Selection of Appropriate Thermal Solution for IBM 6x86 Microprocessors

Application Note

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Revision Summary: This revision contains information regarding thermal solutions for running the IBM 6x86 microprocessor at 150 MHz.

PROCESSOR

Manufactured by IBM

Introduction

This application note shows users of the IBM 6x86 microprocessor how to select a proper thermal solution. Since the amount of generated power in the microprocessor is more than 15 watts, an external heatsink or active cooling device is required for the most common application environment. This application note will show you how to select an appropriate optimized heatsink or an active cooling device.

In order to operate an electronic device, power is supplied from an external source. The generated power in the device is simply the product of supply voltage in volts and current in amps. The supplied power in the electronic device generates heat. If the generated heat is not removed properly, the temperature of the device rises. Every electronic device has a maximum operating temperature limit.

Some manufacturers define this limit by specifying the maximum allowable case temperature of the device package. The case temperature is usually measured at the center of the top surface of the package. However, the main objective is to keep the junction temperature of the device within a specified limit set by the device designer. The junction temperature is the temperature of the junction of the internal circuit of the device. Since it is not easy to measure the junction temperature of the device, most manufacturers specify the case temperature limit based on the package chosen for the device. The case temperature limit is simply the translation of the junction temperature of the device using the internal thermal resistance of the package. Two different device carrier packages such as Ceramic Pin Grid Array and Plastic Quad Flat Pak packages may have different case temperature limits for the same device.

Other manufacturers, however, specify the maximum allowable junction temperature of the device. In any event, if the temperature of the case or junction temperature of the device exceeds the maximum allowable limit specified by a manufacturer, the device may not function properly. A device with higher case or junction temperature than the one specified by the manufacturer may also significantly reduce the performance or the life of the device. Note that in thermal management all the temperatures are measured in degrees Celsius (°C).

Thermal Parmeters

Fixed Thermal Parameters

There are several factors that influence the thermal performance of an electronic device. Major parameters to be considered in the thermal solution of the IBM 6x86 microprocessor are discussed below.

Case and Junction Temperatures

Most device manufacturers provide information on the maximum case temperature limit of the package. When a manufacturer supplies a junction temperature limit for a device, an internal thermal resistance, also known as the junction-to-case thermal resistance of the package, is also provided by the supplier. The internal thermal resistance or the junction-to-case thermal resistance of the package is obtained by first subtracting case temperature from the junction temperature and then, dividing the resultant difference by the generated power in the device. For instance, the maximum case temperature limit of a microprocessor in a 296 pin 50 mm square Ceramic Pin Grid Array package with integral copper-tungsten heat spreader is set at 75 ° C and internal thermal resistance is 0.6 ° C per watt when a heat sinking device is used. The internal thermal resistance of 296 pin 50 mm square Ceramic Pin Grid Array package with integral copper-tungsten heat slug and spreadre is 0.4 C per watt. Note that all the thermal resistances are measured in the ° C per watt.

Power

The most influential factor in the thermal performance of the device is the power generated in the device. Although most electronic devices come with specified voltage and current supply requirements for a proper operation, actual power supply to the microprocessor is slightly altered at the system level due to inherent system variations and the way voltage regulation is designed. A slight alteration in the power supply would affect the junction temperature of the device significantly.

Table 1 shows two different power measurements and internal clock frequencies for the 6x86 microprocessor. As you can see from the table, for a given voltage, as internal clock frequency increases, the demand for supply current increases and thereby generated power in the device is increased. Since the maximum or worst case power generated in the microprocessor is 27.00 watts, a copper-tungsten heat spreader is integrated in the ceramic package to remove generated heat in the device efficiently. The flat side of a 1.25" square and 0.040" thick piece of copper-tungsten composite is attached to the back side of the ceramic substrate while the other side is exposed at the top center of the package for an external heatsink or active cooling device attachment. The revision level 3.x and later packages constructed of integral copper-tungsten heat slug and spreader to improve the thermal resistance of the package and thereby to remove the heat more efficiently from the device. The backside of the device in this package is attached directly to the integral copper-tungsten heat slug and spreader.

CPU Internal Clock Frequency	100 MHz	110 MHz	120 MHz	133 MHz	150 MHz
Supply V_{cc} in Volts	3.60	3.60	3.60	3.60	3.60
Maximum I_{cc} in Amps	6.05	6.58	6.95	7.50	7.50
Maximum P_{max} in Watts	21.78	23.69	25.02	27.00	27.00

Table 1. Maximum or worst case power generated in the 6x86 microprocessor

Variable Thermal Parameters

Air Flow

Another very influential factor in the thermal equation of the device is the air flow over the microprocessor package or heat sinking device. Air flow over the microprocessor or the heat sinking device can be measured using a suitable anemometer. Air flow is usually expressed in feet per minute. Heat can be removed from the device in three different ways. The first is conduction from the device to the package surface, the second is convection, and the third is radiation off the package surface area. The internal thermal resistance characterizes the conduction effect. The radiation heat removal is very negligible compared with conduction and convection and therefore it is not considered in the thermal analysis. The surface area and air flow influence the amount of convective heat transfer.

The system designer usually determines whether a fan or blower is required for the machine in order to remove the heat generated in the system. The system designer also determines the number and location of the air vents in the machine. The amount of air flow over the microprocessor or heat sinking device is dependent on the size and the location of the system fan or blower with respect to the microprocessor and the location of the high system components or baffles installed in the system. Some systems may not have a fan or blower installed due to some other restraints. Since the generated power in the microprocessor device can range up to 27.00 watts, some system designers may opt to choose a fan/heatsink solution. In that case, the air usually impinges on the heatsink's fins in the range of 200 to 800 feet per minute. The impinged air flow over the heatsink's fins is much more effective than the parallel air flow through the vertical fins of the heatsink.

System Temperature

The system temperature, which is usually measured at about 1 - 2 inches over the microprocessor, may be different from the room temperature in which the device is to be operated. Since the other components of the Printed Circuit Board (PCB), such as the voltage regulator, also generate the heat that builds up within the system enclosure, the system temperature is usually 5 to 10 ° C higher than the room temperature. The system temperature rise can be minimized by providing enough air vents in the machine, selecting the proper size and location for the fan, and properly distributing heat generating components on the PCB.

