

Thermal Management Practical Application for the High Power LED emitters.

A. Introduction

The thermal management design of an LED application is very important to ensure its reliability and optimum performance. The maximum junction temperature of the die inside the package is based on the allowable thermal stress of the package material which can not be exceeded to avoid a catastrophic failure of the device. The following is a brief overview of basic thermal properties followed with examples as reference design which may not be suitable for some practical applications due to a variety of constraints from the system package design aspect or operating conditions.

B. The basic thermal modeling

The thermal resistance of a LED package is defined as the ratio of temperature differences between the junction of the LED and the ambient atmosphere over the power dissipation due to a current flowing through an LED accompanied by a forward voltage drop across the device.

$$R_{\Theta \text{ Junction-Ambient}} = (\Delta T_{\text{ junction - Ambient}}) / P_d \quad (1)$$

Where

$$\Delta T = T_{\text{ junction}} - T_{\text{ Ambient}}$$

$$P_d = \text{Forward current (I}_f\text{)} * \text{Forward voltage (V}_f\text{)}$$

As heat generated at the junction of the LED die, its thermal path can be summarized and modeled as shown in the figure 1.0 below

$$R\Theta_{\text{Junction-Ambient}} = R\Theta_{\text{Junction-Slug (J-S)}} + R\Theta_{\text{Slug-Board(S-B)}} + R\Theta_{\text{thermal interface}} + R\Theta_{\text{Hsk-Ambient(B-A)}} \quad (2)$$

Where

$R\Theta_{\text{Junction-Slug (J-S)}}$ can be found in the specific data sheet

$R\Theta_{\text{Slug-Board(S-B)}}$ includes the thermal resistance from the slug in the die package to the board material

$R\Theta_{\text{thermal interface}}$ is the thermal resistance of the material interface between the MCPCB and the heat sink

$R\Theta_{\text{HSK-Ambient(HSK-A)}}$ is the thermal resistance from the heat sink to ambient air

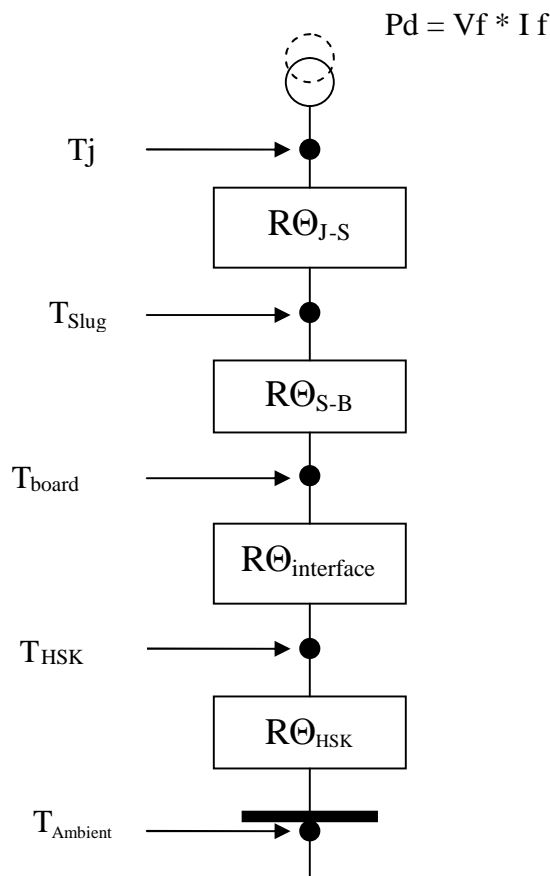


Figure 1: Thermal path Series Resistance Model

For an array of n LED emitters, the total $R\Theta_{\text{junction-board-interface}}$ would follow the equation below

$$1 / R\Theta_{\text{junction-board-interface}} = \sum (1 / R\Theta_{\text{junction-board-interface}})_i \text{ where } i = 1 \dots n$$

$$R\Theta_{\text{Junction-Ambient}} = R\Theta_{\text{junction-board-interface}} + R\Theta_{\text{Hsk-Ambient(B-A)}}$$

$$T_j = T_a + P * [R\Theta_{\text{Junction-Ambient(B-A)}}]$$

C. Thermal Resistance of the Substrate Materials

The thermal resistance is the most important parameter that determines the amount of heat dissipates or travels out of the component. The lower the thermal resistance, the higher ambient temperature that the component can operate. The following table shows the typical thermal resistance of different low thermal resistance (LTI) clad materials from Bergquist (www.bergquistcompany.com) as reference and based on the slug area of 0.01 in² and 0.03 in² of the 5W and 10W emitters, respectively:

Part number	Thermal resistance (⁰ C/W) of the 5 W emitter	Thermal resistance (⁰ C/W) of the 10 W emitter
LTI-04503	4.0	1.64
LTI-06005	7.2	2.96
LTI-07006	8.8	3.61

Table 1: Typical thermal resistance of Bergquist LTI clad materials

For aluminum metal base plate with thermal conductivity of $173\text{W}/\text{m}^{\circ}\text{C}$ and thickness of $0.063''$, its thermal resistance is $\sim 0.03\text{ }^{\circ}\text{C}/\text{W}$. As a result, the thermal resistances of different types of LTI clad materials including the aluminum plate are as followed:

Part number	Thermal resistance ($^{\circ}\text{C}/\text{W}$) of the 5 W emitter family	Thermal resistance ($^{\circ}\text{C}/\text{W}$) of the 10 W emitter
LTI-04503 MCPCB	4.03	1.67
LTI-06005MCPCB	7.23	3.0
LTI-07006 MCPCB	8.83	3.64

Table 2: Typical thermal resistance of MCPCB

D. Thermal Resistance of the Thermal Interface Materials

The thermal interface materials are designed to minimize the thermal resistance between the LED components and their associated heat sink. There are many different types of thermal interface materials: Conductive adhesive tapes, phase change thermal interface, gap fillers, and thermal grease. Each of them has its advantage and disadvantages which can be found in many literatures. Instead, this app. note will focus on its thermal resistance values for comparison based on 5W star MCPCB with diameter, $\phi = \sim 1.7\text{ cm}$, and below is a table for reference

Material Type	Model Name	Manufacturer	Thermal resistance ($^{\circ}\text{C}\text{-in}^2/\text{W}$)	Thermal resistance * ($^{\circ}\text{C}/\text{W}$)
Conductive adhesive tape	T412	Chomerics	0.25@<1psi	0.71
Phase-Change Thermal Interface	T443	Chomerics	0.1@50psi	0.28
Gap Filling	T-	Laird	0.27@20psi	0.55

Material	PLi225	Technologies		
Thermal grease	T660	Chomerics	0.02	0.04

Table 3: Thermal resistance of the thermal interface materials

Note:

*: Based on the interface between an aluminum plate of 1.7 cm diameter and the heat sink (the interface area = 0.35 in²)

E Examples

As mention in the introduction, instead of delve into theory that can be read in many publications, practical examples with the materials like Berquist MCPCB, Alphanovatech heat sink, and the thermal interface materials listed in the table 3 will be referred to as reference design.

Example 1:

Design with a 3W White LED, LE-005003W1G, and given operating temperature of up to 60⁰C, what kind of thermal solution can be used?

Step 1: Find the Power dissipation of the device given in the data sheet. In this example, the Power dissipation of the LE-005003W1G is: $P = 0.7 \text{ Amp} * 4.5 \text{ V} = 3.15 \text{ W}$ -----→ More than 10% over the rated value is chosen: 3.5W

Step 2: Find the thermal resistances of the device, MCPCB, thermal interface from the data sheet

- Thermal resistance of the device shown in the data sheet, $R_{\Theta_{(J-S)}} = 6^0\text{C/W}$
- Thermal resistance of the LTI-04503 MCPCB from Bergquist , $R_{\Theta_{\text{Slug-Board (S-B)}}} = 4.03^0\text{C/W}$ as shown in the table 2.
- Thermal resistance of the material interface: Since it would be a metal core PCB, metal to metal between the heat sink and PCB, Chomerics T412 thermally conductive tape could be used, its thermal resistance $R_{\Theta_{\text{thermal interface}}} = 0.71^0\text{C/W}$ based on the contact area of the star carrier of ~ 0.35 in² as shown in table 3.

