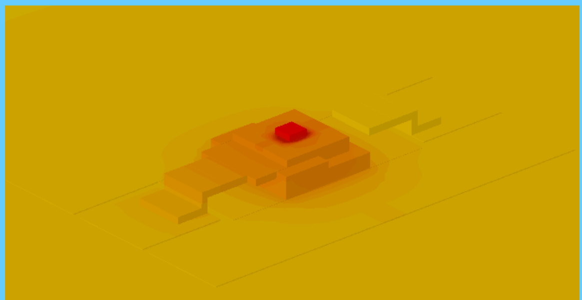
Thermal Management
Thermal Characteristics of LEDs

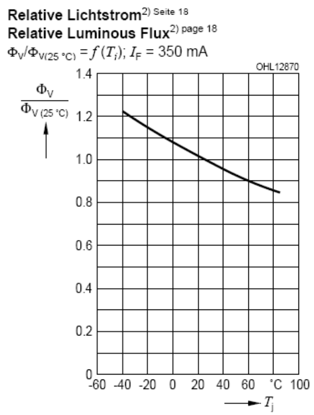
LW W5SG



Increasing

LED Junction Temperature

Light Output ↓



Forward Voltage ↓

Temperaturkoeffizient von V_F Temperature coefficient of V_F I_F = 350 mA; –10°C ≤ T ≤ 100°C	(typ.)	TC_V	–4.0	mV/K

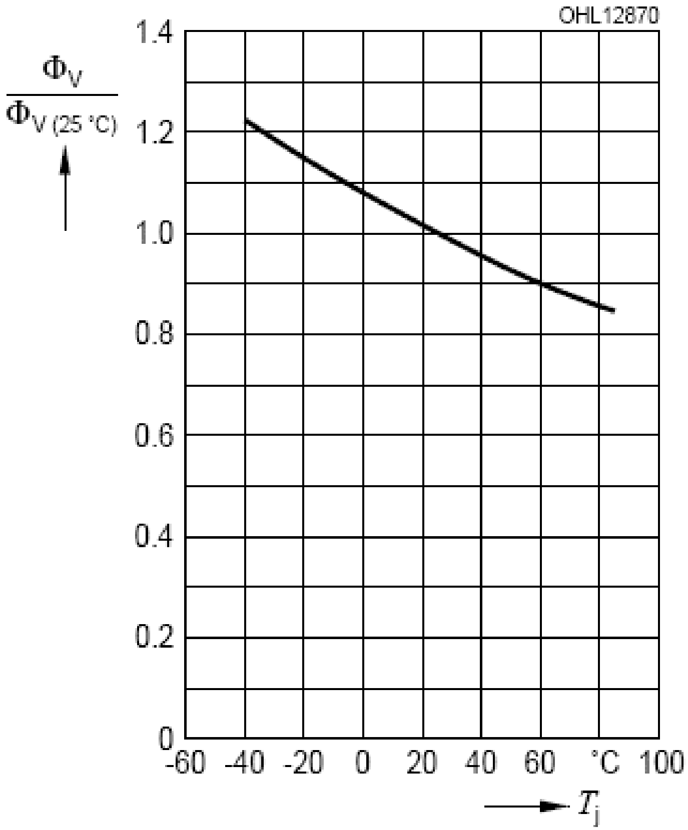
Color Coordinates ↓

Temperaturkoeffizient von x Temperature coefficient of x I_F = 350 mA; –10°C ≤ T ≤ 100°C	(typ.)	TC_x	–0.1	10^{-3}/K
Temperaturkoeffizient von y Temperature coefficient of y I_F = 350 mA; –10°C ≤ T ≤ 100°C	(typ.)	TC_y	–0.2	10^{-3}/K

Characteristics of LED

Thermal Management
Thermal Characteristics of LW W5SG

Relative Lichtstrom[2] Seite 18
Relative Luminous Flux[2] page 18
$\Phi_V/\Phi_{V(25\,°C)} = f(T_j);\ I_F = 350$ mA



Kennwerte
Characteristics
(T_A = 25 °C)

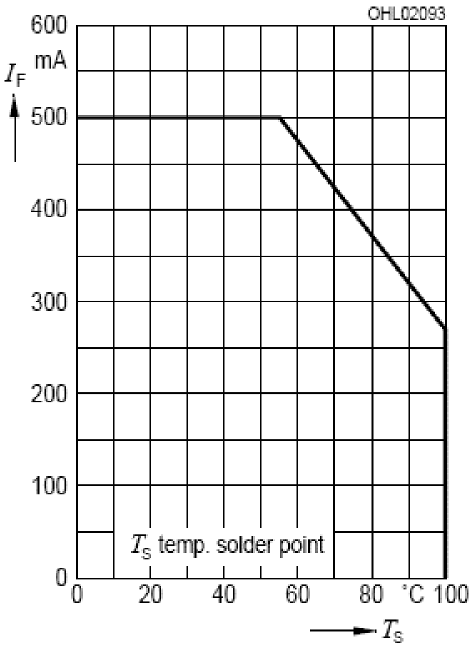
Bezeichnung **Parameter**		**Symbol** **Symbol**	**Wert** **Value**	**Einheit** **Unit**
Temperaturkoeffizient von x Temperature coefficient of x I_F = 350 mA; –10°C ≤ T ≤ 100°C	(typ.)	TC_x	–0.1	10^{-3}/K
Temperaturkoeffizient von y Temperature coefficient of y I_F = 350 mA; –10°C ≤ T ≤ 100°C	(typ.)	TC_y	–0.2	10^{-3}/K
Temperaturkoeffizient von V_F Temperature coefficient of V_F I_F = 350 mA; –10°C ≤ T ≤ 100°C	(typ.)	TC_V	–4.0	mV/K

Grenzwerte
Maximum Ratings

Bezeichnung **Parameter**	**Symbol** **Symbol**	**Wert** **Value**	**Einheit** **Unit**
Betriebstemperatur Operating temperature range	T_{op}	– 40 … + 100	°C
Lagertemperatur Storage temperature range	T_{stg}	– 40 … + 100	°C
Sperrschichttemperatur Junction temperature	T_j	125	°C
Leistungsaufnahme Power consumption (T_A=25°C)	P_{tot}	2.3	W
Wärmewiderstand[4] Seite 18 Thermal resistance[4] page 18 Sperrschicht/Lötpad Junction/solder point	$R_{th\,JS}$	9	K/W

Thermal Management
Failure Mode of LEDs

Maximal zulässiger Durchlassstrom
Max. Permissible Forward Current
$I_F = f(T_S)$



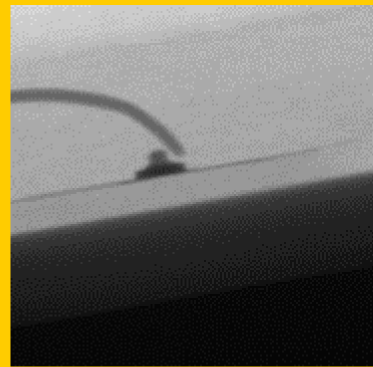
Forward Current > max. allowed I_F

- high current density
- local thermal overstress
- local damage of junction
- growth of non-radiative recombination centres

Strong Light Degradation

Junction temperature > max. allowed T_j

- high mechanical stress on die and wire bond due to thermal expansion within temperature cycles
- open contact between die/leadframe, die/ball bond and broken bond wire may occure



Catastrophic Failure

Thermal Management
Objective of Thermal Management

Ensuring LED's reliable operation with no catastrophic failure.

