Thermal consideration of LEDs in video display applications
Application Note

Introduction

The purpose of this application brief is to show a method to determine the maximum permissible power dissipation of the LEDs in a display application, and allow the junction temperature ($T_J$) to remain below its rated value. Junction refers to the p-n junction within the LED.

In display applications, like the vast other applications, the thermal behavior of the LEDs is an important issue. The view ability requirements of the displays for indoor or outdoor applications lead the designer in some cases to drive the LED at or over their rated limits to achieve the performance needed. This increases the temperature inside the LED and therefore lowers the permissible ambient temperature at these driving conditions, since the temperature inside the LED is directly related to the ambient temperature. Thus, a thorough understanding of the thermal characteristics of LEDs for display applications is useful for several reasons:

a) To ensure a proper operation of the devices for higher reliability

b) Extend operating life of the LEDs by preventing over-stressing drive conditions

c) Enhance the light output performance by driving the LED at the maximum possible current

In order to maintain a long and reliable operation of the LEDs it is significant that the device junction temperature does not rise over a crucial value. Once this value is known the development and design of PCB-layout can begin.

The first section in this paper shows how to use the ratings and the diagrams in OSRAM OS data sheets to obtain the electrical and thermal properties of the LEDs.

Section 2 addresses to thermal aspects of LEDs in display applications and the factors the junction temperature is composed of.

Section 3 describes a procedure to practically determine the junction temperature of the LEDs.

Section 4 evaluates the junction temperature and the maximum permissible power dissipation of the LEDs in a Display application.

The last section shows various methods of reducing the LED junction temperature in order to improve the thermal performance of the devices in displays.

Section 1: Typical data sheet information

The device data sheet presents the performance capabilities of a given LED. OSRAM OS LED data sheets contain three tables of data. The first table is the device selection guide and presents the basic optical characteristics of the device. The color of emission, the color of light emitting area and the range of axial luminous intensity at ambient temperature $T_A = 25^\circ C$, per given current, are listed in this table. Additionally, for most of the LEDs, and for some of the LEDs only, the range of luminous flux is listed in this table.
The second table contains the absolute maximum ratings. This table is very important for the thermal properties of the LED. The operating and storage temperature range, maximum forward and surge currents, maximum power consumption, maximum LED junction temperature, junction to ambient thermal resistance $R_{thJA}$ and the junction to solder point thermal resistance $R_{thJS}$ listed in this table. The thermal resistance and its relation to the junction temperature are discussed in the application note “Thermal management of SMD LEDs”.

The last table, titled Characteristics at $T_A = 25^\circ C$ contains the spectral data. For instance, wavelength at peak emission, dominant wavelength, spectral bandwidth and viewing angle, as well as the forward voltage at a given current and some data concerning the temperature coefficient of the above mentioned values.

In addition to the tables, LED data sheets contain graphs determining the operational conditions of the devices (Figure 1-4).

![Figure 1: Forward current vs. forward voltage](image1)

![Figure 2: Relative luminous intensity vs. Ambient temperature](image2)
Section 2: Thermal aspects of the LEDs in application

Figure 5 shows a typical setup of a LED in the display application. LEDs are mounted on a Printed Circuit Board (PCB) with or without driving circuits on the backside. This board is mounted in an enclosure that protects it from the environmental hazards like wetness and dirt.

According to the configuration in Figure 5, the junction temperature of the LED is affected by the following factors:

1) Thermal resistance of the LED (R_{th_{JS}})
2) Thermal resistance of the solder pad (R_{th_{pad}})
3) Power dissipation of the LED
4) Impact of the power density of all the devices on PCB
5) Thermal resistance of the enclosure (R_{th_{enclosure}})

This section deals with the above factors and eventually the estimation of the junction temperature incorporating all these factors.
Thermal resistance

Once a LED is driven at a current the power dissipated within the LED converts to a high percentage into the heat. This heat is produced inside the LED, at the PN-junction. The junction temperature \( T_J[^\circ C] \), is the sum of the ambient temperature \( T_A[^\circ C] \), and the temperature rise caused by the power dissipated in the LED, which is the product of this power dissipation, \( P_{LED} \) [W], and the thermal resistance junction-to-ambient, \( R_{thJA}[\text{K/W}] \).

\[
T_J = T_A + P_{LED} \times R_{thJA} \tag{1}
\]

and thus

\[
R_{thJA} = \frac{\Delta T}{P_{LED}} ; \text{ with } \Delta T = T_J - T_A \tag{2}
\]

The thermal resistance of a LED is comprised of different paths. The primary thermal path for the heat dissipation is the junction to the solder point. This is for the most of the LEDs the cathode lead. This portion is defined as the thermal resistance junction-to-solder point \( R_{thJS} \). This device thermal resistance is given by the package geometry and the material the LED.

