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Thermal Considerations for Hybrid DC-DC Power Converters

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INTRODUCTION

Hybrid DC-DC converters such as VPT's DV Series are usually rated for the full military temperature range of -55ºC to +125ºC and can be operated at full rated power within that range as long as the power dissipation and temperature rise is properly addressed. DC-DC power converters always have an efficiency less than 100% and therefore always waste a percentage of their input power. This wasted power is dissipated as heat and will cause the temperature of the DC-DC converter to rise above the ambient system temperature. The temperature rise of the DC-DC converter must be considered during the system mechanical and thermal design to ensure the converter does not exceed its maximum rated operating temperature.

CHARACTERISTICS OF HYBRID PACKAGING

Hybrid packaging technology uses thick film conductors, bare semiconductor die and high thermal conductivity materials to achieve high temperature operation. A diagram of the typical hybrid package is shown in Figure 1. In its basic form, the bare silicon die is mounted to a ceramic substrate, usually Al_2O_3 (alumina), which is mounted to the metal package, usually steel or Kovar. Power is dissipated in the semiconductor die, which may be an IC, power transistor, or power rectifier. The die has a maximum semiconductor junction operating temperature, typically 150ºC or 175ºC, as specified by the manufacturer.

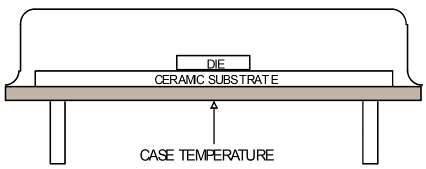

Figure 1. Internal Hybrid Construction

The semiconductor junction temperature inside the hybrid, Tj, is determined by the following formula:

$$Tj = Tcase + \Delta T \quad (1)$$

$$\Delta T = Pd \cdot \theta jc \quad (2)$$

Tcase is the case temperature of the hybrid; ΔT is the temperature rise from junction to case; Pd is the power dissipated in the die; and θjc is the thermal resistance from the junction to the case. θjc is the sum of any intermediary thermal resistances, in this case the ceramic substrate, the attachment materials, and the case itself.

THERMAL RESISTANCE CALCULATION

The thermal resistance θ for any material can be calculated according to the formula:

$$\theta = \frac{x}{K \cdot A} \quad (3)$$

where A is the cross sectional area normal to the direction of the heat flow, x is the distance that the heat travels, and K is the thermal conductivity of the material. For example a 0.5" tall aluminum heat spreader with dimensions 3" x 1.5" which could be used under a side leaded hybrid package has a thermal resistance of:

$$\theta = \frac{0.5in}{3.957\frac{W}{in-C} \cdot 3.0in \cdot 1.5in} = 0.028\frac{°C}{W} \quad (4)$$

The thermal conductivity of aluminum is 3.957W/in-C. From (2), each Watt of power dissipated through this aluminum block causes a temperature rise across the block of 0.028°C.

DC-DC CONVERTER APPLICATION

From Figure 1, it is apparent that the thermal path of the hybrid is entirely through the bottom of the package. The operating temperature is specified, and must be measured, on the bottom surface of the case. The lid offers very little path for heat transfer. Any temperatures measured on the lid will give inaccurate results and any heatsinking added to the lid will have only minimal effect. The system thermal design must allow for the primary thermal path through the bottom of the package.

The case temperature will always be slightly higher than the heatsink or ambient temperature due to the power dissipated in the hybrid and the thermal resistance of the assembly. Case temperature cannot be assumed to be equal to the heatsink or ambient temperature. This wrong assumption is the cause of many system thermal problems. Proper system design will allow high system temperatures, in excess of 100ºC, yet maintain hybrid component temperatures well below 12ºC.

If the case of the hybrid is maintained below +125ºC, the internal semiconductor junction temperatures will remain at safe levels, typically between 130º and 140ºC, well below their maximum ratings. If the output power of the hybrid is reduced, it is possible that the maximum allowable case temperature can be increased further without increasing the internal junction temperatures. Consult the hybrid manufacturer for details.

Although hybrid DC-DC converters can be operated up to +125ºC, reliability can be increased by operating them at a lower case temperature. Every electronic component has a failure rate which is in theory related to its operating temperature. Lowering the operating temperature of the hybrid by 5°C can result in a 10-20% increase in MTBF according to MIL-HDBK-217 type calculations. In general the system design should attempt to reduce thermal resistances and minimize the temperature rise between the DC-DC converter and the system ambient. For maximum reliability, the DC-DC converter should be operated as close as possible to the ambient temperature rather than near its maximum operating temperature.

CONSIDERATIONS FOR PROPER MOUNTING

DV series DC-DC converters are typically used in applications where the dominant mode of heat transfer is conduction. Any radiation or convection cooling is usually neglected in the thermal analysis. Lower power or high efficiency hybrids can often be mounted without a heatsink or rely on the PCB for heatsinking. On the other hand, higher power hybrids will usually require a low thermal resistance connection to a substantial heatsink, such as a system chassis.

