150 mils and an outer diameter to 300 mils. Define the ring to have at least eight ground connections. Set the solder mask opening for these holes with a radius of 300 mils.

Figure 7 and Figure 8 show the location and size of the PCB holes needed for attaching the default thermal solution. (Also see Section 4.3, “Extruded Heat Sinks” on page 16.)

Figure 7. Reference Board Anchor Holes for Attaching Default Thermal Solution



4.4.2 Thermal Interface Material (PCM45HD*)

The recommended thermal interface is PCM45HD* from Honeywell*. PCM45HD thermal interface pads are phase-change materials suitable for high-performance IC devices, as shown in Figure 8 on page 19.

These materials exhibit excellent wetting at interfaces during the typical operating temperature range, resulting in very low surface contact resistance. Wetting refers to the ability of a liquid to coat a surface. For wetting to occur, a solid-air interface must be exchanged for a solid-liquid interface. (For additional information, see Section 4.6.2.2, "Wetting/Filling Characteristics of the Material" on page 20.)

The manufacturer's recommended attachment procedure for its thermal interface includes:

1. Ensure that the component surface and heat sink are free from contamination. Using proper safety precautions, clean the package top with a lint-free wipe and Isopropyl Alcohol.
2. Remove the PCM45HD liner and carefully position the Thermal Interface Material (TIM) on the center of the heat sink. (See Figure 9 on page 19.)
3. Prior to assembly of the heat sink onto the heat dissipating component, place the heat sink and TIM at room temperature (between 21 - 25° C.) for approximately two hours.
4. Remove the taped liner and verify that the TIM is uniformly and securely attached to heat sink.
5. Assemble heat sink to the Internal Heat Spreader (IHS).

   The IHS is the heat spreader contained within the component package.

Additional notes:

- Dents and minor scratches in the material will not affect performance since the material is designed to flow at typical operating temperatures.
- PCM45HD pads can be removed for rework using a single-edged razor. Subsequently clean the surface with isopropyl (IPA) solvent.

Note: Each PCA, system, and heat sink combination varies in attachment strength. Carefully evaluate the reliability of tape attachments prior to making high-volume use of that method. (See Section 4.5, “Reliability” on page 19.)

Figure 8. PCM45 Phase Change Tape

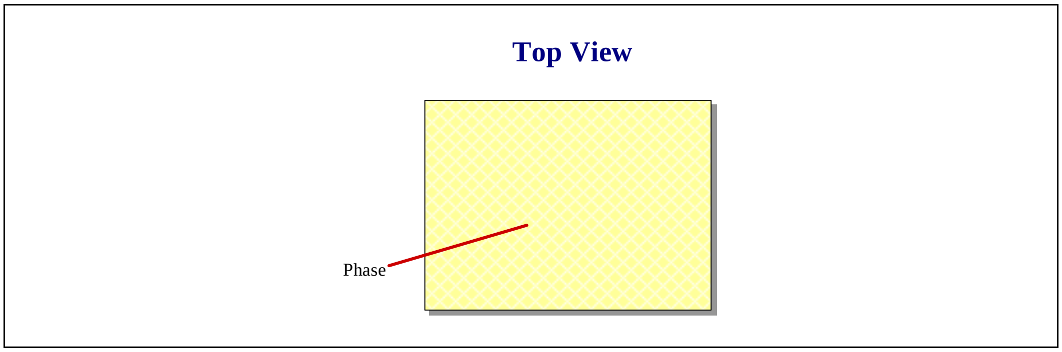
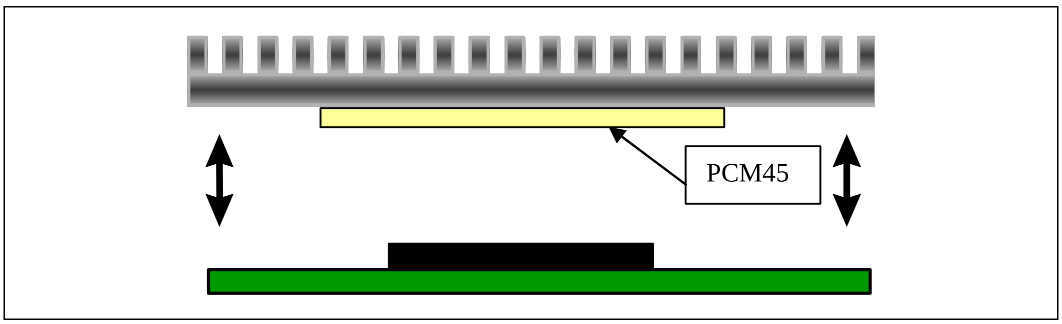


