Thermal Management of Avago Mono PLCC LED

Application Note 5373

Introduction

Avago SMD LED that provides high luminous intensity output has common semiconductor component character with maximum permissible junction temperature in the range of 110 – 125° C. This means that the temperature of the LED die inside must not exceed this value when exposed to the expected operating conditions. In order to maximize the performance of the product, system level thermal management must ensure the recommended operating range of the product is not exceeded.

This application note provides guidelines on how to determine heat sinking requirements within an applications constraints and user requirements.

Heat Sink Requirements

Apart from software simulation, an easy way to determine the heat sink requirement is by using the thermal resistance model.

Introduction to thermal resistance

Thermal resistance, Rθ, is defined as the temperatures increment between two locations along the heat path when 1 watt of heat is being dissipated. In general, the formula of thermal resistance between location x and location y is:

$$R\theta_{x\text{-}y} = (Tx - Ty) / Pd \ [°C/W] \qquad [1]$$

Where:

Tx = temperature at location x

Ty = temperature at location y

Pd = total heat dissipation

The 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 reality, the total heat dissipation is lower than total electrical power as a certain amount of electrical power has been converted to the emission of photons (both visible and non-visible).

Pd = forward current x forward voltage

$= I_F \times V_F$ [W]

The thermal resistance of an Avago SMD LED between the LED die junction and the solder point can be written as:

Rθ junction – solder point = $R\theta_{J\text{-}P}$

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

$$= (T_J - T_P) / Pd \ [°C/W] \qquad [2]$$

Where:

T_J = LED die junction temperature

T_P = LED solder point temperature

The thermal resistance $R\theta_{J\text{-}P}$ is a property of the LED and can be found in the product datasheet. (Example: The typical $R\theta_{J\text{-}P}$ for a PLCC2 InGaN LED is 280° C/W. This indicates that by supplying the LED with 0.1 W of electrical power, the Tj will increase by 28° C compared to TP).

Other types of thermal resistance that are of interest in this application note are:

- Thermal resistance from LED junction to ambient,

$$R\theta_{J\text{-}A} = (T_J - T_A) / Pd \qquad [3]$$

- Thermal resistance from LED solder point to PCB,

$$R\theta_{P\text{-}PCB} = (T_P - T_{PCB}) / Pd \qquad [4]$$

- Thermal resistance from PCB to ambient,

$$R\theta_{PCB\text{-}A} = (T_{PCB} - T_A) / Pd \qquad [5]$$

- Thermal resistance from heat sink to ambient,

$$R\theta_{HS\text{-}A} = (T_{HS} - T_A) / Pd \qquad [6]$$

Another assumption made in using the thermal resistance model is that all heat generated at the LED junction is transferred through a single major conduction path. Heat transfer through radiation and convection paths is neglected as generally they are considerably small.

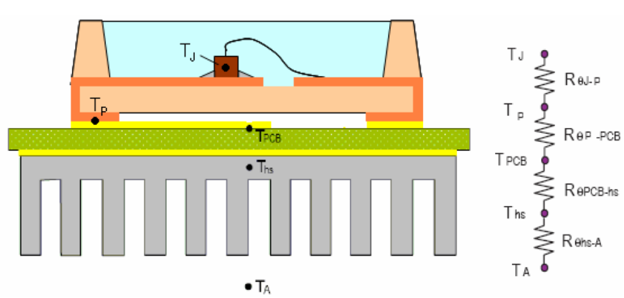

Figure 1. Thermal resistance model for a single LED

Thermal resistance model for a single LED

The major heat path for PLCC LED is:

LED die junction -> Solder Point -> PCB -> Heat Sink -> Ambient Environment

In this model, the thermal path can be modeled using a series resistance circuit, as illustrated in Figure 1. Heat transfers through the encapsulate and LED body are omitted due to their much lower thermal conductivity as compared to the metal lead frame. The overall thermal resistance $R\theta_{J\text{-}A}$ of a system can be expressed as the sum of the individual resistance along the thermal path from junction to ambient:

$$R\theta_{J\text{-}A} = R\theta_{J\text{-}P} + R\theta_{P\text{-}PCB} + R\theta_{PCB\text{-}HS} + R\theta_{HS\text{-}A} \quad [7]$$

