Application Note AN10
Effective Thermal Management of Bridgelux LED Arrays

Introduction

The Bridgelux family of LED Array products delivers high performance, compact and cost-effective solid-state lighting solutions to serve the general lighting market. These products combine the higher efficiency, lifetime, and reliability benefits of LEDs with the light output levels of many conventional lighting sources.

As noted in the Bridgelux LED Array Product Data Sheets, several performance characteristics of the LED Array products, including flux, forward voltage, color, and reliability are dependant upon temperature. This is a common characteristic for all LEDs, a characteristic of the semiconductor-based technology. As temperature increases, several performance parameters experience a temporary and recoverable shift. With increasing temperature; light output (or flux) decreases, forward voltage (or V_f) decreases, and the color temperature shifts towards blue.

Furthermore, absolute maximum ratings, such as maximum case temperature and maximum junction temperature, must not be exceeded. Exceeding the absolute maximum ratings, as listed in the Product Data Sheets, may irreversibly damage the product and cause permanent shifts in performance.

Optimization of performance and reliability in a lighting system using Bridgelux LED Arrays requires proper thermal management. Although a critical design parameter, thermal management is not as difficult as many would believe. Understanding the basics allows every lighting designer to optimize their products and meet specification requirements.

This application note describes basic thermal management concepts and guidelines for proper use of Bridgelux LED Arrays in a lighting system. Included is an overview of basic heat transfer concepts, a description of a thermal model, a sample calculation using this thermal model, a description of various thermal components, and recommendations for measuring the case temperature of the Bridgelux LED Array to validate the performance of the thermal management solution.

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Heat Generation

When voltage is applied across the junction of an LED, current flows through the junction generating light. It is a common misconception that LEDs do not generate heat. While essentially no heat is generated in the light beam (unlike conventional light sources), heat is generated at the junction of the LED Array and must be effectively managed. As LEDs are not 100% efficient at converting input power to light, some of the energy is converted into heat and must be transferred to the ambient. The amount of heat generated from the LED Array that must be transferred to the ambient may be conservatively estimated to be 85% of the power that is applied to the LED Array and is calculated by multiplying the forward voltage (V_f) times the current (I_f) times 0.85. This is described in Equation 1.

$$P_d = V_f * I_f * 0.85$$

Equation 1: Thermal power to be dissipated

Where:

P_d is the thermal power to be dissipated
V_f is the forward voltage of the device
I_f is the current flowing through the device

The power calculation should be made for maximum dissipated power, which is computed using the Maximum V_f at the drive current desired. The Maximum V_f can be obtained from the electrical characteristics table in the Bridgelux LED Array Product Data Sheet for the array being used. Product data sheets are available at www.bridgelux.com.

Heat generated by additional sources, such as a power supply located near the LED Array, must also be managed. In order to reduce the size and cost of the thermal management solution, and to minimize the amount of additional heat added to the system, power supplies and other heat generating components should not be located in close proximity to the LED Array.

Thermal Path

Heat generated at the LED junction must be transferred to the ambient via all elements that make up the thermal management solution. These elements include the LED Array, the thermal interface material used between the LED Array and heat sink, the heat sink, the luminaire enclosure (if applicable), and other components that come in contact with the lighting assembly. These elements transfer heat to the ambient through conduction, convection, or radiation. These heat transfer modes will be discussed in greater detail in the next section of this application note. For a simple thermal management solution that consists of an LED Array mounted to a heat sink, we consider that all the heat from the LED junction is typically transferred to the ambient through the following thermal path:

1. Heat is conducted from the semiconductor chip within the LED Array to the elements that make up the LED Array, including the metal board and the resin.

2. Heat is then conducted from the LED Array through a thermal interface material to the heat sink of the lighting system. This is a critical component in transferring the heat. We will discuss this point in detail later.

3. Heat is then conducted through the heat sink.

4. Finally, the heat is convected to the air around the heat sink and is radiated to the ambient.

Modes of Heat Transfer

There are three basic modes of heat transfer; conduction, convection, and radiation. All heat flow is driven by temperature gradients; heat moves from hot to cold. Each heat transfer mode plays an important role in transferring heat away from the LED junction to the ambient. Table 1 provides a summary describing the various heat transfer modes and the equations that govern them.

Table1: Heat transfer modes and governing equations

Mode	Governing Equation	Definition of Variables
Conduction	$Q_{COND} = -k\ A\ dT/dx$ Equation 2: Heat Conduction	Q_{COND} is the heat that is conducted (°C/Wm) k is the thermal conductivity of the material (W/mK) A is the cross sectional area of the medium the heat is conducted through (m^2) dT is the temperature gradient across the material (°C) dx is the distance the heat is traveling through the material (m)
Convection	$Q_{CONV} = h\ A\ (T_s – T_\infty)$ Equation 3: Heat Convection	Q_{CONV} is the heat convected h is the convection heat transfer coefficient (W/m^2K) A is surface area T_s is the surface temperature of the hot surface T_∞ is the temperature at infinity, typically the ambient air temperature
Radiation	$Q_{RAD} = \varepsilon\sigma\ A\ (T^4_s – T^4_\infty)$ Equation 4: Heat Radiation of Gray Bodies*	Q_{RAD} is radiated heat ε is emissivity and provides a measure for how a surface emits energy relative to a blackbody σ is the Stephan-Boltzmann Constant, $5.6703\ 10^{-8}$ (W/m^2K^4) A is the area of the emitting body T_s is the surface temperature T_∞ is the temperature at infinity, typically the ambient air temperature

* In the real world, the ideal models of Physics do not absolutely apply. Typically, engineers assume that heat radiation does not depend on the sample's surface conditions. In these cases, the heat source is known as a "*Gray Body*".

