3.0 AMPSS® Thermal Management

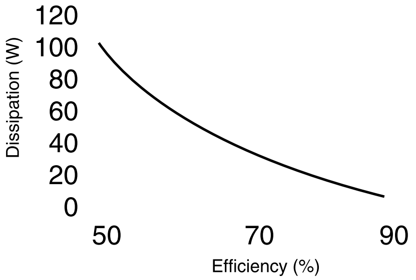
3.1 Introduction

The quality of thermal management techniques employed in equipment design directly affects performance and reliability. Where ***AMPSS*** modules form part of a design, good thermal management will ensure that heat generated by the modules is effectively controlled to maintain the required level of reliability and performance of the modules and the equipment they are used in over the full range of operating conditions.

3.1.1 Efficiency vs Heat Dissipation

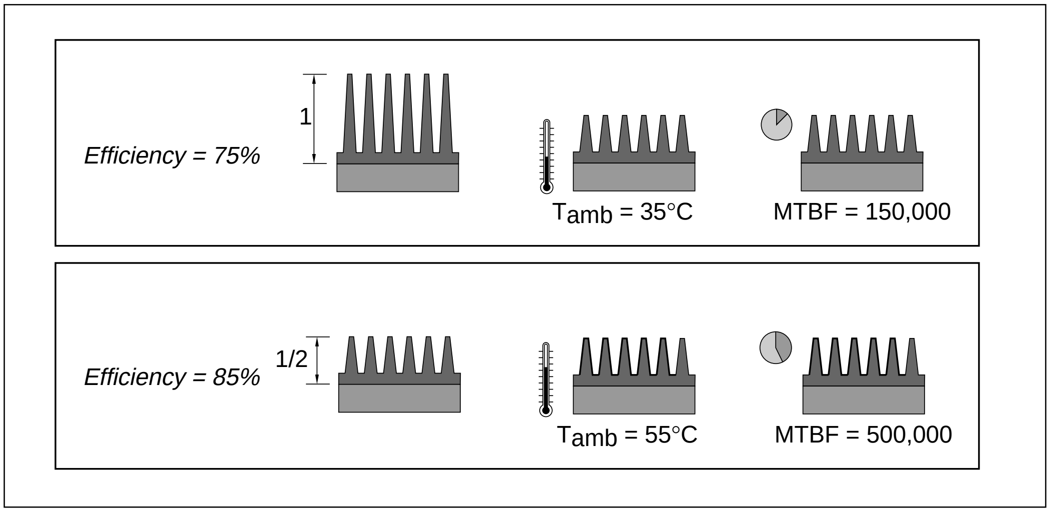
In a DC-DC converter, a small proportion of the input power is not converted to output power, but is dissipated as heat inside the module. The amount of power dissipated depends on the efficiency of the converter, defined as the ratio of useful output power to supplied input power.
Higher efficiency is the key to simplified thermal requirements, lower operating temperature and increased reliability.

Efficiency vs.
Dissipation



The graph illustrates the effect of efficiency on dissipation of a 200W DC-DC converter. As efficiency approaches 100%, small improvements have a large effect on dissipation, so that for example, a 10% improvement in efficiency from 75% to 85% results in a 50% reduction in dissipation . This allows reduced heatsink size, greater reliability or operation in higher ambient temperatures.

