

# Determination of Resistances for Brightness Compensation

## Application Note

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### Abstract

This application note describes the procedure for adjusting the brightness of light emitting diodes (LEDs) in applications by means of resistors.

For better repeatability, the calculation of the required resistance values is shown by means of an example.

### Introduction

Due to manufacturing tolerances during production, LEDs cannot be produced with a particular brightness; rather, one obtains a certain brightness distribution in which the LEDs lie. The LEDs are sorted by means of type-specific grouping currents into predetermined brightness groups with defined upper and lower limits.

In order to be able to guarantee the best possible deliverability, the customer must approve several brightness groups for his respective application.

LEDs within the individual brightness groups are delivered in separate reels.

In order for an application to employ various brightness groups, the LEDs must either be dimmed by means of pulse width modulation (PWM) (see application note „Dimming InGaN LEDs“) or be driven with differing constant current levels. The latter is usually achieved by means of different resistors in the driver circuitry.

### Basic Procedure

#### 1. LED selection

The LEDs are selected corresponding to the given application requirements. Brightness, color, radiation angle and component size are the most important criteria when selecting an LED.

#### 2. Measurement of sample LEDs

For a few LEDs of the selected type, the exact brightness value should be determined or measured. These samples serve as a reference for determining the operating current in the application.

#### 3. Measurement of reference LEDs in the application

The reference LEDs should be incorporated into a production-ready prototype of the application, if possible. The further away the application is from production, the more likely it becomes that deviations will arise during production.

With this prototype, the optical parameters, e.g. luminance, of the entire system are measured.

#### 4. Determination of the operating current required

Depending on the measurement results, the required current for the LEDs in the application can be determined.

#### 5. Verification of temperature influences on brightness

Estimation of the junction temperature dependent on the calculated forward current and determination of the influence of temperature on LED brightness;

Figure 1 summarizes the principal procedure for calculating resistances and forward currents for brightness compensation when

using different LED brightness groups in an application.

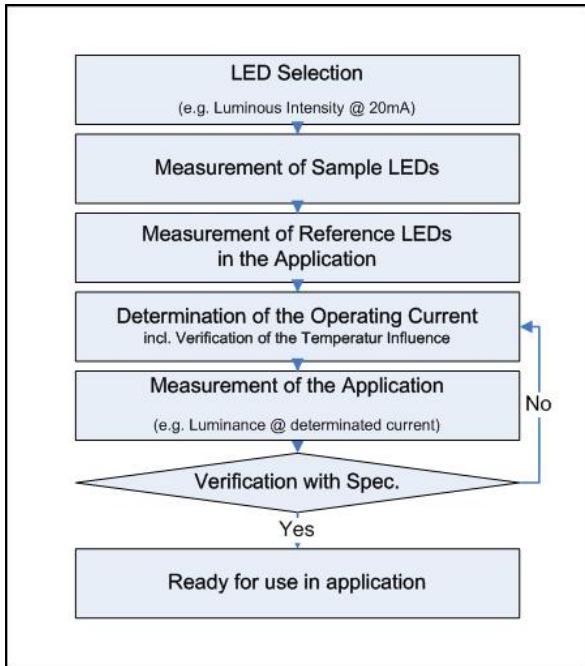


Figure 1: Principal Procedure

## Possible Sources of Errors

In general, it is important that the maximum allowable current specified in the data sheet is never exceeded. In addition, care should be taken that the maximum allowable junction temperature of the LED is never exceeded.

### Temperature

The forward voltage, luminous intensity and dominant wavelength are all dependent on the junction temperature of the LED. For this reason, care should be taken that the measurements are always performed with the same environmental conditions. Above all, this means that measurements must always be carried out at the same ambient temperature, and that the measurement always occurs at a predefined time after power up.

## Forward Voltage

Due to manufacturing tolerances, each LED has a particular variance in its forward voltage.

Due to this variation, LED brightness measurements and thus the classification according to brightness groups, occurs at a particular, type-specific forward current, ( $I_f$  = grouping current).

LEDs of a type and within a brightness group have the same forward current; the forward voltage, however, can vary between  $U_{f,min}$  and  $U_{f,max}$ .

Therefore, the current through the LED should be designed based on a typical value for the forward voltage.

For LEDs which have a lower forward voltage, the use of a typical series resistor results in a higher current flow. The application is then correspondingly brighter.

If LEDs with higher forward voltage are used, a lower current flows with the same series resistor and the application appears correspondingly dimmer.

