System Level Design Considerations for IBM 6x86 Microprocessor Thermal Management

Application Note

Author: Janak G. Patel

Revision Summary: This is the initial release version of this application note.

Introduction

The objective of this application note is to provide tips for efficient thermal management of IBM 6x86 microprocessors at the system level. It is imperative that the user be familiar with the thermal solutions of IBM 6x86 microprocessors by reading document #40209 available on the Faxback service (415-855-4121), as well as on the World Wide Web (http://www.chips.ibm.com), to appreciate the system level design considerations for thermal management of IBM 6x86 microprocessors. Specific solution recommendation is also provided in document #40214. It is the user's responsibility to make the final decision to implement any of the tips since it may involve redesign, logistics, cost, etc.

Actual Microprocessor-Generated Power

The generated power values of the microprocessor at various internal clock frequencies published in the data book and the thermal solution application note are based on a supply voltage of 3.6 volts at the microprocessor pins. The supplied voltage to the microprocessor in an individual system board application can be different depending upon the scheme used by the system board designer (a supply voltage of 3.3 volts can also be chosen). Some system board designers may use a single level of the supply voltage for all components on the board with the supply voltage being provided to the system board from the power supply unit via system board power connectors. The actual supply voltage to the microprocessor in that case may be less than the supplied voltage to the system board due to the drop in the lines.

The drop in the line depends on several factors such as line width of the traces, routing of the traces and the schematics of the system board design. The user can determine the actual supply voltage to the microprocessor by attaching a voltmeter across the Vcc and ground pins of the microprocessor. Several commercially available personal computer application software packages have been evaluated to determine the maximum amount of current drawn by the IBM 6x86 microprocessor. It can be safely concluded at this point that Landmark's** Speed200 version 2.0 draws the maximum amount of current consistently during the run. Note that the amount of current drawn by the IBM 6x86 microprocessor during Speed200 execution varies with time.

The published data on the power values of IBM 6x86 microprocessors was calculated using the maximum value of the current drawn during the Speed200 run and at supply voltage of 3.6 volts. The average current value drawn by the microprocessor or the statistical approach may be used to derive the thermal solution. Some system level thermal engineers may consider the absolute worst case values of the power in order to design the thermal solution. This may provide extra safety due to unknown unforeseen variations in the system level thermal parameters which are beyond control. IBM has chosen the absolute maximum values of drawn current by 6x86 during Speed200 execution. In any event, the main objective of the thermal solution is to keep the case temperature of the package under 70 degrees C.

The supply voltage to the IBM 6x86 may be less than 3.6 volts in various system boards depending upon the scheme employed by the system board designer to provide power to the microprocessor. The amount of drawn current in the microprocessor is also dependent on the supply voltage level. It can be said that with a higher supply voltage, a higher current is drawn. For example, the maximum current drawn by the IBM 6x86 at 3.6 supply voltage in Speed200 application run is 6.05 amp while the maximum current drawn by the IBM 6x86 at supply voltage 3.3 volts in the same application run is 5.32 amp. This means the power generated in the IBM 6x86 at supply voltage 3.3 volts would be 17.56 watts maximum and at supply voltage 3.6 volts would be 21.78 watts maximum. It is clear that running the microprocessor at the lower supply voltage, where it can be applicable, results in lower power consumption. Therefore, it will be easier to manage thermally.

Microprocessor Location

The following configurations are typical industry standards for location of various system components in desktop and tower-type cases. In the desktop cases, the microprocessor can be located in the front left quarter of the system. Next to that, in the front right corner, are the bays for drives such as floppy diskette drive, CD-ROM drive, hard disk drives and back up drive. The power supply unit with an integrated exhaust fan is located in the rear right quarter, and the expansion slots are located in the rear left corner. Vents in the desktop type case are positioned in the lower left corner on the front panel and in the lower rear corner of the left side panel. The desktop type configuration will be used as reference for this paper.

