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The Basics of Heat Management for DC/DC Converters

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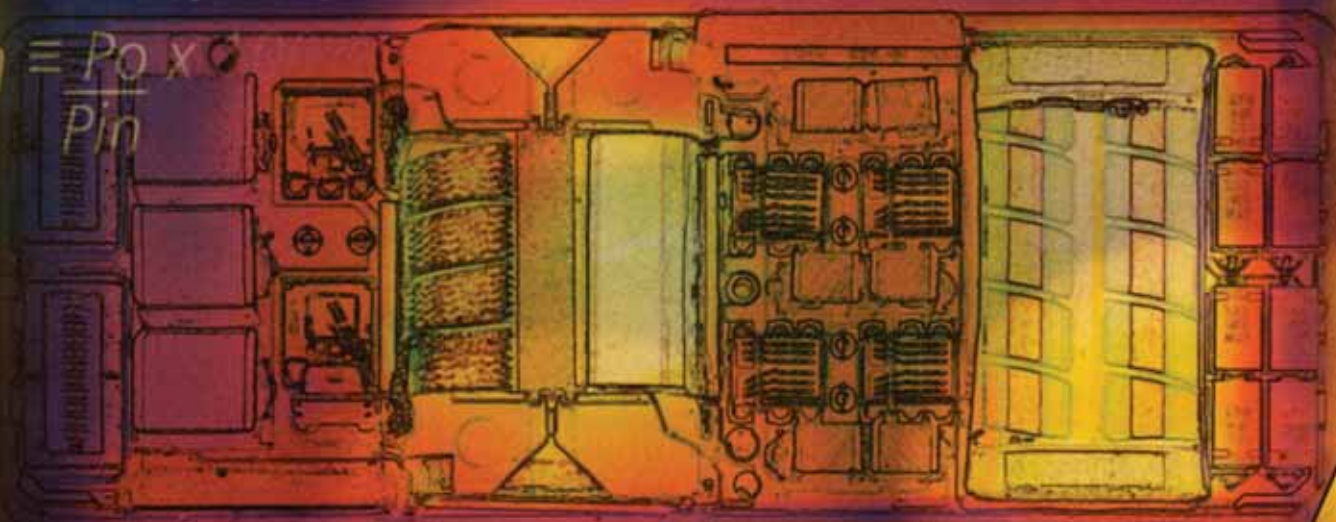
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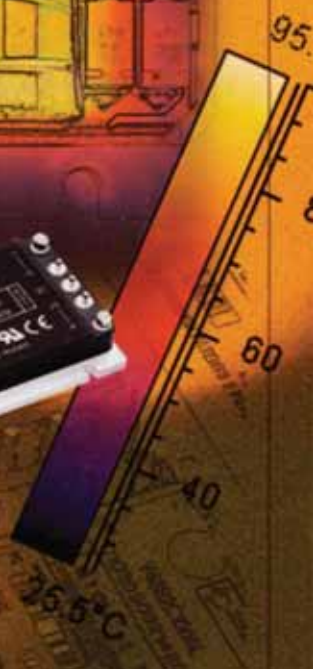
October 2005

Power dissipated (P_d) $P_d \equiv \frac{P_o}{\eta} - P_o$
Efficiency = η

$$\eta \equiv \frac{P_o \times \theta}{P_{in}}$$



Power Sources



The Basics of Heat Management for DC/DC Converters

In order to get the most usable power to the load, proper thermal management must be achieved. This is especially true as the modular DC-DC converter industry realizes ever-greater power densities. Dealing with the heat generated by the conversion process should not be underestimated nor overlooked when designing or selecting a power supply. Product reliability and operating life are inversely proportional to operating temperature.

All power product manufacturers specify the maximum operating temperature and publish thermal data for their converters. Assuring a robust design requires that temperature limits not be exceeded under any operating conditions and that sufficient margins be built in. This requires careful analysis, understanding of the application, and verification through experimentation that the chosen thermal management approach can deal effectively with the environmental and load induced demands.

Efficiency, while not the only element in thermal management to consider, is important. The manufacturer of the device will normally publish efficiency values. However, a designer should not assume that the published efficiency specification applies at all operating conditions. Traditionally, DC-DC converter manufacturers provide efficiency information that applies only at a specific line and load combination. Unfortunately, the device is usually not operated at only this one point; so it's important to look at the full efficiency map. For a good thermal management design, use the worst-case efficiency expected over the planned operating range to calculate the worst-case power dissipation.