The first of these, conduction, is the transfer of heat between adjacent molecules of a material, usually a solid. Equation 2 provides the basis for our first set of guidelines for designing meaningful thermal solutions.

Considerations for heat sink design or selection:

- Minimize the distance heat must travel (dx). In practical terms this means that if a heat sink is too large, it may loose effectiveness. However, this distance should not be so small that a bottleneck is created, constricting the flow of heat.
- Select heat sinks made of materials that have a high thermal conductivity (k). As a reference, Table 2 compares thermal conductivity of various metals typically used for heat sinks and the thermal conductivity of air. Although aluminum is not as an effective heat conductor as copper, it is frequently the material of choice as it minimizes the cost and the weight of the thermal solution.
- Use heat sinks with large surface areas (A).
- Eliminate air gaps and voids between the LED Array and the heat sink. Air is a very poor conductor of heat. During assembly, the flat bottom surface of the LED Array should be in full contact with the flat surface of a heat sink. If air gaps or voids exist between the two, a thermal interface material should be used to fill the gaps.

Nature has two great thermal insulators. The first great insulator is a vacuum, and the second is air. Therefore, it is critical to have a sufficient volume of the thermal interface material to displace the air. However, if there is any excess thermal interface material, for example more than 0.3 mm, then the system thermal resistance will begin to increase. On the surface this may not appear to make sense. What one needs to consider is that while the thermal interface material is better at removing heat than air, it is much worse than the metal in the heat sink which conducts the heat away from the LED Array.

Table 2: Thermal conductivity of common heat sink materials and air

Material	**Thermal Conductivity (W/mK)**
Iron	79.5
Aluminum	205
Copper	385
Air (at 0°C)	0.024

Convection describes heat transfer due to random molecular motion and bulk motion of a fluid. In other words, convection is the heat transfer from the heat sink to air (or water) and is directly dependant upon the amount of flow of the air or water. In the case of the natural convection in air, where, for example, the movement of air molecules in not aided by a fan, the convection heat transfer coefficient ranges from 2 to 15 W/m^2K.

Forced convection is a result of movement in the fluid (water or air), which results from other forces, such as the use of a fan or pump. With forced convection, the convection heat transfer coefficients range from 25 to 250 for gases and from 100 to 20,000 for liquids. Both natural convection and forced convection may be used to effectively convect heat away from the LED Array. Equation 3 can be used to develop guidelines for enabling heat transfer through convection.

Considerations for heat sink design or selection:

- Use heat sinks with the largest surface area (A) that is physically or economically feasible. As a general rule of thumb, for a well-ventilated heat sink, there should be 10 square inches of heat sink for every 1 Watt of thermal power dissipated.
- Orient heat sink fins in a manner allowing hot air to flow upward and away from the heat sink and cold air to flow onto the surfaces of the heat sink.
- Avoid constricting the airflow.
- If natural convection is insufficient, then consider using fans, moving membranes, heat pumps, or liquid cooling elements that can dramatically increase the convection heat transfer coefficient and hence dramatically increase heat transfer. Active heat sinks also allow for thermal solutions with much smaller footprints.
- Use heat sinks with surfaces that have high emissivity values.

Radiation is energy transfer by electromagnetic waves. By analyzing Equation 4, guidelines for enabling heat transfer through radiation can be developed.

- Radiation heat transfer has a very strong dependency on temperature. The hotter the heat sink, the more significant the heat transfer through radiation. However, as the maximum case temperature of the LED Array is 105°C, heat transfer due to radiation is very small when compared to other heat transfer modes.

Keeping in mind how heat is transferred and consciously optimizing specific heat transfer modes should make the task of designing a cost effective and optimally sized thermal management solution easier. In a typical single LED Array lighting assembly using simple heat sinks, the amount of heat that is conducted, convected, and radiated is a function of the heat sink geometry, surface area, material properties, surface properties, fin geometry (including thickness and spacing), and heat sink temperature. While this may sound complicated, the application of effective heat sink design is straightforward.

Thermal Model

A simple thermal model or thermal circuit can illustrate the heat flowing through an LED Array. This model is analogous to an electrical circuit where heat flow is represented by current, voltages represent temperatures, heat sources are represented by constant current sources, and resistors represent thermal resistances. Figure 1 shows a thermal circuit for a single LED Array mounted to a heat sink.

