beta dyne

Application Note DC-009
DC/DC CONVERTERS

COOLING HIGH-DENSITY OPEN-FRAME DC/DC CONVERTERS

The demand for high-power density systems such as those powering Intel CPUs, thermoelectric coolers for lasers and other high-power demanding systems have forced DC/DC converter manufacturers to increase the power density of their converters. Both the converter manufacturer and the system manufacturer rely on a forced-air cooling of the individual power components within the system.

Improved component characteristics and new manufacturing techniques such as lower R_{ON} MOSFETs and multilayer PCBs made it possible to design more efficient converters and allowed manufacturers to achieve higher power density. As efficiency increases, higher power density converters will be introduced. Multilayer PCBs allow the designers to design both magnetics and the control circuitry on a single board thus reducing IR drops and improving reliability and quality while reducing cost.

As the power density increases so does the power dissipation inside the converter and unless the efficiency approaches 99% (not in the near future), the system designer must apply the same cooling techniques for DC/DC converters as one would for any power transistor such as TO-3 220, etc. One must keep in mind that a 100W DC/DC converter with 90% efficiency will deliver 100W to the load and it will dissipate 10W inside, therefore the system designer must allow 10% more cooling capacity in his system.

The highest component contributors in the internal power dissipation are:

1) Input switching MOSFETs,
2) Output switching MOSFETs (synchronous rectifiers),
3) Magnetics (power transformer and inductors)

The PowerWatt series of converters are based on a single input transistor forward topology and synchronous rectifier output. The input power transistor with all the $I_{IN}^2 * R_{ON}$ and switching losses account for 20% to 25% of dissipated power (Pd). Another 20% to 25% of Pd is due to the magnetics mostly the power transformer (the output inductor has 99%) efficiency. The remaining 40% to 45% of Pd is due to $I_O^2 * R_{ON}$ dissipation and switching losses of the synchronous rectifiers.

The switching losses of the input power transistor and synchronous rectifier make up the overhead power required for the converter to operate. These switching losses greatly contribute to no load input current, which can be 10 to 200 times as much as the input current of some power converters with output rectifying diodes. Some manufacturers use additional circuitry and turn off the synchronous rectifiers at low output current in order to make the converter look good at no load. The following are reasons Beta Dyne offers open-frame, high-density converters over potted or thermal plate-cooled converters.

The thermal resistance from the semiconductor junction to the ambient in both the potted and thermal cooled types increases. Even when all the power components are placed on a thermal plate, like those offered by Bergquist or Thermagon, minimize only the thermal resistance from the junction to the case and *not the junction to ambient*. Additional cooling, such as heatsinks and forced air, must be applied to the surface to reduce the thermal resistance from the case to ambient. This increases cost and reduces reliability, as well as, lowers the efficiency of the converter.

$Q=H \cdot A \cdot \Delta T$
(the rate of heat transfer is proportional to the area exposed to air)

Thermal plate consturction requires all the power connections from the power transistors to the transformer, inductor and synchronous rectifiers to be made on a single-sided thermal plate. Even with 4 to 5 oz. of copper thickness, it will not come close to a multilayer PCB. The power runs connecting these components, especially in converters with high output current, dissipate power. For example, on a 0.005Ω copper connection with 15A passing through it, the dissipated power is $I^2 * R = 15^2 * 0.005 = 1.125W$. For a 50W converter, 1.125W translates to a 2.2% drop in efficiency. In the multilayer board, all these connections are eliminated or minimized. Also, the integrity of the power and signal connections suffer when a thermal plate is used for the converter. In the PowerWatt converters, all layers are connected at each pin, which offers better vibration performance and lower DC resistance.

Potted converters rely on the thermal conductivity of the potting and the increase in the area of the case for cooling. The thermal resistance from junction to case is higher than that of the thermal plate mentioned above. They do not offer high power densities, so a heatsink(s) or forced air cooling may be necessary. The only advantage they have over open-frame or thermal plate converters is that they can be designed to operate in harsh environments. The open-frame converters offer the minimum thermal resistance from junction to ambient and the multilayer PCB acts as both heatsink and thermal equalizer by distributing the heat over the entire unit and its connectors. The PowerWatt is designed for use in forced air systems.

To minimize the thermal resistance we have to remove most of the solder mask from the top and bottom surfaces allowing direct air (conduct on the metal.) From temperature measurements taken before and after the removal of the solder mask from a 0.7"×0.2" area and at a constant air circulation of 400LFM, the PCB temperature dropped by 25°C. One may argue that in exposed conductors in converters there exists the possibility of an accidental short circuit or damage. If that were the case then we must eliminate all ICs, open-frame AC/DC, DC/DC, etc.

If cost, performance and reliability are the most critical parameters in your application, open-frame DC/DC converters are your answer. Do not believe the high power density figures some DC/DC manufacturers use or the claims that a low-profile design offers operation without a heatsink(s). The power density should be calculated with all the needed components in the application such as heatsinks, air fans, etc. Some low-profile converters may well operate without a heatsink, but not at the desired power level. To attain high power levels, you will most likely have to employ a heatsink(s). Check for derating curves or how large the heatsink(s) needs to be, then you will see how low the low profile design actually is!