

## 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 cannot be exceeded to avoid a catastrophic failure of the device. The following is a brief overview of basic thermal properties which needs to be taken into account when designing for the application, followed with examples of thermal calculations which may not be directly 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.

$$R\theta_{\text{Junction-Ambient}} = (\Delta T_{\text{Junction} - \text{Ambient}}) / P_d \quad (1)$$

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

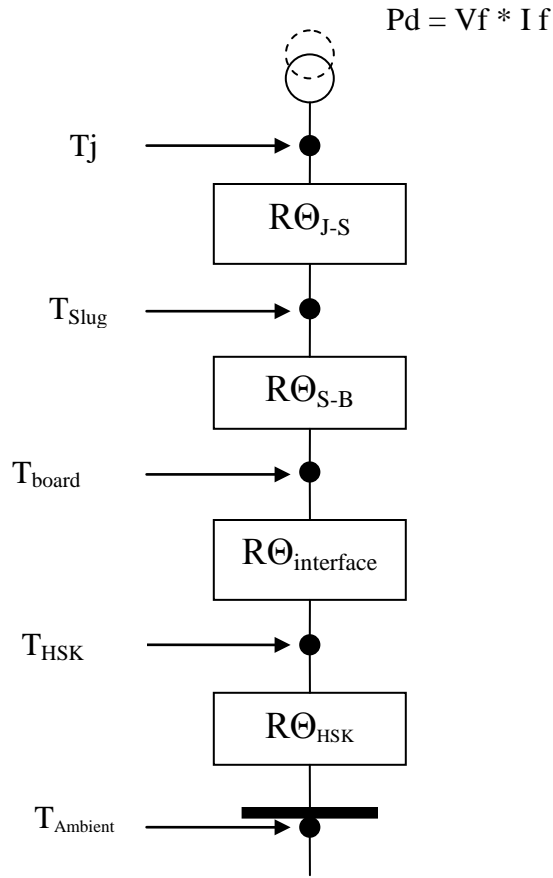


Figure 1: Thermal path Series Resistance Model

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 that can be transferred from the die. The lower the total thermal resistance of the complete stack, the higher the ambient temperature under which the LED can operate. For the thermal resistance of the slug to board the selection of the dielectric material is very important. The higher the thermal conductivity and the lower the thermal impedance of the dielectric layer the easier the heat is transported to the heatsink. The following overview shows the typical thermal performance of clad materials from Bergquist: ([www.bergquistcompany.com/t-clad](http://www.bergquistcompany.com/t-clad))

SINGLE LAYER		THERMAL PERFORMANCE			DIELECTRIC PERFORMANCE		OTHER		
Part Number	Thickness <sup>1</sup> [.000"/μm]	Impedance <sup>2</sup> [°C/W]	Impedance <sup>3</sup> [°C in <sup>2</sup> /W] / [°C cm <sup>2</sup> /W]	Conductivity <sup>4</sup> [W/m-K]	Breakdown <sup>5</sup> [kVAC]	Permittivity <sup>6</sup> [Dielectric Constant]	Glass Transition <sup>7</sup> [°C]	U.L. Index <sup>8</sup> [°C]	Peel Strength <sup>9</sup> [lb/in] / [N/mm]
HT-04503	3/76	0.45	0.05 / 0.32	2.2	8.5	7	150	140/140	6 / 1.1
HT-07006	6/152	0.70	0.11 / 0.71	2.2	11.0	7	150	140/140	6 / 1.1
MP-06503	3/76	0.65	0.09 / 0.58	1.3	8.5	6	90	130/140	9 / 1.6
MULTI-LAYER									
HT-09009	9/229	0.90	0.16 / 1.03	2.2	20.0	7	150	140/140	6 / 1.1
HT-07006	6/152	0.70	0.11 / 0.71	2.2	11.0	7	150	140/140	6 / 1.1
CML-11006*	6/152	1.10	0.21 / 1.35	1.1	10.0	7	90	130/130	10 / 1.8
HIGH POWER LIGHTING									
HPL-03015	1.5/38	0.30	0.02 / 0.13	3.0	2.5	6	185	140/140	5 / 0.9

