VI Chip® BCM® Bus Converter Thermal Management

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Introduction

The purpose of this Application Note is to determine the power capability of the BCMs given certain ambient temperature and air flow conditions plus heat sink options.

Using BCM VI Chip case temperature measurements to develop thermal impedance curves will also be described. These curves are used along with the efficiency of the module to calculate maximum power dissipation (and maximum available power) for a given ambient temperature and airflow.

Efficiency & Dissipation

During operation, a BCM's internal semiconductors, transformer cores, control silicon and PCB traces all dissipate heat. The amount of heat generated is a direct function of the BCM's efficiency, as shown per Equation 1. BCMs are typically ~95% efficient so dissipation averages roughly 5W for every 100W of load.

$$P_{DIS} = P_{OUT} \bullet \left(\frac{1}{\eta} - 1 \right) \qquad (1)$$

Equation 1:
P_{DIS} is power dissipated by the BCM as heat
P_{OUT} is output (load) power
η is the percentage efficiency of the module expressed as a decimal

Heat Dissipation Paths

The heat produced within the BCM is coupled to the VI Chip case and PCB (through the J-leads) via effective thermal impedances, $RØ_{JC}$, and $RØ_{JB}$.

The heat is then coupled to the ambient environment by either the case-to-ambient thermal impedance ($RØ_{CA}$) or the board-to-ambient thermal impedance ($RØ_{BA}$) as shown in Figure 1.

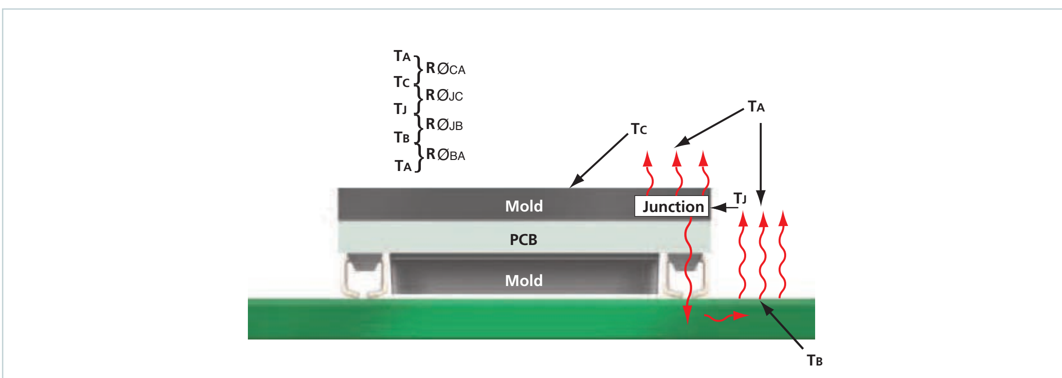


Figure 1
Heat is Coupled to the Ambient by Case and PCB

In most applications, cooling of the BCM through the board is a function of how much copper is surrounding the BCM, how much air is passing over that copper, and how much heat is coupled into the PCB from surrounding components. For the purpose of this application, it will be assumed that there is no cooling of the BCM due to the PCB (as $RØ_{BA}$ is very large) and that all of the cooling occurs through the case (thus $RØ_{CA}$ should be kept as small as possible).

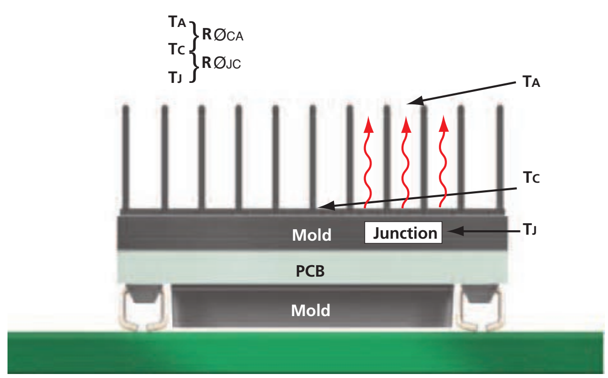
In most applications, there is a small amount of cooling that occurs through the PCB, and this will provide additional margin on the cooling by increasing usable power. BCM® case-to-ambient thermal impedance ($RØ_{CA}$) is a function of the surface area of the case (which is fixed for the BCM) and the volume of air passing over the case (which is a function of the application and the system's fan capability).

Heat Sinking Options

Part of the strategy for reducing $RØ_{CA}$ would be to increase the effective surface area of the BCM case. This can be accomplished by adding a heat sink to the case as shown in Figure 2. The resulting thermal impedance model is shown in Figure 3 assuming that there is no cooling of the BCM due to the PCB.

Figure 2
Mounting a Heat Sink to the BCM Increases the Effective Surface Area and Lowers $RØ_{CA}$.

Figure 3
Thermal Impedance Neglecting $RØ_{JB}$ and $RØ_{BA}$. Shown with Optional Heat Sink



Heat sinks are available in two heights; 6.3mm (Figure 4) and 11mm (Figure 5) and two orientations; transverse (Figure 6) and longitudinal (Figure 7). These heat sinks come with a pre-attached interface material that provides good thermal contact between the chip and the heat sink. They are attached with two spring-loaded pushpins which create a total interface pressure of 5lb/psi. Pushpins are available in four lengths to fit PCB thicknesses from 0.055in to 0.172in. For more information, please visit the website at the link below:

www.vicorpower.com/dc-dc-converters-board-mount/bus-converter-module

Figure 4
6mm Heat Sink

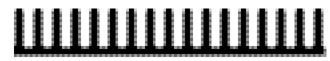


Figure 5
11mm Heat Sink

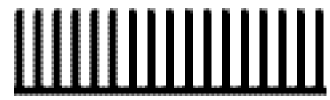


Figure 6
Transverse Airflow

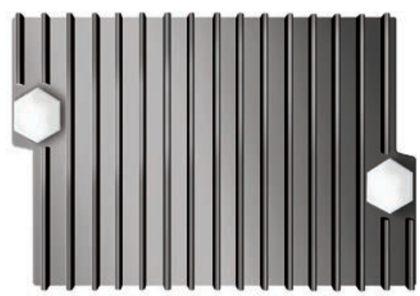
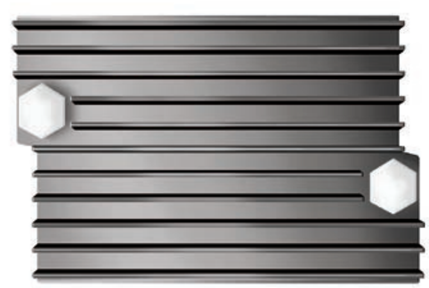


Figure 7
Longitudinal Airflow

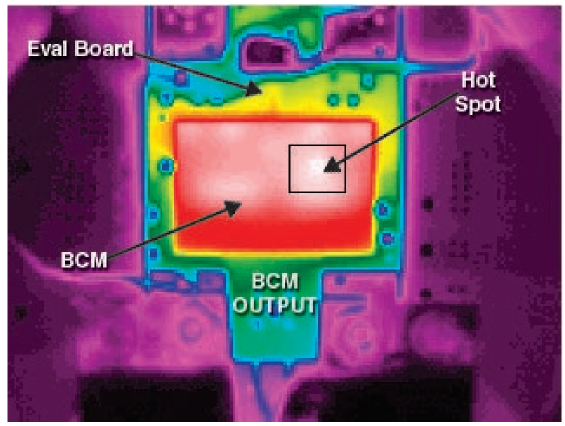


Measurement Techniques

In order to determine $RØ_{CA}$ for a BCM® without a heat sink, case temperature measurements are taken in a wind tunnel at varying airspeeds using an IR imaging camera. During testing, the BCM is mounted on a six-layer evaluation board consisting of 2oz. copper on the outer layers and 3oz. copper on the inner layers. Ambient temperature (T_A) is measured using a thermocouple located within the chamber.

An example infrared (IR) image is shown in Figure 8 with no heat sink. Adding a heat sink will distribute the heat evenly across the case, leading to less concentration of heat in a given area. Prior to testing, the BCM® is uniformly covered in a black stencil ink with a characterized emissivity. The reference point for the measurement is the hottest point on the module case, which is model dependent. When making case temperature measurements using a thermocouple, use the IR image as a reference to determine the thermocouple placement. Model specific IR images are shown below in the appropriate section.

Figure 8
Example IR Image. No Heat Sink



Thermal Derating Curves

Thermal derating curves are provided to the user as guidelines to determine what power levels a device can be safely operated at in a given environment. To ensure that components inside the molding do not exceed a junction temperature (T_J) of 125°C, the case of the module should be limited to 100°C.

Measurements are taken at a 0°, and 90° orientation with no heat sink, a 6.3mm heat sink, and an 11mm heat sink to determine the case-to-ambient thermal impedance ($RØ_{CA}$) vs. airflow. In the 0° orientation, airflow is from front to back and a longitudinal heat sink is used (Figure 9). Conversely, in the 90° orientation, airflow is from side to side and a transverse heat sink is used (Figure 10).

Figure 9
0° Airflow Orientation with Longitudinal Heat Sink

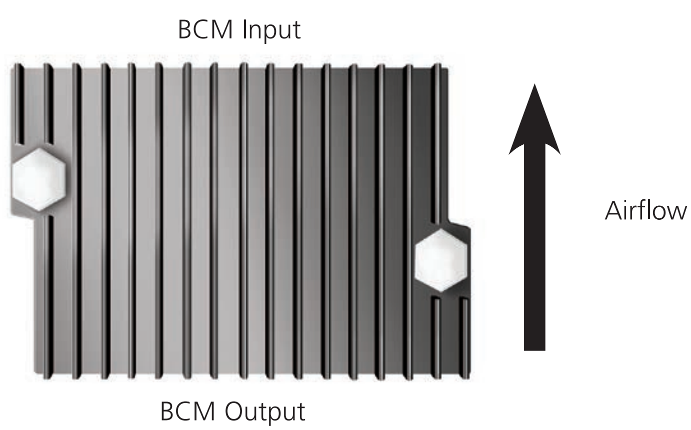
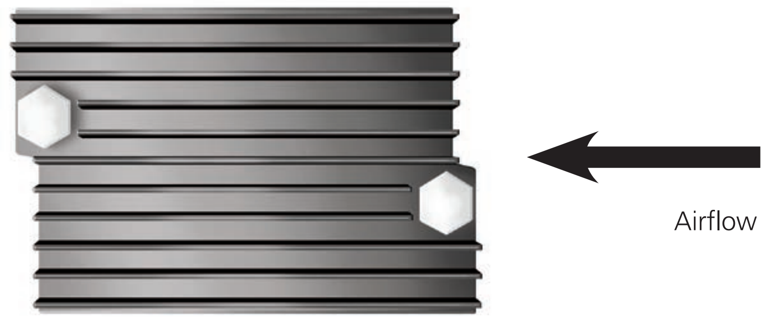


Figure 10
90° Airflow Orientation with Transverse Heat Sink



The resulting typical thermal impedance curves are shown in Figure 11, and Figure 12. For model-specific thermal impedance curves, please see the the appropriate section. From the thermal impedance curves, a maximum power dissipation level can be determined for a given ambient temperature and airflow by the following:

$$P_{DIS(max)} = \frac{(T_{CASE(max)} - T_A)}{RØ_{CA}} \qquad (2)$$

Equation 2:
$P_{DIS(max)}$ is the maximum allowable power dissipation of the BCM®
$T_{CASE(max)}$ is the maximum allowable case temperature (100°C for BCMs)
T_A is the ambient temperature in °C
$RØ_{CA}$ is the case-to-ambient thermal impedance for a given airflow, and heat sink configuration.

For each BCM, the maximum power dissipation will correspond to an output power level based on its efficiency. These levels are determined based on worst-case efficiency vs. load data

and plotted as a function of T_A at various airflow levels for each of the 48V Input BCMs. Results are shown on the following pages. Please note that the worst-case values will vary from “typical” values shown on the data sheet. Due to differences in environment, and test set up, users should ensure that the module case temperature does not exceed 100°C in the final system.

Figure 11
Typical Case-to-Ambient Thermal Impedance (RØ$_{CA}$) vs. Airflow for 48V Input BCMs, 0° Orientation

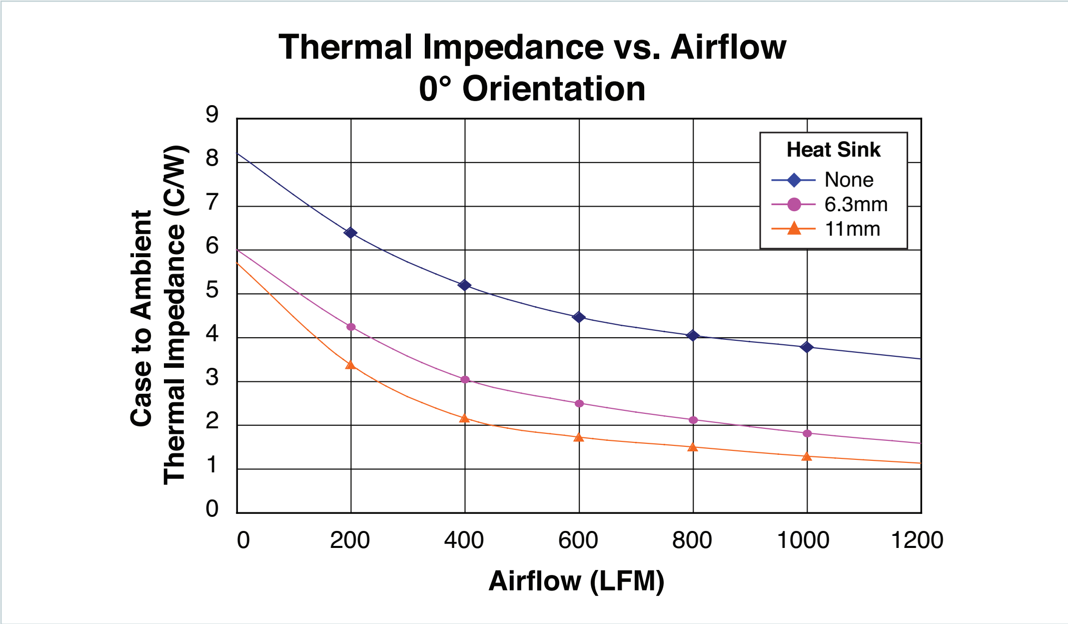
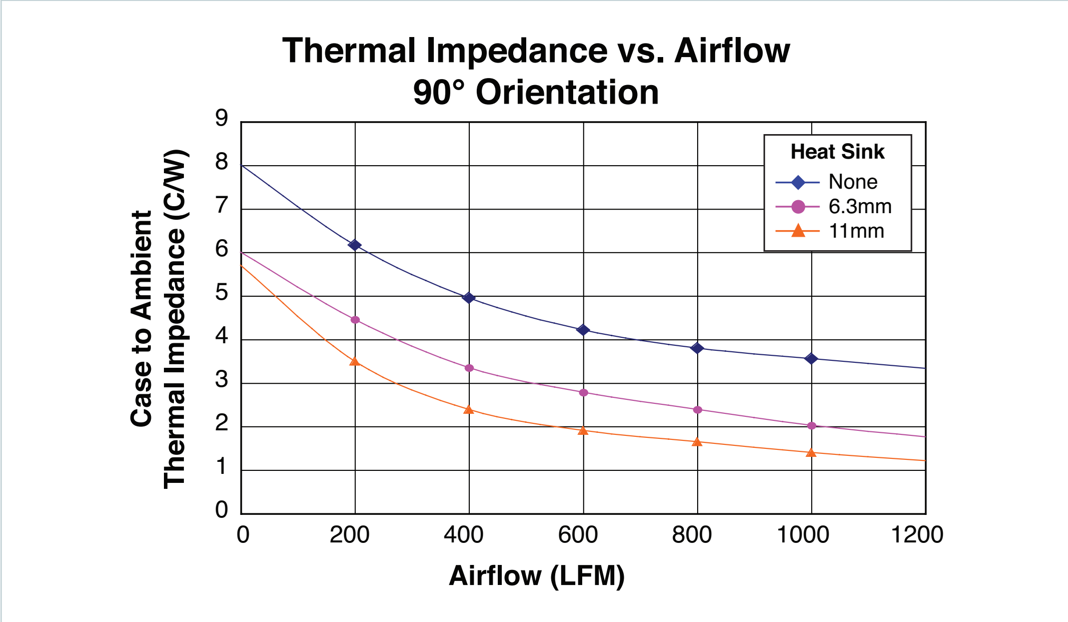


Figure 12
Typical Case-to-Ambient Thermal Impedance (RØ$_{CA}$) vs. Airflow for 48V Input BCMs, 90° Orientation



Heat Sink Selection (If Required)

The following procedure can be used to determine what size heat sink (if any) is required to operate the BCM® at a given power level for a known maximum ambient temperature and airflow:

1. Determine the maximum ambient temperature in °C ($T_{A(max)}$)
2. Determine the maximum available airflow in LFM (AF_{max}) and the direction of airflow in the system
3. Determine the maximum required output power ($P_{OUT(max)}$)
4. Locate the section containing derating curves for the BCM being used and the direction of airflow
5. Start with the "No heat sink" graph and locate the point on the graph corresponding to $T_{A(max)}$ and AF_{max}

   a. If the output power is greater than $P_{OUT(max)}$, no heat sink will be required. If not, proceed to 6
6. On the "6.3mm heat sink" graph, locate the point on the graph corresponding to $T_{A(max)}$ and AF_{max}

   a. If the output power is greater than $P_{OUT(max)}$, a 6.3mm heat sink will be required. If not, proceed to 7
7. On the "11mm heat sink" graph, locate the point on the graph corresponding to $T_{A(max)}$ and AF_{max}

   a. If the output power is greater than $P_{OUT(max)}$, a 11mm heat sink will be required. If not, the amount of airflow will have to increase in order to operate at $P_{OUT(max)}$.