Room or Ambient Temperature

The environment in which the system operates also influences the thermal performance of the device. The environment is usually specified by maximum room temperature and altitude at which the device operates. A Class B environment designates a maximum room temperature of 32.2 ° C (90 ° F) and 2250 meters (7000 feet) in altitude while a Class C environment designates a maximum room temperature of 40.6 ° C (105 ° F) and 2250 meters (7000 feet) in altitude.

Notice that some of the parameters discussed above are fixed by the manufacturer while others can be changed by the customer application. The fixed parameters for a selected microprocessor and package are supply voltage, and current, case temperature or junction temperature, and internal thermal resistance. These parameters are already specified by the manufacturer. For a given microprocessor, a customer can choose the operating room temperature limit, change the air flow over the microprocessor or heat sinking device and configure the system design in different ways to reduce the system temperature rise. These parameters are obviously variable parameters and are very influential in the selection of a proper thermal solution.

Selecting an Optimized Heatsink

Sink-to-Ambient Thermal Resistance

Once the fixed and variable thermal parameters discussed above are gathered for a specific microprocessor and application, choosing an optimized heatsink is the next step. In thermal management, a heatsink is usually characterized by sink-to-ambient thermal resistance. This is defined as the ratio calculated by subtracting the system temperature from the temperature of the bottom of the heatsink where it makes contact with the microprocessor package and dividing the resultant difference by the generated power in the device.

Most of the heatsink suppliers specify the sink-to-ambient thermal resistance for the heatsinks listed in their catalogs. Since 6x86 100, 110, 120, 133 and 150 MHz microprocessors in a 296 pin Ceramic Pin Grid Array package are most likely used in desktop, server and industrial computers, most customers may have two distinct operating environments -- namely Classes B and C which were discussed earlier.

Table 2 below lists the maximum required sink-to-ambient thermal resistance of heatsink for a 296 pin CPGA package 6x86 microprocessor 100, 110, 120, 133 and 150 MHz internal clock frequencies and in Class B and C environments. Since the amount of power generated in the microprocessor is considerably high, a 10 ° C system temperature rise was considered to derive the sink-to-ambient thermal resistances. 0.14 ° C per watt interface thermal resistance (known as case-to-sink thermal resistance) was estimated based on the interface material's bond thickness of 0.004", 100% coverage on the available bonding area of 1.25 inches square and 0.7 watt per meter-degrees K thermal conductivity of the interface bonding material.

IBM 6x86 Microprocessor Package Type	Internal Clock Frequency in MHz	Operating Environment Class B (32.2 C) or Class C (40.6 C)	System Temperature in Degrees C	Thermal Resistance in Degrees C/Watt
296 PIN CPGA	100	32.20	42.20	1.36
296 PIN CPGA	100	40.60	50.60	0.98
296 PIN CPGA	110	32.20	42.20	1.24
296 PIN CPGA	110	40.60	50.60	0.89
296 PIN CPGA	120	32.20	42.20	1.17
296 PIN CPGA	120	40.60	50.60	0.84
296 PIN CPGA	133	32.20	42.20	1.07
296 PIN CPGA	133	40.60	50.60	0.76
296 PIN CPGA	150	32.20	42.20	1.07
296 PIN CPGA	150	40.60	50.60	0.76

Table 2. Sink-to-Ambient Thermal Resistance in Degrees C per Watt

For a selected 6x86 microprocessor with an internal clock frequency in a given package and a chosen operating environment, the required sink-to-ambient thermal resistance of a heatsink can be obtained from Table 2. For instance, for a 296 pin Ceramic Pin Grid Array package 6x86 microprocessor at 100 MHz and Class B operating environment, 1.36 ° C per watt, sink-to-ambient thermal resistance of the heatsink has been obtained from Table 2. Now, for a given air flow, an appropriate heatsink can be selected from either Appendix A or the heatsink catalog provided by the supplier. Appendix A also provides some limited number of heatsinks selected from a few major heatsink suppliers. It is the user's responsibility to verify the thermal resistance values provided by the vendor in Appendix A.

A list of major heatsink suppliers is provided in Appendix C for reference only. This list is not a complete list of all heatsink suppliers nor has IBM qualified their products. Other heatsink suppliers not listed here may offer products better suited to your needs. When selecting a supplier, note that the lower the sink-to-ambient thermal resistance of the heatsink, the better the thermal performance of the heatsink.

Also note that the listed heatsinks are only some of the possible solutions. One suggested heatsink solution may be ideal for a certain customer while it may not be ideal for another customer due to physical constraints in the system. Some systems may have height constraints while others may have x-y size constraints. Some may have both height and x-y size constraints. Appendix A shows some heatsinks with various physical variations in x, y and z directions to select the one which fits the best in a specific application.

For a required sink-to-ambient thermal resistance, a variety of heatsinks in different configurations and sizes can be selected from the heatsink catalog provided by the supplier. If the physical constraints in the system do not allow any possible heatsink solution, air flow and operating environment may be reviewed to see whether either or both can be changed to relax the sink-to-ambient thermal resistance requirement. Lower operating room temperature allows you to choose a heatsink with higher sink-to-ambient thermal resistance that, in turn, allows you to reduce the size of the heatsink. Greater air flow over the heatsink reduces the sink-to-ambient thermal resistance of the heatsink.

A heatsink that does not meet thermal performance requirement but fits in an available physical window in the system, may be enhanced by optimizing the fin geometry or employing a hollow fin concept to increase the surface area. The hollow fins can further be serrated to obtain more surface area. The heatsink can also be treated with secondary mechanical or chemical processes such as sand blasting or chemical etching to generate more surface area. The greater the surface area on the heatsink, the lower the thermal resistance of the heatsink. External coating such as black anodize or chromate coat surface treatments not only protects the heatsink against corrosion but also enhances the esthetics and improves the thermal performance of the heatsink. However, the effect of the last two options may not be significant compared with the effect of previous three options for some applications.

The required sink-to-ambient thermal resistance of the heatsink can also be relaxed by lowering the interface thermal resistance (also known as case-to-sink thermal resistance) by utilizing the best thermally conductive bonding material, the least bonding thickness and the maximum bonding area.