Aluminum is typically used for a heatsink or heatspreader material, since it has high thermal conductivity, low weight and is easily machined. A thermally conductive gap filler material should be used between the mounting surface of the hybrid and the heatsink. This gap filler is typically a thermal pad, thermal grease, or adhesive. It will fill any surface irregularities and decrease the thermal resistance of the interface. Materials are available from various manufacturers with various properties: thickness, hardness, dielectric breakdown, adhesive, outgassing, etc.

The DC-DC converter should be mounted securely to the heatsink for good thermal conductivity. A flanged package, adhesive, or a mounting strap is recommended for best performance. Some gap filler materials require adequate mounting pressure to maintain good thermal performance. Solder connections to the pins are usually not sufficient if a good thermal interface is required.

DETERMINING THE CASE TEMPERATURE

The operating temperature of the hybrid should be verified by both analysis and measurement. For design purposes the operating temperature can be calculated using computerized finite element analysis methods or a simple thermal resistance model. A thermocouple mounted on the baseplate of the hybrid in the actual system is a good method of verification but usually must wait until late in the development cycle. Basic thermal resistance calculations, although approximate, are a good design tool early in the development cycle before full system thermal models are developed.

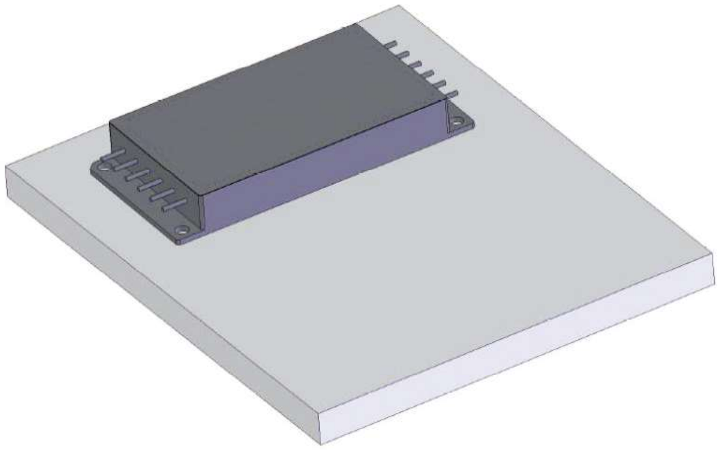

Figure 2. Hybrid DC-DC Converter Mounted to a Metal Heat Spreader.

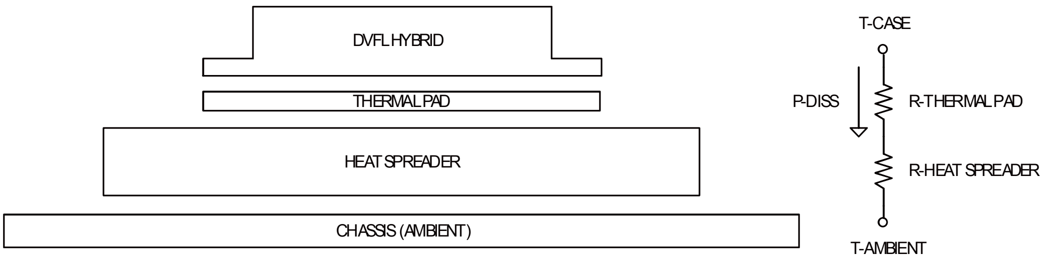

Figure 3. Mechanical Stackup and Thermal Resistance Model for DVFL.

Figure 2 shows a side-leaded power hybrid mounted directly to a heatspreader. Figure 3 shows the mechanical stackup and equivalent thermal resistance model, assuming the heatspreader is mounted to a chassis with a known ambient temperature.

The case temperature of the hybrid is calculated similarly to (1) and (2):

$$T_{case} = T_{amb} + P_d \cdot \sum\theta \qquad (5)$$

Tamb is the known ambient temperature of the system chassis. Pd is the total power dissipation of the hybrid. It can be calculated from the output power and efficiency of the hybrid. The efficiency can be measured or read from the datasheet. The total thermal resistance $\sum\theta$ is the sum of the all intermediate thermal resistances from the hybrid to the ambient, in this case the thermal pad and the heat spreader. The thermal resistance of the thermal pad can be read from the manufacturers datasheet. The thermal resistance of the heatsink can be obtained from its manufacturer or calculated according to equation (3).

The power dissipated internal to the hybrid can be assumed to be spread evenly across its baseplate, so the area in (3) would be the area of the hybrid baseplate, not the entire area of the heat spreader. If the heatsink is unusual or nonrectangular in shape, its thermal resistance can be approximated by breaking it up into rectangular blocks which are in series with respect to the heat flow. The thermal resistance of each block can be calculated individually and summed to obtain the total thermal resistance.