Method Description: 1 - Optical; 2 - MET-5.4-01-40000- Test Thermal Performance of Insulated Metal Substrates (IMS); 3 - Calculation from ASTM 5470; 4 - Extended ASTM 5470; 5 - ASTM D149; 6 - ASTM D150; 7 - Internal MDSC test RD 2014; 8 - U.L. 746 E; 9 - ASTM D2861  
\*CML is available in prepreg form

Table 1: Summary of thermal performance of Bergquist clad materials

Led Engin is using the Bergquist HT04503 dielectric layer with an aluminum base layer for the star MCPCBs. In table 2 an overview of the typical thermal resistance of LedEngin star boards is presented.

LED	Thermal resistance (°C/W) of the star MCPCB with HT04503
LZ1 series	1.5
LZ4 series	1.1
LZC series	0.6

Table 2: Typical thermal resistance of LED Engin star 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 LZ1 star MCPCB with diameter,  $\phi = \sim 1.6$  cm, and below is a table for reference:

Material Type	Model Name	Manufacturer	Thermal resistance (°C-in <sup>2</sup> /W)	Thermal resistance *(°C/W)
Conductive adhesive tape	T412	Chomerics	0.25@<1psi	0.80
Phase-Change Thermal Interface	T443	Chomerics	0.1@50psi	0.32
Gap Filling Material	T-PLi225	Laird Technologies	0.27@20psi	0.87
Thermal grease	T660	Chomerics	0.02	0.06

Table 3: Thermal resistance of the thermal interface materials

Note\*: Based on the interface between an aluminum plate of 1.6 cm diameter and the heat sink (the interface area = 0.31 in<sup>2</sup>)

## E Examples

As mentioned in the introduction, below one can find some practical examples with the materials like the LED Engin Bergquist star MCPCB, Alphanovatech heat sink, and the thermal interface materials listed in the table 3 as examples for thermal calculations.

### Example 1:

Design with a LZ1 White LED, LZ1-00CW00, with a maximum  $T_j$  of  $150^{\circ}\text{C}$  and given ambient temperature of up to  $40^{\circ}\text{C}$ , 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 LZ1-00CW00 is:  $P = 1 \text{ Amp} * 3.6 \text{ V} = 3.6 \text{ W}$ .

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,  $R\Theta_{\text{Junction-Slug (J-S)}} = 10^{\circ}\text{C/W}$
- Thermal resistance of the LZ1 star MCPCB from Bergquist,  $R\Theta_{\text{Slug-Board (S-B)}} = 1.5^{\circ}\text{C/W}$  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  $R\Theta_{\text{thermal interface}} = 0.71^{\circ}\text{C/W}$  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

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

$$150 = 40 + 3.6 * [10 + 1.5 + 0.8 + R\Theta_{\text{heatsink-Ambient (HSK -Air)}}]$$

$$R\Theta_{\text{heatsink-Ambient (HSK -Air)}} = 18.2\text{C/W}$$

For a natural convection heat sink with no air flow, the N19-20B from Alpha Novatech could be used given its thermal resistance of  $\sim 17^{\circ}\text{C/W}$  in natural convection.

### Example 2:

Design with a LZ4 White LED, LZ4-00CW00, with a maximum  $T_j$  of  $150^{\circ}\text{C}$  and given operating temperature of up to  $50^{\circ}\text{C}$ , 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 LZ4-00CW00 is:  $P = 0.7 \text{ Amp} * 14 \text{ V} = 9.8\text{W}$

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,  $R\Theta_{\text{Junction-Slug (J-S)}} = 1.1^{\circ}\text{C/W}$
- Thermal resistance of the LZ4 star MCPCB from Bergquist,  $R\Theta_{\text{Slug-Board (S-B)}} = 1.1^{\circ}\text{C/W}$  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,  $R\Theta_{\text{thermal interface}} = 0.32^{\circ}\text{C/W}$  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

