Thermal Management for Sharp's Mini-Zenigata LED Modules

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INTRODUCTION

Sharp's new smaller size, lower cost, high-power mini-Zenigata LED modules provide high luminous flux, efficiency, CRI, and reliability in a smaller 12 mm × 15 mm ceramic substrate. Sharp's mini-Zenigata LED is suitable for lighting applications such as down lights, architectural, accent, and HID replacements.

Next-generation lighting requires high luminous efficiencies, high reliability, and long life. The mini-Zenigata parts offer these and more. They save energy, reduce waste, contain no hazardous substances, and convert energy to light more efficiently when compared to typical light sources used today.

Effects of Heat

The majority of LED failure mechanisms are caused by excessive or long term high temperature. Elevated junction temperatures can cause a reduction in light output, degradation of chromaticity performance, and reliability.

In this application note, we will study ways to remove heat from LED designs to keep from exceeding the maximum rated LED junction temperature. We will review basic heat transfer modes, guidelines for heatsink design, thermal model, show some sample calculations, and highlight other considerations that must be taken into account.

HEAT TRANSFER MODES

Heat transfer is the transition of thermal energy from a hotter mass to a cooler mass. When an object is at a different temperature than its surroundings or another object, transfer of thermal energy occurs in such a way that the body and the surroundings attempt to reach thermal equilibrium.

There are three basic modes of heat transfer; conduction, convection, and radiation.

Conduction

Conduction is the transfer of heat by direct contact of particles of matter. Heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Metals are generally the best conductors of thermal energy. This is due to the large amount of free-moving electrons which are able to transfer thermal energy rapidly through the metal.

Convection

Convection is the transfer of thermal energy by the movement of molecules from one part of the material to another. As the fluid motion increases, the convective heat transfer increases. In our case, we will focus on the fluid material being the ambient air surrounding the heatsink.

Radiation

Radiation is the transfer of heat energy through empty space. No medium is necessary for radiation of heat to occur, since it is transferred via far infrared electromagnetic waves. Emissivity is the measure of how well a surface emits the radiated energy.

HEATSINK DESIGN GUIDELINES

Each heat transfer mode plays a role in transferring heat away from the LED junction to the ambient air. We will focus here on the convection mode of heat transfer, since for most designs it is how the majority of the heat is transferred from the LED package to the ambient air.

Ambient Temperature

The ambient temperature for the environment must be considered. This evaluation should include a realistic expectation of the air temperature surrounding the device, including the heating factor generated by the source if it is contained in the same space. Reducing the amount of heat to be removed can help reduce the size of the required heatsink.

Minimizing Thermal Interface Effects

Heat from the LED module must pass though various and differing materials before it can be removed via convection by the heatsink. Because air is a poor conductor of heat, eliminating air gaps between materials, even microscopic ones, can drastically improve the efficiency of the conduction heat transfer. Using thermal compounds will help improve the conduction heat transfer from the LED to the heatsink. It is important to use a thin layer of thermal compound, as excessive amounts can actually increase the thermal resistance. Thermal conductivity numbers for some common thermal compounds and pastes are listed in Table 1.

Table 1. Thermal Conductivity

THERMAL COMPOUND	THERMAL CONDUCTIVITY (W/M K)	THERMAL RESISTANCE (APPR.)
Cool Silver	10	0.0002
Arctic Alumina	4.0	0.01
Arctic Silver 5	5.0	0.06
Dow Corning TC-5022	4.0	0.06
Aavid Thermalloy Sil-Free 1020	0.79	0.36

Heatsink Material Selection

The material used should have a high thermal conductivity for best heat transfer. Typically, cost and thermal conductivity are closely related, so these tradeoffs, including size, should be considered. Thermal conductivity numbers for various materials are listed in Table 2.

Table 2. Heatsink Materials

MATERIAL	THERMAL CONDUCTIVITY
Air	0.025
Wood	0.04 - 0.4
Thermal grease	0.1 - 3.0
Aluminum	120 - 240
Gold	318
Copper	401
Silver	429

Minimize the Distance the Heat Travels

The goal is to get the heat out of the LED and into the ambient air. Minimizing the material thickness without creating a bottleneck will help accomplish this. Finned heatsinks are a common solution, but the heat must be able to easily move into the heatsink to be dissipated.

Surface Area

Convection transfer takes place at the surface of the heatsink. Therefore, heatsinks should be designed to maximize surface area. A larger surface area can be obtained by using fins, increasing the size of the heatsink itself or changing its orientation. When using fins to increase the surface area, consideration between a large number of fins and too many fins must be made. Too many fins can reduce effectiveness if they are very close and the heat from one fin is transferred into the adjacent fin.