Advantages
of higher
efficiency



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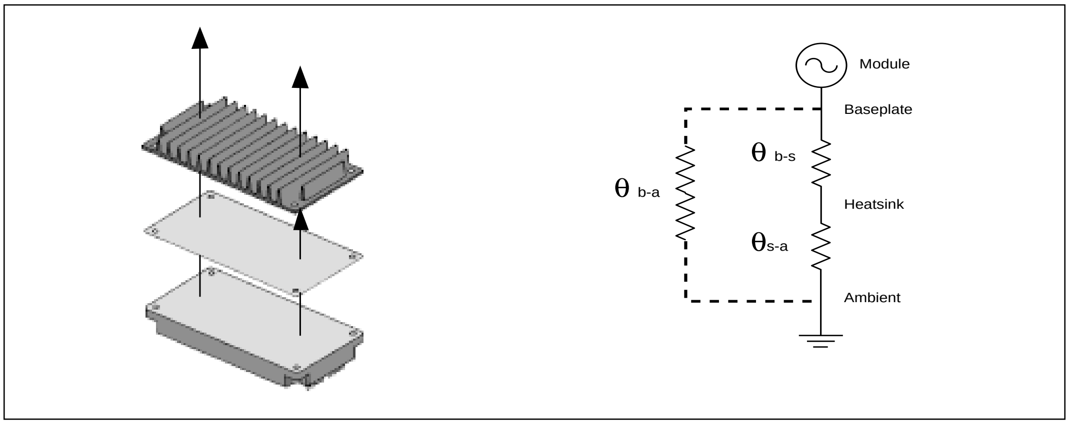
3.2 The Thermal Circuit

In a DC-DC converter module, there is a small difference between the input power to the module and the power that can be extracted from it. This difference is dissipated as heat in key components such as switching transistors and transformers inside the module. This heat is transferred to the baseplate of the module from where it must be removed using a heatsink.

DC-DC converter module thermal circuit



The heatsink is bolted to the module using thermally conductive material to fill the imperfections between the heatsink and module baseplate. The baseplate, thermally conductive material and heatsink each have their own thermal resistance which may be illustrated as in the diagram above. This circuit is expressed mathematically as:

$$\theta_{b-a} = \theta_{b-s} + \theta_{s-a}$$

where: θ_{b-a} = Thermal resistance, baseplate-to-ambient
θ_{b-s} = Thermal resistance, baseplate-to-heatsink
θ_{s-a} = Thermal resistance, heatsink-to-ambient

3.2.1 The baseplate-to-heatsink junction (q_{b-s})

The thermal interface between the baseplate of the module and the heatsink is a crucial part of the thermal design strategy. Inadequate measures taken here will quickly negate any other attempts to control the baseplate temperature.
Using a conventional dry insulator, for example, can result in a case-heatsink thermal impedance of >0.5°C/W compared to around 0.1°C/W using one of the recommended interfacing methods (silicon grease or conformant thermal pads available from Astec).
For a 200W, 85% efficient module and a 1.2°C/W heatsink, this translates to a baseplate temperature of 85°C (at 25°C ambient) compared with 70.1°C using one of the recommended interfacing methods.

To optimize the case-to-heatsink junction:

- *Use an effective interfacing method such as thermal joint compound or a conformant thermal pad.*
- *Ensure that the surface of the heatsink in contact with the module is flat, smooth and free of debris.*
- *Ensure the correct torque is used when bolting the heatsink to the module.*

3.2.2 The heatsink-to-ambient junction (q_{s-a})

In theory, the cooling effect of a heatsink should be directly proportional to its surface area, but in practice factors such as the boundary effect and thermal gradients limit this effect.

The boundary effect tends to slow down the movement of air close to the surface of the heatsink. If the distance between the fins is too small, the volume of air passing through the gaps will be significantly reduced. Increasing the airflow pressure will reduce or break up the boundary layers, allowing heatsinks in forced-air applications (usually described as high pressure heatsinks) to be designed with less space between the fins.
Temperature gradients result from poor conduction of heat to the extremities of thin or tall fins. To reduce this effect, heatsinks are generally designed with a thick section in contact with the component surface, and fins which are thick at the base, becoming thinner towards the tips.

To optimize the heatsink-to-ambient junction:

- *Use a heatsink designed to match the module and with correctly oriented fins.*
- *Ensure that the airflow across the heatsink is not obstructed by other components in the equipment.*
- *Ensure that forced airflow follows natural convection paths.*

3.3 Cooling techniques

Cooling techniques basically fall into two categories, natural (free) convection or forced air.

