Thermal Management of Avago High Power LED Emitter ASMT-Mx00

Application Note 5313

1. Introduction

Avago ASMT-Mx00 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 performance. In order to fully harvest the capability of this product for its optical and reliability performance, system level thermal management need to be appropriately designed in order not to exceed recommended operating range of the product.

The purpose of this application note is to provide a guideline to user 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 2 locations a long 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 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).

P_d = forward current x forward voltage

$= I_F \times V_F$ [W]

Thermal resistance of Avago ASMT-Mx00 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 RθJ-ms is a property of the LED and can be found in the product datasheet. The typical $R_{\theta J\text{-}ms}$ for ASMT-Mx00 is 10°C/W. This indicates that by supplying the LED with 1W of electrical power, the T_j will increase by 10°C compare 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 are 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 ASMT-Mx00 power LED emitter is:

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

In this model, 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 resistance 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 additional heat sink is not used, the model can be simplified as:

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

Thermal resistance $R_{\theta ms\text{-}PCB}$ is referring 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 specially use thermal compound such as thermal grease or thermal epoxy, Avago ASMT-Mx00 can be directly soldered onto 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 as $T_{ms} \approx T_{PCB}$. With this, equation [8] becomes:

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

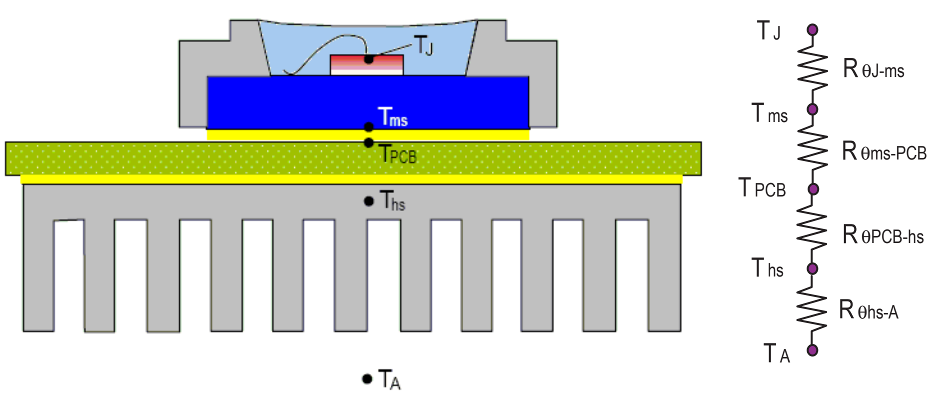

Figure 3. Thermal resistance model for single LED emitter

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 unit. 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 $R_{\theta J\text{-}ms}$ total using parallel thermal resistance model as illustrated in Figure 4. It can be obtained in similar way like calculating the resultant resistance of resistors in parallel.

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

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

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

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

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

If this simply model is to be used, total Pd of all the emitters need to be considered.

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

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 high power LED, below requirements need to be predetermined by the user.

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

B. Maximum LED junction temperature ($T_{j\ max}$)
   - can be obtained from technical datasheet of ASMT-Mx00.

C. Maximum power dissipation per emitter ($P_{d\ max}$, where $P_{d\ max} = I_{F\ max} \times V_{F\ max}$)
   - can be obtained from technical datasheet of ASMT-Mx00.

Worst case condition should always be considered when determining the required heat sinking requirement of the system. Heat sinking requirement is referring to the last interface of heat transfer to the ambient environment. For system without additional heat sink, the heat sinking requirement is $R_{\theta PCB\text{-}A}$. By inserting equation [3] into equation [9],

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

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

Since all parameters on the right side of equation [13] are known, the heat sink requirement RθPCB-A can be determined.

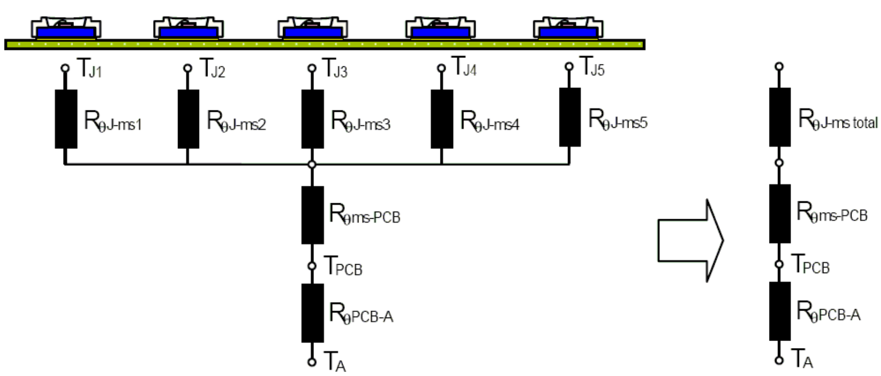

Figure 4. Thermal resistance model for multiple LED emitters on the same carrier

3. Type of Mounting (Carrier) Options

There are generally 3 types of mounting options for Avago ASMT-Mx00 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)

3.1 Recommended soldering land pattern

Recommended soldering land pattern as shown below, can also be found in the technical datasheet. The metal slug of ASMT-Mx00 can be directly soldered on the land pattern through reflow process or manual soldering process.