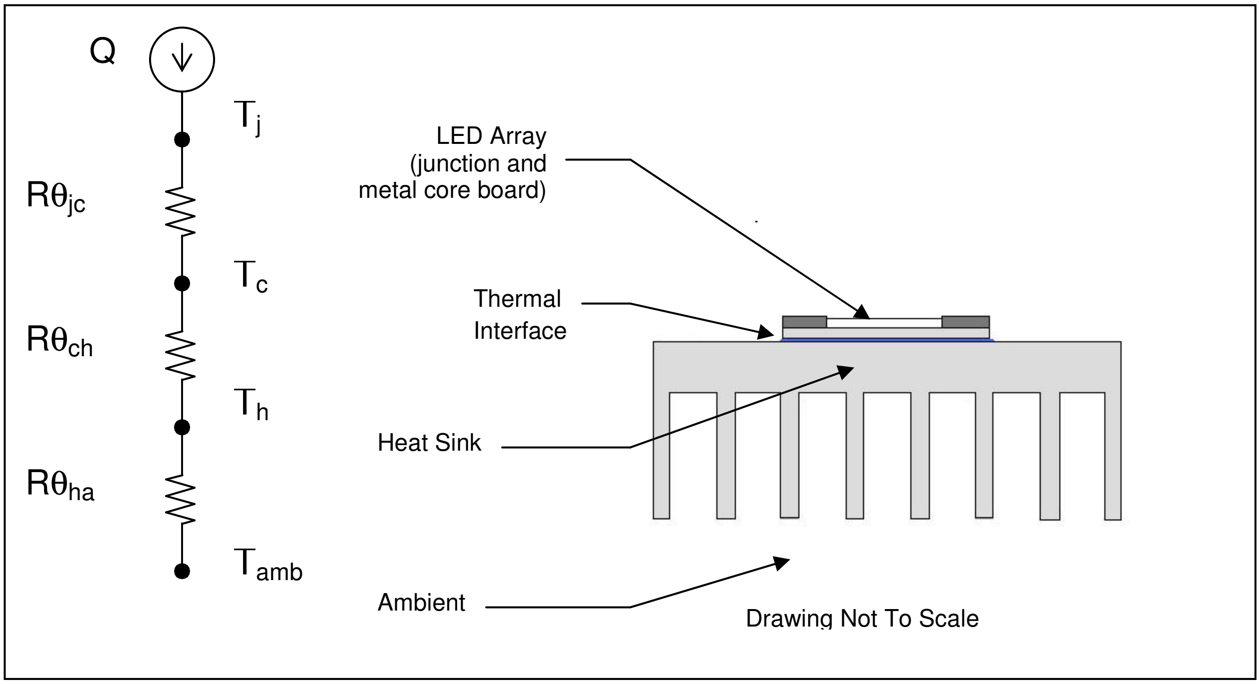


Figure 1: Simple thermal circuit

Where:

Q is heat flowing from hot to cold, through the LED

T_j is the temperature at the junction of the device

T_c is the temperature at the case of the LED Array

T_h is the temperature at the point where the heat sink is attached to the LED Array

T_{amb} is the ambient air temperature

$R\theta_{jc}$ is the thermal resistance from junction to case of the LED Array

$R\theta_{ch}$ is the thermal resistance between the case of the LED Array and the heat sink

$R\theta_{ha}$ is the thermal resistance of the heat sink

With the exception of T_j, all temperatures listed above can be easily measured. For Bridgelux LED Arrays, case temperature measurements are made in the area noted in the mechanical drawings section of the Product Data Sheets. Note that this area is on the same surface of the LED Array as the resin area, providing an easy to measure location after assembly to the heat sink. Although traditionally case temperature measurements are conducted on the back side of a device, the difference in temperature between the defined case temperature measurement point location on the top of the Bridgelux LED Array and bottom are very small. Bridgelux has characterized the difference between these two points to be typically 1°C or less, and considers the difference negligible. For practical lab and field measurements, a small thermocouple mounted under the head of the array mounting screw can be used. While less accurate than the defined case measurement point, this method is usually within 2 or 3 degrees of the case temperature, which is sufficiently accurate for most situations. The use of non-contact thermal measurement techniques such as IR thermometers or thermal imaging cameras are not recommended.

The thermal resistances that make up the thermal model may be calculated and solved for using the following equation:

$$R\theta_{xy} = (T_x - T_y) / Q_t$$

Equation 5: Thermal Resistance

Where:

$R\theta_{xy}$ is the thermal resistance from x to y, where x and y are points along the thermal circuit

T_x is the temperature at x

T_y is the temperature at y

Q_t is heat flow and may be approximated to be P_d (see equation 1)

Substituting “x” with “j “and “y” with “c”, we get $R\theta_{jc}$, or the thermal resistance from junction to case of the LED Array. $R\theta_{jc}$ values are included in the Product Data Sheets for all Bridgelux LED Arrays and therefore do not need to be calculated. Instead, by knowing $R\theta_{jc}$ values and by using Equation 5, we may solve for T_j, the temperature at the junction.

By substituting “x” and “y” with appropriate values, both $R\theta_{ch}$ and $R\theta_{ha}$ may be solved for using Equation 5. When using thermal interface materials, such as thermal pastes and adhesives, $R\theta_{ch}$ describes the thermal resistance of the thermal interface material. Thermal interface materials, and their impact on thermal resistance, will be discussed in greater detail later in this application note. $R\theta_{ha}$ describes the thermal resistance of a heat sink or heat sink assembly. Once maximum operating conditions are known, including drive current, forward voltage, and maximum ambient temperature, this value is solved for, and a heat sink may be sized and selected to achieve this value.

