Thermal Management of Avago High Power Plug and Play LED Module

Application Note 5316

1. Introduction

Avago High Power LED Plug and Play modules are high performance, extraordinarily user friendly high brightness light sources that give a new perception towards the packaging of LED light source. Its slim and compact footprint makes it easy for horizontal and vertical stacking. Assembly of the light source is extremely simple with the plug and play mechanical mounting and electrical connector, reducing the need of assembly machine investment and tight process control that is inevitable for conventional LED packages.

The package utilizes silicone encapsulation for superior lumen maintenance over conventional epoxy encapsulated LED products. In order to maximize its potential, users are required to carefully plan the thermal management of the system including appropriate heat sink selection and thermal interface material.

2. Package construction

Avago ADJD-Mxxx High Power LED Module utilizes a patented design to dissipate heat efficiently using the whole package body. The array of LED dice are attached directly on a metal core PCB (MCPCB) and covered with a metal reflector body. This direct mounting provides good heat dissipation to the external of the package, enabling it to be driven at higher power with low thermal resistance. Figure 1 below showed the construction of the package.

These LED modules must be properly mounted on an external heat sink prior to light up. Although the package is fully made of metal but it shall not be used as heat sink. Instead, the MCPCB is designed for efficient heat transfer from the LED modules to external heat sink. Driving the modules without appropriate heat sinking capability will cause permanent damage to the LED. Later part of this application note will show the method of selecting an appropriate heat sink that meets the thermal requirement.

These modules also come with tapped holes that can be used as mechanical mounting to attach to external heat sink. This enables pressure to be applied on the attachment and ensure good contact with the thermal interface material.

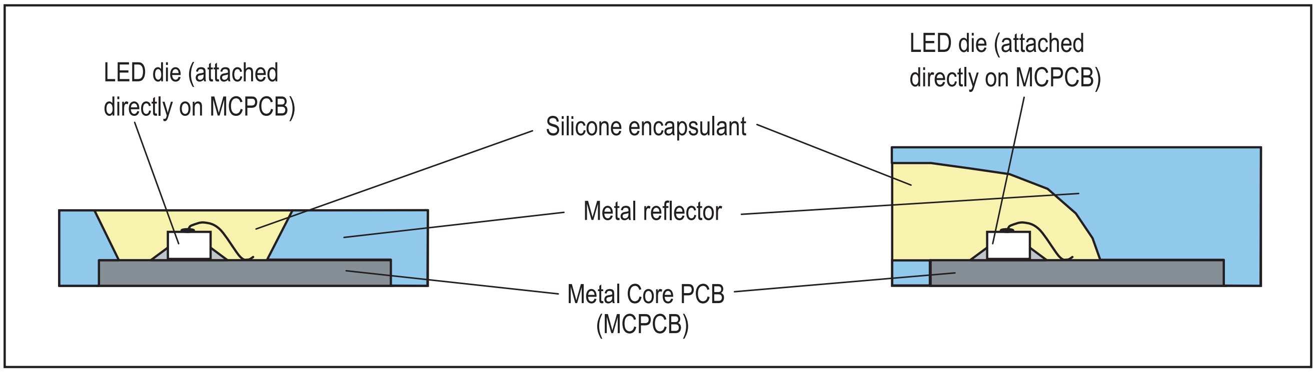

Figure 1. Package construction

3. Thermal resistance model

There are many methods to design a thermal management system. Comprehensive ones include a detail thermal simulation with highly sophisticated simulation software such as Floterm. However, for general estimation of heat sink requirement, a more simple method can be adopted, which is the thermal resistance model.

Thermal resistance, R_θ is defined as the temperatures increment between 2 locations a long the heat path when 1 watt of power is being dissipated between the locations. In general, the formula of thermal resistance between location x and location y is as shown below:

$$R_{\theta x\text{-}y} = (T_x - T_y) / P_d \ [°C/W] \qquad \{1\}$$

Where

T_x = temperature at location x

T_y = temperature at location y

P_d = total heat dissipation

Assumption made in using the thermal resistance model is that the total heat dissipation is equivalent to the total electrical power applied to the LED. In actual case, total heat dissipation is lower than total electrical power as certain amount of electrical power has been converted to emission of photons (both visible and non-visible). Therefore,

$$P_d = \text{forward current x forward voltage}$$
$$= I_F \text{ x } V_F \ [W]$$

Applying this model to Avago High Power Plug and Play LED module, the thermal resistance between the LED die junction and the MCPCB can be expressed as:

$$R_{\theta junction - MCPCB} = R_{\theta J\text{-}B}$$

= (temperature difference between the LED junction and MCPCB) / total power dissipation

$$= (T_J - T_B) / P_d \ [°C/W] \qquad \{2\}$$

where

T_J = temperature of the LED die junction

T_B = temperature of the MCPCB at the bottom of the package

The thermal resistance $R_{\theta J\text{-}B}$ is a property of the LED and can be found in the product datasheet. The typical $R_{\theta J\text{-}B}$ for ADJD-MJ50 is 2°C/W. This indicates that by supplying the LED with 1W of electrical power, the T_J will increase by 2°C compare to T_B.