Example Thermal Analysis
A 48V to 12V BCM (B048F120T30) is required to be operated at 250W in a system with 400LFM of airflow at a 0° orientation. The maximum ambient temperature ($T_{A(max)}$) is 50°C.

Starting with the "No heat sink" graph from the B048F120T30, 0° airflow section (Figure 13), 400LFM at 50°C corresponds to a maximum output power of 175W. Since this is less than the required 250W, a heat sink will be required.

Moving to the "6.3mm heat sink" graph (Figure 14), 400LFM at 50°C corresponds to a maximum output power of 290W. Since this is greater than the required 250W, using this 6.3mm heat sink at 400LFM is correct for this application.

Using a heat sink may not be desirable. As always there is a trade off between additional airflow, increased size and reduced power. These curves should provide the user with all of the necessary information to make the best decision for the end application.

Figure 13

12V Power Derating Example - No Heat Sink

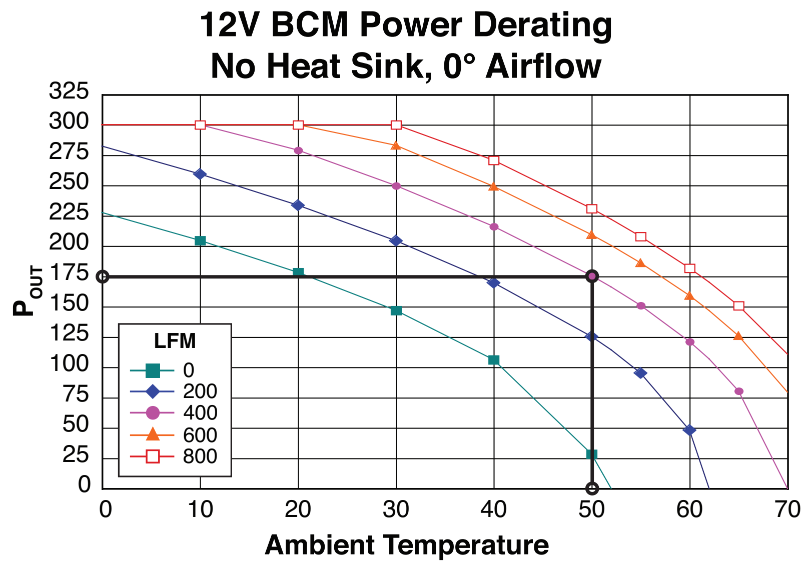
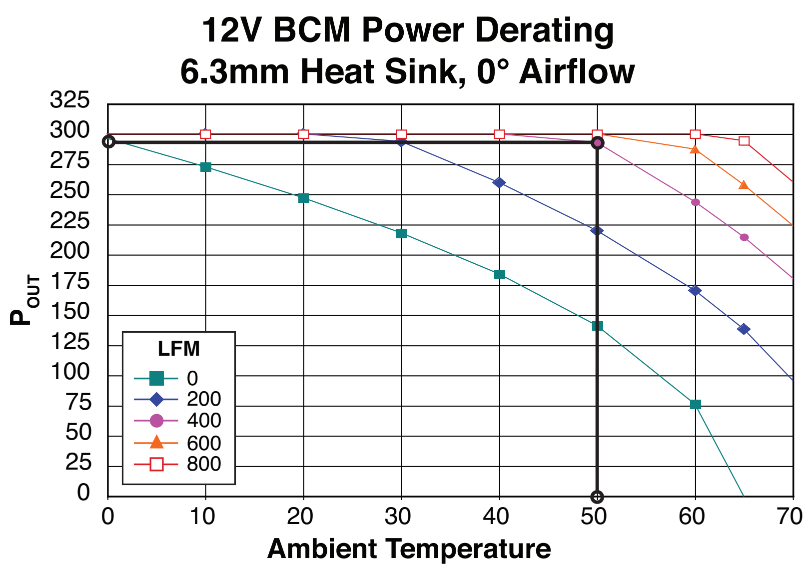


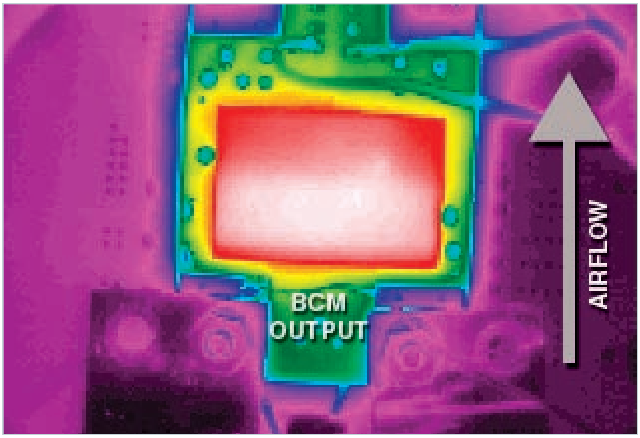
Figure 14

12V Power Derating Example - 6.3mm Heat Sink

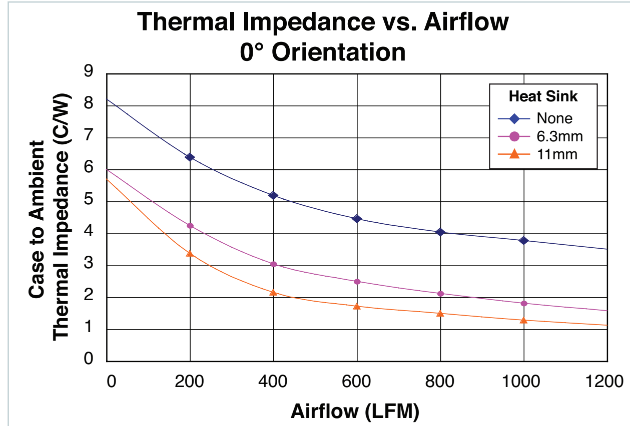


Index for Curves

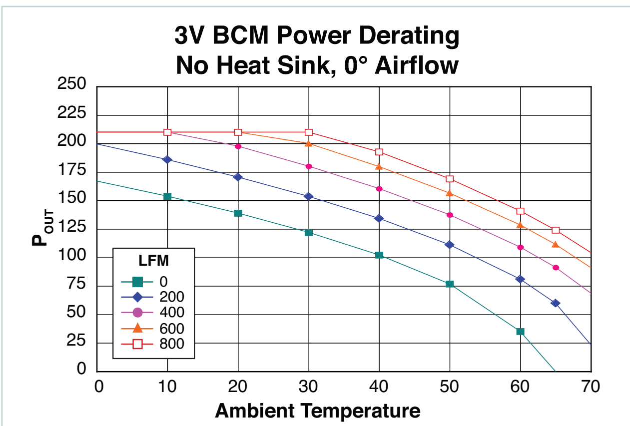
B048F030T21 0˚ Airflow



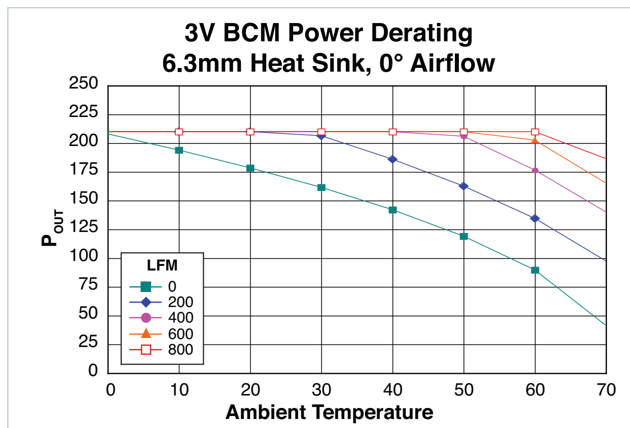
IR image, 0° airflow; Full load, 200LFM, no heat sink



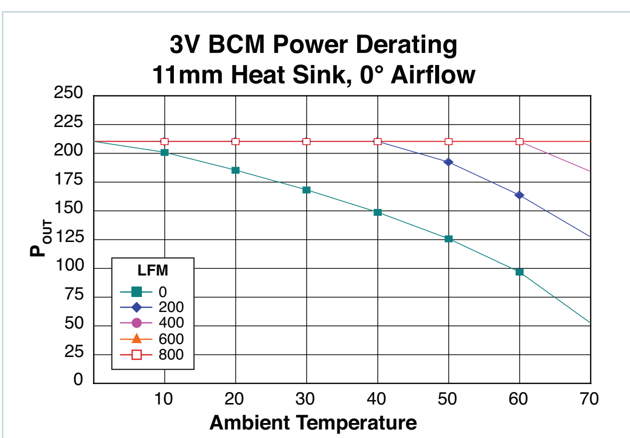
Thermal impedance vs. airflow, 0° orientation



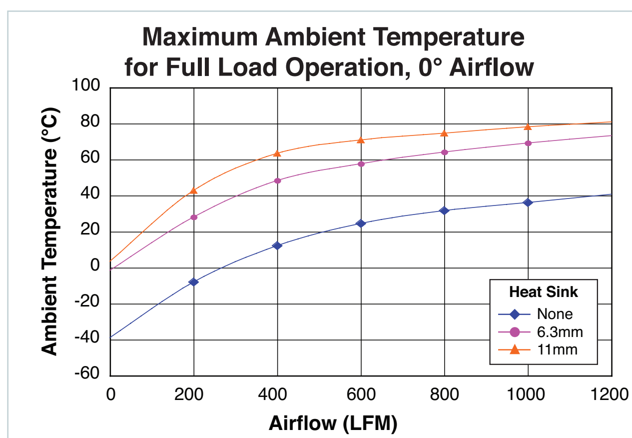
Power derating with no heat sink, 0° airflow



Power derating with 6.3mm heat sink, 0° airflow

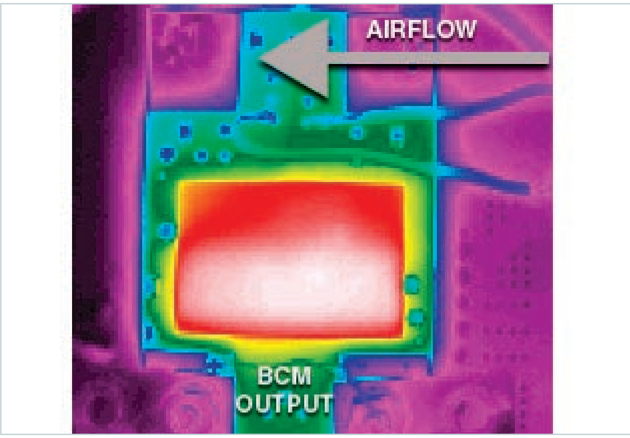


Power derating with 11mm heat sink, 0° airflow

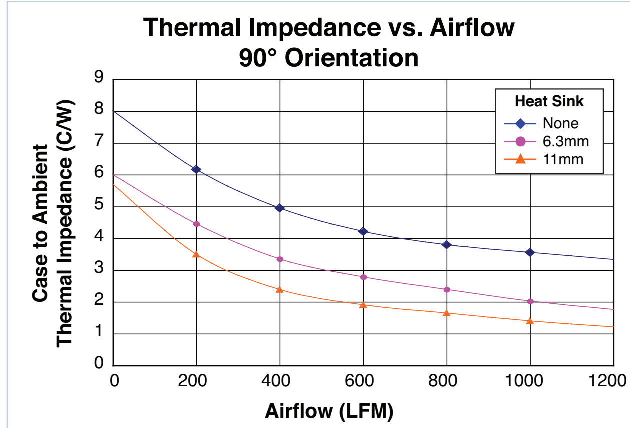


Maximum temperature at which device can be operated at full load

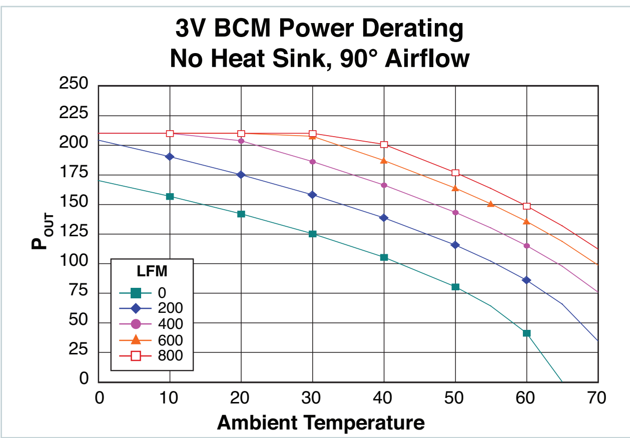
B048F030T21 90° Airflow



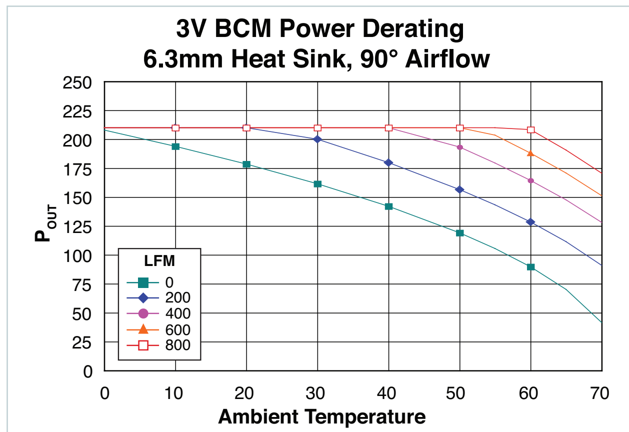
IR image, 90° airflow; Full load, 200LFM, no heat sink