Surface Finish

Heat transfer via radiation is greatly affected by the emissivity of the surface material. Emissivity is the ability of a surface to emit energy through radiation. In general, the duller and blacker a material is, the closer its emissivity is to 1.0 or perfect. The more reflective a material is, typically the lower its emissivity. When using a flat-plate heatsink that relies more on the radiation heat transfer mode, painting the surface can have a dramatic affect on getting the heat out. Table 3 details common metals and their emissivity.

Table 3. Heat Emissivity of Common Metals

SURFACE MATERIAL	EMISSIVITY COEFFICIENT (ε)
Aluminum (Highly Polished)	0.039 - 0.057
Aluminum (Anodized)	0.77
Aluminum (Rough)	0.07
Aluminum paint	0.27 - 0.67
Copper (Polished)	0.023 - 0.052
Copper	0.78
Stainless Steel (Weathered)	0.85
Stainless Steel (Polished)	0.075

THERMAL MODEL

The thermal model used in selecting a heatsink (Figure 1) is similar to those used in basic electronics. The heat source, temperature, and thermal resistance are similar to power dissipation, voltage, and resistance, respectively.

Single LED Model

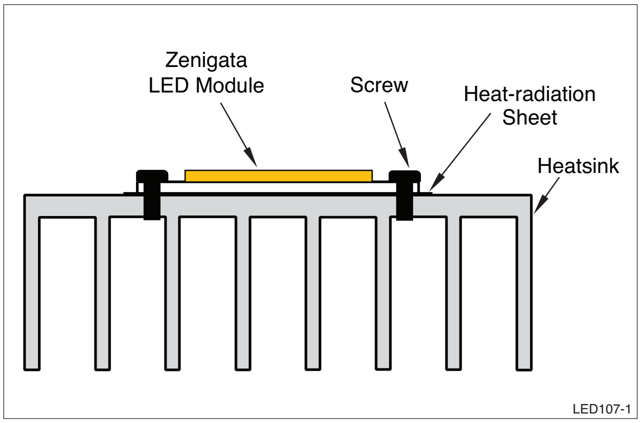
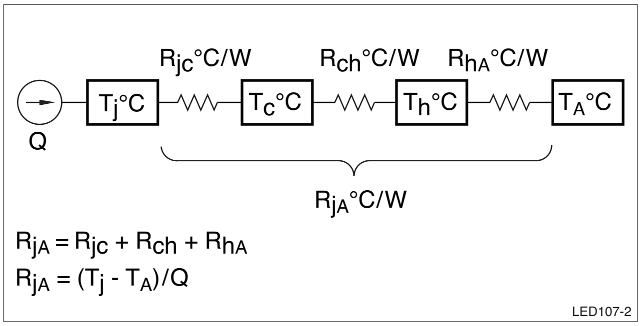


Figure 1. Typical Heatsink

Multiple LED Model

Using multiple LEDs on the same heatsink is a similar model to parallel resistors (Figure 3).



