Thermal Management of Avago High Power LED Emitter ASMT-Mxxx/ASMT-Axxx/ASMT-Jxxx

Application Note 5313

1. Introduction

The Avago Technologies ASMT-Mxxx/ASMT-Axxx/ASMT-Jxxx is a high power LED emitter that provides high luminous flux output with a very low package thickness. It is encapsulated with silicone encapsulant to provide long term reliability. In order to fully harvest the capability of this product for its optical and reliability performance, system level thermal management must be appropriately designed in order to not exceed the recommended operating range of the product.

The purpose of this application note is to provide a guideline to users in determining the required heat sinking capability based on application constraints and requirements determined by the user.

2. Heat Sink Requirement

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

2.1 Introduction to thermal resistance

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

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

Where:

T_x = temperature at location x

T_y = temperature at location y

P_d = total heat dissipation

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 an actual case, 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).

P_d = forward current x forward voltage

= I_F x V_F [W]

The thermal resistance of the Avago ASMT-Mxxx/ASMT-Axxx/ASMT-Jxxx between the LED die junction and the metal slug can be written as:

$R_{\theta junction - metal\ slug} = R_{\theta J\text{-}ms}$

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

= $(T_J - T_{ms}) / P_d$ [° C/W] [2]

where:

T_J = LED die junction temperature

T_{ms} = LED metal slug temperature

The thermal resistance $R_{\theta J\text{-}ms}$ is a property of the LED and can be found in the product datasheet. For example, the typical $R_{\theta J\text{-}ms}$ for ASMT-Mxxx is 10° C/W. This indicates that by supplying the LED with 1 W of electrical power, the T_j will increase by 10° C compared to T_{ms}.

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

- Thermal resistance from LED junction to ambient,

  $R_{\theta J\text{-}A} = (T_J - T_A) / P_d$ [3]

- Thermal resistance from LED metal slug to PCB,

  $R_{\theta ms\text{-}PCB} = (T_{ms} - T_{PCB}) / P_d$ [4]

- Thermal resistance from PCB to ambient,

  $R_{\theta PCB\text{-}A} = (T_{PCB} - T_A) / P_d$ [5]

- Thermal resistance from heat sink to ambient,

  $R_{\theta hs\text{-}A} = (T_{hs} - T_A) / P_d$ [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 minor paths is neglected as generally they are considerably small.

2.2 Thermal resistance model for single LED emitter

The major heat path for the ASMT-Mxxx/ASMT-Axxx/ASMT-Jxxx power LED emitter is:

LED die junction -> metal slug -> PCB -> heat sink -> ambient environment

In this model, the thermal path can be modeled using a series resistance circuit, as illustrated in Figure 3. Heat transfer through the silicone encapsulant and LED body are omitted due to much lower thermal conductivity as compare to the metal slug. The overall thermal resistance $R\theta_{J\text{-}A}$ of a system can be expressed as the sum of the individual resistances along the thermal path from junction to ambient as follows.

$R_{\theta J\text{-}A} = R_{\theta J\text{-}ms} + R_{\theta ms\text{-}PCB} + R_{\theta PCB\text{-}hs} + R_{\theta hs\text{-}A}$ [7]

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

$R_{\theta J\text{-}A} = R_{\theta J\text{-}ms} + R_{\theta ms\text{-}PCB} + R_{\theta PCB\text{-}A}$ [8]

Thermal resistance $R_{\theta ms\text{-}PCB}$ refers to the thermal compound that is used between the metal slug of the LED and the PCB. Unlike other high power LED emitters that need to use special thermal compound, such as thermal grease or thermal epoxy, the Avago ASMT-Mxxx/ASMT-Axxx/ASMT-Jxxx can be directly soldered onto a 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 ($R_{\theta ms\text{-}PCB}$) can be neglected since $T_{ms} \approx T_{PCB}$. With this, equation [8] becomes:

$R_{\theta J\text{-}A} = R_{\theta J\text{-}ms} + R_{\theta PCB\text{-}A}$ [9]