The location of the microprocessor in a tower type case is in the lower front quarter. The bays for the different drives are above the microprocessor in the upper front corner. The power supply with fan is in the upper rear corner and the expansion slots are in the lower rear corner. The vents are located in the bottom front corner of the bottom panel and in the lower rear corner of the left side panel of tower-type cases.

Microprocessor Location with System Fan

IBM 6x86 microprocessor generates heat that must be removed to keep the junction temperature of the die at a predefined limit for proper function and performance in a reliable manner. If the air flow from the system fan is to be utilized to carry the heat away from the surface of the microprocessor, the location of the microprocessor with respect to the fan location is very important. The ideal location for the system fan would be in the left hand side of the front panel. The closer the microprocessor to the fan, the better the air flow over it; the microprocessor can be located up to two fan diameter distances away. If the microprocessor cannot be located near the system fan, ensure that components higher in height than the microprocessor are not placed between the system fan and the microprocessor. Those components can block or reduce the air flow over the microprocessor. Components such as memory SIMMS which are not higher than the microprocessor but are placed between the system fan and the microprocessor may also reduce the air flow over the microprocessor or deflect the air flow possibly resulting in no air flow over the microprocessor. Also note that components which generate high power, such as voltage regulators, should not be placed between the system fan and the microprocessor. These components heat the air prior to air reaches over the microprocessor resulting in the lower thermal performance for the microprocessor.

Multiple System Fans

If more than one system fan is installed, ensure that the resulting air flow does not create a conflict resulting in lower thermal performance or little improvement. Multiple system fans can be installed in several ways. They can be arranged in parallel, mounted side by side on the same panel blowing air in or exhausting the air out of the system chassis. The ideal location for two fans in the parallel configuration is to mount them on the left side of the front panel of the system chassis. They can also be installed on the two opposite side panels of the system chassis. If this is done, you must ensure that a fan mounted on one side is bringing the cold air in from the room while the fan mounted on the other side is exhausting the heated air from the system. Fans placed in opposite sides of the system chassis with both blowing air against each other may not be effective in some cases.

If the system fan cannot utilize cold air from the outside of the chassis, the hot air intake for the fan may result in lower thermal performance. The proper vents in the system chassis are essential to bring in cold air from the room and to remove the heated air from the system back to the room. If adequate vents are not provided for the fan intake air, the performance of the fan may be degraded. The system fan can be flush mounted on the chassis wall with adequate vents. If the system fan is utilized to provide air flow to carry the heat from the components out of the system chassis, it is a good idea to provide a provision to implement a larger system fan for future cooling improvements. The size of system fan can vary from 80 mm to 120 mm. A system fan with the same size but higher output may also be utilized to improve thermal performance. In some instances, a variable speed fan may also be employed to enhance thermal performance. Note that the size, output and the number of system fan can be restricted by the acoustic noise level and the cost.

Microprocessor Location with No System Fan

Bays for Various Drives

Microprocessors in an industry standard case can be located in the front left quarter of the system. However, the microprocessor can be placed where the maximum amount of the air flow may result due to the combination of power supply exhaust fan and the vents in the system chassis. The maximum amount of air flow would occur where the rear end of the front left and right quarters intersect. Selection of a precise location for the microprocessor requires several factors to consider. The microprocessor can be located in such a way that the bays for the various drives, when mounted, do not obstruct or degrade the system air flow over the microprocessor. Some system chassis also come with spare bays for future expansion. Most system chassis come with spare bays for future installation of a hard disk drive, CD-ROM drive, back up drive or floppy diskette drive. Installing additional drives may result in reduced air flow over the microprocessor. Care must be taken to ensure that installation of a drive does not interfere with the external cooling device such as a heatsink or fan/heatsink assembly. The ribbon type of flat signal cables for drives are connected to either the expansion adapter cards or system board. The power cables for the various drives are connected with power supply unit. It is imperative that all cables are tied in such a way that they do not block or reduce the air flow over the microprocessor. If there is no system fan installed, most likely a fan/heatsink assembly would be used to cool the microprocessor. Note that the most fans are rated for 12 volts operation but also work at 5 volts with lower speed. This results in a less air flow over the heatsink. The power supply unit provides several 4 pin connector capable of providing both 5 volts and 12 volts power. Ensure that the fan connectors(male) are connected to the proper connectors(female) of the 4 pin power supply connector. The yellow and black wires of the 4 pin power supply connector provides 12 volts power. If a fan/heatsink assembly is used, ensure that there is at least 0.4 inches clearance on top of the fan for air intake and at least 0.2 inches clearance on the sides to exhaust air from the heatsink fins. A flat ribbon cable could easily block the passage of intake air for the fan/heatsink assembly that may result in the lower thermal performance or little thermal performance.