The second path is the solder point to the surrounding environment. This thermal resistance solder point-to-ambient \( R_{thSA} \) is subjected to big fluctuations, since it is a function of PC board material and the cathode pad size. This PC board mounting assembly thermal resistance added to the device thermal resistance gives the overall thermal resistance junction-to-ambient \( R_{thJA} \).

\[
R_{thJA} = R_{thJS} + R_{thSA} \tag{3}
\]

Thermal resistance according to the Data Sheet

For most OSRAM LEDs, the thermal resistance given in the data sheet is based on a thermal resistance solder point-to-ambient \( R_{thSA} \), for a pad area of usually 16mm\(^2\) and a FR4 PC board. This value is valid only for a single LED mounted on a PC board of large area (>600mm\(^2\)) within a specific environment.

Table 1 and 2 show the characteristic thermal resistance for some OSRAM LEDs.

These tables illustrate the thermal resistance junction-to-ambient \( R_{thJA} \) for a LED mounted on a FR4 PC board, which is given in the OSRAM LED data sheet. In addition, it includes the thermal resistances for different kind of PCBs. The virtual thermal resistance of the Multi TOPLED in table 2, for different driving conditions, is due to the impact of the adjacent dice.

The ratings and diagrams in a data sheet are given for a single LED with a defined solder pad area. For the vast majority of applications, especially indoor display application, the pad size does not match the size mentioned in the data sheet, and the LEDs are mounted with adjacent devices. A closer study of the thermal behavior of the LED in this configuration will be considered.


<table>
<thead>
<tr>
<th>Power TOPLED® And TOPLED®</th>
<th>R_{thJA} [K/W]</th>
<th>R_{thJS} [K/W]</th>
<th>Number of cathode pads x Pad area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flex-Board (PEN, GHE)</td>
<td>FR4</td>
<td>MCPCB (Aluminium core)</td>
<td>On an ideal heat sink</td>
</tr>
<tr>
<td>LB E67C</td>
<td>440</td>
<td>350</td>
<td>210</td>
</tr>
<tr>
<td>LY E67B</td>
<td>390</td>
<td>300</td>
<td>160</td>
</tr>
<tr>
<td>LO E67B</td>
<td>390</td>
<td>300</td>
<td>160</td>
</tr>
<tr>
<td>LA E67F</td>
<td>390</td>
<td>300</td>
<td>160</td>
</tr>
<tr>
<td>LT T673</td>
<td>400</td>
<td>230</td>
<td>180</td>
</tr>
<tr>
<td>LB T673</td>
<td>400</td>
<td>230</td>
<td>180</td>
</tr>
<tr>
<td>LA T676</td>
<td>500</td>
<td>330</td>
<td>280</td>
</tr>
</tbody>
</table>

Table 1: Thermal resistance of some TOPLED®s mounted on different kind of PC boards

<table>
<thead>
<tr>
<th>MULTI TOPLED®</th>
<th>R_{thJA} [K/W] on FR4 PCB (with cathode pad size 16 mm² each)</th>
<th>Number of turned on Chips in the 3 Chip package</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amber (615 nm)</td>
<td>true green (525 nm)</td>
</tr>
<tr>
<td>LATB T686</td>
<td>580</td>
<td>480</td>
</tr>
<tr>
<td>LATB T686</td>
<td>685</td>
<td>570</td>
</tr>
<tr>
<td>LATB T686</td>
<td>825</td>
<td>770</td>
</tr>
</tbody>
</table>

Table 2: Thermal resistance of OSRAM RGB-Multi TOPLED LATB T686 with 3 Chips in one package

**Thermal resistance for different pad area**

As the first step, the thermal resistance, solder point-to-ambient \( R_{thSA} \), can be estimated for different PC board materials, by measuring the thermal resistance of different pad sizes on the printed circuit boards. The thermal resistance \( R_{thSA} \) as a function of solder pad area is illustrated in Figure 6.

The main thermal path of the LED is through the bottom of the die, in most cases the cathode pin. Therefore, for layout, this solder pad should be considered as the cathode.

In the LED data sheets of OSRAM OS, the value of thermal resistance junction-to-ambient \( R_{thJA} \) is stated for a particular cathode pad area. To estimate the thermal resistance junction-to-ambient \( R_{thJA} \) for a different cathode pad area, the thermal resistance difference, according to Figure 6, should be added or deducted from this value, respectively.
Figure 6: Solder pad thermal resistance for MCPCB and FR4

Example:

What is the thermal resistance of a TOPLED LA T676 mounted on a FR4 PC board on a cathode pad of 5mm²?

According to the data sheet the thermal resistance junction-to-ambient for FR4 and a cathode area of 16mm² is:

\[ R_{\text{thJA}}(16\text{mm}^2) = 500\text{K/W} \]

For FR4 according to Figure 6:

\[ R_{\text{thSA}}(16\text{mm}^2) \approx 230\text{K/W} \]
\[ R_{\text{thSA}}(5\text{mm}^2) \approx 330\text{K/W} \]

\[ \Delta R_{\text{thSA}} = R_{\text{thSA}}(5\text{mm}^2) - R_{\text{thSA}}(16\text{mm}^2) = 100\text{K/W} \]

Thus, for a cathode pad of 5mm²:

\[ R_{\text{thJA}}(5\text{mm}^2) = R_{\text{thJA}}(16\text{mm}^2) + \Delta R_{\text{thSA}} = 500\text{K/W} + 100\text{K/W} = 600\text{K/W} \]

Using equation (1) for junction temperature, the maximum allowable current for a defined ambient temperature can be determined. However, this basic thermal resistance equation can give a misleading result, if external heat sources (devices) are mounted near the LED. Therefore, the impact of total power density on the PCB must be added to the total junction temperature.