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

$$150 = 50 + 9.8 * [1.1 + 1.1 + 0.32 + R_{\theta \text{ heatsink-Ambient (HSK-Air)}}]$$

$$R_{\theta \text{ heatsink-Ambient (HSK-Air)}} = 7.7^{\circ}\text{C/W}$$

For a natural convection heat sink with no air flow, the N45-20B from Alpha Novatech could be used given its thermal resistance of  $\sim 6.4^{\circ}\text{C/W}$  in natural convection.

### Example 3:

Design with a LZC White LED, LZC-00CW00, with a maximum  $T_j$  of  $150^{\circ}\text{C}$  and given operating temperature of up to  $55^{\circ}\text{C}$ , 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 LZC-00CW00 is:  $P = 0.7 \text{ Amp} * 42 \text{ V} = 29.4 \text{ W}$

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,  $R_{\theta \text{ Junction-Slug (J-S)}} = 0.7^{\circ}\text{C/W}$
- Thermal resistance of the LZC star MCPCB from Bergquist,  $R_{\theta \text{ Slug-Board (S-B)}} = 0.6^{\circ}\text{C/W}$  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,  $R_{\theta \text{ thermal interface}} = \sim 0.03^{\circ}\text{C/W}$  based on the metal core PCB diameter,  $\Phi = \sim 2.3 \text{ cm}$ .

Based on the equation

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

$$150 = 55 + 29.4 * [0.7 + 0.6 + 0.03 + R_{\theta \text{ heatsink-Ambient (HSK-Air)}}]$$

$$R_{\theta \text{ heatsink-Ambient (HSK-Air)}} = 2.1^{\circ}\text{C/W}$$

For a natural convection heat sink with no air flow, the N90-35B from Alpha Novatech could be used given its thermal resistance of  $1.7^{\circ}\text{C/W}$  in natural convection.

Another option is the ZFlow 65 Par 30 synjet cooler, which is an active cooler from Nuventix.

### Example 4:

Design with a LZP White LED, LZP-00CW00, with a maximum  $T_j$  of  $150^{\circ}\text{C}$  and given operating temperature of up to  $40^{\circ}\text{C}$ , 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 LZP-00CW00 is:  $P = 0.7 \text{ Amp} * 84 \text{ V} = 58.8 \text{ W}$

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,  $R_{\theta \text{ Junction-Slug (J-S)}} = 0.6^{\circ}\text{C/W}$

- Thermal resistance of the LZC star MCPCB from Bergquist ,  $R\Theta_{\text{Slug-Board (S-B)}} = 0.1^{\circ}\text{C/W}$  as presented in datasheet
- 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,  $R\Theta_{\text{thermal interface}} = \sim 0.03^{\circ}\text{C/W}$  on the metal core PCB diameter,  $\Phi = \sim 2.3 \text{ cm}$ .

Based on the equation

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

$$150 = 40 + 58.8 * [0.6 + 0.1 + +0.03 + R\Theta_{\text{heat sink-Ambient (HSK-Air)}}]$$

$$R\Theta_{\text{heat sink-Ambient (HSK-Air)}} = 1.2^{\circ}\text{C/W}$$

An active heat sink from Alpha Novatech like the FH series with a thermal resistance  $< 1^{\circ}\text{C/W}$  or the active cooler Zflow90 Spotlight Cooler 60W from Nuventix could be used.

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 thermoconductive 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.alphanovatech.com](http://www.alphanovatech.com)  
[www.chomerics.com](http://www.chomerics.com)  
[www.lairdtech.com](http://www.lairdtech.com)  
[www.ctscorp.com](http://www.ctscorp.com)  
[www.dynatron-corp.com](http://www.dynatron-corp.com)  
[www.bergquistcompany.com](http://www.bergquistcompany.com)  
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[www.nuventix.com](http://www.nuventix.com)

## **Company information**

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