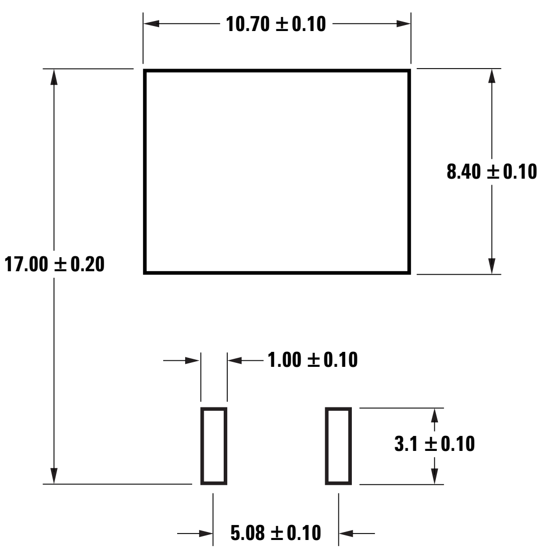

Figure 5. Recommended soldering land pattern for ASMT-Mx00

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 typical configuration of Type I option.

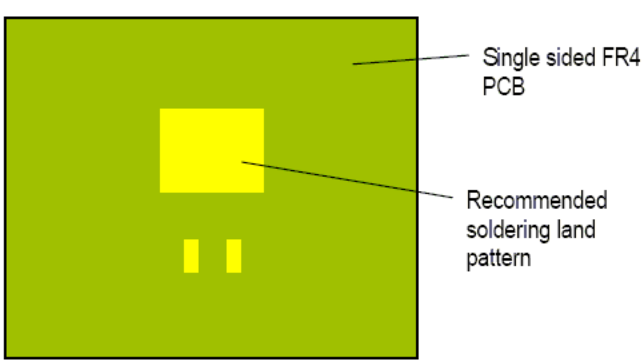

Figure 6a. Single sided FR4 PCB without additional copper pad.

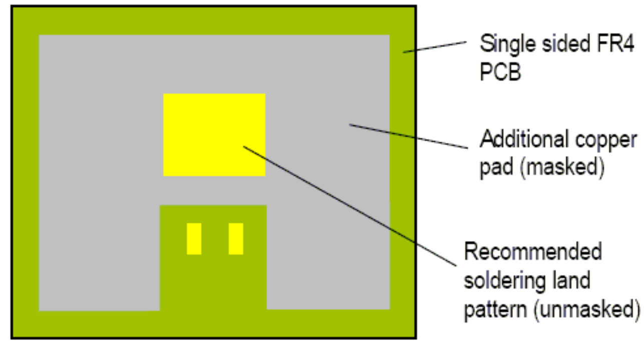

Figure 6b. Single sided FR4 PCB with additional copper pad.

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

Type II mounting option provide additional heat sinking capability through the thermal via to the additional copper pad on the underside of the PCB. The via holes help to transfer and spread the heat to the PCB away from the LED. Additional copper at the bottom side of the PCB may be exposed without solder mask with 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.