Impact of the power density on PCB

Another factor, which causes an elevation of the junction temperature, is the dense mounting of the LEDs on PC board, which affects the overall heating of the PC board.

Physically, the transition of generated heat in a solid device to air occurs by heat convection and heat radiation. For devices mounted on a PCB or a heat sink, the flow of heat occurs primarily by conduction. This causes the PCB to experience an increase in temperature. This heating is influenced by three factors, the power dissipation of the devices mounted on the PCB, the density of
mounted devices and the airflow velocity around the PCB.

In a display application, the PC boards are mounted in two ways. Either the LEDs and driver devices are mounted on separate PC boards, or they are all mounted on one PC board with LEDs on one side and the driver devices on the backside.

In the first case, the distribution of the heat on the PC board is more even, since the only heat-generating devices are the LEDs, which are placed in a grid arrangement.

The heat distribution in the latter case is more gradient. This is due to the driver devices being mounted unevenly on the backside of the PC board. The heat generated by these devices passes through the PC board and reaches the LEDs mounted on the other side of them.

Therefore, these LEDs experience higher junction temperature than the LEDs, which do not have any devices placed on the backside of the same PC board. On the other side, the LEDs in the middle of the PC board are subjected to more heat than the one close to the edges of the PC board. Therefore, it is recommended to either mount the driver devices on a separate PC board or place them close to the edges of the PC board.

The temperature elevation ($\Delta T_D$) due to the power dissipation of the devices can be simplified, by assuming that the heat distribution on the whole PC board is uniform.

Figure 7 shows the elevation of temperature ($\Delta T_D$), as a function of power dissipation over the PC board area. The power dissipation in the case that devices are mounted on both sides of the PC board is the summation of the power, dissipated by all of these devices, where as the area is counted only once. The PC board, in this case, is positioned horizontally, without any externally forced airflow.

![Figure 7: Warm up of the PCB due to the convection and radiation of heat generated by mounted devices](image-url)
For the FR4 typ PCB, the curve in Figure 7 has a linear region that can converge, to the following equation:

$$\Delta T_D = k \times P_D - k_0$$

(terms: $P_D > 0.2\text{mW/mm}^2$)

where:

$\Delta T_D$ = temperature elevation due to the power density on PCB

$P_D$ = Power density

$k$ & $k_0$ = parameter

For the worst case the equation can be approximated to:

$$\Delta T_D = 28\ [\text{Kmm}^2/\text{mW}] \times P_D - 4.2\text{K}$$

(terms: $P_D > 0.2\text{mW/mm}^2$)

**Example:**

What is the additional heat due to the LED array as the Figure 8 for a FR4 PCB?

$X$ = 5mm

Area: $A$ = 15mm $\times$ 15mm = 225mm$^2$

Forwards current: $I_f$ = 10mA (average)
Forward voltage: $U_f$ = 2.0V (for a red LED)

Power dissipation of each LED:

$P_{\text{LED}} = I_f \times U_f = 10\text{mA} \times 2.0\text{V} = 20\text{mW}$

Number of LEDs: 9

Total power dissipation on the PCB:

$P_T = 9 \times 20\text{mW} = 180\text{mW}$

Power density:

$P_D = 180\text{mW} \div 225\text{mm}^2 = 0.8\text{mW/mm}^2$

Thus, the heat increase due to the power density on the PCB is about

$\Delta T_D = 15\text{K} \text{ to } 20\text{K}$.
Thermal resistance of the enclosure

A display panel is generally set up in an enclosure. It is important to realize that the ambient temperature is the temperature of the air surrounding the LEDs. That means the temperature inside the enclosure, which is higher than the temperature out of the enclosure due to the heat, generated by the electronics it contains. To estimate the junction temperature of the LEDs the difference between the internal and external temperature of the enclosure, shown in Figure 9, should be taken into account.

Figure 9: Thermal resistance of the enclosure

Since the thermal resistance is associated with the conduction of the heat, a thermal resistance for the enclosure can be defined as the ratio of the temperature difference between the inside and the outside of the enclosure \((T_A - T_{A2})\) to the rate of the heat transfer between these two areas. Assuming all the electrical power for all the devices inside the enclosure dissipated in the form of heat, an equation for the thermal resistance of the enclosure can be written as follows:

\[
R_{\text{thEN}} = \frac{T_A - T_{A2}}{P_T}
\]

where:

- \(R_{\text{thEN}}\) = thermal resistance of the enclosure
- \(T_A\) = temperature inside the enclosure
- \(T_{A2}\) = temperature outside the enclosure
- \(P_T\) = total power dissipation of all devices inside the enclosure

As conclusion, the junction temperature can be estimated as the equation below, illustrating how the previously described factors interact.