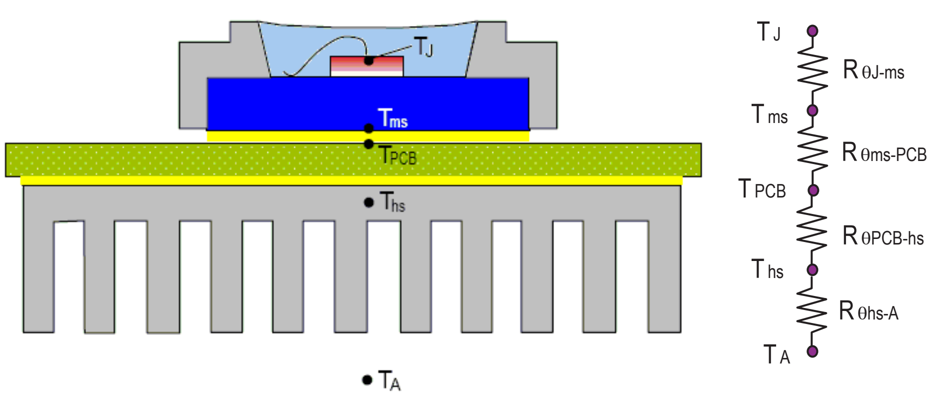


Figure 3. Example of a thermal resistance model for a single LED emitter, ASMT-Mxxx

2.3 Thermal resistance model for multiple LED emitters 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 emitters on the PCB, the $R_{\theta J\text{-}ms}$ of multiple LED emitters can be simplified to a single total $R_{\theta J\text{-}ms}$ using a parallel thermal resistance model as illustrated in Figure 4. It can be obtained in a similar way by calculating the resultant resistance of the resistors in parallel.

$$R_{\theta J\text{-}ms\ total} = [\ (1/\ R_{\theta J\text{-}ms1}) + (1/\ R_{\theta J\text{-}ms2})\ (1/\ R_{\theta J\text{-}ms3}) \ldots.. + (1/\ R_{\theta J\text{-}msn})\ ]^{-1} \qquad [10]$$

where n = number of LED emitters on the same PCB.

As $R_{\theta J\text{-}ms1} = R_{\theta J\text{-}ms2} = R_{\theta J\text{-}ms3} = \ldots\ldots. = R_{\theta J\text{-}msn}$,

$$R_{\theta J\text{-}ms\ total} = [\ (n/\ R_{\theta J\text{-}ms})\ ]^{-1}$$

$$= R_{\theta J\text{-}ms} / n \qquad [11]$$

If this simple model is used, the total Pd of all the emitters must be considered.

$$R_{\theta J\text{-}ms\ total} = (\ T_J - T_{ms}\ ) / P_{d\ total} \qquad [12]$$

where $P_{d\ total} = P_{d1} + P_{d2} + P_{d3} + \ldots\ldots + P_{dn}$

2.4 Determining heat sink capability requirement

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

A. Maximum operating ambient temperature ($T_{A\ max}$)
   - Based on user intended application condition.

B. Maximum LED junction temperature ($T_{j\ max}$)
   - Obtained from the datasheet of the ASMT-Mxxx/ASMT-Axxx/ASMT-Jxxx.

C. Maximum power dissipation per emitter ($P_{d\ max}$, where $P_{d\ max} = I_{F\ max} \times V_{F\ max}$)
   - Obtained from the datasheet of the ASMT-Mxxx/ASMT-Axxx/ASMT-Jxxx.