Figure 9. Completing the Attach Process



4.5 Reliability

Each PCA, system, and heat sink combination varies in attach strength and long-term adhesive performance. Carefully evaluate the reliability of the completed assembly prior making high-volume use of this method.

Some reliability testing recommendations are shown in Table 7 on page 19.

Table 7. Reliability Validation

Test 1	Requirement	Pass/Fail Criteria 2
Mechanical Shock	• 50 G, board level • 1 ms, 3 shocks/axis	Visual and Electrical Check
Random Vibration	• 7.3 G, board level • 45 minutes/axis, 50 to 2,000 Hz	Visual and Electrical Check
High-Temperature Life	• 85° C • 2,000 hours total • Checkpoints occur at 168, 500, 1,000, and 2,000 hours	Visual and Mechanical Check
Thermal Cycling	• Per-Target Environment (for example: -40° C to +85° C) 500 Cycles	Visual and Mechanical Check
Humidity	• 85% relative humidity • 85° C, 1,000 hours	Visual and Mechanical Check

4.6 Thermal Interface Management for Heat Sink Solutions

To optimize the 667 MHz IXP46X network processor heat sink design, it is important to understand the interface between the heat spreader and the heat sink base. Specifically, thermal conductivity effectiveness depends on the following:

- Bond-line thickness.
- Interface material area.
- Interface material's thermal conductivity.

4.6.1 Bond Line Management

The gap between the heat spreader and the heat sink base impacts heat sink solution performance. The gap is the space that will exist between the heat sink and the component's heat spreader, when the two items are attached. 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 heat spreader, plus the thickness of the thermal interface material (such as PSA, thermal grease, or epoxy) used to join the two surfaces.

The gap should be made as small as possible for best results.

The planarity of the 667 MHz IXP46X network processor package is 6 mils.

4.6.2 Interface Material Performance

The following two factors impact the performance of the interface material between the heat spreader and the heat sink base:

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

4.6.2.1 Thermal Resistance of the Material

Thermal resistance describes the ability of the thermal interface material to transfer heat from one surface to another. The higher the thermal resistance, the less efficient the heat transfer.

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 larger the temperature drop is required across the interface.

4.6.2.2 Wetting/Filling Characteristics of the Material

The wetting/filling characteristic of the thermal interface material is its ability to fill the gap between the heat spreader top surface 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, thus increasing the efficiency of the thermal solution.

5.0 Measurements for Thermal Specifications

Determining the thermal properties of the system requires careful case-temperature measurements. Guidelines for measuring IXP45X/IXP46X product line case temperature are provided in this section.

5.1 Case Temperature Measurements

The T_{CASE} of the IXP45X/IXP46X product line must be maintained at or below the maximum case temperatures listed in Table 1 on page 7 to ensure functionality and reliability. Special care is required when measuring the case temperature to ensure an accurate temperature measurement.

Use the following guidelines when making case measurements:

- Measure the surface temperature of the case in the geometric center of the case top.
- Calibrate the thermocouples used to measure T_{CASE} before making temperature measurements.
- Use 36-gauge (maximum) K-type thermocouples.

