Thermal Solutions for the IBM 6x86MX Microprocessor

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Introduction

This application note provides the values of maximum power generated in the IBM 6x86MX™ processor[1] at various internal clock frequencies for a proper thermal design. The case-to-ambient or external thermal resistance in degrees C per watt for various system ambient temperatures and internal clock frequencies are provided so that the user can select an appropriate thermal solution for their specific system ambient temperature and internal clock frequency. Several example thermal solutions, such as heatsink and fan/heatsink, are selected for various operating room temperatures and air flow conditions. The example heatsink and fan/heatsink solutions for various internal clock frequencies are also presented for a most commonly used operating room temperature of 35^{o}C (95^{o}F).

Chip Carrier Package

The IBM 6x86MX processor device is packaged in a 296 pin ceramic pin grid array (CPGA) 50 mm by 50 mm square chip carrier. The ceramic package is integrated with copper-tungsten alloy heat slug and spreader to remove the heat generated in the device effectively. This thermally enhanced package reduces the internal or junction-to-case thermal resistance of the package significantly.

Power

The generated power in the IBM 6x86MX 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 6x86MX 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.

1. The IBM 6x86MX Microprocessor is designed by Cyrix Corp., and manufactured by IBM Microelectronics.

The supply voltage to the I/O of the IBM 6x86MX 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 below provides the values of the maximum generated power in watts for various internal clock frequencies (in MHz) of the IBM 6x86MX processor. The typical or average power generated in the IBM 6x86MX processor is about 15% less than the 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. However, the thermal solution must be designed for the maximum power dissipation. Note that the absolute maximum power values to be used for power supply design are approximately 10 to 15% higher than the maximum power dissipation values given here.

Internal Clock Frequency (MHz)	Maximum Generated Power (Watts) when Core Supply Voltage at 2.8 - 3.0 Volts	
	Last digit of part number: B,C,D,E	Last digit of part number: F or higher
133	17.3	-
150	18.70	-
166	20.10	18.1
188	21.90	19.7
200	23.00	20.5
208	23.7	21.3
225	-	22.3
233	-	22.8

Table 1: Max. Generated Power of the IBM 6x86MX 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 (^{o} C) from the case temperature of the IBM 6x86MX processor in degrees C and then dividing the resultant difference by the maximum generated power in watts. Thus, the unit of the thermal resistance would be degrees C per watt. The case temperature is measured at the

center of the top surface of the package and system ambient temperature is the temperature of the air surrounding the microprocessor. Ambient temperature referred to in this application is the same as system ambient temperature. The case temperature of the IBM 6x86MX processor must not exceed 70^{o} C during its operation. The following table provides the values of the required case-to-ambient thermal resistance for various system ambient temperatures to meet 70^{o} C case temperature specification of the IBM 6x86MX processor.

Internal Clock Frequency (MHz)	System Ambient Temperatures:									
	Last digit of part number: B,C,D,E					Last digit of part number: F or higher				
	at 30^{o} C	at 35^{o} C	at 40^{o} C	at 45^{o} C	at 50^{o} C	at 30^{o} C	at 35^{o} C	at 40^{o} C	at 45^{o} C	at 50^{o} C
133	2.31	2.02	1.73	1.45	1.16	-	-	-	-	-
150	2.13	1.87	1.60	1.37	1.07	-	-	-	-	-
166	1.99	1.74	1.49	1.24	1.00	2.21	1.93	1.66	1.38	1.10
188	1.83	1.60	1.37	1.14	0.91	2.03	1.77	1.52	1.27	1.01
200	1.74	1.52	1.30	1.09	0.87	1.95	1.71	1.46	1.22	0.98
208	1.69	1.48	1.27	1.06	0.84	1.88	1.64	1.41	1.17	0.94
225	-	-	-	-	-	1.79	1.57	1.34	1.12	0.90
233	-	-	-	-	-	1.75	1.53	1.31	1.10	0.88

Table 2: Required Case-to-Ambient Thermal Resistance at Various System Ambient Temp. and Internal Clock Freq. at 2.8 - 3.0 V Core Supply Voltage to the IBM 6x86MX processor

When an external heat sinking device (such as a heatsink or a fan/heatsink) is used to achieve the required case-to-ambient thermal resistance, the external heat sinking device is attached to the top surface of the IBM 6x86MX 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 6x86MX 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. The mechanical fastening device, such as a clip or a spring, is usually employed to provide contact pressure to the bond and the mechanical strength to the assembly to sustain shock and vibration.

