Thermal Design Guidelines for the IBM 6x86LV Microprocessor in Mobile Computers

Application Note

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Revision Summary: This is the initial release of this Application Note.

X86 applications notes and databooks can be found on the website at
http://www.chips.ibm.com/products/x86

Introduction

This application note provides typical average power, average maximum power, and absolute maximum power generated by the IBM 6x86LV™ processor[1] at low supply voltage for various internal clock frequencies. The typical average power is useful to estimate the battery life of the mobile computer. The average maximum power is to be used for thermal design. The absolute maximum power can be used to design power supply for the microprocessor. Several thermal solutions, such as heatsink and heatpipe, are provided for a typical maximum operating room temperature of 35° C (95° F) and natural convection condition. Some useful mechanical information for the socket in which the IBM 6x86LV processor to be plugged are provided for layout and thermal solution estimation.

Power

The generated power in the IBM 6x86LV processor was measured with a specially designed socket. This socket blocks the system board power supply to the microprocessor. An external power supply unit provided the precisely measured separate supply voltages to the core and the I/O of the processor. The currents drawn by the core and the I/O of the IBM 6x86LV processor were measured with tapped ammeters. The sense lines were incorporated from the processor's voltage pins to the external power supply unit to compensate for the voltage drops in the lines from the external power supply unit to the microprocessor's voltage pins. It was previously determined that Landmark's Speed200 Version 2.0 drew the maximum amount of current during its execution.

The supply voltage to the I/O of the IBM 6x86LV processor in each measurement was set at 3.3 volts. The amount of current drawn by the I/O during the Speed200 execution was very low. *Table 1* on the following page provides the values of the average typical power, the average maximum and the absolute maximum generated power in watts for various internal clock frequencies (in MHz) of the IBM 6x86LV processor. The average typical power generated in the IBM 6x86LV processor is about 15% less than the average maximum power generated during Speed200 execution. The value of the typical power generated in the microprocessor was calculated by running 20 typical application software packages, such as word-processing, spreadsheet, database, business graphics and utility, in the typical operating systems and at nominal supply voltage. However, the thermal solution must be designed for the average maximum power dissipation. The average maximum power dissipation is measured at nominal supply voltage and executing Landmark's Speed200 Version 2.0. Note that the absolute maximum power values to be used for power supply design are 10% higher than the average maximum power dissipation values. The absolute maximum power is measured at worst-case or maximum supply voltage and executing Landmark's Speed200 Version 2.0.

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[1] The IBM 6x86LV (low-voltage) Microprocessor is designed by Cyrix Corp., and manufactured by IBM Microelectronics

PR Rating	Internal Clock Freq. (MHz)	Ave. Typical Generated Power (Watts) when Core Supply is 2.45 V.	Ave. Max Generated Power (Watts) when Core Supply is 2.45 V.	Absolute Max. Generated Power (Watts) when Core Supply is 2.665 V.
PR 150	120	7.91	9.3	11.2
PR 166	133	8.42	9.9	12.1
PR 200	150	9.37	11	13.2

Table 1. Generated Power Values of the IBM 6x86LV processor at Various Internal Clock Frequencies.

Case-to-System Ambient Thermal Resistance

The case-to-system ambient or external thermal resistance is obtained by first subtracting the system ambient temperature in degrees C (° C) from the case temperature of the IBM 6x86LV processor in ° C and then dividing the resultant difference by the average maximum generated power in watts. Thus, the unit of thermal resistance would be ° C per watt. The case temperature is measured at the center of the top surface of the package as shown in *Figure 1* and the system ambient temperature is the temperature of the air surrounding the microprocessor. The ambient temperature referred to in this application is the same as the system ambient temperature. The case temperature of the IBM 6x86LV processor must not exceed 85° C during its operation. *Table 2* provides the values of the required case-to-ambient thermal resistance for various system ambient temperatures to meet 85° C case temperature specification of the IBM 6x86LV processor.

PR Rating	Internal Clock Frequency (MHz)	System Ambient Temperatures:			
		at 35° C	at 40° C	at 45° C	at 50° C
PR 150	120	5.37	4.84	4.30	3.76
PR 166	133	5.05	4.55	4.04	3.54
PR 200	150	4.54	4.09	3.63	3.18

Table 2. Required Case-to-Ambient Thermal Resistance at Various System Ambient Temp. and Internal Clock Freq. at 2.45 V Core Supply Voltage to the IBM 6x86LV Processor.