Worst case conditions should always be considered when determining the required heat sinking requirement of the system. Heat sinking 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],

$$(T_{J\ max} - T_{A\ max}) / P_{d\ max} = R_{\theta J\text{-}ms} + R_{\theta PCB\text{-}A}$$

$$R_{\theta PCB\text{-}A} = (T_{J\ max} - T_{A\ max}) / P_{d\ max} - R_{\theta J\text{-}ms} \qquad [13]$$

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

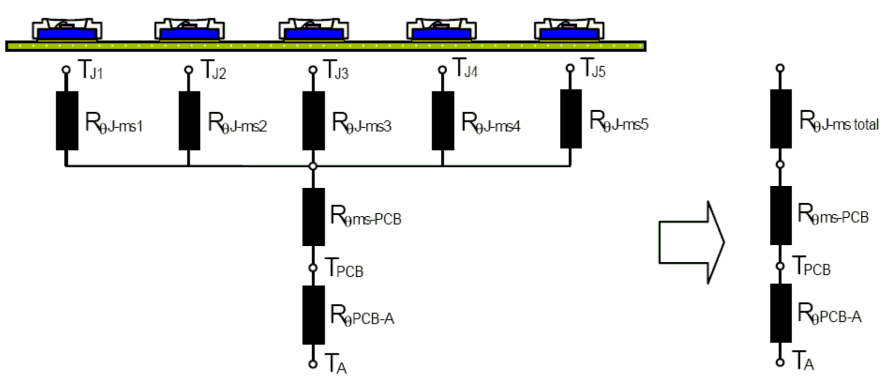


Figure 4. Example of a thermal resistance model for multiple LED emitters. ASMT-Mxxx on the same carrier

3. Type of Mounting (Carrier) Options

There are generally three types of mounting options for the Avago ASMT-Mxxx/ASMT-Axxx/ASMT-Jxxx LED emitter 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)

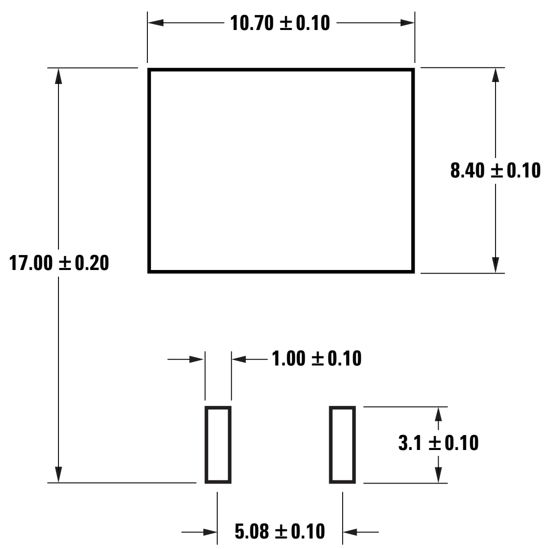


Figure 5a. Recommended soldering land pattern for the ASMT-Mxxx (except the ASMT-MT00)

3.1 Recommended soldering land pattern

Recommended soldering land patterns shown in Figure 5, can also be found in the datasheet. The metal slug of the ASMT-Mxxx/ASMT-Axxx/ASMT-Jxxx can be directly soldered on the land pattern through a reflow process or manual soldering process. See Figure 5.