3.3.1 Natural Convection Cooling

The principal behind natural convection cooling is that air becomes less dense and rises when heated. This sets up a circulation current which draws in cooler air to the heated surface. Because no fan is required, natural convection cooling is far more reliable than forced air cooling.
Natural convection only works well where there is an unobstructed path for the air to flow from an inlet at the bottom of the equipment to a vent at the top. Cooling is most effective where the heatsink is mounted vertically, and heatsink data is almost always given for this orientation. If it is necessary to mount the heatsink horizontally, de-rate the heatsink thermal resistance accordingly or consider using forced air cooling.

<u>To calculate required heatsink thermal resistance</u> :

- *Calculate the maximum power to be dissipated. This is done using the formula below:*

$$P_{diss} = \frac{P_{out}}{\eta} - P_{out}$$

where:
P_{diss} *= maximum power delivered to the load*
η *= module efficiency at the operating power level (*P_{out} *).*

- *Calculate the required thermal resistance of the heatsink using the formula below:*

$$\theta_{s-a} = \left\{ \frac{T_{baseplate} - T_{ambient}}{P_{diss}} \right\} - \theta_{b-s}$$

where:
$T_{baseplate}$ *= baseplate temperature*
$T_{ambient}$ *= maximum ambient operating temperature*
P_{diss} *= maximum dissipated power*
θ_{b-s} *= thermal resistance between baseplate and heatsink*
(i.e. thermal resistance of the thermal pad or grease)

Using the heatsink-air thermal resistance figure calculated above, a suitable heatsink of the dimensions required may be selected using natural convection thermal resistance figures published by heatsink manufacturers.

Bear in mind that figures quoted are correct for heatsinks mounted with fins running vertically and with unimpeded airflow to all parts of the heatsink. If the module is to be mounted horizontally, or other components will obstruct the airflow, these figures will need to be de-rated accordingly.

3.3.2 Forced Air Cooling

In some cases it may not be possible to achieve sufficient cooling using natural convection. In these cases, forced air cooling will provide an effective solution by significantly reducing heatsink-air thermal resistance.

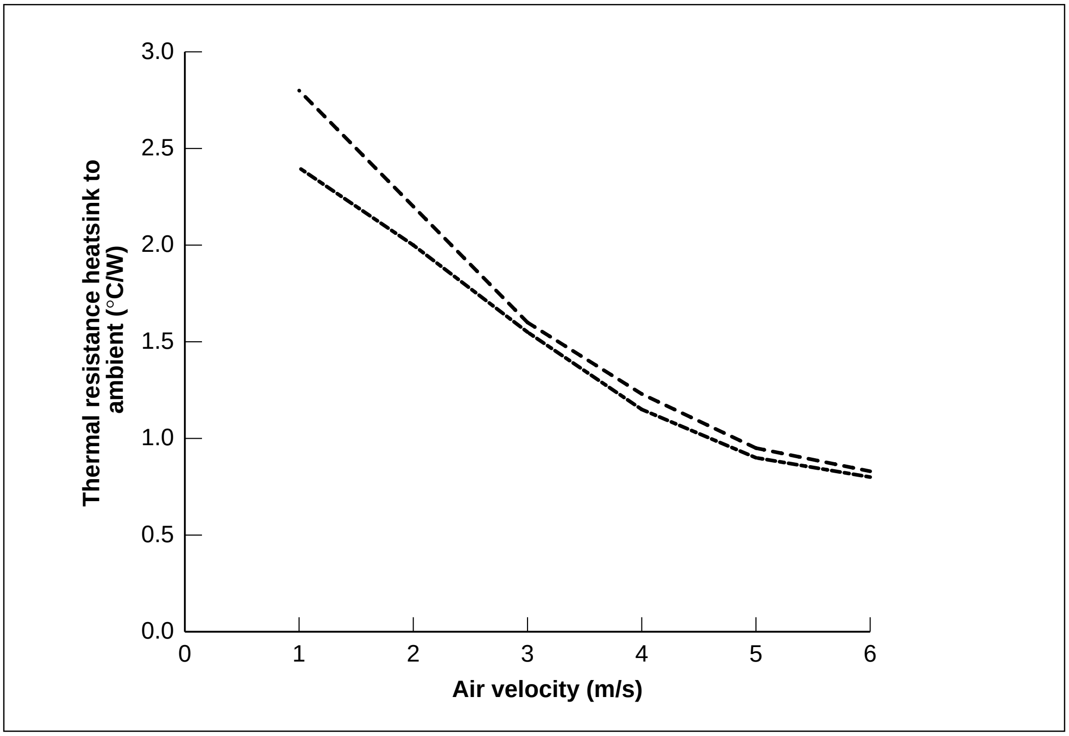
Heatsink manufacturers frequently provide two sets of curves for each heatsink, defining pressure drop through the heatsink as a function of airflow, and thermal resistance as a function of airflow.

