

# Thermal Management for LED Applications

## What is the role of the PCB?

[http://saturnelectronics.com/thermal\\_pcb\\_design\\_led\\_signup.htm](http://saturnelectronics.com/thermal_pcb_design_led_signup.htm)

### Presented by Clemens Lasance

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# Motivation

## Providing the right information the first time

The goal is to provide the LED application engineer with the right information to select the most optimal MCPCB from a thermal point of view. Thus, ensuring the best decision is made for a specific application in regards to thermal performance and cost.



# Main Goal of Thermal Management

The Calculation of application-specific junction temperatures

## Reasons / Key Issues

- Lifetime
- Color point
- Efficiency

All these key issues are significantly dependent on the junction temperature.



# Basics of Heat Transfer

## Fundamentals of Critical Temperature Calculation

Determining critical temperatures is contingent upon a critical understanding of:

- The electrothermal analogue
- Thermal conductivity  $k$
- Heat transfer coefficient  $h$
- Thermal resistance  $R_{th}$

# Electro-Thermal Analogue

$$?T = q * R_{th}$$



$$?V = I * R$$

Temperature drop (°C)



Voltage drop (V)

Power dissipation (W)



Current (A)

Heat flux (W/m<sup>2</sup>)



Current density (A/m<sup>2</sup>)

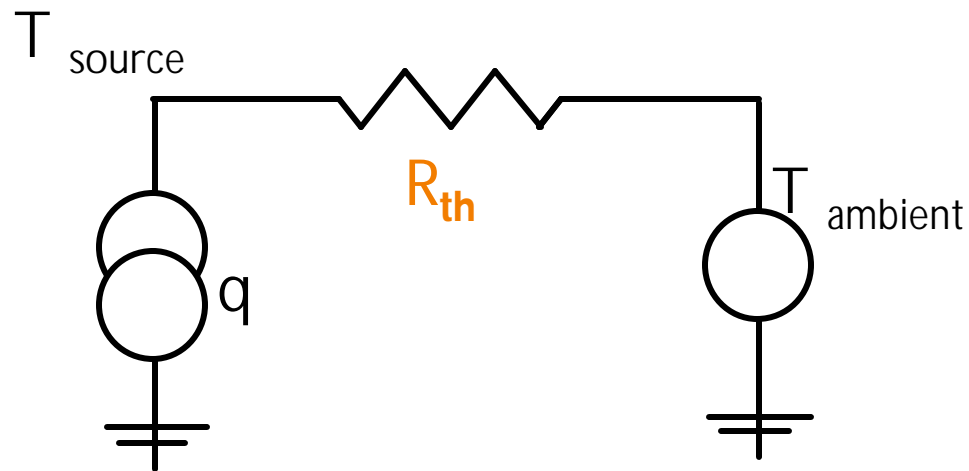
Thermal resistance (K/W)



Resistance (Ohm)