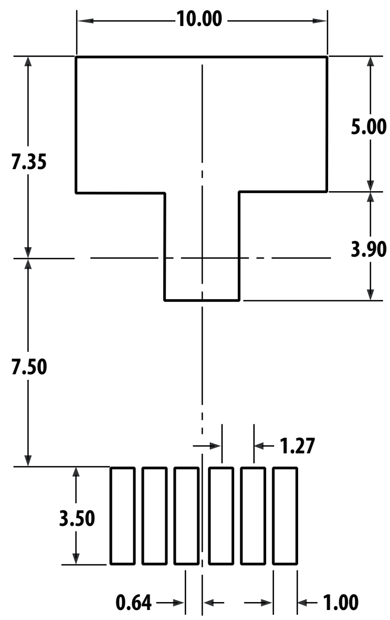


Figure 5b. Recommended soldering land pattern for the ASMT-MT00

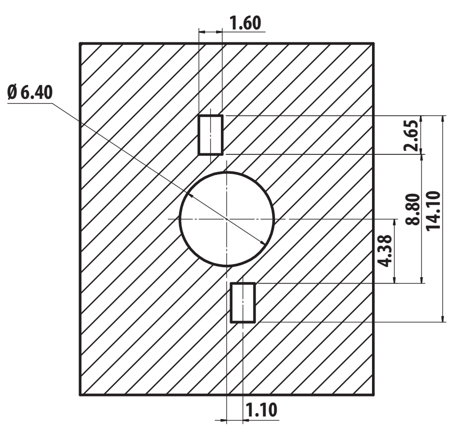


Figure 5c. Recommended soldering land pattern for the ASMT-Axxx

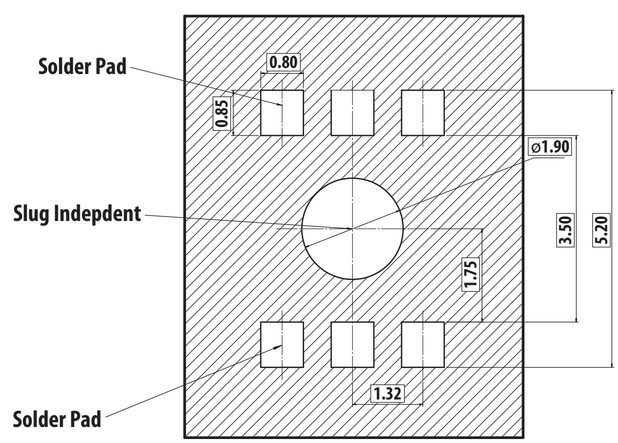


Figure 5d. Recommended soldering land pattern for the ASMT-Jxxx

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

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

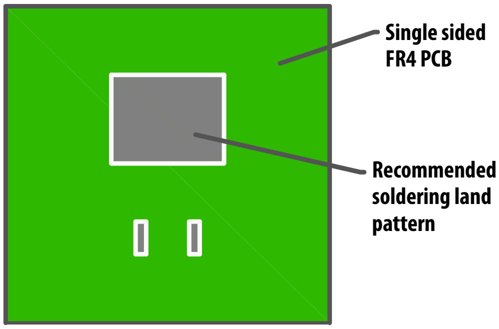


Figure 6a. Single sided FR4 PCB without an additional copper pad for the ASMT-Mxxx (except the ASMT-MT00)

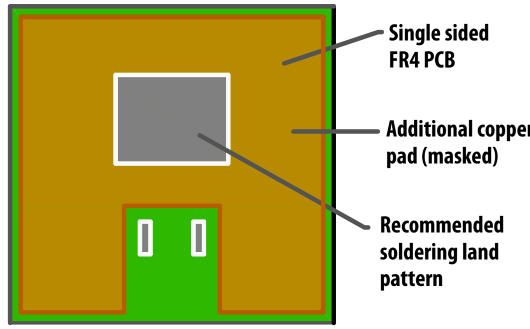


Figure 6b. Single sided FR4 PCB with an additional copper pad for the ASMT-Mxxx (except the ASMT-MT00)

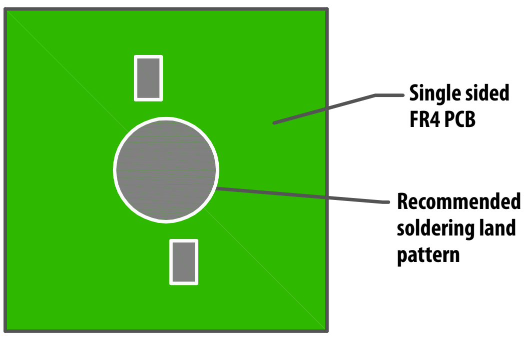


Figure 6c. Single sided FR4 PCB without an additional copper pad for the ASMT-Axxx

