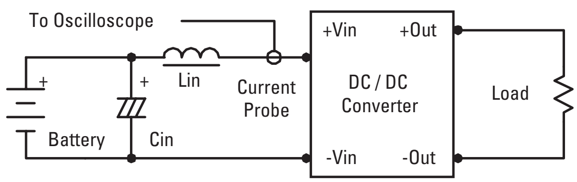
APPLICATION NOTES

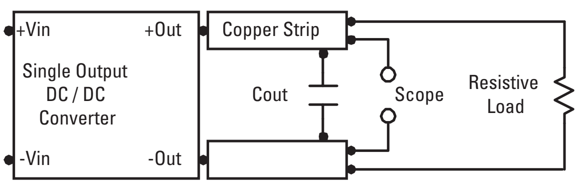
Input Reflected-Ripple Current Test Setup

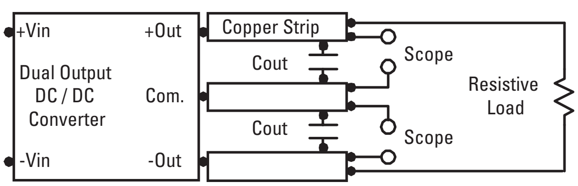
Input reflected-ripple current is measured with an inductor Lin (4.7µH) and Cin (220µF, ESR < 1.0 Ohm at 100Khz) to simulate source impedance. Capacitor Cin, offsets possible battery impedance. Current ripple is measured at the input terminals of the module, measurement bandwidth is 0 - 500KHz.



Peak-to-Peak Output Noise Measurement Test

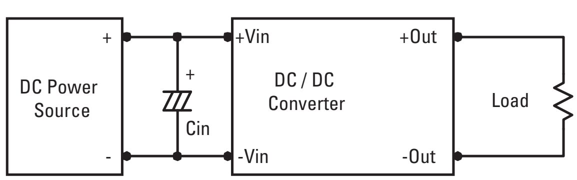
Use a Cout 0.47µF ceramic capacitor. Scope measurement should be made by using a BNC socket, measurement bandwidth is 0 - 20 Mhz. Position the load between 50 mm and 75 mm from the DC/DC converter.





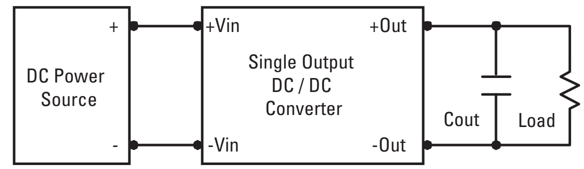
Input Source Impedance

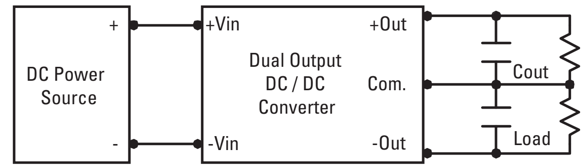
The power module should be connected to a low AC-impedance input source. Highly inductive source impedances can affect the stability of the power module. In applications where power is supplied over long lines and output loading is high, it may be necessary to use a capacitor at the input to ensure startup.



Output Ripple Reduction

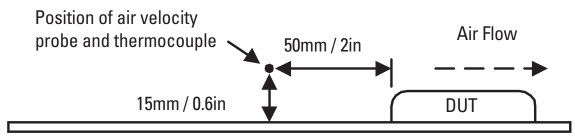
A good quality low ESR capacitor placed as close as practicable across the load will give the best ripple and noise performance. To reduce output ripple, it is recommended using 3.3µF capacitors at the output.





Thermal Consideration

Many conditions affect the thermal performance of the power module, such as orientation, airflow over the module and board spacing To avoid exceeding the maximum temperature rating of the components inside the power module, the case temperature must be kept below 90° C. The derating curves are determined from measurements obtained in an experimental apparatus.



DC/DC CONVERTER THERMAL CHARACTERISTICS

All power converters consume power that is dissipated internally as heat. If this heat is not drawn out of the converter, away from critical components, performance will degrade and the reliable life of the module will be shortened. The amount of power dissipated by a device can be derived from the efficiency specification. Efficiency (η), normally specified under ideal conditions (+25° C ambient, nominal input line and full output load) is equal to:

$$\text{Efficiency} = \eta = P_{out} / P_{in}$$

Internal power dissipation (P_D) is given by the equation:

$$\text{Internal Power Dissipation} = P_D = P_{in} - P_{out} = P_{out}(1 - \eta) / \eta$$

The heat generated by the internal power dissipation of a converter must be brought out to the module case. This is typically accomplished via conduction cooling. Conduction cooling involves the transfer of heat through a solid material.