\[
T_J = T_{A2} + (P_{\text{LED}} \times R_{\text{thJA}}) + \Delta T_D + P_T \times R_{\text{thEN}}
\]

where:

- \(T_{A2}\) = ambient temperature
- \(P_{\text{LED}}\) = power dissipation of the LED
- \(R_{\text{thJA}}\) = thermal resistance junction-to-ambient
- \(\Delta T_D\) = temperature elevation due to the power density on PCB
- \(P_T\) = power dissipation of all the devices inside the enclosure
- \(R_{\text{thEN}}\) = thermal resistance of the enclosure

Section 3: Practical determination of junction temperature

For LED arrays in display applications, it is almost difficult to determine the exact value of solder point-to-ambient thermal resistance, thus revealing the heating temperature of the solder point. Figures 6 and 7 give merely an estimation, and might be ideal for early evaluations of solder pad areas bigger than 5mm². For very small solder pads, measurements on LED assemblies must be performed in order to determine the solder point-to-ambient thermal resistance, and eventually the junction temperature of the LED.

For this measurement, the thermal resistance junction-to-solder point \((R_{\text{thJS}})\) of the device under test (DUT), is assumed to be the typical value of the thermal resistance \((R_{\text{thJA}})\) given in the data sheet, minus 240K/W. The latter being the thermal resistance solder point-to-ambient of the single LED, with a solder pad area of 16mm². This value is taken from Figure 6.
For example: The value of \((R_{\text{thJS}})\) of the OSRAM LED LA T676 is:

\[
R_{\text{thJS}} = R_{\text{thJA}} - R_{\text{thSA}} = 500\,\text{K/W} - 240\,\text{K/W} = 260\,\text{K/W}
\]

This is the same value given in table 1.

By making this assumption, measuring the solder point temperature, which delivers the thermal resistance solder point-to-ambient \((R_{\text{thSA}})\), can be performed to calculate the \((R_{\text{thJA}})\) and junction temperature \((T_J)\), respectively. Following the simplified procedure for measuring the \((R_{\text{thJA}})\) and therefore \(T_J\) is described.

1. Assume the \((R_{\text{thJS}})\) of the LED under test, is what was mentioned above, or take the value given in the data sheet.

2. Pick one LED on the PCB to be used as the DUT. The hottest LED should be chosen. This is usually the LED in the middle of the LED array. A LED close to a resistor can be tested as well.

3. Solder a small thermocouple onto the cathode pin of the DUT. This is for radial LEDs near the top surface of the PCB. The thermocouple should be \(\leq 0.25\,\text{mm}\) in diameter. Large thermocouples may alter the thermal properties of the DUT. If used, a correction factor should be added to the measured thermal resistance value.

4. Turn on the LED assembly at the designed electrical conditions. The LED assembly should stay energized for about 30 minutes. This is necessary for allow a thermal stabilization of the assembly. This is reached when no changes in temperature of the pin can be registered for a few minutes.

5. Measure the pin temperature \((T_S)\) of the DUT.

6. Measure the current \((I_f)\) of the thermally stabilized DUT, along with its corresponding forward voltage \((V_f)\).

7. And finally calculate the junction temperature \((T_J)\) of the DUT by the following equation:

\[
T_J = T_S + P_{\text{LED}} \times R_{\text{thJS}}
\]  \hspace{1cm} (6)

where:

\[
P_{\text{LED}} = I_f \times V_f: \text{ power dissipation of the DUT}
\]

Section 4: Evaluating junction temperature and forward current

The primary concern when evaluating the thermal characteristics of a LED assembly is to ensure that the junction temperature of the LEDs is kept below the specified maximum values (125 °C for OSRAM TOPLED 2000 series with High temperature resin). The designer of display panels concerns the performance of the display and the maximum permissible current and therefore power dissipation at a maximum required ambient temperature.

For a predefined highest ambient temperature and by referring to equation 5, the highest permissible current can be determined, using following equation:

\[
T_J = T_{A2} + \Delta T_D \times (I_f \times V_f + R_{\text{thJA}}) + \Delta T_c
\]

where:
\[ \Delta T_e = P_{\text{max}} \times R_{\text{thEN}} \] temperature difference inside and outside of the enclosure

For a single LED on a big PCB area (>600mm²), the maximum permissible forward current vs. ambient temperature is shown in Figure 3. For a LED assembly, like for display applications, this curve should be reduced by the temperature rise, due to the power density on the PCB \( \Delta T_d \) and \( \Delta T_e \).

**Section 5**: Design steps- DC and Pulsed mode design examples

In order to ensure the reliable operation of the display, the designer needs to determine the maximum permissible power dissipation of the LED, for an elevated ambient temperature. This can be done if all of the parameters in the designed circuits are exactly defined, and if the worst case for any parameter has been taken into consideration.

This problem can be solved using equation 5, dismissing the thermal elevation due to the enclosure and using the equation 4 for thermal elevation due to power density.

**Example:**

In this example, the LED array in Figure 8 is used, and the operating temperature is assumed to be \( T_A = 40^\circ \text{C} \).