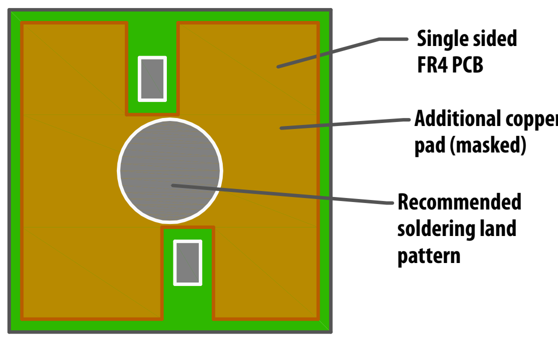


Figure 6d. Single sided FR4 PCB with an additional copper pad for the ASMT-Axxx

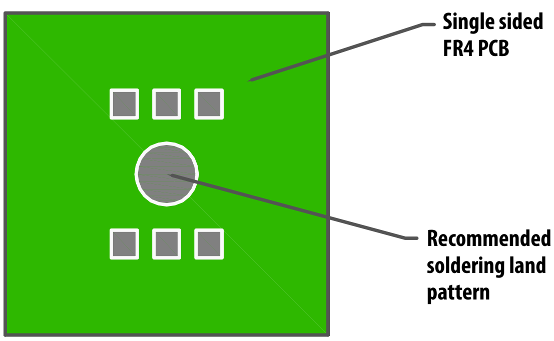


Figure 6e. Single sided FR4 PCB without an additional copper pad for the ASMT-Jxxx

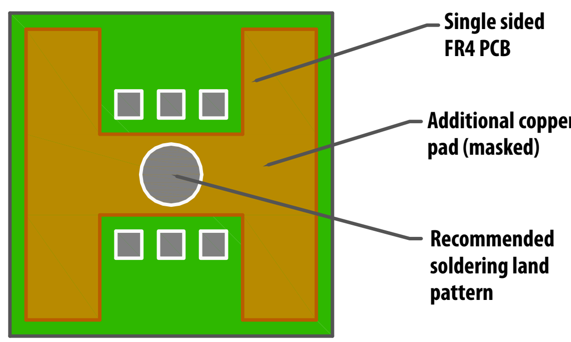


Figure 6f. Single sided FR4 PCB with an additional copper pad for the ASMT-Jxxx

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

The Type II mounting option provides additional heat sinking capability through the thermal vias to the additional copper pad on the underside of the PCB. The via holes help to transfer and spread the heat to the PCB and away from the LED. Additional copper on 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 the ambient environment. It also provides a better interface for attachment to additional heat sink metal.

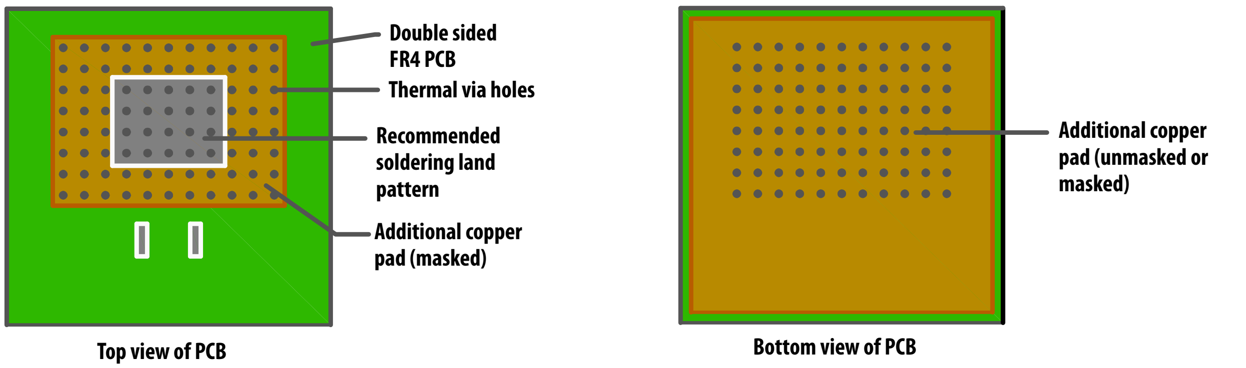


Figure 7a. Double sided FR4 PCB with an additional copper pad and thermal vias for the ASMT-Mxxx (except the ASMT-MT00)