For this example: the ambient temperature is 70ºC; the power dissipated for the DVFL2815S hybrid DC-DC converter at 28V input; full load is 30W; the thermal resistance of the thermal pad TP-001 is 0.06°C/W. The aluminum heat spreader is 0.5" thick. From (4) the thermal resistance of the heat spreader is 0.028°C/W and from (5) the case temperature of the DVFL hybrid is:

$$T_{case} = 70C + 30W \cdot (0.06C/W + 0.028C/W) = 72.64C \qquad (6)$$

This configuration with the hybrid mounted directly to a heatsink will usually result in the lowest possible operating case temperature. It can be applied to down-leaded type packages by adding clearance holes in the heatsink for electrical connections to the pins.

"DEADBUG" STYLE MOUNTING

Figure 4 shows an example of "deadbug" style mounting for a power hybrid with a flanged package. This is a common mounting configuration for severe vibration environments. Electrical connections to the pins can be made with discrete wires or a flexible or rigid printed circuit board.

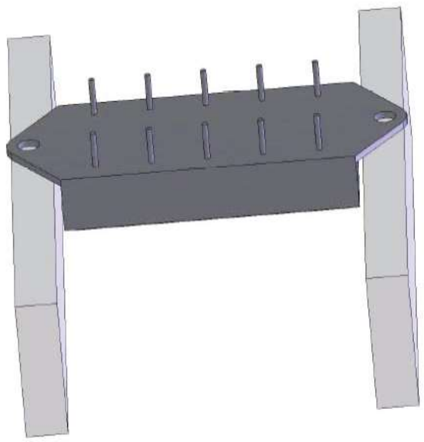

Figure 4. "Deadbug" Style Mounting for Downleaded Flanged Units.

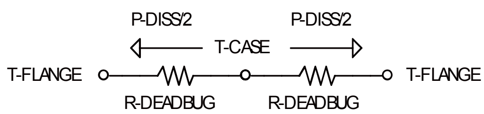

Figure 5. "Deadbug" Thermal Model.

In this case, heat is transferred only through the mounting flanges. The maximum temperature is assumed to be in the center of the hybrid and there is an additional thermal resistance and temperature rise from the center to the mounting flange. For this configuration since power is dissipated across the surface of the baseplate, finite element methods can be used to obtain an effective thermal resistance, R-deadbug, from the center of the package to the flange, as shown in Figure 6. This effective thermal resistance will give a valid hot spot case temperature when used in conjunction with the total power dissipation of the hybrid. This effective thermal resistance can be obtained from the manufacturer. For reference, R-deadbug = 6°C/W for VPT's DVTR flanged package.

The hot spot temperature in the center of the hybrid is given by (7) where each flange is held at the same temperature, T_{flange}. The power dissipated, P_d is divided by 2 since there are two parallel thermal paths, one to each flange.

$$T_{case} = T_{flange} + \frac{P_d}{2} \cdot \theta_{deadbug} \qquad (7)$$

The "deadbug" mounting method will usually result in higher case temperatures than the direct heatsink configuration of Figure 2.

"DEADBUG" STYLE MOUNTING WITH HEAT SPREADER

For applications with high power dissipation or high ambient temperature, the case temperature of the hybrid can be lowered by adding a heat spreader to the basic "deadbug" mounting configuration, as shown in Figure 6. The heat spreader should have a thermal conductivity greater than that of the hybrid package. For example, for a cold rolled steel package, an aluminum heat spreader could be used with a thickness twice the thickness of the hybrid package. To be effective, the spreader must clear the electrical pins and maintain thermal contact along its entire length; a thermally conductive adhesive is recommended.

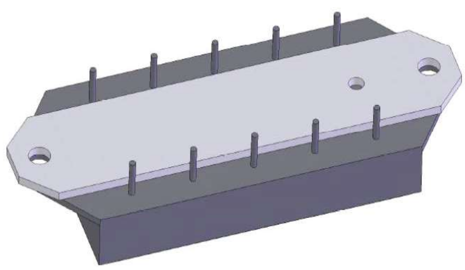

Figure 6. Heat Spreader Attached to Baseplate to Reduce Thermal Resistance.

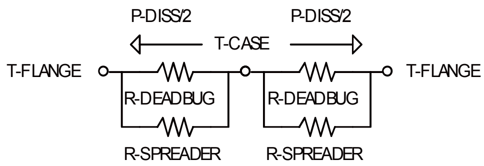

Figure 7. Thermal Model for "Deadbug" Mounting with Heat Spreader.