In certain cases where an additional heat sink is not used, the model can be simplified to:

$$R\theta_{J\text{-}A} = R\theta_{J\text{-}P} + R\theta_{P\text{-}PCB} + R\theta_{PCB\text{-}A} \quad [8]$$

Thermal resistance $R\theta_{P\text{-}PCB}$ refers to the thermal compound that is used between the solder point of the LED and the PCB. Unlike other high power LED emitters that need to use thermal compound, such as thermal grease or thermal epoxy, Avago PLCC LEDs can be directly soldered onto the PCB, using solder material as the thermal compound. As solder is a metal alloy, the heat conductivity is very good and thus its thermal resistance ($R\theta_{P\text{-}PCB}$) can be neglected as $T_P \approx T_{PCB}$. With this, equation [8] becomes:

$$R\theta_{J\text{-}A} = R\theta_{J\text{-}P} + R\theta_{P\text{-}A} \quad [9]$$

Thermal resistance model for multiple LEDs on the same carrier

When multiple power LED emitters are mounted on the same carrier (PCB), the overall thermal resistance will be affected due to additional heating from adjacent units. This will alter the $R\theta_{PCB\text{-}A}$ as all the LEDs are mounted on the same PCB. As there are a number of LEDs on the PCB, the $R\theta_{J\text{-}P}$ of multiple LEDs can be simplified to a single $R\theta_{J\text{-}P}$ total using a parallel thermal resistance model. It can be obtained in a way similar to calculating the resultant resistance of resistors in parallel:

$$R\theta_{J\text{-}P}\ \text{Total} = [(1/R\theta_{J\text{-}P1}) + (1/R\theta_{J\text{-}P2})\ (1/R\theta_{J\text{-}P3})\ \ldots.. + (1/R\theta_{J\text{-}Pn})]\text{-}1 \quad [10]$$

Where n = number of LEDs on the same PCB.

As $R\theta_{J\text{-}P1} = R\theta_{J\text{-}P2} = R\theta_{J\text{-}P3} = \ldots\ldots. = R\theta_{J\text{-}Pn}$,

$$R\theta_{J\text{-}P\ Total} = [(n/R\theta_{J\text{-}P})]\text{-}1 = R\theta_{J\text{-}P} / n \quad [11]$$

If this simplified model is to be used, total Pd of all the LEDs must be considered.

$$R\theta_{J\text{-}P\ Total} = (T_J - T_P) / \text{Pd total} \quad [12]$$

Where $P_{d\ Total} = Pd1 + Pd2 + Pd3 + \ldots\ldots + Pdn$

Determining the heat sink capability requirement

Prior to designing the thermal management for a high power LED, these requirements need to be determined by the user:

A. Maximum operating ambient temperature ($T_{A\ max}$)
   – based on the intended application conditions.

B. Maximum LED junction temperature ($T_{J\ max}$)
   – can be obtained from the PLCC datasheet.

C. Maximum power dissipation per emitter (Pd max, where $P_{d\ max} = I_{F\ max} \times V_{F\ max}$)
   – can be obtained from the PLCC datasheet.

The worst case condition should always be considered when determining the required heat sinking requirement, of the system. The heat sink requirement refers to the last interface of heat transfer to the ambient environment.

For a system without an additional heat sink, the heat sinking requirement is $R\theta_{PCB\text{-}A}$. By inserting equation [3] into equation [9]:

$$(T_{J\ max} - T_{A\ max}) / P_{d\ max} = R\theta_{J\text{-}P} + R\theta_{P\text{-}A}$$

$$R\theta_{P\text{-}A} = (T_{J\ max} - T_{A\ max}) / P_{d\ max} - R\theta_{J\text{-}P} \quad [13]$$

Since all parameters on the right side of equation [13] are known, the heat sink requirement $R\theta_{PCB\text{-}A}$ can be determined.