If any of the above suggested solution can not be accommodated, an alternate solution such as fan/heatsink, thermoelectric cooler or heat pipe may be selected. Each alternate thermal solution has its own advantages and disadvantages. Selecting an appropriate alternate solution requires careful consideration of factors such as cost, thermal performance, reliability and manufacturability.

Heatsink Solutions

Fan/Heatsink Solution

The fan/heatsink option is the best the thermal solution for IBM 6x86 microprocessors. Choosing a fan/heatsink solution requires consideration of several things.

First of all, for a given physical constraint, a fan must be chosen and the amount of air flow in feet per minute must be estimated. Most of the fan suppliers provide cubic feet per minute (cfm) flow capacity of the fan. The quickest way to estimate the amount of air flow in feet per minute (FPM) for a given cfm would be to divide cfm by the fan area i.e. length times width of the fan in square feet.

Once the information on air flow is obtained, the next step is to select an appropriate heatsink that meets the sink-to-ambient thermal resistance requirement. The selected heatsink and fan assembly also has to be contained within the available physical envelope. If the physical size of the fan/heatsink assembly exceeds the available physical envelope, an optimization of heatsink may be done by utilizing one or a combination of the previously mentioned methods such as selecting a proper fin geometry, hollow fins, serrated fins, coarse surface and external coating.

If all the heatsink optimization resources are exhausted, a fan with more air flow capacity and the same size or a thinner fan with the same air flow capacity and a larger heatsink to gain more surface area or a combination of both can be employed to meet the sink-to-ambient thermal resistance requirement.

Since the air is impinging on the heatsink in the fan/heatsink thermal solution, heat carrying capacity of the air is more effective than the air flowing parallel over the heatsink's fins. Most systems have a fan or blower that also provides air flow over the fan/heatsink assembly which, in turn, aids in carrying the heat away effectively.

Although fans come in a variety of sizes and capacities, most of the fans employed for this kind of application are DC brushless rotary fans operate on either 5 or 12 volts and generating less than one watt of power depending on the supply voltage and current specifications of the fan. Most of the DC rotary fans for this kind of application operate at low dBA over an operating range of -10 ° C to +65 ° C. The fan from 40 to 55 mm square in size and 10 mm thickness are the most appropriate candidates for this kind of application. A fan with 6 mm thickness in a limited size and capacity can also be employed where physical constraints are severe in the system.

Although a fan/heatsink thermal solution seems better than a conventional passive heatsink solution, long term reliability at elevated temperature is the most significant factor that must be considered. The mean time between failures (MTBF) is a good measure to determine the fan reliability. The ball bearing type of fan has better MTBF than the sleeve bearing type of fan. MTBF for a ball bearing type of fan can be in the range of 40,000 to 50,000 hours.

Air flow capacity ranges from 3.2 cfm to 20 cfm for a fan in the size of 40 to 55 mm square. A fan 40 mm square has a capacity of 4 cfm to 9 cfm and provides air flow in the range from 200 to 800 feet per minute.

Mechanical fastening using screws at all four corners of the fan and the fins of heatsinks, is the most commonly employed fan and heatsink attach method. The size of the screws and depth of the screw insertion in the heatsink's fins to be determined such that the assembly can sustain operating shock and vibration. Other attachment methods such as thermally conductive tape and thermal epoxy can also be employed depending on the requirements.

Some heatsink and fan suppliers also provide the fan/heatsink assembly with sink-to-ambient thermal resistance and size specifications. For instance, 979 series convoluted fansink socket clip fan/heatsink assembly from Wakefield Engineering claims thermal resistance of 0.43°C per watt[1]. Users may contact Wakefield Engineering for size, specification and more details. A fan/heatsink part number 353155B00000 of Aavid Thermal Technologies in size of 2.54" X 2.54" X 0.75" allows 18 ° C temperature rise of the mounting surface above ambient temperature at 20 watts power dissipation.

A list of some fan suppliers is provided in Appendix D for reference only. This list is not a complete list of all fan suppliers nor were they qualified by IBM. Other fan supplier not listed here may provide solutions that are as good as or better than the ones listed. The price of the fan generally runs from $3 to $10 and the fan/heatsink assembly is sold from $8 to $30.

Heatsink and Fan/Heatsink Attachment

The selected heatsink or fan/heatsink assembly can be attached to the 6x86 microprocessor in several ways. Thermal epoxies, thermally conductive adhesive, and mechanical fastening systems such as clip and screws are three major methods commonly employed to attach a heatsink to the microprocessor. Each method has its own advantages and disadvantages. Since the amount of generated power in the microprocessor is more than 15 watts, junction-to-ambient thermal resistance would be very low. The junction-to-ambient or the overall thermal resistance is calculated as the ratio of the temperature difference obtained by subtracting the system temperature from the junction temperature and dividing the result by the generated power in the device. 5 - 10% of the junction-to-ambient thermal resistance is contributed by the interface thermal resistance. Interface

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[1] Wakefield Engineering Heatsink Catalog

thermal resistance or the case-to-sink thermal resistance is the conduction resistance due to the added layer of bonding material between the heatsink and the microprocessor. Note that the package has been enhanced with integral copper-tungsten heat slug and spreader to reduce the internal thermal resistance of the package on revision level 3.x and later.

When the required sink-to-ambient thermal resistance of the heatsink is low, the required surface area of the heatsink would be more and therefore the heatsink becomes larger and heavier. A larger and heavier heatsink requires good shear and torque bonding strength. Care must taken to choose the appropriate interface bonding material to accomplish thermal performance and mechanical strength. And, of course, cost, manufacturability and environmental impact are also to be considered in choosing an interface bonding material. The chosen interface bonding material must have a coefficient of thermal expansion compatible with both copper-tungsten and the heatsink material or else a premature failure of interface bond may occur.

There are a variety of thermal epoxies available in the market. Sylgard 6605 and Loctite 384 are commonly used thermal epoxies. Some thermal epoxies require curing at elevated temperature. Most of the thermal epoxies are not reworkable. Some thermal epoxies also require specific material handling. A custom fixture may also be required for curing. Although the Sylgard 6605 and Loctite 384 are commonly used heatsink attachment thermal epoxies, other thermal epoxy or mechanical fastening or thermally conductive tape can also be employed. Due care must be taken to ensure that the interface thermal resistance from case-to-sink of 0.14°C per watt or less has been maintained in any attachment method.

