GE
Lighting

Application Notes
Thermal

# Vio® High Power White LED

The **look** that **lasts**.™

# Thermal Management



imagination at work

## T.1 Heat Transfer Basics

Heat is a form of energy that is related to vibration at the atomic/molecular level, and is a common byproduct of many processes. Since LEDs and other electronic components are sensitive to heat, it's important to remove any excess heat that can adversely impact performance. When traditional light sources are used, like incandescent, only a small portion of the electrical energy is actually converted to useful light. The majority of the energy becomes heat that must be removed from the light source. Heat is transferred in one of three methods: By conduction, convection or radiation.

**Conduction** is the method in which heat energy is transferred between two objects that are in contact with each other.

**Convection** is the method in which heat is transferred through the movement of a gas or liquid from an area of higher temperature to one of lower temperature. Hot air rising is an example of natural or free convection. Using a fan or pump is called forced convection.

**Radiation** is the method in which heat is transferred through the emission of energy in the infrared region.

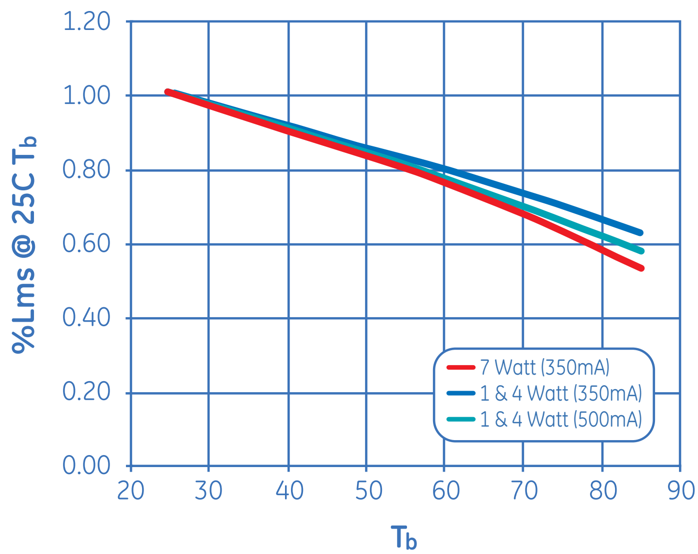
Current lighting systems, like incandescent lamps, transfer a majority of their heat by radiation. However, LEDs are quite different in that they transfer most of their heat through conduction. When the heat from the LED is dissipated into the fixture by conduction, convection can be used to transfer the heat into the surrounding air. It is because of this conductive heat path that LED systems must be designed differently than other traditional lighting systems for them to work properly.

## T.2 Thermal Characteristics

Electrical/Optical characteristics of LEDs depend on the operating temperature. Changes in the operating temperature affect the nature of charge transport in LED devices leading to various changes in the electro/optical characteristics, such as forward voltage, lumen output, and color temperature, etc.

## T.2a Impact on optical performance

As previously stated, the thermal performance of a system can significantly change the optical characteristics of an LED. This includes both the light output and color. Figure T.1 illustrates how board temperature of the Vio device will affect the relative light output.



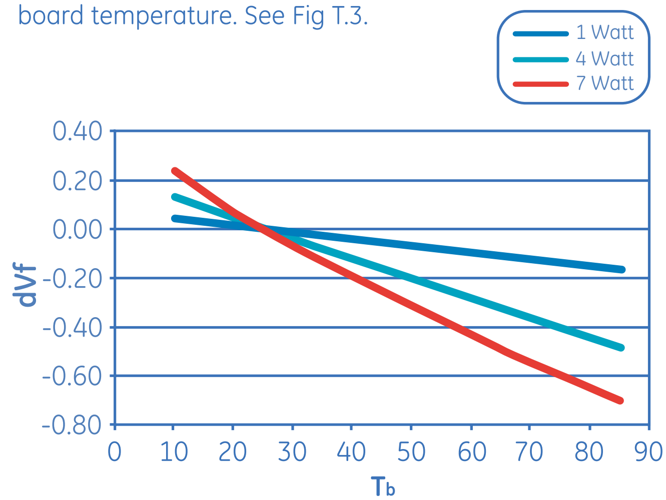

Data collected under steady operation. Results may vary in applications.

**Fig T.1** Board Temperature vs. Relative Light Output

**Note:** Further information on the interaction between temperature and light output can be found in the **Vio Optical Application**.

## T.2b Thermal impact on electrical characteristics

The forward voltage of the Vio device will change with board temperature. See Fig T.3.




5 second pulse @ 350mA

**Fig T.3** Voltage Change with Board Temperature

## T.3 Basic Thermal Management

The following section will discuss the thermal design of the Vio LED and explain how to construct a useful thermal model. The thermal characteristics of the Vio device, and the operating conditions that affect an LED system design are critical to achieving the desired performance.

