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Technical application guide

The LEDset (Gen2) interface

Light is OSRAM

OSRAM

Contents

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1 Introduction

LED technology is changing the world of general lighting. In luminaire design, however, the various benefits of LEDs, e.g. their high level of flexibility in operating luminaires, can only be achieved with perfectly matched LED drivers. This is further complicated by the rapid improvement of the efficacy and current capability of LED technologies, which ask for even greater adaptability of the corresponding LED drivers.

OPTOTRONIC® LED drivers with LEDset interfaces can meet this demand for greater adaptability by supporting a wide power and current range and by their future-proof design, which makes them ready for coming LED generations.

Purpose of this application guide:
The purpose of this application guide is to provide basic technical information on the LEDset Generation 2 interface, focusing on application solutions that illustrate the specific functions of this new interface and show how these can be used. The application solutions demonstrate that the LEDset Gen2 interface opens up many opportunities for customizing your LED-based luminaire: The simplicity and flexibility of LEDset gives you the freedom to develop new luminaire system features.

1.1 Features and benefits

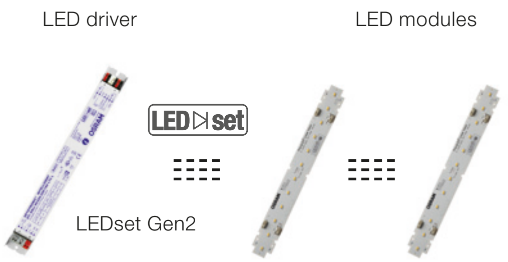
LEDset helps you to meet important market requirements:

- Future-proof solutions in terms of lumen output
- Long-life operation
- Luminaire customization
- Energy and cost saving

In combination with OSRAM LED drivers, the LEDset Gen2 interface offers full flexibility and a future-proof system with the following features and benefits:

- Simplified wiring for easy setting of the LED driver current, according to system and load configuration
- Versatile connectivity of several LED modules, either in parallel or in series (or a mix of both)
- Thermal protection for LED modules

Figure 1: LEDset Gen2 application features



1.2 Differences between LEDset Gen1 and Gen2: What's new in the LEDset Gen2?

LEDset Gen2 is the enhanced interface between OPTOTRONIC® LED drivers and LED modules (such as OSRAM PrevaLED®). It can be identified by the LED driver product name, including the letters "LT2" at its end (while LEDset Gen1 ends with "LT" only).

LEDset behavior has been changed in order to obtain the following advantages:

- To add the parallel modules operation, especially for linear and area SSL systems, while optimizing the operating range with spot and downlight systems
- To simplify assembly (only one additional wire instead of three)

The table below shows the improvements of the LEDset Gen2 compared to the previous version:

Table 1: What's changed in LEDset Gen2?

	LEDset Gen1	LEDset Gen2
Current setting method	R_{set} resistor	R_{set} resistor with new coding
Current coding	Relative (in % of the maximum output current of the LED driver)	Absolute (within the range of 0.1 A to 5 A)
Typical number of LED modules in the system	1	From 1 up to many (series and parallel combinations)
Number of wires for LEDset	3	1
Multi-vendor	No (provided by OSRAM only)	Yes (being adopted by other vendors)

Note:
There is no cross-compatibility and interchangeability between the first and second generation of LEDset.

For simplicity reasons, the "LEDset" notation will be used throughout the entire document instead of "LEDset Gen2". LEDset implicitly refers to the latest LEDset version.

1.3 Special application Ultraflat: Compact light control with sensor and LED driver via LT2

The LS/PD LT2 LI UF sensor transmits brightness and motion detection information to the OTi DALI Ultraflat LED driver. The LED driver takes over the role of the light control unit. (This function is only available in OTi DALI Ultraflat LED drivers.)

2 LEDset specifications

2.1 General overview

LEDset is a low-cost analog interface based on a three-wire connection between the LED driver and one or more LED modules. Only one additional wire – besides the two LED current supply wires (LED+, LED-) – is used for transferring information from the LED module/s to the LED driver.