If the interface case-to-sink thermal resistance exceeds the suggested case-to-sink thermal resistance, an adjustment can be made in the sink-to-ambient thermal resistance of the heatsink.

Thermoelectric Cooler (TEC) Solution

When a known input current is supplied to a closed circuit consisting of two dissimilar metals, a temperature differential is produced at the junction of the two dissimilar metals. This phenomenon was discovered by a French watchmaker named J. C. A. Peltier and is known as the Peltier effect. The thermoelectric cooler works on the Peltier effect. In fact, the thermocouple employed in the temperature measurement also works on the same principle.

The thermoelectric cooler is made of a number of p and n type semiconductor pairs, electrically connected in series, sandwiched between two plates which act as a cold and a hot junction. Bismuth telluride is the commonly used material to create the p and n type semiconductors and ceramic plate is used to form the junction, to isolate the electrical conductors and to provide mechanical strength.

When a dc current is supplied to the thermoelectric cooler, the current produces the hot and the cold sides. The cold side would be placed in contact with the top hot side of the microprocessor while a hot side would be attached with a heatsink or any heat sinking device to remove the heat from the hot junction. The amount of generated power in the microprocessor and the temperature differential between the hot and cold sides are the most important factors to determine the required stages of thermoelectric cooler. And, of course, total surface area to be cooled and the system temperature are important too in selecting or designing a thermoelectric cooler.

A list of some thermoelectric cooler suppliers is provided in Appendix E for reference only. This list is not a complete list of all thermoelectric cooler suppliers nor did IBM qualify any of these products. IBM does not endorse any of these suppliers or their products. Other suppliers not listed may provide products that are as good as or better than those listed.

Since the thermoelectric coolers are compact, they can be utilized where the space constraint is critical. Multi-stage thermoelectric coolers can also be employed to meet more severe heat dissipation and environmental requirements.

Heat Pipe Solution

A heat pipe is a heat transferring device that consists of an evacuated tube partially filled with a small amount of heat carrying fluid. The device is used to transfer the heat from a source to a remote heatsink. Thus where the space constraint is very critical, such as in mobile computers, a heat pipe may be the ideal solution. The fluid in the heat pipe evaporates at the heat source. The heat is then carried along with vapor in the tube to a remote heatsink due to a pressure gradient developed. The vapor gives up its latent heat of vaporization at the remote heatsink end. As a result the vapor condenses to the liquid form and returns to the heat source end by capillary action with built in porous wick structure such as fine mesh or serrated channels in the tube. A variety of fluids such as ammonia, water, acetone and methanol are employed as a heat transferring medium. Since the thermal conductivity of the heat pipe is up to 10000 times better than copper, the heat removal process is very efficient. A heat pipe also works against the gravity.

A heat pipe supplier is listed in Appendix F for reference only. This is not a complete list of heatpipe suppliers nor has IBM qualified their products. Other heatpipe suppliers not listed here may have products that are better suited to your needs. System designers can contact the listed vendor or any other vendor for an appropriate heat pipe design for their specific requirements.

Summary

The intent of this application note has been to familiarize you with the thermal management of 6x86 microprocessor. This application note provides a step by step process to help you understand the thermal management of 6x86 microprocessor. It also provides you with heatsink and fan/heatsink solutions that you may use as guidelines. More advanced thermal solution such as thermoelectric cooler and heat pipe were also briefly discussed for critical thermal requirements. Although the most of the major thermal parameters are considered in the process, it is advisable to carry out thermal performance experiments in an actual system for verification.

References

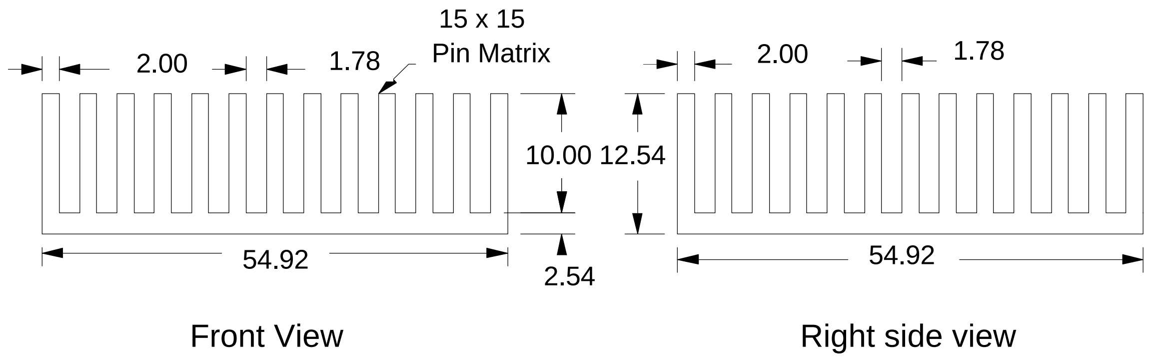
1. Electronic Products, August, 1995

Appendix A

Custom Design Heatsinks

#1

All Dimensions are in mm.