The pressure drop curve is plotted on a graph along with the airflow curve for the fan to calculate the airflow through the heatsink. This calculation, however, assumes that the entire airflow from the fan is routed through the heatsink. This is not usually practical in typical applications using DC-DC converter modules, so it is more usual to use an airflow meter to measure the actual airflow at the heatsink surface.

Once the airflow has been measured or calculated, the thermal resistance for the heatsink can then be read directly off the thermal resistance against airflow curve for the heatsink.

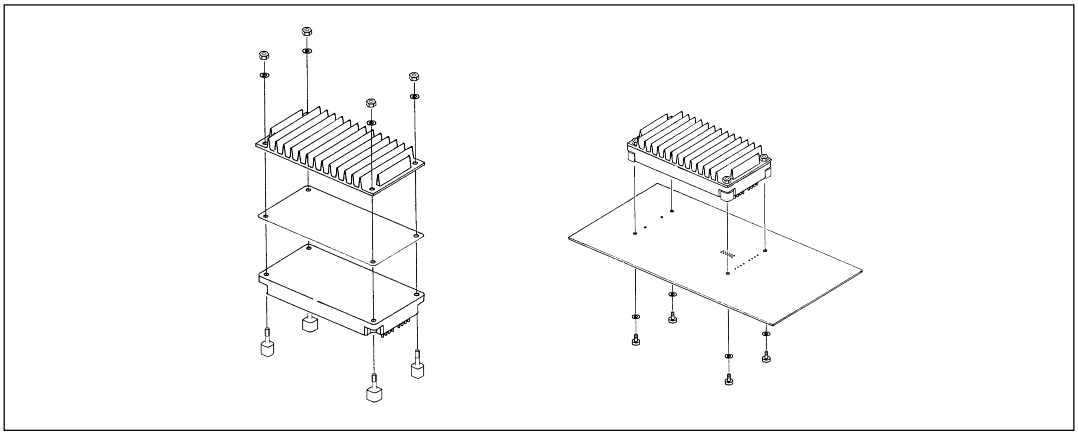
Note: *baseplate and heatsink must be connected to protective earth.*

Typical heatsink thermal resistance curves



3.4 Heatsink Mounting Advice

A heatsink mounting kit is available for all ***AMPSS*** modules and provides the most convenient way to mount the heatsink to the module and then mount the assembly onto a circuit board.



AMPSS modules may be retained by their input and output pins only, or may be fixed to the board using bolts screwed into the tapped studs which are provided as part of the mounting kit. In both cases the studs provide clearance between the module and the circuit board to facilitate PCB cleaning operations.

3.4.1 Converting CFM to LFM

Most fans are rated in cubic feet per minute (CFM) while the most effective measurement for heatsink calculations is linear feet per minute (LFM).
To convert from CFM to LFM :

- *Convert from CFM to LFM using the formula below:*

$$LFM = \frac{CFM}{Area}$$

Where $Area$ *is the cross sectional area through which the air flows.*

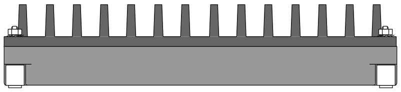
For example, if the module/heatsink combination is mounted in a cabinet with an air channel cross sectional area of cross sectional area of 4.8 in by 1.0 in and the fan is rated at 20 CFM, the calculated airflow in linear feet per minute would be:

$$\frac{\text{20 CFM}}{\text{0.033 sq ft.}} = \text{600 LFM}$$

Channelling can make a big difference by concentrating the airflow through the heatsink, although increased back-pressure will tend to reduce the throughput of the fan.