By preventing LEDs from exceeding the maximum permissible junction temperature.

Ensuring LED's life time with no significant early degradation.

By preventing LEDs from being over-driven within the required ambient temperature range.

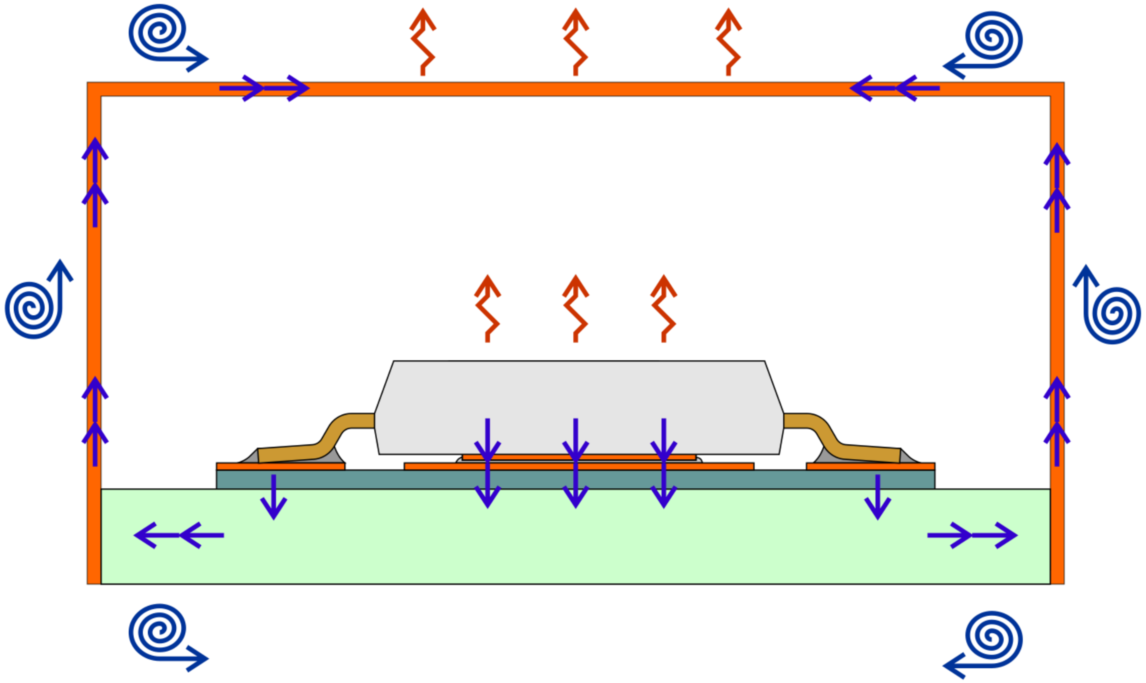
Optimizing LED's optical performance.

By driving the LEDs at the maximum possible current within the required ambient temperature range.

Thermal Management for LEDs

Heat transfer to the surrounding environment by conduction, convection and radiation

Thermal Management
Heat Transfer Modes



Conduction

$$\dot{q} = \frac{k}{s} \cdot \Delta T$$

Convection

$$\dot{q} = h \cdot (T_S - T_A)$$

Radiation

$$\dot{q} = \sigma \cdot \varepsilon \cdot \left(T_1^4 - T_2^4\right)$$

Thermal Management

Heat Transfer from the die to the surrounding environment by conduction, convection and radiation.

Thermal Management Strategy

Cooling Technology

Packaging / Module Related

$R_{th\ JS}$

Thermal Spreader
Materials
Package Geometry

$R_{th\ SB}$

Substrate Technology
Thermal Vias
Heat Spreader

System Related

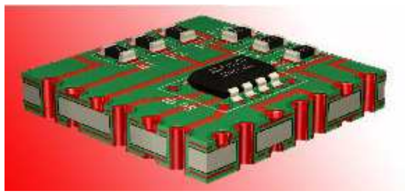
$R_{th\ BA}$

Velocity
Heat Fins

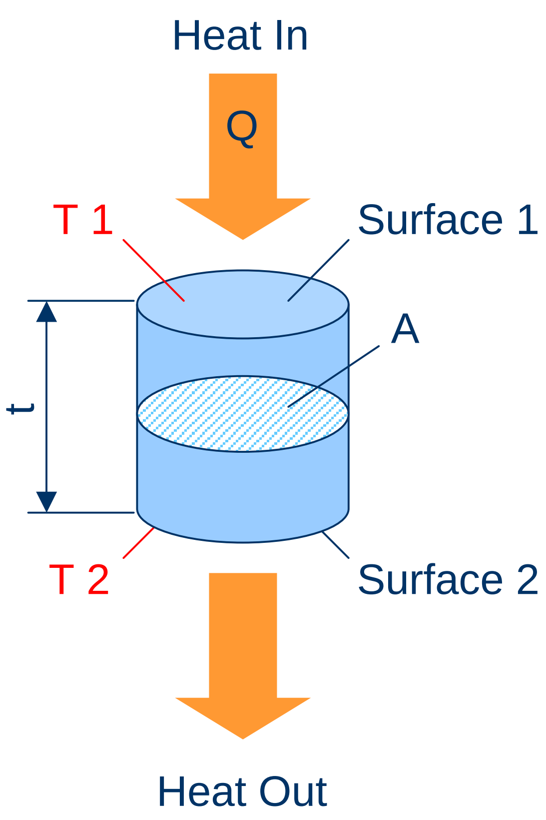
Special Techniques

$R_{th\ BA}$

Thermoelectric
Heat Pipes
Fluid Cooling



Thermal Management
Thermal Resistance

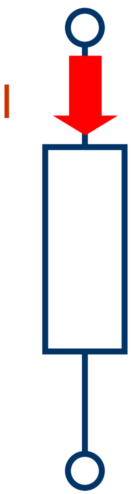


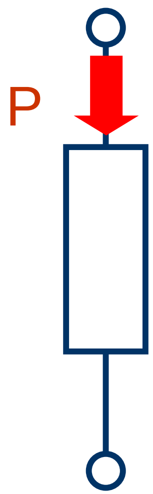
$$R_{th12} = \frac{T_1 - T_2}{Q} \qquad R_{th12} = \frac{t}{A \cdot \lambda}$$

- Thermal resistance is a mathematical concept analogous to the electrical resistance
- "The temperature difference between isothermal surfaces divided by the heat that flows between them is the thermal resistance of the material enclosed between the two isothermal surfaces and the flux tube originating and ending on the boundaries of these two isothermal surfaces. (one dimensional heat conduction)"
- The thermal resistance can also defined as a temperature difference between two reference points divided by the heat
- Definitions:

T	temperature at boundaries [℃]
λ	thermal conductivity [$Wm^{-1}K^{-1}$]
Q	heat flow [W]
t	thickness [m]
A	cross section area [m^2]