# Electro-Thermal Analogue

A heat transfer path can be described by an electrical network

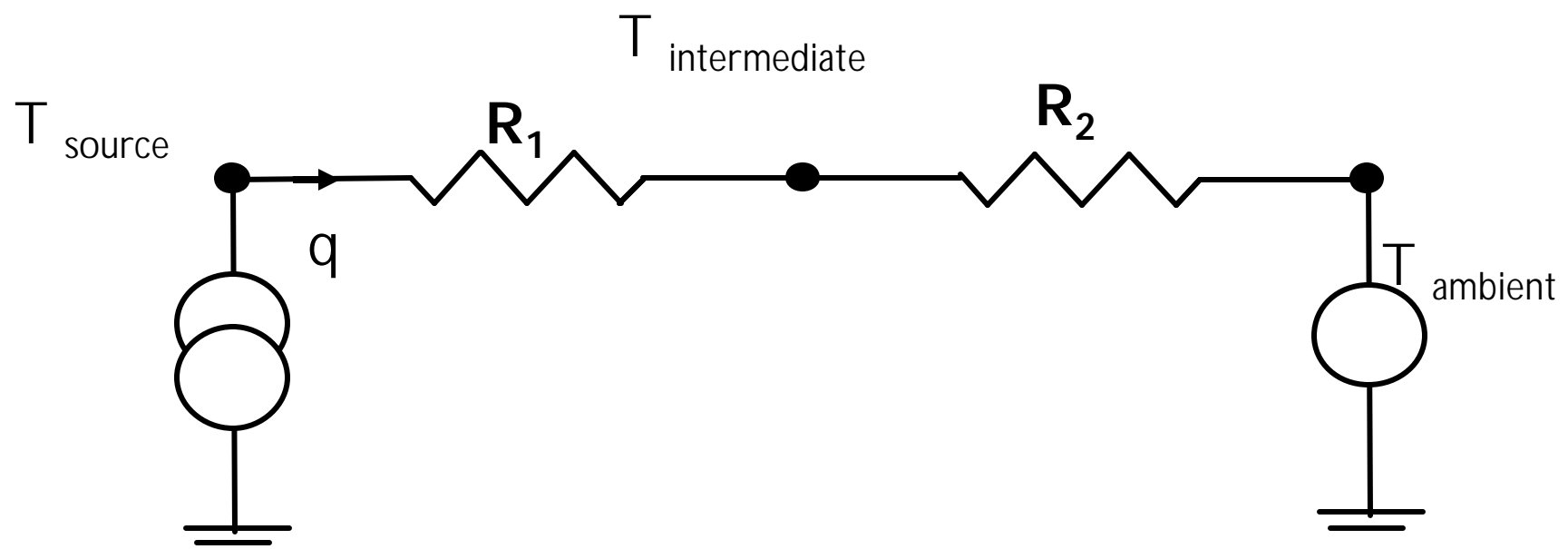


$$? T = T_{\text{source}} - T_{\text{ambient}}$$

$R_{\text{th}}$  (K/W) = thermal resistance

# Series Circuit

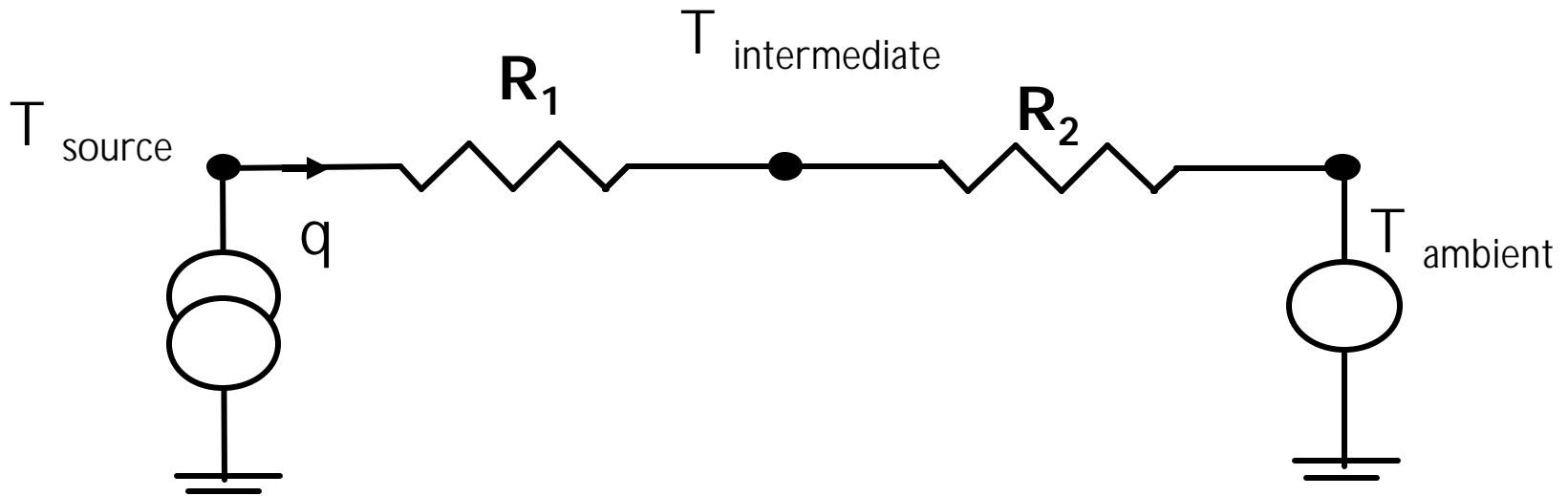
Example for two resistances in series



$$DT = T_{\text{source}} - T_{\text{ambient}} = q * R_{\text{total}}$$
$$R_{\text{total}} = R_1 + R_2$$