Assuming a gap of 10mm \( X \) between two LEDs the maximum permissible power dissipation of each LED is to be determined.

\[ T_J = T_A + (P_{\text{LED}} \times R_{\text{thJA}}) + \Delta T_D \]

Using equation (4):

\[ T_J = T_A + (P_{\text{LED}} \times R_{\text{thJA}}) + 28 \left[ \frac{\text{Kmm}^2}{\text{mW}} \right] \times \frac{P_{\text{LED}}}{X^2} \times 4.2 \text{K} \]

Hence:

\[ P_{\text{LED}} = \frac{T_J - T_A + 4.2 \text{K}}{R_{\text{thJA}} + (28 \left[ \frac{\text{Kmm}^2}{\text{mW}} \right] \times \frac{1}{X^2})} \]

Once the value for the thermal resistance junction-to-ambient \( R_{\text{thJA}} \) is determined, the required maximum permissible power dissipation of each LED can be calculated.

This calculation is valid for single LEDs only. For a RGB MULTILED the power dissipation of each chip cannot be used for the total power dissipation of the LED, and therefore for the calculation of power density.

In this case the designer should determine the de-rated drive conditions for which the application requirements are met, and calculate the junction temperature for this drive condition, to see if it doesn't exceed the maximum rating. This ensures the reliable operation of the LED device and display tiles, respectively.
The basic design steps are:

1. Define the terms of operation, like pixel pitch, ambient temperature and required luminance.
2. Determine the brightness, thermal resistance and electric parameters according to the data sheet, for a particular bin group.
3. Determine the brightness of each pixel, and therefore each LED, to achieve the required luminance at white balance.
4. Determine the needed brightness for the maximum ambient temperature, with respect to relative luminous intensity of the LED vs. ambient temperature.
5. Determine the needed brightness of each chip, and the corresponding current to achieve the required brightness for each MULTILED.
6. Calculate the power dissipation of each LED chip for the needed current, considering the worst case.
7. Calculate the temperature elevation due to the power density according to Figure 7.
8. Calculate the junction temperature of each chip considering the change in thermal resistance, due to the designed. PCB footprint with respect to the maximum required ambient temperature

9. If necessary, reduce the value of thermal resistance solder point-to-ambient ($R_{thSA}$) and consequently the junction temperature by redesigning the layout for device footprints.

For the examples below, the thermal resistance of the enclosure is dismissed. This is explained in the last section.

**DC mode design example**

To ensure a reliable operation of LED the calculations use the maximum ratings contained in LED data sheets. For this example a display tile should be designed using the Multiled LATB T686.

The conditions are:

- **Pixel pitch** = 10mm
- **Max. operating ambient temperature** = 40°C
- **Luminance** = 1000cd/m²

For this example a Multiled LATB T686 in the binning group "Q R L" is used. The representative typical values for luminous intensity is given in the table below.

The data sheet parameters are:

<table>
<thead>
<tr>
<th>LATB T686-Q R L</th>
<th>Amber (615 nm)</th>
<th>True green (528)</th>
<th>Blue (465)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical luminous intensity at 20mA, $I_v$ (25°C)</td>
<td>90mcd</td>
<td>150mcd</td>
<td>14mcd</td>
</tr>
<tr>
<td>Max. junction temperature</td>
<td>125°C</td>
<td>125°C</td>
<td>100°C</td>
</tr>
<tr>
<td>Thermal resistance junction-to-ambient for 3 Chips on (pad size = 16mm²)</td>
<td>825K/W</td>
<td>770K/W</td>
<td>825K/W</td>
</tr>
<tr>
<td>Max. forward voltage at 20mA</td>
<td>2.4V</td>
<td>3.9V</td>
<td>4.1V</td>
</tr>
</tbody>
</table>

**Table 3: Some representative data typically contained in the data sheet of LATB T686**
The required luminance of the display is 1000cd/m². This value is mostly required for the white balance. Since in a display assembly the pixels are set up in a unit order of column and rows (Figure 10), the luminous intensity of each pixel or each Multiled can be calculated as follows:

\[ I_{\text{LED}} = L_v \times A \]

Where:

- \( I_{\text{LED}} \) = Luminous intensity of each LED perpendicular to the display surface
- \( L_v \) = Luminance of the display
- \( A \) = average area of each LED

For a pixel pitch of 10mm the area

\[ A = 10\text{mm} \times 10\text{mm} = 100\text{mm}^2 \]

The luminous intensity of each LED is:

\[ I_{\text{LED}} = 1000\text{cd/m}^2 \times 100\text{mm}^2 = 100\text{mcd} \]

The luminous intensity calculated above should be valid even for the maximum elevated ambient temperature. For the maximum ambient temperature of 40°C the relative luminous intensity for all the chips of the Multiled is over 90% of the value at 25°C which is given in the table 3.

As a result the required luminous intensity of each LED is:

\[ I_{\text{LED}} \approx 100\text{mcd} \times 90\% \approx 110\text{mcd} \]

Since the luminous intensity above is required for the white balance the intensity ratio of each color is needed to calculate the required luminous intensity of each chip. Table 4 illustrates the intensity ratio of each color for white balance with different chromaticity coordinates used in different video systems.