Rules governing a thermal circuit are also analogous to those of an electric circuit. Equation 6 depicts the method for adding series thermal resistance values.

$$R\theta_{ja} = R\theta_{jc} + R\theta_{ch} + R\theta_{ha}$$

Equation 6: Summation of Series Thermal Resistances

Where $R\theta_{ja}$ is typically referred to as the system thermal resistance.

Furthermore, when assembling multiple LED Arrays on a single heat sink, the rule of parallels applies. This is depicted in Equation 7.

$$1/\ R\theta_{jh} = 1/\ R\theta_{1\ jh} + 1/\ R\theta_{n\ jh} + \ldots + 1/\ R\theta_{n\ jh}$$

Equation 7: Summation of Parallel Thermal Resistances

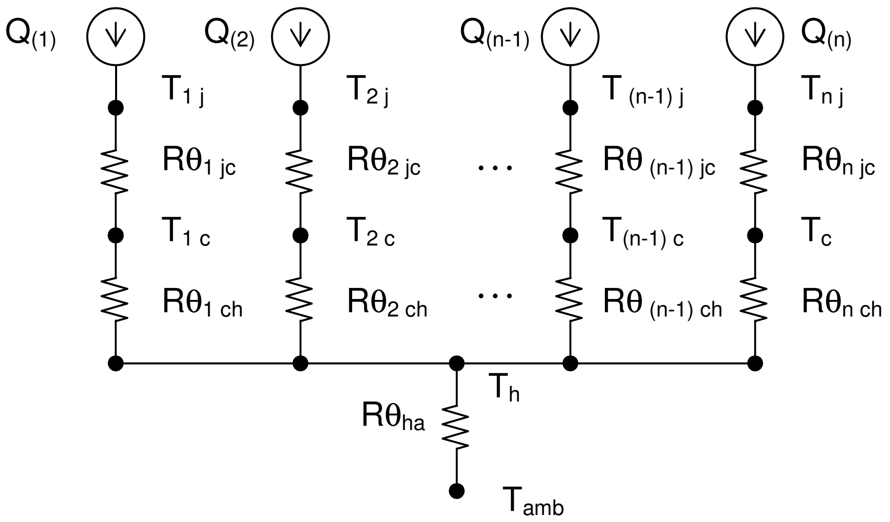
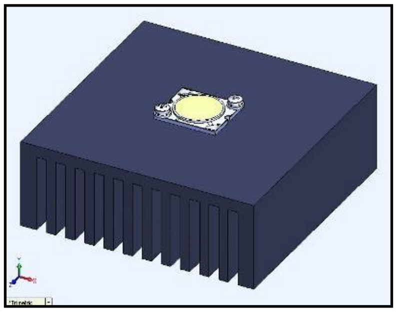


Figure 2: Simple thermal circuit of multiple LED Arrays on a single heat sink

In Equation 7, “n” refers to the number of LED Arrays mounted onto a single heat sink and $R\theta_{n\ jh}$ is the thermal resistance from the LED junction to the heat sink of each of the individual LED Arrays. It should be noted that when using this model the total power (sum of all LED Arrays mounted to the single heat sink) must be multiplied by the system thermal resistance to calculate the case or junction temperature.

Thermal Model Example

Design Challenge:



A luminaire is to be designed using the BXRA-C1202-00000 LED Array driven at 1050mA. The maximum ambient temperature will be 40°C and the case temperature cannot exceed 70°C in the application. A thermal paste, with a thermal conductivity of 4W/mK and a resulting thermal resistance of 0.07°C per Watt has been selected. Shifts in forward voltage due to temperature are assumed negligible. Given this information the thermal resistance of the heat sink required for this design must be calculated and the minimum surface area for an extruded aluminum heat sink must be determined.

Solution:

To solve for the thermal resistance of the heat sink we use equation 5, where "x" is "h" and "y" is "a":

$$R\theta_{ha} = (T_h - T_a) / Q_t$$

Here, T_a is 40°C and T_h is unknown at this time, but may be solved for. Q_t can be solved for using Equation 1.

$$\begin{aligned} Q_t &= V_{fmax} * I_f * 0.85 \\ &= 13.8\text{ V} * 1050\text{ mA} * 0.85 \\ &= 12.3\text{ Watts} \end{aligned}$$

As the thermal resistance of the thermal interface material is known, to solve for T_h we use equation 5, substituting "x" with "c" and "y" with "h":

$$R\theta_{ch} = (T_c - T_h) / Q_t$$

Solving for $T_{h,}$ we determine:

$$\begin{aligned} T_h &= T_c - (R\theta_{ch} * Q_t) \\ &= 70°\text{C} - (0.07°\text{C/W} * 12.3\text{ W}) \\ &= 69.1°\text{C} \end{aligned}$$

Now solving for $R\theta_{ha}$:

$$\begin{aligned} R\theta_{ha} &= (69.1°\text{C} - 40°\text{C}) / 12.3\text{ Watts} \\ &= \mathbf{2.37°C/ W} \end{aligned}$$

The surface area of a black anodized aluminum extruded heat sink with at thermal resistance of 2.37°C/W is estimated to be at least 73.8 square inches for a heat sink with fins that are oriented vertically, or 123.0 (12.3W x 10 in^2/W) square inches if the fins are oriented non-vertically. While these values may appear large, this is the total surface area required and may consist of surfaces that make up the luminaire itself, such as the housing and reflector, in addition to the surfaces that make-up the heat sink. The final required surface area of the heat sink depends on many variables, including, but not limited to, fin orientation, the ability of hot air to move away from the heat sink, the ability of cold air to enter and flow through the heat sink, and the existence of other heat sources near the LED Array.