Care must be taken to avoid errors when measuring a surface temperature that is a different from the surrounding local-ambient air. Measurement errors can be due to a poor thermal contact between the thermocouple junction and the surface of the package, heat loss by radiation, convection, conduction through thermocouple leads, or contact between the thermocouple cement and the heat sink base (if used).

5.1.1 Attaching the Thermocouple (No Heat Sink)

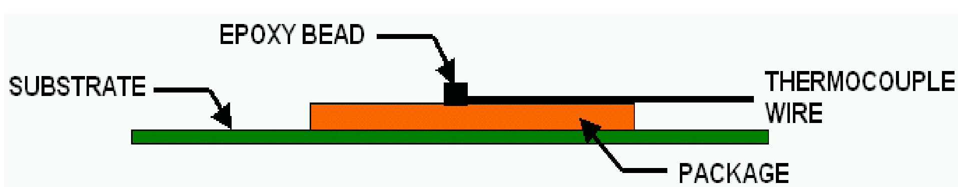
The following approach is recommended to minimize measurement errors while attaching the thermocouple with no heat sink:

- Use K-type thermocouples with a diameter of 36 gauge or less.
- Ensure that the thermocouple has been properly calibrated.
- Attach the thermocouple bead or junction with high-thermal-conductivity cement to the top surface of the package (case), in the center of the heat spreader.

  Note: It is critical that the entire thermocouple lead be butted tightly to the heat spreader.
- If there is no interference with the thermocouple attach location or leads, attach the thermocouple at a 0° angle as shown in Figure 10.

  This is the preferred method and is recommended for use with non-enhanced packages.

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



5.1.2 Attaching the Thermocouple (With Heat Sink)

Note: This section is applicable to IXP46X network processors operating at 667 MHz only.

The following approach is recommended to minimize measurement errors while attaching the thermocouple with heat sink:

- Use 36-gauge or smaller diameter K-type thermocouples.
- Ensure that the thermocouple is properly calibrated.

- Attach the thermocouple bead or junction with high-thermal-conductivity cement to geometric center of the top surface of the package (case).

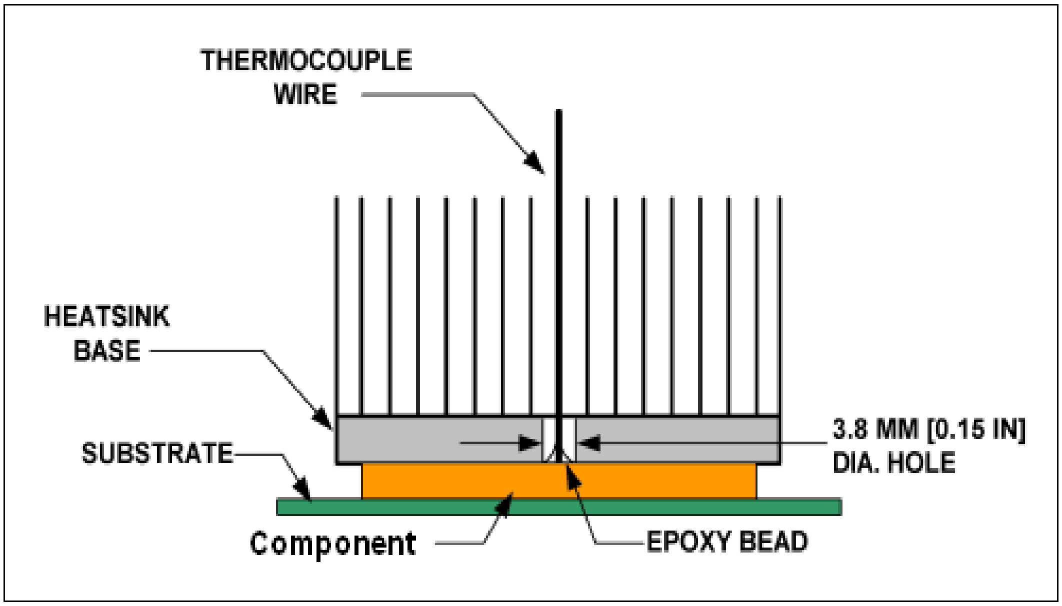
  Note: It is critical that the entire thermocouple lead be butted tightly to the heat spreader.