## Application Example

The following example serves as a practical demonstration as to how the various resistances must be determined for the different brightness groups.

An automobile switch is to be backlit with an LA T676 LED. The LED is driven with a series resistor connected to a supply voltage of 13.5 V. The desired luminance of the switch is  $4 \text{ cd/m}^2$  ( $\pm 20\%$ ). Given the dimensions of the switch and the transmittance of the plastic used, a minimum required brightness of 200 mcd is estimated. For this configuration, Brightness Groups R2, S1 and S2 can be used.

**How should the current through the LED and thus the resistance value be chosen, in order to achieve the desired luminance of  $4 \text{ cd/m}^2$ ?**

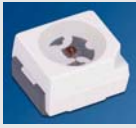
For the first prototype, an LA T676 LED from Group S1 will be used. From the data sheet,

the following relevant information can be obtained (see also the LA T676 data sheet):

- The grouping current of the LA T676 is 20 mA
- Group S1 has a luminous intensity  $I_v$  of 180 to 224 mcd. The average luminous intensity lies at  $I_v = 202$  mcd.

After selecting the LED, the next step is to measure the exact brightness value of a few sample LEDs at the grouping current.

For example, the following values are obtained:

	LA T676		
	Current $I_f$	Voltage $U_f$	Brightness $I_v$
LED #1	20 mA	2.05 V	183 mcd
LED #2	20 mA	2.10 V	190 mcd
LED #3	20 mA	2.10 V	185 mcd
LED #4	20 mA	2.10 V	191 mcd
LED #5	20 mA	2.00 V	187 mcd
LED #6	20 mA	2.15 V	182 mcd
LED #7	20 mA	2.05 V	183 mcd
LED #8	20 mA	2.00 V	185 mcd
LED #9	20 mA	2.00 V	186 mcd
LED #10	20 mA	2.05 V	189 mcd

**Table 1: Measurement results for LA T676 (example)**

According to the initial estimate, the desired luminance of  $4 \text{ cd/m}^2$  for the switch must be achieved with an LED from the middle of Brightness Group S1. This corresponds to a brightness or luminous intensity of 202 mcd. Since none of the reference LEDs lie in the middle of Brightness Group S1 in this example, LED #4 with  $I_v = 191$  mcd ( $I_{v_{\text{measured}}}$ ) is chosen as the reference LED for determining the luminance of the application, since this is closest to the desired luminous intensity of 202 mcd ( $I_{v_{\text{calibrated}}}$ ).

In order to "simulate" a brightness of 202 mcd, LED #4 must be driven at a higher current than 20 mA:

$$\frac{I_{v_{\text{calibrated}}}}{I_{v_{\text{measured}}}} = \frac{202 \text{ mcd}}{191 \text{ mcd}} = 1.06$$

This results in a factor of 1.06, required to drive LED #4 at a higher brightness. The respective current  $I_{f_{\text{calibrated}}}$  can now be obtained from the diagram "Relative Luminous Intensity" in the data sheet (Figure 2, please see also application note "Dimming LEDs with respect to grouping current"). For the determination of current the degradation over temperature was neglected, because change in power dissipation is very low.

For the prototype unit and the subsequent measurements, LED #4 must be driven with a current of 21.2 mA for the luminance determination.

As mentioned at the beginning, care must be taken that the basic conditions remain constant when measuring the application, and that these correspond to conditions present during mass production. This means, for example, that

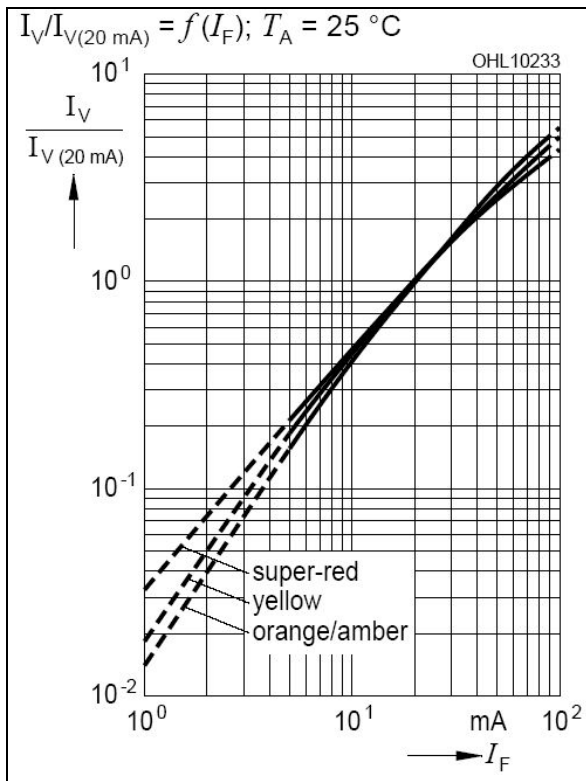
- the ambient temperature always remains the same
- the time of measurement always remains the same
- the material used in the switch has the same optical characteristics as that which will be used in production

In this example, the switch is measured at an ambient temperature of  $25^\circ\text{C}$  after a period of 1 minute.