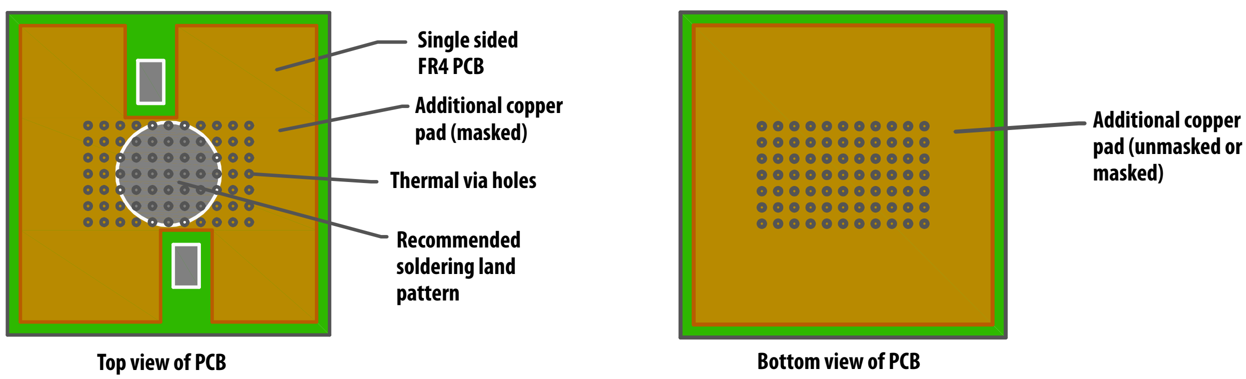


Figure 7b. Double sided FR4 PCB with an additional copper pad and thermal vias for the ASMT-Axxx

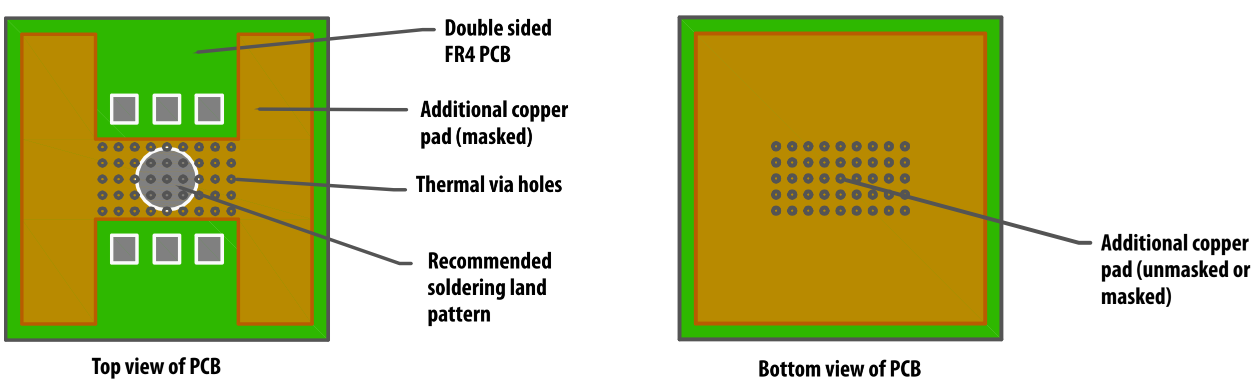


Figure 7c. Double sided FR4 PCB with an additional copper pad and thermal vias for the ASMT-Jxxx

3.4 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 out effectively through out the MCPCB and eventually to the ambient environment. Compared to FR4 substrate, MCPCB has superior performance with respect to keeping the LED junction temperature low.

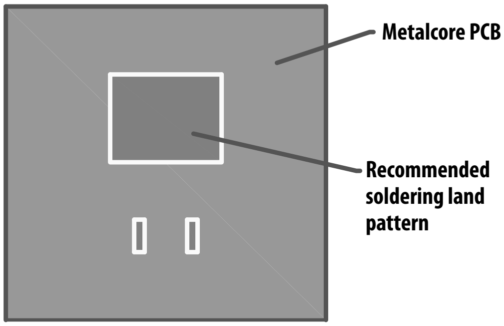


Figure 8a. Metal core PCB for the ASMT-Mxxx (except the ASMT-MT00)