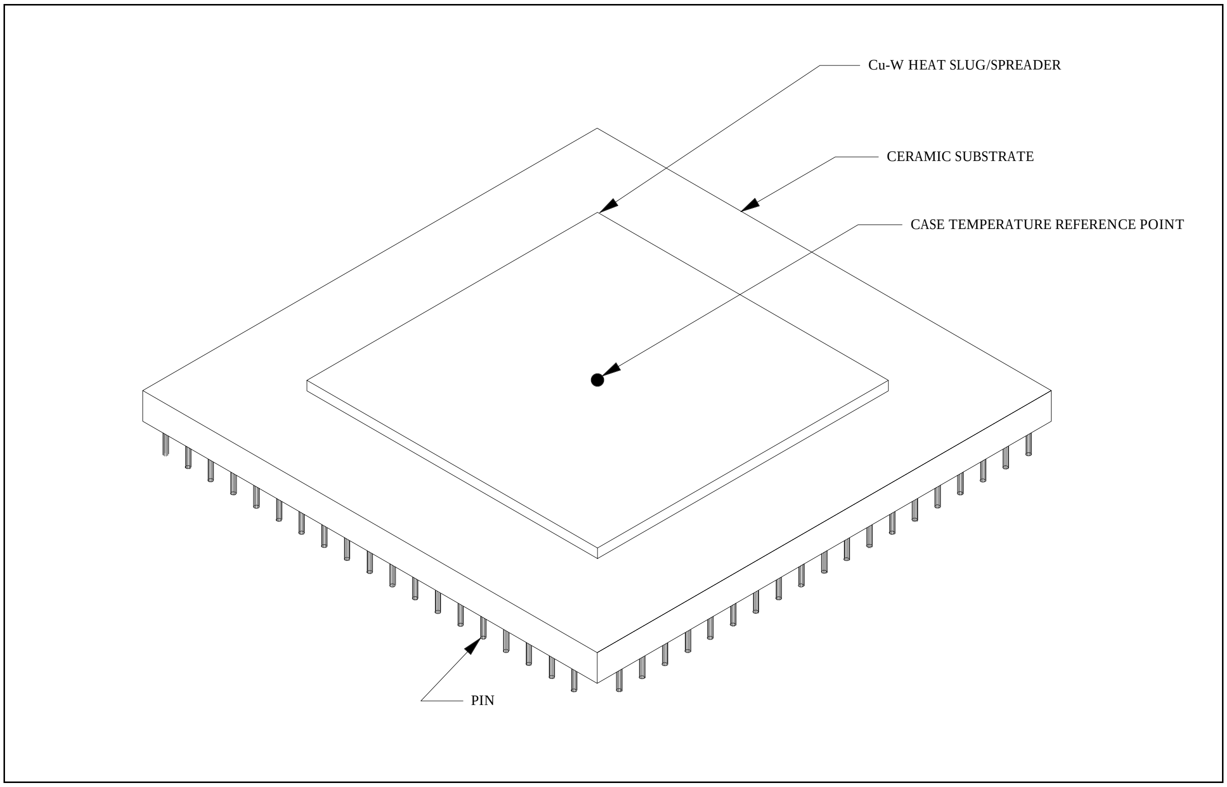

Figure 1. 296 Pin Ceramic Pin Grid Array w/ Cu-W Heat slug and spreader IBM 6x86LV Module.

As you can see from *Table 2*, the required maximum case-to-ambient thermal resistance for the best case is 5.37° C/W and the 296 Pin CPGA with Cu-W heat slug and spreader module's total thermal resistance is more than 5.37° C/W. Therefore, an external heat sinking device (such as a heatsink or heatpipe/heatsink combination) is needed to achieve the required case-to-ambient thermal resistance. Note that the higher the required case-to-ambient thermal resistance for a given internal clock frequency of the microprocessor and the system ambient temperature, the less stringent are the requirements on the thermal solution.

The external heat sinking device is attached to the top surface of the IBM 6x86LV processor. The case-to-ambient thermal resistance is now the sum of the case-to-sink thermal resistance and the sink-to-ambient thermal resistance. The value of the case-to-sink thermal resistance depends on attachment parameters such as thermal conductivity of the bonding material, the thickness of the bond, the effective area of bonding and the contact pressure applied to the bond. Neither the top surface of the IBM 6x86LV processor nor the bottom surface of the heat sinking device is perfectly flat. Hence, a small amount of thermally conductive grease is dispensed between these surfaces to fill the air gap and to create a proper thermal path from the case to the sink.