Thermal Solution Components – Heat Sinks

There are many commercially available components, including heat sinks and heat pipes, which may be used with Bridgelux LED Arrays. The most commonly used components are heat sinks, typically made of aluminum or copper. Heat sinks conduct heat from a heat source and then convect the heat to the ambient. The size of a required heat sink depends on many variables, including the temperature requirements for the application (such as maximum ambient and case temperature), the material of the heat sink, the surface characteristics of the heat sink, and the physical constraints for the application.

In some applications, space requirements may not allow for a large heat sink. In these cases, designers should consider using forced convection elements, such as fans, moving membranes or other air movement systems. Consult heat sink suppliers to explore forced convection heat sink options. Heat sink suppliers can provide detailed technical data on their heat sinks to customers. Data supplied includes heat sink temperature rise above ambient as a function of air flow speed and heat sink thermal resistance as a function of air flow speed. This information aids in the design and heat sink selection process.

Impact of Fin Orientation on Heat Sink Performance

Thermal performance presented by heat sink manufacturers usually pertains to the most favorable heat sink orientation, which is with the fins of the heat sink oriented vertically (see Table 3). In this orientation, hot air rises readily, allowing cool air to flow through the fins. Other orientations give varying results. Rules of thumb on the impact of varying fin orientation are shown in Table 3. However, please note that that the actual performance of a heat sink is dependant on many variables such as heat sink location within an assembly, the location of other heat generating elements such as a power supply, effective airflow, fin spacing, fin height, fin thickness, base thickness, base surface area, shape, fin geometry, and overall length. Consequently, the effectiveness of a heat sink mounted in varying orientations is not a fixed number, and depends on the inter-relationship between many variables. A much larger poorly positioned heat sink will not be as effective as a properly oriented thermal system.

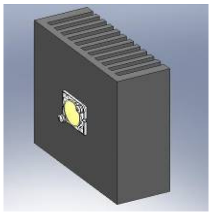
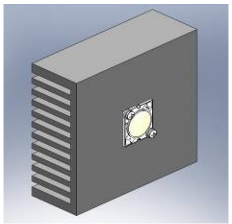
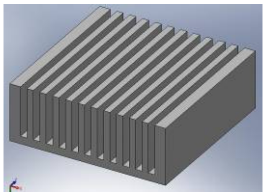
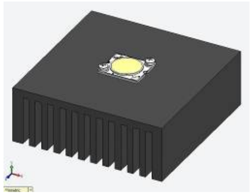
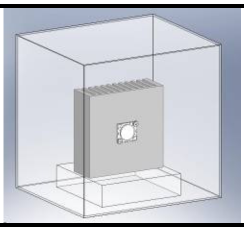
To illustrate the effect of fin orientation and limiting airflow, measurements of case temperature and heat sink temperature of a BXRA-C1200 LED Array were conducted. The LED Array was mounted to a 121 x 121 x 32 mm heat sink with a surface area of 774cm^2. A thin layer of thermal paste was applied between the LED Array and the heat sink. The dissipated power for this LED Array was 18.4 watts. The heat sink was then placed in the orientations listed in Table 3. When sitting on a flat surface, the heat sink sat on a 1-inch thick foam board to minimize conduction to the bottom surface. Measurements were taken after one hour of operation in each configuration.

Some results vary from the guidelines listed in Table 3, illustrating the need to measure a proposed or calculated design to gauge true effectiveness of a thermal management solution. There may be many variables that cause differences in results, such as uncontrolled forced convection from central heating units and differing amount of heat conduction to surroundings. All must be taken into consideration when designing a thermal solution.

Note that the worst performance was achieved by placing the LED Array in a box, and limiting both conduction and natural convection airflow paths. The thermal resistance of the system could be significantly improved in this case by providing a convective path to ambient. Typically LED-based luminaires are constructed in such a manner as to conduct the heat to the exterior case of the luminaire, significantly improving the thermal performance of the system.

As mentioned previously, fans may be used to dramatically increase the convection heat transfer coefficient, and hence dramatically increase heat transfer from the heat sink to the ambient. If fans are used, make sure that they pull-in the cold ambient air to the heat sink surfaces and that they push hot air away from the heat sink. Also, make sure the lifetime of any active thermal management system is evaluated to ensure it is suitable, matching or exceeding the expected life of the lighting assembly.

