PH-SERIES Thermal Design

1. THERMAL DESIGN

To ensure proper operation of power module, it is necessary to keep 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 PH150F280-5. The flow chart is shown in Figure1-1.

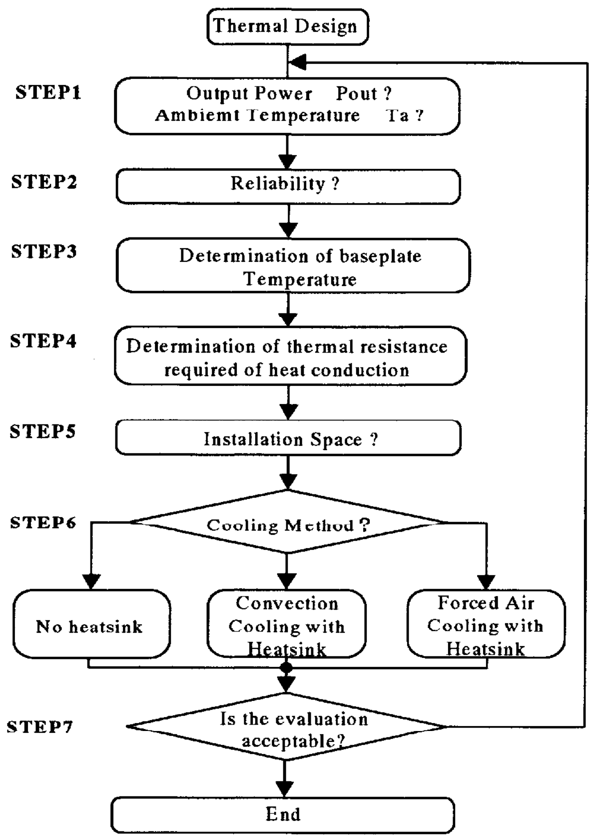

Figure1-1 : Flow Chart of Thermal Design

● STEP 1

Determine the required output power (P_{out}) and ambient temperature (T_a).

Model : PH150F280-5 P_{out} = 150 (W) T_a = 50 (°C)

● STEP 2, 3

The baseplate temperature is determined by the required reliability.

Refer to Table1-1 : Baseplate Temperature and Reliability , determine the baseplate temperature.

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

Table1-1 : Baseplate Temperature and Reliability

Assuming the equipment is for industrial purpose, the baseplate temperature is set up below 80°C.

● STEP4

Determine the required thermal resistance.

(1) Calculate the internal power dissipation

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

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

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Efficiency is calculated by following equation.

$$\eta = \frac{P_{out}}{P_{in}} \times 100 \qquad \text{(Equation1-2)}$$

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

Efficiency changes with input voltage and output current. It depends on each model, then refer to the individual data.
Here "PH150F280-5" is used as an example.
To determine the internal power dissipation, give 1~2 % margin of the efficiency value which is calculated by Characteristics of Efficiency vs. Output Current.

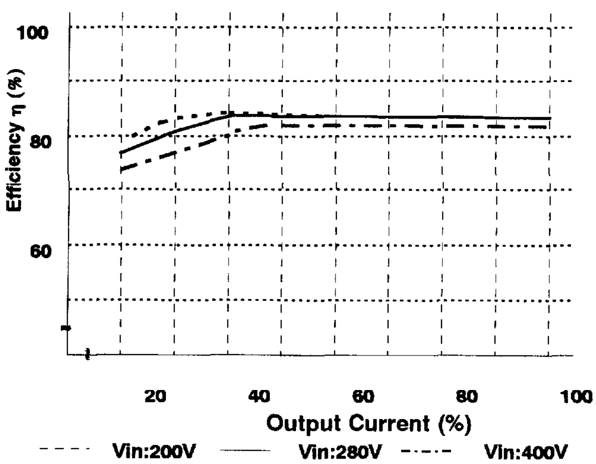

Figure1-2 : PH150F280-5 Characteristics of Efficiency vs. Output Current

Efficiency is obtained by Figure1-2.
The efficiency of PH150F280-5 is obtained by operating in 280VDC nominal voltage.
Then the efficiency is 81% at 280VDC input voltage and 100% output current.
To give 2% margin, the efficiency will be :

