COOLING DC-DC CONVERTERS

This application note pertains only to Power-One isolated DC-DC “brick” converters that are equipped with metal base plates, with provisions for heat sink attachment.

Cooling:

Power-One's high density power converters are designed for either natural or forced convection cooling. The best cooling can be achieved by cooling both the unit and an attached heat sink with forced air.

The typical operating temperature range of these converters is -40° to +100° C. This is both the ambient air and the baseplate temperature range. When operating a converter with an external forced air, the flow rate must be maintained in order keep the module baseplate at or below +100° C. at the maximum ambient air temperature and the maximum power dissipation (in the module). The power dissipation can be estimated from the operating efficiency, or from equations or graphs in the discussion of efficiency in the application information for the specific module.

The dissipated power is calculated from the output power with the following equation:

$$\boxed{P_d = \left(\frac{P_o}{\eta}\right) - P_o}$$

where: P_d is the power dissipated in Watts, and
P_o is the output power in Watts, and
η is the minimum operating efficiency over the input line range while producing P_o.

The module baseplate temperature is:

$$\boxed{T_c = T_a + (P_d * \theta)}$$

where T_c is the module case temperature,
T_a is the local ambient temperature,
P_d is the power dissipated in Watts, and
θ is the thermal resistance from baseplate to air.

Every application is different; it is suggested that the user always verify the theoretical results with measurements.

Optimum cooling is obtained with forced convection. Without a heatsink, the typical thermal resistance will decrease approximately as shown below with air flow:

Chart of Normalized Thermal Resistance vs. Air Flow:

AIR FLOW RATE	TYPICAL θca (normalized)
Natural Convection	1.00°C/W
100 LFM	0.67°C/W
200 LFM	0.45°C/W
300 LFM	0.33°C/W
400 LFM	0.25°C/W

These numbers are normalized. This means that the ratio of the thermal resistance of a particular module with forced air to that without forced air approximately follows the relationship shown above. The actual value of the thermal resistance depends primarily on the size of the module. Refer to the specific application information for the individual module for exact information. This relationship holds for operation at roughly sea level.

For a given application, the maximum ambient operating temperature is derived as follows: Using the maximum output power, divide it by the efficiency estimated from the graphs, at the input voltage extreme which produces the lowest efficiency. Use the lowest value of efficiency which is within the actual operating conditions. This result is the input power. From it, subtract the output power. This is the power dissipated in the unit. Although not all of the power goes through the base, assuming that it does gives a worst case result. Then, multiply the power dissipated by the thermal resistance, using the lowest value of air flow anticipated. This gives the base temperature rise. Subtracting this value from the maximum allowable base temperature of +100° C. gives the highest allowable ambient temperature.

Naturally, a prudent engineer would not wish to operate any power converter, at or near its rated maximum base temperature. A good measure of engineering conservatism is recommended.

The numbers calculated must be considered as the initial point for any design, only. There are a great many factors which influence thermal resistance. Air density (altitude) and temperature, distance from the fan blades, relative humidity and others. In addition, back pressure causes fans to slow down and generate less CFM of air than the maximum rating. Air must often be ducted to flow where the cooling is needed, rather than around it. In any application, the temperature rise MUST be measured and controlled.

Cooling with Attached Heatsinks:

Cooling with Natural Convection:

Attaching a heatsink to the module will permit higher output power with lower case temperatures. Once again, the designer must know the maximum amount of power being dissipated by the unit and the maximum local ambient temperature. The size of the heatsink can be traded for the case temperature of the module.

Cooling with Forced Convection:

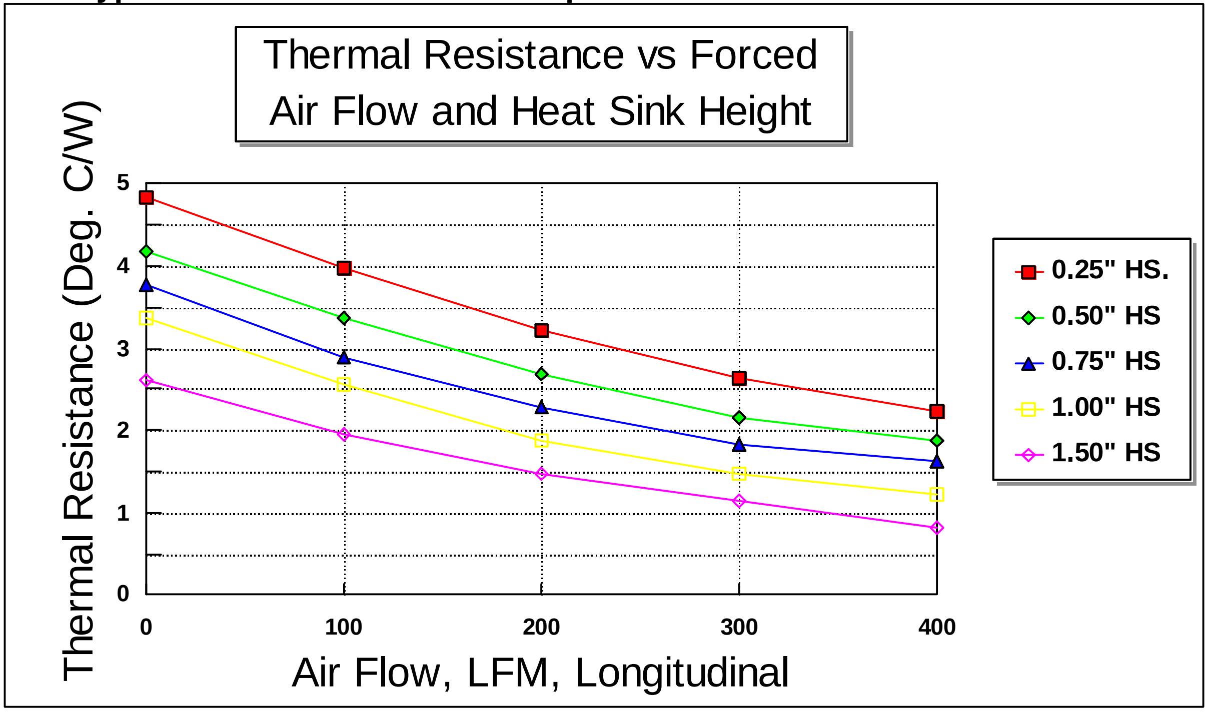
The graphs below show the <u>APPROXIMATE</u> thermal resistance of a TES Series module and same size attached heat sink in a forced air environment. The module temperature is:

$$\boxed{T_c = T_a + (P_d * \theta)}$$

where: T_c is the module case temperature,
T_a is the local ambient temperature,
P_d is the power dissipated in Watts, and
θ is the thermal resistance.

The thermal resistance is a function of the size of the module, the size of the heatsink and the air flow. A typical example is shown below:

Typical Thermal Resistance Graph:



This graph shows how much the thermal resistance decreases with the amount of air flow and the height of the heatsink, for a typical natural convection extruded heatsink being used with forced air. Special heatsink construction techniques, such as bonded fin types or high fin density extrusions, can produce much better results.

Heat Sink Installation:

The installation of a heatsink on a power module is a critical step to obtaining a reliable product. An incorrect installation can shorten the life of the product if it results in an excessive thermal resistance. An incorrect installation can also produce an early failure if it causes the baseplate of the power module to deform.

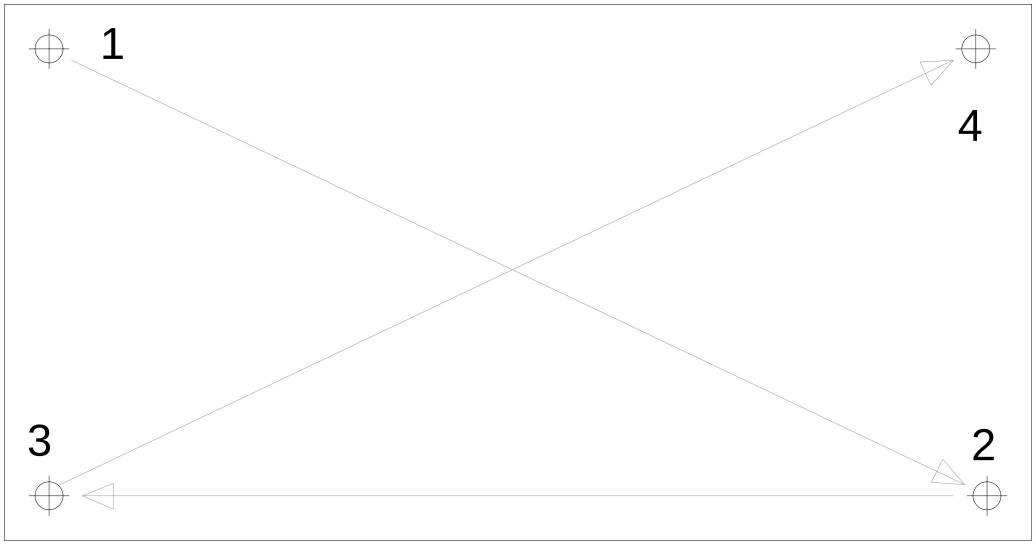
Power-One's open-frame power modules are extremely rugged. However, like all high density modules today, there are electronic components directly soldered to the IMS baseplate. Any operation which causes the baseplate to deform produces stress on the solder joints, and can result in cracked components or failed joints.