Another thermal resistance that is commonly used in the calculation is the thermal resistance between the LED die junction and the ambient environment. It can be expressed as follow:

$$R_{\theta junction - ambient} = R_{\theta J\text{-}A}$$
$$= (T_J - T_A) / P_d \ [°C/W] \qquad \{3\}$$

Figure 2 shows the general construction of the thermal resistance model of the entire thermal management system that uses Avago High Power LED module.

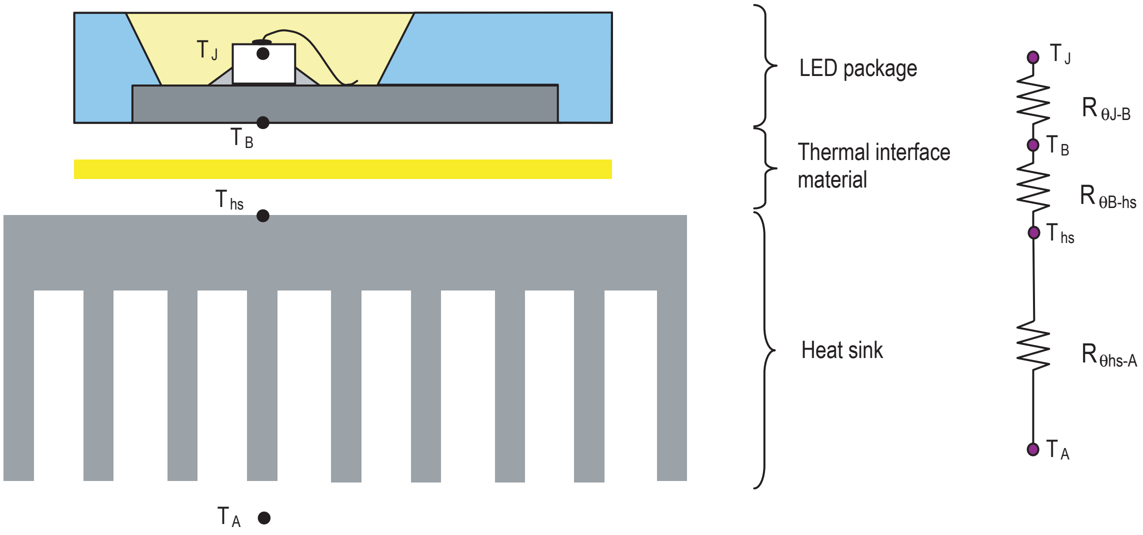

Figure 2. Thermal resistance model

As discussed, thermal resistance $R_{\theta J\text{-}B}$ denotes the capability of the LED package to transfer heat from the LED junction to the MCPCB. Mean while, thermal resistance $R_{\theta B\text{-}hs}$ is referring to the performance of thermal interface material that comes in between the LED module and the heat sink. Further details of thermal interface material will be covered in later section of the application note. Lastly, $R_{\theta hs\text{-}A}$ is the capability of a heat sink to dissipate heat to the ambient environment through convection and radiation.

Another assumption made in using the thermal resistance model is that all heat generated at the LED junction are transferred through a single major heat conduction path. Heat transfers through minor paths are neglected as they are considerably smaller.

As shown in Figure 2, the thermal resistances through the heat transfer path resemble several resistors connected in series. As such, the total thermal resistance of the system can be derived by arithmetically adding all the thermal resistances in series.

$$R_{\theta J\text{-}A} = R_{\theta J\text{-}B} + R_{\theta B\text{-}hs} + R_{\theta hs\text{-}A} \qquad \{4\}$$

The thermal resistance model above can be used to determine the heat sink requirement to achieve the design limit as well as estimating the actual LED junction temperature for a system.

4. Heat sink

There are many types of heat sink available in the market. Depending on the requirement, they can come in a wide range of shapes, types, materials and price. Most commonly used heat sink is the aluminum extrusion type, with black anodized finishing. Various parameters of a heat sink such as thermal resistance characteristic versus dissipated power and air flow, emissivity, weight and dimensions can be obtained from the heat sink supplier. These information are useful for user to consider when selecting a heat sink that meets the thermal requirement.