Efficiency η = 81 (%)

$$Pd = \frac{1-0.81}{0.81} \times 150$$
$$= 35 \text{ (W)}$$

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

$$\theta_{bp\text{-}a} = \frac{T_p - T_a}{Pd} \qquad \text{(Equation1-4)}$$

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

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

$$\theta_{hs\text{-}a} = \theta_{bp\text{-}a} - \theta_{bp\text{-}hs} \qquad \text{(Equation1-5)}$$

$\theta_{hs\text{-}a}$: Actual Thermal Resistance of Heatsink (°C/W) (Baseplate -Air)
$\theta_{bp\text{-}hs}$: 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, use silicone grease.

Recommended torque of screws to fix the power module is 5.5 kg · cm.

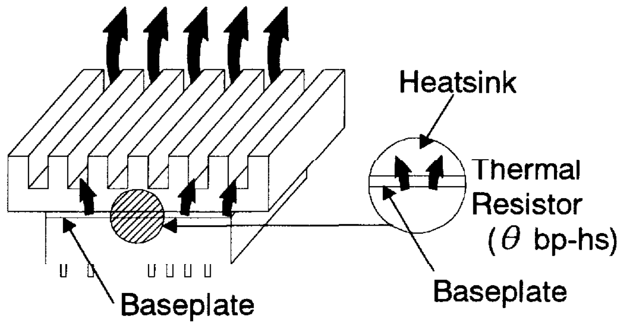

Figure1-3 : contact Thermal Resistance

- STEP 5

$\theta_{bp\text{-}a}$ = (80-50)/35
= 0.86 (°C/W)
Assume the contact thermal resistance ($\theta_{bp\text{-}hs}$) to be 0.2°C/W,
then thermal resistance of heatsink is calculated.
$\theta_{hs\text{-}a}$ = 0.86 - 0.2

See how much space can be physically kept for heatsink when the power module is mounted.

Assume mounting space to be
90(W) x 50 (H) x 90 (D) mm
Then size of PH150F is
86 (W) x 12.7 (H) x 83 (D) mm
Hence, the available thermal space is approximately
90 (W) x 37 (H) x 90 (D) mm

- 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.

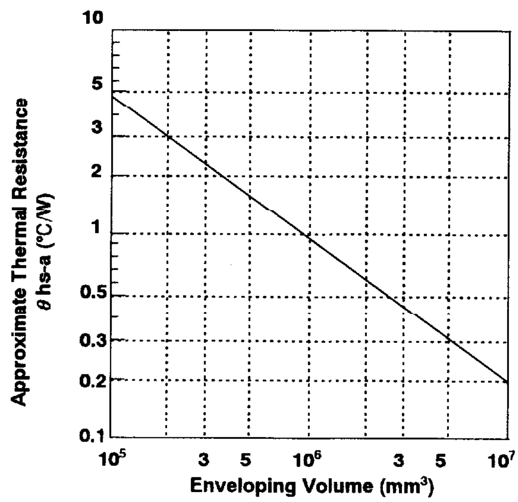

Figure1-5 : Enveloping Volume of Heatsink vs. Thermal Resistance

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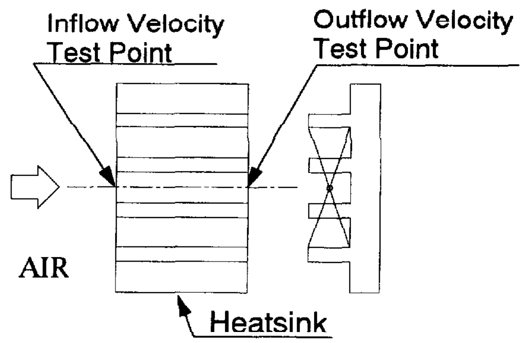
In the most of cases, the thermal resistance data from the manufacturer is data of vertical mounting. Hence, be noticed that cooling efficiency would be greatly decreased in a case that the heatsink horizontally mounted. If the selected heatsink satisfied into the mounting space, proceed to STEP7. Otherwise, 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 convection. This is causes of complicated shape and construction of chassis and disheveled convection inside of chassis by fans and high density of mounted component. Moreover, many literature introduce the calculation method, nevertheless, most of them are not utility for many specified conditions.
Therefore, a method that measures wind velocity of chassis model and then estimates the thermal resistance.
At first, make a chassis model that is considered with shape of chassis, number of fans and its disposition, direction wind blows 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 shown as Figure1-6. In 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.



