Intel® IXP43X Product Line of Network Processors

Thermal Design Application Note

January 2008

Order Number: 316846; Revision: 003US

Contents

Figures

Tables

Revision History

Date	Revision	Description
January 2008	003	Added Section 3.3.2
December 2007	002	Section 1.1 and Table 1: Removed references to 266 MHz clock speed Section 5.2 and Figure 7: Modified the power dissipation value for Intel® IXP43X Product Line of Network Processors to 3.13W
April 2007	001	Initial release

§ §

1.0 Introduction

This document describes the thermal characteristics for the Intel® IXP43X Product Line of Network Processors.

This document helps you to design a thermal solution for systems implementing the Intel® IXP43X Product Line of network processors with Intel XScale® Processor frequency of 400, 533 or 667 MHz.

Properly designed solutions must provide adequate cooling to maintain the case temperature (T_{CASE}) of the Intel® IXP43X Product Line at or below the values listed in Table 2 on page 9. 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 the temperature exceeds the maximum specified in Table 2. Maintain the case temperature at or below the values recommended in this document to enable proper functioning of the Intel® IXP43X Product Line of Network Processors.

1.1 About This Document

This document contains the following sections:

Section Name	Description
Section 1.0 “Introduction”	Acronyms and terminology, related documentation, product package thermal specification, thermal conditions and considerations, and importance of thermal management
Section 2.0 “Thermal Specifications”	Case temperature specifications and where to find power requirements and thermal packaging techniques of the Intel® IXP43X Product Line
Section 3.0 “Thermal Attributes”	Thermal characteristic data, package mechanical attributes, and package thermal characteristic data of Intel® IXP43X Product Line. Use this section to determine your thermal solution requirements.
Section 4.0 “Measurement for Thermal Specifications”	Guidelines for measuring the case temperature of the Intel® IXP43X Product Line
Section 5.0 “Intel® IXP43X Product Line CRB Thermal Simulation”	System level thermal simulation example
Section 6.0 “Conclusion”	Understanding the thermal characteristics of the Intel® IXP43X Product Line and comparing them to your system environment
Appendix A, “PCB Guidelines”	Recommended PCB design guidelines to maximize the thermal performance of PBGA packages

1.1.1 Intended Audience

The intended audience for this document are system design engineers using the Intel® IXP43X Product Line of Network Processors. 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 will be required to provide better cooling solutions for silicon devices.

1.1.2 Acronyms and Terminology

The following is a list of acronyms and packaging terminology used in this document:

- **Ambient**: Refers to local ambient temperature of the bulk air approaching the component. It can be measured by placing a thermocouple approximately 1" upstream from the component edge.

- **CRB**: Customer Reference Board
- **LFM**: Linear Feet per Minute (airflow)
- **Junction**: Refers to a P-N junction on the silicon. In this document, it is used as a temperature reference point; for example, Θ_{JA} refers to the junction to ambient temperature.
- **PBGA Ball Grid Array**: A surface mount package whose PCB-interconnect method consists of lead-free solder ball array on the interconnect side of the package.

  Note: The PBGA package is rated for commercial temperature for the IXP43X network processors.
- **PCB**: Printed Circuit Board.
- **Printed Circuit Assembly (PCA)**: An assembled PCB.
- **SKU**: Stock Keeping Unit
- **Thermal Design Power (TDP)**: The estimated maximum possible/expected power generated in a component by a realistic application.

  Use estimated maximum power numbers from Table 1.
- Θ_{JA} — A parameter specifying the Junction-to-Ambient thermal resistance, °C/W.
- Ψ_{JT} — A parameter specifying the Junction-to-Package-Top thermal resistance, °C/W. Please do not confuse this parameter with the Junction-to-Case thermal resistance.
- $T_{J\ MAX}$ — Maximum junction temperature, °C.
- T_{CASE} — Case Temperature, °C.
- $T_{CASE\text{-}NO\ HS}$ — Case Temperature with No Heat Sink, °C.