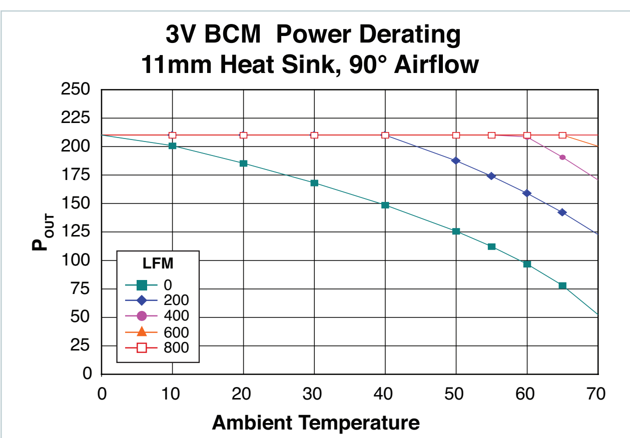
Thermal impedance vs. airflow, 90° orientation



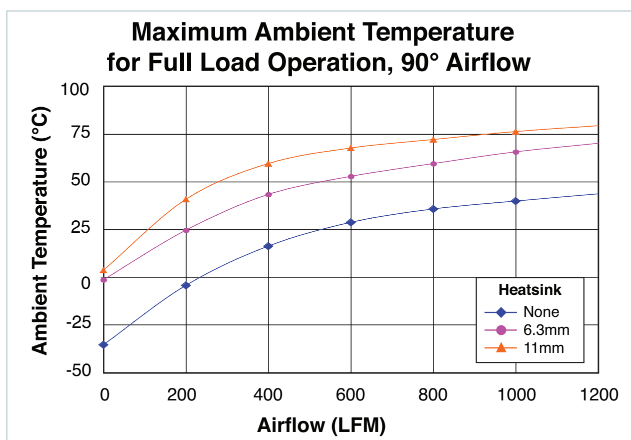
Power derating with no heat sink, 90° airflow



Power derating with 6.3mm heat sink, 90° airflow

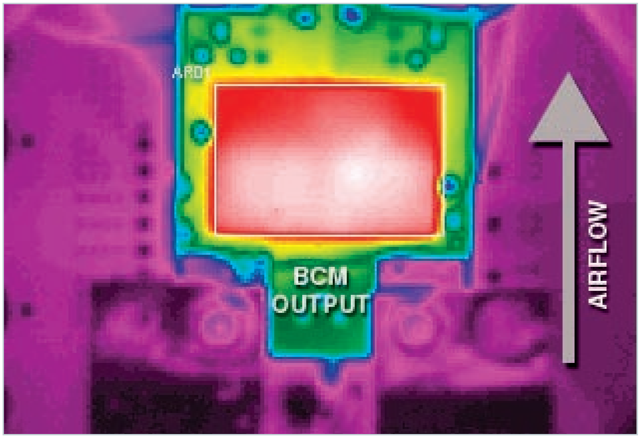


Power derating with 11mm heat sink, 90° airflow

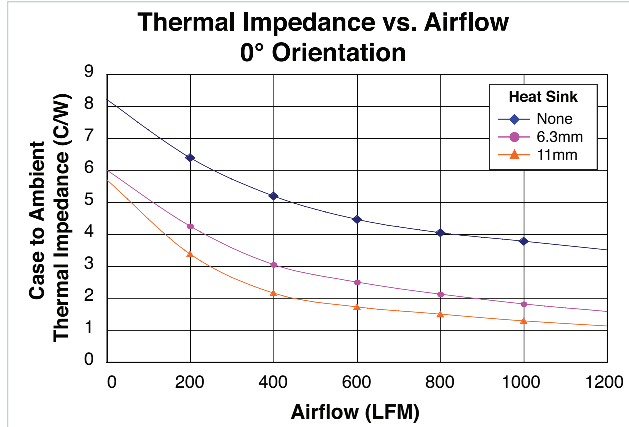


Maximum temperature at which device can be operated at full load

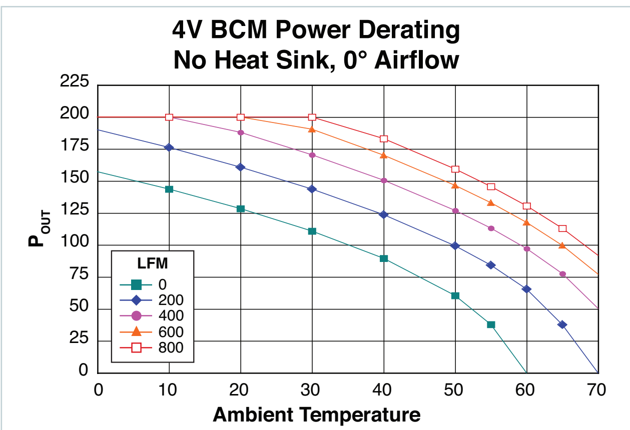
B048F040T20 0˚ Airflow



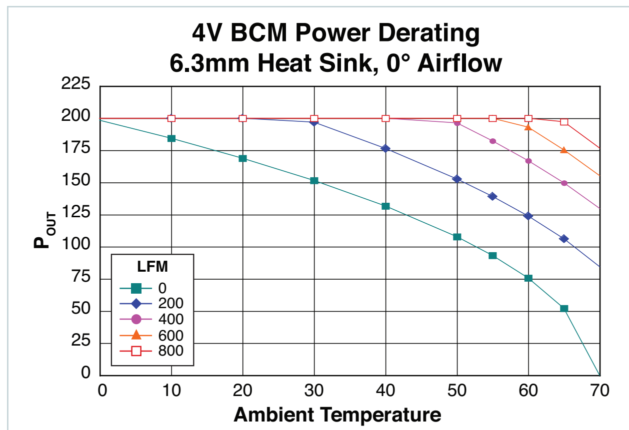
IR image, 0° airflow; Full load, 200LFM, no heat sink



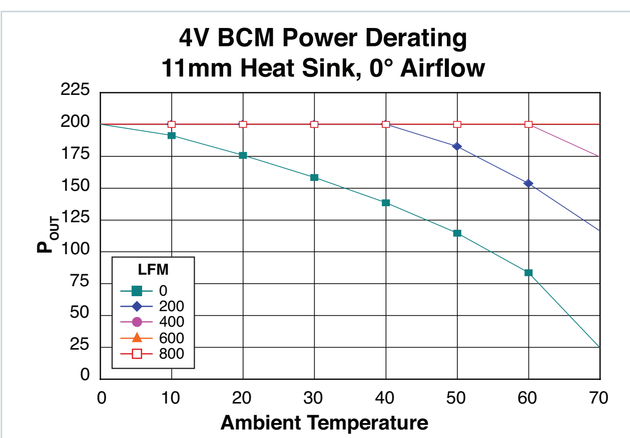
Thermal impedance vs. airflow, 0° orientation



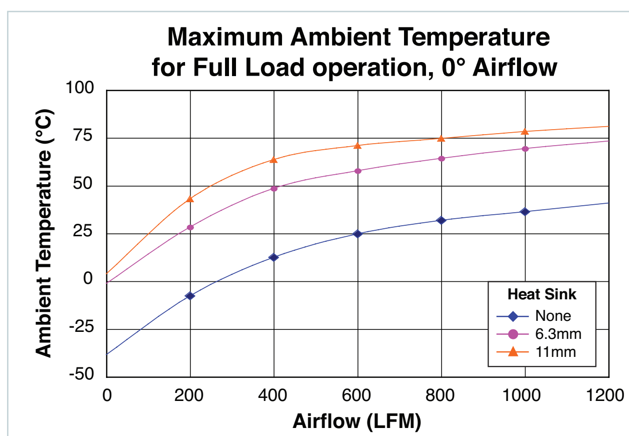
Power derating with no heat sink, 0° airflow



Power derating with 6.3mm heat sink, 0° airflow

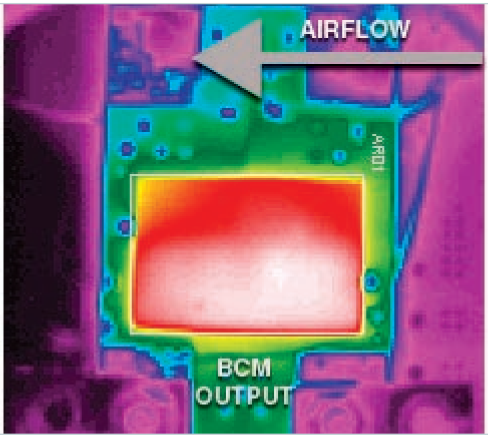


Power derating with 11mm heat sink, 0° airflow

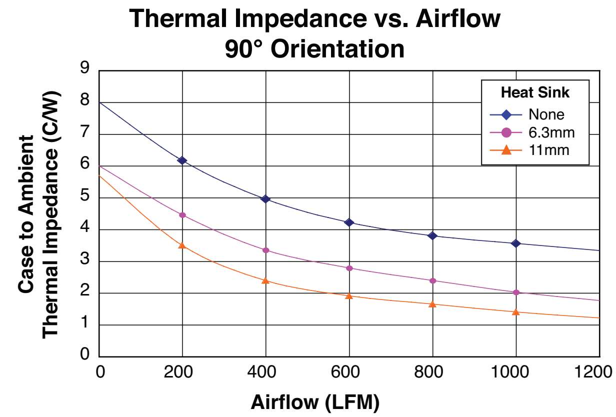


Maximum temperature at which device can be operated at full load

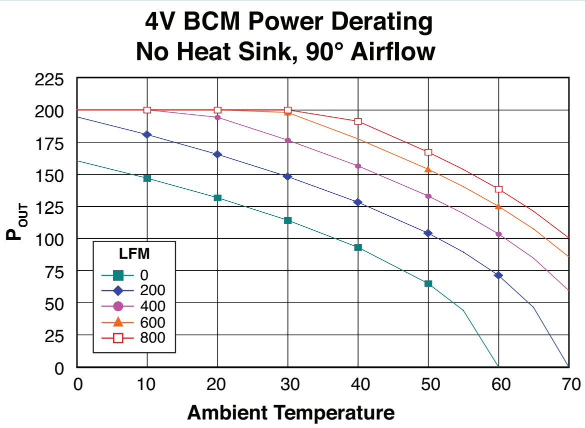
B048F040T20 90° Airflow



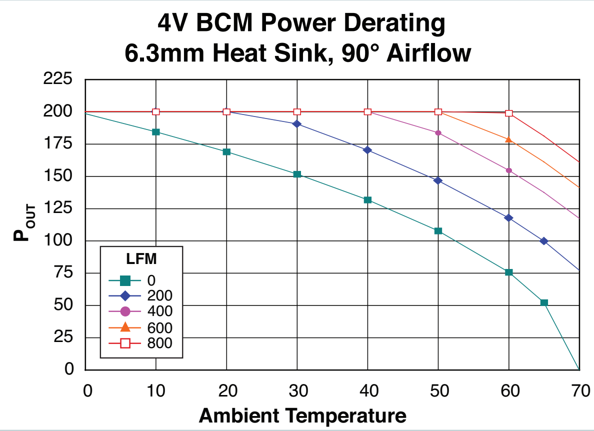
IR image, 90° airflow; Full load, 200LFM, no heat sink



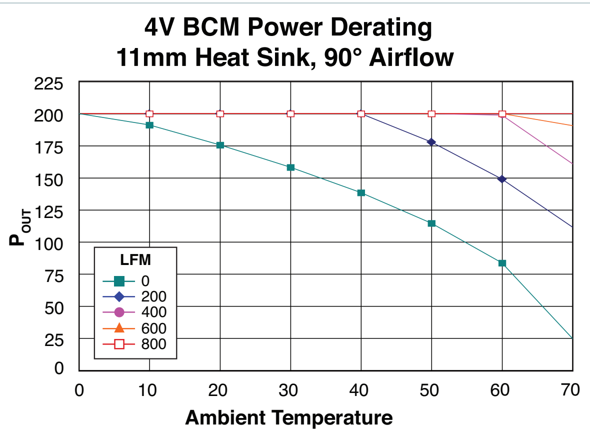
Thermal impedance vs. airflow, 90° orientation



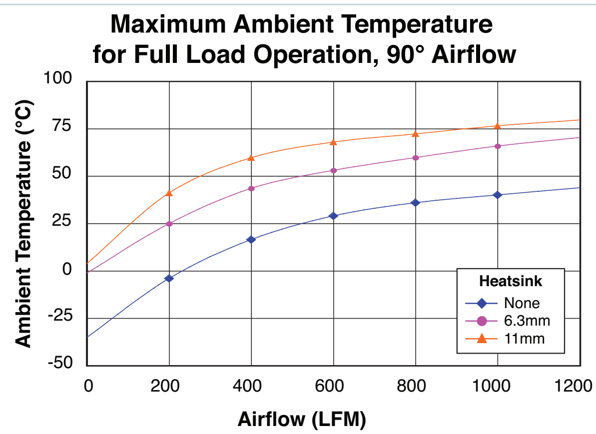
Power derating with no heat sink, 90° airflow



Power derating with 6.3mm heat sink, 90° airflow

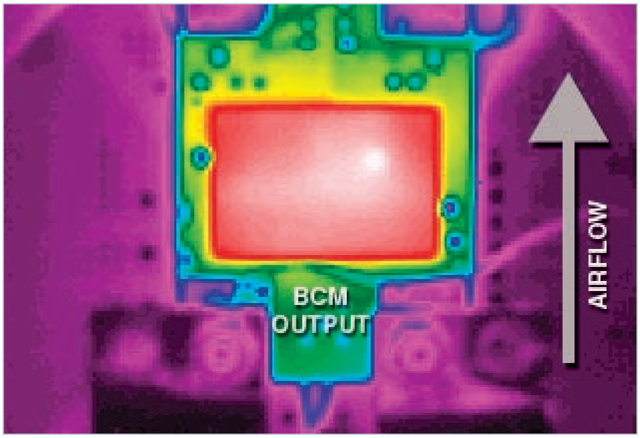


Power derating with 11mm heat sink, 90° airflow

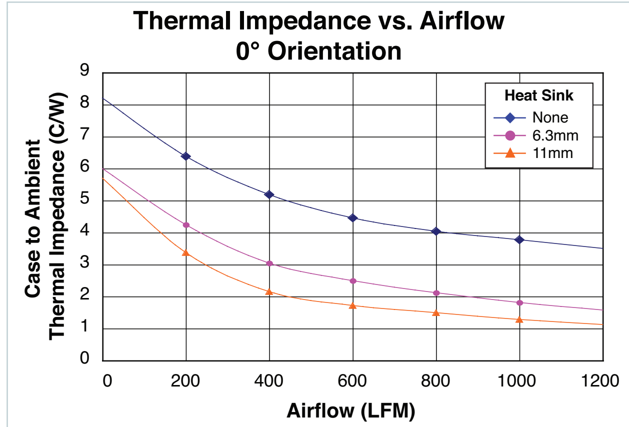


Maximum temperature at which device can be operated at full load

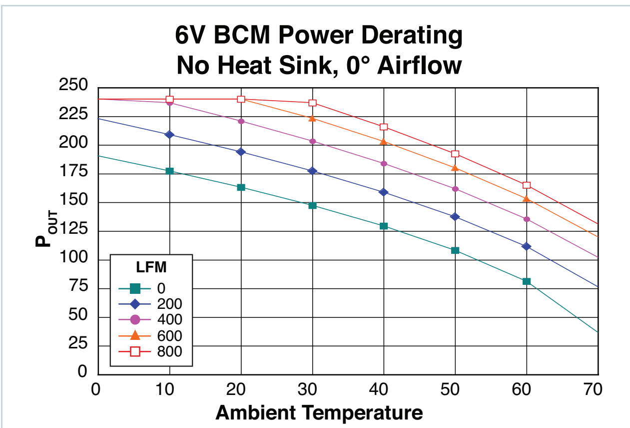
B048F060T24 0˚ Airflow



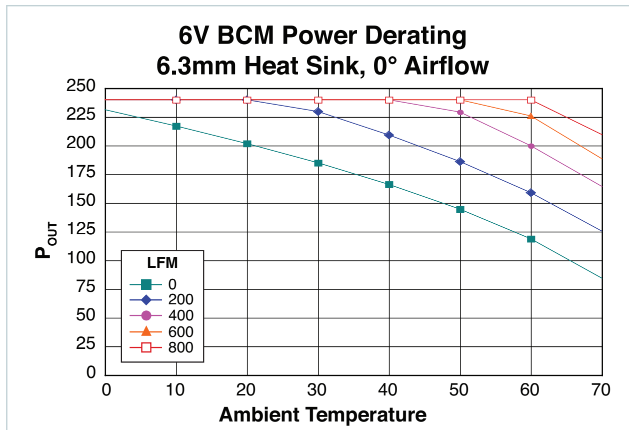
IR image, 0° airflow; Full load, 200LFM, no heat sink