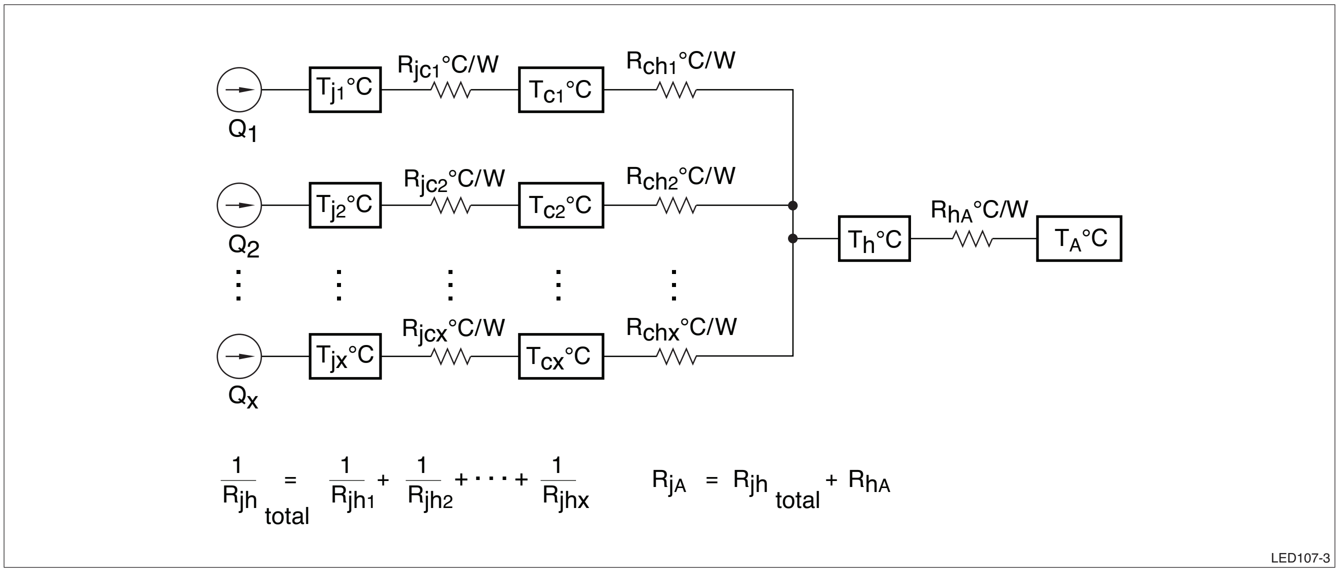
$$R_{jA} = R_{jc} + R_{ch} + R_{hA}$$

$$R_{jA} = (T_j - T_A)/Q$$

Figure 2. Single LED Thermal Model

Table 4. Variable Definitions for Figure 3

SYMBOL	DEFINITION
Q	Heat flowing from the LED junction
Tj	Junction temperature of the LED
Tc	Case temperature of the LED (°C)
Th	Heatsink temperature (°C)
Ta	Ambient air temperature (°C)
Rjc	Thermal resistance between the junction and case of the LED
Rch	Thermal resistance between the case and the heatsink
Rha	Thermal resistance of the heatsink



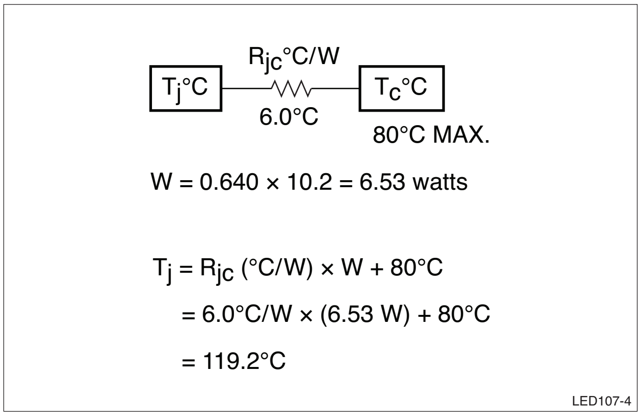
$$\frac{1}{R_{jh\,total}} = \frac{1}{R_{jh1}} + \frac{1}{R_{jh2}} + \cdots + \frac{1}{R_{jhx}} \qquad R_{jA} = R_{jh\,total} + R_{hA}$$

Figure 3. Multiple LED Thermal Model

DESIGN EXAMPLE

As an example, we will do a thermal design for the GW5BTF30K00 Mini-Zenigata. The GW5BTF30K00 will be driven at the recommended current of 640 mA. According to the Specification sheet, the case temperature is required to stay below 80°C when used at 640 mA. A maximum ambient air temperature of 40°C will be assumed for this example. This design will rely on natural convection and will not use forced air.

Maximum junction temperature can be calculated:



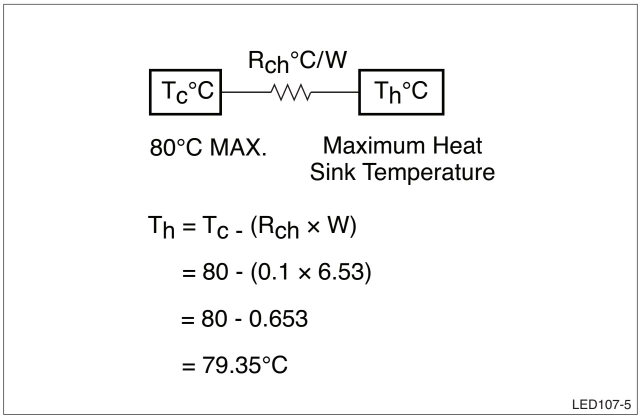
$$W = 0.640 \times 10.2 = 6.53 \text{ watts}$$

$$\begin{aligned} T_j &= R_{jc}\,(°\text{C/W}) \times W + 80°\text{C} \\ &= 6.0°\text{C/W} \times (6.53\text{ W}) + 80°\text{C} \\ &= 119.2°\text{C} \end{aligned}$$

Figure 4. Calculating Maximum Temperature

Calculate Th

Assume the thermal paste used in this example has a resistivity of 0.1 °C/W.