Expansion Adapter Cards

The microprocessor and expansion slots can be located in such a way that adding full size or half size adapter cards in the slots would not interfere with the heatsink or fan/heatsink assembly or obstruct or reduce the air flow over the microprocessor. If the design of the system board is already completed, arrange the adapter cards such as video card, sound card, fax/modem card, network card or any other expansion adapter card in such a way that they do not interfere with the microprocessor heatsink or fan/heatsink. Each card generates a specific amount of heat. The expansion adapter cards can be arranged in such a way that power density is balanced to avoid any hot spot in the system.

Vents

If the vents are not located properly, the hot air recirculates inside the system and thus lowers the thermal performance. For example, if the vents are located only by the power supply fan, the cold air from the room enters the vents and leaves from the power supply exhaust fan without being routed over the microprocessor or expansion slots adapter cards located on the other side of the chassis. Excessive vents also do not create good air flow over the microprocessor.

Duct

The microprocessor can be located in a way that allows some spare space over and around it to utilize a larger heatsink to meet higher power demand for future upgrade. It may require that the duct be implemented in some situation to utilize the air flow effectively over the microprocessor heatsink fins. It is essential to verify that an air path connected between the microprocessor location and the system fan exists. The shortest air space path would be ideal for the duct implementation because it results in less cost for duct and aids minimizes losses in the duct. The space for a system fan implementation must also be considered.

System Board Design

The generated heat in the die conducts through the package. Most of the conducted heat flows to the top of the package where it comes in contact with an external cooling device such as heatsink or fan/heatsink assembly. A percentage of the heat also flows to the system board through pin conduction. The amount of heat flow to the system board depends upon several factors. The most common and obvious one is the temperature difference between the pin and the system board temperature. The temperature of the system board can be kept low by keeping the heat generated components away from the microprocessor. Since the IBM 6x86 microprocessor has 296 kovar pins, a large amount of heat could flow to the system board and convected off the system board surface areas.

The amount of heat flow to the system board can be increased by improving the thermal conductivity of the system board. This can be done in several ways. The number of power and ground planes significantly influences the thermal conductivity of the system board. It can be said that the more power and ground planes the better the thermal conductivity of the system board. The amount of copper in the plating also improves the thermal conductivity. Increasing from one ounce to two ounces of copper in the plating improves the thermal conductivity significantly, however, the cost of fabricating the system board also increases and the electrical characteristics of the board may change. The easiest way to improve thermal conductivity of the system board in the area of microprocessor vicinity is to increase the percentage of copper coverage. The thermal resistance of the system board in the vicinity of microprocessor area can be reduced by half by simply increasing the amount copper coverage from 5% to 10%. This can be done when the system board is being routed.

Voltage Regulator

A voltage regulator is incorporated in the system board design to provide either 3.3 volts or 3.6 volts to the microprocessor when the system board is supplied with 5 volts power from the power supply unit. It is usually located near the microprocessor to minimize the voltage drop in the line. The line width of the output traces of the voltage regulator are also wider than the rest of the traces to minimize the resistance. The generated power in the voltage regulator can range from 10 watts to 12 watts due to 1.65 volt drop across the voltage regulator and output current range from 6 to 7.5 amperes. This also has to be dissipated to maintain the device temperature within the operating temperature limit. The voltage regulator for this kind of application would most likely be a 3-pin TO-220 package. The junction temperature of the voltage regulator device must not exceed 125 degrees C. The junction to case thermal resistance of this kind of package is about 0.6 degrees C per watt and hence the case temperature can be as high as 118 degrees C. It is imperative that an appropriate external heatsink be utilized to dissipate the generated heat in the voltage regulator to maintain the junction temperature of the device below 125 degrees C.