Type of Mounting (Carrier) Options

There are generally three types of mounting options for Avago PLCC LEDs for various ranges of heat sinking performance:

Type I: Single sided FR4 PCB with / without additional copper pad

Type II: Double sided FR4 PCB with additional copper pad and thermal vias

Type III: Metal core PCB (MCPCB)

Type I: Single sided FR4 PCB with / without additional copper pad

This type option is the cheapest and least effective for heat dissipation. Illustrations below show a typical configuration of the Type I option.

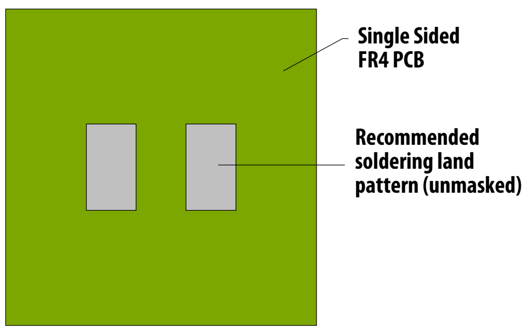

Figure 2a. Single sided FR4 PCB without additional copper pad.

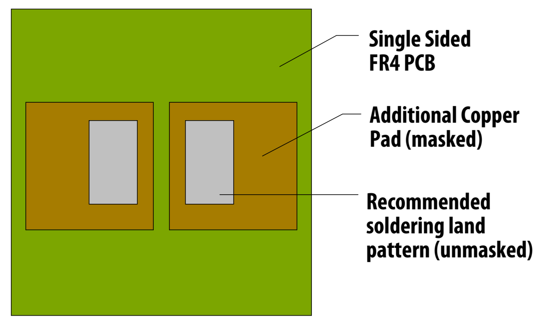

Figure 2b. Single sided FR4 PCB with additional copper pad.

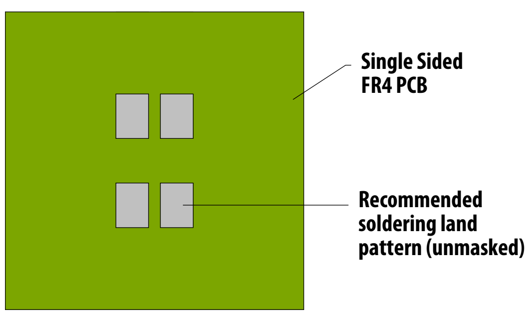

Figure 2c. Single sided FR4 PCB without additional copper pad.

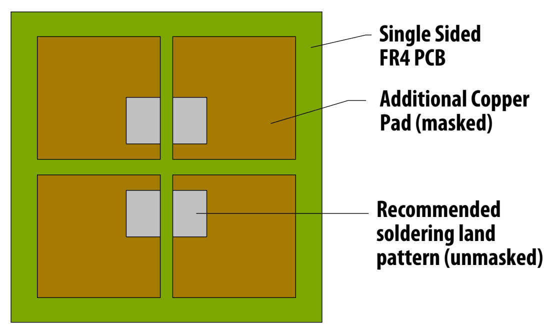

Figure 2d. Single sided FR4 PCB with additional copper pad.

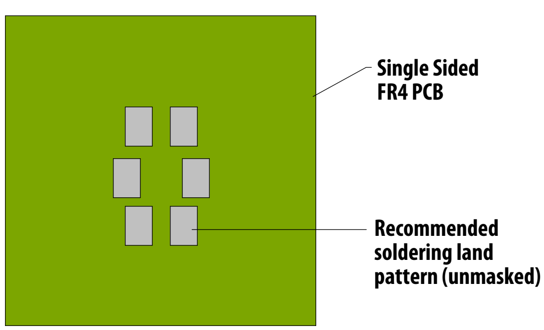

Figure 2e. Single sided FR4 PCB without additional copper pad.

