PAH-S48 SERIES

THERMAL DESIGN

POWER MODULE

DRAWING NO. : PA548-04-02		
NLS R&D		
PREPARED	CHECKED	APPROVED
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DATE ISSUE : ↟	⁶| ⁹ ⁹		

PAH-S48 SERIES Thermal Design

1. THERMAL DESIGN

To ensure proper operation of power module, it is necessary to keep the baseplate temperature within the allowable temperature limit. The reliability of the system is determined by design of the baseplate temperature.

The process of thermal design is described through an example of PAH-S48 Series. The flow chart is shown in Figure1-1.
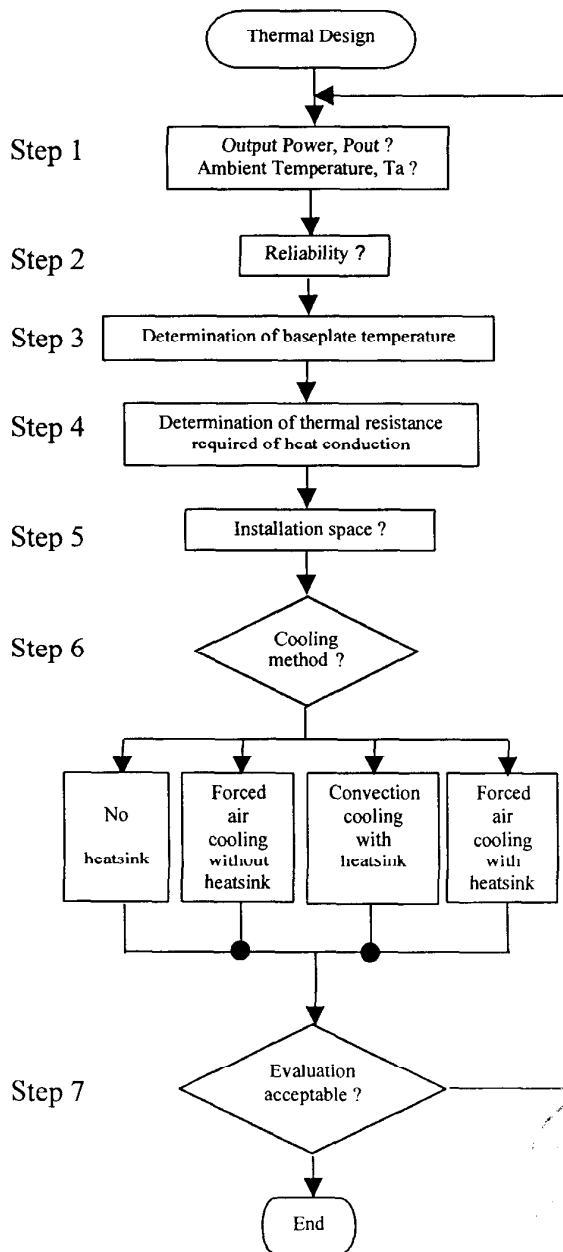

Figure1-1 Flow Chart of Thermal Design

● STEP 1
Determine the required output power (P_{out}) and ambient temperature (T_a) of power module.

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Model :-  PAH75S48-5
      Pout = 75W
      Ta = 30°C
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● STEP 2, 3
The baseplate temperature is determined by the required reliability. Table 1-1 shown below is the baseplate temperature required by the application and the grade.

Application	Baseplate Temperature	Equivalent Grade
Public	below 70°C	G1
Industrial	below 80°C	G2
General	below 85°C	G3
General	below 100°C	G4

Table1-1 Baseplate Temperature and Reliability

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Assuming the apparatus is
for general, the baseplate
temperature is set up to
below 100°C.
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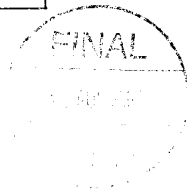
● STEP 4
Determine the required thermal resistance of the heatsink.