- If there is no interference with the thermocouple attach location or leads, attach the thermocouple at a 90° angle as shown in Figure 11.

  This is the preferred method and is recommended for use with packages with heat sinks.

- For testing purposes, a hole (no larger than 0.150 in. in diameter) must be drilled vertically through the center of the heat sink to route the thermocouple wires out.
- Ensure there is no contact between the thermocouple cement and heat sink base. Any contact affects the thermocouple reading.

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



6.0 Conclusion

Increasingly complex systems require better power dissipation. 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, passive or active heat sinks, or any combination of those methods.

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

This document has presented the conditions and requirements to properly design a cooling solution for systems implementing the IXP45X/IXP46X product line. Properly designed solutions provide adequate cooling to maintain the IXP45X/IXP46X product line case temperature at or below those listed in Table 1 on page 7. Ideally, this is accomplished by providing a low, local-ambient temperature and creating a minimal thermal resistance to that local ambient temperature. Alternatively, heat sinks may be required if case temperatures exceed those listed in Table 1.

By maintaining the case temperature at or below those recommended in this document, the IXP45X/IXP46X product line should function properly and reliably.

Use this document to understand the IXP45X/IXP46X product line thermal characteristics and compare them to your system environment. Measure the IXP45X/IXP46X product line's case temperatures to determine the best thermal solution for your design.

Appendix A Heat Sink and Attachment Suppliers

Note: This section is only applicable to IXP46X network processors operating at 667 MHz.

Extruded Heat Sink Sales Locations

- Aavid Thermalloy, LLC*
  Phone: (972) 633-9371
  http://www.aavidthermalloy.com/

Heat sink option 1: Thermalloy* Part Number: 374624B60024

Figure 12. Extruded Heat Sink Photo: Option 1

Heat sink option 2: Thermalloy* Part Number: 10-5607-04

Figure 13. Extruded Heat Sink Photo: Option 2

A.1 Attachment Interface Material Sales Locations

See the following Web site for information on the Honeywell line of phase change thermal interface material, particularly the PCM45* line.

http://www.honeywell.com

Appendix B PCB Guidelines

The following general PCB design guidelines are recommended to maximize the thermal performance of HSBGA packages:

1. When connecting ground (thermal) vias to the ground planes, do **not** use thermal-relief patterns.

   Thermal-relief patterns are designed to limit heat transfer between the vias and the copper planes, thus constricting the heat flow path from the component to the ground planes in the PCB.
2. As board temperature also has an effect on the thermal performance of the package, avoid placing the IXP45X/IXP46X product line of network processors adjacent to high-power-dissipation devices.
3. If air flow exists:
   - Locate the components in the mainstream of the air flow path for maximum thermal performance.
   - Avoid placing the components downstream, behind larger devices or devices with heat sinks that obstruct the air flow or supply excessively heated air.

Note: The above guidelines are not all-inclusive and are defined to give you known, good design practices to maximize the thermal performance of the components.