The typical value for the case-to-sink thermal resistance for the IBM 6x86MX processor can usually range from 0.1^{o} to 0.2^{o} 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. Although the thermally conductive grease with a mechanical retention clip method is referenced here for the heatsink attachment to the IBM 6x86MX 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 6x86MX processor. Note that the IBM 6x86MX processor chip carrier package 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.

Note that the system ambient temperature is usually 5^{o} to 10^{o} C higher than the room temperature and 10^{o} to 15^{o} C higher than the room temperature in a natural convection environment.

Heatsinks

The heatsink is characterized by the sink-to-ambient thermal resistance in degrees 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 air flow over the heatsink surface area.

The amount of air flowing over the IBM 6x86MX pro-

cessor's heatsink surface area depends on many parameters such as the number, location and air flow capacity of system fan, the number and the location of air vents, etc.. Since the amount of air flowing over the processor's heatsink surface area differs from system to system, no air flow (natural convection) can be considered as a worst case situation.

It is obvious that 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 6x86MX 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. However, it cannot simply be set to zero for a worst case situation. The heatsink suppliers usually provide the various heights for a given area of an extruded or a pin fin heatsink.

As you can see from Table 2, the required sink-to-ambient thermal resistance spreads from 0.69 to 2.16 ^{o} C per watt for the IBM 6x86MX processor.

Once the information on the required sink-to-ambient thermal resistance, air flow and available volume for a heatsink are determined for the IBM 6x86MX 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 can be chosen from any heatsink suppliers' catalogs.

Table 3 below provides some heatsink examples found through suppliers' catalogs based on the information provided there in on the thermal resistance and the mechanical specification. These heatsinks were further characterized in the laboratory using industry standard desktop type personal computer system chassis and presented here so that the user can gain benefit from the collected data. Note that the thermal resistance values of the example heatsinks presented here may be different than the supplier provided values. This difference may be due to various reasons such as wind tunnel testing versus actual system testing. It is the user's responsibility to verify the value in their own system. The intent of providing this information is not to endorse or qualify the supplier or their products but an attempt to show the user how to proceed to select an appropriate thermal solution for the IBM 6x86MX processor.

Vendor	Part Number	Overall Size LxWxH in inches	Case-to-Ambient Thermal Resistance in C/W at Air Flow of:		
			100 ft/min	200 ft/min	400 ft/min
IERC	PS519B	2.28X2.14X1.25	2.40	1.80	1.40
Thermalloy	2502B	2.04X2.68X1.25	2.20	1.70	1.30
Wakefield	779L-150AB	2.66X2.48X1.5	1.60	1.40	1.10

Table 3: Example of heatsinks selected from vendor catalogs for IBM 6x86MX processor.

A retention clip like IERC's SA54-2 or SC5 can be used with PS519B heatsink to secure heatsink to the socket 7. The Thermalloy clip CLP-7000 can be used with 2502B heatsink to secure heatsink to the socket 7. Wakefield's 779L-150AB heatsink comes with an integrated clip. As you can see from Tables 1 and 3, these example heatsinks can be used for the IBM 6x86MX processor in a various combinations of internal clock frequency, operating room temperature and air flow. For example, at 20^{o} C operating room or 30^{o} C system ambient temperature and with minimum of 200 feet per minute air flow, PS519B heatsink can be used for an internal clock frequency of 166 MHz. Similarly, at 35^{o} C operating room or 45^{o} C system ambient temperature and with minimum of 400 feet per minute air flow, 779L-150AB heatsink can be used for an internal clock frequency up to 188 MHz.

Depending upon the user's internal clock frequency of IBM 6x86MX processor in a given environment of room temperature and available system air flow over heatsink surface, an appropriate heatsink can be selected using both Table 2 and 3. It may not be necessary to choose a heatsink from these examples. The user may select any other comparable

heatsink from any other supplier's catalog not listed here, however, it is user's responsibility to verify that the selected heatsink can maintain the case temperature within 70^{o} C. In some situations a heatsink solution may not be possible, due to a rigorous combination of internal clock speed, operating room temperature, air flow and available system volume for thermal solution. For example, for 35^{o} C room or 45^{o} C system ambient temperature with a max. available system air flow of 200 feet per minute and available volume for thermal solution confined to socket 7 area, none of these example heatsinks are suitable for the processor at 166 MHz. In this situation, an active fan/heatsink solution is required.