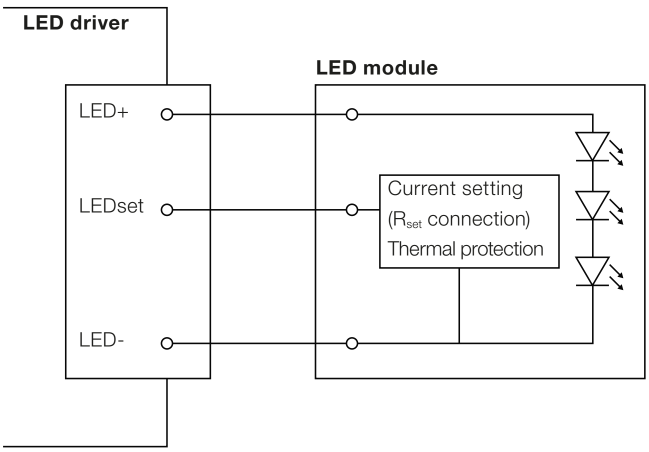
This interface is designed to allow communication between the LED module and the LED driver, performing LED current setting and thermal protection functionality.

The interface supports the following functionalities:

- Absolute output current setting of the constant-current LED driver (LED module self-recognition)
- Handling of parallel/serial LED module connection
- Thermal protection of the LED module

Typical applications of this interface are single or parallel or serial LED module connections, offering an increasing choice of modular capabilities and low-cost thermal protection. In case of multiple module connection, all connected modules must be identical (with the same current set) and with matched forward voltages.

Figure 2: LEDset interface wiring (block diagram)



2.2 LEDset characteristics

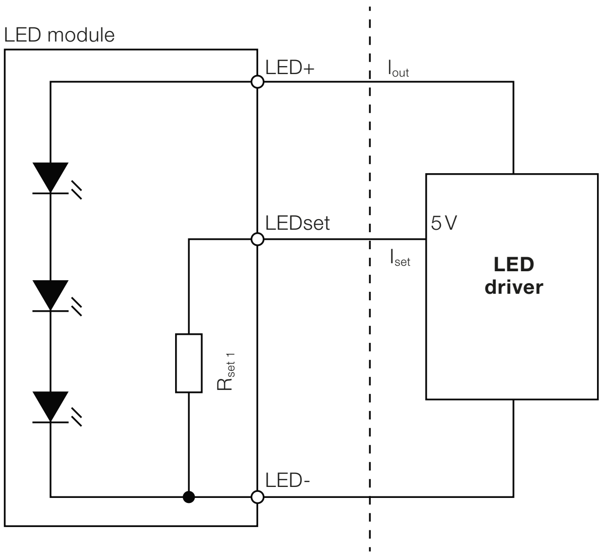
2.2.1 General description

The LEDset interface operates on the basic principle of Ohm's law. By selecting the ohmic value of a simple resistor R_{set}, it's possible to adjust the output current I_{out} of the LED driver as desired.

The relationship I_{out} vs. R_{set} is defined by the following formula:

(1) $$I_{out[A]} = \frac{5\,V}{R_{set[\Omega]}} \times 1000$$

Figure 3: LEDset interface wiring



The basic working principle of the LEDset interface is to measure the current I_{set} which flows from a LEDset port to one or more R_{set} setting resistors which are located on the LED module(s).

LED drivers with LEDset interface are able to measure I_{set} and to set the LED driver output current I_{LED} depending on the measured value of I_{set} according to the equation:

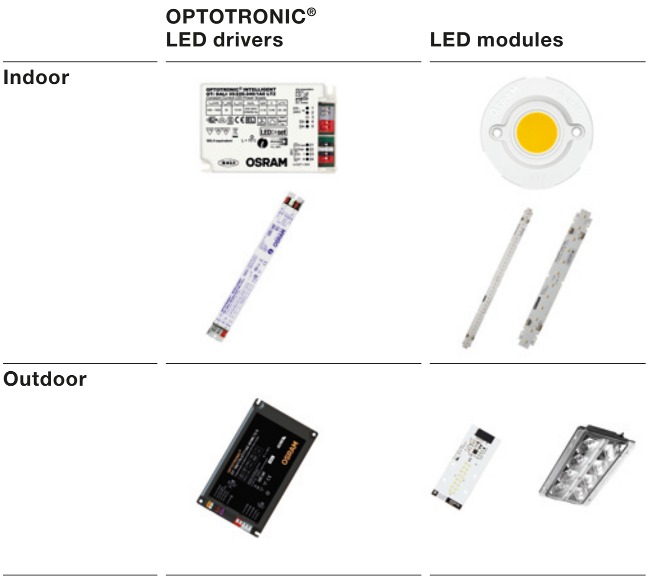
(2) $$I_{out[A]} = I_{set[A]} \times 1000$$

The R_{set} resistor can be mounted onto the LED module and connected to the LED driver by means of a dedicated LEDset wire. Alternatively, it can be used as a discrete part and plugged into the push-in connector of the LED driver.