(1) Calculate the internal power dissipation

$$P_d = \frac{1-\eta}{\eta} \times P_{out} \qquad \text{(Equation1-1)}$$

P_d : Internal Power Dissipation (W)
P_{out} : Output Power (W)
η : Efficiency (%)

PAH-S48 SERIES Thermal Design

Efficiency is calculated by following equation.

$$\eta = \frac{Pout}{Pin} \times 100\% \quad \text{(Equation1-2)}$$

η	: Efficiency (%)
P_{out}	: Output Power (W)
P_{in}	: Input Power

Efficiency changes with input voltage and output current and every model have their own efficiency characteristic. For examples, the efficiency data of PAH75S48-5 is shown in Figure 1-2.
To determine the internal power dissipation, give 1~2 % margin of the efficiency value which is obtained from the Characteristics of Efficiency vs. Output Current.

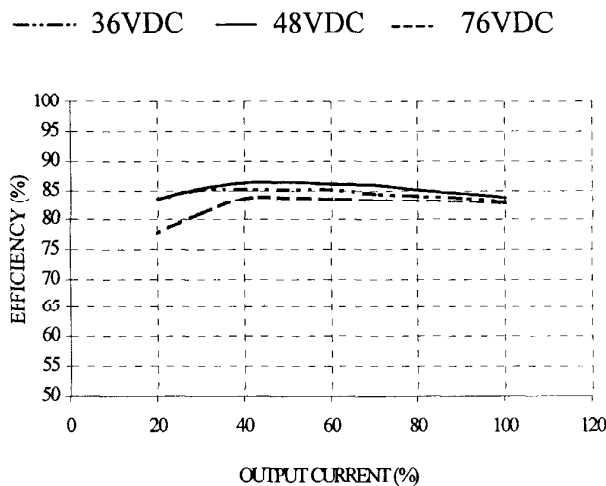------ 36VDC ——— 48VDC ---- 76VDC

Figure1-2 PAH75S48-5 Characteristics of Efficiency vs. Output Current

From Figure 1-2, the efficiency at 48VDC nominal voltage and 100% output current is 83.8%. To give 2% margin, the efficiency will be as follow.

Efficiency, $\eta = 81.8\%$

$$P_d = \frac{1-0.818}{0.818} \times 75$$
$$= 16.687W$$

(2) Calculate the required thermal resistance of the heatsink.

$$\theta_{bp-a} = \frac{T_{bp} - T_a}{P_d} \quad \text{(Equation1-3)}$$

θ_{bp-a}	: Thermal Resistance (°C/W) (baseplate - Air)
P_d	: Internal Power Dissipation (W)
T_a	: Ambient Temperature (°C)
T_{bp}	: Baseplate Temperature (°C)

The actual thermal resistance of heatsink is calculated by the following equation.

$$\theta_{hs-a} = \theta_{bp-a} - \theta_{bp-hs} \quad \text{(Equation1-4)}$$

θ_{hs-a}	: Actual Thermal Resistance of Heatsink (°C/W) (Heatsink -Air)
θ_{bp-hs}	: Actual Contact Thermal Resistance (°C/W) (Baseplate - Heatsink)

Contact thermal resistance is thermal resistance of surface between baseplate and heatsink. To decrease the contact thermal resistance, silicone grease is using.
Recommended torque of screws to fix the power module is 5.5 kgcm.
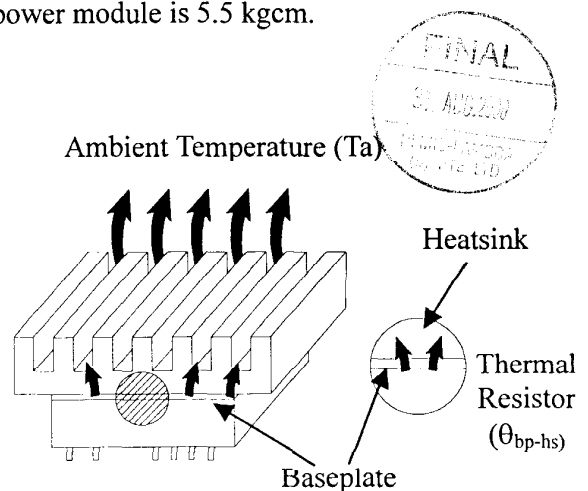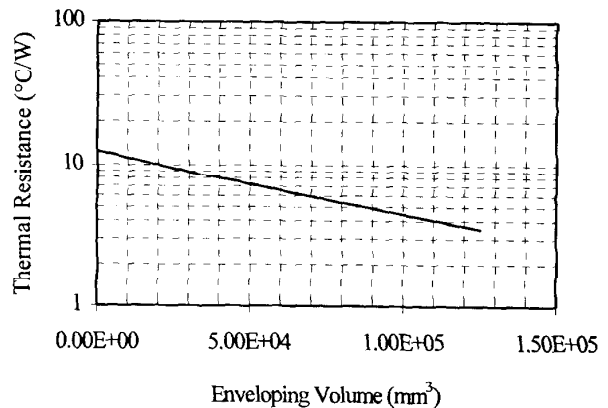
Figure 1-3 Contact Thermal Resistance

