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AB05 Thermal Design Considerations for Luxeon™ Power Light Sources

Proper thermal management design is critical to achieve reliable and optimal performance of Luxeon™ Power Light Sources. Like most electronic components, LEDs have an inherent reliability limitation at high operating temperature; therefore, it is critical that they are operated in a properly managed thermal environment. Proper thermal management is important to keep the LED emitter package below its rated operating temperature. Minimizing temperature rise will also result in improved optical performance (see Luxeon™ OEM Guide for further detail).

This brief will assist the design engineer in strategies to achieve sufficient thermal management when using Luxeon™ Power Light Sources that have a minimum of 25mm spacing between emitters. This includes the Luxeon™ Star used in single emitter or in multiple emitter configurations, as well as the Luxeon™ Line and Luxeon™ Ring products. The high-density emitter packages such as the Luxeon™ Flood and custom products, with less than 25mm spacing between emitters, will be addressed in an future appendix to this brief. These products require greater attention in heatsinking due to the density of dissipated heat.

Heat Sinking is Important

As a rule, product applications using Luxeon™ Power Light Sources require mounting to a heat sink to achieve proper thermal management in all operating conditions. Depending on the application, this heat sink could be as simple as a flat, aluminum plate as a heat sink. For best performance, Luxeon™ Power Light Sources should be mounted directly to a smooth, flat heat sink using mechanical fasteners.

The Luxeon™ Star, Line and Ring (emitter spacing >25mm) consist of LEDs mounted on an aluminum, metal-core printed circuit board (MCPCB) in various configurations (see Luxeon™ Product Guide). The MCPCB on the Luxeon™ Star, Line and

Ring acts as an electrical interconnect, as well as a thermal heat sink interface. While no damage to the LEDs will result, these boards can get very hot ($\approx 70^{\circ}\text{C}$) without additional heat sinking when operated in a 25°C ambient environment. Use appropriate precautions.

We do not recommend any high-density (emitter spacing <25mm), multi-emitter product, such as the Luxeon™ Flood be lit for more than a few seconds at room temperature without an additional heat sink. All high-density emitter products (emitter spacing <25mm), such as the Luxeon™ Flood should be mounted to a heat sink prior to being illuminated for any sustained time interval (more than a few seconds).

Maximum Thermal Ratings

To ensure the reliability of custom Luxeon™ Power Light Sources, observe the absolute maximum thermal ratings for the LEDs pro-

vided in Table 1. Consult the appropriate data sheet to ensure current information.

Parameter	Maximum	Units
LED junction temperature	120	°C
Aluminum-core PCB temperature	105	°C
Storage/operating temperature		
Luxeon™ products without optics (Star, Star/C)	-40 to 105	°C
Luxeon™ Products with optics (Star/O, Line, Ring)	-40 to 75	°C

Table 1. Maximum Thermal Ratings

Thermal Modeling and Analysis

Thermal Resistance Model

Proper thermal design is critical to achieve the best efficiency and reliability of Luxeon™ Power Light Sources. The LED will experience a reversible loss of light output as the junction temperature increases. The word "junction" refers to the p-n junction within the semiconductor die. This is the region of the chip where the photons are created and emitted. The lower the junction temperature is kept, the better the luminous efficiency of the product, i.e. less losses in light output.

One of the primary mathematical tools used in thermal management design is Thermal Resistance ($R\Theta$). Thermal Resistance is defined as the ratio of temperature difference to the corresponding power dissipation. The overall $R\Theta_{\text{Junction-Ambient (J-A)}}$ of a Luxeon™ Power Light Source plus a heat sink would be defined as follows:

$$R\Theta_{\text{Junction-Ambient}} = \frac{\Delta T}{P}$$

Where:

$$\Delta T = T_{\text{Junction}} - T_{\text{Ambient}} \text{ (}^\circ\text{C)}$$

$$P = \text{Power dissipated (W)}$$

Equation 1. Definition of Thermal Resistance

Heat transferred from the die travels along the following thermal path: junction-to-slug, slug-to-board, and board-to-air/ambient. For such complex systems, involving conduction between multiple surfaces, the thermal path can be modeled using a series-

thermal resistance circuit, as shown in Figure 1. The overall thermal resistance ($R\Theta_{J-A}$) of an application can be expressed as the sum of the individual resistances of the thermal path from junction to ambient (Equation 1).