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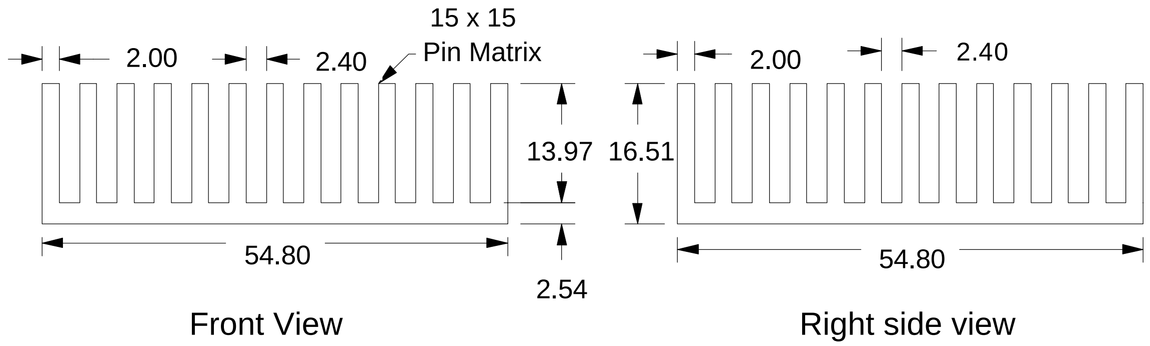
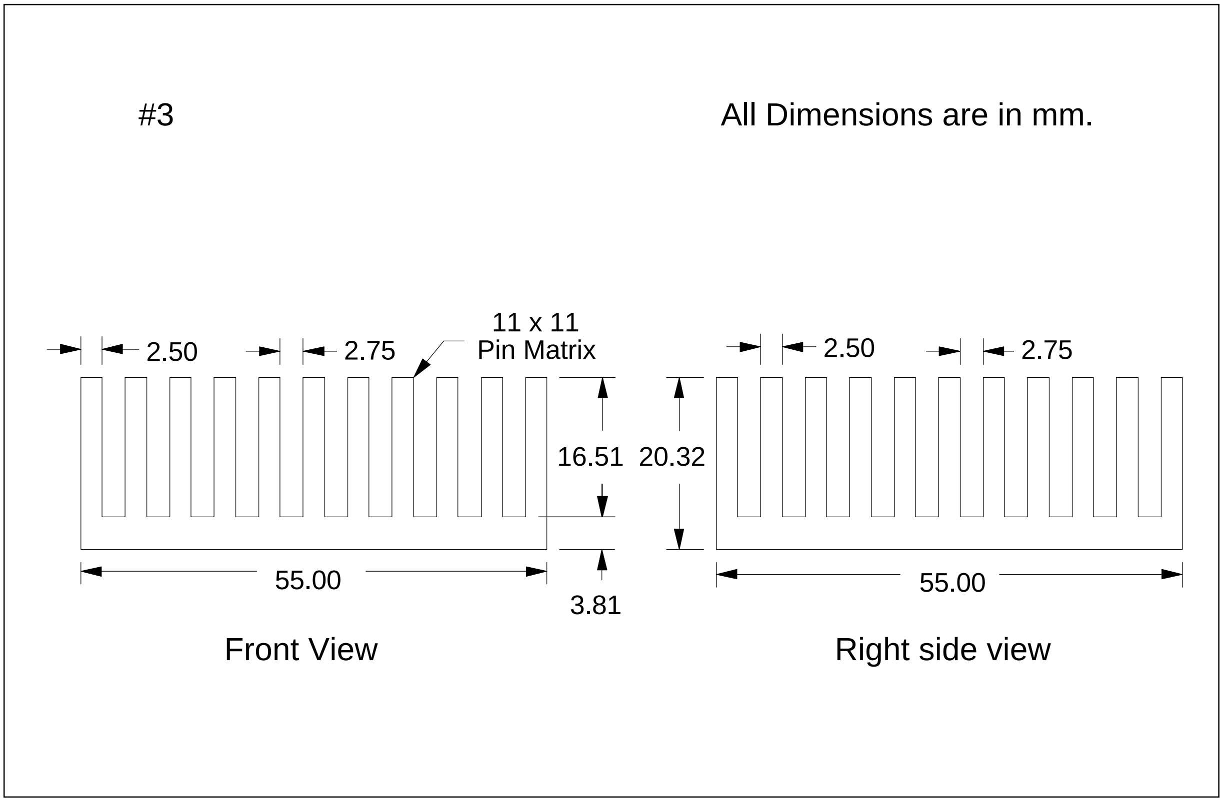
All Dimensions are in mm.