$$\text{Avg. Velocity} = \frac{\text{Inflow Velocity} + \text{Outflow Velocity}}{2}$$

Figure1-6 Flow Velocity Test Point

- [T83] Standard Heatsink (HAA-083)

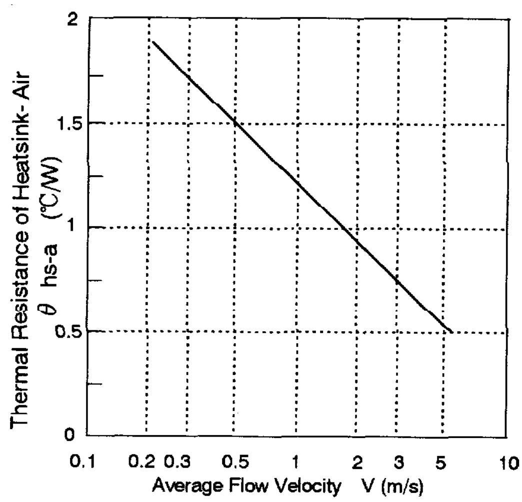


Figure1-7 : Thermal Resistance of Heatsink vs. Flow Velocity Characteristics

Thermal resistance is presumed by assigning the measured wind velocity to characteristics of heatsink.
Confirm this thermal resistance would be less than the calculated thermal resistance in STEP4. If the thermal resistance is not obtained as required, 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 Figure1-5, the enveloping volume of the required thermal resistance supposes to be larger than $1.6 \times 10^6 mm^3$.
In the mounting space condition, volume of heatsink is approximately $3.0 \times 10^5 mm^3$, and it can not be fitted in the mounting space. Therefore, the forced air cooling method is required.
To obtain the thermal resistance below 0.66°C/W on the characteristics of heatsink, HAA-083 shown in Figure1-7, it is necessary to keep the wind velocity more than 3.8 m/s.
Measure the wind velocity in model chassis and confirm the required wind velocity can be obtained.

In forced air cooling method, protections against failure fans, countermeasures against noise and dust of fans, and air flow management must be concerned.
If forced air cooling method is accepted, proceed to Step 7. If not, reconsider another cooling method such as water cooling or redesign.

- Step 7

Confirm the performance designed by experiences. Estimate the baseplate temperature by following equation.

$$T_p = T_a + Pd \times \theta_{bp\text{-}a}$$
$$= T_a + Pd \times (\theta_{bp\text{-}hs} + \theta_{hs\text{-}a})$$

(Equation1-6)

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)
$\theta_{bp\text{-}hc}$ = 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.

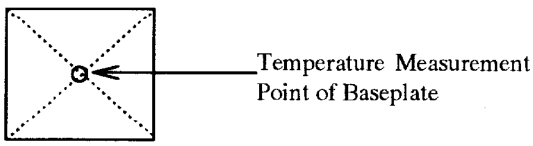


Figure1-7 : Temperature Measurement Point of Baseplate

Experience shall be conducted with PH150F280-5.
Measure the baseplate temperature at actual conditions (P_{out} = 150W, T_a = 50°C).
Then confirm the baseplate temperature has been kept below 80°C.
The thermal design is completed.

2. STANDARD HEATSINK

Standard heatsink is provided in each power module package.
The thermal resistance is a value heatsink with thermal grease.

1. [T41] Heatsink
   size : 86 (W) x 41 (D) x 22.5 (H) mm
   Application : PH50S, PH75S
   <Convection Cooling>
   Thermal resistance : approx. 3.9 (°C/W)
   <Forced Air Cooling>

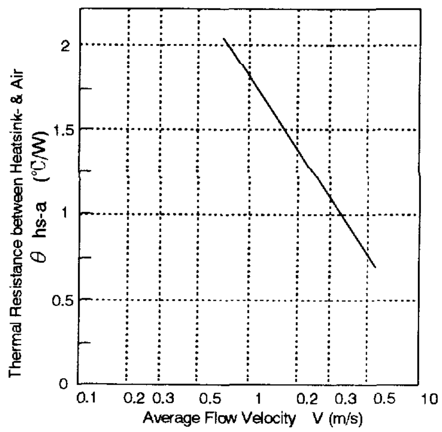


Figure2-1 : Characteristics of Thermal Resistance vs. Wind Velocity for [T41] Heatsink

