Thermal Management

1- Introduction

This application note discusses thermal management of GAIA Converter DC/DC modules.

As with any power electronic circuitry, DC/DC converter do not transform all input power to output power; a portion of input power is dissipated as heat. The amount of heat dissipated is dependent on the output load and converter efficiency. The control and evacuation of this heat is called thermal management.

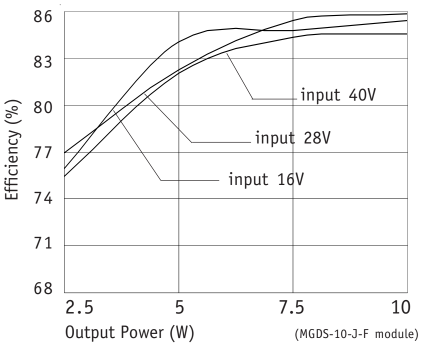
Reasons for thermal management include :
- Maintain DC/DC converter case temperature below maximum admissible temperature
- Improve reliabilty (MTBF)
- Maximize efficiency
- Utilize maximum available output power

Prudent thermal management will result in long term reliable operation and allow maximum power utilization in a minimum amount of space.

1-1 Power Dissipation in the DC/DC

To calculate how much power is dissipated in the converter, input voltage, output power together with DC/DC converter efficiency must be known.
GAIA Converter gives for any converter, the efficiency profiles depending on input and output load as follow (ex : MGDS-10-J-F).

Figure 9 : Typical efficiency versus load at various input



Example : the power dissipated in this MGDS-10-J-F module at 28Vdc input voltage

and used at full load power 10W is : (From the MGDM-10 datasheet–page 4 precedent curve : the efficiency of this module at full load 10W and 28 Vdc input voltage is 86%).

The *power dissipation* is a function of the power used and DC/DC converter efficiency :

Pdiss = (Pused/Efficiency - Pused)

In this example we find : Pdiss=1,6 W

This power dissipated is transformed into heat.

1-2 Heat Transfer

The primary goal in the thermal design is to predict and control the converter's heat so that it does not exceed the maximum rating of temperature admissible by the DC/DC converter.

Heat energy is transferred from regions of high temperature to regions of low temperature via three basic mechanisms :

- radiation : electromagnetic transfer of heat between masses at different temperatures
- conduction : transfer of heat through a solid medium (heatsink for example)
- convection : transfer of heat through the medium of fluid (typically air from venti lation).

All three of these heat transfer mechanisms are active to some degree in every application. All three of these mechanism should be given consideration when developping thermal management.

For locations, phone, fax, E-Mail see back cover

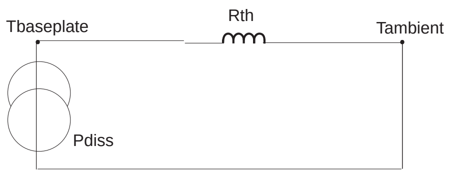
2-Radiation Transfer

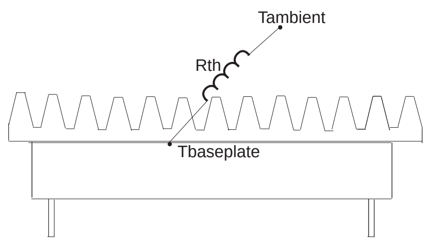
Thermal radiation is the transfer of heat by electromagnetic radiation (primarily in the infra-red wavelengths). Radiation is the only means of heat transfer between bodies separated by a complete space vacuum.
Many factors contribute to thermal radiation efficiency, such as temperature differentials, surface area, and surface emissivity.
Black anodized aluminum is a good thermal medium to take advantage of radiated heat.
A heatsink with a large area for a given volume will take maximum advantage of radiation.
But radiation is a minor contributor to the overall thermal link in most power converter applications and counts in majority of cases for less than 5% of total heat transfer. It is best to use the effects of radiation as a «safety margin» in the thermal design, since its contributions to heat transfer will normally be small, is difficult to quantify, and requires a relatively larger heatsink area to be efficient.

3-Conduction Transfer

3-1 General

Heat is transferred through a solid medium by conduction and it is the most fundamental of all thermal mechanisms. Thermal conduction can be understood as analog as conduction of electrical current in a wire. As the electrical current in a wire is a function of the different electrical resistances and the voltage drop, the thermal transfer is a function of the different thermal resistances and temperature drop from one point to another.
This helpfull modelisation can be depicted as follow :





3-2 Thermal Resistance for Heatsink, DC/DC Converter

Thermal resistance are accessible values (defined in °C/W) given by majority of DC/DC converter manufacturers or heatsink manufacturers. Some examples of thermal resistance values are given thereafter including DC/DC converter values from GAIA Converter, heatsink thermal resistance values from manufacturers like Thermalloy, Fisher Elektronik, ThermaFlo, Radian etc .....