Appendix A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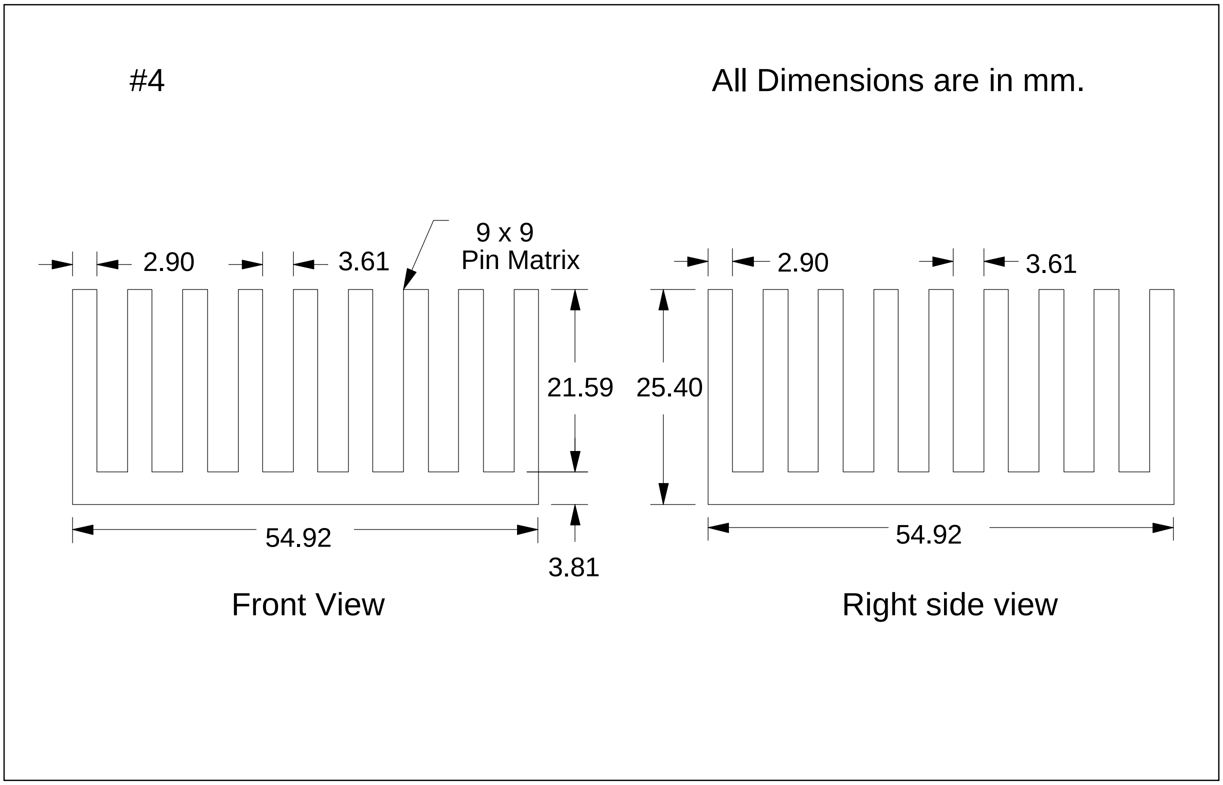
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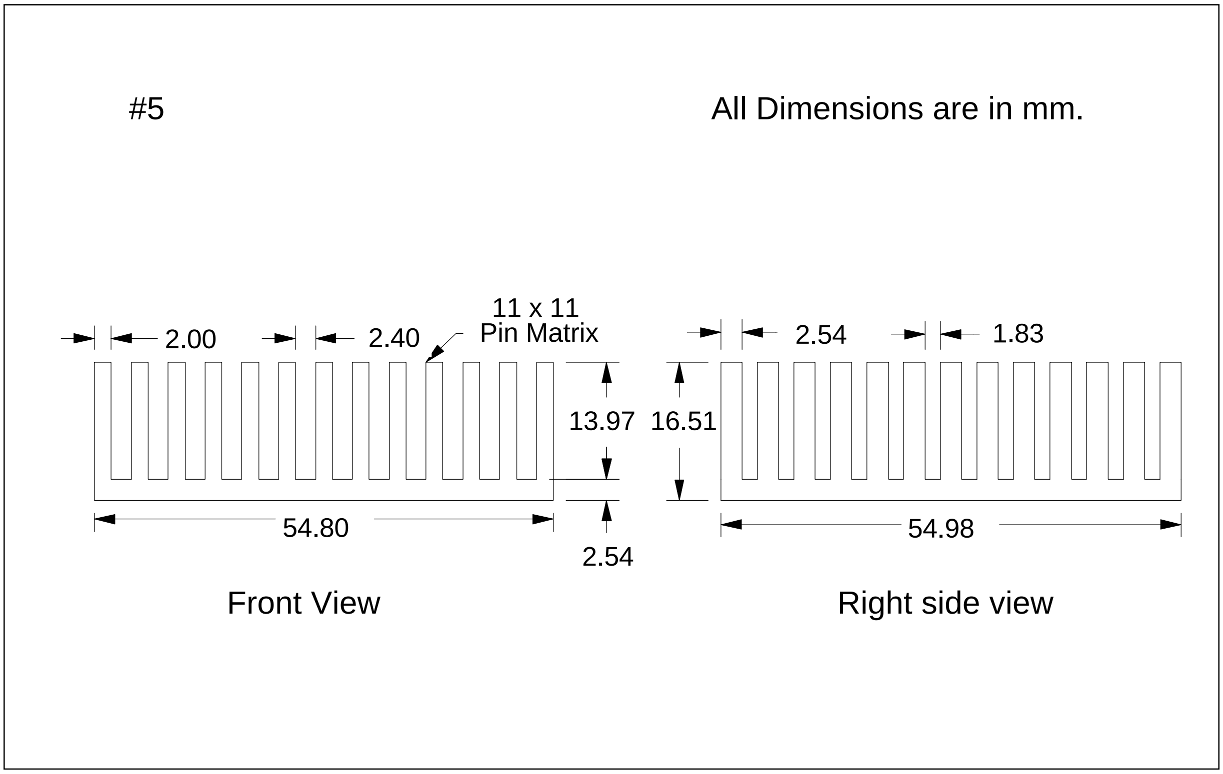
All Dimensions are in mm.