1.1.3 Reference Documents and Information Sources

Document Name or Information Source	Number
Integrated Circuit Thermal Measurement Method-Electrical Test Method	EIA/JESD51-1
Integrated Circuits Thermal Test Method Environmental Conditions - Natural Convection (Still Air)	EIAJESD51-2
Intel® IXP43X Product Line of Network Processors Datasheet	316842
Intel® IXP43X Product Line of Network Processors Developer's Manual	316843
Intel® IXP43X Product Line of Network Processors Hardware Design Guidelines	316844

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 based on the maximum junction temperature and 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	Intel XScale® Processor Frequency	Est. Power (Watts) (TDP)	Θ_{JA}	Ψ_{JT}	$T_{CASE\ MAX}$ †
31mm- 460-PBGA	667 MHz	3.13 W	17.3° C/W	1.6° C/W	106° C
31mm- 460-PBGA	533 MHz	3.08 W	17.3° C/W	1.6° C/W	106° C
31mm- 460-PBGA	400 MHz	3.04 W	17.3° C/W	1.6° C/W	106° C

† Do not exceed this maximum allowable case temperature. This is not the normal operating temperature.

1.3 Thermal Conditions

This document provides a method for determining the junction temperature of the IXP43X network processors 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 IXP43X network processors.

1.4 Thermal Considerations

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

- Local ambient temperature near the component
- Airflow 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
- 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, thermal cooling solution space and airflow 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 the 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 in 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 and/or system damage. Temperatures exceeding the maximum operating limits may result in irreversible changes in the component operating characteristics.

§ §

2.0 Thermal Specifications

The thermal solution must maintain a case temperature at or below the values specified in Table 2 to ensure proper operation and reliability of the IXP43X network processors.

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

Good system airflow is critical to dissipate the highest possible thermal power. The size and number of fans, vents, and/or ducts, and their placement in relation to components and airflow channels within the system determine airflow. Acoustic noise constraints may limit the size and types of fans, vents and ducts that can be used in a particular design.

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

Table 2. Intel® IXP43X Product Line Preliminary Thermal Absolute Maximum T_{CASE} Rating

Parameter	Maximum
$T_{CASE\text{-}NO\ HS}$[1]	106° C

1. $T_{CASE\text{-}NO\ HS}$ is defined as the maximum case temperature without any thermal enhancement to the package.

2.1 Case Temperature

The IXP43X network processors are designed to operate reliably as long as the thermal and electrical specifications provided in this Application Note are not violated. T_{CASE} must never be exceeded. Section 4.1, "Case Temperature Measurements" on page 15 discusses proper guidelines for measuring the case temperature.

2.2 Designing for Thermal Performance

The PCB and system design recommendations required for the IXP43X network processors to achieve thermal performance are documented in Appendix A, "PCB Guidelines" on Page 22.

§ §

3.0 Thermal Attributes

This section describes the thermal attributes of the IXP43X network processors simulated in the environment described in Section 3.1.

3.1 Key Notes to Remember

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

The following system example is used to generate thermal characteristics data:

1. The evaluation board is a four-layer 4 x 4.5 inch PCB
2. No other components are simulated.

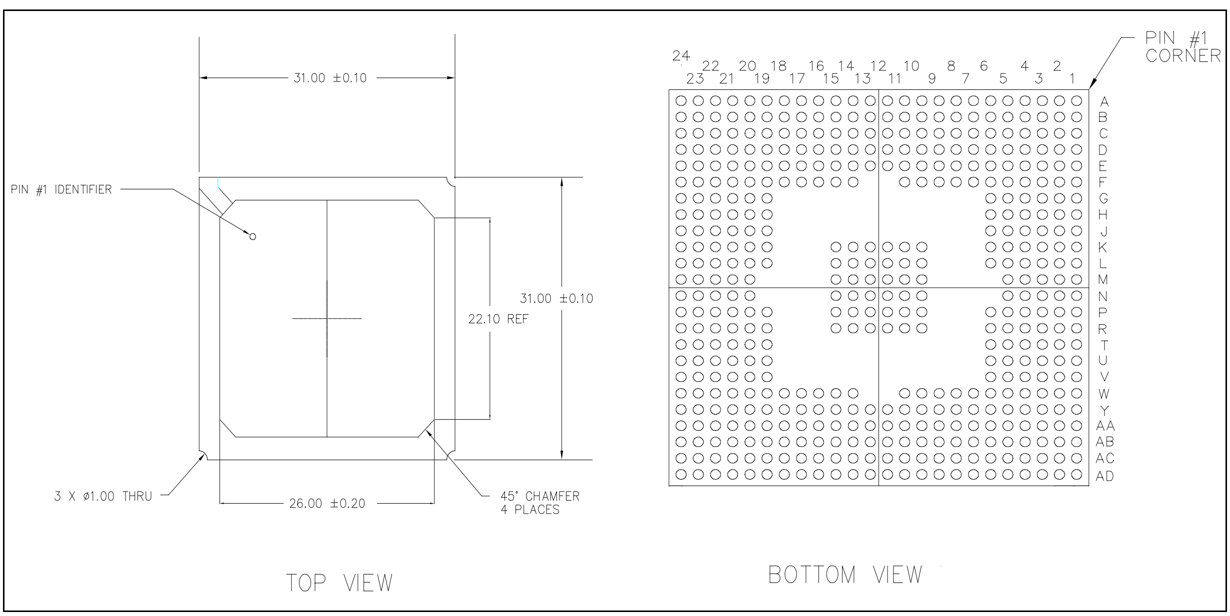
Note:

- All data is preliminary and is not validated against physical samples
- Your system design can be significantly different
- A larger board size with more than six Copper layers can increase the thermal performance of the IXP43X network processors

3.2 Intel® IXP43X Product Line Package Mechanical Attributes

The IXP43X network processors are packaged in a 31mm by 31mm 460 PBGA. The mechanical drawing is shown in Figure 1.

Figure 1. Intel® IXP43X Product Line 460 PBGA Mechanical Drawing (Reference Only)



Note: Refer to the *Intel® IXP43X Product Line of Network Processors Datasheet* for more information on package description.

3.3 Intel® IXP43X Product Line Thermal Attributes

Thermal attributes for the IXP43X network processors are dependent on the processor speed as described in the following sections.

3.3.1 Thermal Characteristics at 667/533 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 3 and Table 4.

The 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 2 and Figure 3 show the maximum local ambient temperature versus airflow for the IXP43X network processors with Intel XScale processor frequency of 667 MHz and 533 MHz respectively.

Figure 2. Maximum Allowable Ambient Temperature vs. Air Flow (667 MHz)

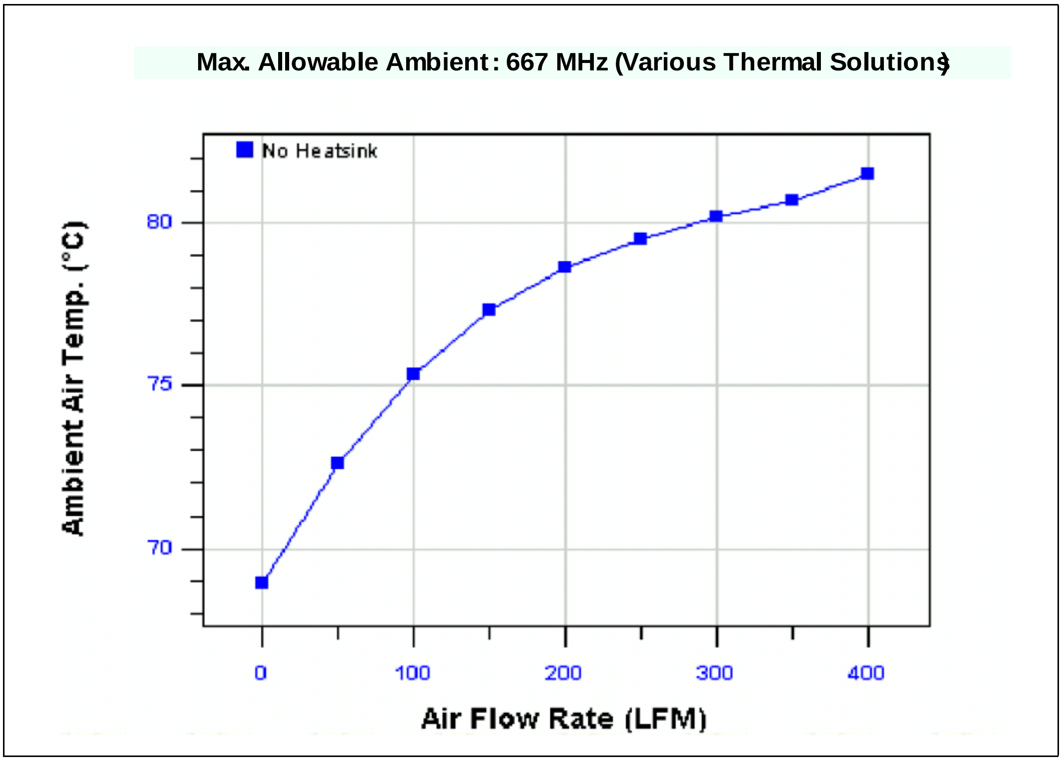


Figure 3. Maximum Allowable Ambient Temperature vs. Air Flow (533 MHz)