PAH-S48 SERIES Thermal Design

● **STEP 5**

$$\theta_{bp\text{-}a} = (100 - 30) / 16.687 \text{ °C/W}$$
$$= 4.1948 \text{ °C/W}$$

Assume the contact thermal resistance
($\theta_{bp\text{-}hs}$) to be 0.2 °C/W,
then thermal resistance of heatsink shall be

$$\theta_{hs\text{-}a} = 4.1948 - 0.2 \text{ °C/W}$$
$$= 3.9948 \text{ °C/W}$$

Below shown the calculation for heatsink space when the power module is mounted.

Assume mounting space to be

61.0 mm (W) x 60.0mm (L) x 25.7mm (H)

The size of PAH75S48 is

61.0mm (W) x 57.9mm (L) x 12.7 mm (H)

Hence, the available thermal space is approximately

61.0mm (W) x 60.0mm (L) x 13.0 mm (H)

● **Step 6**

Investigate cooling method which satisfies the power module in allowable mounting space.

(1) Convection Cooling

The required volume of heatsink to be obtained the thermal resistance calculated in Step 4 at convection cooling given by relation of enveloping volume of heatsink and thermal resistance shown in Figure1-4.

This characteristic is for aluminum heatsink that has proper fin intervals (if the intervals are too narrow, ventilation resistance increase and also heat dissipation decreased.) Enveloping volume is the volume occupied by the outline of heatsink. The enveloping volume which is calculated here is the approximate volume of required heatsink of convection cooling. However, thermal resistance would be influenced by shape of heatsink; therefore, refer to the detailed thermal resistance data supplied by the manufacturer prior to the selection.

Figure1-4   Enveloping Volume of Heatsink vs. Thermal Resistance

In most cases, the thermal resistance data from the manufacturer is data of vertical mounting. Hence, be noticed that cooling efficiency would be greatly decreased in a case that the heatsink horizontally mounted.

If the selected heatsink satisfied into the mounting space, proceed to STEP 7. Otherwise, investigate forced air method.

(2) Forced Air Cooling

In forced air cooling method, heat dissipation ability of the heatsink improves much higher than convection cooling.

Thermal design with forced air cooling can not be calculated easily because air inside of chassis is not uniformly convected. This is cause by complicated shape and construction of chassis. Followings show a simplified method (1) to measure wind velocity and (2) to calculate the thermal resistance of a chassis model.

Firstly, make a chassis model that take into consideration the shape of chassis, number of fans and its disposition, wind blows direction against heatsink, and layout of components around heatsink. Then measure the velocity of inflow and outflow wind by anemometer while the fans are operating. It shall be measured at the center of heatsink as shown in Figure 1-5. Consequently, average velocity of inflow and outflow winds is assigned as the velocity in the graph of thermal resistance and wind velocity characteristics of heatsink.
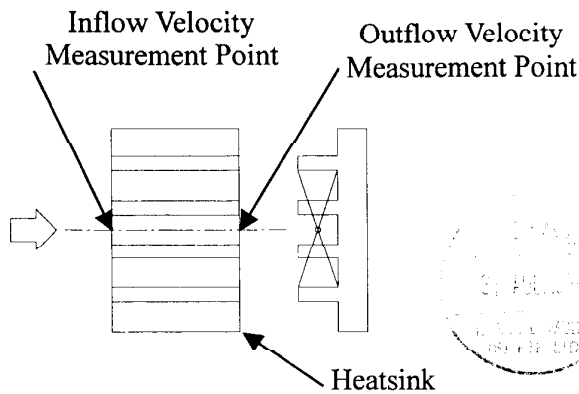
PAH-S48 SERIES Thermal Design