It is critical to understand that there can never be a single value of thermal resistance assigned to a particular heat sink. In fact, it varies with the external cooling condition. Air flow condition need to be determined by the user prior to selecting a heat sink as the performance of the heat sink is very much affected by this. Air flow can be classified as natural convection or forced convection. Natural convection occurs when there is no externally induced flow and heat transfer relies solely on the free convection flow of the surrounding air. On the other hand, forced convection occurs when air flow is induced by force through mechanical means, such as a fan or blower. Figure 3 below shows an example of the thermal resistance characteristic towards change of air flow velocity. As for natural convection, the thermal resistance is dependent of the total dissipated power as shown in Figure 4.

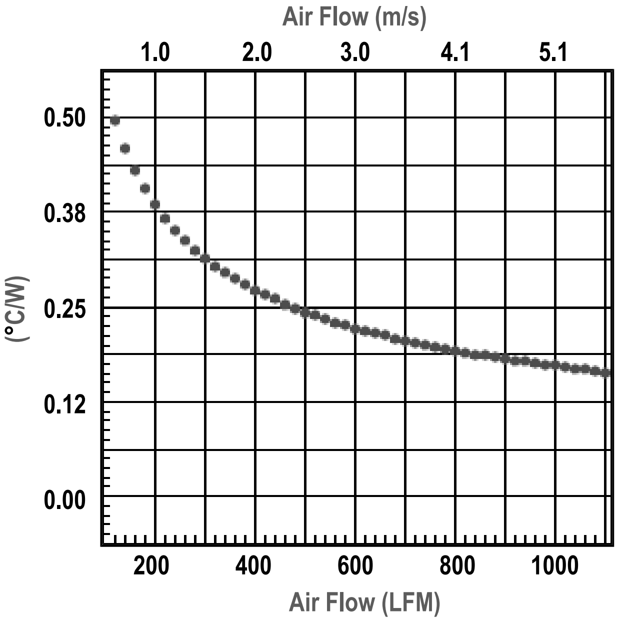

Figure 3. Heat sink thermal resistance at various air flow velocity (Aavid Thermalloy P/N 74925).

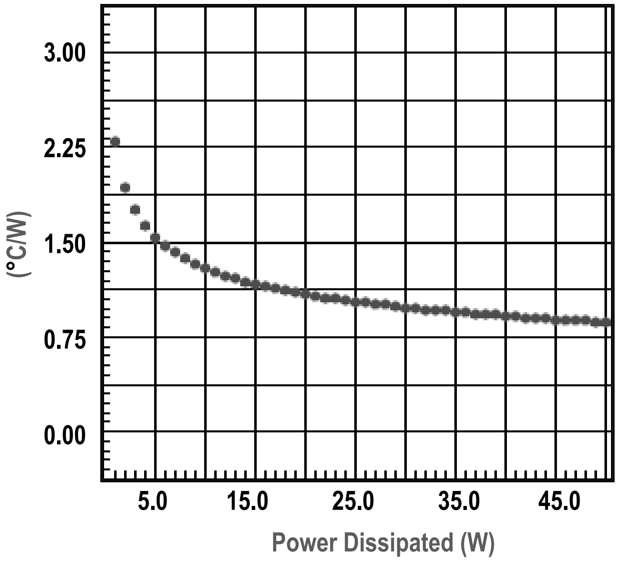

Figure 4. Heat sink thermal resistance versus dissipated power (Aavid Thermalloy P/N 74925).

5. Thermal interface material

One of the problems with transferring heat between the LED module and the heat sink is the thermal interface. Neither the heat sink nor the MCPCB of the LED module has a completely smooth surface. Microscopic peaks and valleys across the mating surfaces create air pockets that leads to poor heat transfer as air is an extremely poor thermal conductor (0.026W/mK). To help alleviate the problem, thermal interface material (TIM) is used to fill in the gaps in order to reduce the contact resistance between the LED module and the heat sink.