3.4.2 Tips on installation of AMPSS modules

3.4.2.1. Ensure the module/heatsink interface is smooth, flat and free of debris. Always use either thermal grease or AMPSS thermal pads.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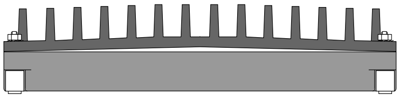
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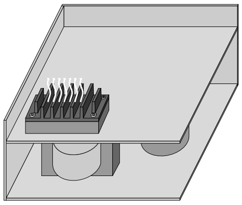
3.4.2.2 Fit modules and other heat generating devices at the top of the cabinet where possible.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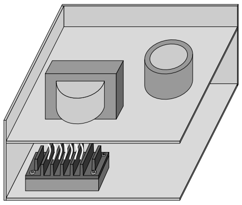
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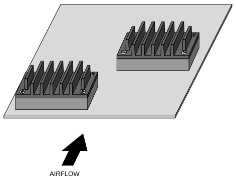
3.4.2.3 Stagger modules to improve cooling and facilitate even heat distribution between modules.



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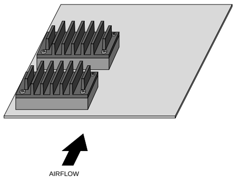

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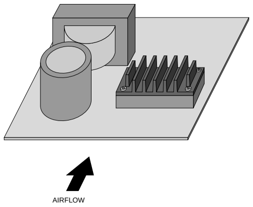
3.4.2.4 Avoid blocking the airflow to the modules with other components.



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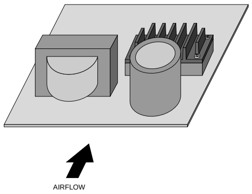

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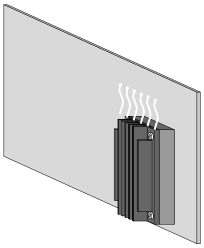
3.4.2.5 Use a heatsink with fins running vertically for natural convection cooling.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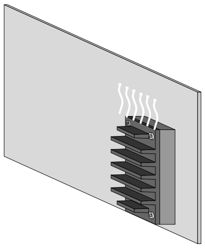
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3.5 Thermal Design Process and Example

3.5.1 Temperature & MTBF

AMPSS modules are designed to be able to run at baseplate temperatures of 100°C in the case of the AM80 series and 85°C for other series. However, for normal operation the modules should not be run at the maximum allowable temperature since the Mean Time Between Failures (MTBF) will reduce sharply as temperature increases. For example, an AM80-300L-050F40 operating at 5V@40A output, with a baseplate temperature of 50°C, has an MTBF of over one million hours. If the temperature is doubled to 100°C this figure drops to 155,000 hours.

The following rules should be followed to ensure reliable operation -

- *At the maximum system ambient temperature the **AMPSS** baseplate temperature rating should not be exceeded.*

- *At the normal system ambient operating temperature the **AMPSS** baseplate temperature must be low enough to meet MTBF requirements.*

3.5.2 The Thermal Design Process

1. Determine heat generated by module from its losses. The minimum efficiency at relevant line and load conditions should be used in calculating the losses.

2. Determine maximum baseplate temperature rise to stay within module temperature rating at maximum system ambient.

3. Define maximum system baseplate temperature to meet MTBF in normal system operating conditions or at the temperature at which the MTBF is specified.

4. Select/design heatsink and airflow requirement.

5. Test using the ***AMPSS*** imbedded TEMP-MON feature which allows direct and convenient monitoring of baseplate temperature. (BM/AM/AL/AK Series)

3.5.3 Thermal Design Example

This example is for the following parameters:

- Single 5V AM80 module used in a distributed power system.