Figure1-5 Flow Velocity Test Point

$$\text{Velocity Average} = \frac{(\text{Inflow} + \text{Outflow})}{2}$$
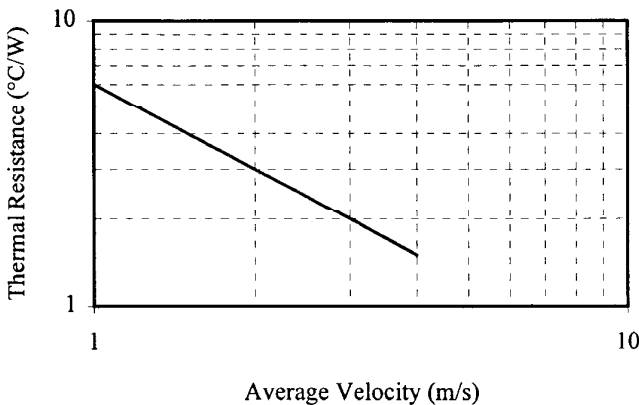
● **Standard Heatsink (6515B) [Thermalloy]**

Figure1-6 Thermal Resistance of Heatsink
vs. Flow Velocity Characteristics

Thermal resistance can be obtained by assigning the measured wind velocity to characteristics of heatsink.

Confirm this thermal resistance would be less than the calculated thermal resistance in STEP 4. If the thermal resistance does not meet the requirement, change the number and/or characteristic of fans or reconsider the structure of chassis to obtain the required thermal resistance.

Calculate the required enveloping volume of heatsink in convection cooling. According to Figure 1-4, the enveloping volume of the required thermal resistance suppose to be larger than $7.5 \times 10^{-4}\ \text{mm}^3$.

For the mounting space condition, volume of heatsink is approximately $4.3 \times 10^{-4}\ \text{mm}^3$ hence, it can not be fitted. Therefore, the forced air cooling method is required. To satisfy above condition, Thermalloy (vendor) standard heatsink is used in this model.

From Figure 1-6, in order to obtain the thermal resistance below 3.9948 °C/W, it is necessary to keep the wind velocity more than 1.6m/s.

In forced air cooling method, protections against failure fans, countermeasures against noise and dust of fans, and air flow management must be taken into consideration.

If forced air cooling method is accepted, proceed to Step 7. If not, redesign again.

● **Step 7**

Confirm the design by experiment. Estimate the baseplate temperature by following equation.

$$\begin{aligned} T_p &= T_a + P_d \times \theta_{bp\text{-}a} \\ &= T_a + P_d \times (\theta_{bp\text{-}hs} + \theta_{hs\text{-}a}) \quad (\text{Equation1-6}) \end{aligned}$$

T_p : Baseplate Temperature (°C)
T_a : Ambient Temperature (°C)
Pd : Internal Power Dissipation (W)
$\theta_{bp\text{-}a}$: Thermal Resistance (°C/W)
     (Baseplate - Air)
$\theta_{bp\text{-}hs}$: Contact Thermal Resistance (°C/W)
     (Baseplate - Heatsink)
$\theta_{hs\text{-}a}$: Thermal Resistance of Heatsink (°C/W)
     (Heatsink - Air)

Confirm the baseplate temperature is lower than its target temperature in Step 3. If it is achieved, the thermal design is completed. If not, redesign.

Measure the baseplate temperature at the center of the baseplate. If it is impossible such as structural problem of the heatsink, measure at a point as close as possible to the center.