<table>
<thead>
<tr>
<th>Chromaticity coordinates</th>
<th>Intensity ratio of each chip for white balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>y</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>0.31</td>
<td>0.32</td>
</tr>
<tr>
<td>0.31</td>
<td>0.33</td>
</tr>
<tr>
<td>0.33</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Table 4: Typical intensity ratio of each die of the RGB LED for White balance
According to PAL/SECAM the required luminous intensity of each chip is:

\[ I_{\text{Amber}} = 28\% \times 110\text{mcd} = 30.8\text{mcd} \]
\[ I_{\text{True green}} = 64\% \times 110\text{mcd} = 70.4\text{mcd} \]
\[ I_{\text{Blue}} = 8\% \times 110\text{mcd} = 8.8\text{mcd} \]

To determine the corresponding currents to achieve these values, the relative luminous intensity for the binnings in table 3 is to be calculated.

\[ \frac{I_{\text{Amber}}}{I_{\text{Amber}}(20\text{mA})} = \frac{30.8\text{mcd}}{90\text{mcd}} = 34\% \]
\[ \frac{I_{\text{True green}}}{I_{\text{True green}}(20\text{mA})} = \frac{70.4\text{mcd}}{150\text{mcd}} = 47\% \]
\[ \frac{I_{\text{Blue}}}{I_{\text{Blue}}(20\text{mA})} = \frac{8.8\text{mcd}}{14\text{mcd}} = 63\% \]

The corresponding currents can now be retrieved from the diagram for relative luminous intensity vs. forward current contained in all LED data sheets of OSRAM OS. From Figure 11, the following values for currents are determined:

\[ I_{F\text{Amber}}(30.8\text{mcd}) = 6.5\text{mA} \]
\[ I_{F\text{True green}}(70.4\text{mcd}) = 7.5\text{mA} \]
\[ I_{F\text{Blue}}(8.8\text{mcd}) = 10\text{mA} \]

![Graph](image)

**Figure 11:** Relative luminous intensity vs. forward current; \[ I_v/I_v(20\text{mA}) = f(I_F), T_A = 25^\circ\text{C} \]

The corresponding maximum ratings of forward voltage for these currents is determined from the diode characteristic diagram - forward current vs. forward voltage.

Considering the maximum ratings for forward voltages, the voltage difference between the maximum rating, table 3, and the value determined from the characteristic diagram at the corresponding current should be added to any value determined from the curve.

The determined values for forward voltages are:

\[ V_{F\text{Amber max}}(6.5\text{mA}) = 2.3\text{V} \]
\[ V_{F\text{True green max}}(7.5\text{mA}) = 3.5\text{V} \]
\[ V_{F\text{Blue max}}(10\text{mA}) = 3.8\text{V} \]

The maximum power dissipation on each chip is:

\[ P_{\text{LEDAmber max}}(30.8\text{mcd}) = 2.3\text{V} \times 6.5\text{mA} = 14.95\text{mW} \]
\[ P_{\text{LEDTrue green max}}(70.4\text{mcd}) = 3.5\text{V} \times 7.5\text{mA} = 26.25\text{mW} \]
\[ P_{\text{LEDBlue max}}(8.8\text{mcd}) = 3.8\text{V} \times 10\text{mA} = 38\text{mW} \]

The power density for the above conditions is given as the ratio of the sum of the power dissipations of all chips to the average area of each LED.

\[ P_D\max = \frac{(14.95 + 26.25 + 38)(\text{mW})}{100(\text{mm}^2)} = 0.79\text{ mW/mm}^2 \]

From Figure 7 the maximum temperature elevation due to the power density is:

\[ \Delta T_D\max = 17.92\text{ K} \]

The junction temperature of each chip using equation 5 with respect to the maximum ambient temperature and table 2
considering a solder pad area of 16mm² (Figure 10) for white balance gives:

\[
T_{J_{\text{Amber}}} = T_{A_{\text{max}}} + (P_{\text{LED}_{\text{Amber max}} x R_{\text{th JA}}}) + \Delta T_{D_{\text{max}}} = 40^\circ C + (14.95\text{mW} x 825\text{K/W}) + 17.92K = 70.25^\circ C
\]

\[
T_{J_{\text{True green}}} = T_{A_{\text{max}}} + (P_{\text{LED}_{\text{True green max}} x R_{\text{th JA}}}) + \Delta T_{D_{\text{max}}} = 40^\circ C + (26.25\text{mW} x 770\text{K/W}) + 17.92K = 78.13^\circ C
\]

\[
T_{J_{\text{Blue}}} = T_{A_{\text{max}}} + (P_{\text{LED}_{\text{Blue max}} x R_{\text{th JA}}}) + \Delta T_{D_{\text{max}}} = 40^\circ C + (38\text{mW} x 825\text{K/W}) + 17.92K = 89.27^\circ C
\]

These results are less than the maximum allowable junction temperature included in the data sheet. Assuming a solder pad area of 10mm² which means an increase of thermal resistance of approximately 35K/W (Figure 6), results to a junction temperature of 91°C for blue chip, which is the most critical one. This is still less than the maximum rating for junction Temperature of 100°C.