Once the heat reaches the module case (or heatsink if one is used) convection cooling is used to transfer the heat away from the module and into the ambient air surrounding the converter. Convection cooling is the transfer of heat from a surface such as the module case

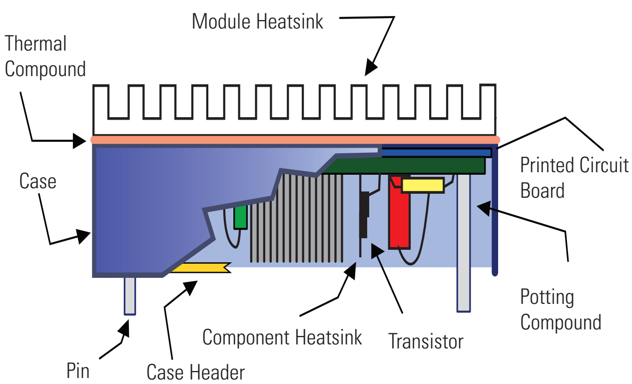


Figure 1- Simplified DC/DC Converter Construction

into the cooler air mass surrounding it. "Free-air" convection means that the natural movement of air is sufficient to cool the module case surface; "Forced-air" convection means that the air movement must be assisted by a fan

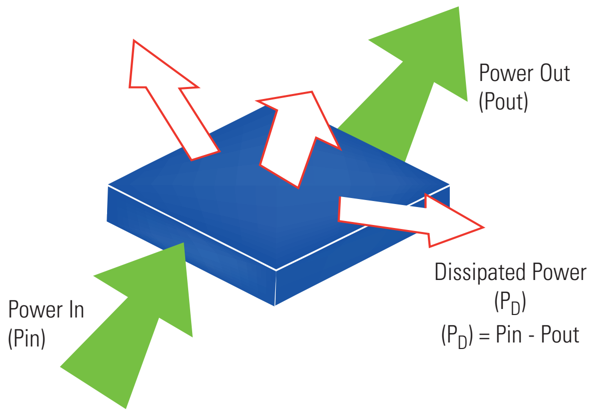


Figure 2- DC/DC Converter Power Flow

or blower (a third type of cooling, thermal radiation, is not a significant factor in the majority of DC/DC converter applications). How this is accomplished is shown by looking at the typical construction of an encapsulation DC/DC converter, as shown in Figure 1.

The transistor switch is a significant heat source in a converter (due to the IR drop across the collector to emitter potential). Typically, the switch is heatsinked as shown (for some higher power converters, the switches and output rectifiers are attached directly to the inside of the module case). The power dropped across the junction resistance of the switch is dissipated as heat.

Even in this simplified example, to get to the ambient air surrounding the converter (by rising upward in the diagram toward the module heatsink), the heat generated by this junction must travel through a number of materials and across a number of material junctions. These include:

- C-E Junction to Transistor Case
- Transistor Case to Transistor Heatsink
- Heatsink to Potting Compound/PCB
- PCB to Potting Compound
- Potting Compound to Module Case

As the heat generated at the transistor junction pass through each material and across each junction of different materials, there will be a temperature drop. This drop is caused by the thermal resistance of the material/junction. These temperature drops can be viewed as a number of resistances in series between the transistor junction and the module case. The thermal resistance (θ) of a material/junction is equal to the temperature drop across the material/junction divided by the power flowing through it. This is expressed as:

$$\text{Thermal resistance} = \theta = \Delta T/P_D$$

The worst case operating temperature limits of the converter are set by the maximum junction temperature (T_J) ratings of the internal semiconductor (IC) components. The IC junction temperatures must not be exceeded or failure will occur. To prevent this, the converter designer calculates the maximum module case temperature by identifying the IC junction with the lowest temperature threshold. All thermal resistances from the IC junction to the module case are then identified. Figure 3 shows a simplified thermal model for a path such as this. Each of the thermal resistances shown produces an internal temperature drop.

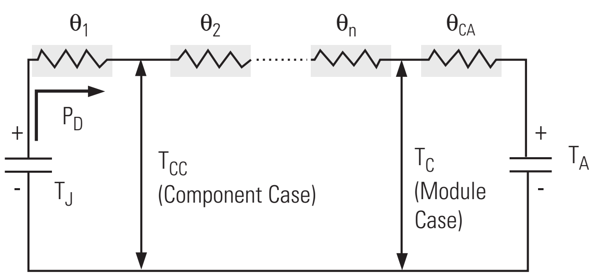


Figure 3 - Simplified Power Converter Thermal Model

T_J = Component Junction Temperature
P_D = Internal Power Dissipation
T_A = Ambient Temperature
θ_1 = Component Junction To Component Case Thermal Resistance
θ_2 to θ_n = Component Case to Module Case Thermal Resistance
θ_{CA} = Module Case to Ambient Air Thermal Resistance
T_C = Module Case Temperature = $T_A + (\theta_{CA} \text{ X } P_D)$
T_{CC} = Component Case Temperature = $T_A - (\theta_{CA} \text{ X } P_D)$