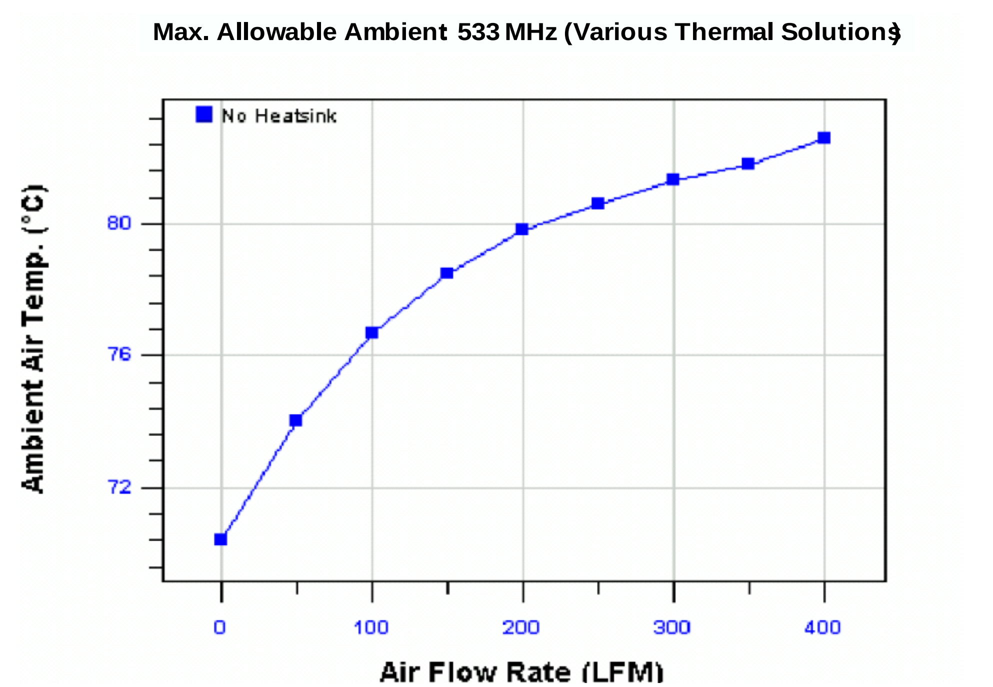


Table 3 and Table 4 show T_{CASE} as a function of airflow and ambient temperature at the TDP for the IXP43X network processors with Intel XScale processor frequency of 667 MHz and 533 MHz respectively. Use the data in these tables to determine the optimum air flow and heat sink combination required to maintain T_{CASE} below $T_{CASE\ MAX}$.

Note: Your system design can vary considerably from the typical system board environment used to generate Table 3 and Table 4.

Table 3. Expected T_{CASE} (°C) for No Heat Sink Attached at TDP (667 MHz)

No Heat Sink Attached					$T_{CASE\ MAX}$ = 106 °C				
Airflow (LFM)	0	50	100	150	200	250	300	350	400
85 °C ambient	124	120	116	114	112	111	110	110	109
80 °C ambient	119	115	111	109	107	106	105	105	104
75 °C ambient	114	110	106	104	102	101	100	100	99
70 °C ambient	109	105	101	99	97	96	95	95	94
65 °C ambient	104	100	96	94	92	91	90	90	89
60 °C ambient	99	95	91	89	87	86	85	85	84
55 °C ambient	94	90	86	84	82	81	80	80	79
50 °C ambient	89	85	81	79	77	76	75	75	74
45 °C ambient	84	80	76	74	72	71	70	70	69

Note: The red-colored values, indicate air flow/local ambient combinations that exceed the allowable case temperature for the IXP43X network processors. See Section 3.1, “Key Notes to Remember” on page 11 for system assumptions.

Table 4. Expected T_{CASE} (^{o}C) for No Heat Sink Attached at TDP (533 MHz)

No Heat Sink Attached					$T_{CASE\ MAX}$ = 106 °C				
Airflow (LFM)	0	50	100	150	200	250	300	350	400
85 °C ambient	122	118	115	113	111	110	109	109	108
80 °C ambient	117	113	110	108	106	105	104	104	103
75 °C ambient	112	108	105	103	101	100	99	99	98
70 °C ambient	107	103	100	98	96	95	94	94	93
65 °C ambient	102	98	95	93	91	90	89	89	88
60 °C ambient	97	93	90	88	86	85	84	84	83
55 °C ambient	92	88	85	83	81	80	79	79	78
50 °C ambient	87	83	80	78	76	75	74	74	73
45 °C ambient	82	78	75	73	71	70	69	69	68

Note: The red-colored values, indicate air flow/local ambient combinations that exceed the allowable case temperature for the IXP43X network processors. See Section 3.1, “Key Notes to Remember” on page 11 for system assumptions.