## T.3a Vio Thermal Design

The Vio LED is a chip-on-board (COB) design that provides improved thermal performance by reducing thermal interfaces in the system. Incorporating a thermocouple measurement point on the top of the metal core printed circuit board (MCPCB) offers a useful aid that simplifies both the design and validation process. Figure T.4 illustrates the Tb measurement point.


**Fig T.4** Vio Device with $T_b$ Point

The Vio device requires external heat sinking. It is recommended that a thermally conductive material be placed between the metal core printed circuit board and heat sink. See Fig T.5.

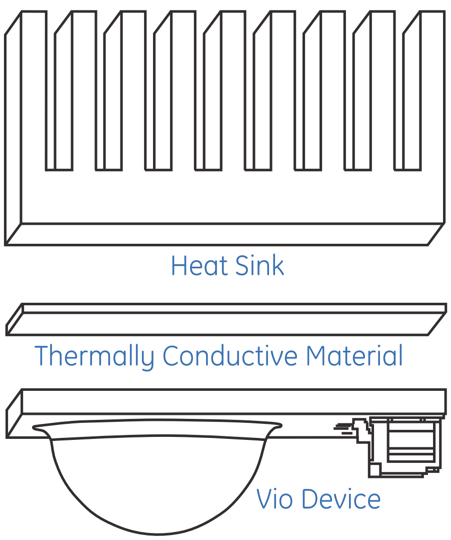



**Fig T.5** Example of Material Stack-up in Thermal Design

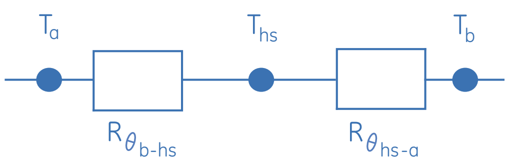



**Fig T.5** Series Resistance Thermal Diagram

## T.3b Thermal Model

As with any thermal management design, the primary mathematical tool used to explain the impedance between various surfaces is thermal resistance, Eq.1 Thermal resistance is the ratio of temperature difference to the power consumption across one or more surfaces. Eq.1, represents a basic definition for the thermal resistance between two surfaces:

$$R_{\theta\, surface1\ -\ surface2} = \frac{\triangle T_{surface1\ -\ surface2}}{P_{total\ power\ through\ material}}$$

**Eq.1** Definition of Thermal Resistance

Fig. T.6, illustrates a simplified series-thermal resistance circuit model. The circular nodes represent the temperatures at each layer, while the rectangular boxes represent the thermal resistance through a given layer.

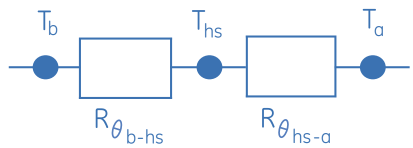



**Fig T.6** Series-Thermal Resistance Circuit

Using the above circuit, it is possible to calculate the total thermal resistance of a system and begin to understand how ambient and heat sinking conditions will affect the performance of the Vio device. Equation, Eq.2, represents the total thermal resistance for a given system:

$$R_{\theta b\text{-}a} = R_{\theta b\text{-}hs} + R_{\theta hs\text{-}a}$$

**Eq.2** Thermal Resistance Model

By modifying equation Eq.1 and solving for $T_{board}$, equations Eq.3 and Eq.4 illustrate how to calculate for the board temperature of a given system.

$$\left(R_{\theta\, surface1\ -\ surface2}\right) * \left(P_{total\ power\ through\ material}\right) = \left(T_{surface1\ -\ surface2}\right) \quad \textbf{Eq.3}$$

$$T_b = \left(R_{\theta b\text{-}a}\right) * \left(P_{total\ power\ through\ the\ system}\right) + T_a \quad \textbf{Eq.4}$$

Applying Fig T.6 and equation Eq.4 in an example, one (1) Vio 4W LED is mounted to a heatsink. Assuming the total thermal resistance from board to ambient to be 12°C/W (1°C/W $R_{\theta b\text{-}hs}$ + 11°C/W $R_{\theta hs\text{-}a}$), the ambient conditions to be 25°C, and the forward voltage of the device to be 10.2V at 0.350A, the following calculations can assist a system designer:

$$T_b = (12°C/W) * (10.2V * 0.350A) + 25°C$$

$$T_b = 67.8°C$$

**Note:** The 1°C/W $R_{\theta b\text{-}hs}$ resistance is an estimated value. Results will vary based on the attachment method used. It is recommended that a thermally conductive adhesive or paste be used.