The user may contact the suppliers for the detailed mechanical specifications, availability and cost of these or any other heatsinks.

When a heatsink solution is selected for the IBM 6x86MX processor, care must be taken to ensure that an appropriate heatsink for the voltage regulator be implemented. An inadequate heatsink for the voltage regulator may result in exceeding the junction temperature limit. This may cause the shut down of the voltage regulator.

Fan/Heatsinks

A fan/heatsink solution is usually sought when the maximum generated power exceeds 18 watts and the allowable operating room temperature approaches 40^{o} C in a zero air flow environment. In some cases, even for less than 18 watts power with controlled lower operating room temperature less than 40^{o} C, a fan/heatsink solution is sought. This is because either the required heatsink volume is not available to dissipate the heat or the required air flow over the heatsink surface area does not exist.

Vendor	Part Number	Overall Size of Assembly LxWxH in mm (inch)	Case-to-Ambient Therm. Resistance in C/W
Aavid	355455F00267	49.8 (1.96) X 50.1 (1.97) X 17.0 (0.67)	1.55
ACT-RX	ACC 5856-06HW	54.85 (2.16) X 54.75 (2.15) X 12.6 (0.50)	1.85
Oryx/Cooler	TI5-6025SBC1	59.6 (2.35) X 67.00 (2.64) X 40.0 (1.58)	0.80
Oryx/Cooler	TI5-5020SBC1	53.09 (2.09) X 49.78 (1.96) X 30.5 (1.20)	0.94
Oryx/Cooler	TI5-5015SBC1	53.09 (2.09) X 49.78 (1.96) X 24.5 (0.96)	1.0
Oryx/Cooler	TI5-4515SB7C1(C2)	49.78 (1.96) X 49.78 (1.96) X 25.6 (1.01)	1.10
Oryx/Cooler	TI5-4010SB7C1(C2)	49.78 (1.96) X 52.50 (2.07) X 20.5 (0.81)	1.50
Chip Coolers	HTS108B	50.8 (2.00) X 50.8 (2.00) X 23.62 (0.93)	1.35
Chip Coolers	HTS114B	50.8 (2.00) X 50.8 (2.00) X 24.89 (0.98)	1.15
IERC	PS520CB/F01	55.5 (2.19) X 54.3 (2.14) X 25.4 (1.0)	1.10
Sanyo Denki	109P5412H8026	54.25 (2.14) X 54.85 (2.16) X 18 (0.71)	1.60
Sanyo Denki	109P5412H2026	49.78 (1.96) X 49.78 (1.96) X 25.6 (1.01)	1.20
TennMax	50-2B-OP-C4	49.68 (1.96) X 53.10 (2.1) X 27.50 (1.08)	1.20
TennMax	50-2B-OP-C4-K	51.80 (2.04) X 57.80 (2.28) X 29.80 (1.17)	0.95
Thermalloy	2325B-TCM42S-PF33	51.18 (2.02) X 53.34 (2.10) X 20.2 (0.80)	1.60
Thermalloy	2321B-TCM42S-PF33	41.28 (1.63) X 43.18 (1.70) X 18.9 (0.75)	1.70
Thermalloy	20675B	47.88 (1.85) X 48.26 (1.9) X 17.51 (0.69)	1.28
Thermalloy	20961	51.18 (2.02) X 53.34 (2.1) X 17.51 (0.69)	1.13
Wakefield	709-100AB121	49.53 (1.95) X 45.50 (1.79) X 25.4 (1.0)	1.50
Wakefield	709-80AB121	49.53 (1.95) X 45.50 (1.79) X 20.3 (0.80)	1.90
Wakefield	979L-100AB121	62.48 (2.46) X 67.56 (2.66) X 20.3 (1.02)	0.90
Vantec	SI5-6025-B	62 (2.44) X 59 (2.32) X 40 (1.48)	0.80
Vantec	SI5-5024-B	62 (2.44) X 56.5 (2.22) X 30 (1.18)	1.00