A mechanical fastening device, such as a clip or a spring, is usually employed to provide contact pressure to the bond and mechanical strength to the assembly to sustain shock and vibration. However, in mobile computers, the mechanical fastening device may not be implemented due to the space constraint in some situations.

The typical value for the case-to-sink thermal resistance for the IBM 6x86LV processor can usually range from 0.1 to 0.2° C per watt. Subtracting case-to-sink thermal resistance from the given value of the case-to-ambient thermal resistance in *Table 2* yields a required sink-to-ambient thermal resistance for a given internal clock frequency and a core supply voltage of the microprocessor. The estimated case-to-sink thermal resistance using a thermal grease with thermal conductivity of 0.7 Watts/meter - °K and the bond thickness of .004" (0.1016 mm) with 100% of 31.75 mm X 31.75 mm area utilized is 0.15° C/W.

Although the thermally conductive grease with a mechanical retention clip method is referenced here for the heatsink attachment to the IBM 6x86LV processor, the user may employ any other method, such as thermally conductive epoxy or the double sided adhesive tape, to attach the heatsink to the IBM 6x86LV processor. However, the value of case-to-sink thermal resistance may be higher and therefore the sink-to-ambient thermal resistance of the heat sinking device has to be lower to compensate the higher case-to-sink thermal resistance. Note that the IBM 6x86LV chip carrier module shown in *Figure 1* is usually plugged into an industry standard socket 7 on the mother board designed for dual rail supply voltages. The socket 7 usually provides tabs for thermal solution attachment.

It may be noted that the system ambient temperature is usually 10° to 15° C higher than the room temperature due to the absence of the system fan and reduced ventilation in mobile computers.

Heatsinks

The heatsink is characterized by the sink-to-ambient thermal resistance in ° C per watt. The smaller the value of the sink-to-ambient thermal resistance of a heatsink, the better the heat dissipation capacity of the heatsink. A smaller value of the sink-to-ambient thermal resistance of a heatsink can be achieved by increasing either the surface area of the heatsink or the air flow over the heatsink surface area. However, the forced air flow is not available in the mobile computer so the thermal performance of the heatsink can be increased by adding more surface area on the heatsink. Although the forced air flow is not available in the mobile computer, a small amount of air flow is created around the fins depending upon the fin configuration of heatsink due to the air molecules around the fins gaining the dissipated heat energy.

The amount of surface area of a heatsink is a function of the volume it occupies. Increased volume can provide an increase of surface area of the heatsink. The available volume for the heatsink varies from system to system depending upon the layout of system components. Since the IBM 6x86LV processor would be plugged into a socket 7, the area of the socket 7 can be considered as the best available area for the heatsink in a worst case situation. The socket 7 has a minimum area of 55 mm (2.16") X 62 mm (2.44"). Thus, the best available area for the heatsink would be 55 mm (2.16") X 62 mm (2.44") in a worst case situation. The available height can vary from system to system depending on the layout of the system components and the height of the socket 7 from the PCB seating plane to the 296 pin CPGA IBM 6x86LV processor's seating plane on socket 7. Since mobile computers are compact in size, especially in thickness, the available height for the thermal solution is very much constrained.

Figure 2 shows a portion of cross section showing the possible height available for thermal solution. It is imperative that at least a small amount of free space be kept for thermal solution implementation in a worst case situation. The heatsink suppliers usually provide the various heights for a given area of an extruded or a pin fin heatsink.

Socket 7

Note that the low profile zero insertion force(ZIF) socket 7 such as part numbers 916657-1, 916657-2 and 916657-3 of AMP, Inc. has 5.41 mm (.213") height from the PCB seating plane to the 296 pin CPGA module's seating plane on socket 7. This low profile socket allows not only additional space for the thermal solution but also helps reduce the overall weight of the mobile computer. Another low profile socket 7 style part number, 390094-1 of AMP, Inc. has 4.78 mm (.188") height from the PCB seating plane to the 296 pin CPGA module's seating plane on socket 7. However, this socket 7 is not ZIF style, insertion and extraction forces are required to plug and unplug the microprocessor. You may contact the supplier directly for detail mechanical specification, availability and cost of low profile socket 7. The intent of providing this information is not to endorse or qualify the supplier or their products but to show the user available option for better product design. It may also be possible that the product better than mentioned here may be available from other supplier.