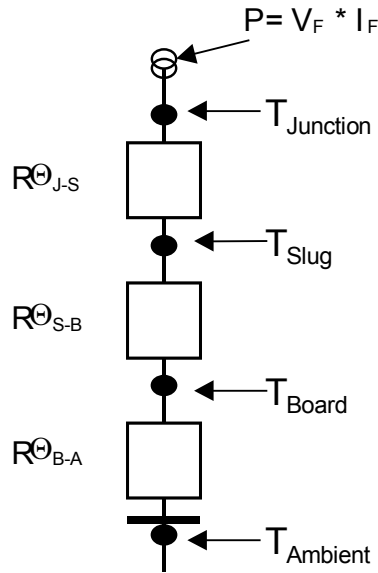


Figure 1. Series Resistance Thermal Circuit

$$R\Theta_{Junction-Ambient} = R\Theta_{Junction-Slug} + R\Theta_{Slug-Board} + R\Theta_{Board-Ambient}$$

Equation 2. Thermal Resistance Model

The dissipated power (P) can be estimated as the forward voltage (V_f) of the emitter times the forward current (I_f). The portion of power emitted as visible light is negligible. Equation 3 can be used to calculate the junction temperature of the Luxeon™ device.

$$T_{Junction} = T_{Ambient} + (P)(R\Theta_{Junction-Ambient})$$

Where:

- T_A = Ambient temperature
- P = Forward current * forward voltage
- $R\Theta_{J-A}$ = Thermal resistance junction to ambient

Equation 3. Junction Temperature Calculation

Inputs to the Thermal Model

Luxeon™ Power Light Sources require the addition of a heat sink to the board for proper operation in all conditions. This additional heat sink is represented by the $R\Theta_{Board-Ambient (B-A)}$ in Figure 1. $R\Theta_{B-A}$ is the combined value of the contact $R\Theta$ (or adhesive $R\Theta$, if used) between the heat sink and the board, as well as the $R\Theta$ of the heat sink into ambient air.

Assess Ambient Conditions

Due to the various applications and environments suitable for Luxeon™ Power Light Sources, the responsibility of thermal design, board to ambient, lies with the engineer using the product. The designer must take into account the maximum ambient temperature (T_A) the Luxeon™ Power Light Source will experience over its lifetime. Please note that the ambient temperatures should include other sources of heat such as electronics or heating due to sun exposure.

In some cases, product standards can be used to determine the worst case T_A . Otherwise, representative temperature measurements should be made.

Set Limit for Junction Temperature

The maximum junction temperature (T_J) should be determined from the smaller of: the maximum temperature requirement shown in Table 1 or the light output based maximum temperature requirement for the application. The maximum junction temperature based on the light output requirements can be determined by referring to the Luxeon™ OEM Guide and must never exceed the maximum thermal ratings.

By knowing the thermal resistance of the entire system, the minimum and maximum range of the ambient temperature and the power dissipated, one can approximate a safe range for the junction temperature (T_J). The variables in the thermal model can be used as control factors to the design.

Thermal Resistance of Luxeon™ Light Sources

In Luxeon™ Power Light Sources, the junction-to-board thermal path has been carefully optimized by Lumileds to minimize the

thermal resistance. This thermal resistance representing this path, $R_{\Theta \text{ Junction-Board (J-B)}}$, is equal to:

$$R_{\Theta \text{ Junction-Board}} = R_{\Theta \text{ Junction-Slug}} + R_{\Theta \text{ Slug-Board}}$$

Substituting $R_{\Theta \text{ Junction-Board (J-B)}}$ for the sum ($R_{\Theta \text{ Junction-Slug}} + R_{\Theta \text{ Slug-Board}}$) in Equation 1 yields:

$$R_{\Theta \text{ Junction-Ambient}} = R_{\Theta \text{ Junction-Board}} + R_{\Theta \text{ Board-Ambient}}$$

Typical values for $R_{\Theta \text{ J-B}}$ per emitter are shown in Table 2.

The thermal resistance of the Luxeon Emitter, junction to board ($R_{\Theta \text{ Junction-Board}}$) is:	
Batwing Emitter	$R_{\Theta \text{ J-B}} = 17^{\circ}\text{C/W}$
Lambertian Emitter	$R_{\Theta \text{ J-B}} = 20^{\circ}\text{C/W}$
Note: Consult current data sheet for $R_{\Theta \text{ J-B}}$.	

Table 2. Emitter Thermal Resistance Junction to Board

Thermal Resistance of Multiple-Emitter Luxeon™ Products

The total system thermal resistance of multiple-emitter Luxeon™ Products such as the Luxeon™ Line, Ring or multiple Stars can be determined using the parallel thermal

resistance model as shown in Figure 2. In this model, each emitter is represented by individual, parallel thermal resistances.