Note:
The LEDset interface is not meant to be used as a control interface (for instance 1...10 V). If this is not observed, both performance and safety requirements of the installation may be affected.

2.2.2 LEDset implementation in OSRAM's SSL system
OSRAM offers a complete portfolio of LED modules (e.g. PrevaLED®) and OPTOTRONIC® LED drivers interfaced by LEDset, suitable for both indoor and outdoor application.

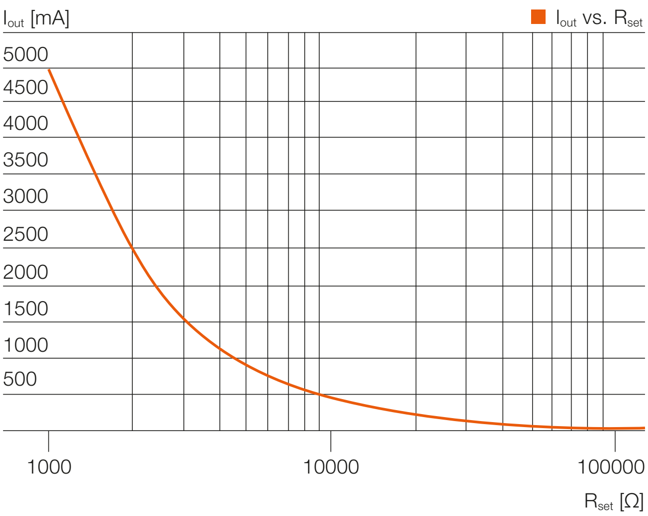
Figure 4: OSRAM SSL components with LEDset



2.3 Technical details

With the LEDset interface, the output current can be set to "absolute" by selecting the ohmic value of a simple R_{set} resistor. The interface is intended to cover an output current range from 0.1 A to 5 A, according to the LEDset equation (see figure 5, below), the correspondent valid R_{set} resistor range is therefore between 50 kΩ and 1 kΩ.

Figure 5: LEDset characteristics



The output current I_{out}, selected via the R_{set} resistor and within the valid LEDset range, must match the driving current of the LED components in the module and the nominal current range of the utilized LED driver.

In the above condition, the maximum nominal LED driver rated current I_{out_max} is set by the minimum R_{set} value ($R_{set\_min} = 5\,V/I_{max} \times 1000$) and the minimum nominal LED driver rated current I_{out_min} is set by the maximum R_{set} value ($R_{set\_max} = 5\,V/I_{min} \times 1000$).

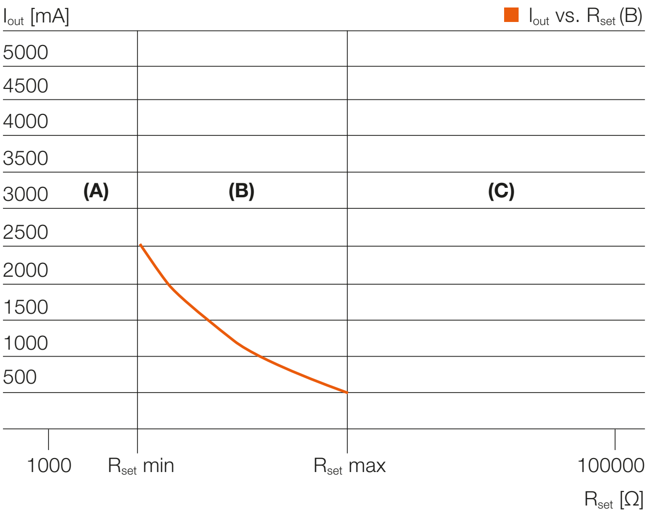
The interface behavior is compliant with the following table:

Table 2: Interface behaviors

R_{set} selection	I_{out}
$R_{set} < R_{set\_min}$ (A)	I_{out} behavior defined by product specification.
$R_{set\_min} < R_{set} < R_{set\_max}$ (B)	$I_{out[A]} = \frac{5\,V}{R_{set[\Omega]}} \times 1000$
$R_{set} > R_{set\_max}$ (C)	I_{out} behavior defined by product specification.