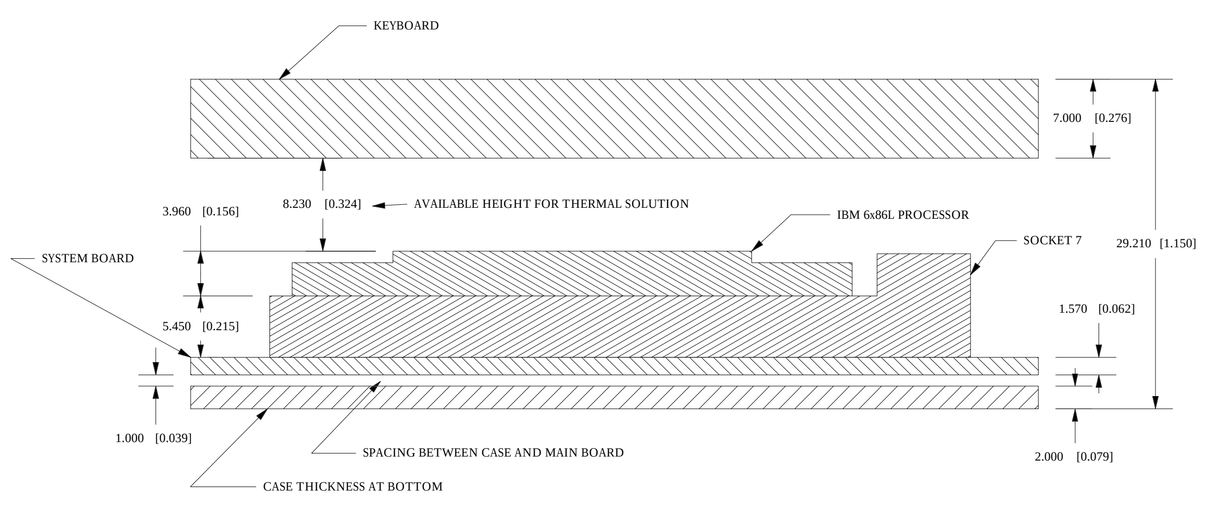

Figure 2. A portion of a cross-section of possible mobile computer showing IBM 6x86LV processor.

Figure 2 shows a portion of a cross-section of a typical mobile computer showing IBM 6x86LV processor. The mobile computer's thickness usually ranges from about 1" to 1.25". In *Figure 2*, it is assumed that the thickness of mobile computer is 1.15". The case, system board and keyboard thickness are also typical values. However, it can vary from system to system. The intent of showing this cross-section is to assist the system designer estimate the height of the thermal solution. The system designer may also note that components taller than the combined height of socket 7 and the IBM 6x86LV processor should be kept away from the socket 7 to accommodate a heatsink larger than socket 7 area. Note that all the dimensions are in millimeters with dimensions in brackets in inches.

As shown in *Table 2*, the required sink-to-ambient thermal resistance spreads from 3.03 to 5.22° C per watt for the processor at various internal clock frequencies and system ambient temperatures.

Once the information on the required sink-to-ambient thermal resistance (for a given internal clock frequency and the system ambient temperature, obtained from *Table 2*) and available volume for a heatsink (obtain from the system design) are determined for the IBM 6x86LV processor, the search for the suitable heatsink can be performed through the heatsink suppliers' catalogs. The heatsink suppliers provide the sink-to-ambient thermal resistance and the mechanical specifications for their products. An appropriate heatsink, which can meet both thermal and mechanical requirements, can be chosen from any heatsink suppliers' catalogs. The mobile computer is usually compact in size especially in terms of its thickness or height, the selection of heatsink is limited to a thinner heatsink. *Table 4* provides some example heatsinks for possible thermal solution of IBM 6x86LV processor in the mobile computer. The user may contact the suppliers for the detail mechanical specifications, availability and cost of heatsinks.