Type of Product	Thermal Resistance
GAIA Converter MGDS-10 DC/DC converter series	12 °C/W
GAIA Converter MGDS-20 DC/DC converter series	7 °C/W
Thermalloy heatsink type 6512B	9,1 °C/W
Thermalloy heatsink type 6516B	4,4 °C/W
Fisher Elektronik heatsink type SK DC 5 1 59 SA	3,9 °C/W
Fischer Elektronik heatsink type SK DC 5 59 SA	4,1 °C/W
ThermaFlo heatsink type 423000B00000	4,67 °C/W
Radian heatsink HS1579EX	4,5°C/W

3-3 Thermal Resistance for Interface Membrane Path

An *interface* thermal resistance path is present at the junction of each conductive media (e.g., between baseplate and heatsink). It is important for the media to maintain close intimate contact with each other to minimize thermal resistance. The thermal resistance of *still air* is very high ... more than 5000 times that of aluminum. An air gap of 10 mils across an area of (2" x 2") would yield a thermal resistance of 3.5 °C / W, significantly reducing the effectiveness of the mating heatsink . When attaching a heatsink to the converter, an attempt should be made to minimize the *global thermal resistance by using thermal membrane in between the baseplate and the heatsink*. the following guidelines should be observed :

- Maintain flat and smooth surfaces.
- Torque fasteners (if used) according to fastener size/type to optimize clamping pressure (i.e between 25 and 100 psi).

The thermal resitivity of a uniform conducting membrane can be defined as: **Rth = L / K x A**
where :
Rth = Thermal Resistance (°C / watt)
L = Length or width (inch) or (mm)
A = Cross Sectional Area (inch2) or (mm2)
K = Material Thermal Conductivity (watt/inch°C or mm°C)

K is an accessible value given by manufacturers; but manufacturers are given also the thermal impedance wich is the thermal resistance by surface unit which is more easy for calculation. Examples of thermal pad values are given thereafter from Bergquist manufacturer.

Type of Thermal Pad Interface	Thermal Impedance
Bergquist «Silpad 400» 0.009 width, 50psi	1,45 °C-inch2/W
Bergquist «Silpad 900S» 50 psi	0,61 °C-inch2/W
Bergquist «Hi-Flow 625, 50 psi	0,7 °C-inch2/W

6

4-Convection Transfer

Heat transfer by *Convection (Natural or Forced)* involves the transfer of heat to a surrounding fluid by conduction, typically air. This mode of heat transfer is dependent on a number of variables and is somewhat complex to calculate. Surface area, temperature gradient, thermal conductivity of fluid (air), velocity of fluid (air), fluid (air) density and other variables affect convection.

4-1 Natural Convection

Natural convection is sometimes also referred as *Free convection*. Natural convection is easier to implement than forced convection, but at the expense of increased thermal resistance.
Natural convection produces its own air velocity, due to the local heating of air at the heatsink surface. The air density is reduced when heated, causing it to rise, thus causing the air movement.
Natural Convection is not as effective at higher altitudes due to air density reduction.
«Free air» movement across a thermal dissipator is required to perform adequately.
«confined air» would not conduct to natural convection. This would occur with a converter mounted (without thermal contact) within an enclosed box.
To maximize the transfer of heat by natural convection the following rules apply :

- Mount heat sinks so the maximum length of convection surfaces (fins) are in the vertical plane.
- Place the heat sink above the converter, allowing air to rise above.
- Provide sufficient enclosure ventilation for natural convection of the air.
- Note that close heatsink fin spacing will reduce the effectiveness of the heatsink.