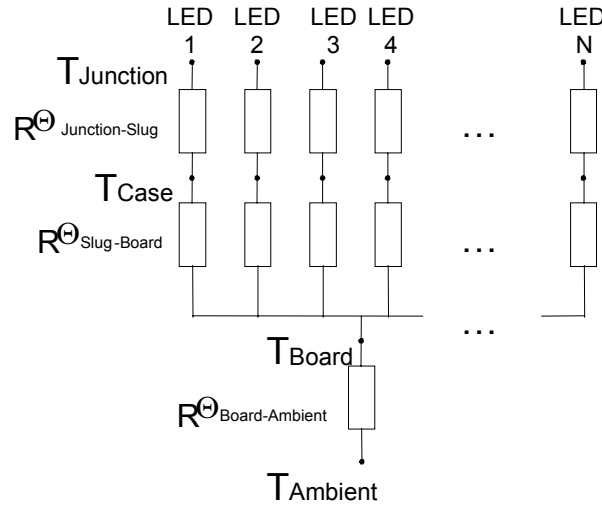


Figure 2. Parallel Thermal Resistance Model of Multiple Emitter Products

The $R_{\theta_{J-B}}$ of the multiple-emitter array is obtained by using the parallel resistance equation:

$$\frac{1}{Total_Array_R_{\theta_{Junction-Board}}} = \frac{1}{LED(1)_R_{\theta_{Junction-Board}}} + \dots + \frac{1}{LED(N)_R_{\theta_{Junction-Board}}}$$

All the parallel resistances are equivalent, so the equation becomes:

$$\frac{1}{Total_Array_R_{\theta_{Junction-Board}}} = \frac{N}{LED_Emitter_R_{\theta_{Junction-Board}}}$$

or:

$$Total_Array_R_{\theta_{Junction-Board}} = \frac{LED_Emitter_R_{\theta_{Junction-Board}}}{N}$$

Equation 4. Multiple Emitter to Single Emitter Thermal Resistance Relation

For example, in a Luxeon™ Line, there are 12 emitters, $N=12$. The Luxeon™ Line uses a batwing emitter; therefore, the Total Array $R_{\theta_{J-B}}$ is: $(17^{\circ}\text{C/W})/12 = 1.42^{\circ}\text{C/W}$.

The Total Array $R_{\theta_{Junction-Ambient(J-A)}}$ for the Luxeon™ Line is:

$$Total_Array_R_{\theta_{Junction-Ambient}} = 1.42 + R_{\theta_{Board-Ambient}}$$

The Total Array Power must be used in any calculations when using a Total Array thermal resistance model. The Total Array Power is the sum of $V_F \cdot I_F$ for all the emitters.

$$Total\ Array\ R\theta_{J-A} = \frac{\Delta T}{P_{Total}}$$

Where :

$$\Delta T = T_{Junction} - T_{Ambient} (\text{°C})$$

$$P_{Total} = \text{Total Array Power (W)}$$

Equation 5. Thermal Resistance of a Multiple Emitter Array

Heat Sink Characterization -- Test Set Up

Some typical heat sink configurations were tested on Luxeon™ Stars. The Luxeon™ Star LEDs and heat sinks were instrumented with thermocouples at locations shown Figure 3. Two conditions were tested: free (or natural) convection environment where no fan was used, and forced convection with a fan. The LEDs were driven at a current of 350 mA. The Luxeon™ Stars tested did not have optics. The optics do not affect the

$R\theta_{J-B}$ of the Luxeon™ emitter; however, depending on the orientation they may affect the convection flow over the attached heat sink. The tests were run in a closed volume test box to control the free convection and to improve repeatability. The samples were tested resting on the bottom of the test box oriented in two positions: horizontally and vertically, as illustrated in Figure 3.

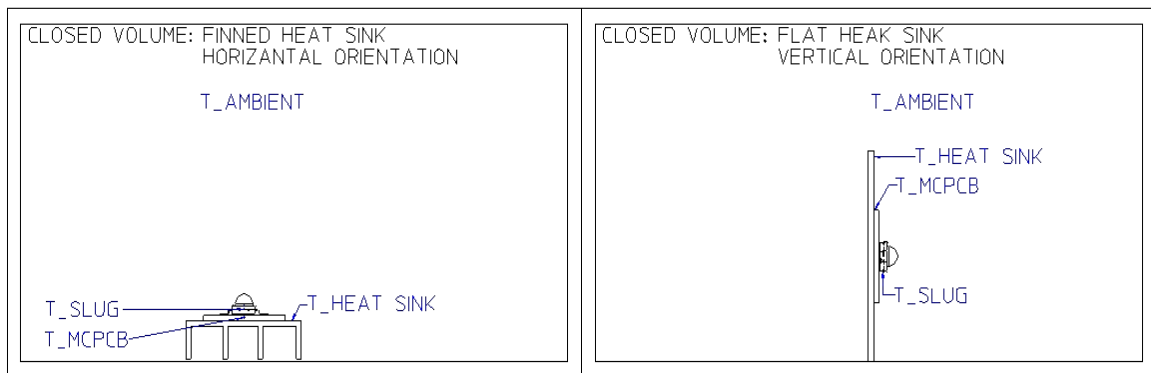


Figure 3. Test Set Up

Two types of heat sinks were tested: finned heat sinks and flat, rectangular heat sinks. All heat sinks were constructed of aluminum. Several different sizes of the flat heat sinks were tested and two different sizes of finned heat sinks were tested. Mechanical fasteners were used to mount the Luxeon™ Stars to the heat sinks. All measurements were made at steady state conditions. Initial am-

bient conditions were nominally 25°C, but the ambient temperature increased as the LEDs reached steady-state temperatures.