- Average load 30A (150 Watts)

- Normal operating ambient temperature 25°C

- Maximum ambient temperature 60°C

- MTBF required - 800,000 hours (from system requirements)

- Efficiency measured at 83% (Efficiency = Output power/ Input power)

1. Heat generated = Power Out x [(1/Efficiency)-1]
   = 150 x [(1/0.83)-1]
   = 31 Watt

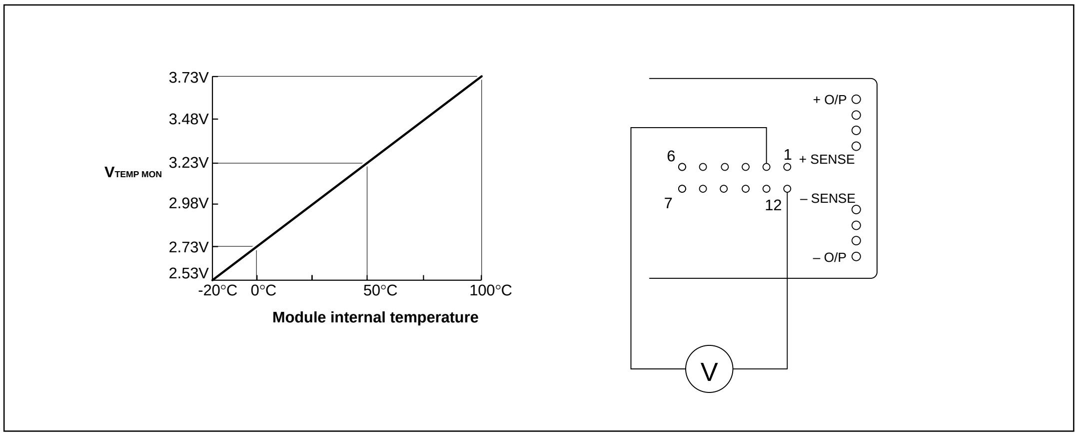
2. Maximum baseplate temperature 100°C (from AM80 specifications).
   ⇒ At 60 °C (max. ambient temp.) the maximum baseplate temperature rise is 40°C.

3. To achieve 800,000 hours MTBF, baseplate temperature must not exceed 61°C.
   ⇒ Maximum baseplate temperature rise (from 25°C operating ambient) is 36°C.

4. Choose the lowest temperature rise of ② or ③ i.e. 36°C.
   The cooling system must dissipate 31 Watts with a maximum baseplate temperature rise of 36°C.
   ⇒ Thermal resistance = 36/31 = 1.16°C/Watt.

   To ensure good thermal contact Astec recommends the use of Thermstrate® thermal mounting pads. Thermal resistance of the Thermstrate® interface between baseplate and heatsink is 0.1°C/W.
   For this example (overall thermal resistance 1.16 °C/W) the heatsink thermal resistance should be a maximum of 1.06°C/W. A 10% safety margin is desirable so a heatsink achieving 0.95°C/W is chosen.
   To achieve this level of cooling using natural convection would require an very large heatsink. It would therefore be better to employ forced air cooling. A thermal resistance vs air flow characteristic should be referenced to determine the required airflow for the heatsink you are using.

3.5.4 Temperature Monitoring (BM/AM/AL/AK series)



AM80 module temperature monitoring connection diagram & characteristic.

Certain ***AMPSS*** modules are equipped with a temperature monitoring facility. The TEMP MON pin provides an indication of the module's baseplate temperature. The voltage at the TEMP MON pin is proportional to the temperature of the module interior at 10mV per °C, where:

Module temperature (°C) = ($V_{TEMP\ MON}$ x 100) - 273

The temperature monitor signal can be used by thermal management systems (e.g. to control a variable speed fan). It can also be used for overtemperature warning circuits and for thermal design verification of prototype power supplies and heatsinks.