Table 3 provides the approximate heatsink surface area required for various internal clock frequencies of the IBM 6x86LV processor and system ambient temperatures. The purpose of providing this estimated surface area is to assist the system integrator with custom heatsink design, if an off-the-shelf heatsink cannot be found for their particular system design. Mobile computers are compact and light in weight and hence the weight control is important. The mobile computer layout varies from one system designer to another. The system designer sometimes would be able to utilize the other parts of the design to dissipate the microprocessor's heat. In such situations, the surface area of other system parts can be estimated from their mechanical specifications. The required surface area for the microprocessor heatsink then can be estimated based upon the available system parts surface area.

The weight of the mobile computer usually ranges from 6 to 8 lb.. As a rule of thumb, the weight of the thermal solution should be about 2-3% of the total weight and should not exceed 5% of the total weight of the mobile computer. Note that the performance of a heatsink depends upon not only the surface area but also the configuration of the heatsink and the system design. The same heatsink may perform differently on different system designs. It is the user's responsibility to verify the final heatsink solution in their own system by monitoring the case temperature of IBM 6x86LV processor. The case temperature of the IBM 6x86LV processor must not exceed 85° C. It is also essential that the outer skin temperature of the mobile computer be monitored. The outer skin temperature must not exceed 50° C for user's safety and comfort.

PR Rating	Internal Clock Frequency in MHz	Minimum Required Surface Area of Heatsink in Square mm for a System Ambient Temperature			
		at 35° C	at 40° C	at 45° C	at 50° C
PR 150+	120	19,200	21,300	24,100	27,700
PR 166+	133	20,400	22,700	25,700	29,500
PR 200+	150	22,800	25,400	28,800	33,000

Table 3. Minimum required surface area of heatsink in square mm for various system ambient temperatures and internal clock frequencies of IBM 6x86LV processor.

Table 4 provides some selected example heatsinks from major heatsink suppliers. The sink-to-ambient thermal resistance, weight and dimensions are obtained from the respective suppliers' catalogs. The user may contact the supplier for detail mechanical, thermal specifications, availability and cost of these heatsinks. Note that these heatsinks are larger than the socket 7 area which makes the mechanical fastening device, such as a clip or spring, unemployable unless the heatsinks are modified to facilitate the attachment to the socket 7 tabs. An alternative method such as heatsink attachment to the system board using four holes in the corners of the heatsink and corresponding four holes on the system board with mechanical retention clip or fastening device can be employed. The sink-to-ambient thermal resistance values may be different in the user's particular system design. It's the user's responsibility to verify the performance of the heatsink by monitoring the case temperature in their own system.

Heatsink Vendor	Part Number	Overall Dimension LXWXH in mm (inches)	Sink-to-Ambient Thermal Resistance in °C/W	Weight of Heatsink in gms.(lb.)
Aavid	61585	101.6 (4") X 76.2 (3") X 7.62 (.3")	3.3	79.4 (.175)
Thermalloy	19318	121.92 (4.8") X 76.2 (3") X 6.1 (.24")	3	86.2 (.19)
Thermalloy	19631	100.33 (3.95") X 76.2 (3") X 6.1 (.24")	3.2	74.9 (.165)
Wakefield	4434-P1	101.6 (4") X 76.2 (3") X 7.62 (.3")	3	62.4 (.1375)

Table 4. Example of some selected heatsink from major heatsink suppliers.

When the space required to accommodate heatsink surface area is not adequate, an alternative thermal solution such as heatpipe in conjunction with heatsink can be used.

Heatpipe

A heatpipe is a device which transports the heat from the source to a remote area effectively. As the name implies, the heat is carried from the heat source via pipe to a remote area where the heat is removed. The pipe is usually made of commonly used metal such as copper or stainless steel. The medium used to transport the heat inside the heatpipe is usually a small amount of liquid such as water, ammonia, acetone and methanol etc. The pipe is vacuumed first and then the heat transfer medium is filled at lower pressure in the pipe and the whole assembly is sealed.

The liquid medium at the heat source end evaporates once heated up and the liquid is changed into a vapor. Now, due to pressure differential built up in the heatpipe, the vapor travels toward the cooler, other end of the heatpipe. The heat is dumped at the cooler end of the heatpipe to ambient or to a heatsinking device. The vapor changes into a liquid state and travels back to the heat source end by built-in capillary action. The heatpipes do not require an external power and thus are considered passive devices. The heatpipes do not require maintenance and reliability is excellent. The heatpipe can work against gravity due to built-in capillary device.