3.3.2 Thermal Characteristics for Extended Temperature at 667/533 MHz

Simulation result shows that in 85°C ambient (extended temperature), heat sink size of 14 mm x 38 mm x 38 mm (HxLxW) and minimum of 150 LPM airflow is needed to cool the IXP43X network processors.

An equivalent performance heat sink can also be used; for example, 14 mm x 60 mm x 60 mm with natural convection.

Note: It is better to conduct the test on the system so that the T_{CASE} maximum specification does not exceed.

§ §

4.0 Measurement for Thermal Specifications

Accurate case temperature measurements are required to determine the thermal properties of the system. Guidelines for measuring the case temperature of the IXP43X network processors are provided in this section.

4.1 Case Temperature Measurements

The T_{CASE} of the IXP43X network processors must be maintained at or below the maximum case temperature listed in Table 2 on page 9 to ensure functionality and reliability. Special care is required while measuring the case temperature to ensure an accurate temperature measurement.

Use the following guidelines while making the 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

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

4.1.1 Attaching the Thermocouple (No Heat Sink)

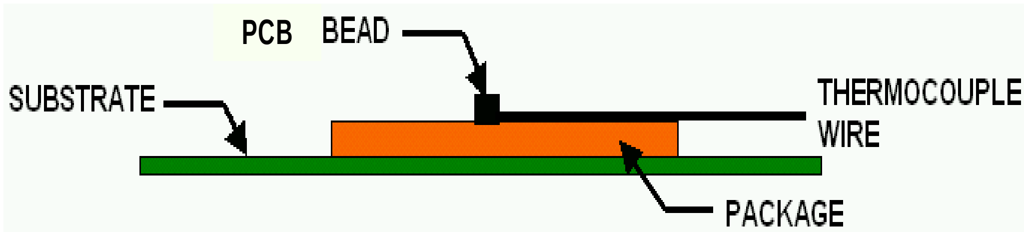
The following approach is recommended to minimize measurement errors while attaching the thermocouple with no heat sink:

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

  Note: It is critical that the entire thermocouple lead be butted tightly to the heat spreader.
- Attach the thermocouple at a 0° angle if there is no interference with the thermocouple attach location or leads. Refer to Figure 4, "Technique for Measuring TCASE with 0° Angle Attachment, No Heat Sink" on page 16.

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

Figure 4. Technique for Measuring T_{CASE} with 0° Angle Attachment, No Heat Sink



§ §

5.0 Intel® IXP43X Product Line CRB Thermal Simulation

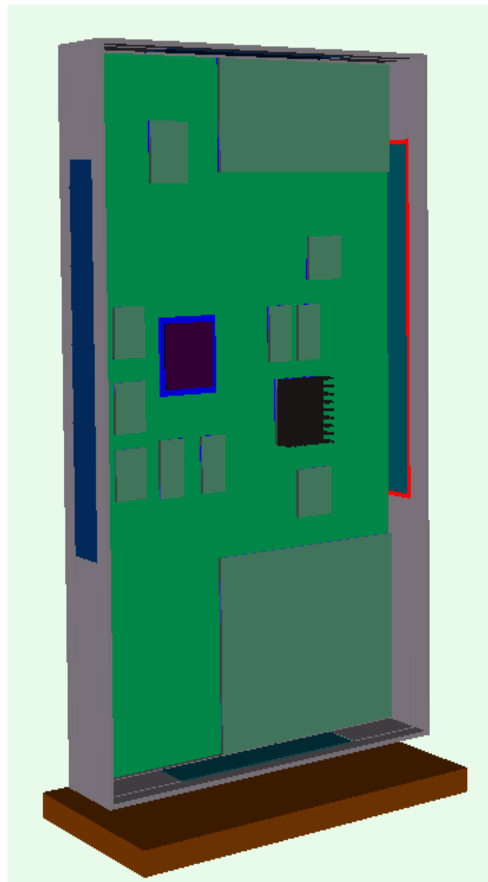
This section provides an example of a system level thermal simulation using a simulated customer reference board to predict the thermal performance of the IXP43X network processors. It provides guidelines on the room ambient requirement based on the board and chassis orientation. The simulation is done based on the components typical power as shown in Figure 7 though the IXP43X network processors are simulated based on the Thermal Design Power (TDP) as defined in Section 1.1.2. The assumptions made during the simulation are:

1. The board is embedded in a chassis of 280 x 180 x 38 mm box.
2. Most of the components are PBGA package and with the size given, 95% of the heat is dissipated into the board.
3. The 4 layer board is 279 x 178 mm, with thickness of 1.6 mm.
4. The chassis is 2 mm thick material with 0.2 W/mK thermal conductivity.
5. The components powers are typical power. The power does not take into account any particular real life application scenario.
6. Maximum Tambient is 50 degree Celsius. In contrast to the local ambient defined in Section 1.1.2; the ambient in this section refers to the room ambient outside the chassis or box.
7. $T_{CASE\ MAX}$ is 106 degree Celsius.
8. The simulation assumed that the maximum junction temperature of other components were not exceeded.

There are two different chassis orientations (Figure 5 and Figure 6) being simulated

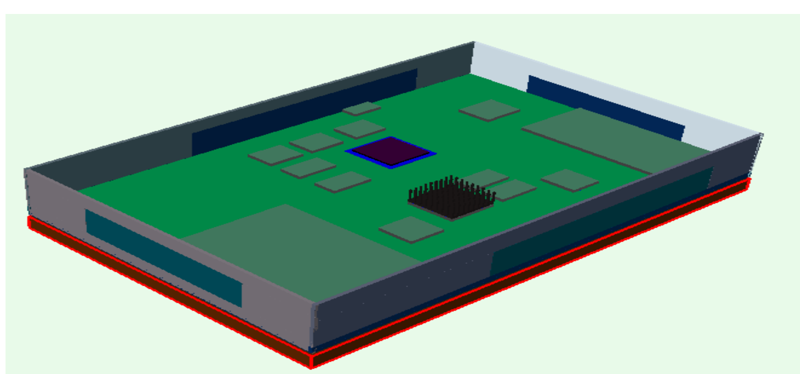
The results shown in this section are based on the conditions and assumption above. Changes to the component layout, power, board size, ventilation hole, chassis dimensions and other factors can change the power dissipation capability of the IXP43X network processors. The farther the IXP43X network processors are from the high power device (in this case the PNX 1700 chip and power circuit), the cooler the chip is.

Figure 5. Chassis Simulated in Vertical Orientation



The chassis consists of two side vents, one top and bottom vent. The ventilation are: 100x20 mm for top, bottom (30% opening), and 100x20 mm for side (50% opening).