After the design trade-offs of architecture, product efficiency and thermal management are made, the designer must perform a careful analysis of the application to develop a cooling approach. The power designer must ensure that the maximum specified temperature at which a product can operate is not exceeded under all operating conditions and that sufficient margin is built into the design. The analytical process is described, calculations are made, and examples given to, for example:

- Determine the baseplate temperature rise over ambient caused by the dissipated power.

- If a heat sink is needed, calculate the thermal impedance required to keep the baseplate temperature within specification.

- Ascertain the need for and the level of forced air.

The first step in this process is to determine the worst-case power dissipation that the system is likely to develop. Use the following equations to determine the efficiency of the converter over the desired operating range and the maximum loading the device will deliver. Conversion efficiency, η in percent, is defined as:

$$\eta = \frac{P_o}{P_{in}} \times 100 \quad (\text{Equation 1})$$

Where P_o is the output power and P_{in} is the input power.

Figure 1 shows that the efficiency for this device remains very flat over most of the operating range. Traditionally, DC/DC converter manufacturers provide efficiency information that applies at a specific line and load combination. Unfortunately, the device is usually not operated at only this one point; that is why it is important to look at the full efficiency map. For a good thermal management design, use the worst-case efficiency expected

over your operating range in the calculation to determine the worst-case power dissipation.

From Figure 1, the efficiency at nominal line is 89 percent for most of the output range. We'll use this as the worst-



by Jeffrey Ham,
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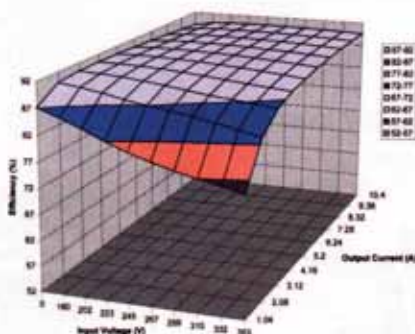


Figure 1. Efficiency vs. Input voltage and Output Current

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case efficiency in our examples. If this converter were operating at full load ($P_o = 500\text{ W}$), the power dissipated (P_d) as heat is:

$$P_d = \frac{P_o}{\eta} - P_o \quad (\text{Equation 2})$$

$$\eta$$

Therefore $P_d = 61.8\text{ W}$

Now we must determine the baseplate temperature rise over ambient caused by this power dissipation. All manufacturers publish thermal data for their converters. For the product in question, the maximum specified operating temperature, as measured at its baseplate, is 100°C (T_b). The published thermal impedance (θ) value in free air is 4.9°C/W . Therefore, the temperature rise over ambient is simply:

$$T_r = P_d \cdot \theta \quad (\text{Equation 3})$$

or 303°C .

A heat sink or other means of reducing the thermal impedance of the baseplate is needed. To find a suitable heat sink, we need to find the allowable temperature rise in order to determine the thermal impedance required to keep the baseplate temperature within specification. The allowable temperature rise is the difference between the maximum baseplate temperature and the maximum expected ambient temperature.

If the maximum ambient temperature were 55°C , for example, the allowable temperature rise for this module would be 45°C ($= 100^\circ\text{C} - 55^\circ\text{C}$). The thermal impedance needed is the allowable temperature rise divided by the maximum power dissipated, P_d (Equation 4). In this example, the thermal impedance is calculated as 0.73°C/W . This is the maximum thermal impedance that can be tolerated, and will result in the module operating at its maximum specified temperature when delivering full rated load at the maximum expected ambient temperature. This thermal impedance is not just that of the heatsink but the sum total of all the individual interface impedances in the system. This has particular

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importance with respect to the selection of a thermal interface material. In all cases, the lower the thermal impedance of this interface, the better.

A derating factor of 0.75 should be applied to the maximum thermal impedance needed whenever possible.

$$\theta_{\max} = \frac{T_r \text{ allowed}}{P_d} \quad (\text{Equation 4})$$

Applying the derating factor results in a more desirable θ of 0.55°C/W. This low impedance is achieved by employing one of the following cooling methods:


- Natural Convection Cooling — transfer of heat energy to a fluid, primarily air.
- Forced Convection Cooling — transfer of heat energy to a moving fluid.
- Conduction Cooling — transfer of heat through a solid medium.

Many telecom applications have large rack-mounted units that contain multiple PCBs very close together. This inter-board spacing is referred to as "pitch". In order to maximize the utility of their products, the more PCB cards they can get into a given space the better. This makes component height above the PCB an important issue. But that's another story.


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Editor's note: View the online version of this article at www.ecnmag.com for a couple of thermal calculation examples.

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