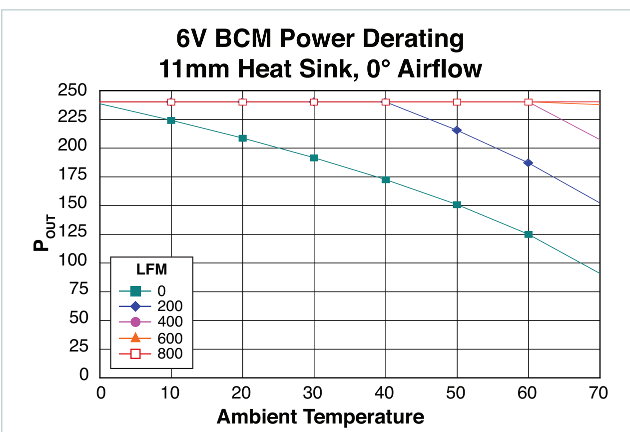
Thermal impedance vs. airflow, 0° orientation



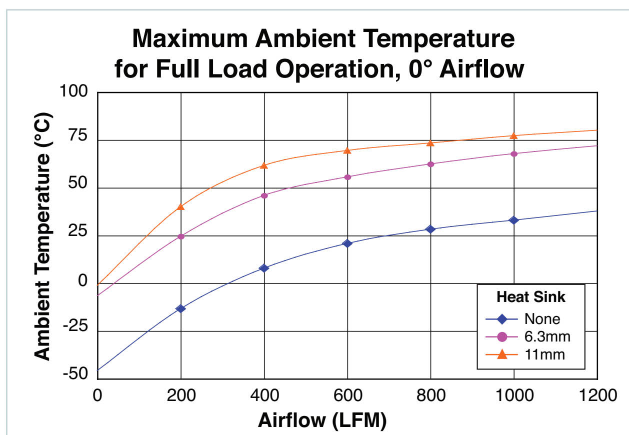
Power derating with no heat sink, 0° airflow



Power derating with 6.3mm heat sink, 0° airflow

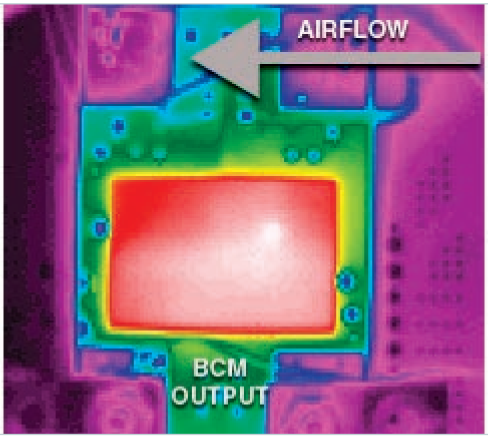


Power derating with 11mm heat sink, 0° airflow

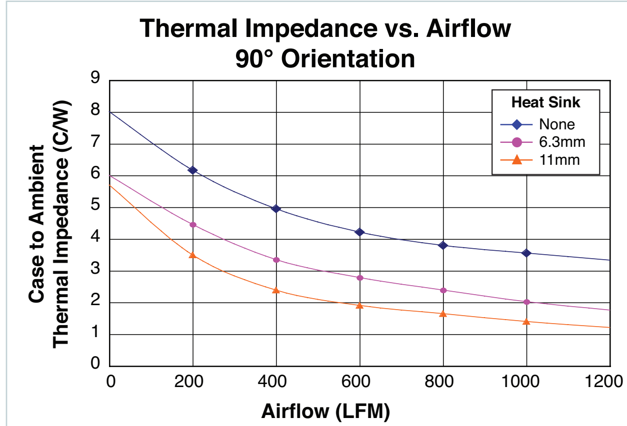


Maximum temperature at which device can be operated at full load

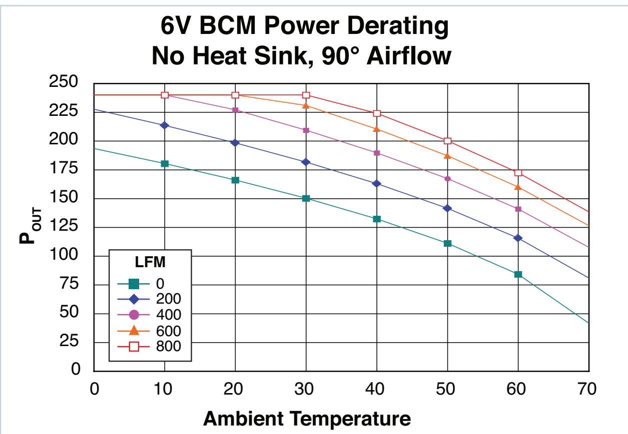
B048F060T24 90° Airflow



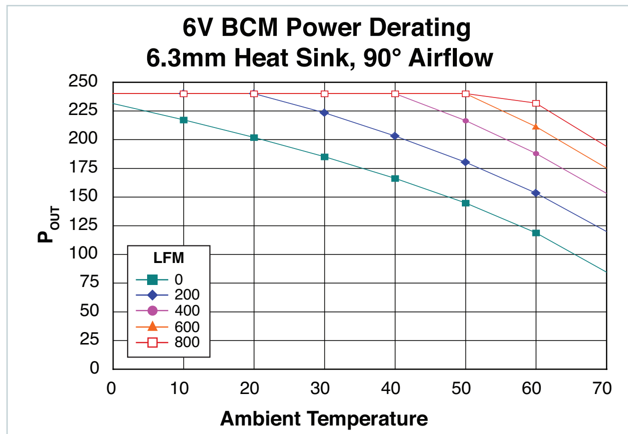
IR image, 90° airflow; Full load, 200LFM, no heat sink



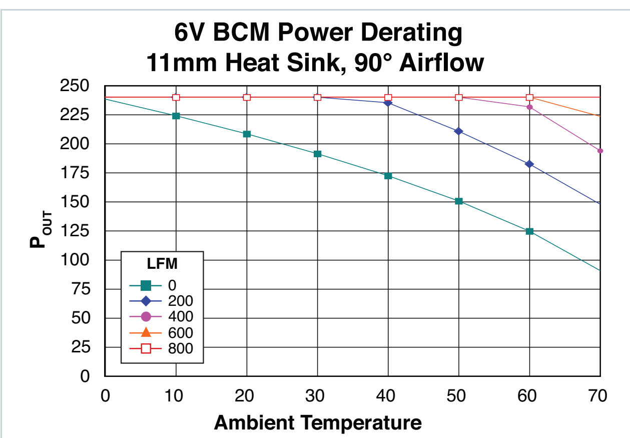
Thermal impedance vs. airflow, 90° orientation



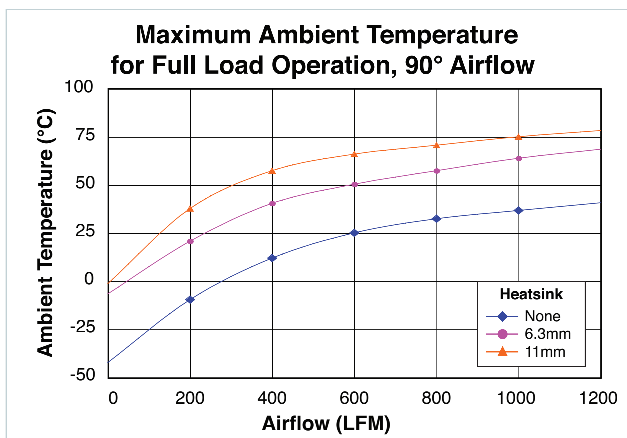
Power derating with no heat sink, 90° airflow



Power derating with 6.3mm heat sink, 90° airflow

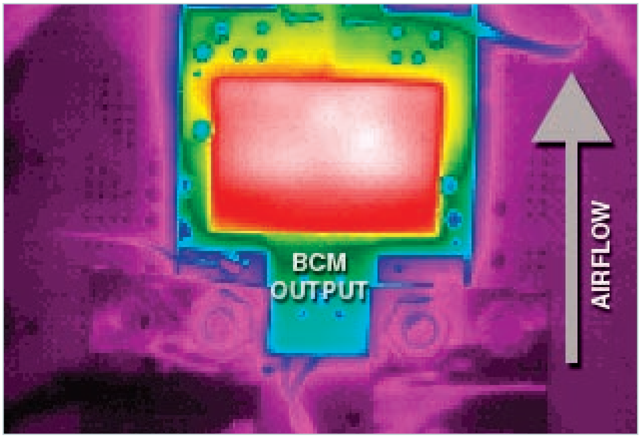


Power derating with 11mm heat sink, 90° airflow

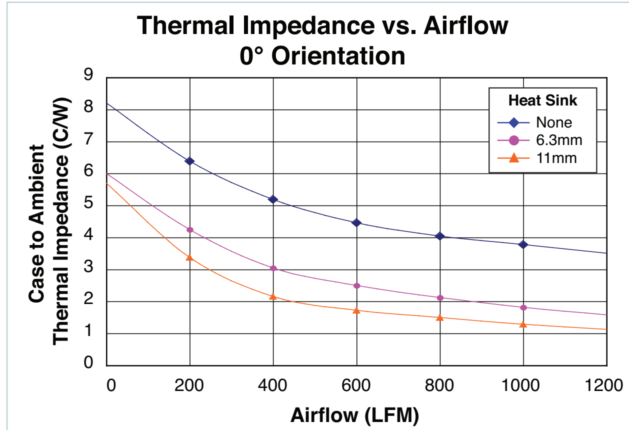


Maximum temperature at which device can be operated at full load

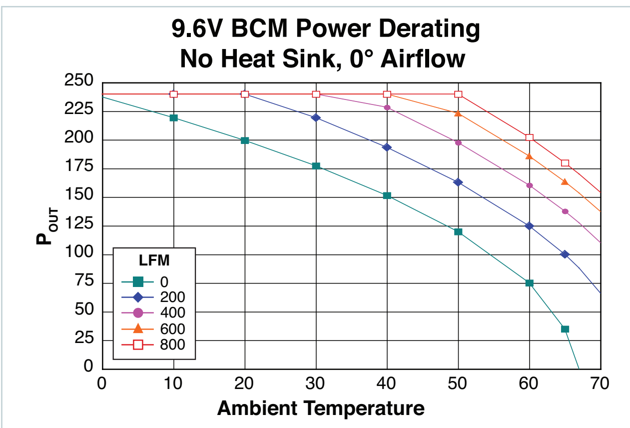
B048F096T24 0˚ Airflow



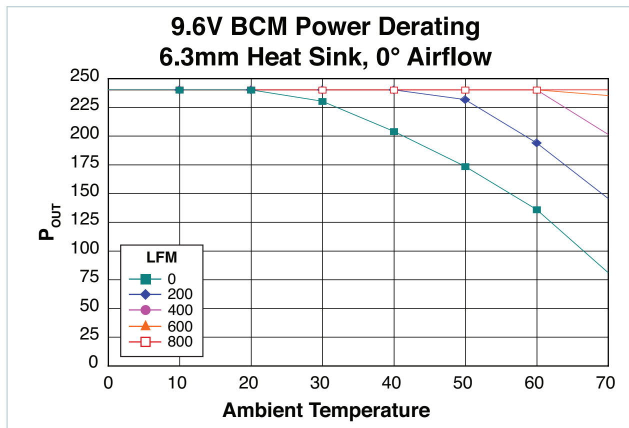
IR image, 0° airflow; Full load, 200LFM, no heat sink



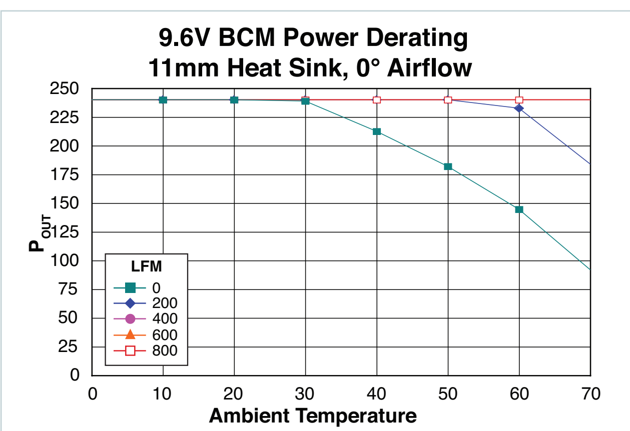
Thermal impedance vs. airflow, 0° orientation



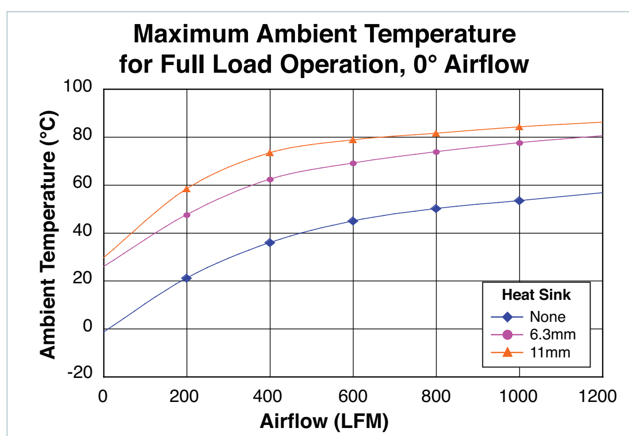
Power derating with no heat sink, 0° airflow