Figure 6. Chassis Simulated in Horizontal Orientation

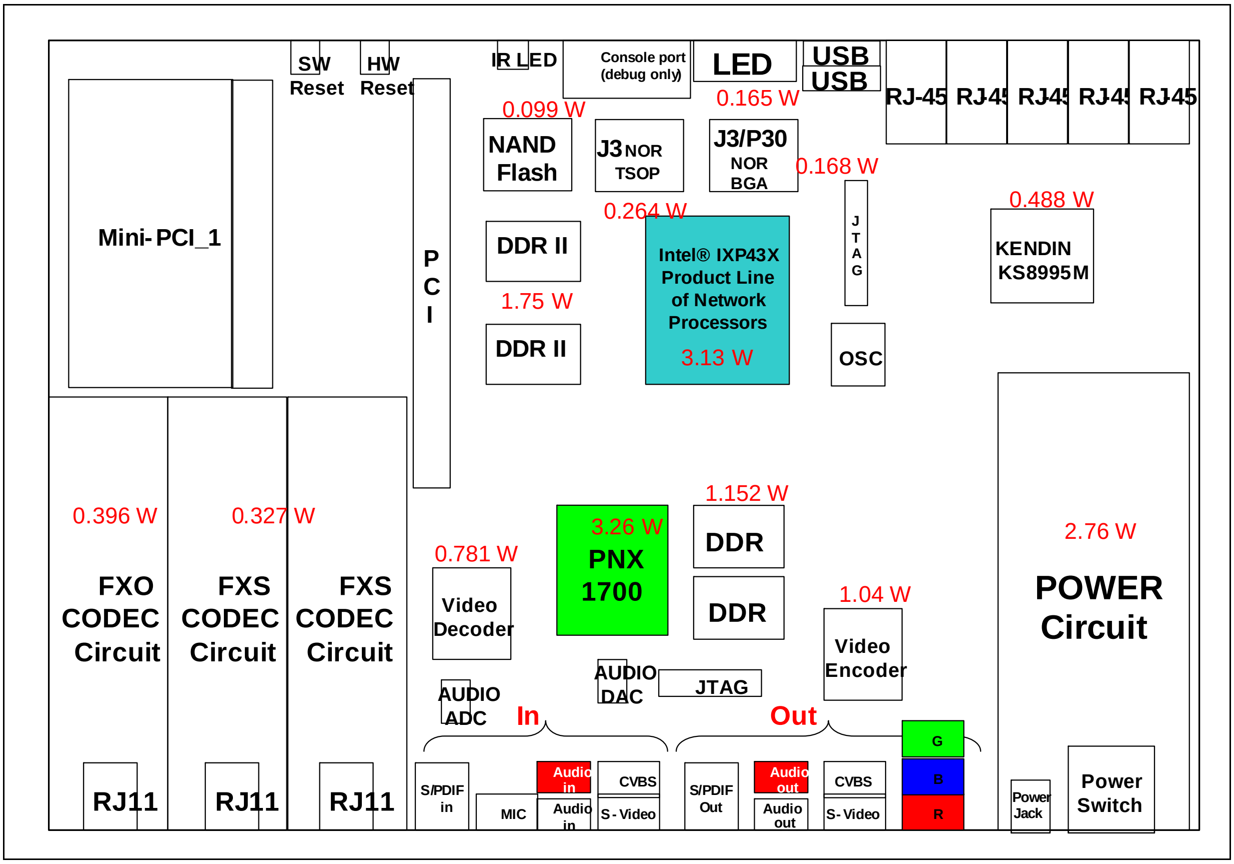


The chassis consists of four side vents and one top vent. The ventilations are 60x60 mm top (30% opening) and 100x20 mm for side (50% opening).

5.1 Power Source on Intel® IXP435 Multi-Service Residential Gateway Reference Platform

Figure 7 shows the estimated power for each component on the IXP435 multi-service residential gateway reference platform.

Figure 7. Power Sources on Intel® IXP435 Multi-Service Residential Gateway Reference Platform



5.2 Simulation Result

The maximum allowable ambient temperature in the horizontal and vertical orientation are shown in Table 5.

For vertical direction, there is no $T_{CASE\ MAX}$ violation to operate up to the maximum power dissipation (3.13W) at maximum room ambient of 50 degree Celsius.

Table 5. Intel® IXP43X Product Line T_{CASE} for Both Vertical and Horizontal Orientation

Room temperature (in Celsius)	T_{CASE} (in Celsius)	
	Horizontal	Vertical
20	83.3	69.6
30	93.3	79.6
40	103.3	89.6
50	113.3	99.6
Note: All measurements are in degree Celsius		

It is recommended to design the system in the vertical orientation to run the IXP43X network processors at room temperature of 50 degree Celsius for this application scenario.

If the system is designed in the horizontal orientation, it is recommended that the room ambient should not exceed 40 degree Celsius.

§ §

6.0 Conclusion

Increasingly complex systems require better power dissipation. Care must be taken to ensure that the additional power is properly dissipated. Heat is dissipated using improved system cooling, selective use of ducting, passive or active heat sinks, or any combination.

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 presented the conditions and recommendations to design a cooling solution for systems implementing the IXP43X network processors. Properly designed solutions provide adequate cooling to maintain the case temperature of the IXP43X network processors at or below those listed in Table 2. 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 2.

You can ensure reliable functioning of the IXP43X network processors by maintaining the case temperature of the IXP43X network processors at or below the recommended measurement in this document.

This document is used to understand the thermal characteristics of the IXP43X network processors and compare them to your system environment. Measure the case temperatures of the IXP43X network processors to determine the best thermal solution for your design.