Tests were also done to quantify the effect of forced convection on finned heat sinks as compared to free convection. The free convection tests were with the heat sinks mounted in a small wind tunnel.

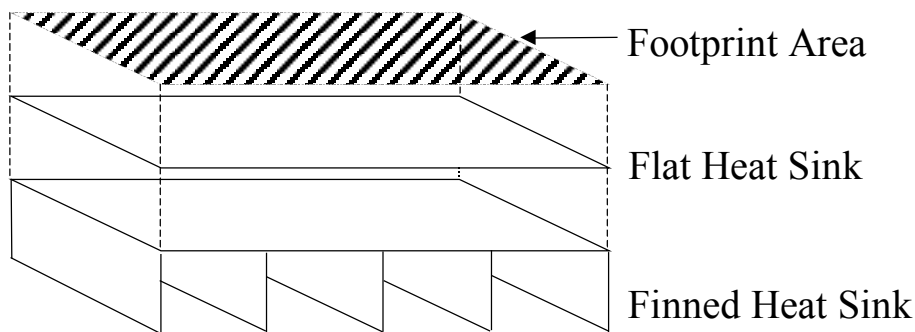
Heat Sink Characterization -- Results

The following results (Figures 4 to 8) are intended to guide the design engineer in selecting the size and type of heat sink required for an application. Figures 4 to 8 show $R_{\Theta_{B-A}}$ per emitter plotted on the y-axis vs. heat sink size on the x-axis. To obtain the total thermal resistance ($R_{\Theta_{J-A}}$) of the Luxeon™ Light Source plus heat sink, $R_{\Theta_{J-B}}$ of the emitter needs to be added.

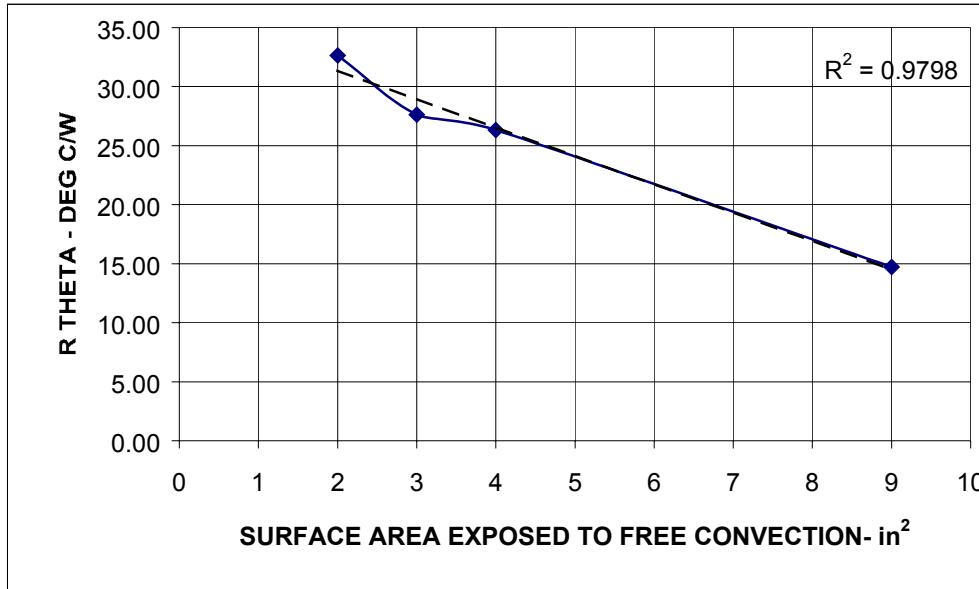
Table 2 lists $R_{\Theta_{J-B}}$ for the batwing and lambertian emitter. Check the current product data sheet for $R_{\Theta_{J-B}}$ specific to Luxeon™ Light Source used in your application.

Definition of Heat Sink Size

The heat sink sizes in these results are quantified in two ways. The term “exposed surface area” is the sum total of all surfaces of the heat sink exposed to convection. The “footprint area” quantifies the projected area of the heat sink as shown in following diagram. A finned heat sink can fit more exposed surface area in a given footprint than a flat heat sink.



Flat Heat Sinks in Free (Natural) Convection



**Figure 4. Thermal Resistance (Board to Ambient) vs. Surface Area
Flat Heat Sink, 0.09" (2.3mm) -- Horizontal on Non-Conductive Surface
Dashed Line: Linear Fit of Data**

Horizontal, Flat Heat Sink

As exposed surface area increases, there is a decrease in thermal resistance. Figure 4 illustrates this linear relation with a flat, horizontal heat sink.

In the horizontal orientation, only a single, upward-facing surface of the flat heat sink is exposed to convection.