Thermal Management Resistance Analogy

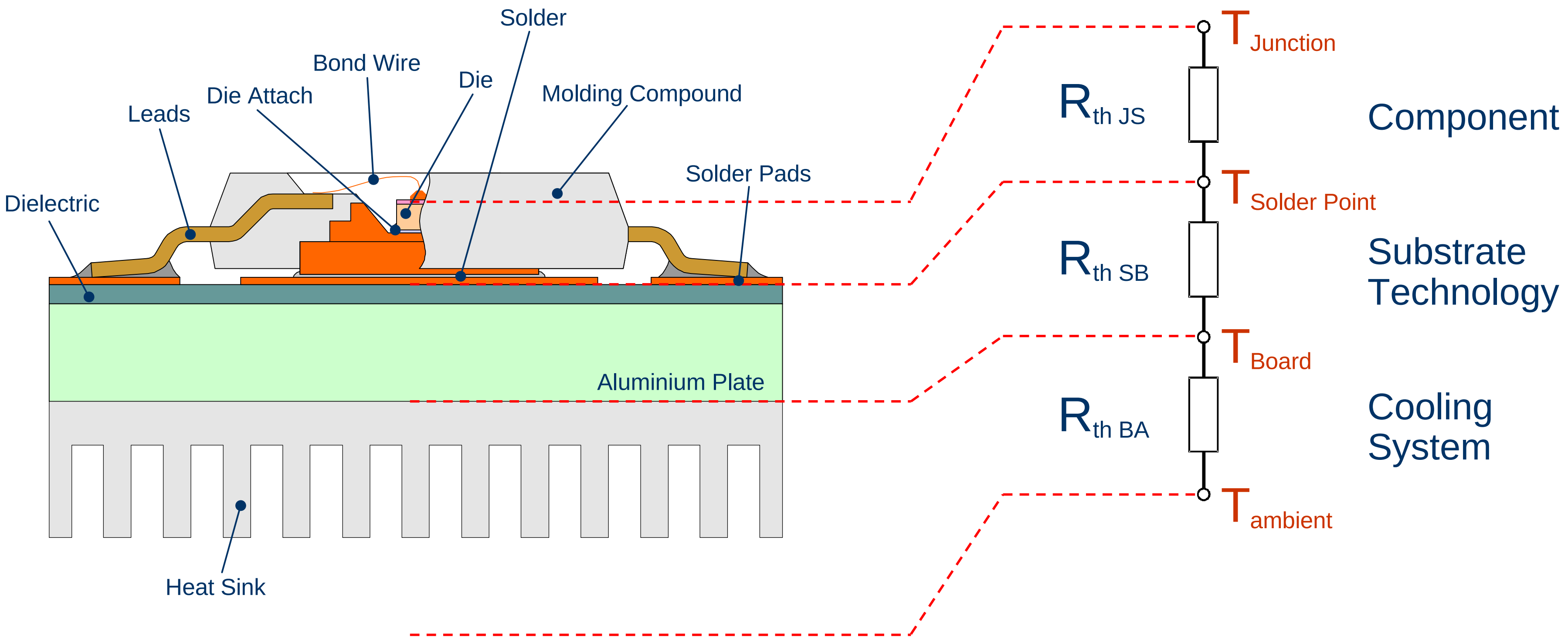
Electrical System				Thermal System	
	U_1	Voltage U [V]	→	Temperature T [V]	T_1
	R	Current I [A]	→	Power Dissipation P [W]	$R_{th\ 12}$
	U_2	Resistance R [A]	→	Thermal Resistance R_{th} [K/W]	T_2



$$I = \frac{U_1 - U_2}{R}$$

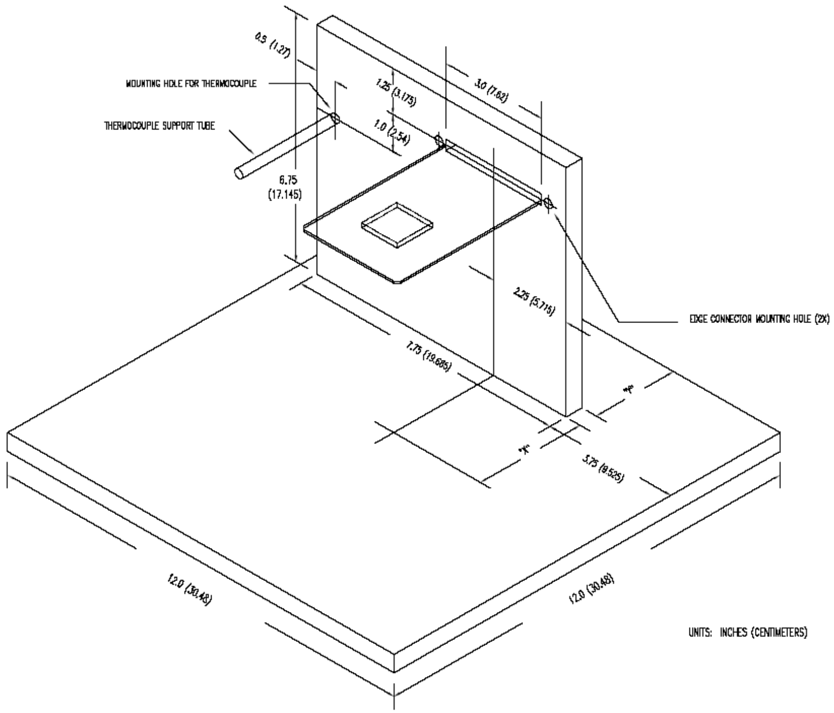
$$P = U \cdot I \qquad P = \frac{T_1 - T_2}{R_{th12}}$$

Thermal Management
Thermal System Configuration



Thermal System Configuration **Thermal Resistor Network**

Thermal Management
Thermal Resistance Rth_{JA}

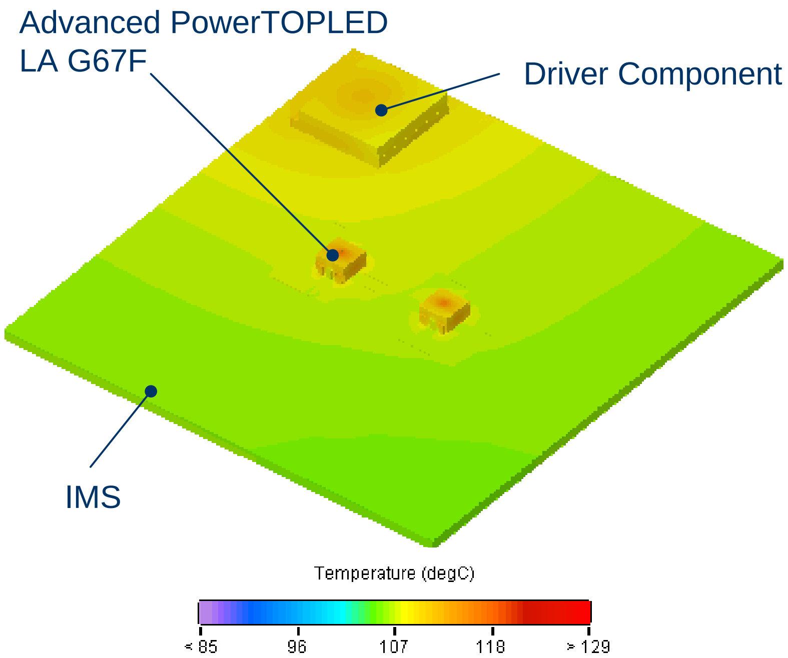


- Based on test environment similar to JEDEC Standard 51 in natural convection (still air)
- The intent of R_{thJA} measurements is solely for a thermal performance comparison of one package to another in a standardized environment.
- This metrology is not meant to and *will not predict the performance of a package in an application-specific environment.*

Thermal Resistance Rth_{JA}

Value should be used with great caution. Usually gives the wrong answer due to differences between the standard and application environment.