There are some simple rules to follow when installing a heatsink on a module which will insure a reliable result.

1. The **surface** of the heatsink must be **flat**. The measured flatness should not exceed 0.001" per inch of the surface. Over the length of a 4.6" long heat sink, the surface should be flat within 0.0046 inches. Over the width of a 2.4" wide heat sink, the surface should be flat within 0.0024 inches. This requirement is typical of that of other power converter manufacturers, but is tighter than normal extrusion tolerances. Large extruded heatsinks may require special machining to improve the stock flatness.

2. The **torque** of the mounting screws must be within a **controlled range**. For Power-One modules with M3 screws, the recommended torque is 3.5 to 5.2 in-lbs (4 to 6 cm-kg). A controlled and calibrated torque screwdriver is mandatory.

3. The **pattern of torquing** the mounting screws is critical. The screws should be first inserted finger tight, and then torqued in a sequence as shown below. This is EXTREMELY IMPORTANT. Both the pattern, the torque setting and the heatsink flatness MUST be followed in order to avoid potential damage to the converter.



HEATSINK SCREW TORQUE SEQUENCE

4. In order to achieve a sufficiently low interface thermal resistance, the **surface finish** (degree of roughness) of the heatsink may have to be improved from extrusion grade.

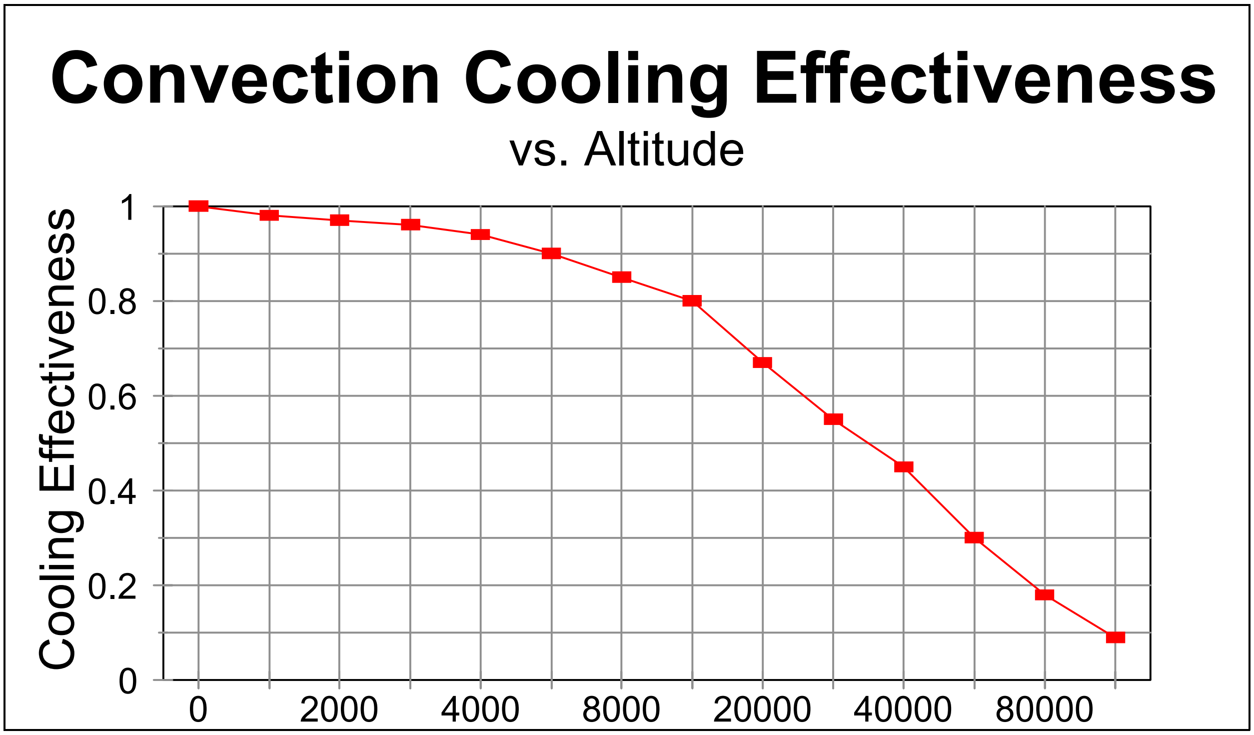
5. In order to achieve a sufficiently low interface thermal resistance, there must be either a Grafoil (Registered trademark of Union Carbide company, US Patent # 3,404,061) pad or other suitable **thermal interface material** between the module and the heat sink. Note that the interface thermal resistance, typically 0.1 to 0.3°C/W, between the module and heatsink contributes significantly to the final result.