Manufacturers generally specify the performance of their TIM using either thermal impedance or thermal conductivity. Thermal impedance is the amount of heat absorbed by the TIM rather than transferred through it to the other surface. As a result, the lower the thermal impedance, the more effective it will be at transferring heat. With its unit in [°C-in^2/W], the thermal resistance of the TIM used in a system can be estimated by dividing the thermal impedance with the contact area of the TIM. In contrast to thermal impedance, thermal conductivity (K) shows the amount of heat energy that can be transferred through the compound. Therefore, more effective TIM will have a high thermal conductivity rating. Thermal resistance can be derived from thermal conductivity through formula below:

Interface thermal resistance (°C/W) =>

$$= \frac{\text{interface thickness (mm) x 1000}}{\text{thermal conductivity (W/mK) x contact area (mm}^2\text{)}} \quad \{5\}$$

Calculation above can only provide an estimation of the TIM performance, but in actual case its thermal resistance is very much affected by factors such as the mounting pressure and bond line thickness (BLT). Details information regarding the effect of these factors can be obtained from the manufacturers. Generally thinner BTL gives higher effectiveness of the compound.

There are several types of TIM available in the market, such as thermal tape, thermal pads, thermal grease and thermal epoxy. The pros and cons of these TIM are shared in Table 1 below.

Table 1.

Type	Characteristic	Advantages	Disadvantages
Thermal tape	• Very similar to double sided adhesive tapes.	• Easy to attach. • No mounting clip or bracket needed.	• Poorest heat transfer performance of all (~0.5°C-5in^2/W) • Limited gap filling ability.
Thermal grease	• Greasy characteristic. • Viscous. • Generally silicone based.	• Low thermal impedance (0.05~0.005°C-in^2/W). • Easily conforms to surface irregularities. • No curing needed. • Reusable. • No delamination concern. • Thin BLT with minimal pressure.	• Can be messy to handle. • Susceptible to grease pump-out. • Requires additional mounting clip or bracket.
Thermal pad / phase change material	• Solid at room temperature and soften at ~50°C to fill surface irregularities. • Normally pre-attached on the heat sink.	• Easy to handle at room temperature. • Easily conforms to surface irregularities. • No curing needed. • Reusable. • No delamination concern. • No pump-out	• Requires additional mounting clip or bracket. • Thermal cycle or subsequent phase change may introduce voids that cannot be refilled. • Thermal impedance slightly higher than thermal grease.
Thermal epoxy	• Epoxy based.	• Low thermal impedance (similar to thermal grease). • Easily conforms to surface irregularities before curing. • No mounting clip or bracket needed.	• Curing process is needed. • Susceptible to delamination due to CTE mismatch induced stress. • Non-reworkable.

Thermal grease is highly recommended to be used with Avago High Power LED Module. Tapped holes available on the package can be used to fasten the module to the heat sink, thus eliminating the need for additional mounting.

6. Example

Two calculation examples are given in this section for better understanding of the aforementioned information. The intention of the first example is to determine the heat sink requirement based on listed criteria. The second example will demonstrate the method to determine the junction temperature based on selected materials.

6.1 Example 1

LED Module part number = ADJD-MJ50

LED junction temperature, $T_J = 120°C$
(obtained from datasheet)

LED Module thermal resistance, $R_{\theta J\text{-}B} = 2°C/W$
(obtained from datasheet)

Power dissipation, $P_d = 24W$
(intended driving current x forward voltage)

Maximum operating ambient temperature, $T_A = 40°C$
(based on user's application)

Thermal interface material: Thermal grease with 0.01°C-in^2/W

Contact area = 3.86 in x 0.59 in
= 2.28 in^2

Interface thickness = 0.002 in

Applying formula {5},

$R_{\theta B\text{-}hs}$ = 0.002 / (0.01 x 2.28)
= 0.088°C/W

By rearranging formula {4} and substituting formula {3},

$R_{\theta hs\text{-}A} = (T_J - T_A) / P_d - R_{\theta J\text{-}B} - R_{\theta B\text{-}hs}$
= (120 – 40) / 24 – 2 – 0.088
= 1.25°C/W

The result shows that a heat sink with thermal resistance similar or lower than 1.25°C/W is required.

6.2 Example 2

LED Module part number = ADJD-DW00

LED Module thermal resistance, $R_{\theta J\text{-}B} = 9°C/W$
(obtained from datasheet)

Power dissipation, $P_d = 3.5W$
(intended driving current x forward voltage)

Operating ambient temperature, $T_A = 55°C$

Thermal interface material: Thermal grease with 0.01°C-in^2/W

$R_{\theta B\text{-}hs} = 0.088°C/W$

Selected heat sink thermal resistance, $R_{\theta hs\text{-}A} = 2°C/W$

By rearranging formula {4} and substituting formula {3},

$T_J = (R_{\theta J\text{-}B} + R_{\theta B\text{-}hs} + R_{\theta hs\text{-}A}) \times P_d + T_A$
= (9 + 0.088 + 2) x 3.5 + 55
= 93.8°C