Horizontal vs. Vertical Orientation

When the flat heat sink is oriented vertically, the surface area is doubled, because both sides are exposed to free convection. This results in a more efficient heat sink within the same footprint area. This effect is illustrated with respect to the footprint area in Figure 5.

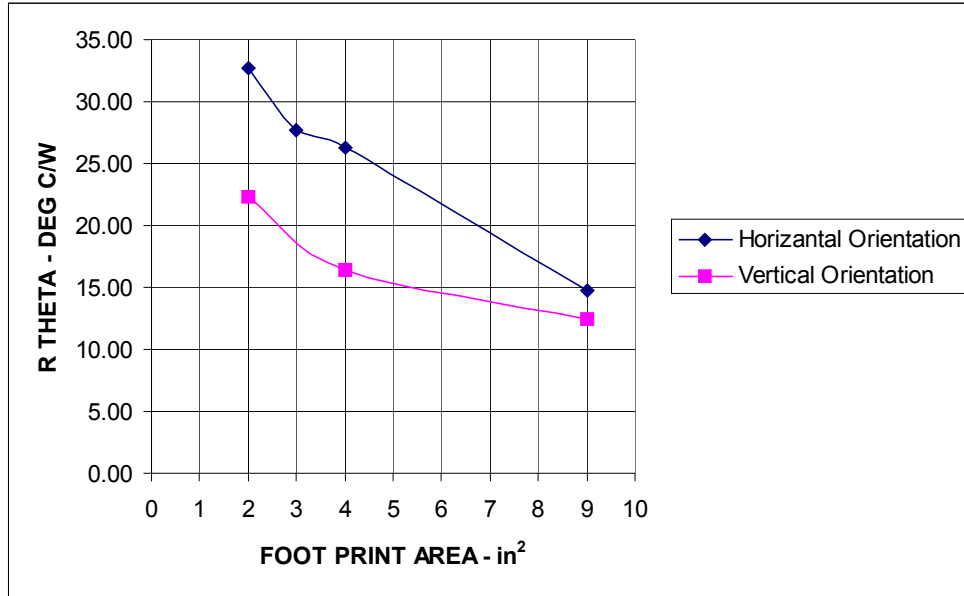


Figure 5. Thermal Resistance in Free Conv. (Board to Ambient) vs. Footprint Area of a Flat Heat Sink, 0.09” (2.3mm) Thick

In the vertical orientation, there is an evident decrease in thermal resistance by doubling the exposed surface area. In Figure 5, the total surface area of the horizontal heat sink is equal to the footprint area. For the vertical heat sink, the total surface area is double the footprint area. As footprint areas approach 9 in², the R_{θ_{B-A}} of the two orientations begin to converge. This indicates that with footprint areas of 9 in² or greater, heat sink orientation is not influential.

Conditions Represent Range of Efficiencies

The two conditions shown in Figure 5 represent a more efficient (vertical) and less efficient (horizontal on non-conductive surface) configuration of a flat heat sink.

Most applications will probably be some where in between. When selecting a heat sink for your application, the engineer needs to determine which condition is most comparable. Using judgement, the engineer can assess other factors that would make the R_{θ_{B-A}} of an application larger or smaller than the two conditions shown in Figure 5.

For instance, factors that would reduce the R_{θ_{B-A}} in the horizontal condition is mounting the heat sink to a conductive surface or mounting it at a 45° angle.

Flat vs. Finned Heat Sinks in Free (Natural) Convection

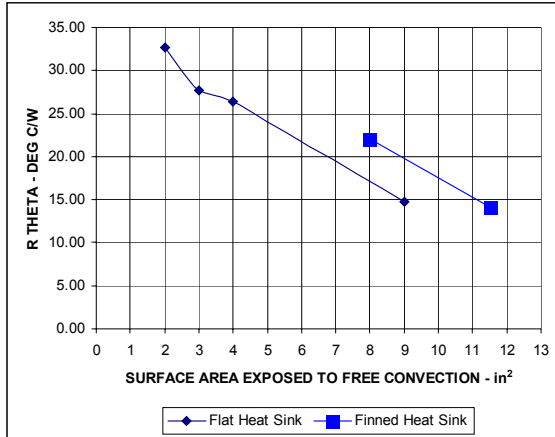


Figure 6.

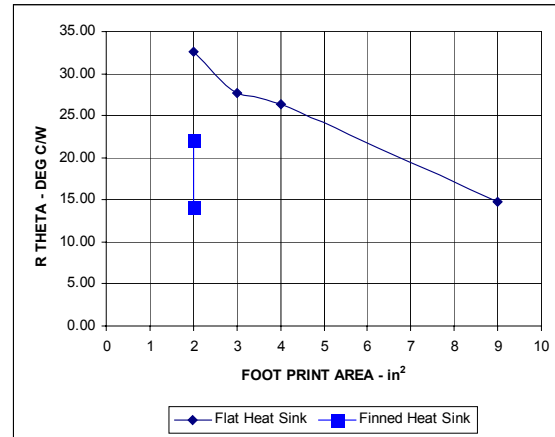


Figure 7.