Thermal Management
Thermal Resistance Rth_{JA}



T_{amb} = 85 ℃ P_D = 0.3 W

LA G67F

Grenzwerte
Maximum Ratings

Bezeichnung **Parameter**	**Symbol** **Symbol**	**Wert** **Value**	**Einheit** **Unit**
Wärmewiderstand Thermal resistance			
Sperrschicht/Umgebung[4) Seite 15] Junction/ambient[4) page 15]	$R_{th\ JA}$	110	K/W
Sperrschicht/Lötpad Junction/soldering point	$R_{th\ JS}$	60	K/W

T_{amb} = 85 ℃ P_D = 0.3 W

$$R_{thJA} = \frac{T_J - T_A}{P} \qquad T_J = R_{thJA} \cdot P + T_{amb}$$

$$T_J = 110\,\frac{K}{W} \cdot 0.3W + 85°C = 118°C$$

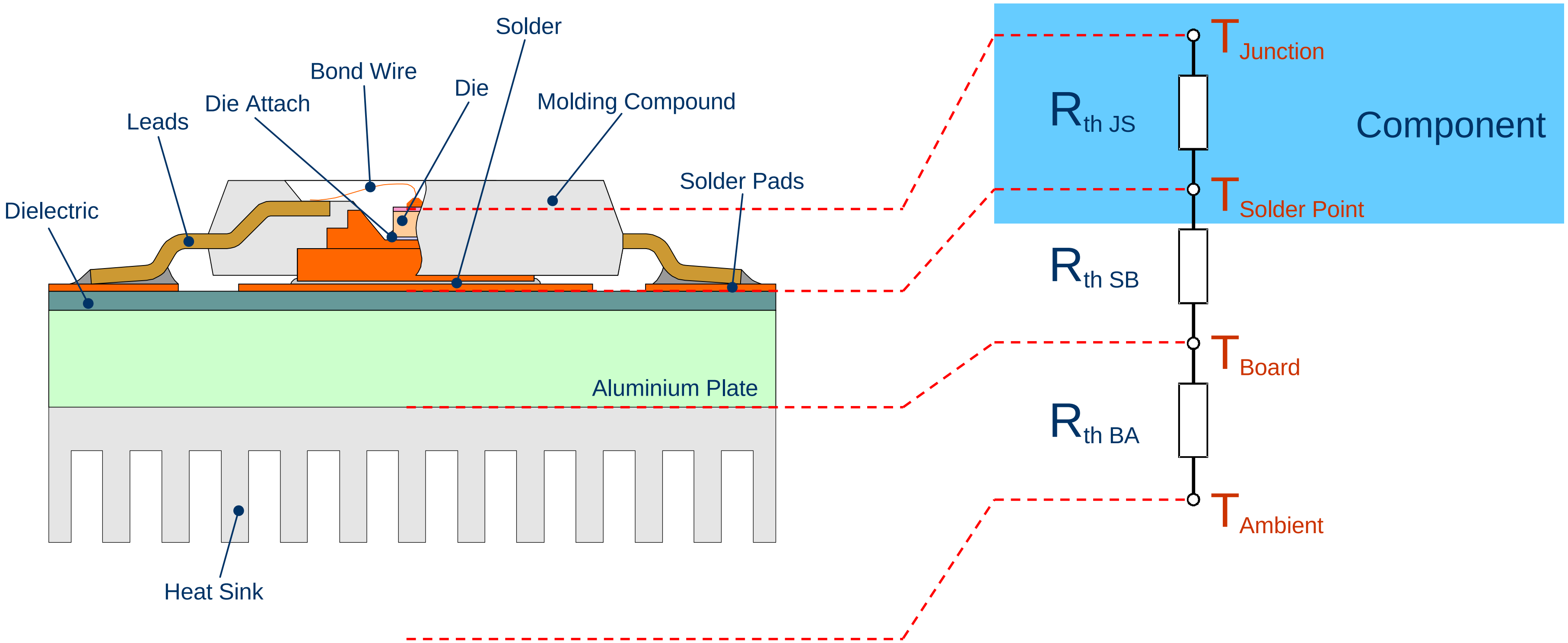
Thermal Simulation

T_{junc} = 128 ℃

Estimation with R_{thJA}