Table 3: Impact of heat sink fin orientation on heat sink effectiveness, general rules and experimental results

Fin Orientation	**Illustration**	**Guideline**
		Typical Relative Effectiveness
Vertical		100%
Horizontal		85%
Horizontal Up		70%
Horizontal Down		60%
Vertical (Inside a 6 x 7 x 7 in^3 Non-Conducting Box)		–

Heat Sink Reference Chart

Thermal management references are available at the end of this document.

Thermal Interface Management

To ensure heat flow from the LED Array to a heat sink, pay close attention to air gaps or voids located between the bottom of the LED Array and the heat sink. Such voids will significantly impede the flow of heat and therefore must be eliminated. The use of thermal interface materials, such as thermal greases, pastes, or adhesives, is recommended to ensure that air gaps and voids are eliminated.

When selecting a thermal interface material many factors must be considered. These include thermal conductivity, operating temperature range, cost, manufacturability (dispensability for pastes), electrical conduction, and the ability to control the thickness of the bond line.

The Thermal Interface Comparison table (table 4) is a reference table to be used as a guide during the thermal design process. It compares some of the leading factors involved in determining which thermal interface material to use in a design. It also contains a Recommendation for Evaluation category which takes into account all the factors involved when making this decision and places emphasis on Reliability and Manufacturability.

Table 4: Thermal Interface Material Category Comparison

	Pad	**Thermal Adhesive**	**Thermal Grease**	**Thermal Grease Based Pad**	**Phase Changing Materials**	**Thermal Tape**
Relative Thermal Conductivity	Various	High	High	High	High	Med
Electrical Isolation	Various	None	None	None	Various	Various
Cost	High	Med/High	Low	Low/Med	High	Med
Manufacturability	Custom stamping of rolls	Screen Printing / Messy	Screen Printing / Messy	Custom stamping of rolls	Custom stamping of rolls	Custom stamping of rolls
Reliability	Good	Good	Potential Long Term Silicone Oil Bleed	Potential Long Term Silicone Oil Bleed	Unproven: Thermal Cycling	Unproven: Peeling/Air gaps
Attachment	None	Permanent	None	None	None	Single or Dbl Adhesive
Other Concerns					Thermal Cycling	Air gaps
Recommended for Evaluation	High	High	Medium	Medium	Low	Low
Reference Materials	Berquist Sil-Pad® A1500	Arctic Silver 5	Omega High Temp Thermal Paste PN# OT-201	AOS Micro-Faze® 3 A-4	N/A	N/A

If using a paste, the amount of paste that is dispensed should be enough to cover the entire base of the LED Array, but not so much as to result in a thick bond line, which will increase the thermal resistance. Application of excess thermal interface material can also create side fillets. Fillet size should be kept at a minimum and must not touch the top of the LED Array.

The following equation shows the relationship between thermal interface material thickness and thermal resistance:

$$R\theta_{ch} = (L * 1000)/ (K * A_c)$$

Equation 8: Thermal resistance of an interface material

Where:

L is the thermal interface material thickness (mm)

K is the thermal conductivity (W/m-K)

A_c is the contact area (mm^2)

For design purposes, the thermal interface material thickness typically ranges from 0.15 to 0.30 mm, depending on the LED Array product and the thermal interface material selected. This range of thicknesses assumes that the planarity of the bottom surface of the LED Array is maintained at or below 0.1mm for all products except RS Array Series products. The planarity for the RS Array Series products is maintained at or below 0.25mm. Hence, when selecting a thermal interface material ensure that the thickness of the material is sufficient to fill gaps between the base of the LED Array and the heat sink while at the same time minimizing the thickness. Thermal conductivities of interface materials vary from product to product.

All thermal interface materials must be applied in a way that ensures the entire bottom of the LED Array is covered and that air gaps or voids between the LED Array and the heat sink are filled. One method of achieving this, which may be used in volume production, is to silkscreen precise quantities of a dispensable thermal interface material on a heat sink surface prior to attaching the LED Array.

Silkscreen templates are made in sizes that mirror the base of the LED Array, or are scaled to a slightly larger size. The final thickness of the interface material is controlled by the force applied on the LED Array from the top when pressing it down on the thermal interface material. These forces can vary from a few hundred grams, which pick and place equipment is capable of handling, to several kilograms, which would require special tooling. If pick and place equipment is used for this processes, consider using “Scrub” mode, while pressing the LED Array onto the heat sink. In all cases care must be taken to avoid contact with the resin area of the LED Array during assembly. Please consult application note AN11 – Handling and Assembly of Bridgelux LED Arrays, for further information.