PAH-S48 SERIES Thermal Design

The maximum baseplate temperature is 100°C. Confirm the baseplate temperature at a measurement point shown as Figure 1-7 in the worst condition.
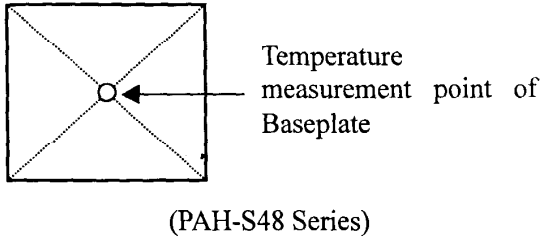
<Convection cooling>
(1) 6517B – 3.2°C/W
(2) 6516B – 4.4°C/W
(3) 6515B – 9.1°C/W
(4) 6514B – 11.0°C/W

Temperature measurement point of Baseplate

(PAH-S48 Series)

Figure1-7   Temperature Measurement Point of Baseplate

Enveloping Volume (mm³)
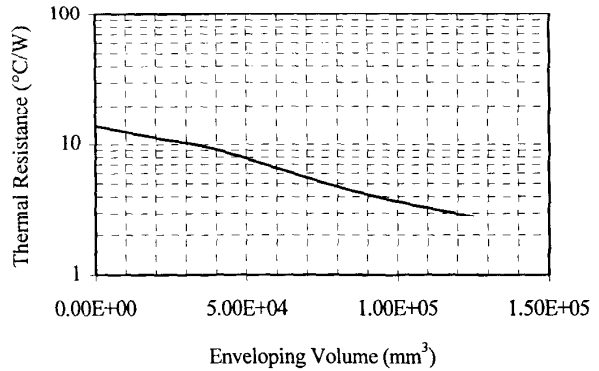
Figure2-1   Characteristics of Thermal Resistance vs. Volume For Standard Heatsink

Experiment shall be conducted with PAH75S48-5. Measure the baseplate temperature at the actual condition (Pout = 75W, Ta = 30°C). Then confirm the baseplate temperature has been kept below 100°C. The thermal design is completed.

<Forced Air Cooling>

2. STANDARD HEATSINK

Standard heatsink is provided in each power module package.
The thermal resistance value is more precise when heatsink is apply with silicone grease.

- **Standard Heatsink [Termalloy]**

Application :- PAH-S48 Series.

<Size>
(1) 6517B – 57.91mm (L) x 60.96mm (D) x 35.56mm (H)
(2) 6516B – 57.91mm (L) x 60.96mm (D) x 24.13mm (H)
(3) 6515B – 57.91mm (L) x 60.96mm (D) x 11.43mm (H)
(4) 6514B – 57.91mm (L) x 60.96mm (D) x 6.10mm (H)
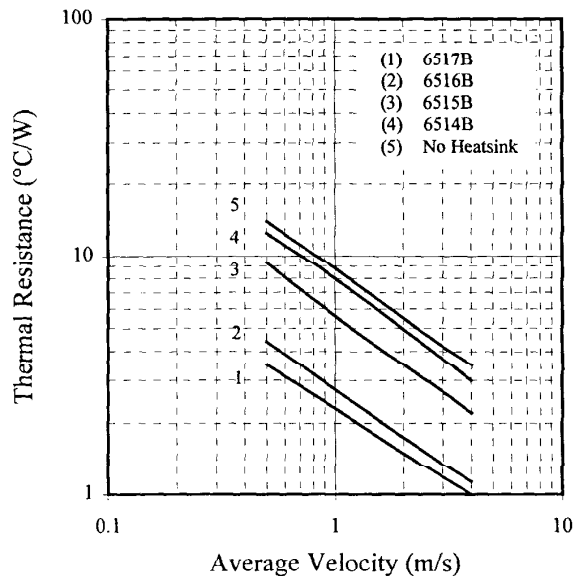

Average Velocity (m/s)

Figure2-2   Characteristics of Thermal Resistance vs. Wind Velocity for Standard Heatsink