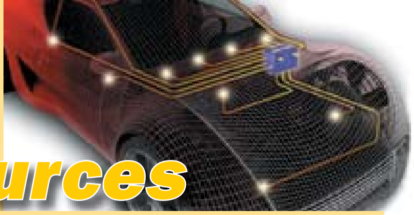

Cooling Power Bricks for Maximum Reliability

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Today there are a large array of high power modules in the range of 300 to 700-watts, both DC-DC converters as well as AC-DC power modules that are commonly referred to as "bricks". Even though these devices feature high conversion efficiencies in the area of 85% to 90% (or higher), some power is lost in the form of heat that must be dealt with in order to maximize the lifespan of the end product.

Baseplate Temperature	MTBF
50°C	750,000 hours
75°C	295,000 hours
85°C	207,000 hours
100°C	113,000 hours

Fig. 1: MTBF vs. Baseplate Temperature (AC-DC, PFE500S-28)

The chart in Fig. 1, shows how the calculated MTBF (Mean Time Between Failure) of a 500-watt power module can be drastically affected by its operating temperature, as measured at the module's baseplate. Even though this AC-DC power module is designed to operate with a baseplate temperature of up to 100°C, it can be seen that its calculated MTBF (Telcordia/Bellcore TR-332) will be vastly improved by maintaining the baseplate temperature just 15 degrees cooler, at 85°C.

Typical MTBF figures for DC-DC converters, at similar power levels, are about three times higher than those shown in the Fig. 1, since these modules do not include the extra circuitry needed for the AC front-end, including full-wave rectification and active power factor correction.

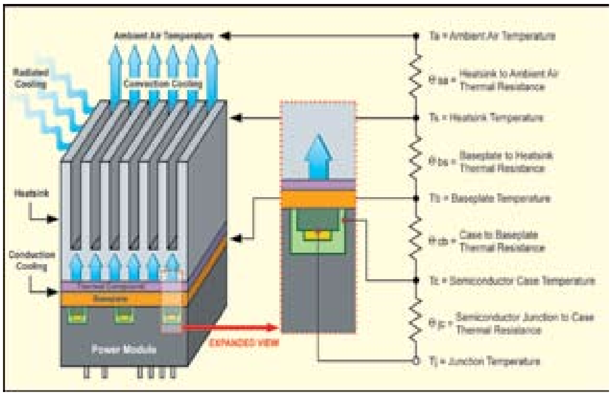


Fig. 2: Thermal resistances and cooling paths for typical power module

With either AC-DC or DC-DC bricks, the concentrated power densities make them a challenge to cool in real world applications. Most high power bricks are packaged in thermally conductive plastic cases with metal baseplates. The high power components within the bricks are thermally coupled to these baseplates, which in turn can be attached to external heatsinks or liquid-cooled cold plates in order to keep the baseplate at or below its maximum operating temperature.

The maximum baseplate temperature is primarily determined by the maximum internal junction temperature of the semiconductors within the power bricks. The term "thermal management" refers to the designer's challenge of cooling these power bricks by considering the many levels for heat transfers via conduction, convection, and thermal radiation, both internal and external to the power module.

Fig 2, shows the series-connected thermal resistances that impede the flow of heat from one level to the next. These impedances need to be considered, beginning with the internal semiconductors' junction temperatures relative to their cases, the thermoplastic power module's case and its metal baseplate, and ending with a mechanically attached heatsink that conducts away the heat from the baseplate to the surrounding ambient air via natural or forced air convection cooling. Heatsinks are designed to cool primarily by substantially increasing the surface area that comes in contact with the ambient air, thereby providing enhanced convection cooling. Because the mating surfaces of the power module's baseplates and heatsinks are not perfectly flat, some type of thermally conductive interface material is required to fill the tiny voids. This interface material can range from a thin layer of thermal grease to a custom designed silicon pad.

Selecting the proper size and shape of a heatsink and determining if forced air cooling is required are among the tradeoffs the designer needs to consider. This process begins with a detailed review of the power module's specifications and knowledge of the end product's heat loads, internal and external operating temperatures, space constraints, and available air flow sources, paths and restrictions.

The next step in this process is to determine the amount of power that will be lost (wasted) within the power module, based on its efficiency. The information for computing this is usually listed on the power module's datasheet or installation manual. For this example, we will use an AC-DC power module (model PFE500S-48) with output ratings of 48 VDC at up to 10.5 Amps and 504-watts. This module has a typical efficiency of 85% when operating from a 120 VAC input (Fig 3). By the way, the 85% efficiency rating is very good considering the fact that this module contains full-bridge rectification and active power factor correction AC front-end circuits, as well as an integral DC to DC converter. In addition, this module has a maximum operating baseplate temperature, as measured at its center point, of 100°C, however since it is good practice to operate bricks below their maximum rating, we will use 85°C as the maximum baseplate temperature. This temperature derating will almost double the MTBF of the module (Fig 1).