Based on the equation

$$T_j = T_a + P * [R_{\Theta \text{ Junction-Slug (J-S)}} + R_{\Theta \text{ Slug-Board(S-B)}} + R_{\Theta \text{ thermal interface}} + R_{\Theta \text{ Hsk-Ambient(B-A)}}]$$

$$125 = 60 + 3.5 * [6 + 4.03 + 0.71 + R_{\Theta \text{ heatsink-Ambient (HSK -Air)}}]$$

$$R_{\Theta \text{ heatsink-Ambient (HSK -Air)}} = 7.80 \text{C/W}$$

For a natural convection heat sink with no air flow, the N40-25B from Alpha Novatech could be used given its thermal resistance of $\sim 6.4^{\circ}\text{C/W}$ in natural convection.

Example 2:

Design with a 5W White LED, LE-005005W1G, and given operating temperature of up to 50°C , what kind of thermal solution can be used?

Step 1: Find the Power dissipation of the device given in the data sheet. In this example, the Power dissipation of the LE-005005W1G is: $P = 1.05 \text{ Amp} * 5.9 \text{ V} = 6.2 \text{ W}$ ----- \rightarrow 10% over the rated value is chosen: 6.82 W

Step 2: Find the thermal resistances of the device, MCPCB, thermal interface from the data sheet

- Thermal resistance of the device shown in the data sheet, $R_{\Theta \text{ Junction-Slug (J-S)}} = 6^{\circ}\text{C/W}$
- Thermal resistance of the LTI-04503 MCPCB from Bergquist, $R_{\Theta \text{ Slug-Board (S-B)}} = 4.03^{\circ}\text{C/W}$ as shown in table 2.
- Thermal resistance of the material interface: Phase change material model T443 from Chomerics as the material interface between the MCPCB and the heat sink could be used, and its thermal resistance, $R_{\Theta \text{ thermal interface}} = 0.28^{\circ}\text{C/W}$ based on the contact area of the star carrier of $\sim 0.35 \text{ in}^2$ as shown in table 3.

Based on the equation

$$T_j = T_a + P * (R_{\Theta \text{ Junction-Slug (J-S)}} + R_{\Theta \text{ Slug-Board(S-B)}} + R_{\Theta \text{ thermal interface}} + R_{\Theta \text{ Board-Ambient (B-A)}})$$

$$125 = 50 + 6.82 * [6 + 4.03 + 0.28 + R_{\Theta \text{ heatsink-Ambient (HSK -Air)}}]$$

$$R_{\Theta \text{ heatsink-Ambient (HSK -Air)}} = 0.69^{\circ}\text{C/W}$$

An active heat sink from Alpha Novatech like the all aluminum FH10040MU with thermal resistance of 0.32°C/W or the all aluminum FH8025MU with thermal resistance of 0.69°C/W would be recommended, and mechanical mounting of the LED is needed.

Example 3:

Design with a 10W White LED, LE-010010W4G, and given operating temperature of up to 55°C , what kind of thermal solution can be used?

Step 1: Find the Power dissipation of the device given in the data sheet. In this example, the Power dissipation of the LE-010010W4G is: $P = 0.7 \text{ Amp} * 18 \text{ V} = 12.6 \text{ W}$ ----- \rightarrow 10% over the rated value is chosen: 13.86W

Step 2: Find the thermal resistances of the device, MCPCB, thermal interface from the data sheet

- Thermal resistance of the device shown in the data sheet, $R_{\Theta \text{ Junction-Slug (J-S)}} = 3^{\circ}\text{C/W}$
- Thermal resistance of the LTI-04503 MCPCB from Bergquist , $R_{\Theta \text{ Slug-Board (S-B)}} = 1.67^{\circ}\text{C/W}$ as shown in table 2
- Thermal resistance of the material interface: Thermal grease T660 from Chomerics as the material interface between the MCPCB and heat sink could be used, its thermal resistance, $R_{\Theta \text{ thermal interface}} = \sim 0.025^{\circ}\text{C/W}$ based on the metal core PCB diameter, $\Phi = \sim 1.0''$.