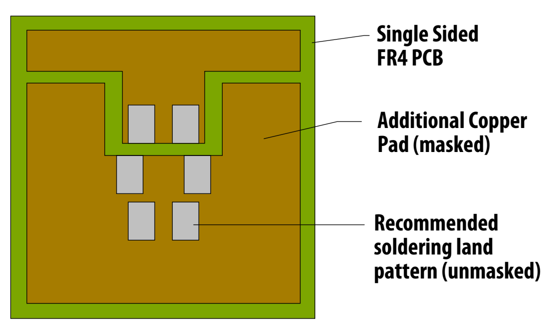

Figure 2f. Single sided FR4 PCB with additional copper pad.

Type II: Double sided FR4 PCB with additional copper pad and thermal via

A Type II mounting option has additional heat sinking capability through the thermal vias to the additional copper pad on the underside of the PCB. The via holes help transfer and spread the heat to the PCB away from the LEDs. Additional copper at the bottom side of the PCB may be exposed without a solder mask with a HASL (hot air solder leveling) finish, if possible, to give better heat dissipation to ambient. It also provides a better interface for attachment to additional heat sink metal.

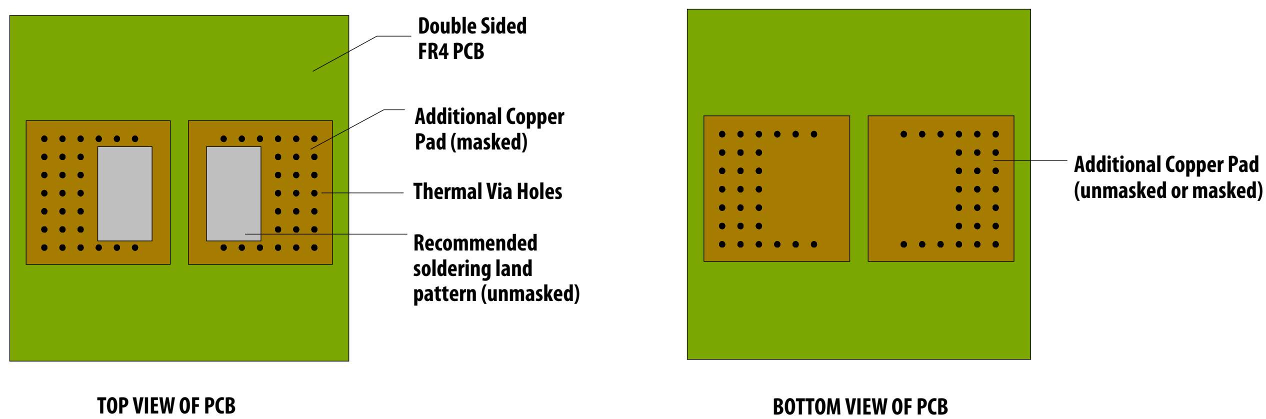

Figure 3a. Double sided FR4 PCB with additional copper pad and thermal via.