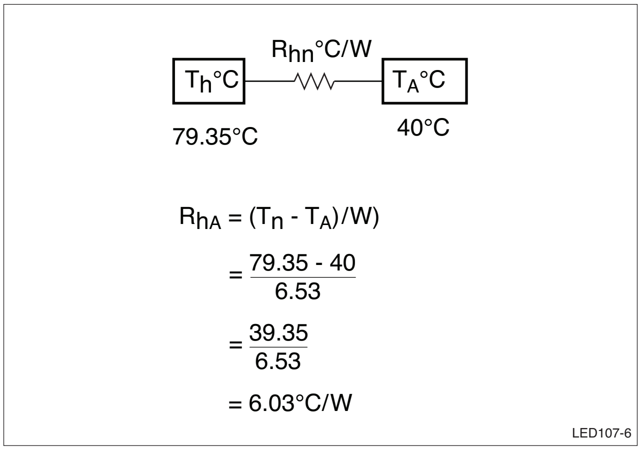


$$\begin{aligned} T_h &= T_c - (R_{ch} \times W) \\ &= 80 - (0.1 \times 6.53) \\ &= 80 - 0.653 \\ &= 79.35°\text{C} \end{aligned}$$

Figure 5. Calculating Th

Calculate Rha

This is the maximum thermal resistance required for the heatsink.



$$\begin{aligned} R_{hA} &= (T_n - T_A)/W) \\ &= \frac{79.35 - 40}{6.53} \\ &= \frac{39.35}{6.53} \\ &= 6.03°\text{C/W} \end{aligned}$$

Figure 6. Calculating Rha

Selecting the Heatsink

Many times the designer has a hard time finding a starting point when selecting a heatsink. Here are formulas that will act as a starting point for selecting or designing the heatsink. For this application we will assume the material to be used is the popular choice of anodized aluminum.

The final size and shape of the heatsink will depend on many variables, such as orientation, fin size, ambient air temp, air flow speed and direction, proximity of other heat sources and the availability of lower temperature air to circulate through the enclosure.

The final heatsink choice depends on many variables, including the temperature requirements for the end application (such as maximum ambient and enclosure temperature), the material of the heatsink, the surface characteristics of the heatsink, and the physical constraints for the application.

APPROXIMATE HEATSINK THERMAL RESISTIVITY

Where A = surface area in cm^2:

$$R_{hA} \cong 50/(\sqrt{A})$$

Re-arranged to find surface area:

$$A = \left(\frac{50}{R_{hA}}\right)^2$$

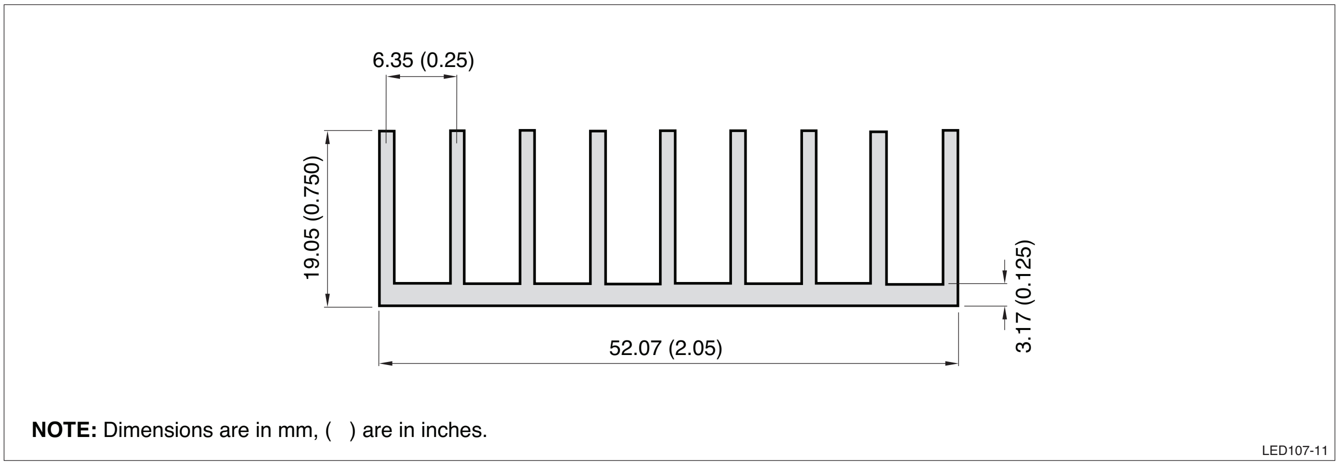
Calculate surface area for our example design:

$$A = \left(\frac{50}{R_{hA}}\right)^2 68.8cm^2 = 10.67in^2$$

As a practical example using part number 65250 at a length of 3" from the Avvid Thermalloy web site.

