35 Hampden Road
Mansfield, MA 02048-1807
Phone: (508)823-8080
Fax: (508)339-0375

Thermal Considerations for High Density DC Modules

General Description

Thermal management is an important part of the system design process. The superior designs of RO's modules make thermal management relatively easy. Their high conversion efficiency minimizes the necessary cooling while their small package sizes with large thermal interfaces allow simultaneous reductions in system size and cost along with substantial improvements in reliability. This application note presents some guidelines for good thermal design of systems using RO converters.

Module Losses

AC/DC and DC/DC modules convert power from an input source into regulated power suitable for the given application. While RO's conversion efficiencies are high, they are not perfect, and some of the input power is lost as heat in the module; which can be calculated from the following equations:

$$P_{MOD} = P_{OUT} \times \left(\frac{1}{\eta} - 1 \right)$$

This equation is derived from the definition of efficiency:

$$\eta = \frac{P_{OUT}}{P_{IN}}$$

The very first step in all thermal management designs is to estimate the worst case power dissipation. This can be estimated from the module efficiency graphs given in the catalog; or for conditions not covered by the graphs, it can be directly measured.

Heat Removal

Mechanisms of Transfer

Heat is removed from RO converters through the module's baseplate. The baseplate is thermally coupled to and electrically isolated from all internal components. The goal of good thermal design is to transfer heat from the baseplate to the outside world; thereby keeping the baseplate temperature below the maximum rating.

Heat energy is transferred from warm objects to cold objects by three fundamental means:

1) Convection: The transfer of energy through a liquid or gaseous media.

2) Conduction: The transfer of energy through a solid media.

3) Radiation: The transfer of energy between masses at different temperatures via predominantly infrared wavelengths.

While all three transfer mechanisms will be present in every application, convection is the dominant means of heat transfer in most. However, some consideration should be given to all three transfer means to ensure the cooling design is successful.

Baseplate to Heat sink Interface

In many applications, heat will be conducted from the module to a heat sink, which is then cooled via one of the three mechanisms mentioned above. The interface between the heat sink and the baseplate can be modeled as a "thermal resistance" in series with the dissipated power flow. The temperature differential across the interface can be considerable if appropriate measures are not taken. These measures include controlling the flatness of the two surfaces and using a filler material such as thermal compound or Grafoil®. With proper care, the thermal resistance across the interface can be less than 0.8 °C in²/Watt; which for a 3.6" x 2.4" module is less than 0.09°C/Watt.
(Grafoil is a registered trademark of the Union Carbide Company.)

Convection cooling

Convection cooling is by far the most popular form of cooling used. In a convection cooled system the heat energy is transferred from the module to a nearby body of air either by direct contact or via a heat sink attached to the module baseplate. The thermal model for convection cooling is shown in Figure 10a. The baseplate temperature depends on the internal power dissipation, the total thermal resistance from the baseplate to the ambient air, and the ambient air temperature. The interface resistance can be minimized as discussed previously. The heat sink-to-air resistance is dependent on a variety of factors including heat sink material, geometry, and surface finish; as well as air temperature, air density, and air flow rate. Fortunately, thermal resistance data is available for a very wide range of standard heat sinks (from RO, Aavid, Thermaloy, and others) for use in convection cooled applications. Convection cooling is usually classified into two types: natural convection, and forced air convection.

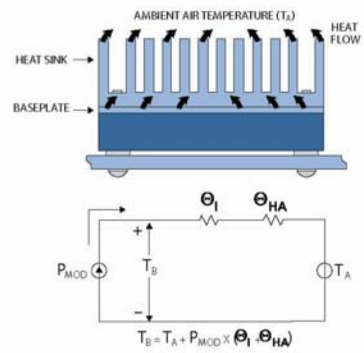

Figure 10a Thermal model for convection cooled systems.