Again using finite element methods, an approximate thermal resistance model can be derived for this configuration. The thermal resistance of the heat spreader can be assumed to be in parallel with the effective thermal resistance of the package with an additional factor of 2. This additional factor was derived through finite element modeling to account for the fact that heat is actually transferred to the heat spreader along its entire length, instead of simply at the center of the hybrid. The thermal resistance of the spreader is calculated from (3) for heat flow along its length, where *x* is the distance from the center of the package to the center of the flange. Using the formula for parallel resistors, the case temperature of the hybrid would be:

$$T_{case} = T_{flange} + \frac{P_d}{2} \cdot \frac{1}{\dfrac{1}{\theta_{deadbug}} + \dfrac{1}{\theta_{spreader}/2}} \qquad (8)$$

Note that θ-spreader is divided by 2 as mentioned above. It is apparent that this configuration with the heat spreader (8) will always result in a lower temperature case temperature than the previous configuration without the heat spreader (7). The thermal resistance of the heat spreader must be low enough to have a significant impact; it must be made of a high thermal conductivity material and have adequate size.

PCB MOUNTING

Lower power hybrids can often be mounted directly to the circuit board or PCB as shown in Figure 8. Good thermal contact should be maintained between the hybrid and the board. An adhesive is often used. Mounting flanges or a mounting strap across the top of the hybrid can also help maintain good thermal contact. The thermal resistance of the PCB should be calculated lengthwise through the PCB material from the center of the hybrid to the mounting locations of the PCB using (3). The case temperature can be calculated from (5). Typical PCB materials are not good thermal conductors. Copper planes are often employed to improve thermal conductivity along the length of the PCB. Likewise, thermal vias are used to improve thermal conductivity through the PCB, usually under the hybrid or at the board mounting locations.

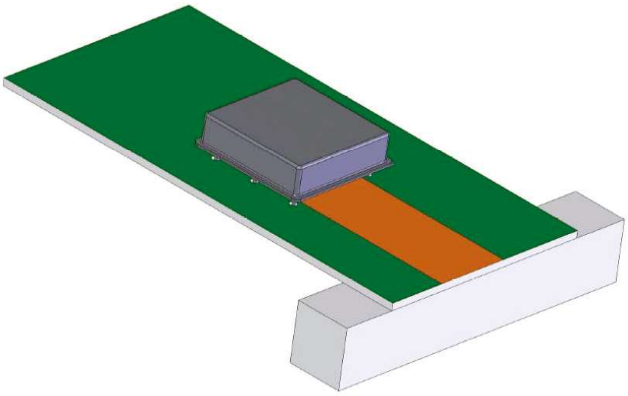

Figure 8. Small Hybrid Mounted to a Circuit Board.

PCB MOUNTING WITH HEAT SPREADER

When the PCB alone is not sufficient to carry heat away from the hybrid, a heat spreader can be added to the assembly as shown in Figure 9. In this case, the thermal path through the PCB can usually be ignored and the case temperature of the hybrid can be calculated directly from (5). Additionally, intentionally isolating the thermal spreader and hybrid from the PCB can serve to lower the temperature of the PCB and surrounding components.

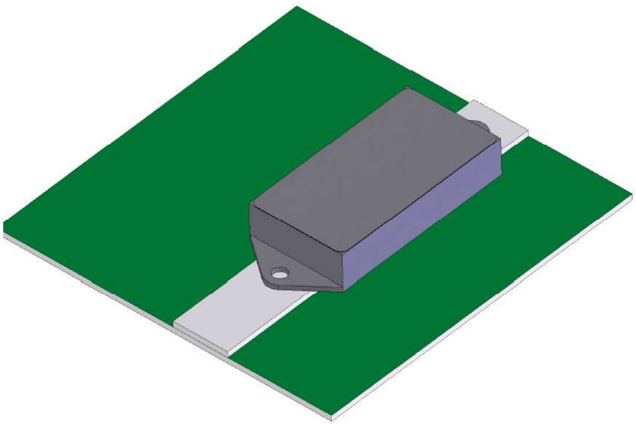

Figure 9. Converter/Heat Spreader/PCB Assembly.

Another option is to cut a hole in the PCB, allowing a heat spreader to protrude up and make contact with the base of the hybrid. The mechanical mounting should again be sufficient to ensure good thermal contact between the hybrid and the heat spreader.

CONCLUSION

Proper system thermal design is necessary to allow hybrid DC-DC converters to operate reliably over the full military temperature range. To ensure maximum ratings are not exceeded, it must be recognized that the hybrid operating temperature will be greater than the ambient or heatsink temperature. The hybrid operating temperature is specified at the bottom center of the baseplate. It can be determined either by analysis or measurement. Knowing the actual temperature will allow accurate reliability calculations and proper tradeoffs between design complexity and reliability.

ADDITIONAL INFORMATION

For additional information on designing power systems for low voltage applications or VPT products, contact VPT:

Phone 425.353.3010
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