Appendix A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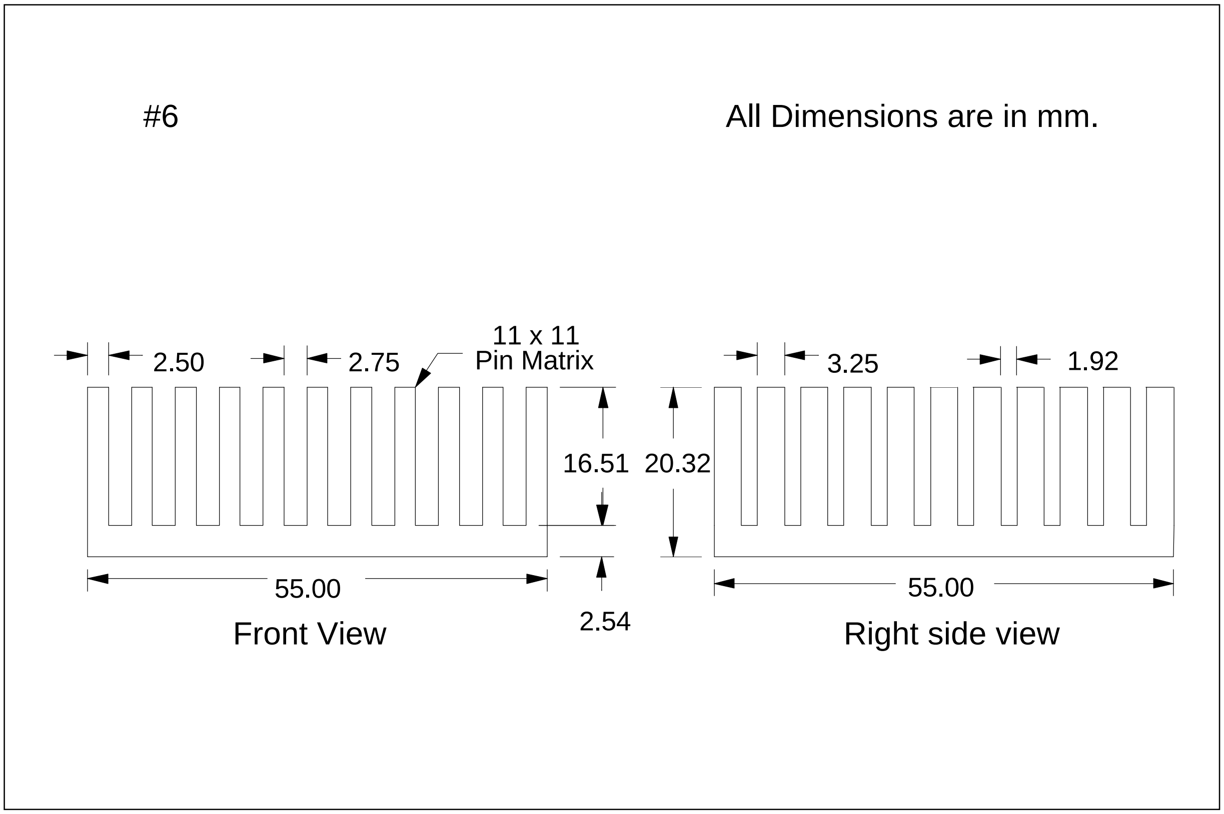
All Dimensions are in mm.
2.00
2.40
11 x 11
Pin Matrix
2.54
1.83
13.97
16.51
54.80
54.98
2.54
Front View
Right side view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All Dimensions are in mm.
2.50
2.75
11 x 11
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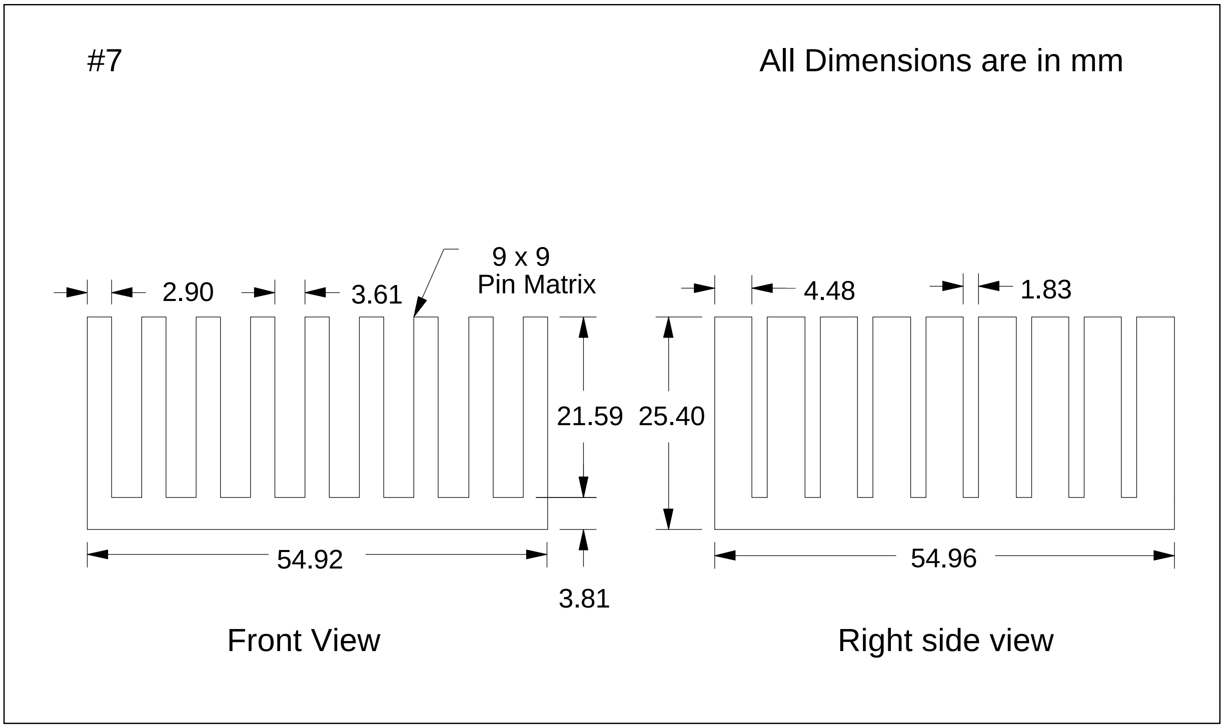
1.92
16.51
20.32
55.00
55.00
2.54
Front View
Right side view

Appendix A



Heatsink Number	Pin Fin Matrix	Heatsink Height	Air Flow 200 FPM	Air Flow 300 FPM	Air Flow 400 FPM	Air Flow 600 FPM	Air Flow 800 FPM	Air Flow 1000 FPM
1	15 X 15	12.54	2.60	1.91	1.53	1.26	1.14	1.08
2	13 X 13	16.51	2.50	1.83	1.47	1.21	1.09	1.05
3	11 X 11	20.32	2.35	1.73	1.38	1.14	1.03	0.99
4	9 X 9	25.40	2.35	1.72	1.37	1.13	1.02	0.98
5	13 X 13	16.51	2.20	1.59	1.25	1.04	0.94	0.91
6	11 X 11	20.32	2.06	1.47	1.15	0.96	0.87	0.80
7	9 X 9	25.40	1.83	1.29	1.00	0.83	0.76	0.72

Table 3. Sink-to-Ambient Thermal Resistance vs. Air Flow

Notes:

1. Thermal Resistance in above Table 3. are in Degrees C per watt.
2. FPM stands for feet per minute.

Appendix A

NO.	VENDOR	PART NUMBER	OVERALL DIMENSIONS IN INCHES	THERMAL RESISTANCE AT 200 FPM	THERMAL RESISTANCE AT 400 FPM
1	IERC	P54B04CB/SC5	1.95X1.95X0.98	2.20	1.30
2	IERC	PS519B/SC5	2.138X2.28X1.25	1.60	1.00
3	IERC	PS507B/SC5	2.138X4.87X0.40	2.00	1.00
4	IERC	PS513B/SC5	2.138X2.96X0.61	1.90	1.10
5	IERC	P54B03CB/SC5	2.72X1.9X0.64	2.20	1.30
6	AAVID	338721B/SC5	2.3X2.3X0.84	1.40	0.90
7	WAKEFIELD	798-100	2.1X1.917X1	1.96	1.10

Table 4. Selected Heatsinks from the Vendor Catalog

The information contained in this appendix was obtained from the respective vendors heatsink catalogs and is subject to change without notice.