Power derating with 6.3mm heat sink, 0° airflow

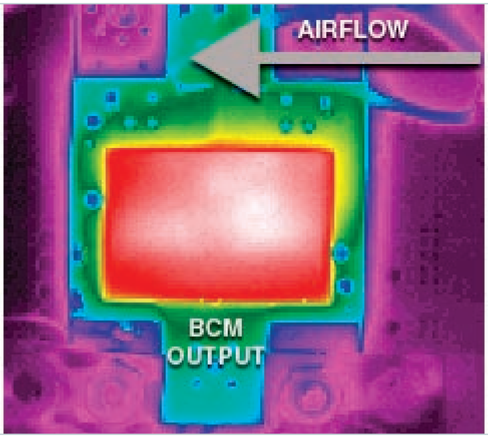


Power derating with 11mm heat sink, 0° airflow

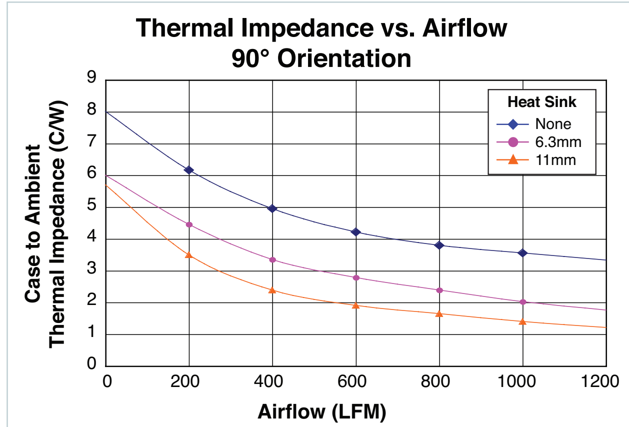


Maximum temperature at which device can be operated at full load

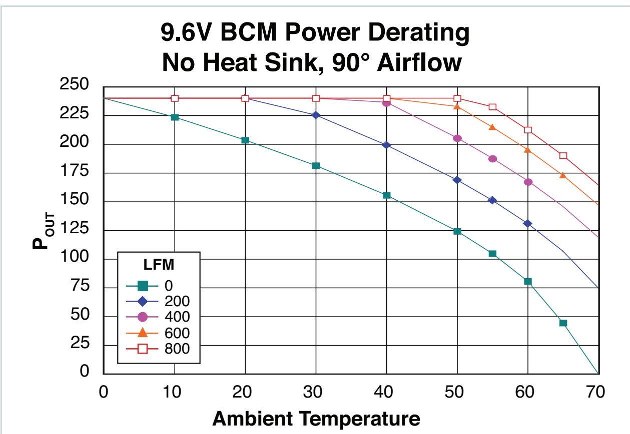
B048F096T24   90° Airflow



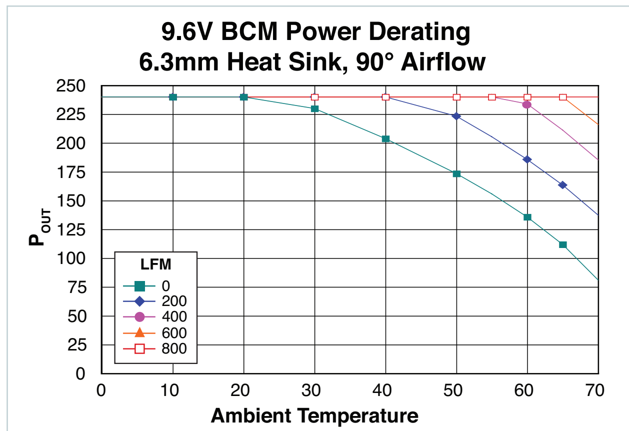
IR image, 90° airflow; Full load, 200LFM, no heat sink



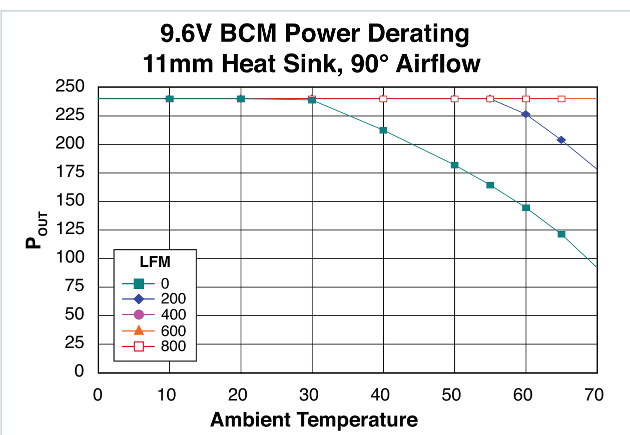
Thermal impedance vs. airflow, 90° orientation



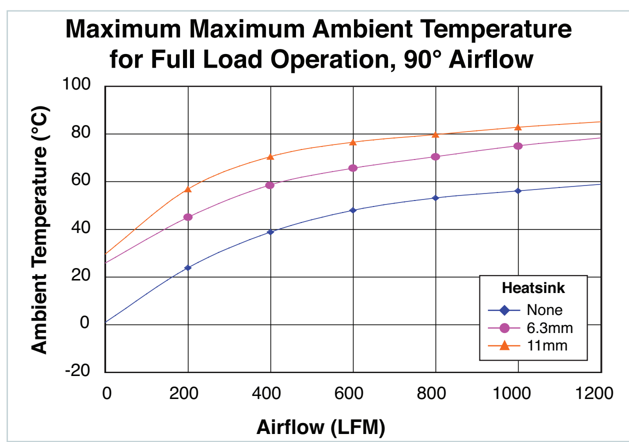
Power derating with no heat sink, 90° airflow



Power derating with 6.3mm heat sink, 90° airflow

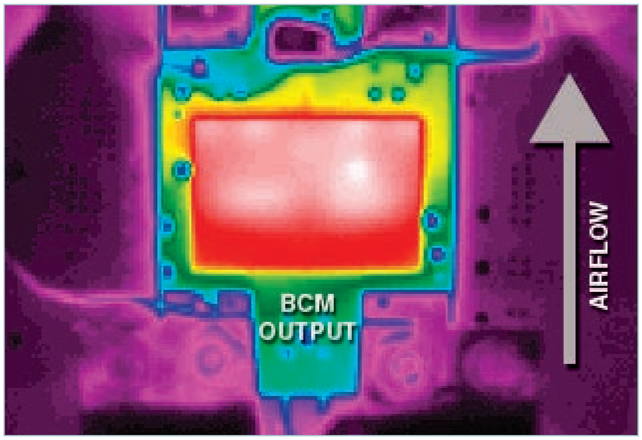


Power derating with 11mm heat sink, 90° airflow

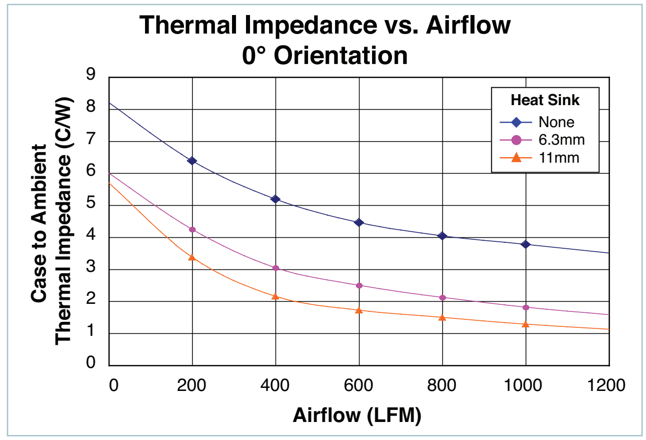


Maximum temperature at which device can be operated at Full load

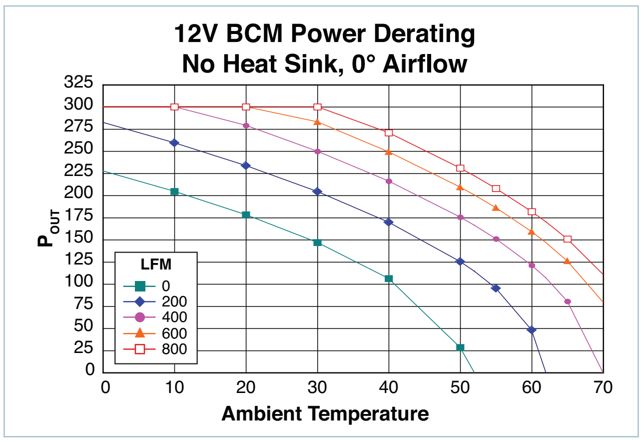
B048F120T30   0˚ Airflow



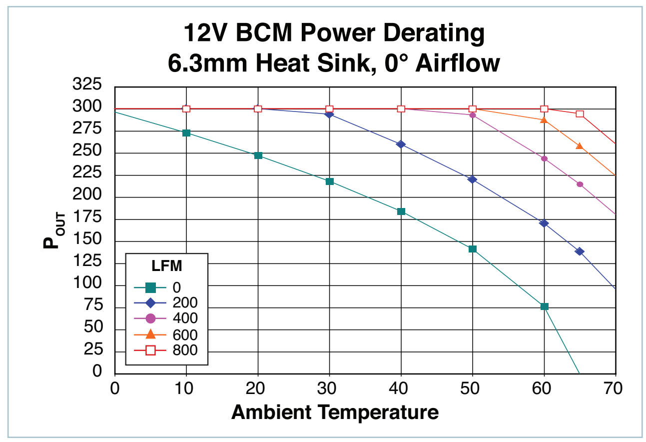
IR image, 0° airflow; Full load, 200LFM, no heat sink



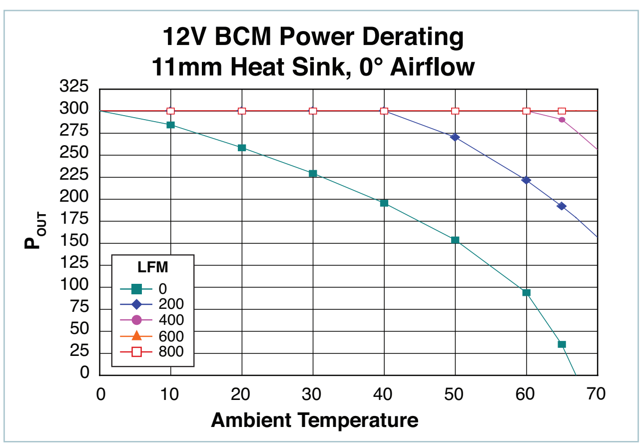
Thermal impedance vs. airflow, 0° orientation



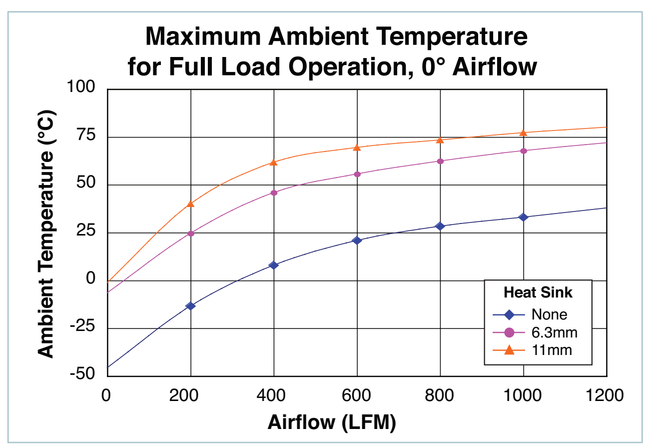
Power derating with no heat sink, 0° airflow



Power derating with 6.3mm heat sink, 0° airflow

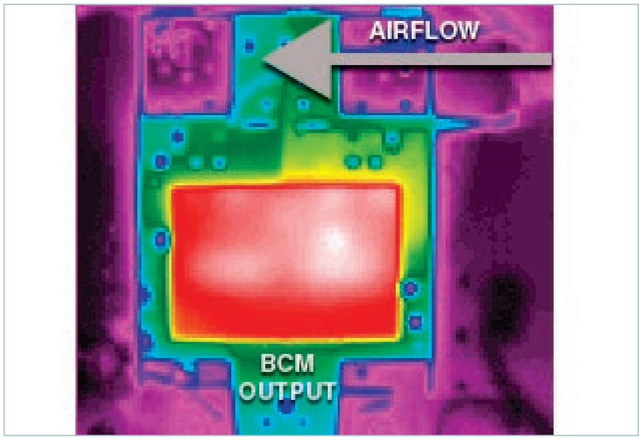


Power derating with 11mm heat sink, 0° airflow

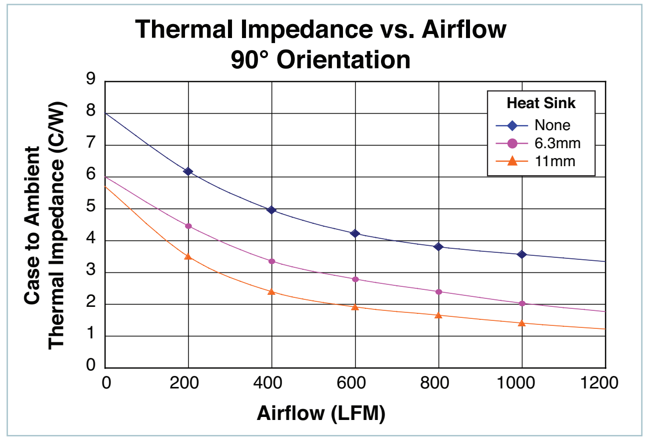


Maximum temperature at which device can be operated at Full load

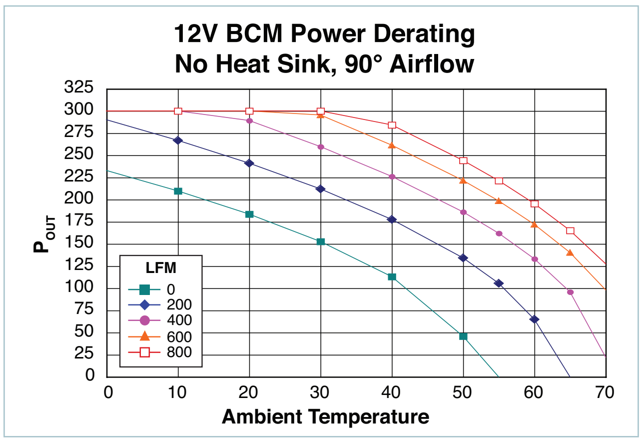
B048F120T30 90˚ Airflow



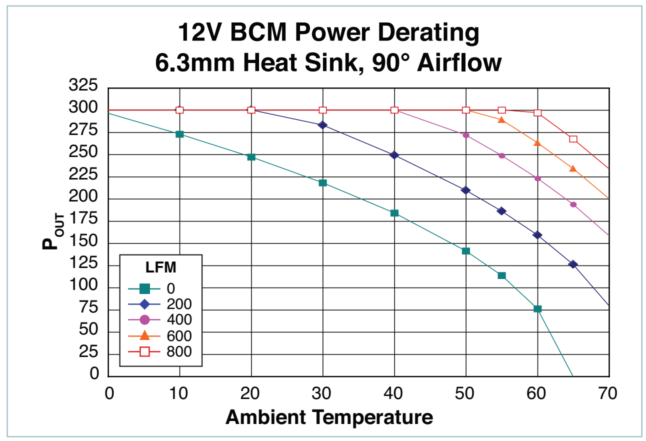
IR image, 90° airflow; Full load, 200LFM, no heat sink



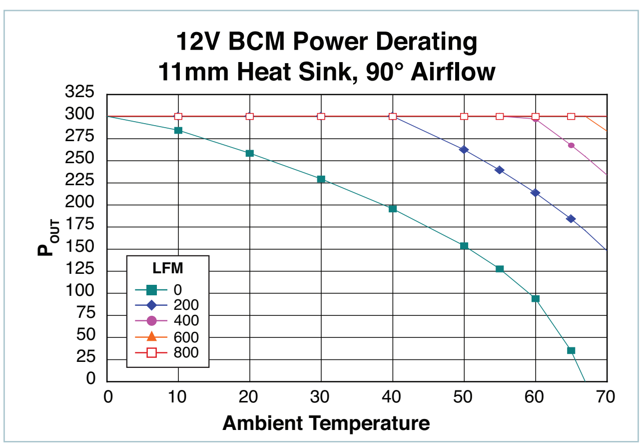
Thermal impedance vs. airflow, 90° orientation