Table 4: P/N, Size, Thermal Resistance and Supplier of Fan/heatsink for the IBM 6x86MX Microprocessor

Table 4 provides information on some selected example fan/heatsink assemblies from the major suppliers[1]. The area of most of these selected fan/heatsinks contains within the socket 7 area envelope to avoid the interference with components beside the socket 7. Some fan/heatsinks are slightly larger than the socket 7 area, however, in many systems fan/heatsink larger than socket 7 do not interfere with surrounding system board components. Since the clearance above the socket 7 varies from system to system, the height of the fan/heatsink assemblies are selected in the range from 12.6 mm to 40.0 mm. These fan/heatsinks were characterized in the industry standard desktop type personal computer system chassis with typical configuration. The case-to-ambient thermal resistance of these example fan/heatsink assemblies ranges from 0.8 to 1.9 ^{o} C per watt. Note that the value of case-to-ambient thermal resistance of these example fan/heatsinks may be different than the supplier provided value due to difference in test procedures. It is the user's responsibility to verify the value in their particular configuration. The user may select any one from Table 4 or any other comparable fan/heatsink, not listed here, which fits in their system layout and are able to keep the case temperature within 70^{o} C.

As you can see from Table 2, the lowest required case-to-ambient thermal resistance is 0.84^{o} C per watt at an internal clock frequency of 208 MHz and at a room temperature of 40^{o} C or system ambient temperature of 50^{o} C.

The fan of the selected fan/heatsink must be ball bearing type for longer fan life. It is imperative that the clearance of at least 0.4" on the top of fan for the intake air and clearance of at least 0.2" on the sides of heatsink for the exhaust air be provided so that the fan can perform efficiently.

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 with an appropriate thermal solution for IBM 6x86MX processor. It is beyond our scope to present each supplier's product. *Appendix A* lists major heatsink and fan/heatsink suppliers for your reference. Other fan/heatsink suppliers not listed here may offer products better suited to your needs.

Thermal Solutions

Table 5 below provides example thermal solutions for an operating room temperature not exceeding 35^{o} C for various internal clock frequencies and air flows. These example heatsinks and fan/heatsinks are selected assuming the system ambient temperature would not exceed 45^{o} C. It is important that appropriate thermally conductive interface material be used between the heatsink bottom surface area and the top of the chip carrier package to create an adequate thermal path. It is also important that once a heatsink or fan/heatsink is selected for IBM 6x86MX processor, a verification run be performed in the actual system. The case temperature monitored in the verification run must not exceed 70^{o} C.

1. The information in Tables 4 and 5 were obtained from supplier catalogs and has not been verified by IBM. IBM makes no representations of the truth of this material.