Improved performance in a forced convection environment can be obtained with oversized heat sinks: they overhang the module. One of these must be individually designed to match the application. A useful reference for this is located at the Aavid Engineering website at www.aavid.com.

Derating for altitude:

At altitudes above sea level, there are fewer molecules of air in each area of volume. Since the air molecules perform the actual convection heat transfer, there is reduced effectiveness as the altitude of use increases.

Effect of Altitude Graph:



To use this curve, divide the sea level thermal resistance by the cooling effectiveness at the applicable altitude. This produces the effective value of thermal resistance at the altitude. Use this number in the calculations above. Again, engineering conservatism will produce successful projects.

Converting CFM to LFM:

Most fans are rated to produce a volume of air flow measured in CFM (cubic feet per minute), while most forced convection heatsink performance is specified at defined levels of LFM (linear feet per minute) of air flow. To convert from a CFM number to a LFM number, divide the CFM by the cross sectional area of the heatsink (in square feet).

$$\boxed{LFM = \frac{CFM}{AREA}}$$

where: LFM is the linear feet per minute of air flow.
CFM is the cubic feet per minute of air volume, and
AREA is the area of the opening in square feet.

The LFM through a heatsink can be maximized by ducting the air to travel only through the fins, and not around the heatsink.

Any impediments to full and complete air flow, such as ducting and heatsinks, will create a back pressure which will reduce the volume of air. Fans are rated to produce a specified CFM of air with zero back pressure, and to produce zero CFM of air with a defined back pressure. Realistic operation is in between, where the back pressure of the environment is overcome by the power of the fan, and the CFM delivered is usually between full and one-half. Fan manufacturers supply curves of air volume CFM versus back pressure.

Thermal Calculation Example:

As an example, we wish to run a model TES150ZE at a full 150 watts of output power at up to 45° C. and up to 10,000 feet altitude. Operation will be limited to an input voltage range of 42 to 60 VDC. For reliability, we wish to maintain the case temperature at or below +85° C.

1. Power dissipated = (150/.81) - 150 = 35.18 Watts.

2. Thermal Resistance required at sea level = (85-45)/35.18 = 1.137°C/W.

3. Derating for 10,000 feet: 1.137 * 0.8 = 0.909°C/W actual required.

4. From the charts of thermal resistance in the TES application note we see that we need about 400 LFM of forced air with a 1.50" high heat sink. Either longitudinal or transverse fin orientation should work properly.

Once again, employing a large dose of engineering conservatism will result in a better product. In addition, all of the information presented above is only for the purposes of selecting an initial air flow. The final results MUST be verified in the actual application by measuring the real temperature rise. Keep in mind that the local ambient temperature for the module may be elevated from the external ambient by the dissipation in other elements.

Other Manufacturing Issues:

Processing of Completed Power-One Power Converters:

The incorporation of completed Power-One power converters into assemblies, or installation into motherboards, can be handled by the conventional industry methods. The stanchions which are fabricated of PPS plastic, along with all the other component parts used by Power-One, will withstand normal preheat temperatures associated with standard soldering operations. The most common method for mass soldering of the power supply to a mother board is “wave soldering” and should be profiled approximately as follows:

1. The solder pot should be set at 500° F and the conveyor should have a speed preset to insure that each section of the bottom side of the assembly dwells in the molten solder wave for 3 to 4 seconds. It is imperative that a correct temperature profile be used, not only to reduce solder defects but to eliminate any chance of thermal shock on the components.

2. The motherboard should attain a top side preheat temperature of 220° to 240° F before it enters the solder wave. The temperature change between the preheat and the soldering zones should be minimized.

3. The cooling rate after the solder wave should be similar in drop in temperature to the preheat rise.

Notes on Processing of Completed Power-One Power Converters:

- The Power-One through-hole pins are tin/lead plated and are easily soldered if all process parameters are met. However, in fluxing, the flux density, the activity and the ratio of flux foam to wave height must be closely monitored and controlled to maintain minimum solder defects.

- In controlling the solder profile, preheating of the assembly in two or three stages minimizes the thermal shock damage and increases the end life of the unit.

- If the power converters are to be hand soldered into the motherboard, a temperature controlled iron of 700° F (MAX) is recommended.

- While the Power-One power converters generally spend about 3 seconds in the wave, they are designed to withstand soldering temperatures of 500° F for up to 10 seconds.

- If non-conventional methods are to be used to solder the Power-One power supplies to the motherboard, contact Technical Support before proceeding.

Cross References and Replacements:

Power-One can supply replacements for converters from other manufacturers, or offer custom solutions. Please contact Power-One for details.