§ §

Appendix A PCB Guidelines

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

1. While connecting ground (thermal) vias to the ground planes, do not use thermal-relief patterns.
2. 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.
3. As board temperature also has an effect on the thermal performance of the package, avoid placing the IXP43X network processors adjacent to high power dissipation devices.
4. If airflow exists:

- Locate the components in the mainstream of the airflow 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 8. Top View of the Vias with Thermal Relief and Solid Connections

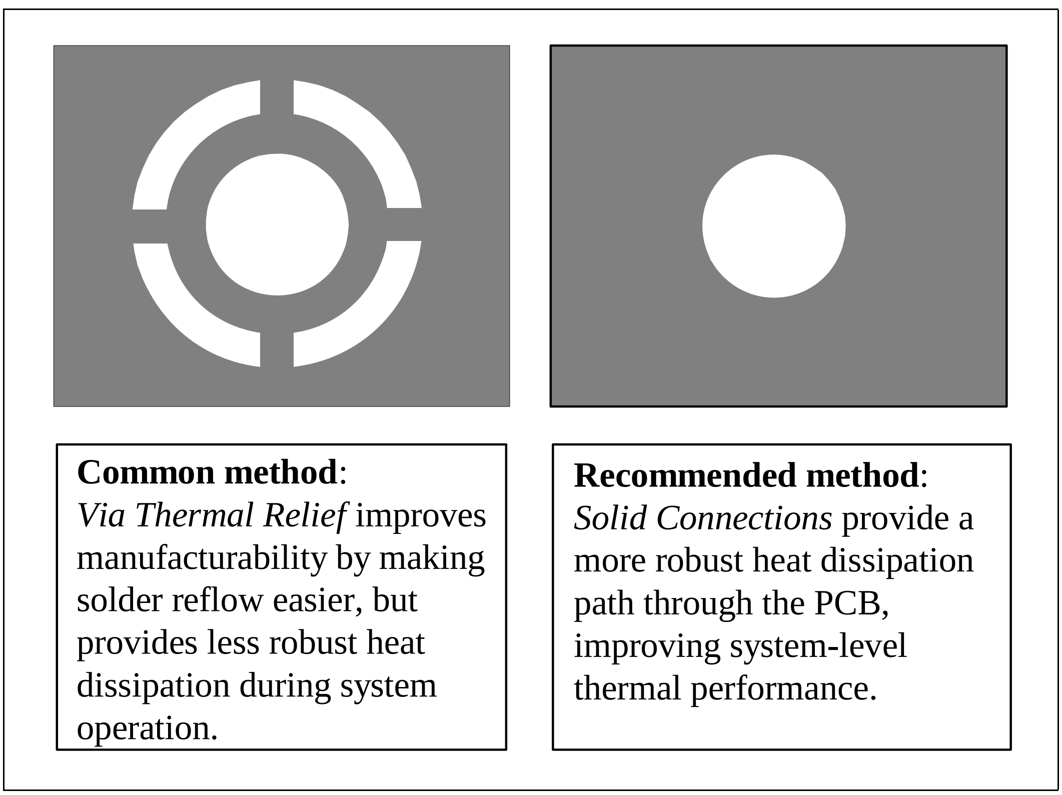
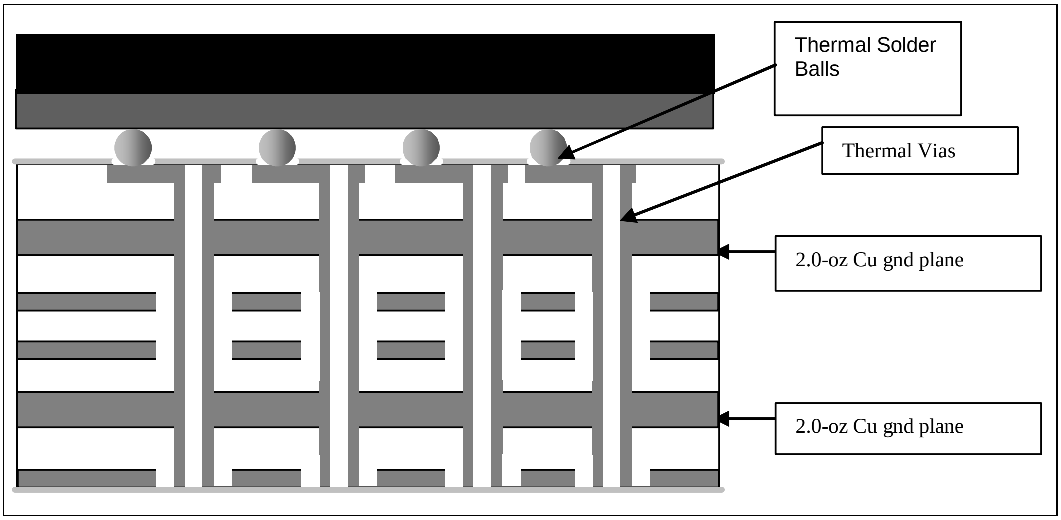


Figure 9. Cross-sectional View of the Recommended PCB Stack-up for Thermal Performance



§ §