Internal Clock Freq. (MHz)	Vendor	Part Number	Overall Size LxWxH (inches)	Min. Required Air Flow over Heatsink (ft/min)
Last digit of part number: B,C,D,E				
133	IERC	PS519B[2]	2.28 X 2.14 X 1.25	300
133	Wakefield	709-100AB121	1.95 X 1.79 X 1.0	Fan/heatsink
133	Aavid	355455F00267	1.96 X 1.97 X 0.67	Fan/heatsink
133	Oryx/Cooler Master	TI5-4010SB7C1	1.96 X 2.07 X 0.81	Fan/heatsink
150	Thermalloy	2502B[1]	2.04 X 2.68 X 1.25	350
150	Chip Cooler	HTS108B	2.00 X 2.00 X 0.93	Fan/heatsink
166	Wakefield	779L-150AB	2.66 X 2.48 X 1.5	300
166	Sanyo Denki	109P5412H2026	1.96 X 1.96 X 1.01	Fan/heatsink
166	Thermalloy	20675B	1.85 X 1.9 X 0.69	Fan/heatsink
188	Chip Cooler	HTS114B	2.00 X 2.00 X 0.98	Fan/heatsink
188	TennMax	50-2B-OP-C4	1.96 X 2.1 X 1.08	Fan/heatsink
188	Thermalloy	20961	2.02 X 2.1 X 0.69	Fan/heatsink
188	Oryx/Cooler Master	TI5-4515SBC1/C2	1.96 X 1.96 X 1.01	Fan/heatsink
200	Oryx/Cooler Master	TI5-5015SBC1	2.09 X 1.96 X 0.96	Fan/heatsink
200	Oryx/Cooler Master	TI5-5020SBC1	2.09 X 1.96 X 1.2	Fan/heatsink
200	TennMax	50-2B-OP-C4-K	2.04 X 2.28 X 1.17	Fan/heatsink
208	Oryx/Cooler Master	TI5-6025SBC1	2.35 X 2.64 X 1.58	Fan/heatsink
208	Wakefield	979L-100AB121	2.46 X 2.66 X 1.02	Fan/heatsink
Last digit of part number: F or higher				
166	IERC	PS519B	2.28 X 2.14 X 1.25	400
166	Wakefield	779L-150AB	2.66 X 2.48 X 1.5	200
166	Thermalloy	2502B	2.04 X 2.68 X 1.25	400
166	Chip Cooler	HTS108B	2.00 X 2.00 X 0.93	Fan/heatsink
188	Thermalloy	2502B	2.04 X 2.68 X 1.25	400
188	Thermalloy	20675B	1.85 X 1.9 X 0.69	Fan/heatsink
188	Wakefield	779L-150AB	2.66 X 2.48 X 1.5	300
200	TennMax	50-2B-OP-C4	1.96 X 2.1 X 1.08	Fan/heatsink
200	Wakefield	779L-150AB	2.66 X 2.48 X 1.5	400
200	Chip Cooler	HTS114B	2.00 X 2.00 X 0.98	Fan/heatsink
208	Oryx/Cooler Master	TI5-5020SBC1	2.09 X 1.96 X 1.2	Fan/heatsink
208	Thermalloy	20961	2.02 X 2.1 X 0.69	Fan/heatsink
208	Sanyo Denki	109P5412H2026	1.96 X 1.96 X 1.01	Fan/heatsink
225	IERC	PS520CB/F01	219 X 2.14 X 1.0	Fan/heatsink
225	TennMax	50-2B-OP-C4-K	2.04 X 2.28 X 1.17	Fan/heatsink
225	Vantec	SI5-5024-B	2.44 X 2.22 X 1.18	Fan/heatsink
233	Vantec	SI5-6025-B	2.44 X 2.32 X 1.58	Fan/heatsink
233	Oryx/Cooler Master	TI5-6025SBC1	2.35 X 2.64 X 1.58	Fan/heatsink
233	Wakefield	979L-100AB121	2.46 X 2.66 X 1.02	Fan/heatsink
1. Clip CLP-7000 of Thermalloy can be employed to attach heatsink to socket 7.				
2. Clip SA54-2 or SC5 of IERC can be used to secure heatsink attachment to socket 7.				

Table 5: Part Number, Size and Supplier of Heatsinks and Fan/Heatsink for the IBM 6x86MX at various speeds.

It may be noted that ATX form factor style personal computer chassis with ATX form factor main board and the microprocessor socket 7 located near fan mounted on power supply unit may be able to provide up to 300 - 400 feet per minute air flow over the heatsink surface area.

Summary

This application note provides power values of the IBM 6x86MX processor and the required case-to-ambient thermal resistance for the thermal solutions of the processor at various internal clock frequencies. The thermal and mechanical characteristics of a few heatsinks as well as fan/heatsinks were presented. The passive heatsink solutions as well as active fan/heatsink solutions were identified for various internal clock frequencies in a different operating room environment as well as different air flow conditions. Although the information to implement a thermal solution for the IBM 6x86MX processor 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 6x86MX processor must not exceed 70^{o} C.

References

1. The IBM 6x86MX Microprocessor Databook
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*

Appendix: Heatsink and Fan/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
Tel (214)348-8678
Fax (214)343-8958

TennMax United (North America)
PO Box 93
Reading, MA 01867
Tel (617) 944-3293
Fax (617) 944-0903
http://www.TennMax.com

Vantec
43185 Osgood Road
Freemont, CA 94539
Tel (510)668-0368
Fax (510)668-0367
http://www.vantecusa.com

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

Oryx International, Ltd.
7F, No. 5, Alley16, Lane235
Pao Chiao Road, Hsintien City
Taipei, Taiwan, R.O.C.
Tel 886-2-9141400
Fax 886-2-9142283

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

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

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

TennMax United (Asia)
9f-3, No. 31-1, Lane 169
Kang-Ning Street, HSI-CHIH
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