For further details and deviations from this basic information, please refer to the datasheet and instruction sheet of the respective LED driver.

Figure 6: I_{out} vs. R_{set}



2.3.1 How to select the proper R_{set} value to get the desired I_{out}

LEDset allows a stepless selection of the output current through the simple selection of the proper R_{set} value and the connection of a potentiometer or a fixed standard resistor to the LEDset line.

The table below shows the output current values in the entire valid LEDset range if the standard resistor series E24 is used.

Table 3: Output current values using standard E24 resistor values

R_{set} E24 [Ω]	Output current [mA]	R_{set} E24 [Ω]	Output current [mA]	R_{set} E24 [Ω]	Output current [mA]	R_{set} E24 [Ω]	Output current [mA]	R_{set} E24 [Ω]	Output current [mA]
51 000	100	22 000	227	9 100	549	3 900	1 282	1 600	3 125
47 000	106	20 000	250	8 200	610	3 600	1 389	1 500	3 333
43 000	116	18 000	278	7 500	667	3 300	1 515	1 300	3 846
39 000	128	16 000	313	6 800	735	3 000	1 667	1 200	4 167
36 000	138	15 000	333	6 200	806	2 700	1 852	1 100	4 545
33 000	151	13 000	385	5 600	893	2 400	2 083	1 000	5 000
30 000	166	12 000	417	5 100	980	2 200	2 273		
27 000	185	11 000	455	4 700	1 064	2 000	2 500		
24 000	208	10 000	500	4 300	1 163	1 800	2 778		

Better current accuracy can be reached using two setting resistors (R_{set1} and R_{set2}) connected in parallel. For the typical LED current values, the table below shows the current selection through the parallel connection of two E24 series resistors with the related output current error.

Table 4: Output current values using two parallel setting resistors (R_{set1} and R_{set2}), standard E24 resistor values

I_{out} [mA]	R_{set1} E24 [Ω]	R_{set2} E24 [Ω]	R_{set} total [Ω] = R_{set1} // R_{set2}	Output current error [%]
100	100 000	100 000	50 000	0
150	43 000	150 000	33 420	-0.252
200	30 000	150 000	25 000	0.004
350	15 000	300 000	14 268	0
500	10 000	–	10 000	0
700	8 200	56 000	7 153	-0.136
1 050	9 100	10 000	4 764	-0.052
1 400	3 900	43 000	3 576	-0.119
1 750	3 000	62 000	2 861	-0.134
2 100	2 700	20 000	2 379	0.088

2.3.2 Connection of multiple LED modules

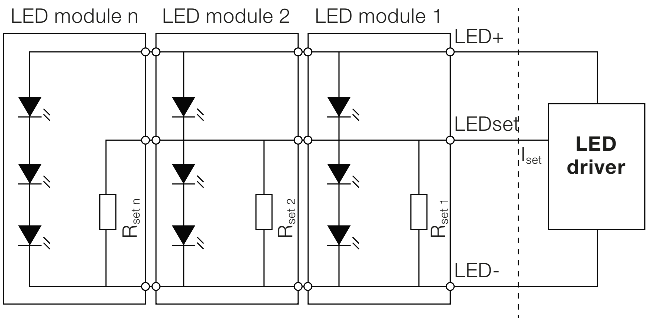
This simple working principle of the LEDset communication allows the connection of multiple modules to the same interface line. The current delivered by the LED driver will, in this case, be set by the equivalent resistance applied to the LEDset line.