As a result of the measurement, a luminance ( $L_{V_{\text{actual}}}$ ) of  $6.2 \text{ cd/m}^2$  was measured at the surface of the switch.

In this case, the brightness of the reference LED is clearly too high to illuminate the surface of the switch with the desired luminance ( $L_{V_{\text{desired}}}$ ) of  $4 \text{ cd/m}^2$ .

The reason for this discrepancy is possibly due to a deviation in the transmittance of the illuminated plastic which led to an incorrect estimation of output.



**Figure 2: Relative Luminous Intensity of the LA T676**

Because luminance is linearly dependent on the luminous intensity of the LED in this build, this means in consideration of the application that the lower the luminous intensity of the LED, the lower the luminance of the switch.

This results in:

$$\frac{I_{V_{desired}}}{I_{V_{actual}}} = \frac{L_{V_{desired}}}{L_{V_{actual}}} = \frac{4.0 \text{ cd/m}^2}{6.2 \text{ cd/m}^2} = 0.65$$

For the desired luminance of 4 cd/m<sup>2</sup>, the output brightness must be reduced by a factor of 0.65 from the original estimate. The desired luminous intensity then becomes:

$$I_{V_{desired}} = I_{V_{actual}} \cdot 0.65 = 202 \text{ mcd} \cdot 0.65$$

$$I_{V_{desired}} = 131 \text{ mcd}$$

To determine the associated forward current  $I_{F_{desired}}$  the diagram "Relative Luminous Intensity" is once again consulted. From the diagram, a current  $I_{F_{desired}}$  of 14 mA is obtained; this applies to the LEDs in Brightness Group S1.

For operation of the LEDs, this current  $I_{F_{desired}} = 14 \text{ mA}$  must be set through the use of a series resistor.

The resistance value can be calculated from Ohm's Law:

$$R = \frac{U_R}{I} = \frac{11.5V}{14 \text{ mA}} = 821 \Omega$$

in which the voltage  $U_R$ , across the resistor is equal to the car battery voltage ( $U_{BAT}$ ) minus the voltage across the LED ( $U_{LED}$ ):

$$U_R = U_{Bat} - U_{LED} = 13.5V - 2.0V = 11.5V$$

For other brightness groups, determination of the series resistances occurs analogous to the previous calculation.

The luminous intensity values for the brightness groups are shown in Table 2. Compared to Group S1, the dimmer Group R2 must be driven with a higher current and the brighter Group S2 with a lower current in order to achieve the desired luminous intensity  $I_{V_{desired}} = 131 \text{ mcd}$  and thus the desired luminance  $L_{V_{desired}}$  of 4 cd/m<sup>2</sup>.

Group	Iv min	Iv mean	Iv max
R2	140	160	180
S1	180	202	224
S2	224	252	280

**Table 2: Brightness group values**

When determining resistance values, the mean value for luminous intensity ( $I_{V_{mean}}$ )

for each group should be chosen as the output value.

Based on this value, the appropriate current can be read from the "Relative Luminous Intensity" diagram.

For Brightness Group S2:

$$\frac{I_{v_{desired}}}{I_{v_{actual}}} = \frac{131mcd}{252mcd} = 0.52$$

The associated current value is  $I_f = 11 \text{ mA}$ . For Group S2, the resistance value is calculated by:

$$R = \frac{U_R}{I} = \frac{11.5V}{11mA} = 1045\Omega$$

For Brightness Group R2:

$$\frac{I_{v_{desired}}}{I_{v_{actual}}} = \frac{131mcd}{160mcd} = 0.82$$

The corresponding current value is  $I_f = 18 \text{ mA}$ . For Group R2, the resistance value results in:

$$R = \frac{U_R}{I} = \frac{11.5V}{18mA} = 639\Omega$$

Thus, for the three brightness groups, individual resistance values were obtained in order to achieve the desired luminance of  $4 \text{ cd/m}^2$  at the surface of the switch.