Natural convection, also referred to as free air convection, operates on the principle that air becomes less dense and rises when it is heated. Cooler more dense air then moves in to take its place and remove additional heat. Free air convection only works well when there is an unobstructed path for the air to flow. Since the hot air rises vertically the module and heat sink fins must be properly oriented in the vertical direction to maximize airflow. The advantages of free air convection cooling over forced air cooling include a lower implementation cost (no fans), and higher cooling system reliability. The heat sink volume, however, will have to be larger to achieve the same baseplate temperature as with forced air convection.

Forced air convection can make a big difference in cooling effectiveness. With a suitable heat sink, the heat sink-to-air thermal resistance can be improved by as much as an order of magnitude when compared to natural convection performance. Forced air implies the use of fans. In many applications, fans must be used to achieve some desired combination of overall system reliability and packaging density. In other applications, however, fans can’t be considered because “dirty” environments require filters which must be changed regularly to maintain cooling efficiency. Neglecting to change a filter or a failure of the fan may cause the system to shut down.

The process for selecting natural convection and forced convection heat sinks are essentially the same. For forced air systems, however, a fan must also be selected to create the required airflow, and the airflow must be channeled so that maximum cooling is achieved.

To calculate the required heat sinking:

1. Determine the worst case power to be dissipated. This should be based upon converter efficiency and worst-case converter power output using the formula given in the section on Module Losses.
2. Determine the thermal resistance from the module to the heat sink. An estimate of 1°C·in²/Watt should provide adequate safety margin. For more accuracy, experimentally measure the interface resistance for your application.
3. Determine the required thermal resistance from the heat sink to the ambient air. Referencing Figure 10a, we can derive the following formula for heat sink-to-ambient thermal resistance:

$$\Theta_{HA} = \left(\frac{T_B - T_A}{P_{MOD}} \right) - \Theta_I$$

where:

$\Theta_{HA} =$ • Maximum acceptable Heat sink-to-ambient thermal resistance.

$\Theta_I =$ • Thermal resistance of the interface between the heat sink and the baseplate determined in step B

$P_{MOD} =$ • Module power dissipation, determined in step 1

$T_A =$ • Worst case anticipated operating ambient air temperature

$T_B =$ • Maximum desired baseplate temperature, up to 100°C.

4. For forced air systems estimate the airflow through the heat sink. This is a non-trivial task and is somewhat iterative with step 5 because the heat sink selected will create back-pressure and will affect the airflow. To convert CFM fan data to LFM use the following formula:

$$LFM = \frac{CFM}{Area_{HS}}$$

(Keep in mind that only the air that flows between the fins contributes to the cooling of the module.)

5. Select a heat sink that meets the thermal resistance, cost, and physical dimension constraints. Keep in mind that every degree that the baseplate temperature is lowered results in significant improvements in the module reliability. You should therefore select the heat sink with the lowest possible thermal resistance within your constraints. Table 10a shows the thermal resistance of RO's heat sinks.

Alternatively, steps 4 and 5 can be done in the opposite order if your heat sink constraints are more severe than your fan constraints, i.e. you can select the heat sink first, and then pick a fan to get the necessary airflow.

6. Estimate the baseplate temperature using the following formula:

$$T_B = T_A + P_{MOD} \times \left(\Theta_I + \Theta_{HA} \right)$$

7. Verify the design via measurement. This is the most important step in the design process.

Table 10a Thermal resistances of RO heat sinks

Airflow RO #	free air (°C/W)	200 LFM (°C/W)	400 LFM (°C/W)
2003	2.9	2.4	1.6
2005	2.2	1.8	1.2
2006	2.0	1.5	1.0

When designing the cooling system keep the following in mind:

- Heat sink data for natural convection is almost always given for vertical fin orientation. Orienting the fins in any other direction will impede the airflow and degrade the cooling effectiveness significantly. If you can't use the preferred orientation then get relevant heat sink performance data from the manufacturer.
- Natural convection depends on air movement caused by air density changes. The manufacturer's thermal resistance data depends on unobstructed air movement in-between and around the fins. If the air movement will be blocked or otherwise affected by the packaging then a larger heat sink may be required. In extreme cases, natural convection cooling may not be useable.
- Radiation cooling can be a significant contributor to natural convection cooled systems. Maximize radiation cooling by using an appropriate finish on the heat sink, such as black anodize.
- It is not necessary for the heat sink to be the same size as the baseplate. Heat sinks that are larger than the baseplate can often be used advantageously. Especially in applications where the fin height may be limited. When using heat sinks that are larger than the baseplate, select one that has a thick base for better conduction to the outer fins and derate the manufacturer's thermal resistance slightly.
- Several modules can be mounted to a common heat sink, but cooling calculations must now take into account the total power dissipation of all the modules. Give consideration to the possibility of localized overheating if the power dissipation isn't uniformly distributed.

Tips on Module Placement

Here are some tips to consider when laying out the system and placing the modules on the PWB:

- Always ensure that the module and heat sink interfacing surfaces are flat, smooth, clean, and free of debris.
- Always use a void filling material such as thermal compound, thermal pads, or some other

thermally conductive, conformable or malleable material. RO offers precut thermal pads made from GRAFOIL® material. Note: thermal pads are pre-installed on all heat sinks purchased from RO.

- Stagger the modules on the PWB to promote good airflow, to minimize thermal interaction between modules, and to facilitate even heat distribution.
- Avoid blocking the airflow to the modules with other components.
- Use a heat sink with the fins running in the direction of the airflow. For natural convection systems the air will flow upward in a vertical direction.

Thermal Equation Summary

Maximum Baseplate Temperature:	$Tmax = 100°C$
Efficiency:	$\eta = \frac{P_{OUT}}{P_{IN}}$
Airflow:	$LFM = \frac{CFM}{Area_{HS}}$
Module Power Dissipation:	$P_{MOD} = P_{OUT} \times \left(\frac{1}{\eta}-1\right)$
Max. Heat Sink Impedance:	$\Theta_{HA} = \left(\frac{T_B - T_A}{P_{OUT}\left(\frac{1}{\eta}-1\right)}\right) - \Theta_I$
Max. Output Power:	$P_{OUT} = \left(\frac{T_B - T_A}{(\Theta_{HA}+\Theta_I)\left(\frac{1}{\eta}-1\right)}\right)$
Baseplate Temperature:	$T_B = T_A + P_{MOD} \times \left(\Theta_I + \Theta_{HA}\right)$

Examples

A µV48-5 module is being operated with 30A of load current in an ambient of 30°C. From the efficiency graph in the catalog it has an efficiency of 82%. The module's losses are then:

$$P_{MOD} = 30A*5V*\left(\frac{1}{0.82}-\right) \approx 33W$$

The desired baseplate temperature is 75°C and a conservative estimate of the interface thermal resistance is 0.2°C/W. We therefore need a heat sink with a thermal resistance of:

$$\Theta_{HA} = \left(\frac{75°C - 30°C}{33W}\right) - 0.2°C/W$$

$$\Theta_{HA} \approx 1.2°C/W \text{ or less}$$

From the catalog we see that the RO 2005 heat sink has a thermal resistance of 1.0° C/W with 400LFM of airflow. The resulting design will operate at a base-plate temperature of:

$$T_B = 30°C + 33W \times (1.0°C/W + 0.2°C/W)$$

$$T_B \approx 70°C$$

Precautions

Observe Max. Temperature Ratings -While the modules will protect themselves if the maximum baseplate temperature rating is exceeded. Operating above the rating for extended periods of time can reduce the reliability of the module.

Don't compress PC Board Material -Don't allow the mounting screws for the modules to exert compressive force on the PWB. The PWB material, typically G-10 or FR-4, will cold flow away from the screw and release the screw tension. The result can be a loss of heat sinking. See application note 19, ***Hole Dimensions and Socket Information***, for further information.

Related Topics

- AP-2 Mechanical Mounting Considerations
- AP-18 Board Layout Considerations and Recommendations
- AP-19 Hole Dimensions and Socket Information
- AP-22 Accessories