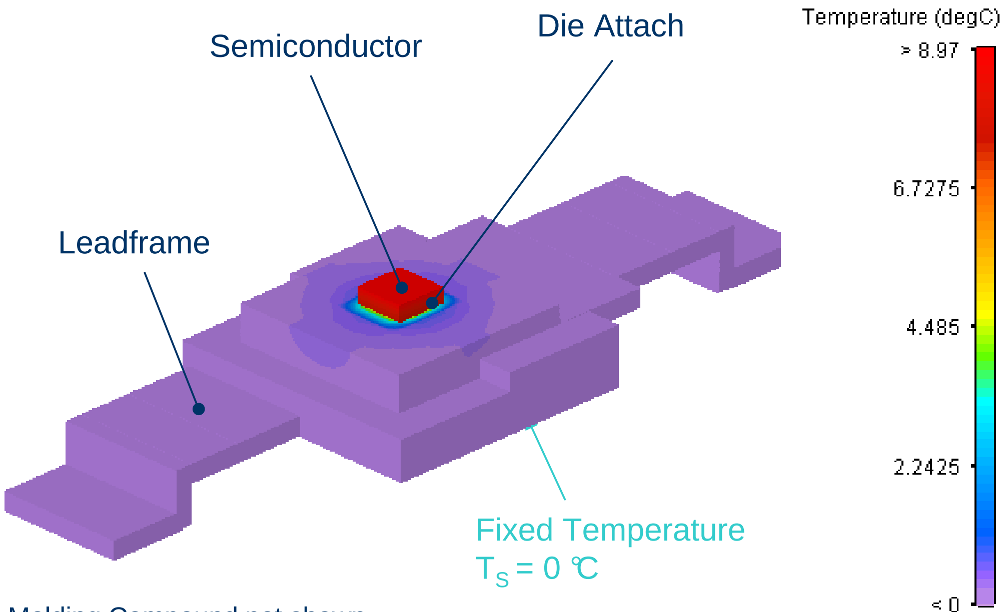
Estimated T_{junc} = 118 ℃

Thermal Management
Thermal System Configuration



Thermal System Configuration **Thermal Resistor Network**

Thermal Management
Internal Thermal Resistance Rth_{JS}



Molding Compound not shown

$T_S = 0\ ℃$

$P_D = 1\ W$

max. $T_{junc} = 8.97\ ℃$

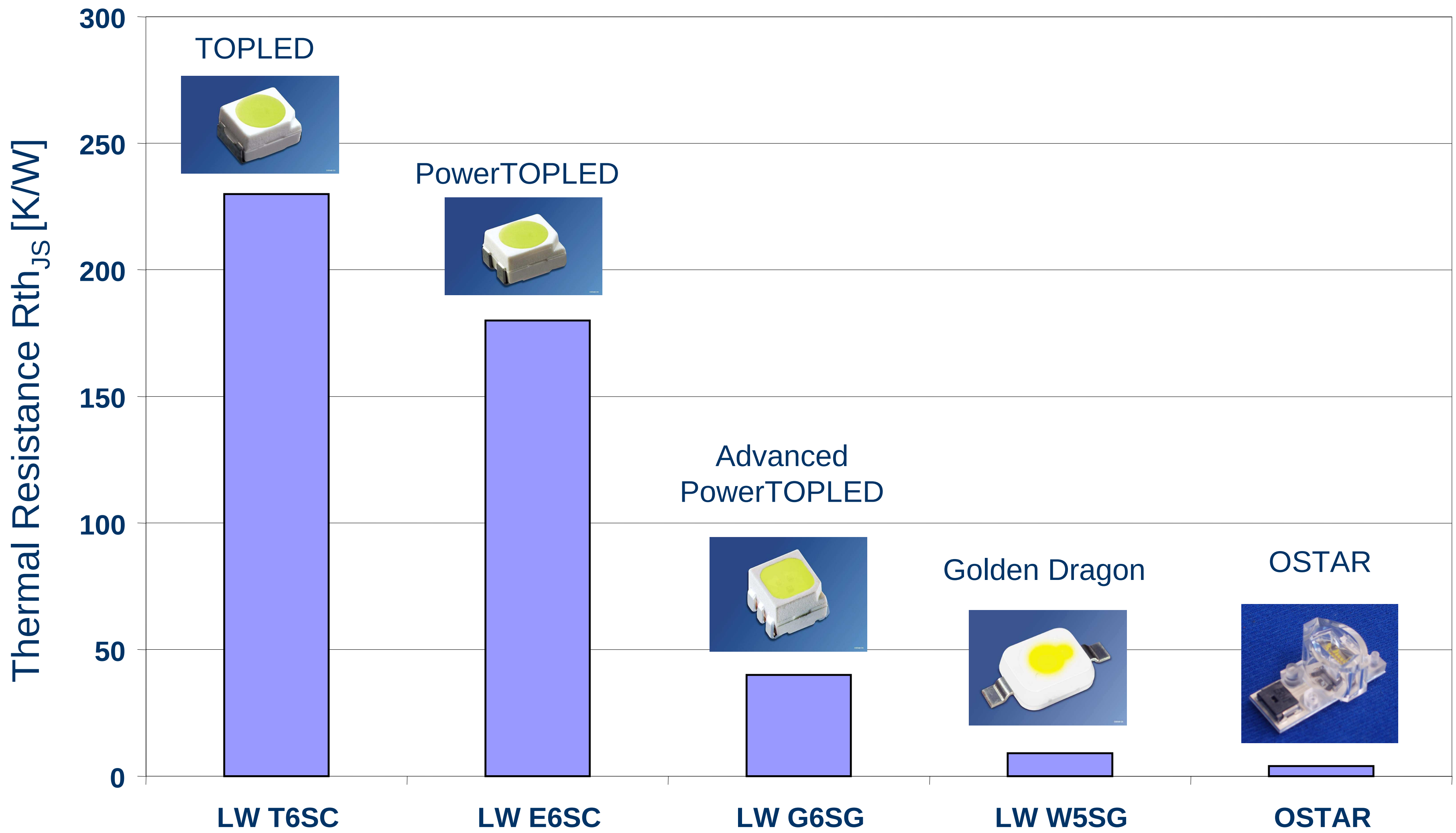
$$R_{thJS} = \frac{T_J - T_S}{P}$$

$$R_{thJS} = \frac{8.97°C - 0°C}{1W} = 9\frac{K}{W}$$

Thermal Resistance Rth_{JS}

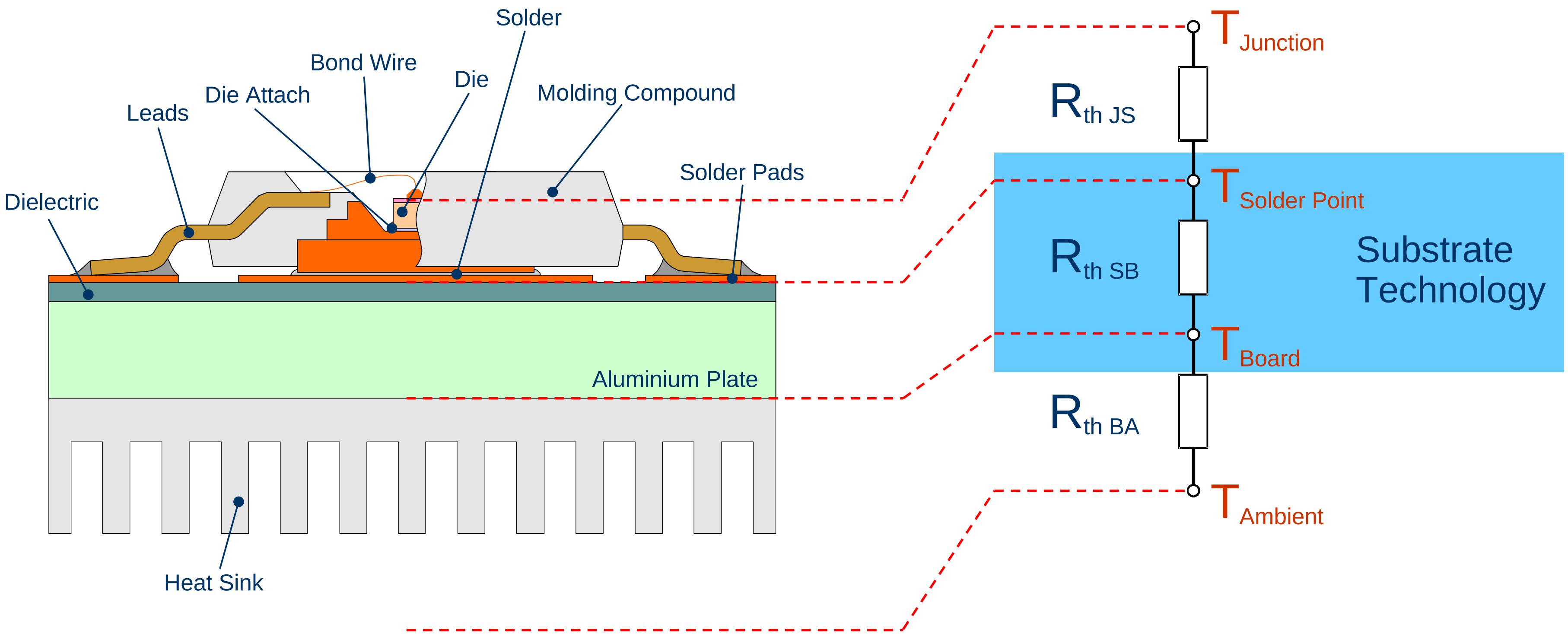
Mainly defined by package construction, e.g. geometry, material selection. Cannot by changed by the customer