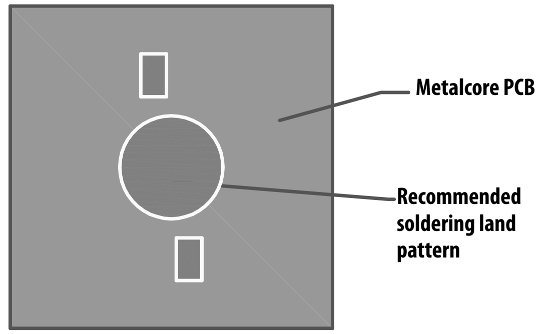


Figure 8b. Metal core PCB for the ASMT-Mxxx (except the ASMT-Axxx)

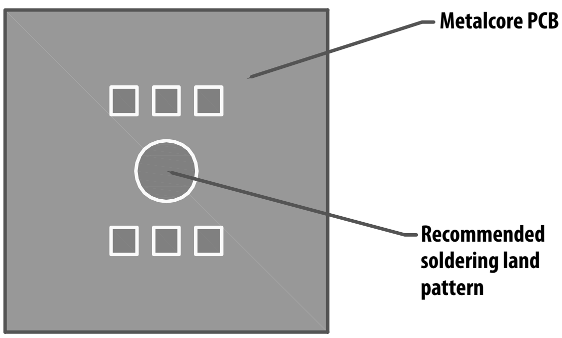
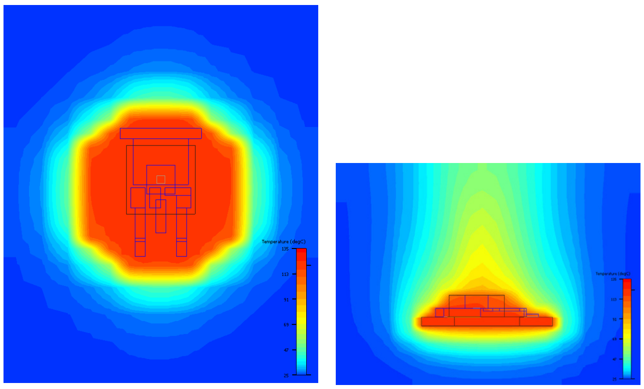


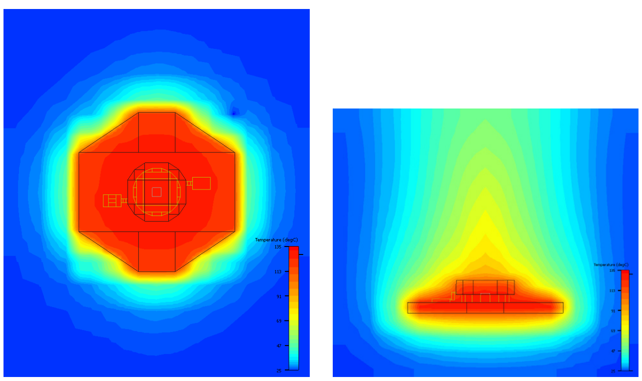
Figure 8c. Metal core PCB for the ASMT-Mxxx (except the ASMT-Jxxx)

3.5 Thermal resistance for different mounting options

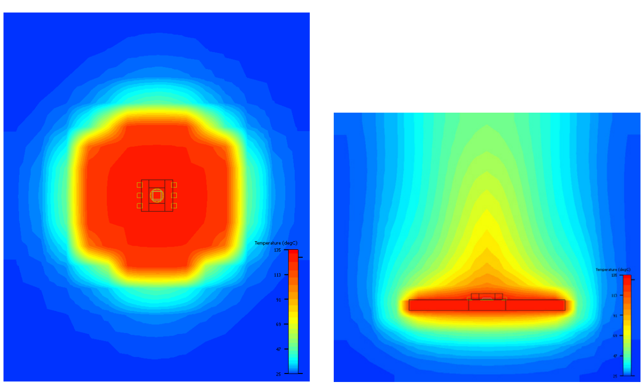
Thermal simulation has been carried out in order to show the thermal impact of PCB a configurations. The conditions were simulated under free convection environment. The simulations were run in a closed volume test box to control the free convection and the models were simulated in a horizontal orientation as illustrated in Figure 9.