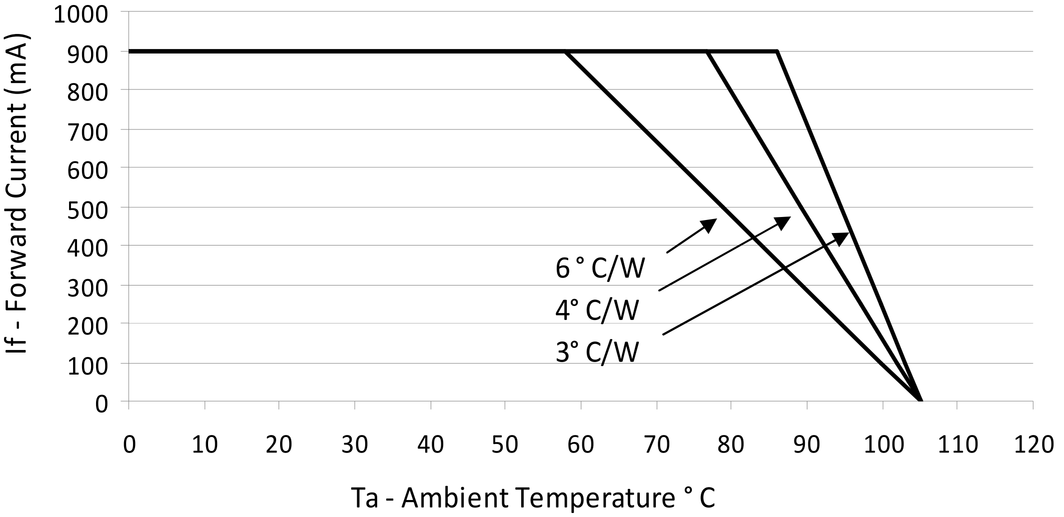
The customer must evaluate the performance of the thermal interface material to ensure adequacy in terms of thermal performance, manufacturability, and durability.

Use of Current Derating Curves

Current derating curves are included in the Bridgelux LED Array Product Data Sheets. These curves provide guidance to customers in developing effective thermal management solutions that meet system design requirements.

A derating curve is included for each Bridgelux LED Array product. When using these graphs, the required system thermal resistance can be estimated when the LED Array is used at the rated test current under various ambient conditions. An example of one of these derating curves is included in Figure 3. Please consult the relevant Product Data Sheets for the most recent versions of these derating curves.

Figure 3: Derating Curve for BXRA-W0400, 900 mA Drive Current



The thermal resistance values indicated on the derating curves are total system thermal resistance values (junction to ambient). Although limited options are included, it is possible to interpolate between these curves for approximation purposes. The safest approach, however, is to calculate the required system thermal resistance using the equations contained in this application note.

The thermal resistance for the BXRA-W0400 product from the Bridgelux LED Array Product Data Sheet is listed as 1.0℃/W. If in a given lighting system the thermal resistance from case to ambient is designed to deliver 3℃/W, the curve in Figure 3 labeled 4℃/W would be applicable for this lighting system (sum of junction to case and case to ambient thermal resistance values).

In this example, as long as the ambient temperature is maintained below 80℃ the maximum temperature ratings of the product will not be violated at the rated forward current of 900 mA. If, however, the ambient temperature was to rise to 85℃, the forward current would need to be reduced to 700 mA based on the 4℃/W system thermal resistance. Alternatively a heat sink could be designed to deliver a case to ambient thermal resistance of 2℃/W. This would result in a system thermal resistance of 3℃/W, allowing for 900mA operation at the 85℃ ambient condition.

Thermal Simulation

It is strongly recommended that computer thermal simulation is performed on any design before prototyping. Thermal simulation allows for cost and time reductions during the design process. A simulation will allow the designer to view any thermal bottle necks or hot spots before the initial build. This allows for quick and relatively cheap redesigns. The figures below show snap shots of a thermal simulation.

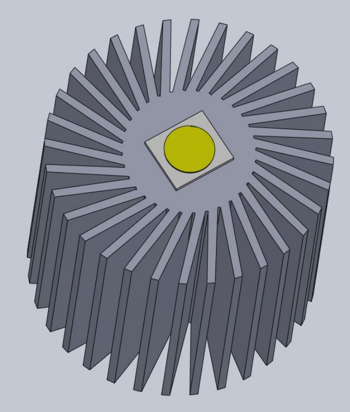
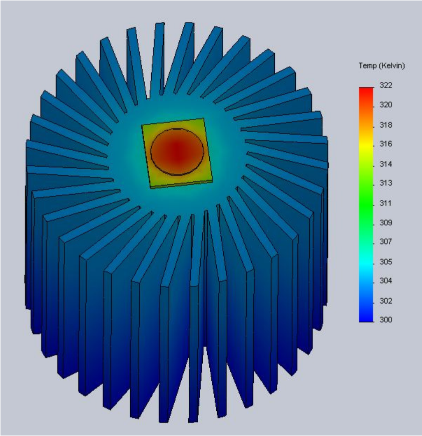


Figure 4: Heat sink 3D Design

Figure 5: Thermal Simulation with Solidworks Simulation software



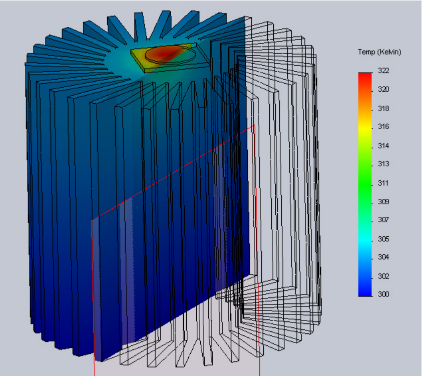


Figure 6: Analysis of Thermal Simulation

Measuring Effectiveness of a Thermal Solution

After a thermal management solution has been designed it is critical to experimentally validate the effectiveness of the solution. This is typically done by building a prototype, simulating the worst-case use conditions, and measuring T_{case}. When simulating worst-case use conditions ensure the following:

- Convection conditions are realistic.
- Material properties and dimensions, including wall thicknesses, surface areas, and component sizes are representative of the design.
- Surface properties, including color and roughness properties, are representative of the design.
- Additional heat sources that may impact the thermal performance of the device are included (such as a power supply that is placed inside a luminaire enclosure or imbedded into a heat sink).