Thermal Management
Thermal Package Performance



Opto Semiconductors OSRAM

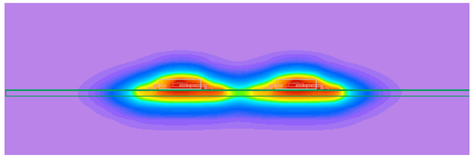
Thermal Management
Thermal System Configuration



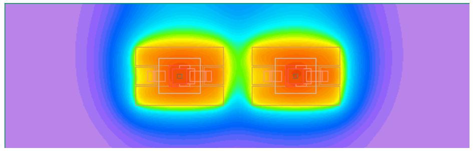
Thermal System Configuration **Thermal Resistor Network**

Thermal Management
External Thermal Resistance Rth_{SB}

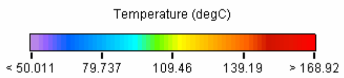
FR4 PCB



Cutting Plane: LEDs



Cutting Plane: PCB

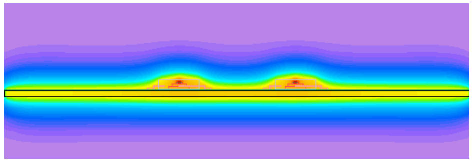


T_{junc} = 168.9 °C

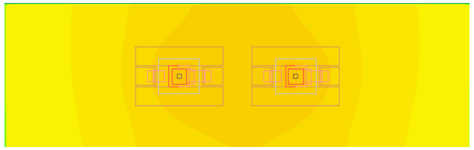
$\Delta T = T_{junc} - T_{amb}$ = 118.9 °C

-55%

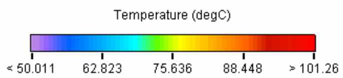
Insulated Metal Substrate



Cutting Plane: LEDs



Cutting Plane: PCB



T_{junc} = 101.3 °C

$\Delta T = T_{junc} - T_{amb}$ = 51.3 °C

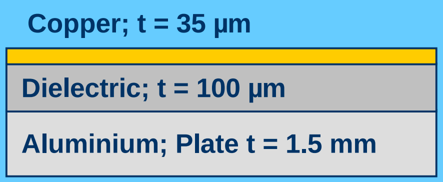
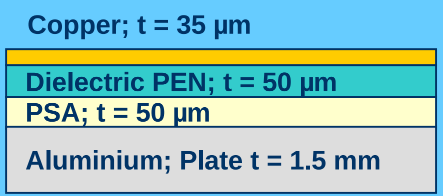
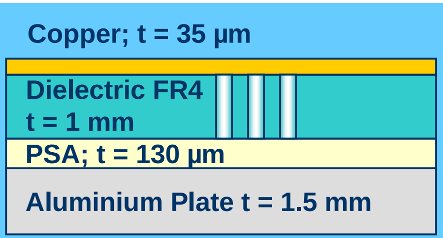
Influencing Factors

- Board material with higher thermal conductivity
- Attach to additional heat spreader (PCB on Aluminium)
- Solder pad layout and placement of other components
- Use of thermal vias

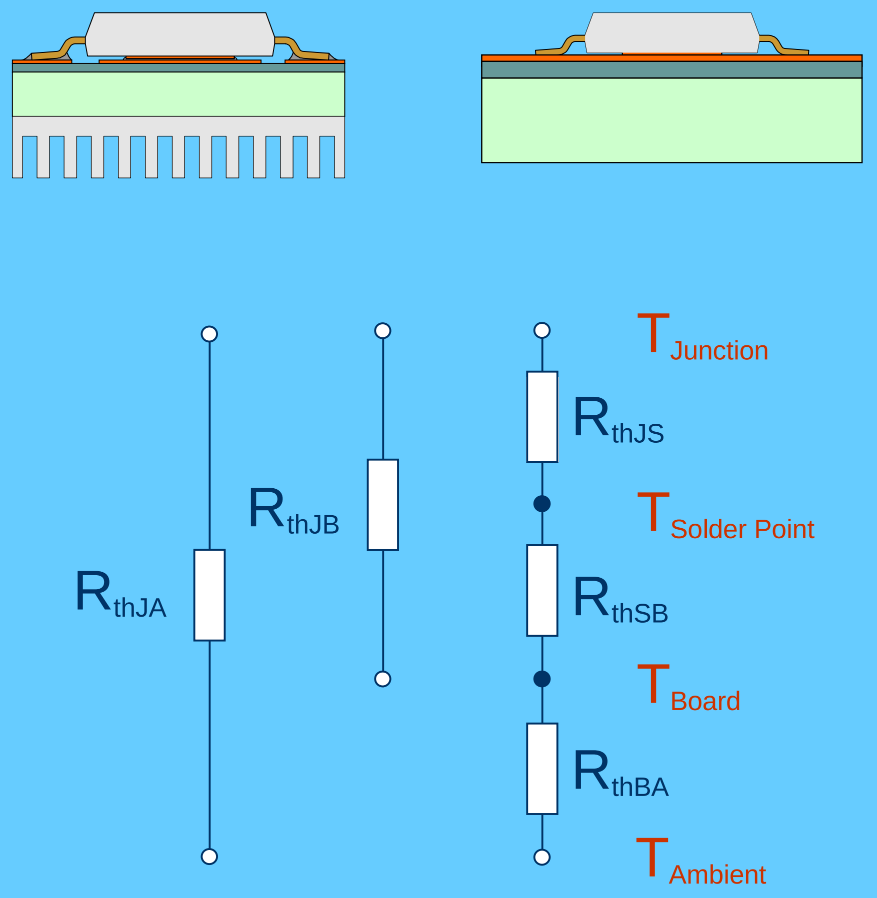
Thermal Resistance Rth_{SB}

Considering the heat transfer trough and within the printed circuit board. The value is application specific.

Thermal Management
Thermal Resistance of Board Material

	Board Material	Rth_{SB}
	IMS with enhanced dielectric	3.5 K/W
	IMS with FR4 dielectric	7.3 K/W
	Flexible PCB on Al with standard PSA	9.5 K/W
	Flexible PCB on Al with enhanced PSA	7.6 K/W
	FR4 with standard PSA and thermal Vias	9.7 K/W