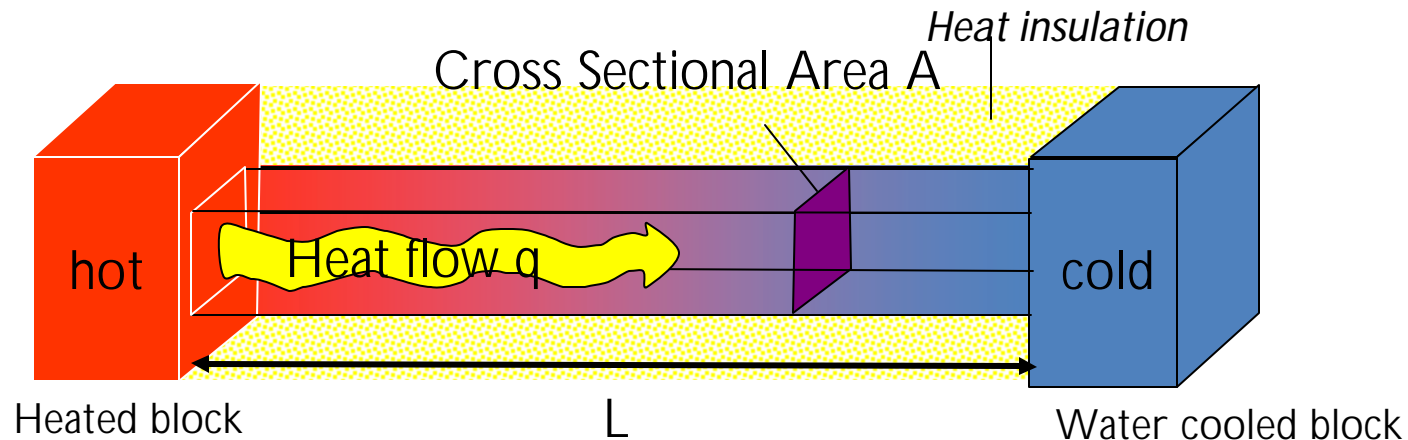
# Consequence of Series Circuit

Often only the largest R is relevant!



Designer's job: find the largest resistance!

# Thermal Conductivity: Fourier's Experiment (1822)



Result of Fourier's experiment:

$$q \sim \Delta T = T_{\text{hot}} - T_{\text{cold}}$$

$$q \sim A = \text{cross-sectional area}$$

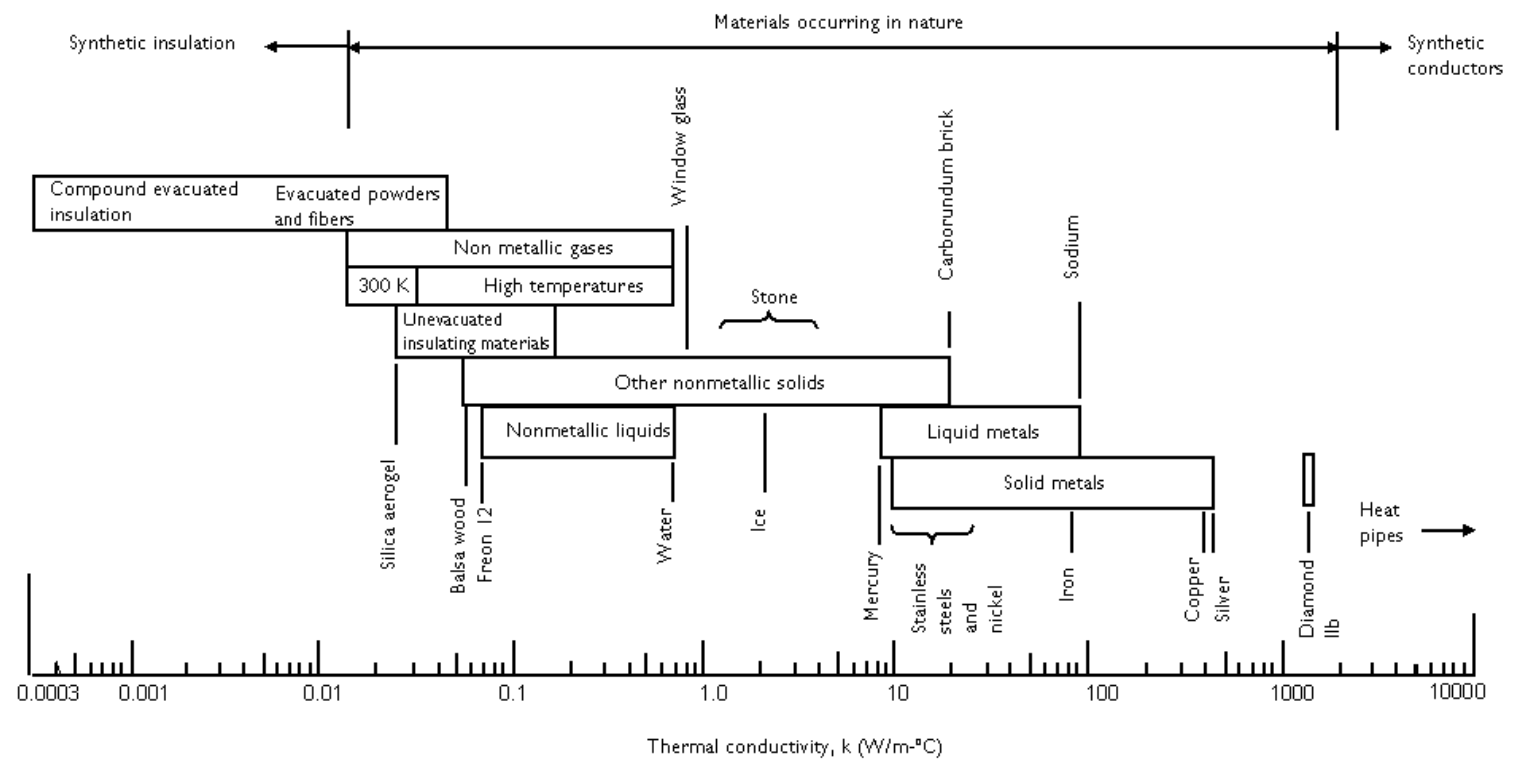
$$q \sim L^{-1}$$



$$q = k \cdot \frac{A}{L} \cdot \Delta T$$

The proportionality constant  $k$  is called the '*thermal conductivity*'

# Typical Thermal Conductivity Values



Approximate ranges of thermal conductivity for various substances  
(All values are in the neighborhood of room temperature unless noted)

# The Heat Transfer Coefficient $h$

The heat transfer from a solid wall into a fluid (air, water) is called convection, and to first order this heat transfer is proportional to the area and the temperature difference between the wall and the fluid:

$$q = h \cdot A \cdot \Delta T$$

The proportionality constant  $h$  is called the  
*'heat transfer coefficient'*

## Typical values:

Natural convection: 10 W/m<sup>2</sup>K

Forced convection: 50 W/m<sup>2</sup>K

## Practice

Suppose a Designer needs 5W to reach a required light output

What procedure is most optimal?

Information required for first order guess:

- Maximum junction temperature: e.g. 120 °C
- Maximum ambient temperature: e.g. 40 °C
- An estimation of all thermal resistances in the total heat transfer path

$$q = \frac{\Delta T}{R_{th-total}}$$

## Practice (2)

### Next steps

- Check if required power is manageable by suitable heat sinks & convection
- Check which thermal resistances are dominant
  - Then focus on them to reduce the total thermal resistance
- Final step should always be a detailed analysis
  - Recall that often we don't talk one-dimensional heat transfer but heat spreading, which is a rather complicated issue
    - For more information please see *Heat Spreading, Not a Trivial Problem* in the May 2008 issue of **ElectronicsCooling**