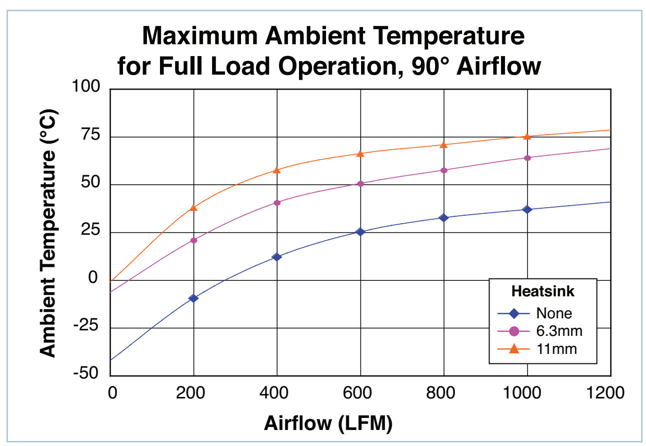
Power derating with no heat sink, 90° airflow



Power derating with 6.3mm heat sink, 90° airflow

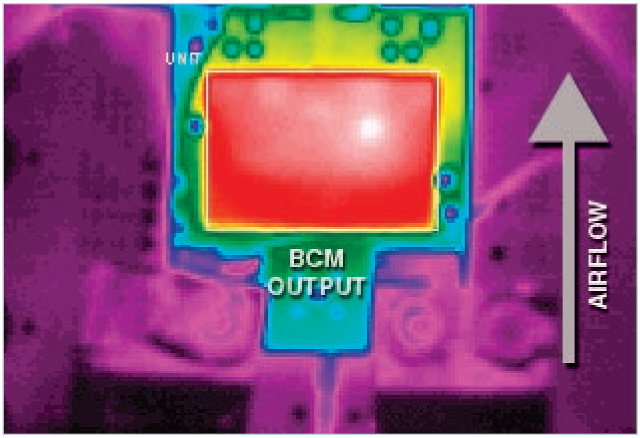


Power derating with 11mm heat sink, 90° airflow

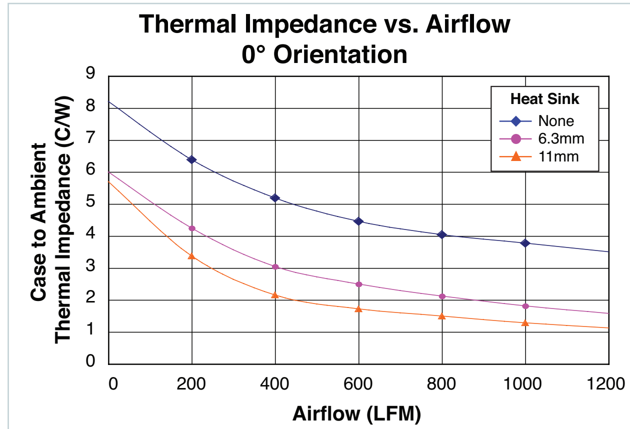


Maximum temperature at which device can be operated at Full load

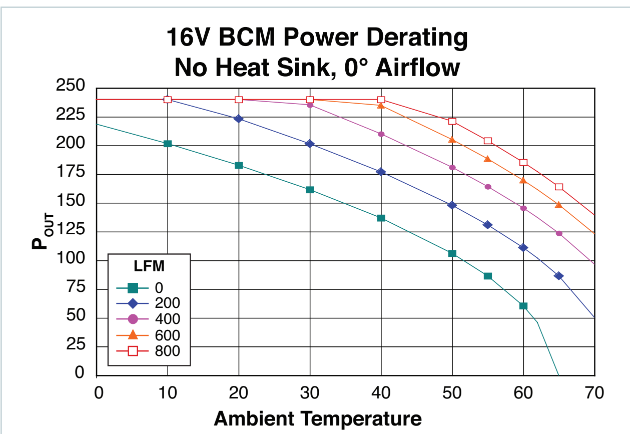
B048F160T24 0˚ Airflow



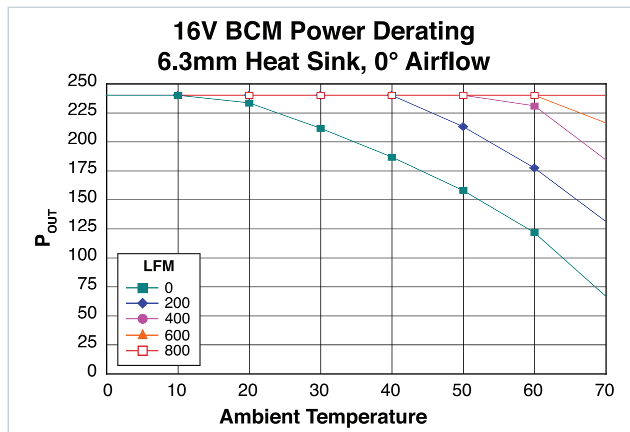
IR image, 0° airflow; Full load, 200LFM, no heat sink



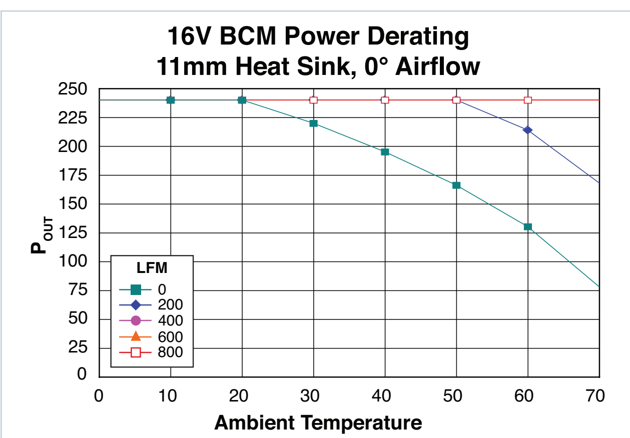
Thermal impedance vs. airflow, 0° orientation



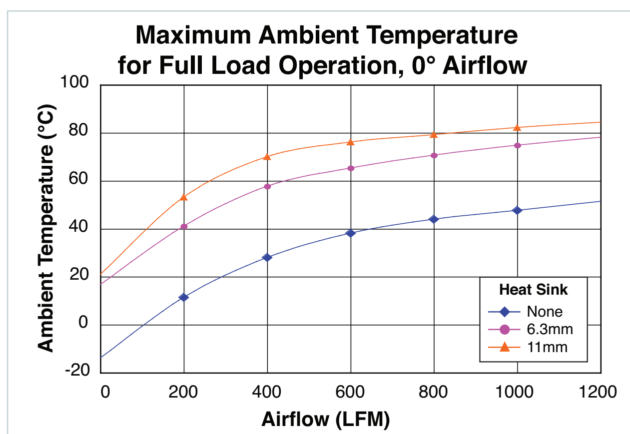
Power derating with no heat sink, 0° airflow



Power derating with 6.3mm heat sink, 0° airflow

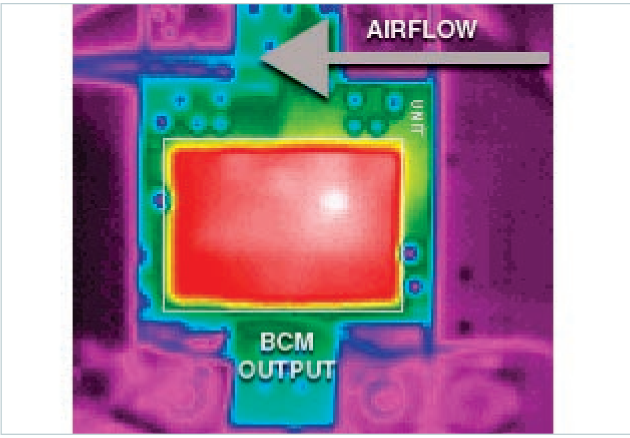


Power derating with 11mm heat sink, 0° airflow

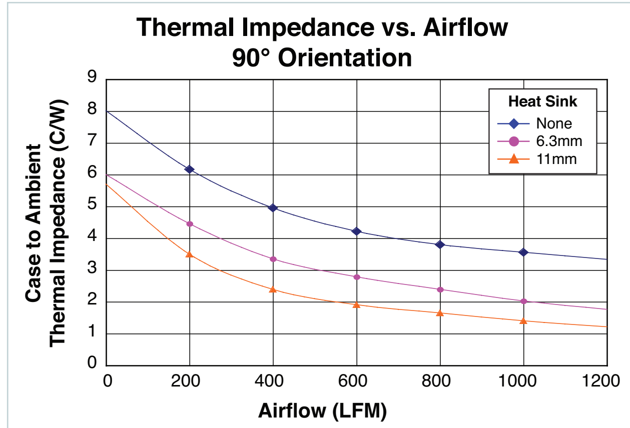


Maximum temperature at which device can be operated at full load

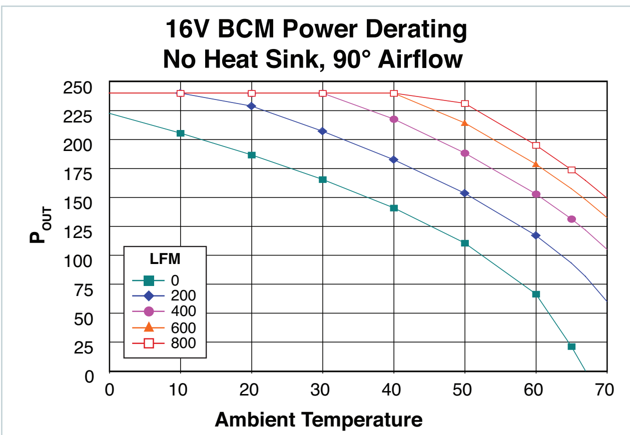
B048F160T24   90˚ Airflow



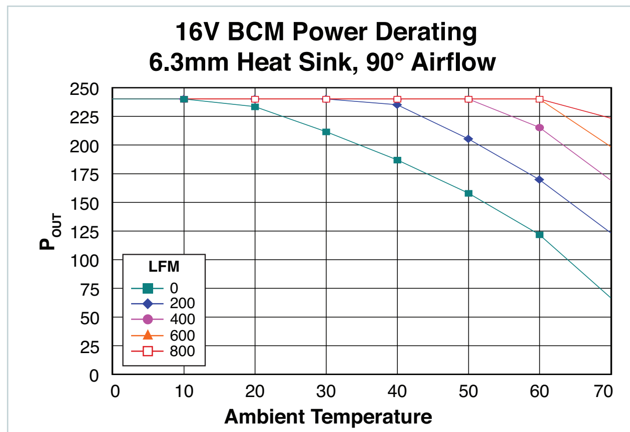
IR image, 90° airflow; Full load, 200LFM, no heat sink



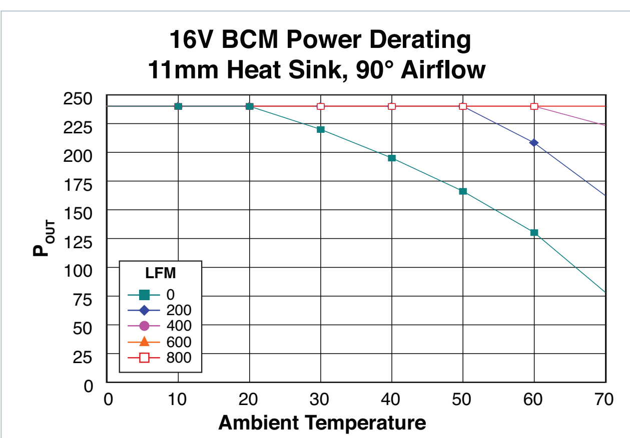
Thermal impedance vs. airflow, 90° orientation



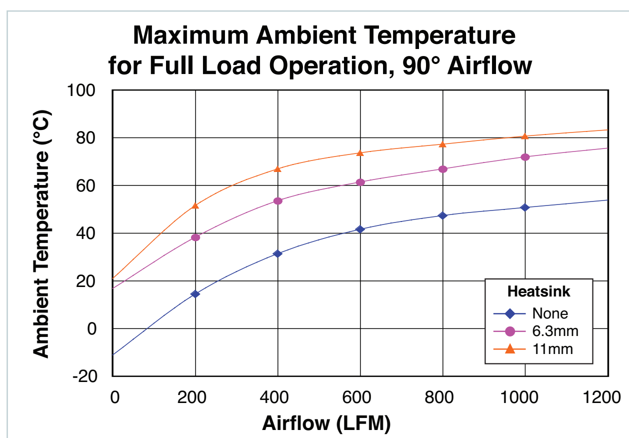
Power derating with no heat sink, 90° airflow



Power derating with 6.3mm heat sink, 90° airflow

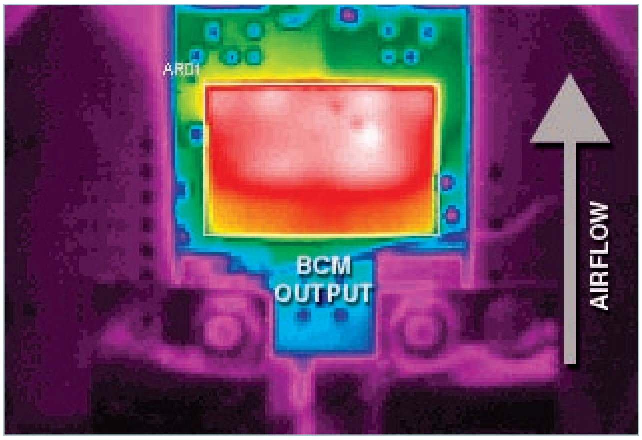


Power derating with 11mm heat sink, 90° airflow

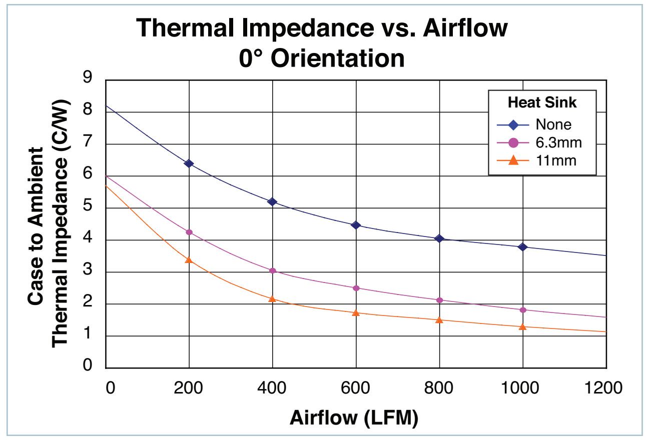


Maximum temperature at which device can be operated at full load

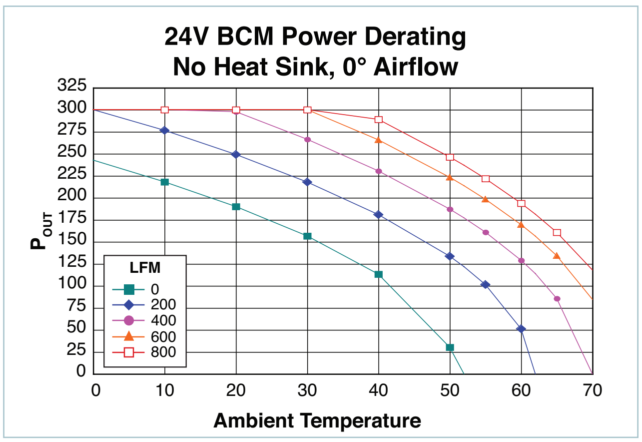
B048F240T30 0˚ Airflow



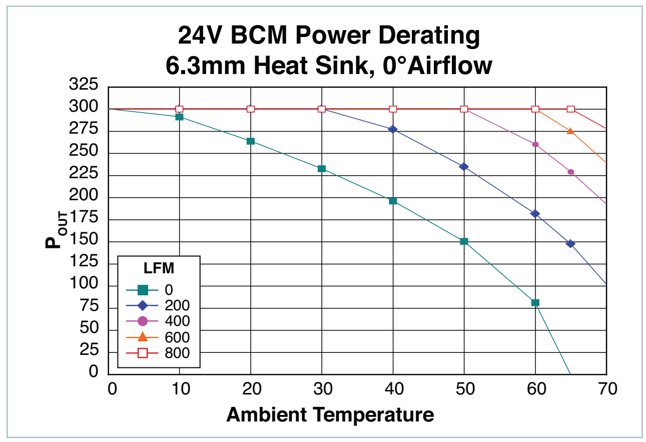
IR image, 0° airflow; Full load, 400LFM, no heat sink