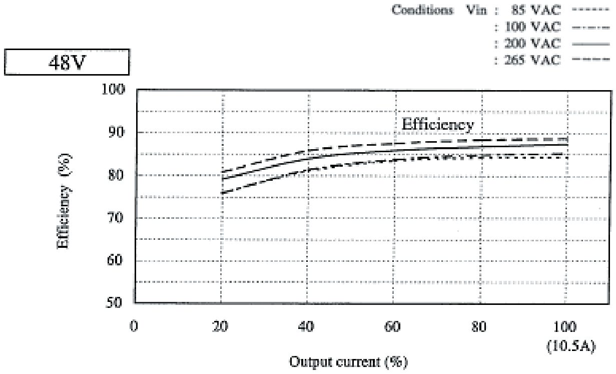


Fig. 3: Efficiency vs. Output Current (at 48VDC) and Input VAC

Based on the above information, to compute the internal power dissipated (wasted heat); we can use the following Equation (1):

$Pd = (Pout / \eta) - Pout$ (Equation 1)

Definitions & Calculation Example

Pd : Internal Power Dissipated (W)
Pout : Output Power (504W)
η : Efficiency (85%)

$Pd = (504W / 0.85) - 504W = \underline{88.}9W$ (Equation 1)

To calculate the required baseplate to ambient air thermal resistance that would be needed for this application, the following Equation 2 would apply:

$\theta ba = Tb - Ta / Pd$ (Equation 2)

Definitions & Calculation Example

θba : Baseplate to Ambient Air Thermal Resistance (°C/W)
Tb : Baseplate Temperature (85°C)
Ta : Ambient Air Temperature (40°C)
Pd : Internal Power Dissipated (88.9W)

$\theta ba = 85°C - 40°C / \underline{88.9}W = \underline{0.51°C/W}$ (Equation 2)

In this example, we would need a heatsink (with or without air flow) that provided a thermal resistance of 0.51°C/W. However, unless the heatsink includes a thermal interface material like thermal grease or a pad in its rating, we need to account for this additional thermal contact resistance (θbs), which can be on the order of 0.2°C/W. Therefore, the required thermal resistance of the heatsink itself, without the thermal interface material included, can be calculated using Equation 3, and this example:

$\theta ba\text{-}bs = \theta ba - \theta bs$ (Equation 3)
$\theta ba - \theta bs = 0.51°C/W - 0.20°C/W = \underline{0.31°C/W}$ (Equation 3)

The next step in this process is to review specifications for potential heatsinks that have a thermal resistance of 0.31°C/W. In this case, the power module has three optional heatsinks to choose from as shown in the chart below (Fig 4).

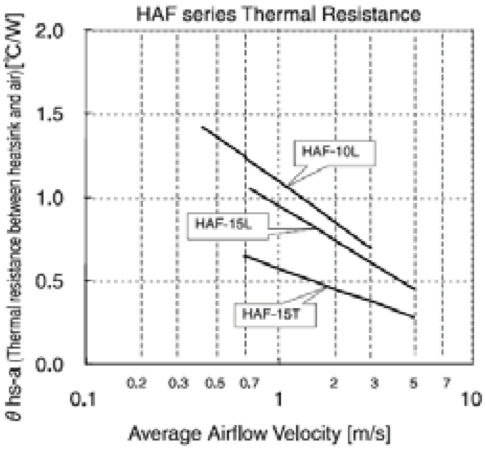
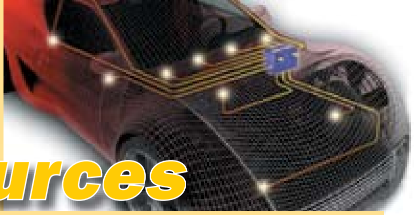


Fig. 4: Thermal resistance of heatsinks with airflow



The Y axis of this chart (Fig. 4) shows the thermal resistance between the heatsink and the air (°C/W) and the X axis shows the required airflow velocity (meters/second) for three heatsinks. In this example we need to find 0.31°C/W along the Y axis and then move to right along the X axis to where it intersects a heatsink curve. In this example, 0.31°C/W intersects with the HAF-15T heatsink curve at about the 3.5 m/s airflow velocity point. To translate m/s (meters/second) into LFM (linear feet/second), use this general conversion factor: 1 m/s = 200 LFM. So, in this case, 3.5 m/s = 700 LFM of forced-air velocity.

Based on the above, we have now determined the requirements for cooling this power module with a heatsink, thermal compound and forced air

There are other tactics we can employ to maximize the reliability and MTBF of the installed power modules. For example, if we decide to operate the power module below its maximum rated output power we can reduce the required airflow velocity. For example, if we choose to derate the module by 20%, this would result in 403-watts of output power. By using the previously discussed methods, we will find that the required airflow will reduce from 700 to 520 LFM, and the expected field reliability will be enhanced.

In summary, we have shown a practical way to determine the correct heatsink for a specific power module application and explored some factors and trade-offs to consider for maximizing the field reliability of these modules. The smart designer will confirm the “paper design” by running extensive thermal tests on the finished product to ensure the final design will indeed be reliable in the field.

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