2. [T62] Heatsink (HAA-062)
   size : 86 (W) x 62 (D) x 22.5 (H) mm
   Application : PH75F, PH100S
   <Convection Cooling>
   Thermal resistance : approx. 3.2 (°C/W)
   <Forced Air Cooling>

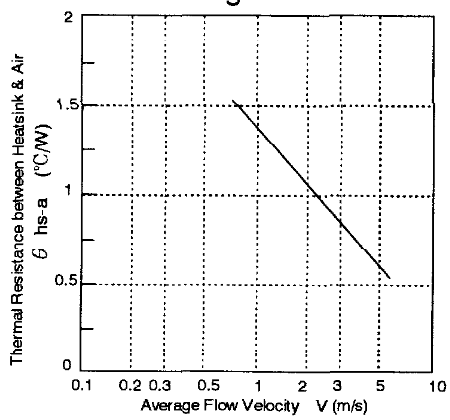


Figure2-2 : Characteristics of Thermal Resistance vs. Wind Velocity for [T62] Heatsink

3. [T72] Heatsink (HAA-072)
   size : 86 (W) x 72 (D) x 22.5 (H) mm
   Application : PH150S
   <Convection Cooling>
   Thermal resistance : approx. 3.0 (°C/W)
   <Forced Air Cooling>

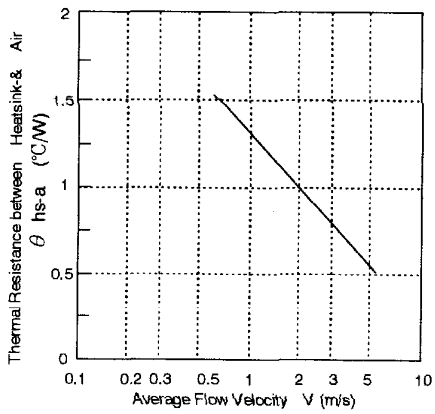


Figure2-3 : Characteristics of Thermal Resistance vs. Wind Velocity for [T72] Heatsink

4. [T83] Heatsink (HAA-083)
size : 86 (W) x 83 (D) x 22.5 (H) mm
Application : PH150F, PH100F
<Convection Cooling>
Thermal resistance : approx. 2.7
(°C/W)

<Forced Air Cooling>

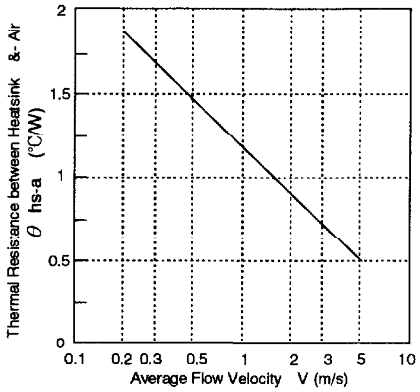


Figure2-4 : Characteristics of Thermal Resistance vs. Wind Velocity for [T83] Heatsink

5. [T146] Heatsink (HAA-146)
size : 86 (W) x 146 (D) x 22.5 (H) mm
Application : PH300F
<Convection Cooling>
Thermal resistance : approx. 1.7
(°C/W)

<Forced Air Cooling>

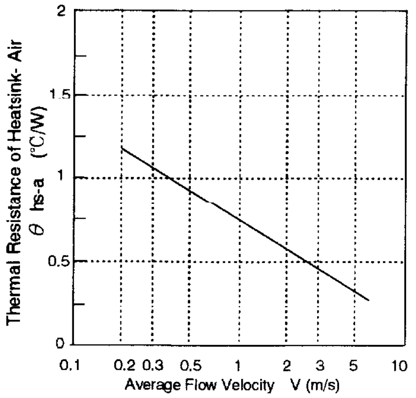


Figure2-5 : Characteristics of Thermal Resistance vs. Wind Velocity for [T146] Heatsink