For this model, the maximum module case temperature (T_{CMAX}) for reliable operation is calculated by:

$$\text{Max. Case Temp.} = T_{CMAX} = T_J - (P_D\,\theta_1 + P_D\,\theta_2 + \ldots\,\theta_n)$$

From this formula and the one for P_D, it can be seen that to achieve reliable operation at high case temperatures, the converter designer must maximize operating efficiency and minimize the number of internal thermal resistances. These factors are essentially set by the converter design (efficiency may very with operating conditions). The user can affect the final thermal resistance, the module case (or baseplate) surface to ambient (T_{CA}), and is asked to do this more and more often to insure reliable product operation.

The amount of cooling that takes place at the surface of a converter is highly independent upon the case size (other factors include case material, thickness and surface finish). This cooling can be maximized (and the ambient temperature limit raised) by increasing the surface area of the case. The relationship of case temperature (T_C), ambient temperature(T_A) and the case to ambient thermal resistance of the case (θ_{CA}) is shown by:

$$\text{Case Temp.} = T_C = T_A + (P_D \text{ X } \theta_{CA})$$

Substituting for T_{CMAX}, we derive:

$$\text{Max. Case Temp.} = T_J - (P_D\,\theta_1 + P_D\,\theta_2 + \ldots\, P_D\theta_n) = T_A + P_D\,\theta_{CA}$$

Thus, the maximum ambient temperature (T_{MAX}) for safe operation is:

$$\text{Max. Ambient Temp.} = T_{AMAX} = T_J - P_D\,(\theta_1 + \theta_2 + \theta_3 + \ldots\,\theta_{CA})$$

The addition of a heatsink (see Figure 4) is the most common solution for cooling high power modules. Additional heatsink volume effectively increases the surface area of the case, lowering θ_{CA}. While the overall impact of heatsinking is to lower the total junction-to-ambient thermal resistance of the converter, there are additional thermal resistances caused by the addition of heatsinking.

The first of these is the case-to-heatsink thermal resist-

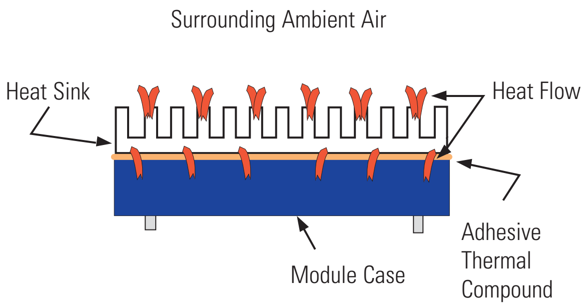


Figure 4 - DC/DC Power Converter Heatsinking

ance (θ_{CS}) . It is critical to move the maximum amount of heat across this junction with the lowest possible temperature drop. Some important principles to follow are:

- Use the maximum possible surface contact area between the case and heatsink
- User thermal joint adhesive (These fill microcracks or voids in the mating surface areas, decreasing the thermal resistance).
- Use screws/bolts to attach heatsinks to the module case (if provided). This will increase the contact pressure.

With proper precautions, the case-to-heatsink thermal resistance can be maintained below 0.1° C/W.

The heatsink itself will also present a thermal resistance to the heat flowing through it. This is a function of the thermal conductivity of the material. The interface of the heatsink surface to ambient air becomes the final thermal resistance; sink to ambient (θ_{SA}). Heatsink materials should be chosen for a number of considerations, including:

- High thermal conductivity
- Structurally fit for application
- Price consistent with application requirements

More heatsink information can be found at www.avvidthermalloy.com.

Forced air flow (also called Forced convection cooling) is typically used in addition to heatsinking. Forced air can improve cooling tremendously, but it adds cost and also affects system reliability. The fan or blower is a mechanical assembly, with its own set of reliability limitations. Some systems also require that moving air be filtered, which introduces periodic maintenance (changing of filters), further increasing system cost.

In forced convection applications, the velocity of the air flow over the exposed surface area of the heatsink is a critical consideration. Fan specifications are typically given in air volume (Cubic Feet per Minute- CFM). To convert this to velocity (Linear Feet per Minute). The conversion is:

$$\text{Linear Feet per minute} = \text{CFM/Area}$$

Where area is the cross sectional area of the heatsink over which the air flow will pass. Also, the fan output should be derated (by 60% to 80%) to compensate for the back pressure encountered in practical application. Care must be taken not to constrict air flow through the application and heat generating devices should be placed toward the end of the air stream.