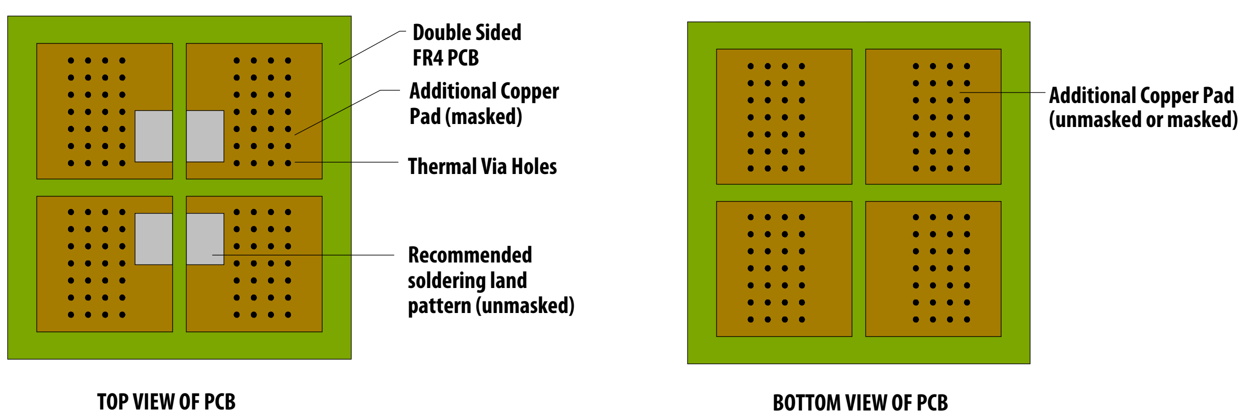

Figure 3b. Double sided FR4 PCB with additional copper pad and thermal via.

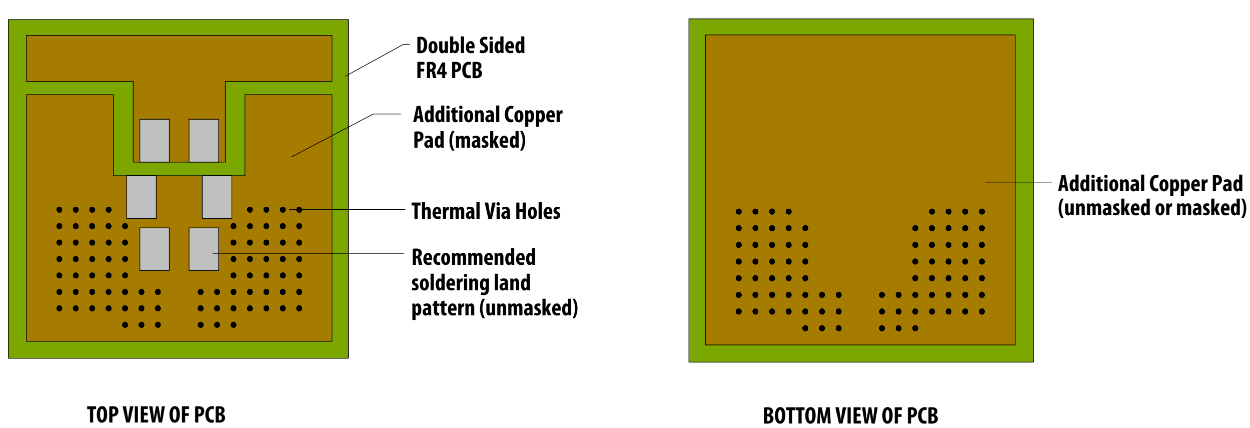

Figure 3c. Double sided FR4 PCB with additional copper pad and thermal via.

Type III: Metal core PCB

A metal core PCB generally uses aluminum as the core substrate. Aluminum has a good thermal conductivity of >200 W/mK. Heat conducting from the LED can be spread effectively through out the MCPCB and eventually to the ambient environment. Compared to an FR4 substrate, MCPCB gives superior performance with respect to keeping the LED junction temperature low.