Table 5. Avid Thermalloy (Part Number 65250)

FORM	PART NO.	THERMAL RESISTANCE (°C AT 3-IN LENGTH)	WIDTH (IN)	HEIGHT (IN)	SURFACE AREA IN^2/IN
	65250	4.53	2.05	0.75	15.4



NOTE: Dimensions are in mm, ( ) are in inches.

Figure 7. Heatsunk Mechanical Drawing

Next we check the natural convection performance graphs to verify the temperature rise of the selected heatsink will be less than the calculated temperature difference of 39.35°C.

Figure 8 shows 37°C, at 6.53 watts.

After the initial heatsink is selected, actual measurements need to be made by testing under the required specifications. The case temperature can then be measured and the junction temperature calculations can be used to verify the GW5BTF30K00 specification is not being exceeded.

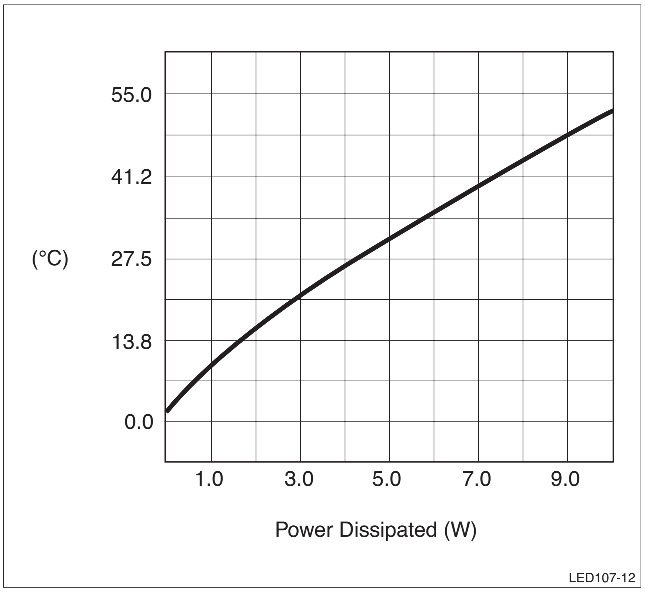


Figure 8. Temperature Rise

Other considerations

Before the final heatsink is selected (or designed in), many other things should be considered. In some cases, the preceeding sections of this Application Note will be a good starting point, but only actual product testing will determine the final proper heatsink specifications.

ORIENTATION

The orientation of the heatsink, especially when using fins, can have a large effect on thermal transfer to the surrounding air. Consider a finned heatsink of the same size used in three different orientations: vertical, horizontal, and flat.

Vertical

Typically, a heatsink oriented with the fins in a vertical position is the most effective orientation. This allows both sides to act as the effective surface area to release heat. It allows for natural convection to be maximized with heat rising and flowing through the channels created by the fins. This is also the most effective position for a flat plate heatsink.

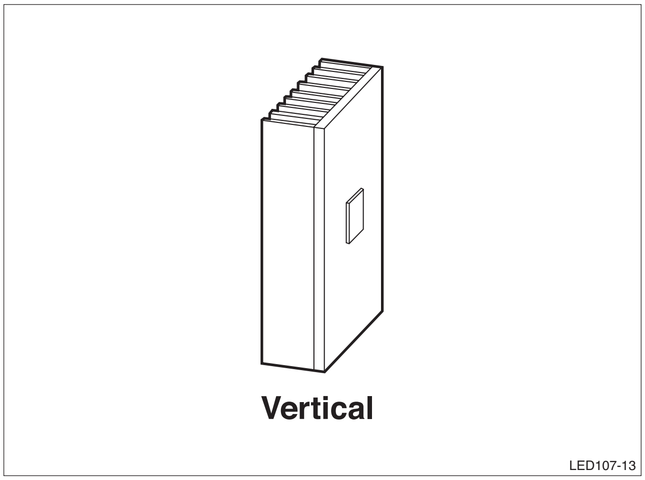


Figure 9. Vertical Orientation Example

Horizontal

The horizontal orientation impedes maximum natural convection and therefore is approximately 80% efficient.