Due to the complexity to calculate heat transfer for only free air convection, majority of DC/DC converter manufacturers or heatsink manufacturers are given their thermal resistance performances in free air convection condition (which will then include conduction and natural convection).
If thermal resistance is given in confined air it will give a margin if the DC/DC converter is used in natural convection environment.
From the previous table in section 3-2 we can complete our discussion by adding the convection condition :

Type of Product	Thermal Resistance	Convection Condition
GAIA Converter MGDS-10 DC/DC converter series	12 °C/W	Free convection
GAIA Converter MGDS-20 DC/DC converter series	7 °C/W	Free convection
Thermalloy heatsink type 6512B	9,1 °C/W	Free convection
Thermalloy heatsink type 6516B	4,4 °C/W	Free convection
Fisher Elektronik heatsink type SK DC 5 1 59 SA	3,9 °C/W	Free convection
Fischer Elektronik heatsink type SK DC 5 59 SA	4,1 °C/W	Free convection
ThermaFlo heatsink type 423000B00000	4,67 °C/W	Free convection
Radian heatsink HS1579EX	4,5°C/W	Free convection

4-2 Forced Convection

Forced convection implies the use of fans to increase the air movement across the heatsink area. Heatsink to air thermal resistivity can be improved by as much as a factor of 10 when compared to natural convection.
This may be the way to go when operating at high ambient temperatures, operating at high power levels, or when space is at a premium. Of course fans are not without their problems. They are noisy, and in dirty environments they often require filters.
They can also cause an unreliable power system if the filters are not changed frequently or the fan itself fails. Therefore proper care must be exercised when fans are used.

Airflow specification is usually given as a function of air velocity in *linear feet per minute* LFM (or m/s). Fan specifications are usually given as a function of air volume in *cubic feet per minute* (CFM). Conversion from volume to velocity is as follows :

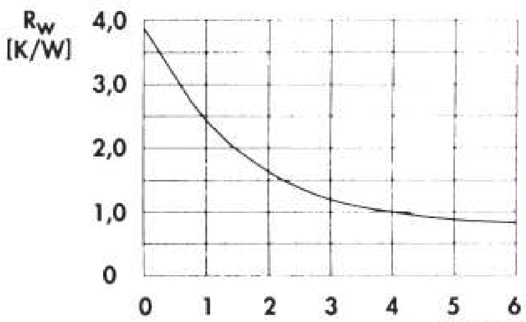
Velocity (LFM) = Volume (CFM) / Area

Area is the cross sectional area through which the air passes.
An amount of airflow (400ft/min or 2 m/s) will have a significant impact to improve heat transfer thru convection. Airflow above 1000ft/min does not significantly improve heat transfer.
To maximize the transfer of heat by forced convection the following rules apply :

- Keep low power components upstream
- Space heatsink fins closer together than in a natural convection design.
- Channel the flow of the air through the spaces between the fins of the heat sink.

Due to the complexity to calculate heat transfer for only forced air cooling, it is best to use the thermal resistance data supplied by various heatsink vendors. Heatsink vendors will either plot thermal resistance vs air velocity or plot temperature rise vs power dissipation for various air velocities : the thermal resistance will then include conduction in forced convection cooling.
An example is given thereafter :

Thermal resistance as a function of air velicity



Air Velocity in m/s

5 Global Thermal Model

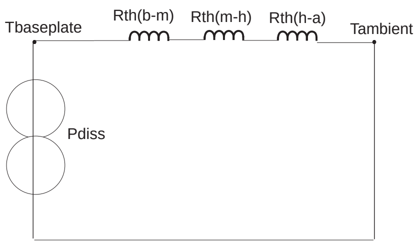
An equivalent global thermal circuit model for the converter is shown in Figure herafter. The relationship between Temperature Rise (DT), Thermal Resistivity (Rth) and Power Dissipation (Pdiss) may be stated as follows:

Rth = DT / Pdiss

The basic thermal model is analogous to Ohm's Law as shown in Table 1. This basic model is used to determine the converter's baseplate temperature rise (above ambient) as a function of converter power dissipation and the thermal resistance path from case to ambient.

Thermal Model Electrical Equivalent :

Temperature Rise (DT) <=> Voltage (V)
Power Dissipation (Pdiss) <=> Current (I)
Thermal Resistance (Rth) <=> Electrical Resistance (R)



5-1 Global Thermal Resistance

The *baseplate to ambient* thermal resistance Rth(b-a) can vary greatly depending on the heat transfer method and configuration.
As indicated in the MGDM-150 data sheet, Rth(b-a) can vary from 1.5 to 8°C/W.
This number reflects a typical range of cooling configurations from *Forced* Air Convection to *Natural* (Free) Air Convection with and without heatsink.

Adding a heat sink to the thermal path produces an added thermal resistance Rth(b-h) to the total path.