Parallel connection of LED modules

If more than one LED module of the same type is connected in parallel (see figure 7, below) to one LED driver, then the current delivered by the driver will be the sum of currents required by each module.

$$I_{out} = \left(\frac{5\,V}{R_{set1}} + \frac{5\,V}{R_{set2}} + \ldots + \frac{5\,V}{R_{setn}}\right) \times 1000 \quad (3)$$

Figure 7: Typical setup for multiple-module parallel configuration

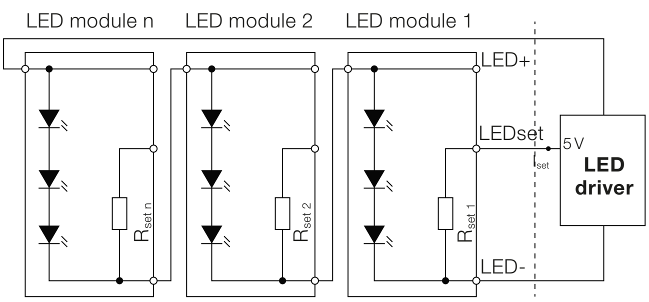


Serial connection of LED modules

The LEDset interface also supports serially connected LED modules (see figure 8, below). In this configuration, only one module is connected to the LEDset line of the LED driver, and thus only the current-setting resistor and thermal protection information of that particular module are detected. Only the LED module which is connected to LED- may be connected to the LEDset port. For missing wiring, refer to the chapter “Incorrect wiring”.

$$I_{out[A]} = \frac{5\,V}{R_{set1}} \times 1000 \quad (4)$$

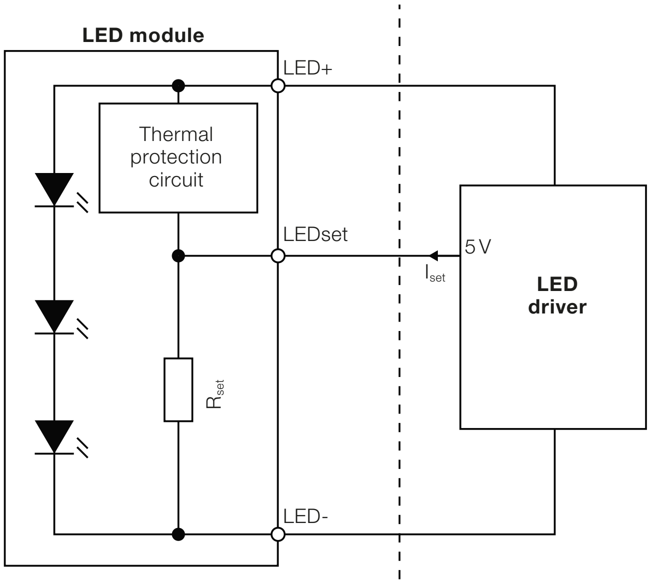
Figure 8: Typical setup for multiple-module serial configuration



2.3.3 Thermal protection for LED modules

With its simple and flexible properties, LEDset also allows users to manage the overtemperature protection, simply by adding an overtemperature protection circuit to the LED module (see figure 9). The thermal protection circuit decreases the setting current in case of an unwanted high temperature and thus limits or holds back the LED driver output current. Several LED modules from OSRAM include this protection.

Figure 9: LED module with thermal protection circuit



The LEDset interface allows users to strategically define their module temperature behavior, thus providing the possibility to implement their own specific solution with reliable accuracy. In order to ensure the compatibility between the LED driver and the LED module, user solutions must be compliant with the absolute maximum ratings shown in the table below.

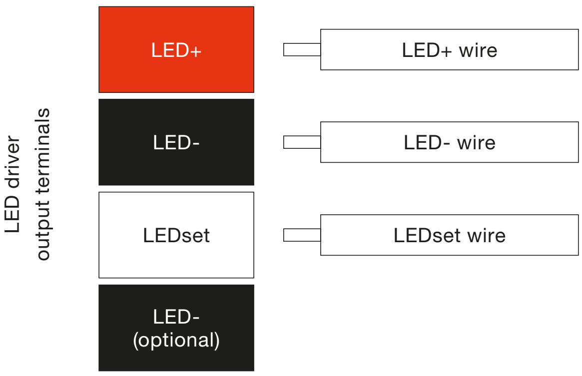
Table 5: Absolute maximum ratings for the LED module

LED module		Min. voltage	Max. voltage
V_{LEDset} design value	Maximum output voltage that the LED module can generate during overheating/thermal derating conditions through the thermal protection circuit	-	11 V
	Minimum input voltage that the LED module shall withstand during normal operation conditions	6 V	-

2.3.4 Terminals

Two output ports (LED+ and LED-) are used for the connection of the LED string/s. LEDset is a one-wire interface and uses the LED- line as the reference ground. The interface is intended for the control of a single-channel, constant-current LED driver with a single or multiple LED string load. The recommended connector colors and order are shown in figure 10 and figure 13.