Based on the equation

$$T_j = T_a + P * (R_{\Theta \text{ Junction-Slug (J-S)}} + R_{\Theta \text{ Slug-Board(S-B)}} + R_{\Theta \text{ thermal interface}} + R_{\Theta \text{ Board-Ambient (B-A)}})$$

$$125 = 55 + 13.86 * [3 + 1.67 + 0.025 + R_{\Theta \text{ heatsink-Ambient (HSK -Air)}}]$$

$$R_{\Theta \text{ heatsink-Ambient (HSK -Air)}} = 0.36^{\circ}\text{C/W}$$

An active heat sink from Alpha Novatech like the FH9040MU with thermal resistance of 0.31°C/W or the all aluminum FH10040MU with thermal

resistance of $0.28^{\circ}\text{C}/\text{W}$ for the 0.983” diameter metal core PCB would be recommended, and mechanical mounting of the LED is needed.

Example 4:

Design with a 15W White LED, LE-015015W4G, and given operating temperature of up to 50°C , what kind of thermal solution can be used?

Due to the LedEngin uniqueness of the patented thermal design, the 15W LED emitter family does not need to have a MCPCB. Instead, it can be attached directly to the heat sink.

Step 1: Find the Power dissipation of the device given in the data sheet. In this example, the Power dissipation of the LE-015015W4G is: $P = 1.05 \text{ Amp} * 18 \text{ V} = 18.9 \text{ W}$ ----- \rightarrow 10% over the rated value is chosen: 20.8W

Step 2: Find the thermal resistances of the device, thermal interface from the data sheet

- Thermal resistance of the device shown in the data sheet, $R\Theta_{\text{Junction-Slug (J-S)}} = 3^{\circ}\text{C}/\text{W}$
- Thermal resistance of the material interface: Thermal grease T660 from Chomerics as the material interface between the LED substrate and heat sink could be used, and its thermal resistance, $R\Theta_{\text{thermal interface}} = \sim 0.26^{\circ}\text{C}/\text{W}$ based on the contact substrate area of 0.076 in^2 .

Based on the equation

$$T_j = T_a + P * (R\Theta_{\text{Junction-Slug (J-S)}} + R\Theta_{\text{thermal interface}} + R\Theta_{\text{Board-Ambient (B-A)}})$$

$$125 = 50 + 20.8 * [3 + 0.26 + R\Theta_{\text{heat sink-Ambient (HSK -Air)}}]$$

$$R\Theta_{\text{heat sink-Ambient (HSK -Air)}} = 0.35^{\circ}\text{C}/\text{W}$$

An active heat sink from Alpha Novatech like the copper-embedded FHC10040MU with thermal resistance of $0.34^{\circ}\text{C}/\text{W}$ for the contact area of 0.076 in^2 could be used, and mechanical mounting of the LED is needed.

If higher operating temperature is required, other cooling methods should be considered, such as, liquid cooling or heat pipe. A typical heat pipe consists of a sealed hollow tube. A thermo conductive metal such as copper or aluminum is used to make the tube. The pipe contains a relatively small

quantity of a "working fluid" with the remainder of the pipe being filled with vapor phase of the working fluid. The advantage of heat pipes is their great efficiency in transferring heat.

F Summary

The basic concept of thermal management detailed in this application note shows the importance of selecting the right materials from the substrate material, thermal interface to the heat sink or other cooling methods to ensure the device operating reliably within the expected ambient temperature range. Additional information about thermal management solutions can be found at:

www.aitechnology.com

www.alphanovatech.com

www.chomerics.com

www.lairdtech.com

www.ctscorp.com

www.dynatron-corp.com

www.bergquistcompany.com

www.cooligy.com

www.ccic.com.tw

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