Table 5 provides information on some selected example heatpipe assemblies from a major heatpipe supplier. The thermal plate-to-ambient thermal resistance of these example heatpipe assemblies are 3.8 °C and 4.2 °C per watt. The thermal plate-to-ambient thermal resistance is the sum of thermal plate-to-heatpipe, heatpipe and fin-to-ambient thermal resistances. Note that the value of case-to-ambient thermal resistance of these example heatpipes may be higher due to the case-to-thermal plate and the thermal plate's thermal resistances are not accounted in the above values. The case-to-thermal plate thermal resistance is the same as case-to-sink thermal resistance and the typical value can range from 0.1 to 0.2 °C/W. The thermal plate resistance depends upon the material, thickness and the cross sectional heat transfer area and can be considered negligible if the thermal conductivity of the material is high and the thickness of the thermal plate is reasonable. The values of these thermal resistances of heatpipe assemblies are obtained from the heatpipe supplier's product data guide and may differ in a particular system. It is the user's responsibility to verify the value in their particular configuration. The user may select one from *Table 5* or any other comparable heatpipes, not listed here, which fits in their system layout and is able to keep the case temperature within 85° C. The heatpipe supplier may also offer custom heatpipe solutions. The user may directly contact the supplier for detail thermal, mechanical specification, availability and cost of heatpipe solution.

Vendor	Part Number	Overall Size of Assembly LxWxH in mm (inch)	Thermal Plate-to-Ambient Therm. Resistance in C/W	Weight of Heatpipe Assembly in gms.
Thermacore[2]	HSNB1A1	219 (8.62) X 80 (3.15) X 5 (.2)	4.2	41
Thermacore	HSNB1A2	219 (8.62) X 80 (3.15) X 5 (.2)	4.2	41
Thermacore	HSNB1A3	279 (10.98) X 100 (3.94) X 5 (.2)	3.8	61
Thermacore	HSNB1A4	279 (10.98) X 100 (3.94) X 5 (.2)	3.8	61

Table 5. Part Number, Size, Thermal Resistance and Supplier of heatpipe for the IBM 6x86LV Microprocessor

As you can see from *Tables 2 and 5*, for both PR150 and PR166 IBM 6x86LV microprocessors with maximum system ambient temperature of 45 °C, either HSNB1A3 or HSNB1A4 heatpipe assemblies can be used as a thermal solution. The worst case required case-to-ambient thermal resistance for PR166 occurs at system ambient of 50° C and is 3.54 °C/W as shown in *Table 2*. Reviewing the thermal resistance data of heatpipe assemblies in *Table 5*, it can be safely said that the heatpipe assemblies larger than the last two of *Table 5* may yield a thermal resistance lower than 3.5 °C/W which can meet the worst case requirement. You can also see from the last column of *Table 5* that the weight of the thermal solution is less than 3% of the overall weight of average mobile computer.

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[2] Product Data Guide. Thermacore, Inc. July, 1996

It is the customer's responsibility to decide which thermal solution is appropriate for their product. The intent of providing the information contained in this application note is not to endorse or qualify the supplier or their products but to assist one in selecting an appropriate thermal solution for the IBM 6x86LV processor in a notebook computer. It is beyond our scope to present each supplier's product. A list of major heatsink suppliers is provided in *Appendix A* and a list of heatpipe suppliers is provided in *Appendix B* for reference. Other heatsink and heatpipe suppliers not listed here may offer products better suited to your needs.

Voltage Regulator

It would be an ideal situation if the system board could provide both core supply voltage of 2.45 volts and I/O supply voltage of 3.3 volts to the IBM 6x86LV microprocessor. However, it may not be practical to provide these supply voltages in most situations. The system board usually provides higher supply voltages and hence the supply voltages for the microprocessor have to be stepped down to the desired values. The voltage regulators can effectively step these voltages down to a desirable point. Two types of voltage regulators are usually used to accomplish this task: Linear and Switching. The linear regulators dissipate more heat and hence additional thermal management. This translates into more cost and weight. It is desirable that the use of linear regulators be avoided in the notebook computer. Switching regulators do not dissipate as much heat and hence can be managed more easily from a thermal stand point of view.

Summary

This application note provides power values of the IBM 6x86LV processor for notebook computers and the required case-to-ambient thermal resistances for thermal solutions of the processor at various internal clock frequencies. The thermal and mechanical characteristics of a few heatpipes were presented. Although the information to implement a thermal solution for the IBM 6x86LV processor in a mobile computer was presented in this application note, it is strongly recommended that the final verification of a chosen thermal solution be carried out by monitoring the case temperature of the processor in the user's system. The case temperature of the IBM 6x86LV processor must not exceed 85^o C.