Once the representative prototype is built, and realistic use conditions are simulated, T_{case} may be measured to validate the design.

Special care is required when measuring the case temperature to ensure an accurate measurement. The following approach is recommended to minimize measurement errors for attaching the thermocouple to the case temperature measurement point of the LED Array:

- Use 36 gauge or smaller diameter K-type thermocouples.
- Ensure that the thermocouple is properly calibrated.
- Attach the thermocouple bead, or junction, to the area on top of the LED Array in the prescribed area (refer to the mechanical drawings section in the relevant Product Data Sheet). Alternatively, if maximum accuracy is not required in the measurement, the thermocouple can be mounted under the screw head of the LED Array mounting screw.
- Attach the thermocouple to the LED Array using an adhesive that has high thermal conductivity. To do this, first place the thermocouple bead on to the prescribed area. Temporarily secure the thermocouple using Kapton tape. Next, using the back of a thin diameter wood stick, such as a tooth pick or the wooden end of a cotton swab, press on the thermocouple bead, ensuring contact with the LED Array board. Lastly, apply a small amount of a fast curing, low viscosity, and thermally conductive adhesive around the base of the thermocouple bead. Allow the adhesive to cure. Remove as much of the wooden stick as possible.
- Note that it is critical that the entire thermocouple bead be secured tightly against the case. There should be no air gaps between the thermocouple tip and the case of the LED Array.

After turning on the LED Array, T_{case} will increase with time as the assembly heats up. Eventually, the lighting assembly should reach a steady state temperature. The time required to reach a steady state temperature depends on the time constant of the assembly, but is likely to be in the range of 45 minutes to an hour. Maintain the Bridgelux LED Array T_{case} at or below the maximum case temperatures listed in the Product Data Sheet to ensure functionality and reliability.

Design Resources

Included below is a partial list of some commercially available resources that may be used to design effective thermal management solutions for the use of Bridgelux LED Arrays. This is by no means an exhaustive and complete list, nor a recommended list of Bridgelux approved or qualified suppliers. It is the responsibility of the customer to fully qualify and validate any thermal management solution designed using the suppliers below.

The Heat Sink Extrusion Companies listed produce heat sink products that are suitable for use with Bridgelux LED Arrays. Many of these products can be procured quickly directly from the company or their distributor for expediting concept and prototype testing processes.

The Thermal Modeling Service Companies are intended for the use by companies in need of thermal and mechanical engineering assistance during their design, prototype or manufacturing processes. These companies offer services ranging from mechanical design to thermal simulation to manufacturing.

Heat Sink Extrusion Companies
www.aavidthermalloy.com
www.alutronic.de
http://ecd.coolermaster.com/
http://www.mmmetals.com/
http://www.hpt-first.com/en/cpzs.asp?bid=46
www.wakefield.com
www.nuventix.com
Thermal Modeling Service Companies
www.thermoanalytics.com
www.sunmantechnology.com
www.nextreme.com
www.arccoinc.com
www.norenproducts.com

Thermal Interface Material Company References

Manufacturer	Website
3M	www.3m.com
Aavid Thermalloy	www.aavidthermalloy.com
AOS	www.aosco.com
Arctic Silver	www.arcticsilver.com
Berquist	www.bergquistcompany.com
Chomerics	www.chomerics.com
Dow Corning	www.dowcorning.com
Intermark (USA) Inc.	www.intermark-usa.com
Laird Tech	www.lairdtech.com
Omega	www.omega.com
Shin-Etsu	www.shinetsu.co.jp/e/
Indium Corp. of America	www.indium.com

Heat Transfer Concepts

www.coolingzone.com
www.engineeringtoolbox.com
ww.hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

Disclaimer

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It is the responsibility of the customer to ensure that the design meets all necessary requirements and safety certifications for its intended use.

About Bridgelux

Bridgelux LED Arrays are developed, manufactured and marketed by Bridgelux, Inc. Bridgelux is a U.S. lighting company and leading developer of technologies and solutions that will transform the $40 billion global lighting industry into a $100 billion market opportunity. Based in Silicon Valley, Bridgelux is a pioneer in solid-state lighting (SSL), expanding the market for solid state lighting by driving down the cost of light through innovation. Bridgelux’s patented light source technology replaces traditional lighting technologies (such as incandescent, halogen and fluorescent lamps) with integrated, solid-state solutions, enabling lamp and luminaire manufacturers to develop high performance and energy-efficient white light products. The plug and play simplicity of the Bridgelux LED Arrays enable our customers to address the rapidly growing interior and exterior solid state lighting markets, including street lights, retail lighting, commercial lighting and consumer applications. With more than 250 patent applications filed or granted worldwide, Bridgelux is the only vertically integrated LED manufacturer that designs its solutions specifically for the lighting industry.

For more information about the company, please visit www.bridgelux.com