Horz. Flat Heat Sink vs. Horz. Finned Heat Sink Thermal Resistance (Board to Ambient) in Free Conv.

Finned vs. Flat Heat Sinks

Two finned heat sinks were tested that had identical 2 in² footprint areas, but different exposed surface areas. Increasing the number of fins on the heat sink increases the surface area. The Figure 6 shows R_{θB-A} per exposed surface area for finned heat sinks and flat heat sinks. All the heat sinks plotted in Figure 6 are horizontal (as shown in Figure 3).

The finned heat sinks needed more exposed surface area for a given R_{θB-A} as compared to the flat heat sinks. In order for the surface area on the finned heat sinks to be fully utilized, the fins must lie in parallel with the convection airflow. The finned heat sinks would probably have a lower R_{θB-A} if oriented vertically.

Finned Heat Sinks Reduce Footprint Size

The Figure 7 shows R_{θB-A} per footprint area for finned heat sinks and flat heat sinks. Each of the finned heat sinks had 2 in² footprints and the flat heat heat sinks had footprints identical to their exposed surface areas.

Figure 7 shows that a small (2 in²) footprint finned heat sink can match the performance of a flat heat sink with a much larger (9 in²) footprint.

If footprint size is a major constraint in the design, the addition of a finned heat sink is an option that proves efficient.

Finned Heat Sinks in Forced Convection

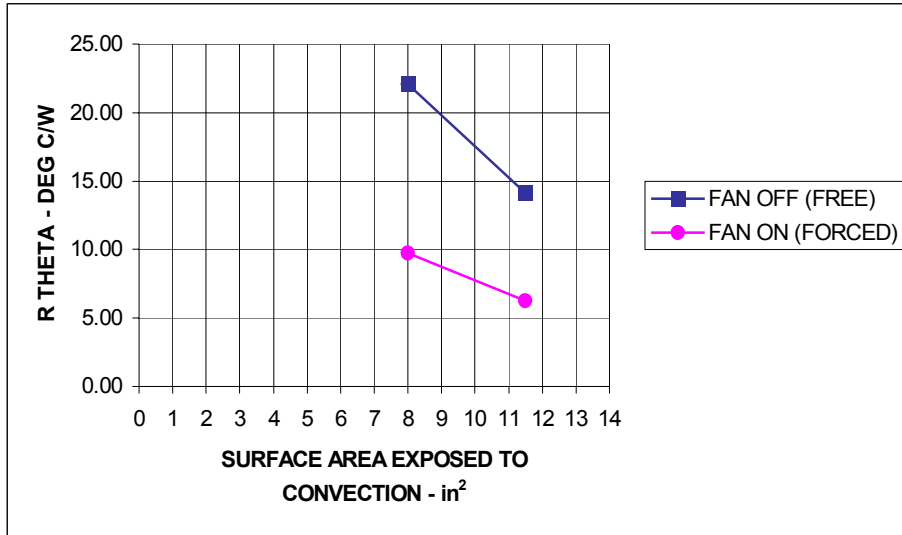


Figure 8. Thermal Resistance (Board to Ambient) vs. Surface Area Exposed to 42f/min (12.8m/min) Air Flow

If the conditions of your application dictate it, forced convection can offer a substantial decrease in thermal resistance (Figure 8).

In the range of heat sink areas that were tested, the reduction in RO_{B-A} was between 8 and 12°C/W.

Comments on Mating to Heat Sink

Importance of Smooth, Flat Interface

We tested two thicknesses (0.063 in. and 0.090 in.) of flat heat sinks under similar conditions. The thinner one had a lower thermal resistance, despite having less mass. The reason it did was because it had a smooth, machined interface surface. The thicker heat sink the original rolled surface of the sheet aluminum. This highlights the importance of mounting your Luxeon™ Power Light Sources to a smooth, flat heat sink.

Attachment to Heat Sinks

For best performance we recommend mounting Luxeon™ Power Light Sources directly to a heat using mechanical fasteners. Tapes and adhesives can aid in thermal contact with uneven surfaces, but they add thermal resistance, which may offset this benefit.

Typical thermal resistances of commercially available glues and tapes are shown in Table 3.