Brightness Group	Current	Resistance
R2	18 mA	639 Ohm
S1	14 mA	821 Ohm
S2	11 mA	1054 Ohm

**Table 3: Brightness groups with associated resistance values**

When constructing the prototype, the calculated resistances must be adjusted to match the resistance series (E3-E96). The resistance series E3-E96 describes commercially available resistance values. For the application, this means that the calculated resistance may not necessarily represent a commercially available resistance value; the next higher or lower value must be chosen instead. To be safe, in order to prevent operation with excessive currents, the selection of the next higher resistance value is recommended.

As a final step, the influence of LED brightness due to the junction temperature should be verified.

The expected junction temperature in relation to the calculated forward currents can be found by the following formula:

$$R_{th, \text{Junction-Ambient}} = \frac{\Delta T_{\text{Junction-Ambient}}}{P_D}$$

where:

$$\Delta T [K] = T_{J(\text{unction})} - T_{A(\text{mbient})}$$

$$P_D [W] = U_f \cdot I_f = \text{power dissipation}$$

$$U_f [V] = \text{forward voltage}$$

$$I_f [A] = \text{forward current}$$

The junction temperature is then found by:

$$T_J = R_{th,JA} \cdot U_f \cdot I_f + T_A$$

The total thermal resistance  $R_{th,JA}$  is represented by the sum of the individual resistances along the thermal path from the active semiconductor layer to the outer ambient temperature.

For LEDs, the total thermal resistance can be separated into an internal and an

external application-specific thermal resistance.

$$R_{th,JA} = R_{th,JB} + R_{th,BA}$$

$$R_{th, J(unction)-B(oard)}$$

$$R_{th, B(oard)-A(mbient)}$$

The internal thermal resistance  $R_{th,JB}$  is defined by the physical construction of the LED.

It describes the thermal characteristics of the LED from the junction layer of the semiconductor chip to the material used for securing the chip (e.g. adhesive, solder) and continuing on to the leadframe.

The values of  $R_{th,JB}$  can be found in the data sheets for the LEDs and are specified by the design of the component.

The external thermal resistance  $R_{th,BA}$  describes the connection between the LED and a heatsink (e.g., the circuit board) and the thermal properties of the application-specific cooling. It is strongly influenced by various factors such as layout of the components, material and properties of the LED connection, cooling design, fans etc.

For an exact determination of the junction temperature, detailed information about the assembly of the product during production is required.

$$T_J = (R_{th,JB} + R_{th,BA}) \cdot U_f \cdot I_f + T_A$$

For an initial overview, the total resistance  $R_{th,JA}$  stated in many data sheets can be applied to simplify the process.

This value describes a simple assembly and/or a typical application.

For the application example, a total thermal resistance of  $R_{th,JA} = 500 \text{ K/W}$  can be obtained from the data sheet for the LA T676.

In this case, the resistance is defined for mounting on an FR4 circuit board with a pad size  $\geq 16 \text{ mm}^2$  for each pad.

For the LEDs in Brightness Group S1, an average junction temperature at the given ambient temperature  $T_A$  of  $25^\circ\text{C}$  and current  $I_f$  of 14 mA can be calculated:

$$T_J = 500 \frac{\text{K}}{\text{W}} \cdot 2\text{V} \cdot 0.014\text{A} + 25^\circ\text{C}$$

$$T_J = 39^\circ\text{C}$$

The junction temperatures for the other brightness groups can be determined in the same way (Table 4).

Brightness Group	Current	Junction Temperature
R2	18 mA	43 °C
S1	14 mA	39 °C
S2	11 mA	36 °C

**Table 4: Brightness groups with current dependent junction temperatures**

The amount of influence can now be estimated from the diagram "Relative Luminous Intensity of the LA T676 vs. Junction Temperature" in the data sheet (Figure 3). The diagram describes the progression of LED brightness (according to chip technology), dependent on junction temperature.

For the calculated junction temperatures, the following influences and reductions in brightness in relation to the grouping values can be obtained (Table 5).

In order to determine the degree of influence within the application, the reference measurement in step 3 must be chosen as a reference point, however, since this serves as the reference point for determining the currents.