ASMT-Mx00



ASMT-Axxx



ASMT-Jxxx

Figure 9. Examples of thermal simulations

The material data and the standard boundary conditions are listed in the following table.

Outer PCB dimension	Variable
Board material	FR4 and MCPCB
Board thickness	1.6 mm
Material for solder pads	35 µm Cu (1 oz)
Power dissipation	1 W
Air velocity	Still Air (Free Convection)
Ambient temperature	25° C

The steady state calculations are always performed with a fixed power dissipation of 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 10 shows the thermal resistance from metal slug to ambient ($R_{\theta PCB\text{-}A}$) for the type I, II and III mounting options.

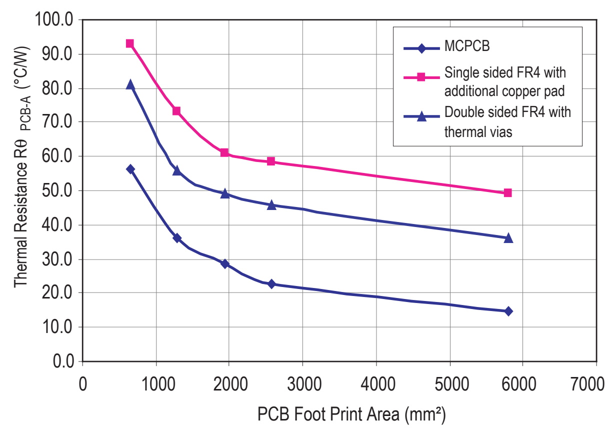


Figure 10. Simulated thermal resistance $R_{\theta PCB\text{-}A}$ vs PCB foot print area

4. Example to Determine Required Heat Sinking Capability

4.1 1 W example

Application requirements:

i) Drive current, I_F = 350 mA

ii) Maximum operating ambient temperature, $T_{A\ max}$ = 50° C

iii) 1 ASMT-Mx00 LED per assembly

Calculation boundary constraint:

i) Maximum power dissipation,

Pd max $= I_F \times V_{F\ max}$

$= 0.35 \times 4.0$

$= 1.4$ W

ii) Maximum LED junction temperature, $T_{J\ max}$ = 110° C

iii) Thermal resistance of ASMT-Mx00, $R\theta_{J\text{-}ms}$ = 10° C/W

Objective:

To determine the mounting option and size needed to fulfill application requirements.

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

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

$= [(110 - 50) / 1.4] - 10$

$= 32.9°$ C/W

By referring to Figure 10, heat sinking capability of $R\theta_{PCB\text{-}A}$ of 32.9° C/W can be achieved by using MCPCB with 1500 mm² foot print size.

4.2 3 W example

i) Drive current, I_F = 700 mA

ii) Maximum operating ambient temperature, T_A max = 50° C

iii) 1 ASMT-MW20 LED per assembly

Calculation boundary constraint:

i) Maximum power dissipation,

Pd max $= I_F \times V_F$ max

$= 0.7 \times 4.3$

$= 3.01$ W

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

iii) Thermal resistance of ASMT-MW20, $R\theta_{J\text{-}ms}$ = 10° C/W

Objective:

To determine the mounting option and size needed to fulfill application requirements.

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

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

$= [(120 - 50) / 3.01] - 10$

$= 15°$ C/W

By referring to Figure 10, heat sinking capability of $R\theta_{PCB\text{-}A}$ of 15° C/W can be achieved by using a MCPCB with 5000 mm² foot print size.

5. Additional Methods to Reduce Thermal Resistance

Avago high power LED dissipates approximately 0.5 W/1 W/3 W of thermal energy depending on the respective power dissipation. It is crucial to reduce the overall thermal resistance in order to reduce the LED junction temperature and maximize its optical performance. Other than the three types of aforementioned mounting options, additional methods that help to improve the thermal resistance of the system are:

i) Attaching the PCB to metal casing, metal frame or metal bracket

ii) Attaching the PCB to finned heat sink

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

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