Appendix B

Fan/Heatsink Solution

A few options are available in selecting a fan/heatsink solution. One is to select a fan/sink assembly offered by a supplier of your choice. The supplier usually provides the sink-to-ambient thermal resistance of the fan/sink assembly along with mechanical specifications. Table 5 below aids in selecting an appropriate fan/sink assembly for a given system ambient temperature and microprocessor internal clock frequency. For instance, for a given system ambient temperature of 40 degrees C in the user's system and an IBM 100 MHz 6x86 microprocessor, the maximum required sink-to-ambient thermal resistance of the fan/sink assembly would be 1.47 degrees C per watt and can be found at the first row and fourth column of Table 5. If the selected fan/sink assembly has a sink-to-ambient thermal resistance of 1.47 degrees C per watt or less, the fan/sink assembly would keep the case temperature of the IBM 6x86 microprocessor within the specification limit of 75 degrees C.

Internal Clock Freq. in MHz	System Ambient Temperature:				
	30 Degree C	35 Degree C	40 Degree C	45 Degree C	50 Degree C
100	1.92	1.70	1.47	1.24	1.01
110	1.76	1.55	1.34	1.13	0.92
120	1.66	1.46	1.26	1.06	0.86
133	1.53	1.34	1.16	0.97	0.79
150	1.53	1.34	1.16	0.97	0.79

Table 5. Sink-To-Ambient Thermal Resistance in °C per Watt for the IBM 6x86 Microprocessor

A 709-100AB124 fan/sink assembly offered by Wakefield Engineering has a sink-to-ambient thermal resistance of 1.30 degrees C per watt[2]. As you can see from Table 5, this fan/sink assembly provides an adequate thermal solution for the 6x86 microprocessor at 100 MHz and a maximum system ambient temperature between 40 and 45 degrees C, for the 6x86 microprocessor at 120 MHz and a maximum system ambient temperature between 35 and 40 degrees C and for the IBM 6x86 microprocessor at 110 MHz and a maximum system ambient temperature just above 40 degrees C.

The second option is to select an appropriate heatsink first and then select an adequate fan for the heatsink. For a given system ambient temperature and internal clock frequency of the IBM 6x86 microprocessor, determine the required maximum sink-to-ambient thermal resistance from the Table 5. For instance, for a 40 degree C system ambient temperature and the 6x86 microprocessor at 120 MHz, the maximum required sink-to-ambient thermal resistance would be 1.26 degrees C per watt found from Table 5. Now, select a heatsink that satisfies the thermal resistance requirement (1.26). The sink-to-ambient thermal resistance of the heatsink varies with the air flow. The greater the air flow, the lower the thermal resistance of the heatsink. Determine the minimum air flow

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[2] Wakefield Engineering Heatsink Catalog

required to achieve the required sink-to-ambient thermal resistance for a selected heatsink. For instance, heatsink #7 from Table 3 in Appendix A provides the sink-to-ambient thermal resistance of 1.0 degrees C per watt at 400 linear feet per minute air flow over the heatsink pins. Select a fan which provides at least 400 feet per minute air flow. Note that impinged air flow is 10 - 20% more effective than the linear air flow. Some system may have a fan or blower installed that also provides some linear air flow. This, in turn, allows you to select a smaller heatsink or to select a fan with less capacity. The fan can be mounted on the top of the heatsink with an appropriate attachment method.

Option three is similar to the second option. The fan is selected first and then the heatsink is chosen. Once a fan is selected, determine the air flow capacity in linear feet per minute. Now, for a given system ambient temperature and internal clock frequency of the IBM 6x86 microprocessor, determine the required maximum sink-to-ambient thermal resistance from Table 5. Select a heatsink that has at least the minimum sink-to-ambient thermal resistance at the fan's linear air flow capacity.

Note that once the thermal requirements are met in any of three options, the next step is to ensure that the selected thermal solution fits physically in the system. If the selected thermal solution does not fit physically in the system, an alternate fan, heatsink or fan/sink assembly can be selected using the same steps above.

Appendix C

Heatsink Suppliers

Aavid Thermal Technologies
One Kool Path
PO Box 400
Laconia, NH 03247
Telephone (603)528-3400
FAX (603)528-1478

Thermalloy Inc.
2021 W. Valley View
Dallas, TX 75234
Telephone (214)243-4321
FAX (214)241-4656

Wakefield Engineering
60 Audubon Road
Wakefield, MA 01880
Telephone (617)245-5900
Fax (617)246-0874

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

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

Appendix D

Fan Suppliers

Densitron Corp. **
Camden, SC
Tel. (803)432-5008
Fax (803)432-1165

ETRI **
Monroe, NC
Tel. (704)289-5423

EME Fan & Motor, Inc./Sunon****
Tel. (714)583-9802

Evox-Rifa**
100 Tri-state International
Ste. 290
Lincolnshire, IL 60069
Tel. (708)948-9511
Fax (708)948-9320

North American Capacitor Company**
7545 Rockville Road
Indianapolis, IN 46214
Tel. (317)273-0090
Fax (317)273-2400

Operating Technical Electronics, Inc. **
Grand Prairie, TX
Tel. (214)988-6828

Panasonic Industrial Company**
Division of Matsushita Electric **
Corporation of America,
Industrial Motor Department
Two Panasonic Way, Panzip 7E-4
Secaucus, NJ 07094
Tel. (201)392-4923
Fax (201)392-4315

Sanyo Denki Co., Ltd. **
Torrance, CA
Tel. (310)212-7724
Fax (310)212-6545

Vemaline**
Division of Square Head Inc.**
Warwick, RI
Tel. (401)739-7600
Fax (401)732-6119

Appendix E

Thermoelectric Cooler Suppliers

Alpha & Omega Computer **
Tel. (714)577-7688

Atramet Inc. **
Farmingdale, NY
Tel. (516)694-9090 x135
Fax (516)694-9177

International Thermoelectric, Inc. **
Chelmsford, MA
Tel. (508)452-0212
Fax (508)452-0104

Marlow Industries, Inc. **
10451 Vista Park Road
Dallas, TX 75238
Tel. (214)342-4296
Fax (214)341-5212

Melcor **
1040 Spruce Street
Trenton, NJ
Tel. (609)393-4178
Fax (609)393-9461

Appendix F

Heat Pipe Supplier

Thermacore Inc. **
780 Eden Road
Lancaster, PA 17601
Tel. (717)569-6551
Fax (717)569-4797

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