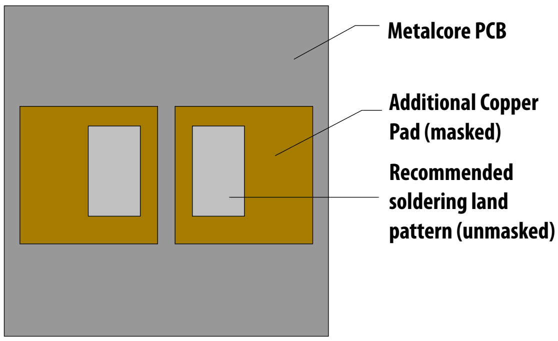

Figure 4a. Metalcore PCB

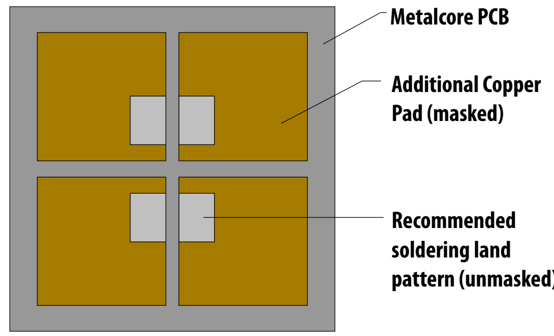

Figure 4b. Metalcore PCB

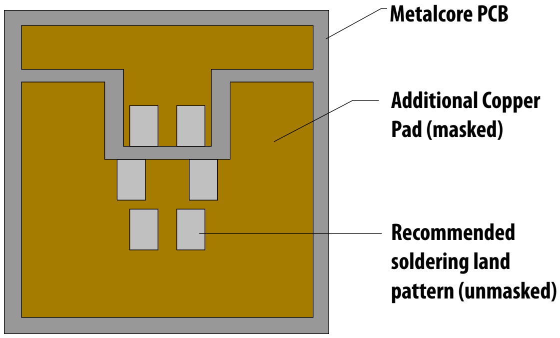

Figure 4c. Metalcore PCB

Recommended soldering land patterns

Recommended soldering land patterns as shown in Figure 5, can also be found in the product datasheets. The solder lead (Pin) of the PLCC package can be directly soldered on the land pattern through a reflow solder process or by a manual soldering process.

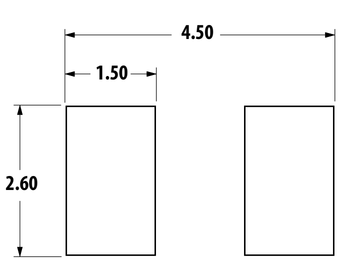

Figure 5a. Recommended soldering land pattern for the PLCC2

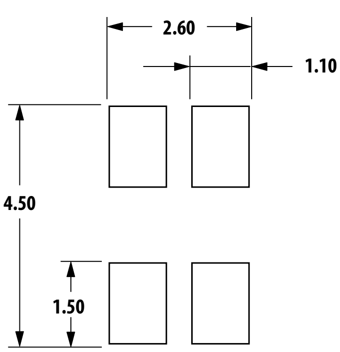

Figure 5b. Recommended soldering land pattern for the PLCC4

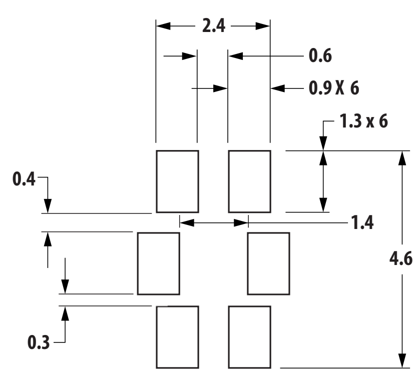

Figure 5c. Recommended soldering land pattern for 0.5 W PLCC4

Thermal resistance for different mounting options

A printed circuit board can act as a heat sink, resulting in a lower solder point-to-ambient thermal resistance due to the increased heat transfer area. A thermal simulation has been carried out to show the thermal impact of PCB configurations. This effect can be seen in the temperature distribution in Figure 6. The cathode[1] solder pads distribute the heat over the PCB depending on the solder pad area. The board materials, solder pad area and the standard boundary conditions are listed in Table 1.

The steady state calculations are always performed with a fixed power dissipation of 0.1 W. Other heat sources, e.g. resistors, voltage regulator etc., are not considered in the analysis. All the simulation results are valid under the mentioned boundary conditions. Figure 7 shows the simulated thermal resistance from solder point to ambient ($R\theta_{P\text{-}A}$) for Type I, II and III mounting options.