Thermal Management
Estimate Thermal Resistance Rth_{JB} for single LED



Serial Thermal Resistance

- The general equation for thermal serial resistances is:

$$R_{th_{total}} = \sum_{i=1}^{N} R_{th_i}$$

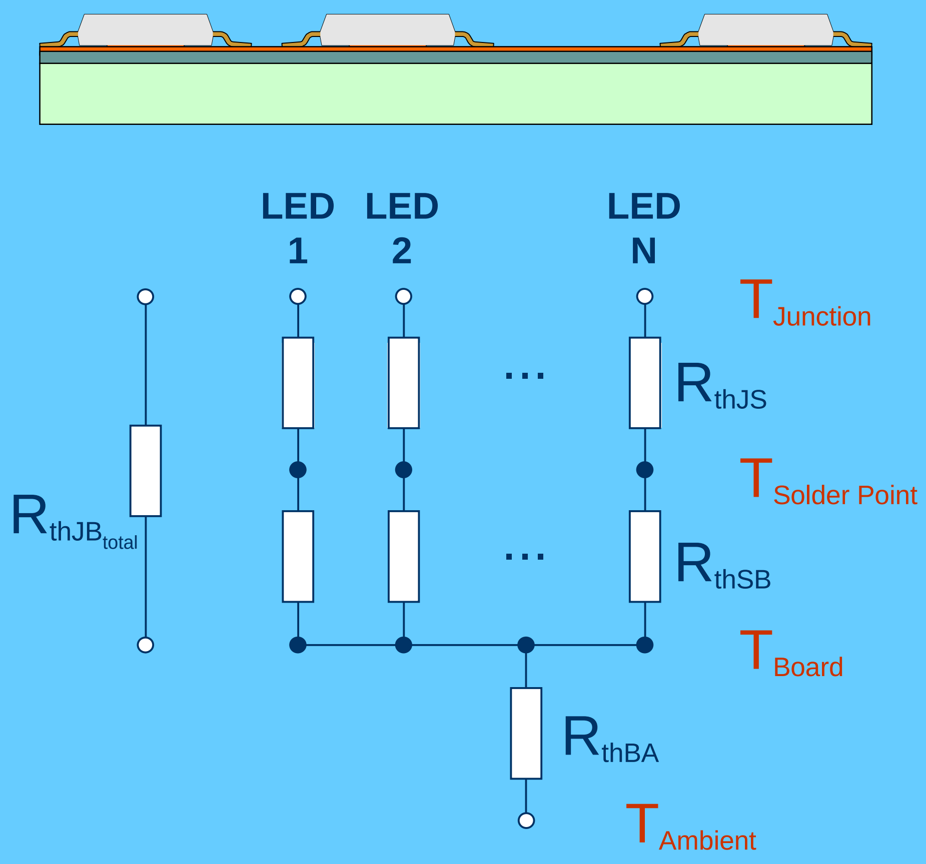
- For a single LED mounted on a substrate the R_{thJB} is:

$$R_{thJB} = R_{thJS} + R_{thSB}$$

- The total thermal resistance R_{thJA} is the sum of components:

$$R_{thJA} = R_{thJS} + R_{thSB} + R_{thBA}$$

Thermal Management
Estimate Thermal Resistance Rth_{JB} for multiple LEDs



Parallel Thermal Resistance

- The general equation for thermal parallel resistances is:

$$\frac{1}{R_{th_{total}}} = \sum_{i=1}^{N} \frac{1}{R_{th_i}}$$

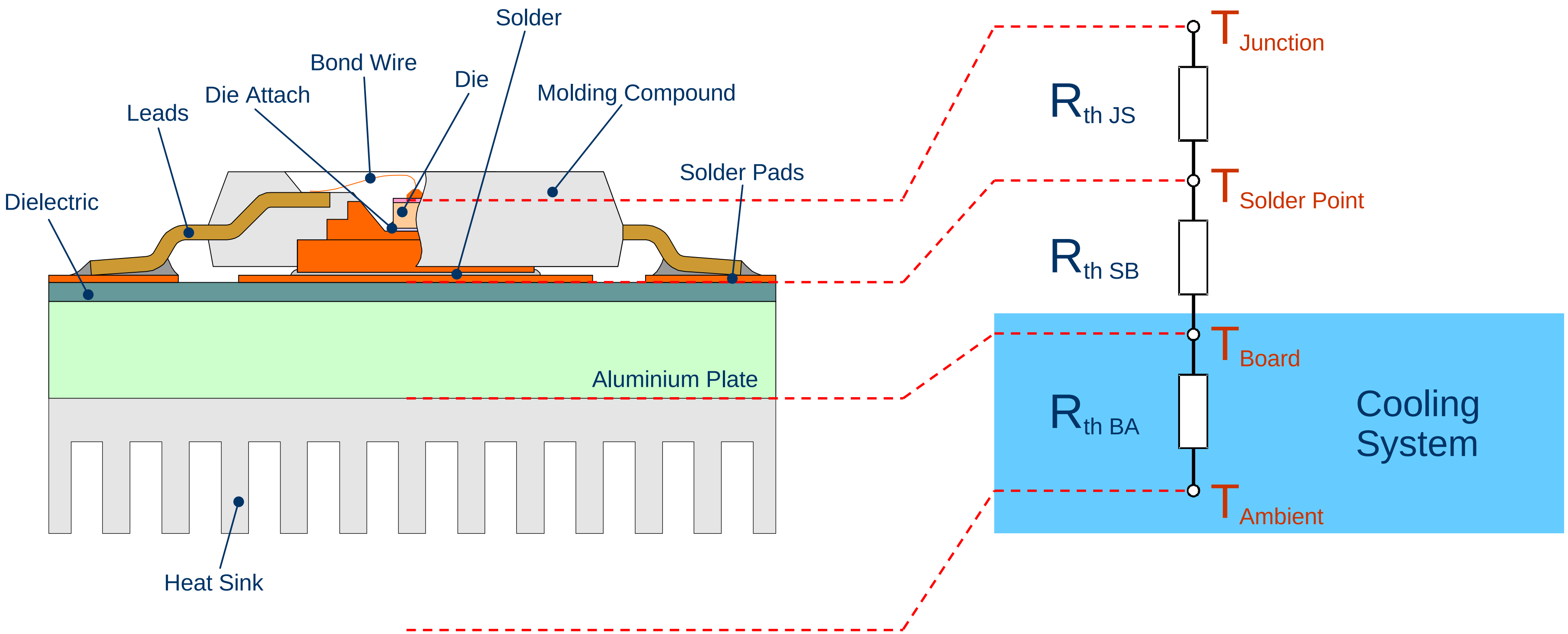
- For multiple LEDs the equation is:

$$\frac{1}{R_{thJB_{total}}} = \sum_{i=1}^{N} \frac{1}{R_{thJS_i} + R_{thSB_i}}$$

- For equivalent parallel thermal resistances:

$$R_{thJB_{total}} = \frac{R_{thJS} + R_{thSB}}{N}$$

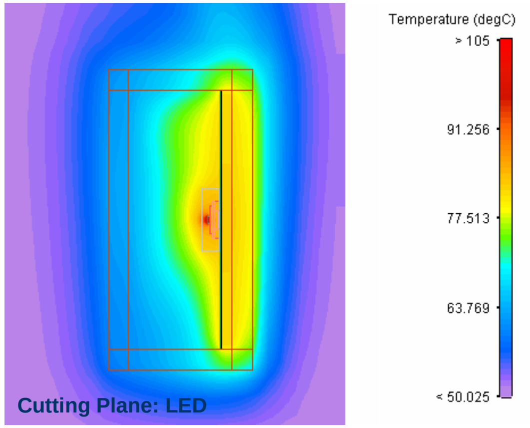
Thermal Management
Thermal System Configuration



Thermal System Configuration **Thermal Resistor Network**

Thermal Management
External Thermal Resistance Rth_{BA}

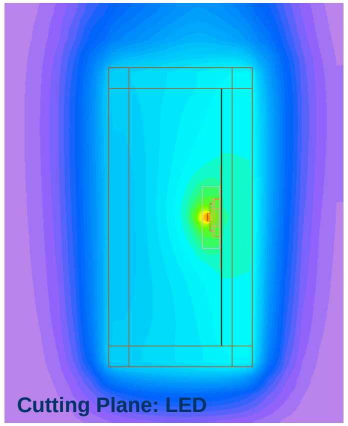
Housing material:
Standard Plastic ($\lambda = 0.3\ Wm^{-1}K^{-1}$)