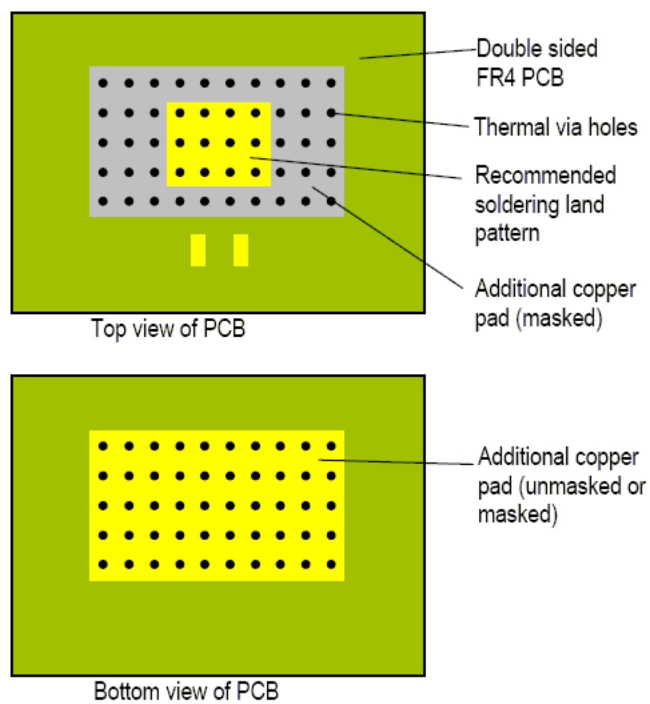

Figure 7. Double sided FR4 PCB with additional copper pad and thermal vias

3.4 Type III: Metal core PCB

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

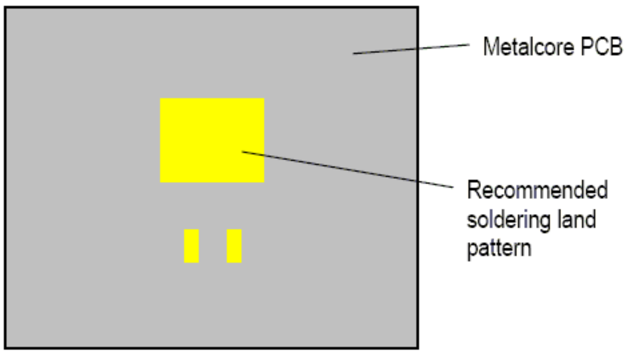

Figure 8. Metal core PCB

3.5 Thermal resistance for different mounting options

Thermal simulation has been carried out in order to show the thermal impact of PCB 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 horizontal orientation as illustrated in Figure 5. 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	1.6mm
Material for solder pads	35 µm Cu (1oz)
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 below shows the thermal resistance from metal slug to ambient ($R_{\theta PCB-A}$) for mounting option type I, II and III.

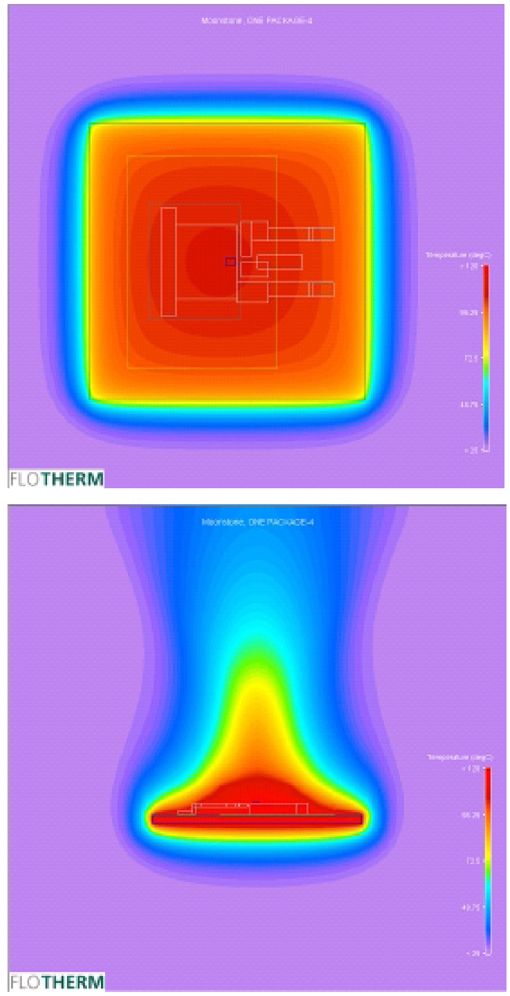

Figure 9. Example of thermal simulation illustration

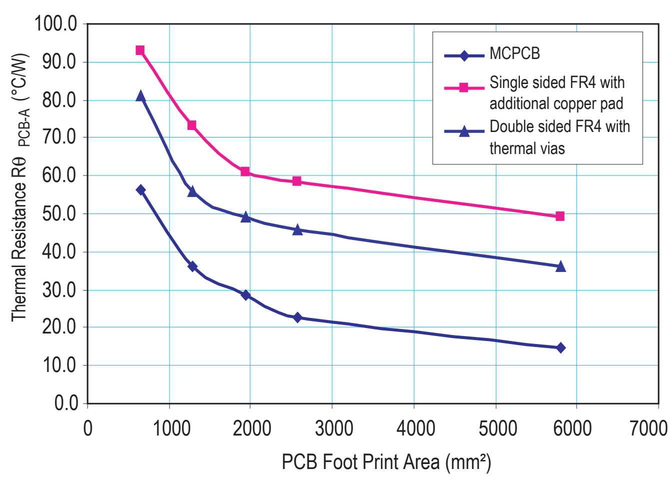

Figure 10. Simulated thermal resistance $R_{\theta PCB-A}$ vs PCB foot print area

4. Example to Determine Required Heat Sinking Capability

4.1 1W example

Application requirements:

i) Drive current, I_F = 350mA

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 x $V_{F\ max}$

= 0.35 x 4.0

= 1.4W

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 1500mm² foot print size.

4.2 3W example

i) Drive current, I_F = 700mA

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

iii) 1 ASMT-MW20 LED per assembly

Calculation boundary constraint:

i) Maximum power dissipation,

Pd max = I_F x V_F max

= 0.7 x 4.0

= 2.8W

ii) Maximum LED junction temperature, $T_{J\ max}$ = 120°C

iii) Thermal resistance of ASMT-MW20, $R\theta_{J\text{-}ms}$ = 8°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) / 2.8 – 8

= 17°C/W

By referring to Figure 10, heat sinking capability of $R\theta_{PCB\text{-}A}$ of 17°C/W can be achieved by using MCPCB with 5000 mm² foot print size.

5. Additional Methods to Reduce Thermal Resistance

The ASMT-Mx00 high power LED dissipates approximately 1W of thermal energy. It is crucial to reduce the overall thermal resistance in order to reduce the LED junction temperature to maximize its optical performance. Other than 3 types of aforementioned mounting options, below are additional methods that help to improve the thermal resistance of the system.

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

ii) Attaching the PCB to finned heat sink.

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