Note:
1. Refer to the datasheet for the marking of the cathode lead or major heat path.

Table 1.

Outer PCB Dimension	Variable
Board Material	FR4 and MCPCB
Solder Pads Size	Refer to Figure 7
Board Thickness	1.6 mm
Material for Solder Pads	35 µm Cu (1oz)
Power Dissipation	0.1 W
Air Velocity	Still Air (Free Convection)
Ambient Temperature	25° C

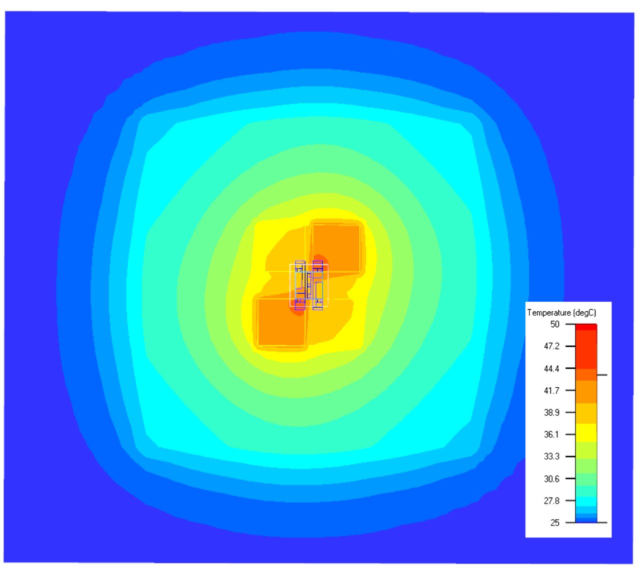

Figure 6a. Pad area per cathode: 16 mm^2

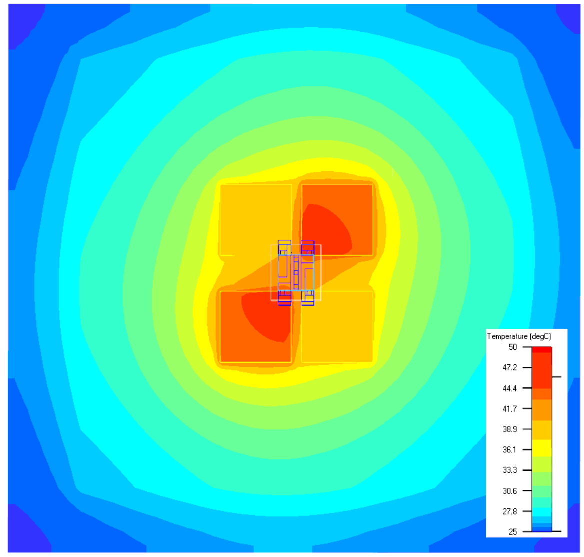

Figure 6b. Pad area per cathode: 12 mm^2

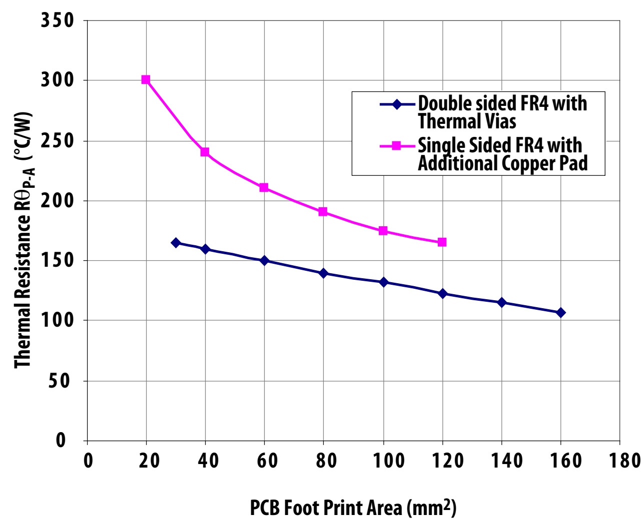

Figure 7. Simulated thermal resistance $R\theta_{P\text{-}A}$ of LED vs. PCB foot print area

Note: The actual thermal resistance might vary from the simulated value depending on the ambient condition, material used and other thermal loading around the LED. Please refer to the next section on how to measure the actual $R\theta_{P\text{-}A}$ thermal resistance of the LED module.