The following figure, Fig T.7, illustrates a system that incorporates two (2) or more Vio LED devices:

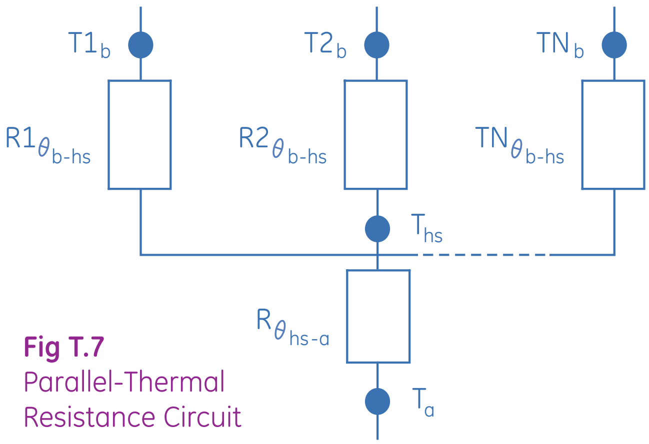



**Fig T.7**
Parallel-Thermal Resistance Circuit

In Fig T.7, the total thermal resistance between a given number (N) of LED boards and a heat sink can be calculated using the following equation, Eq.5:

$$\frac{1}{\text{Vio Array } R_{\theta b\text{-}hs}} = \frac{1}{R1_{\theta b\text{-}hs}} + \frac{1}{R2_{\theta b\text{-}hs}} + \frac{1}{RN_{\theta b\text{-}hs}} \qquad \textbf{Eq.5}$$

As in the previous example, assuming the $R_{\theta}$b-hs for each Vio device to be 1°C/W, the total thermal resistance between the board and heat sink for a three (3) Vio LED design is calculated using the following equations:

$$\frac{1}{\text{Vio Array } R_{\theta b\text{-}hs}} = \frac{1}{1°C/W} + \frac{1}{1°C/W} + \frac{1}{1°C/W}$$

$$\text{Vio Array } R_{\theta b\text{-}hs} = 1/3° \ C/W$$

## T.4 Heat Sink Design Considerations

The following section describes basic design considerations for heat sinks. Understanding the thermodynamics of a design, and how to best dissipate heat from the Vio LED, will help achieve the desired performance characteristics of the system.

## T.4a Operating Temperature Range

It is important to understand the minimum and maximum operating conditions of the LED system. The heat sink should be designed to manage system thermals at the maximum ambient temperature where the system could operate.

Examining equation Eq.4, $T_a$ represents the ambient condition where an LED system will operate. In order to calculate the required heat sink thermal resistance for a given LED power level, one must estimate the board temperature ($T_b$) and maximum ambient temperature ($T_a$) for the intended application (as indicated in equation Eq.6). The following sections will explain how to use this value in a system design

$$R_{\theta b\text{-}a} = \frac{T_b - T_a}{P_{\text{total power through the system}}} \qquad \textbf{Eq.6}$$

## T.4b Surface Area Requirements

The surface area of a heat sink is the critical dimension for removing heat from the Vio LED. It is the thermal resistance value that quantifies this effect. There is an inverse relationship between the thermal resistance and the ability of the heat sink to move heat. A high thermal resistance yields a lower capacity to remove heat and a low resistance yields a high capacity.

Airflow is another factor affecting thermal resistance. The more airflow a heat sink is exposed to, the lower the thermal resistance. The following chart, Figure T.8, illustrates this effect with two (2) natural convection curves. The blue line represents a design with adequate airflow, while the red line illustrates the thermal resistance of heat sinks under restricted airflow. Note that these values are estimates.

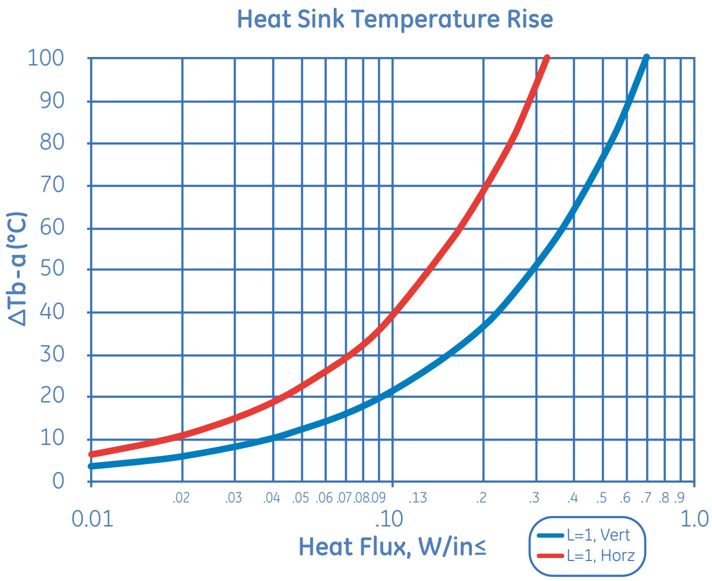



**Fig T.8** Heat Sink Natural Convection Curves

To illustrate this effect, the following example will be considered:

- One (1) Vio 4W LED (10V * 0.350A = 3.5W)
- Max ambient temperature = 35°C
- Design limit for board temperature = 60°C

Using equation Eq.6:

$$R_{\theta b\text{-}a} = \frac{60°C - 35°C}{3.5W}$$

$$R_{\theta b\text{-}a} = 7.14°\ C/W$$

Based on these calculations, a 25°C rise from board to ambient while under 3.5 watts of energy requires a 7.14° C/W heat sink design. Fig T.9, demonstrates how to estimate the required heat sink surface area for this application.

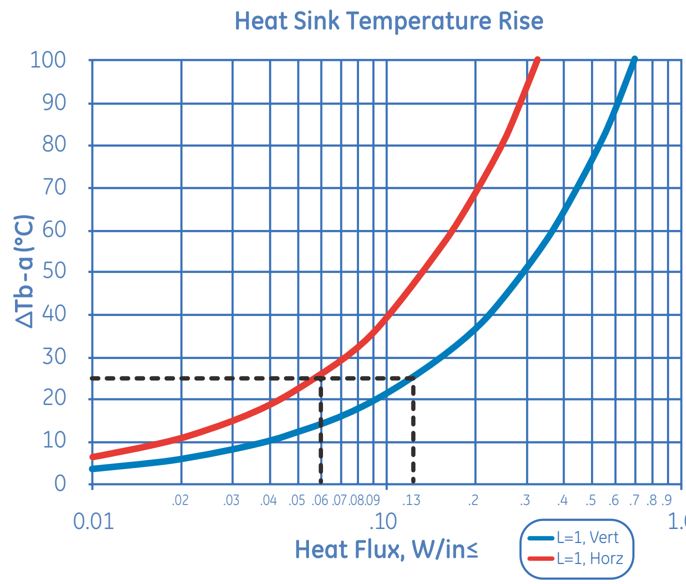



**Fig T.9** Heat sink natural convection curves highlighting a 25°C delta

The 25°C change in temperature corresponds to a heat flux of 0.06 W/in$^2$ in the heat sink design with restricted airflow, while the same temperature change for the design with adequate airflow generates a heat flux of 0.13 W/in$^2$. These heat flux values correspond to surface areas of 58in$^2$ and 27in$^2$ respectively, and illustrate the impact the application environment will have on the design. The following equations demonstrate how to calculate these values:

$$Required\ Surface\ Area = \frac{3.5W}{0.06\ W/in^2} = 58in^2$$

$$Required\ Surface\ Area = \frac{3.5W}{0.13\ W/in^2} = 27in^2$$

## T.4c Heat Sink Design

Ensuring adequate cooling is critical for any application. The following figure, Fig T.10, illustrates a standard heat sink design that delivers an $R_\theta$ of 7.2°C/W with a 3-inch length. This design enables adequate cooling for the example described in section T.4b.

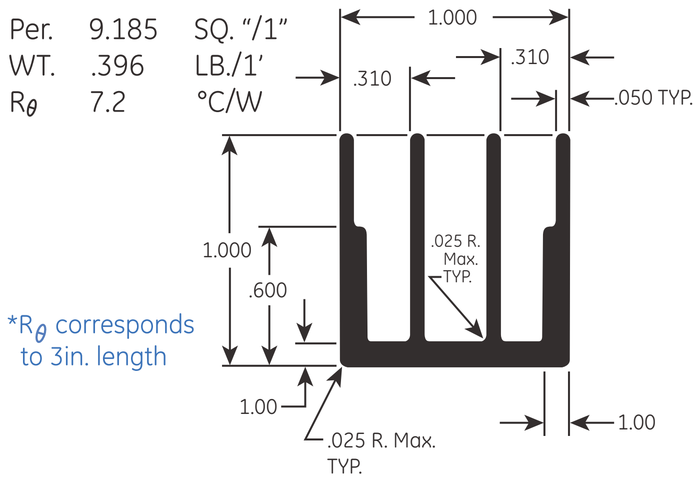



**Fig T.10** Example of 7.2°C/W Heat Sink

Please note, there are a number of manufacturers that can provide both off-the-shelf and custom heat sink solutions to fit a variety of needs. To locate suppliers, go online and search for "heat sink", "thermal management" or "heat sink solutions".

## T.5 Maximum Ratings/Life Claims

The Vio LED device is rated to operate at or below a board temperature of 85°C to achieve a 50,000-hour rated life at 70% lumen maintenance at specified drive currents.

E319084

For additional product and application information, please consult GE's Website: **www.gelighting.com**