T_{junc} = 103.2 ℃
$\Delta T = T_{junc} - T_{amb}$ = 53 ℃

-19%

Housing material:
Thermal enhanced plastic ($\lambda = 8\ Wm^{-1}K^{-1}$)



T_{junc} = 93.3 ℃
$\Delta T = T_{junc} - T_{amb}$ = 43 ℃

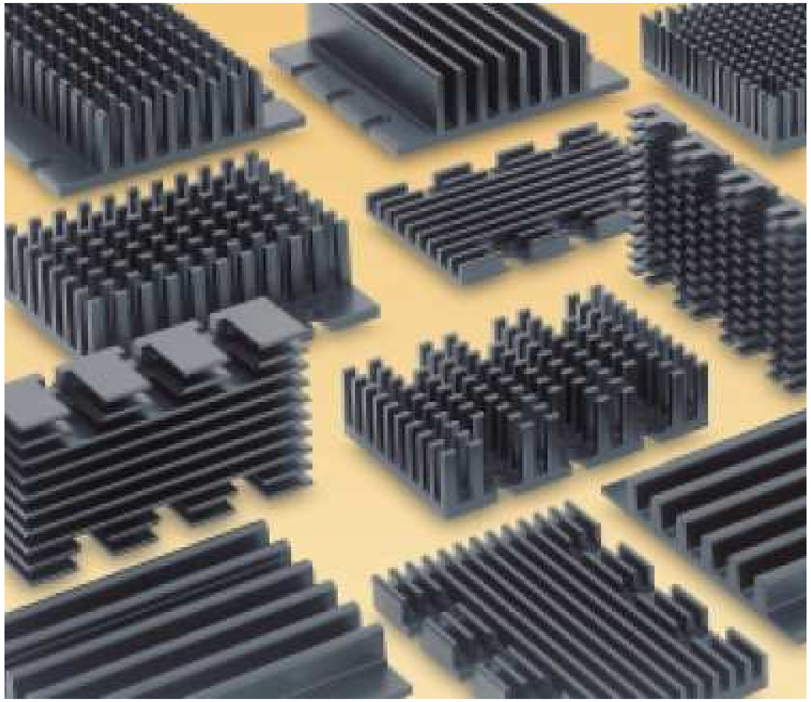
Influencing Factors

- Attach heat sink
- Attach the board housing surface
- Choose housing material with high thermal conductivity
- Use of active cooling (fan)

Thermal Resistance Rth_{BA}

Characterize the heat transfer from the board to the surrounding environment. This value is also application specific.

Thermal Management
Heat Sinks



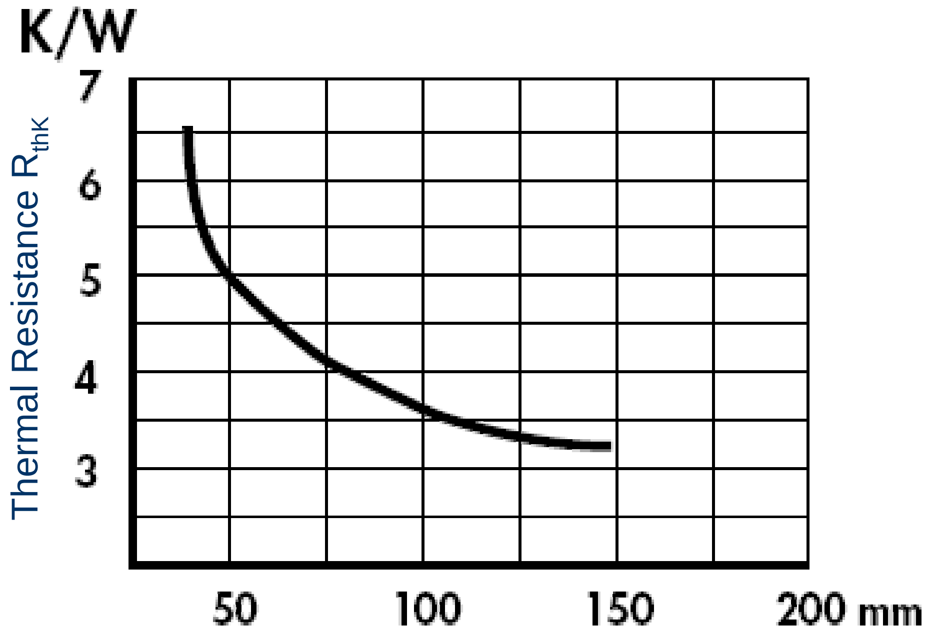
Influencing Factors

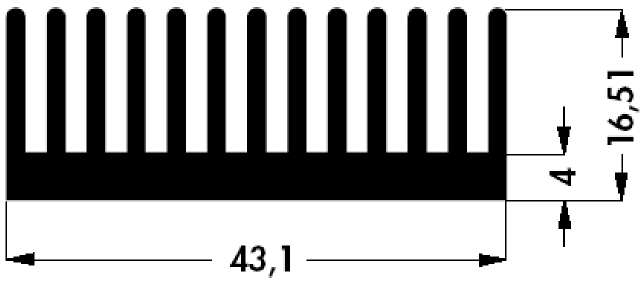
- Air flow conditions
- Material of heat sink
- Orientation with respect to gravity
- Base plate thickness
- Cross sectional geometry
- Fin geometry
- Number of fins
- Spacing of fins

Thermal Resistance Rth_K

Characterize the heat transfer from heat sink to the surrounding environment. This value is also application specific.

Thermal Management
Heat Sink Characteristics





Heat Sink Profile

Thermal Resistance R_{thK}

- There are no agreed international standard methods for determination of the thermal resistance.
- The diagrams and values have been determined under practical operation conditions
- The values indicated in the diagrams apply only for heat sinks with black anodised surface mounted vertically and natural convection

Correction factors:
Natural surface: +10 to 15 %
For horizontal mounting: +15 to 20 %

Thermal Management
Heat Sink Selection

Define boundary conditions	Total Power Dissipation of the system; Max. Ambient Temperature T_{amb}; Max. junction temperature T_j
Estimate system thermal resistance	$R_{thJA} = \frac{T_J - T_A}{P_{total}}$
Estimate heat sink thermal resistance	$R_{thBA} = \frac{T_J - T_A}{P_{total}} - R_{thJB}$ — R_{thJB} depends on the configuration of the LEDs (single, multiple)
Select heat sink thermal resistance	Using the estimated R_{thBA} as a target for a possible heat sink profile and examine the performance curve in the supplier catalogue

Check the design when physical prototypes of the application are available with thermal measurements.

Thermal Management
Reference Information

OSRAM Opto Semiconductors Application Notes

"Thermal Management of SMT LED"

"Thermal Management of Golden DRAGON LED"

"Temperature Measurement with Thermocouples"

Websites about Electronic Thermal Management

www.coolingzone.com

www.mhtl.uwaterloo.ca

www.electronics-cooling.com