Determine Required Heat Sinking Capability

The heat sinking capability of system that used an Avago super 0.5 W ASMT-QWBE-Nxxxx LED will now be calculated.

Application requirements:

i) Drive current, I_F = 150 mA

ii) Maximum operating ambient temperature, T_A max = 25° C

iii) One ASMT-QWBE-Nxxxx LED per assembly

Calculation boundary constraint:

i) Maximum power dissipation,

$$P_{d\,max} = I_F \times V_{F\,max} = 0.150 \times 4.1 = 0.615W$$

ii) Maximum LED junction temperature, $T_{J\,max}$ = 125° C

iii) Thermal resistance of a ASMT-QWBE, $R\theta_{J-P}$ = 60° C/W

Objective:

Determine the mounting option and size needed to fulfill the application requirement.

Referring to formula [13], the required heat sink capability $R\theta_{P-A}$ can be determined:

$$R\theta_{P-A} = (T_{J\,max} – T_{A\,max}) / P_{d\,max} - R\theta_{J-P} = (125 – 25)/0.615 – 60 = 102.6° C/W$$

By referring to Figure 7, the heat sinking capability of $R\theta_{P-A}$ of 102.6° C/W can be achieved by using double sided FR4 PCB with a 160 mm^2 foot print size.

Measurement Techniques for Real Applications

Due to difficulties in direct measurement of junction temperature T_J, it has to be evaluated indirectly by using the thermal resistance model. For this procedure the thermal resistance, solder point to ambient $R\theta_{P-A}$ of the device under test is measured. With this value a calculation of the junction temperature can be made.

Procedures for measuring the $R\theta_{P-A}$ and therefore calculating T_J are described as below:

1. Take the $R\theta_{J-P}$ of the LED from the respective data sheet
2. Solder the LED on the PCB to be used as the device under test (DUT)
3. Place a small thermocouple onto the cathode/anode pin of the DUT. Refer to technical datasheet for the package marking (either cathode or anode) that indicates the major heat path.
4. Turn on the LED assembly at the necessary forward current. The LED assembly should remain on for about 30 minutes to reach the thermal equilibrium. This is reached when no temperature change is registered for a few minutes.
5. Record the solder point temperature T_P, the ambient temperature T_A, the current I_F and the corresponding forward voltage V_F.
6. Calculate the $R\theta_{P-A}$ of the system and T_J of the DUT with equations [14] & [15] respectively:

$$R\theta_{P-A} = (T_P – T_A) / (I_F \times V_F) \quad [14]$$

$$T_J = T_P + (I_F \times V_F \times R\theta_{J-P}) \quad [15]$$

Example of calculation:

For a PLCC2 HSMC-A100 application, the design current is estimated as an I_F of 20 mA. According to the datasheet of the HSMC-A100, the junction temperature must not exceed 110° C. Therefore, it is necessary to measure the ambient temperature T_A, solder point temperature T_P and forward voltage V_F.

The test results are:

T_P = 28° C

V_F = 2.0 V

In the datasheet of the HSMC-A100 a value of 280° C/W for $R\theta_{J-P}$ is given. Calculate the T_J of the DUT using equation [15]:

T_J = 28° C + (20mA x 2.2V x 280° C/W)

T_J = 40.32° C

T_J < 110° C maximum

Benefits of Good Thermal Design

- Ensures that T_J limitation is not exceeded
- Allows operation of the LED at higher currents for more light output per LED
- Minimizes the reduction in LED light output due to self-heating
- Reduces LED light output degradation over time

For product information and a complete list of distributors, please go to our web site: **www.avagotech.com**

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