Removing Heat from a Semiconductor

The following parameters are necessary to determine the required heat sink:

1. **Q** - Amount of Power, (heat = (W)), to be dissipated
2. **Tjmax** - Maximum allowable Junction Temperature (°C)
3. **Ta** – Ambient Temperature of the surrounding fluid, (Air), (°C)
4. **Rθjc** - Thermal Resistance of the device “junction-to-case”
5. **Rθcs** - Thermal Resistance of the Thermal Interface Material, (TIM)
6. **Rθsa** - Natural or Forced Convection Cooling
7. **Air flow** – Linear Feet per Minute, (LFM), (If Forced Convection)

\[
\Theta_{ja} = \Theta_{jc} + \Theta_{cs} + \Theta_{sa} \\
\Theta_{ja} = \frac{T_j - T_a}{Q} \\
\Theta_{jc} = \text{junction-to-case} \\
\Theta_{cs} = \text{case-to-sink} \\
\Theta_{sa} = \text{sink-to-ambient} \\
\Theta_{sa} = \frac{(\Theta_{conv})(\Theta_{rad})}{(\Theta_{conv} + \Theta_{rad} + \Theta_{sink})}
\]
Heat Sink Selection - Example:

- TO-220 package outline device is dissipating 7 watts (Q)
- The Maximum Junction Temperature, is $T_j = 125^\circ C$
- And the Maximum Ambient Temperature, is $T_a = 65^\circ C$
- Component Junction-to-Case Thermal Resistance, is $R_{\theta jc} = 2.5 \, ^\circ C/W$
  (Note: this information can be obtained from the device’s data sheet).

Assuming that:

- Interface material is Silicon Grease – Wakefield 120 Series
- 0.002 inches thick
- 0.36 in² contact area

The Thermal Resistance of Silicon Oil-Based Grease can be found to be as:

Thermal Resistivity, $(\rho)$, (120 Series = 56 C-in/W), thickness, $(t)$, (in) and contact area, $(A)$, (in²)

\[
\Theta_{cs} = \frac{(\rho)(t)}{A}
\]

\[
\Theta_{cs} = 56 \, \text{C-in/W} \times 0.002 \, \text{in} / 0.36 \, \text{in}^2 = 0.311 \, ^\circ C/W
\]

\[
\Theta_{sa} = \frac{(T_j - T_a)}{Q} - (\Theta_{jc} + \Theta_{cs})
\]

\[
\Theta_{sa} = \frac{(125^\circ C - 65^\circ C)}{7W} - (2.5^\circ C/W + 0.31^\circ C/W)
\]

\[
\Theta_{sa} = 5.76^\circ C/W
\]

A heat sink will be required to have a Thermal Resistance of less than or equal to 5.76°C/W.

Extrusion Data:
Published Thermal Performance Data

- Natural Convection = Air Flow is estimated at ~57 LFM
- Vertical Orientation
- 3 inch long piece
- Uniform Heat Load – heat source area is entire base of heat sink

Heat Sink Temperature & Length Correction Factors:

*As ΔT Decreases, the Heat Sink Efficiency Decreases …*

Correct (°C/W/3in) = (Temperature Correction) x (Published °C/W/3in)

### Heat Sink Temperature Correction Factor

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Heat Sink Temperature Correction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>75C</td>
<td>1.000</td>
</tr>
<tr>
<td>70C</td>
<td>1.017</td>
</tr>
<tr>
<td>60C</td>
<td>1.057</td>
</tr>
<tr>
<td>50C</td>
<td>1.106</td>
</tr>
<tr>
<td>40C</td>
<td>1.117</td>
</tr>
<tr>
<td>30C</td>
<td>1.257</td>
</tr>
</tbody>
</table>

### Heat Sink Length Correction Factor

<table>
<thead>
<tr>
<th>Heat Sink Length (inches)</th>
<th>Correction Factor (multiplier)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.80</td>
</tr>
<tr>
<td>2</td>
<td>1.25</td>
</tr>
<tr>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>0.87</td>
</tr>
<tr>
<td>5</td>
<td>0.78</td>
</tr>
<tr>
<td>6</td>
<td>0.73</td>
</tr>
<tr>
<td>7</td>
<td>0.67</td>
</tr>
<tr>
<td>8</td>
<td>0.64</td>
</tr>
<tr>
<td>9</td>
<td>0.60</td>
</tr>
<tr>
<td>10</td>
<td>0.58</td>
</tr>
<tr>
<td>11</td>
<td>0.56</td>
</tr>
<tr>
<td>12</td>
<td>0.54</td>
</tr>
<tr>
<td>13</td>
<td>0.52</td>
</tr>
<tr>
<td>14</td>
<td>0.51</td>
</tr>
<tr>
<td>15</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Selecting Extrusions Lengths for Natural Convection
Wakefield Solutions provides the Thermal Resistance of heat sinks in terms of 3" lengths. To select heat sinks other than 3", WAKEFIELD THERMOVATIONS™ has developed a size selector graph shown below. When a preferred extrusion is selected, this graph will assist in establishing the approximate length necessary to obtain a desired Thermal Resistance.

The above Graph indicates “Resistance Ratio” Verses the Extrusion Length

Suppose that we have selected the Wakefield XX2006 heat sink design (from Example 1) but now need a lower $\theta_{sa}$ value of 5.0°C/W rather than the given catalog value of 5.4°C/W/3". We have available surface area to use an extruded heat sink longer than 3” and want to find out how long the sink must be to get to the desired 5.0°C/W Thermal Resistance.

Since we have both the desired resistance and the 3” length resistance, we can use Eq. (5) to find the Resistance Ratio: $\text{Resistance Ratio} = \frac{5.0}{5.4} = 0.93$

Next, we can find 0.93 on the Y-axis of the chart and follow it horizontally to the line. Reading the value on the X-axis reveals an extrusion length of approximately 4 inches. This result means that we can use a 4” or longer piece of the XX2006 to fulfill our thermal performance requirements.

Alternatively use Eq. (7) to find the extrusion length once we know the Resistance Ratio:

$\text{Extrusion Length} = \frac{(0.93-1.15)}{(-0.055)} = 4.0 \text{ inches}$