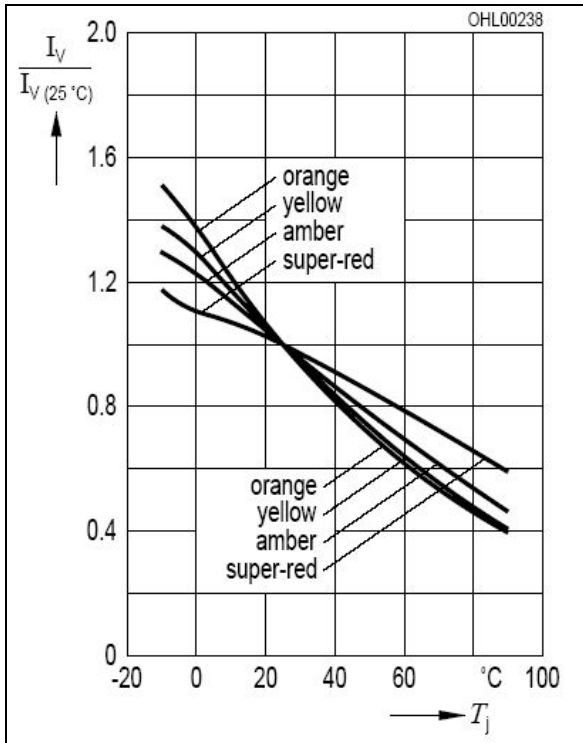


Figure 3: Relative luminous intensity of the LA T676 vs. junction temperature

Brightness Group	Junction Temperature	Rel. Brightness
R2	43 °C	0.84
S1	39 °C	0.87
S2	36 °C	0.92

Table 5: Expected reduction in brightness in relation to junction temperatures

That is, for the reference measurement with Group S1, a reduction in brightness has already been taken into account. If one refers to the previously stated construction with FR4, the junction temperature can also be calculated here, and the reduction in brightness can be established.

$$T_j = 500 \frac{K}{W} \cdot 2V \cdot 0.0212A + 25^\circ C$$

$$T_j = 46.2^\circ C$$

$$\Delta I_v = 0.82$$

From this reference point, in part due to the considerably lower forward currents, we

arrive at a reduced warming of the junction, which finally leads to increased brightness (Table 6).

Brightness Group	Current	Junction Temp.	Rel. Brightness
S1	21.2 mA	46.2 °C	1.0
R2	18 mA	43 °C	~1.02
S1	14 mA	39 °C	~1.05
S2	11 mA	36 °C	~1.1

Table 6: Expected brightness in relation to the reference measurement

For the given total thermal resistance ( $R_{th,JA} = 500K/W$ ) and the calculated operating parameters, a 2 to 10% increase in brightness would be achieved due to the reduction in junction temperature, depending on the brightness group used.

For the application, this means that the luminance can be held within the required range of  $4 \text{ cd/m}^2 \pm 20\%$ .

To minimize the influence due to junction temperature, basically only two parameters can be actively influenced.

$$T_j = (R_{th,JB} + R_{th,BA}) \cdot P_D + T_A$$

One way to achieve this is to reduce the power dissipation  $P_D$  of the LEDs by driving the LEDs at lower currents. This means however, that LEDs with a higher brightness level or a higher number of LEDs must be used.

Total resistance represents the second factor, which, when optimized or minimized, decisively affects system performance. Since the thermal resistance of the LED is predetermined, the total value can only be reduced by altering the external thermal resistance  $R_{th,BA}$ . That means for example, that larger solder pads or a circuit board material with better heat transfer capability should be used, or passive or active cooling should be employed.

## Summary

At first glance, determining the series resistances seems to be quite simple; however, it is much more complex than one would expect.

In general, it can be said that brightness compensation by means of individual resistors represents the simplest and most cost effective method to facilitate the use of LEDs of varying brightnesses within an application.

When selecting a brightness group, generally the lowest group which satisfies the given requirements should be used. Since LEDs are usually most efficient at their grouping current, a reduction in brightness is clearly easier to achieve than an increase. With the LA T676 LED for example, a brightness increase of 10% from the original

value at grouping current of 20 mA requires nearly a doubling of the forward current.

When dimming with series resistors, care must be taken that the reduced current is not too far removed from the grouping current. In spite of the same brightness grouping for the LEDs, too little current can lead to differing brightnesses in the application, since LEDs show a technology-related brightness characteristic dependent on current (see also application note "Dimming LEDs with respect to grouping current").

If it is not possible to dim the LEDs with a current near the grouping current, dimming should alternatively be carried out by pulse width modulation (PWM). This has the advantage that the brightness can be controlled by varying the duty cycle. The LED itself can be driven at the grouping current, however.

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