	Adhesive	Thermal Resistance (C/W)
Glues	Loctite 383	4.83
	Loctite 315	6.33
	Loctite 3873	4.00
	Thermoset ME179	2.17
	Amicon E3503	2.83
Tapes	PPI SP944	18.67
	PPI RD628	16.00
	Kapton	9.50
	Can-Do 454AC	19.67
	Bond Ply 100	14.16

Table 3. Typical Thermal Resistances of Glues and Tapes

Summary of Best Practices

- Mounting surface of the heat sink should be smooth and flat.
- Where practical, mount to heat sinks using mechanical fasteners. Tapes and Adhesives add thermal resistance.
- A flat, aluminum heat sink can be effective with good attachment to the metal-core board.
- When footprint area is a constraint, a finned heat sink can significantly reduce the required area.
- Forced convection reduces thermal resistance.
- If a thermally conductive fixture is used the thermal transfer from the heatsink will be improved, lowering the total system thermal resistance.

Evaluating Your Design

The data presented in this brief can be used to initially size the aluminum heat sink required for your application. The key is to determine maximum $R_{\Theta_{B-A}}$, per emitter, given both the thermal and optical requirements of your application. The data plotted in the Results section of this brief can be used to approximate the heat sink size per

emitter, as well as its orientation and shape. For multi-emitter applications, these heat sink characteristics can also be approximated using the figures, provided the emitter spacing is greater than or equal to 25mm.

In order to select the minimum size heat sink for you application:

Step 1) Determine allowable $R\Theta_{J-A}$

With T_J as the constraining variable, the following equation can be used:

$$T_{Junction} = T_{Ambient} + (P)(R\Theta_{Junction-Ambient})$$

The absolute maximum T_J and the worst case operating conditions T_A should be entered into the equation. You may need to specify a maximum T_J lower than 120°C in

order to achieve the optical performance required for your application. See the Luxeon™ OEM Guide for more information.

The dissipated power per string, P , can be determined by:

$$P = (V_F)(I_F)$$

Solve for $R\Theta_{J-A}$ using:

$$R\Theta_{Junction-Ambient} = \frac{(T_{Junction} - T_{Ambient})}{P}$$

Step 2) Subtract the $R\Theta_{J-B}$ (found in Table 2, also check current product data sheet) of Luxeon™ emitter from $R\Theta_{J-A}$ to obtain the target $R\Theta_{B-A}$

Step 3) Using the calculated $R\Theta_{B-A}$ as a target, review the data plotted in Figures 4 to 7 of the results section, to determine the heat sink configuration that best suits your application. Look up the heat sink area that corresponds to the target $R\Theta_{B-A}$. The aim is to determine the range of heat sink size your application requires. Using a finned heat sink can reduce footprint area of heat sink.

If the heat sink size constraints of an application are already known, a target $R\Theta_{B-A}$ for the particular heat sink design can be obtained first. In the process of evaluating a design, input variables used in Step 1 can be changed in an iterative fashion using the heat sink size as a constraint.

For example, an application may be able to run at a lower drive current, I_F , and still meet the light output requirements. This would reduce the dissipated power, P , resulting in a larger target $R\Theta_{B-A}$ that could be met using a smaller heat sink.

Utilizing Other Thermal Analysis Resources

In addition to the data in the results section, other resources can be used to determine the type of heat sink that will meet the target $R_{\Theta_{B-A}}$. These resources include published heat sink characterization data references or thermal analysis software. When using reference materials, realize the Luxeon™ emitters act as point sources of heat that are not evenly distributed over an entire mounting surface.

Aavid Thermalloy is a manufacturer of extruded heat sink products. They offer a free selector tool software for choosing standard heat sink profiles size with a given R_{Θ} . That software tool, as well as links to other thermal analysis can be accessed from the fol-

lowing web link:

<http://www.aavidthermalloy.com/>

Check Your Design

When physical prototypes of the application are available, it is important to monitor the metal-core PCB temperature of the emitters and compare with results from the thermal model. The thermocouple should be mounted as close as possible to the base of the emitter, preferably in a tight-fitting hole drilled into the metal-core PCB.

The design should be evaluated across the range of expected ambient temperatures, using an oven if require

Examples

Example 1: Luxeon™ Star -- Single Emitter

A flat, aluminum heat sink using free convection is desired for single-emitter Luxeon™ Star application. The application uses an amber batwing emitter that is driven at 335mA.

Step 1) Determine allowable $R_{\Theta_{Junction-Ambient}}$.

Using the heat transfer formula:

$$T_{Junction} = T_{Ambient} + (P)(R_{\Theta_{Junction-Ambient}})$$

or:

$$R_{\Theta_{Junction-Ambient}} = \frac{(T_{Junction} - T_{Ambient})}{(P)}$$

Where:

$$T_J = 120^\circ\text{C} \text{ (max. junction temp.)}$$

$$T_A = 85^\circ\text{C} \text{ (max. based on operating conditions)}$$

Maximum $V_f = 3.3 \text{ V}$ for amber batwing (consult data sheet)

$$P = (V_f)(I_f)$$

$$P = 3.3 \text{ V} * 335\text{mA} = 1.1\text{W}$$

Solving for $R_{\theta_{J-A}}$:

$$R_{\theta_{J-A}} = (120-85)/1.1$$

$$R_{\theta_{J-A}} = 32 \text{ }^\circ\text{C/W}$$

Step2) Obtain the target $R_{\theta_{\text{Board-Ambient}}}$.