Figure 14. Top View of the Vias with Thermal Relief and Solid Connections

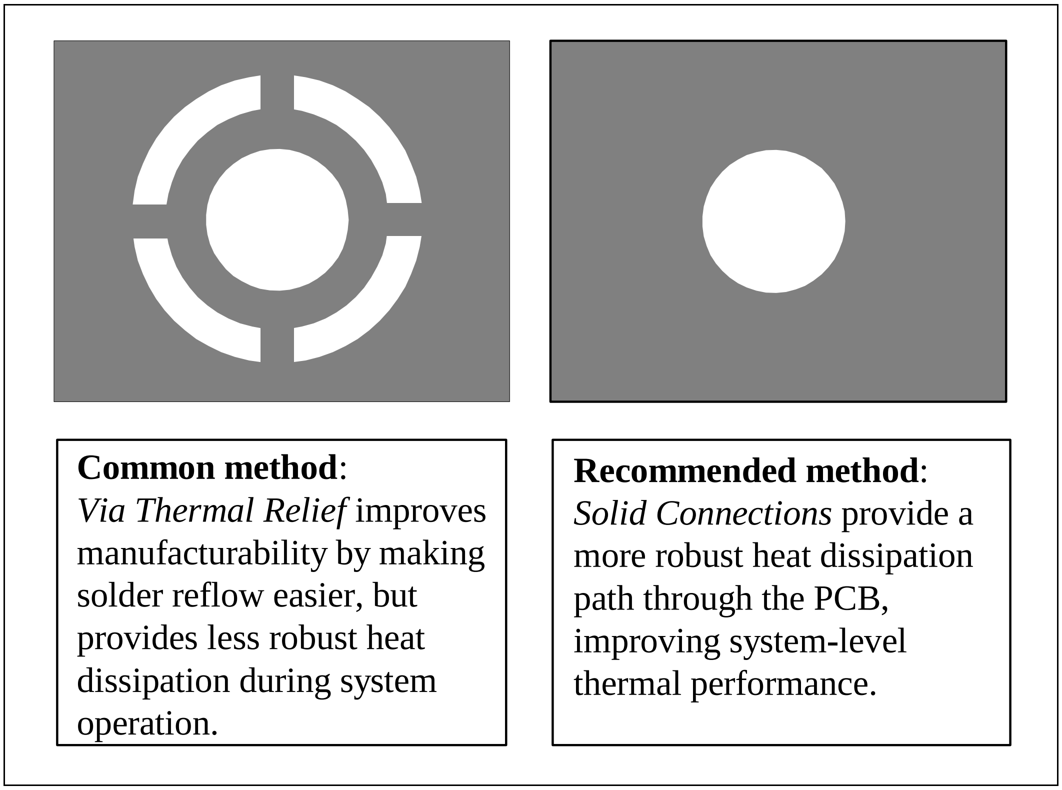
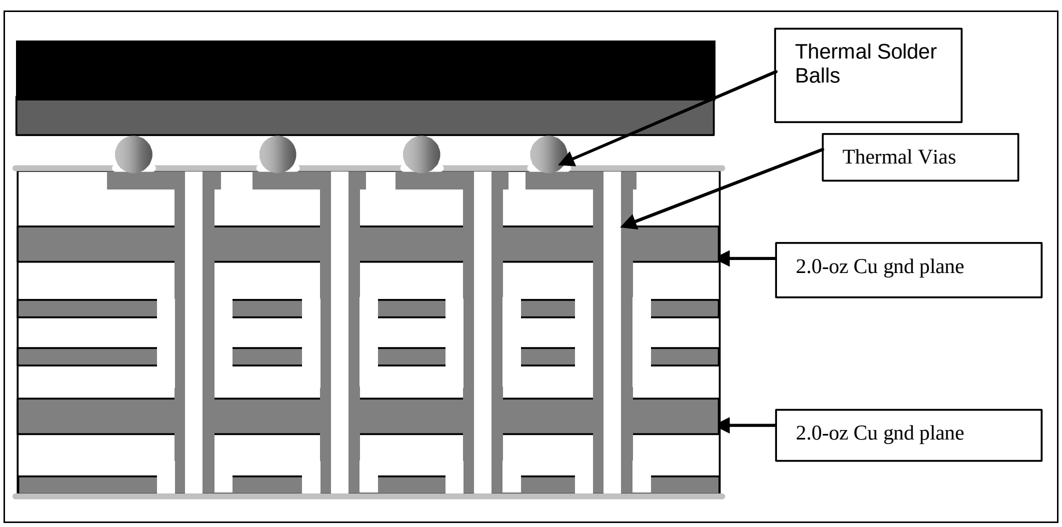


Figure 15. Cross-Sectional View of Recommended PCB Stack-up for Thermal Performance



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