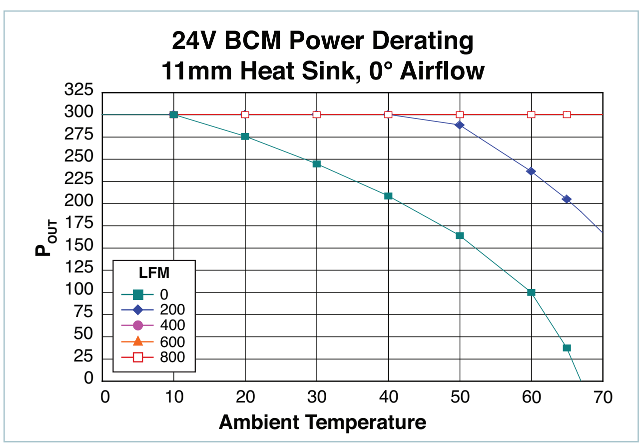
Thermal impedance vs. airflow, 0° orientation



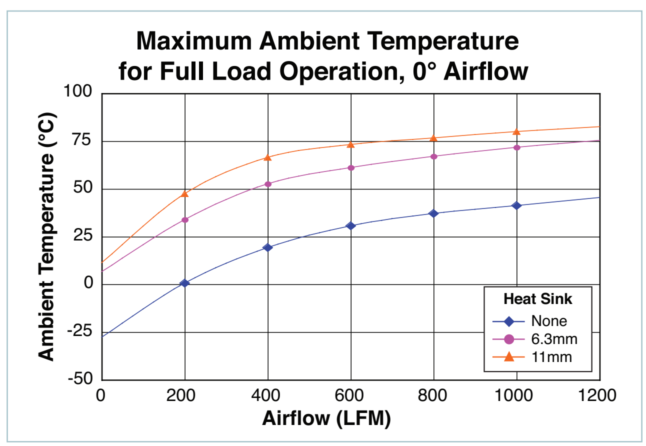
Power derating with no heat sink, 0° airflow



Power derating with 6.3mm heat sink, 0° airflow

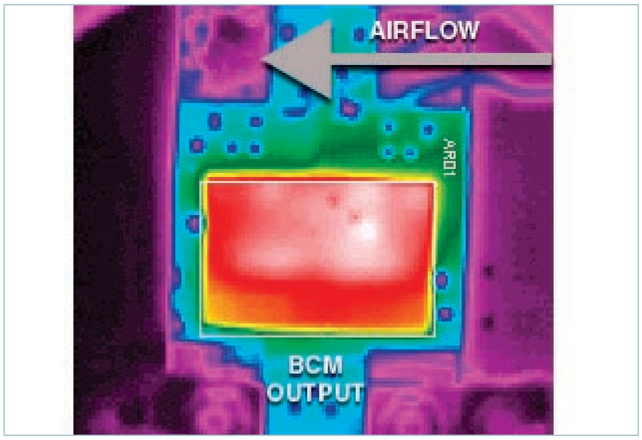


Power derating with 11mm heat sink, 0° airflow

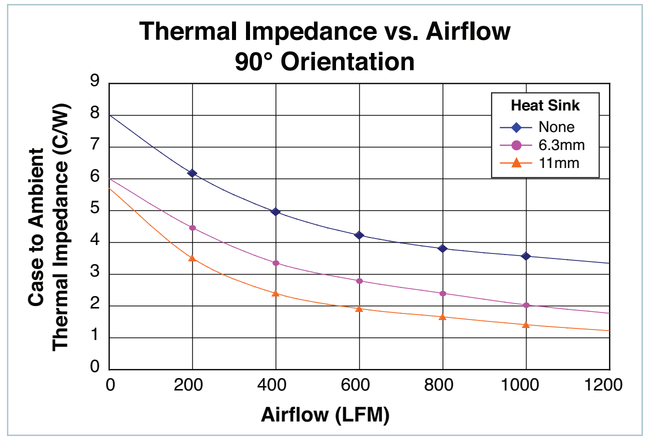


Maximum temperature at which device can be operated at full load

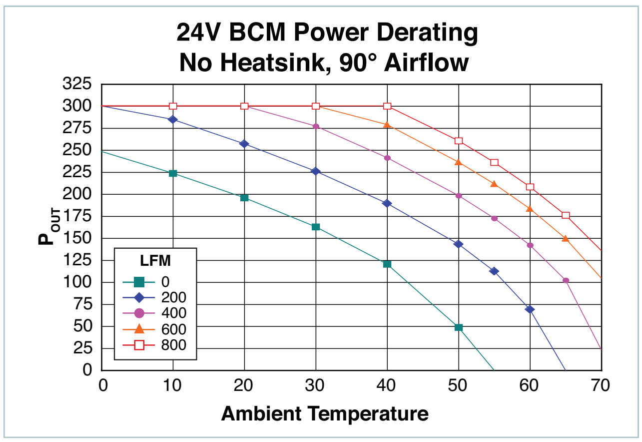
B048F240T30 90˚ Airflow



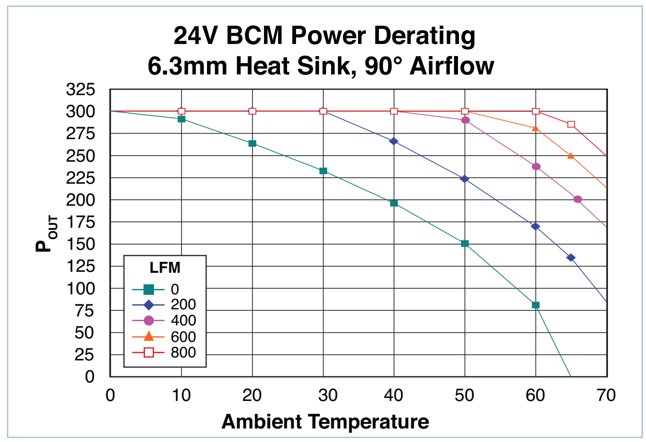
IR image, 90° airflow; Full load, 400LFM, no heat sink



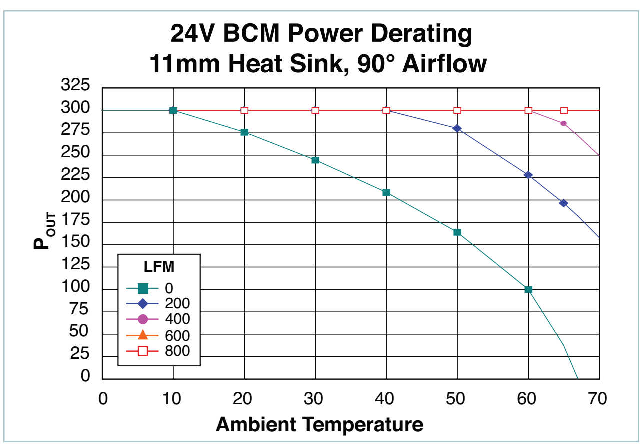
Thermal impedance vs. airflow, 90° orientation



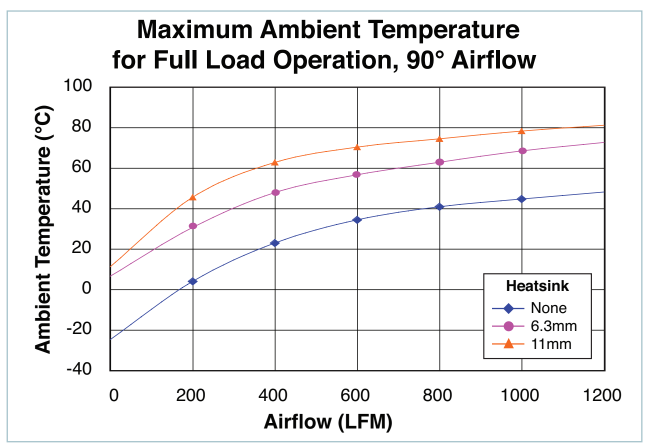
Power derating with no heat sink, 90° airflow



Power derating with 6.3mm heat sink, 90° airflow

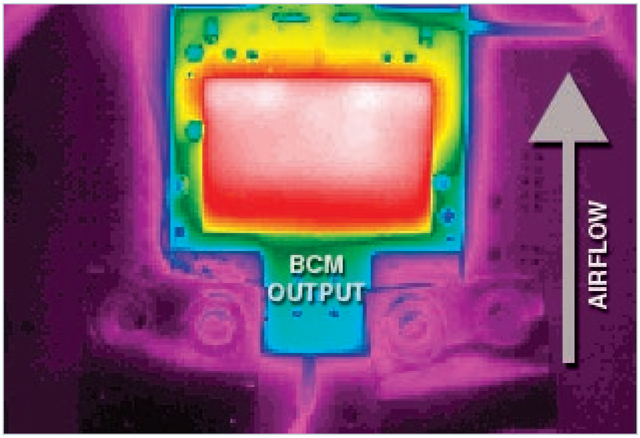


Power derating with 11mm heat sink, 90° airflow

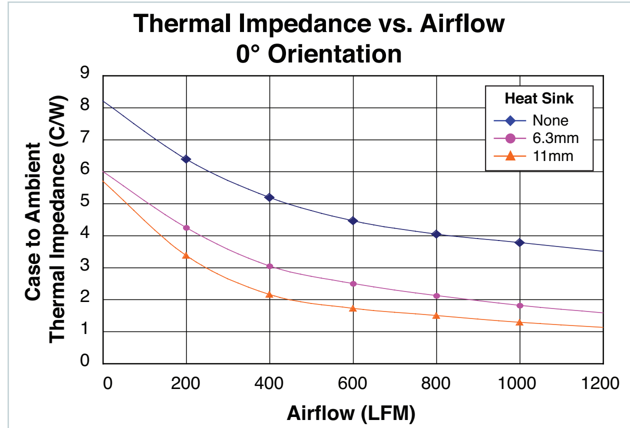


Maximum temperature at which device can be operated at full load

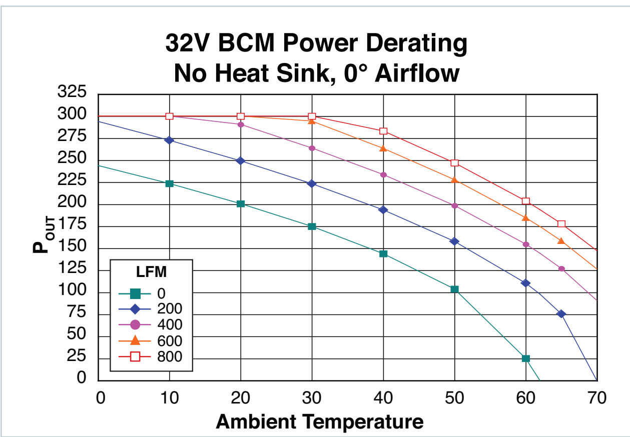
B048F320T30 0˚ Airflow



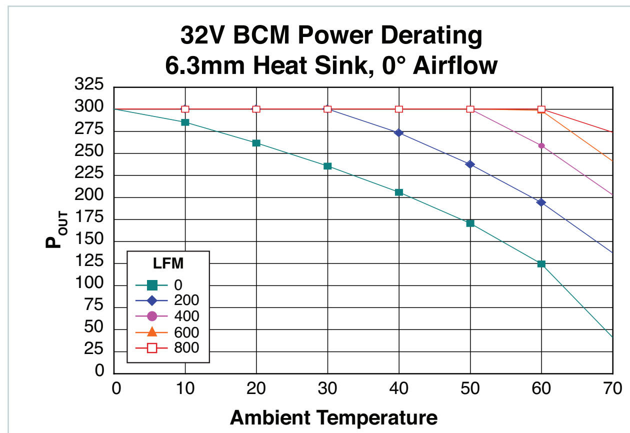
IR image, 0° airflow; Full load, 200LFM, no heat sink



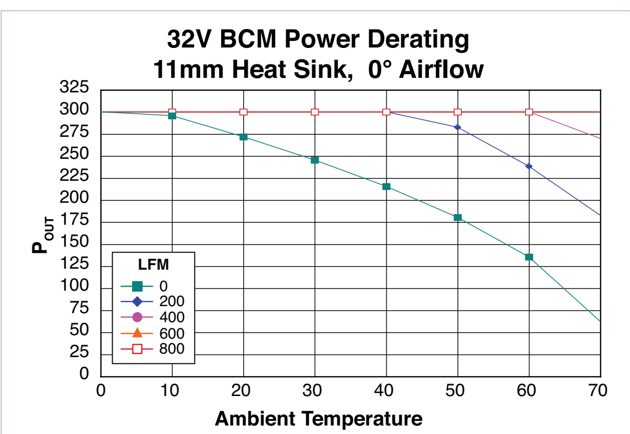
Thermal impedance vs. airflow, 0° orientation



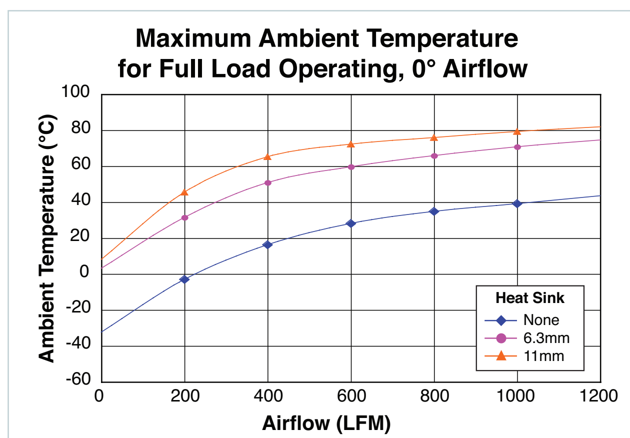
Power derating with no heat sink, 0° airflow