Subtract $R_{\theta_{J-B}}$ of the Luxeon™ emitter:

$$R_{\theta_{B-A}} = 32 \text{ }^\circ\text{C/W} - 17^\circ\text{C/W} \text{ (for Batwing LED)}$$

$$R_{\theta_{B-A}} = 15^\circ\text{C/W}$$

Step 3) Review heat sink characterization data in results section.

Depending on the space requirements of the application, the thermal resistance target ($R_{\theta_{B-A}} = 15^\circ\text{C/W}$) could be met with several different heat sink designs. The area required for a flat, horizontal heat sink with only one free convection surface would be about 9 in^2 (Figure 4). The design could also be executed using a 4 in^2 flat, vertical heat sink that has two free convection surfaces (Figure 5). To reduce the footprint area to 2 in^2 , a finned heat sink may be used with a total surface area of about 11.5 in^2 (Figure 8).

If the required drive current of the emitter was 350mA , then the target $R_{\theta_{B-A}}$ would have been slightly lower, necessitating a heat sink with a slightly larger area.

Example 2: Luxeon™ Line - 12 emitter

A Luxeon™ Line (12 emitters) will be mounted in a vertical position. The maximum ambient operating condition is 75°C for Luxeon™ Products with Optics. The emitters are red and are driven at 325mA .

Step 1) Determine allowable $R\Theta_{\text{Board-Ambient}}$.

Using the heat transfer formula:

$$R\Theta_{\text{Junction-Ambient}} = \frac{(T_{\text{Junction}} - T_{\text{Ambient}})}{(P)}$$

Where:

$$T_J = 120^\circ \text{ (max. junction temp.)}$$

$$T_A = 75^\circ\text{C}$$

Maximum $V_f = 20 \text{ V} / 6$ emitters in series (consult data sheet)

$$\text{Maximum } V_f = 3.3 \text{ V}$$

$$P = 325\text{mA} * 3.3 \text{ V} = 1.1\text{W per emitter}$$

Solving for $R\Theta_{\text{J-A}}$:

$$R_{\text{J-A}} = \frac{(120 - 75)}{1.1}$$

$$R_{\text{J-A}} = 41^\circ\text{C/W}$$

Step2) Obtain the target $R\Theta_{\text{Board-Ambient}}$.

Use Equation 4 to obtain the $R\Theta_{\text{J-B}}$ per emitter:

$$\text{Total_Array_}R\Theta_{\text{Junction-Board}} = \frac{\text{LED_Emitter_}R\Theta_{\text{Junction-Board}}}{N}$$

Total $R\Theta_{\text{J-B}} = 1.4^\circ\text{C/W}$ for Luxeon™ Line (consult data sheet)

$$R\Theta_{\text{J-B}} \text{ per emitter} = (1.4^\circ\text{C/W})(12)$$

$$R\Theta_{\text{J-B}} \text{ per emitter} = 17^\circ\text{C/W}$$

$$R\Theta_{\text{B-A}} = 41^\circ\text{C/W} - 17^\circ\text{C/W}$$

$$R\Theta_{\text{B-A}} = 24^\circ\text{C/W per emitter}$$

Step 3) Review heat sink characterization data in results section.

Reviewing Figure 5, the Luxeon™ Line would require 2 in² footprint of flat heat sink per emitter with two vertically oriented, free convection surfaces. That would correspond to a total HS area of 48 in² with a 24 in² footprint.

The total system $R\Theta_{J-A}$ can be obtained by using a calculation similar to Equation 4, where N is the number of emitters.

$$Total_System_R\Theta_{Junction-Ambient} = \frac{Emitter_R\Theta_{Junction-Ambient}}{N}$$

$$Total_System_R_{J-A} = 3.4^{\circ}C/W$$

The T_J at a given T_A can be calculated using Equation 3. The total array power must be used when using the total system $R\Theta_{J-A}$.

Calculate T_J at $T_A = 25^{\circ}C$

$$Total\ Array\ Power = 12(1.1\ W) = 13.2\ W$$

Equation 3:

$$T_{Junction} = T_{Ambient} + (P)(R\Theta_{Junction-Ambient})$$

$$T_J = 25^{\circ}C + (13.2\ W)(3.4^{\circ}C/W)$$

$$T_J = 70^{\circ}C$$

Validation of method

Luxeon™ Line 12-emitter array with 48 in² of flat heat sink was instrumented and measured. In a vertically oriented position, the measured $R_{B-A} = 2.5^{\circ}C/W$. By adding the Total Array R_{J-B} of $1.42^{\circ}C/W$, the measured Total System R_{J-A} is $3.9^{\circ}C/W$ versus the predicted R_{J-A} of $3.4^{\circ}C/W$.