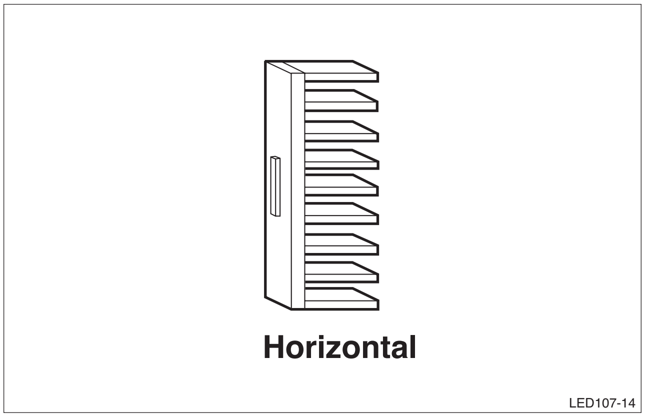


Figure 10. Horizontal Example

Flat

The flat orientation with the fins on the top and heat source on the bottom is approximately 60% effective. In addition to reduced natural convection, the bottom of the heatsink is no longer useful as a thermally radiant surface due to it not being in direct contact with the lower temperature air.

The less effective the heatsink is for convective heat transfer, the greater the need to utilize any available conductive and radiant heat transfer. Reducing the materials emissivity is an important factor in increasing radiant emission. Increasing the volume of the heatsink can improve its conductive performance by moving the heat further from the source.

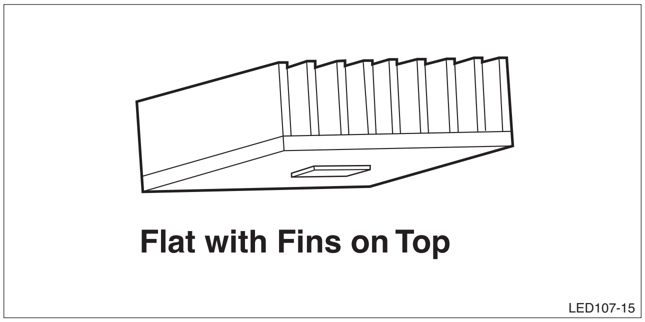


Figure 11. Flat Example

LENGTH AND WIDTH

The average performance of a typical heatsink is proportional to the width of the heatsink in the direction perpendicular to the airflow and approximately proportional to the square root of the fin length in the direction parallel to the flow. Therefore, an increase in the width of a heatsink by a factor of two would increase the heat dissipation capability by a factor of two, whereas an increase in the length of the heatsink by a factor of two would only increase the heat dissipation capability by a factor of 1.4. Therefore, if the choice is practical, it is beneficial to increase the width of a heatsink rather than the length of the heatsink.

AIRFLOW

As previously mentioned, one of the most important ways to get heat out of the LED is to transfer it efficiently to the heatsink and then into the surrounding air. If constrictions limit the size of the heatsink or the optimal design is not possible, then forced air may be needed. Forced air, by the means of fans or blowers, allows for a way to reduce Rha and increase the heatsink's effectiveness.

SPREADING RESISTANCE

We have assumed until now that the heatsink surface where the LED is attached is at a consistent temperature. While this is a good approximation as a starting point, in many cases the heat source, the LED in this case, is significantly smaller than the base area of the heatsink. When this is true, there is another thermal resistance we have not addressed. Spreading resistance is created when the source is smaller than the base and such a factor can increase the thermal resistance of the heatsink by 5 to 30%.

ALTITUDE

Another design criterion to consider in the selection of a heatsink is the altitude effect. Indoor air pressure changes with the altitude and it is necessary to derate the heat-sink performance due to the lower air density caused by the lower air pressure at higher altitude. Although the actual effect is not linear, a good estimate is to derate the performance by 10% for every 5000 feet of elevation above sea level.

REFERENCES

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6. The Engineering ToolBox, "Thermodynamics, The effects of work, heat and energy on a system", www.engineeringtoolbox.com/thermodynamics-t_36.html

NOTICE: The formulas and diagrams given in this application note should be considered a guide for thermal management of Sharp's mini-Zenigata products. Thermal design and heatsinking depends on numerous parameters that cannot be predetermined; therefore results cannot be guaranteed. Testing should be done on the final product to ensure the LED is maintained at or below its maximum temperature as indicated in the Specifications.

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