Most available heatsinks have a provision to attach the heatsink to the system board via the standoff pins and soldered mechanism. Since the temperature difference between the case of the voltage regulator and the system board is much higher, the heat from the voltage regulator may conduct to the system board through the voltage regulator pins and heatsink standoff pins. This-then increases the system board temperature near the microprocessor and reduces the heat flow from the microprocessor to the system board. If an appropriate heatsink for the voltage regulator is selected and the heatsink is not attached to the system board, a less stringent fan/heatsink assembly for the microprocessor can be selected as long as the exhaust air flow from the fan/heatsink is blown over the voltage regulator heatsink effectively. Note that it does not make much difference between parallel fin heatsink and pin fin heatsink if the fan is mounted on top of the heatsink to provide air flow. The parallel fin heatsink provides the greater amount of air flow for voltage regulator heatsink due to the outgoing air flow in two directions are blocked by the parallel fins. The parallel fins of the heatsink of the microprocessor fan/heatsink can be mounted in such a way that the outgoing exhaust air from the parallel fins of the heatsink blows over the voltage regulator heatsink effectively.

Case to Sink Thermal Resistance

A significant improvement in the thermal performance for the microprocessor can be achieved if proper attention is paid to the interface thermal resistance also known as case to sink thermal resistance. Case to sink thermal resistance can be reduced in several ways. The thermal conductivity of the interface attach material can be maximized to reduce the interface thermal resistance. The bond thickness between the case of the package and heatsink bottom surface can be minimized to reduce the interface thermal resistance. The bond area can also be maximized to reduce the interface thermal resistance. Most of the heatsink or fan/heatsink assembly is attached to the microprocessor top surface with some sort of retention clip. It can be said that the more contact pressure between the top of the microprocessor and bottom surface of the heatsink, the less the interface thermal resistance.

A variety of retention clips are available from major heatsink and fan/heatsink suppliers. An appropriate clip can be selected to minimize the interface thermal resistance. Since the top of the microprocessor surface and the bottom of the heatsink surface are neither perfectly flat nor smooth, a small amount of high thermally conductive grease can be dispensed to fill the air gap between the top of the microprocessor and the bottom of the heatsink surface to improve the heat flow path. Care must be taken to ensure that appropriate amount of thermal grease is dispensed becasue excessive theramal grease increases the interface thermal resistance. At higher power dissipation, the significance of the interface thermal resistance is critical.

Summary

The intent of this application note has been to provide information for efficient thermal management of the IBM 6x86 at the system level. Although some of the tips are not applicable to all systems, most can be implemented without significant effort. It is always advisable to carry out the actual thermal measurement by monitoring the case temperature of the microprocessor once you implement any of these tips.

IBM Corporation 1995. All rights reserved.
IBM and the IBM logo are registered trademarks of International Business Machines Corporation. IBM Microelectronics is a trademark of the IBM Corp.
All other product and company names are trademarks/registered trademarks of their respective holders. 1995 IBM Corp.

The information contained in this document is subject to change without notice. The products described in this document are NOT intended for use in implantation or other life support applications where malfunction may result in injury or death to persons. The information contained in this document does not affect or change IBM's product specifications or warranties. Nothing in this document shall operate as an express or implied license or indemnity under the intellectual property rights of IBM or third parties. All the information contained in this document was obtained in specific environments, and is presented as an illustration. The results obtained in other operating environments may vary.

THE INFORMATION CONTAINED IN THIS DOCUMENT IS PROVIDED ON AN "AS IS" BASIS. In no event will IBM be liable for any damages arising directly or indirectly from any use of the information contained in this document.

The following are trademarks of the IBM Corporation in the United States or other countries or both:
IBM OS/2
6x86 is a trademark of Cyrix Corporation
Other company, product or service names, which may be denoted by a double asterisk (**), may be trademarks or service marks of others.