The thermal resistance (Rth(b-a)) is the sum of all thermal resistances in the thermal path from *baseplate to ambient*.
When a heatsink is attached to the converter baseplate, two distinct thermal resistance paths must be added :

Rth(b-a) = Rth(b-h) + Rth(h-a)

Rth(b-a) = Thermal Resistance - Baseplate to Ambient (°C / W)

Rth(b-h) = Thermal Resistance - Baseplate to Heatsink (°C / W)

Rth(h-a) = Thermal Resistance - Heatsink to Ambient (°C / W)

Any additional thermal resistance paths must be added to the total thermal resistance calculation. An application which conducts heat from the converter baseplate to a remote dissipating surface through a thermally conductive member would add two additional paths to the total :

Rth(b-a) = Rth(b-m) + Rth(m-h) + Rth(h-a)

Rth(b-a) = Thermal Resistance - Baseplate to Ambient (°C / W)

Rth(b-m) = Thermal Resistance - Baseplate to Member (°C / W)

Rth(m-h) = Thermal Resistance - Member to Heatsink (°C / W)

Rth(h-a) = Thermal Resistance - Heatsink to Ambient (°C / W)

Heat (due to power dissipation) is removed from the metal baseplate of the converter to its surrounding environment.
There are 3 basic thermal mechanisms :
to transfer heat:

- Conduction
- Convection (Natural & Forced)
- Radiation

In most applications heat is removed by a combination of all mechanisms. The Thermal Resistance in the above model is a measure of the ability of all combined thermal mechanisms to transfer heat away from the converter's baseplate.

A higher Thermal Conductivity will result in a lower thermal Resistance, hence a lower baseplate temperature rise.

6 Altitude Impact on Thermal Model

Any air-cooled surface temperature calculation or measurement at sea level has to be adjusted for altitude effects.
The altitude effect should be considered in all cases : radiation transfer, conduction transfer and convection transfer.
Many thermal studies have been conducted to measure such impacts and are quite complex (see references). Overall mechanism can only be precise with a 3D Computational Fluid Dynamics (CFD).

6-1 Approximativ Methods

An approximativ method using appropriate 'derating' multiplier can be used as preliminary approach.

This method is based on applying 'derating' multiplier to the heat sink performance to take into account the lower air density caused by the lower air pressure at higher altitude.

The table hereafter shows typical performance derating factors for typical heat sinks at high altitudes. For example, in order to determine the actual thermal performance of a heat sink at altitudes other than sea level, the thermal resistance values read off from the performance graphs should be divided by the derating factor before the values are compared with the required thermal resistance.

Table 1 - Typical Altitude Derating Factors

Altitude (Metres)	Altitude (Feet)	Derating Factor
0 (sea level)	0	1.00
1,000	3,000	0.95
1,500	5,000	0.90
2,000	7,000	0.86
3,000	10,000	0.80
3,500	12,000	0.75

Example: A 1°C/W heatsink would become 1.16°C/W at an altitude of 2,000 metres, or 1.25°C/W at 3,000 metres.

The multipliers in Table 1 are only as good as the assumptions used to derive them, and will never be as precise as a good 3D Computational Fluid Dynamics (CFD) model or a temperature measurement at high altitude. However, in the absence of these costly resources, a very reasonable estimate for the effects of altitude can easily be obtained.

6-2 References

(1) Altitude Effects on Heat Transfer Processes in Aircraft Electronic Equipment Cooling, Doron Bar-Shalom Feb 1989 MIT

(2) Thermal Analysis and Control of Electronic Equipment by Kraus, Allan and Bar-Cohen McGraw-Hill 1983

(3) Electronics Cooling–Theory and Applications, Azar, Kaveh, Short course, 1998.

(4). White, F. M., Fluid Mechanics, Second Edition, pg. 60, McGraw-Hill Book Company, New York, 1986.

(5). Heat Transfer, Sixth Edition, Holman, J.P., McGraw-Hill Book Company, New York, 1986.

(6) The Problems of Cooling High Performance Aircraft. AGARD Conference proceedings No.196 on :
AVIONIC COOLING AND POWER SUPPLIES FOR ADVANCED AIRCRAFT, November, 1976.Howells I.

For more detailed specifications and applications information, contact :

International Headquarters
GAÏA Converter - France
ZI de la Morandière
33185 LE HAILLAN - FRANCE
Tel. : + (33)-5-57-92-12-80
Fax : + (33)-5-57-92-12-89

North American Headquarters
GAÏA Converter Canada, Inc
4038 Le Corbusier Blvd
LAVAL, QUEBEC - CANADA H7L 5R2
Tel. : (514)-333-3169
Fax : (514)-333-4519

Represented by :

Printed in France by GAIA Converter Gaia Converter FC03-029.08/04 Revision B. Graphisme : Philippe Clicq