In practice the junction temperature of each die can be determined by using the equation (6). The thermal resistance junction-to-solder point \(R_{\text{th JS}}\) of each die for the Multiled LATB T686 is given in the data sheet and can be gathered from the table below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Number of driven chips</th>
<th>Amber</th>
<th>True green</th>
<th>Blue</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal resistance junction-to-solder point</td>
<td>(R_{\text{th JS}})</td>
<td>1 chip on</td>
<td>340</td>
<td>260</td>
<td>340</td>
<td>K/W</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 chips on</td>
<td>490</td>
<td>420</td>
<td>490</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Thermal resistance junction-to-solder point \(R_{\text{th JS}}\) of the Multiled LATB T686

By operating the LED device in pulsed current mode, the junction temperature is related not only to the current peak but also to the pulse width and the refresh rate. The ratio of the pulse width to the refresh time, as duty cycle, and the pulse peak define the average current and the average power dissipation in the LED. However, it is not the average junction temperature but the peak junction temperature that governs the performance of the LED. For refresh times higher than 1ms the peak junction temperature is higher than the average junction temperature. That is why, the permissible peak currents decreases for refresh times less than approximately 1ms, as can be seen by curves of Figure 4 for different duty cycles.

As a result, it is recommended to drive the LEDs with lower refresh times (or higher refresh rates >1000Hz) in order to reduce the heat generated in the device. The less heat generated in the device the higher is the luminous intensity of the LEDs.

Figure 12 shows the increase of the luminous intensity of some devices due to higher refresh rates. For the optimum condition the frequencies of 1kHz to 10kHz should be taken. At higher frequencies the luminous intensity drops off, a behavior attributed to pulse width approaching the switching time of the LEDs.
Figure 12: Luminous intensity vs. Refresh rate; D= duty
Pulsed mode design example

In this example, a yellow color display is to be designed as a semi-outdoor information panel assuming a refresh time of 1 ms. The following requirements has to be met:

- $T_{A,\text{max}} = 50 \degree C$
- Duty cycle $D=1/8$
- LED: LY T676-R1
- Pixel pitch: 5 mm
- Luminance: $L_V = 2000 \text{cd/m}^2$

For this requirement the luminous intensity of each pixel is to be:

$$I_{\text{vpixel}} = L_V \times A_{\text{pixel}} = 2000 \text{cd/m}^2 \times 5^2 \text{mm}^2 = 50 \text{mcd}$$

Where:

$A_{\text{pixel}}$: Average area of each LED on PCB

This value has to be valid even at 50°C. According to the data sheet the luminous intensity at 50°C reduces to 75% of it's value at 25°C.

Hence:

$$I_{V,\text{pixel}}(25 \degree C) = 50 \text{mcd} / 0.75 = 67 \text{mcd}$$

This requires an average current of $I_{AVG} = 11 \text{mA}$ for the binning group "R1" (typ. $I_V (20 \text{mA}) = 126 \text{mcd}$). For the peak current we yield:

$$I_{\text{peak}} = 8 \times 11 \text{mA} = 88 \text{mA}$$

Since the relative efficiency factor $\eta_V$ at this current is about 90% of the value at 20mA the necessary peak current is:

$$I_{\text{peak(min)}} = 88 \text{mA} / 0.9 = 98 \text{mA}.$$ 

To simplify the calculation we take 100mA for the peak current.

According to the data sheet (Figure 1) the forward voltage at 100mA, $V_f (100 \text{mA})= 2.3 \text{Volts}$. 

The time average power dissipation is:

$$P_{\text{LED}} = I_{\text{peak}} \times V_f (100 \text{mA}) \times D = 100 \text{mA} \times 2.3 \text{ V} \times 0.125 = 28.75 \text{mW}$$

Assuming a solder pad area of only 3mm² and from the Figure 6 the thermal resistance junction-to-ambient is:

$$R_{\text{thJA}}(3 \text{mm}^2) = R_{\text{thJA}}(16 \text{mm}^2) + R_{\text{thSA}}(3 \text{mm}^2) - R_{\text{thSA}}(16 \text{mm}^2) = 500 \text{K/W} + 360 \text{K/W} - 240 \text{K/W} = 620 \text{K/W}$$

The power density on the PCB assuming no other devices are mounted on the PCB is:

$$P_D = P_{\text{LED}} / A_{\text{pixel}} = 28.75 \text{mW} / 25 \text{mm}^2 = 1.15 \text{mW/mm}^2$$

The maximum temperature rise due to this power density from Figure 7 is:

$$\Delta T_{D,\text{max}} = 28 \text{K}$$

Using equation 5 for LED junction temperature without considering the thermal resistance of the enclosure:

$$T_J = T_{A,\text{max}} + (P_{\text{LED}} \times R_{\text{thJA}}) + \Delta T_{D,\text{max}} = 50 \degree C + (28.75 \text{mW} \times 620 \text{K/W}) + 28 \text{K} = 96 \degree C$$

The new MOVPE TOPLEDs of OSRAM are designed for an improved junction temperature of 125°C. As a result, this is less than the maximum allowable junction temperature.