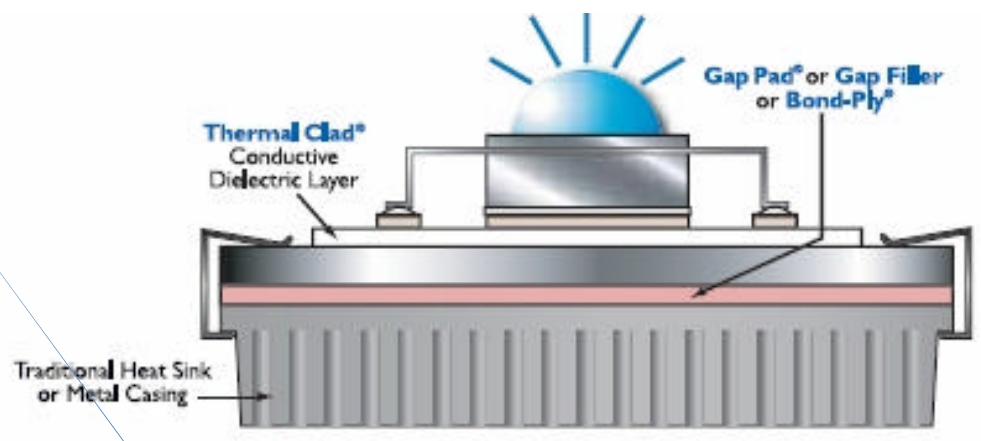
# Practical Example

$$q = k \cdot \frac{A}{L} \cdot \Delta T$$

$$R_{th} = \frac{L}{k \cdot A}$$

$$q = h \cdot A \cdot \Delta T$$

$$R_{th} = \frac{1}{h \cdot A}$$



## Relevant thermal resistances, assume 1 cm<sup>2</sup> PCB

	K/W	
R <sub>th</sub> -LED	16	Luxeon Rebel
R <sub>th</sub> -MCPCB	0.5	t = 100 μm, k = 2 W/mK
R <sub>th</sub> -TIM	1	t = 100 μm, k = 1 W/mK
R <sub>th</sub> -heatsink	50	A = 20 cm <sup>2</sup> , h = 10 W/m <sup>2</sup> K
R <sub>th</sub> -heatsink	2	A = 100 cm <sup>2</sup> , h = 50 W/m <sup>2</sup> K
R <sub>th</sub> -heatsink	1	A = 1 cm <sup>2</sup> , h = 10000 W/m <sup>2</sup> K

# Practical Example

We need 5W for our light output

Can we find a suitable heat sink?



We have:

$$T_{\text{junction}} = 120 \text{ }^{\circ}\text{C}$$

$$T_{\text{ambient}} = 40 \text{ }^{\circ}\text{C}$$

$$R_{\text{th-LED}} + R_{\text{th-MCPCB}} + R_{\text{th-TIM}} = 17.5 \text{ K/W}; R_{\text{th-heatsink}} = ?$$

Can we dissipate 5W? No way:

$$q = 80 / (17.5 + R_{\text{th-heatsink}})$$

$$q = \frac{\Delta T}{R_{\text{th-total}}}$$

Conclusion:

Even with an ideal heat sink ( $R_{\text{th-heatsink}} = 0$ ) we cannot dissipate the required 5W. In this case we need an LED with less thermal resistance.

# Practical Example

We need 1W for our light output

We have again:

$$T_{\text{junction}} = 120 \text{ }^{\circ}\text{C}$$

$$T_{\text{ambient}} = 40 \text{ }^{\circ}\text{C}$$

$$R_{\text{th-LED}} + R_{\text{th-MCPCB}} + R_{\text{th-TIM}} = 17.5 \text{ K/W}; R_{\text{th-heatsink}} = ?$$

Which heat sink is OK?

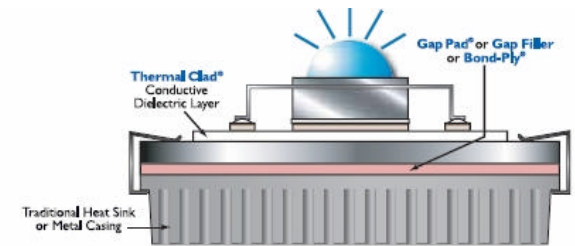
$$q = 80 / (17.5 + R_{\text{th-heatsink}}) ; R_{\text{th-heatsink}} = 62.5 \text{ K/W}$$

We found earlier:

$$A=20 \text{ cm}^2, h=10 \text{ W/m}^2\text{K} \rightarrow R_{\text{th-heatsink}} = 50 \text{ K/W}$$

Conclusion:

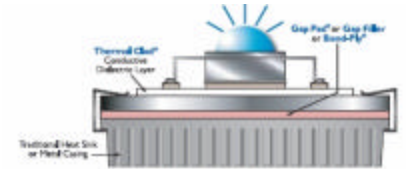
We can use a simple heat sink with natural convection.



$$q = \frac{\Delta T}{R_{\text{th-total}}}$$

# Practical Example Conclusion

## Thermal resistance of the MCPCB does not play any role



- In our first case, the LED thermal resistance was dominant; while in the last case, the convective resistance was dominant.
- Hence, *from a thermal point only*, you can choose MCPCBs with a much lower thermal performance and, hence, lower cost.
- The thermal performance of the PCB is relevant only for very high heat flux cases (e.g. liquid cooling) and for top-of-the-bill LEDs.

## Nomenclature

### The confusing situation regarding '*thermal impedance*'

#### Fact:

'*Electrical impedance*' is historically reserved to describe time-dependent electrical resistance. In the limit of steady state, thermal impedance equals thermal resistance → hence, units should be the same!

#### Hence,

'*Thermal impedance*', as used by U.S. vendors, violates the electro-thermal analogy, because:

- Unit does not correspond (K/W vs.  $m^2K/W$ )
- Definition does not correspond (time-dependent vs. steady state)

#### Is this a problem?

Yes, because time-dependent (dynamic) test methods will be increasingly used, one output of which is the 'correct' thermal impedance.

#### Proposal:

Use thermal resistance per unit area, or unit  $R_{th}$ .