Power derating with 6.3mm heat sink, 0° airflow

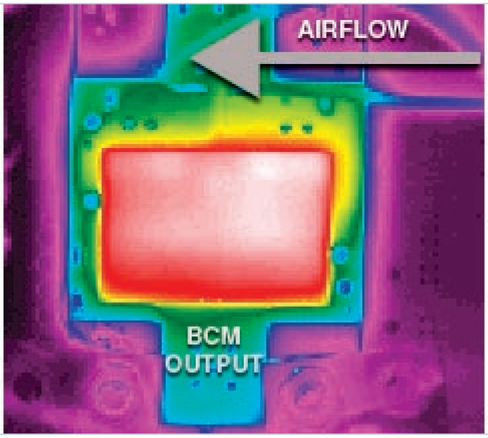


Power derating with 11mm heat sink, 0° airflow

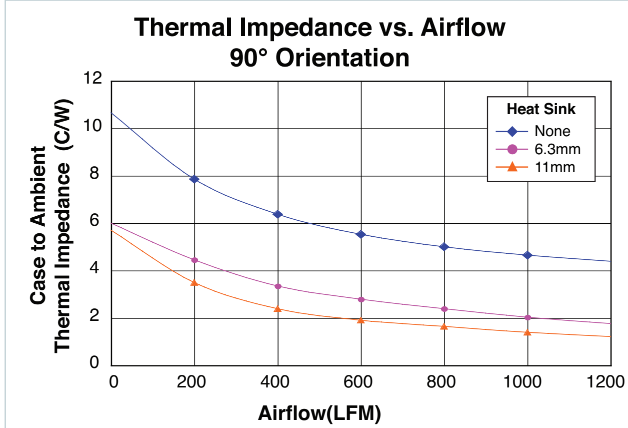


Maximum temperature at which device can be operated at full load

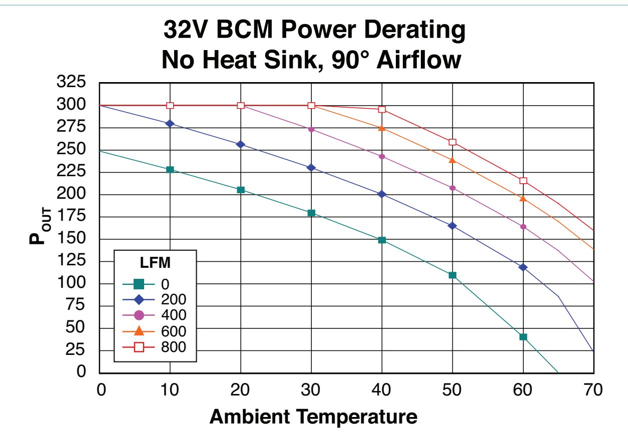
B048F320T30 90° Airflow



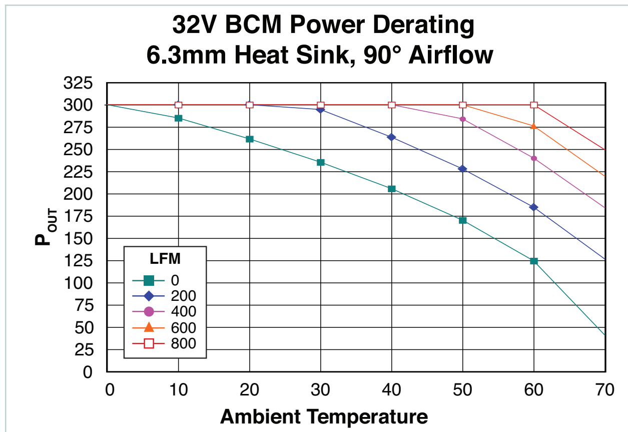
IR image, 90° airflow; Full load, 200LFM, no heat sink



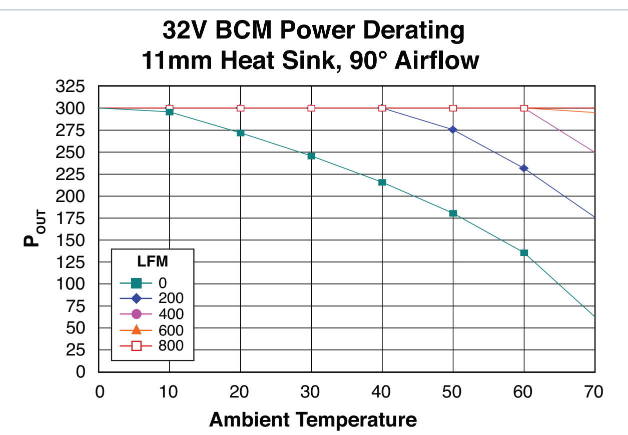
Thermal impedance vs. airflow, 90° orientation



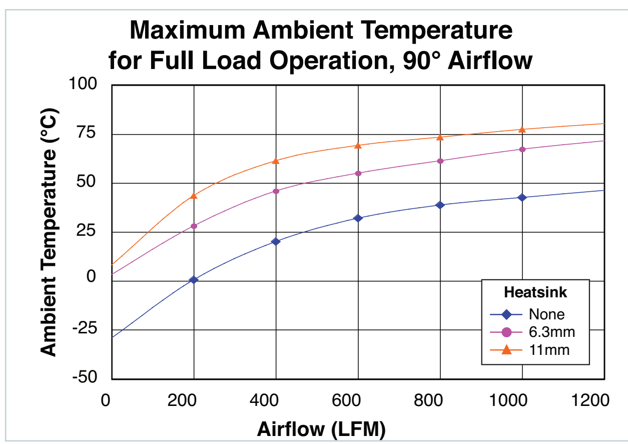
Power derating with no heat sink, 90° airflow



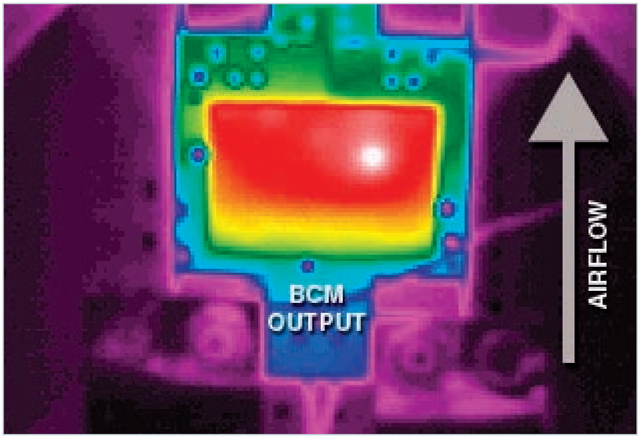
Power derating with 6.3mm heat sink, 90° airflow



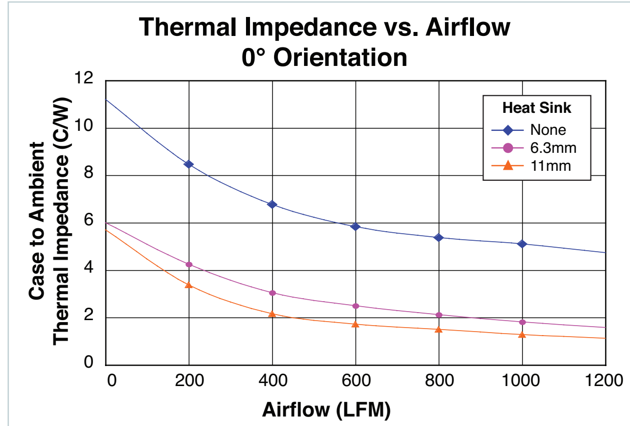
Power derating with 11mm heat sink, 90° airflow



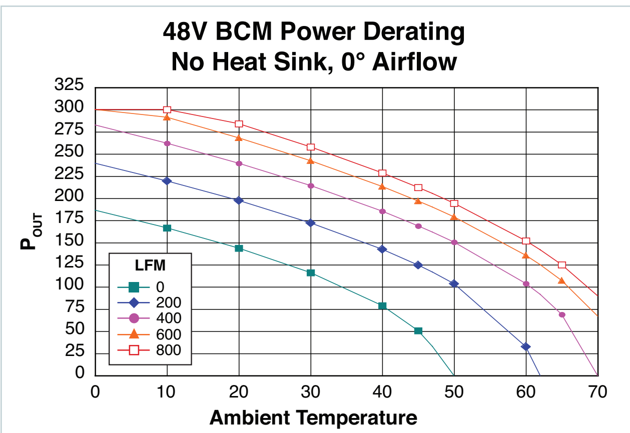
Maximum temperature at which device can be operated at full load



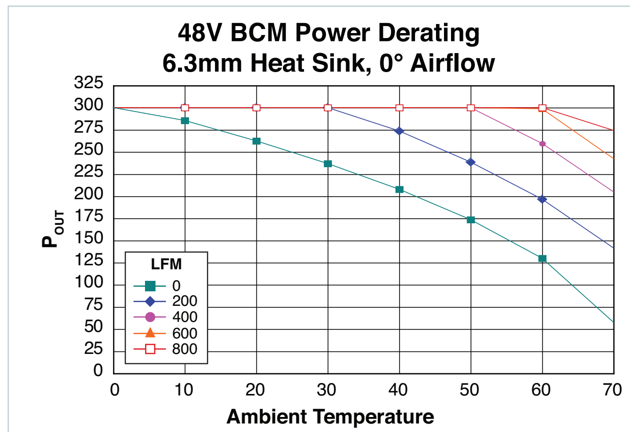
IR image, 0° airflow; Full load, 400LFM, no heat sink



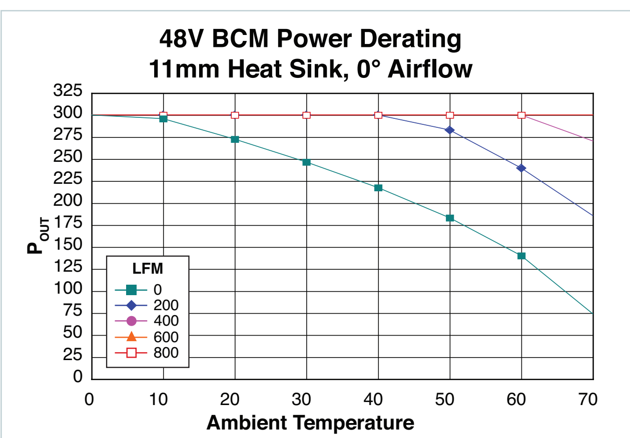
Thermal impedance vs. airflow, 0° orientation



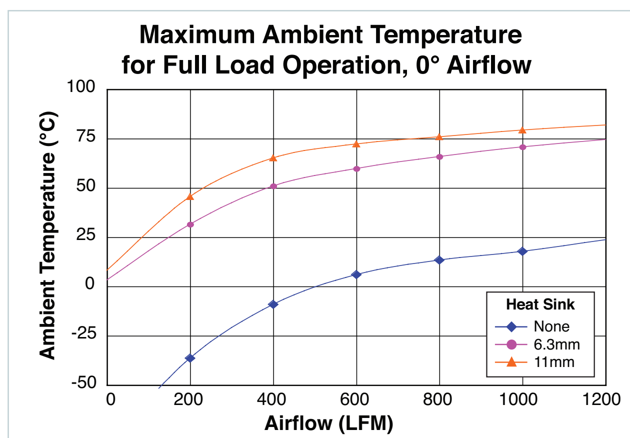
Power derating with no heat sink, 0° airflow



Power derating with 6.3mm heat sink, 0° airflow

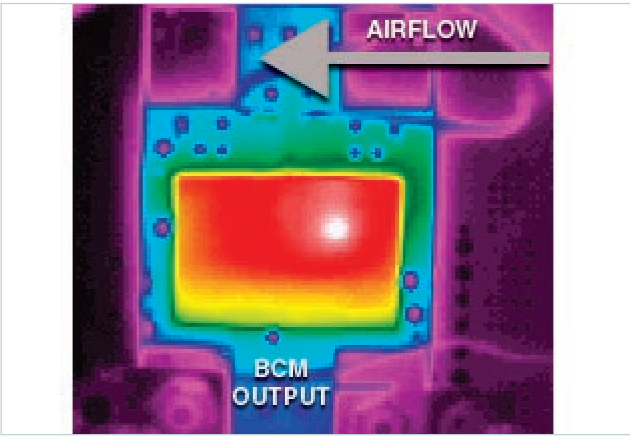


Power derating with 11mm heat sink, 0° airflow

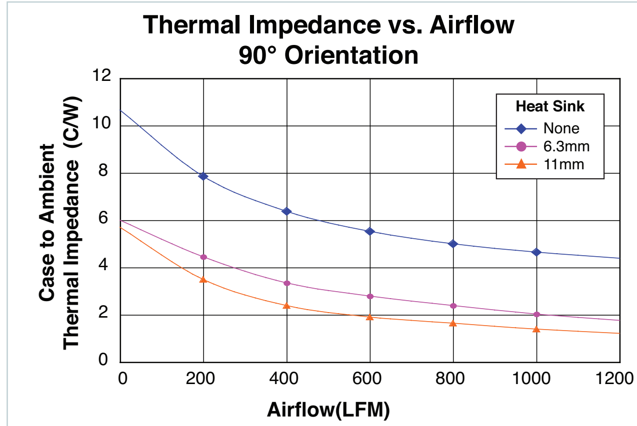


Maximum temperature at which device can be operated at full load

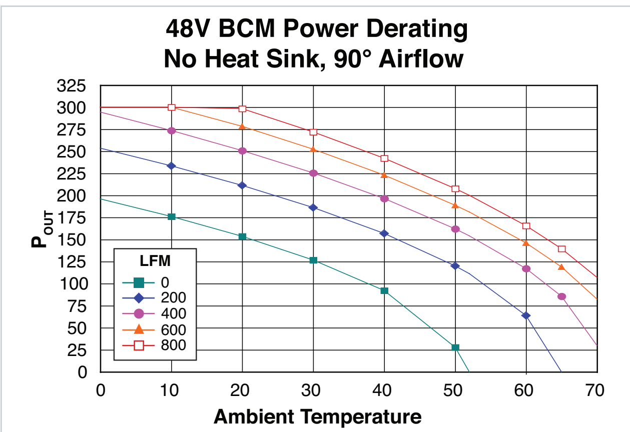
B048F480T30 90˚ Airflow



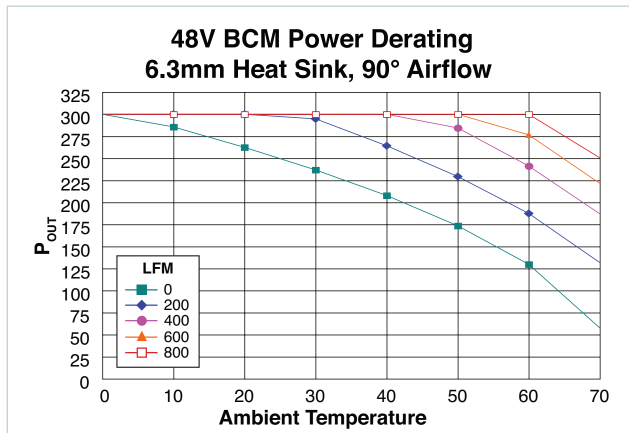
IR image, 90° airflow; Full load, 400LFM, no heat sink



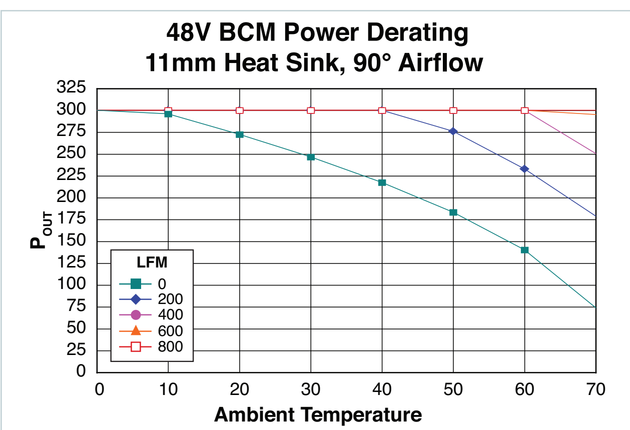
Thermal impedance vs. airflow, 90° orientation



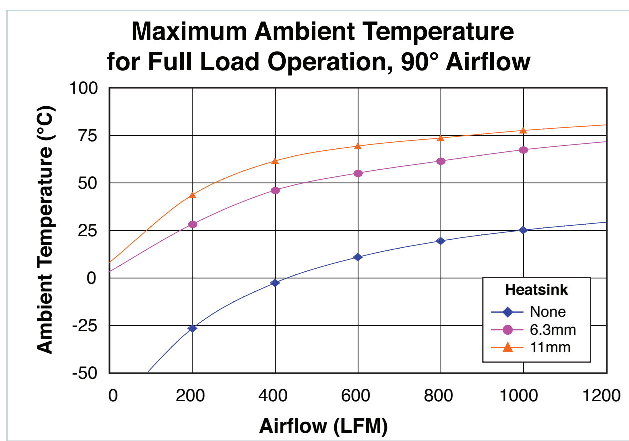
Power derating with no heat sink, 90° airflow



Power derating with 6.3mm heat sink, 90° airflow



Power derating with 11mm heat sink, 90° airflow



Maximum temperature at which device can be operated at full load

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