The time average luminous intensity at 25°C is:

$$I_V(25 \degree C) = I_V(20 \text{mA}) \times [100 \text{mA} / 20 \text{mA}] \times \eta_V (100 \text{mA}) \times D$$

$$= 126 \text{mcd} \times 5 \times 0.9 \times 0.125 = 71 \text{mcd}$$

The time average luminous intensity at 50°C is:

$$I_V(50 \degree C) = I_V(25 \degree C) \times 0.75 = 53 \text{mcd}$$
For the worst case, the forward voltage should be considered to be the highest possible value which is 2.8V at 100mA.

Therefore:

\[ P_{\text{LED max}} = I_{\text{peak}} \times V_{\text{f max}}(100\text{mA}) \times D = 100\text{mA} \times 2.8V \times 0.125 = 35\text{mW} \]

The max. power density on the PCB would be:

\[ P_{\text{D max}} = \frac{P_{\text{max}}}{A_{\text{pixel}}} = \frac{35\text{mW}}{25\text{mm}^2} = 1.4\text{mW/mm}^2 \]

The maximum temperature rise due to this power density from Figure 7 is:

\[ \Delta T_{D,\text{max}} = 35\text{K} \]

Using equation 5 for LED junction temperature without considering the thermal resistance of the enclosure:

\[ T_{J,\text{max}} = T_{A,\text{max}} + (P_{\text{LED max}} \times R_{\text{th JA}}) + \Delta T_{D,\text{max}} = 50^\circ\text{C} + (35\text{mW} \times 620\text{K/W}) + 35\text{K} = 107^\circ\text{C} \]

Which is still below the maximum rating of junction temperature.

Pulsed parameter summary (typical values):

- \( T_{A,\text{max}} = 50^\circ\text{C} \)
- \( R_{\text{th JA}} (3\text{mm}^2) = 620\text{K/W} \)
- \( I_{\text{peak}} = 100\text{mA} \)
- \( I_{\text{AVG}} = 12.5\text{mA} \)
- \( V_{f} (100\text{ mA}) = 2.3\text{V} \)
- \( D = 1/8 \)
- Refresh time \( T = 1\text{ms} \)
- \( T_{J} (50^\circ\text{C}) = 96^\circ\text{C} \)
- \( I_{V} (25^\circ\text{C}) = 71\text{mcd} \)
- \( I_{V} (50^\circ\text{C}) = 53\text{mcd} \)
- Luminance at 25°C \( L_{V} (25^\circ\text{C}) = \frac{I_{V} (25^\circ\text{C})}{A_{\text{pixel}}} = 71\text{mcd/25mm}^2 = 2840\text{cd/m}^2 \)
- Luminance at 50°C \( L_{V} (50^\circ\text{C}) = \frac{I_{V} (50^\circ\text{C})}{A_{\text{pixel}}} = 53\text{mcd/25mm}^2 = 2120\text{cd/m}^2 \)

**Improving thermal Performance of LEDs in Displays**

The first step to decrease the temperature of the display module is to create an air flow and therefore take the air surrounding the modules out of the enclosure.

This can be understood as a power input with negative direction and therefore with negative sign that counteracts the increase of the heat according to the thermal resistance of the enclosure.

That is why, the thermal resistance of the enclosure was not considered in the calculations above.

Following approaches can reduce the temperature on the PCB and furthermore the junction temperature of the LEDs.

- Layout of bigger solder-pad area in a sub-layer of a multi-layer board and replacing the standard traces with copper lands
- Design thermally relieving through holes in these copper lands for better soldering performance
- Furnishing the backside with aluminum plates
- Using pins as connection of the top side and the bottom side of the PCB in order to remove the heat off the LEDs.
- Using separate PCBs for driver circuitry and LEDs
- Using fans to remove the heated air to the outside of the enclosure and to augment convection cooling
- Lower peak currents at lower refresh rates (<1KHz)
It is recommended that the temperature of any designed display be measured, since the thermal resistance in the data sheets has been given for the worst case. In addition to that the power density on the PCB is almost not distributed evenly.

The calculations above consider the case, where all the LEDs mounted on the PCB light up. This is mostly not the case. Nevertheless, for a safe function of a display the calculations above can be performed.

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OSRAM, with its headquarters in Munich, is one of the two leading lighting manufacturers in the world. Its subsidiary, OSRAM Opto Semiconductors GmbH in Regensburg (Germany), offers its customers solutions based on semiconductor technology for lighting, sensor and visualization applications. OSRAM Opto Semiconductors has production sites in Regensburg (Germany) and Penang (Malaysia). Its headquarters for North America is in Sunnyvale (USA). Its headquarters for the Asia region is in Hong Kong. OSRAM Opto Semiconductors also has sales offices throughout the world. For more information go to www.osram-os.com.

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