References

1. The IBM 6x86LV Microprocessor Databook *(available on the x86 website, see address below)*
2. Application note #40209: *Selection of Appropriate Thermal Solution for IBM 6x86 Microprocessors*
3. Application note #40214: *Heatsink and Fan/heatsink For IBM 6x86 Microprocessor*
4. Application note #40216: *System Level Design Considerations for IBM 6x86 Microprocessor Thermal Management*
5. Application note #40223 *System Board Component and Peripheral Device Temperature Measurements of Personal Computers with the IBM 6x86 Microprocessor*
6. Application note #40253 *Thermal Solutions for IBM 6x86MX Microprocessor*

These application notes can be downloaded from the World Wide Web at:
http://www.chips.ibm.com/products/x86.

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Appendix A: Heatsink Suppliers

Aavid Thermal Technologies
One Kool Path
P.O. Box 400
Laconia, NH 03247
Telephone (603)528-3400
Fax (603)528-1478
http://www.aavid.com

IERC
135 W. Magnolia Blvd.
Burbank, CA 91502
Telephone (818)842-7277
Fax (818)848-8872
http://iercdya.com

Sanyo Denki America
2612A South Miami Blvd.
Durham, NC 27703
Telephone (919)598-1680
Fax (919)598-1744
http://www.sanyodenki.co.jp

Thermalloy Inc.
2021 W. Valley View
Dallas, TX 75234
Telephone (214)243-4321
Fax (214)241-4656
http://www.thermalloy.com

Web Automation, Ltd.
11411 Plano Road
Dallas, TX 75243
Telephone (214)348-8678
Fax (214)343-8958

Chip Coolers
333 Strawberry Field Road
Warwick, RI 02887
Telephone (401)739-7600
Fax (401)732-6119
http://www.chipcoolers.com

Oryx International Ltd.
7F., No. 5, Alley 16, Lane 235
Pao Chiao Road, Hsintien City
Taipei, Taiwan. R.O.C.
Telephone 886-2-9141400
Fax 886-2-9142283

Cooler Master, Inc.
115 Fourier Avenue
Fremont, CA 94538
Telephone (510)770-8566
Fax (510)770-0855
http://www.coolermaster.com

Wakefield Engineering
60 Audubon Road
Wakefield, MA 01880
Telephone (617)245-5900
Fax (617)246-0874
http://www.wakefield.com

ACT-RX Technology Corporation
10F, No. 525, Chung Cheng Road
Hsin Tien City
Taipei Hsien, Taiwan, R.O.C.
Telephone 886-2-218-8000
Fax 886-2-218-8800

Appendix B: Heatpipe Suppliers

Thermacore Incorporated
780 Eden Rd
Lancaster, PA 17601
Telephone (717)569-6551
Fax (717)569-4797
http://www.thermacore.com

Noren Products Inc.
1010 Obrien Dr
Menlo Park, CA 94025
Telephone (415)322-9500
Fax (415)324-1348

Fujikura America Incorporated
100 Galleria Pkwy SE
Atlanta, GA 30339-3122
Telephone (770)956-7200

Furukawa Electric America Incorporated
200 Westpark Dr
Peachtree City, GA 30269-1804
Telephone (770)487-1234

Appendix C: Socket 7 Suppliers

AMP Incorporated
Harrisburg, PA
Telephone (717)564-0100
Fax (717)986-7575
http://www.amp.com

Precicontact, Incorporated
2556 Metropolitan Dr
Trevose, PA 19053
Telephone (215)322-3424

Augat Incorporated
452 John Dietsch Blvd
P.O. Box 2510
Attleboro Falls, MA 02763
Telephone (508)643-3111
Fax (508)695-8769

McKenzie Technology
A Berg Electronics Company
910 Page Ave
Freemont, CA 94538
Telephone (510)651-2700
Fax (510)651-1020

Molex Incorporated
2222 Wellington Court
Lisle, IL 60532
Telephone (708)969-4550
Fax (708)969-1352
http://www.molex.com

Yamaichi Electronics USA Incorporated
2235 Zanker Rd
San Jose, CA 95131
Telephone (408)456-0797
Fax (408)456-0799