Figure 10: LED driver output terminal configuration and color code; view from above



- LED+ is the LED driver terminal for the positive power supply wire connection (color: red).
- LED- is the LED driver terminal for the negative power supply wire connection as well as the ground reference for the interface logic (signal ground, color: black).
- LEDset is the LED driver terminal for the control wire connection (color: white).
- LED- (optional) is the LED driver auxiliary terminal equipotential with the LED- terminal (color: black). This connector terminal can be used with a stand-alone resistor or when a second ground reference is adopted to increase the system accuracy.

Figure 11: Example of use with LED- (optional) with standard stand-alone resistor

Figure 12: Terminal example of an isolated resistor (suitable for automatic insertion)

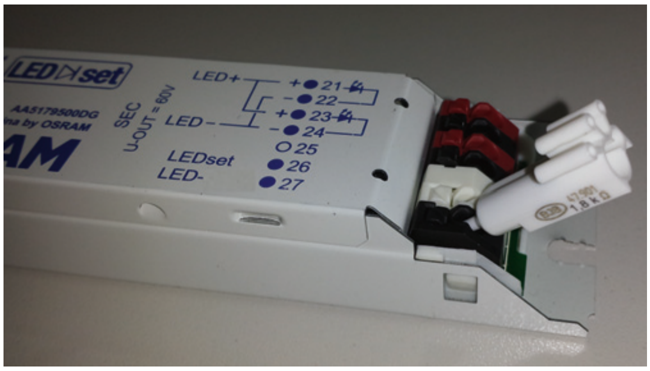
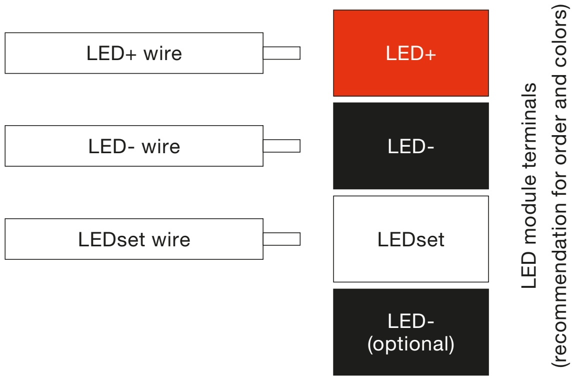


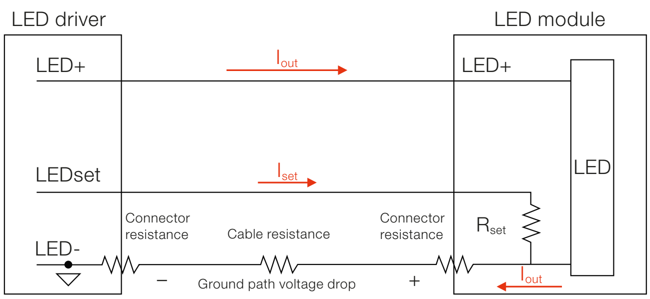
Figure 13: LED module terminal configuration and color code; view from above



2.3.5 Output current accuracy and ground path resistance

The accuracy of the LEDset system is affected by the voltage drop on the ground return path:

Figure 14: Ground path resistances



The total ground path resistance R_{gpr} (connectors plus cable resistances) reduces the effective voltage across the R_{set} resistor and consequently the I_{set} current. This parameter reduces the output current previously selected by R_{set}, introducing a current offset error. The real output current can be re-calculated using the following formula:

$$I_{out\_real} = \left(\frac{5\,V}{R_{set} + (1000 \times R_{gpr})} \right) \times 1000 \qquad (5)$$

In order to preserve the LEDset interface accuracy, the cable and connectors have to be properly selected so that they maintain the ground path voltage drop below 40 mV at the maximum current allowed by the LED driver (about 50 mΩ with 700 mA of output current).

Note:
When the second ground reference is adopted, using the optional LED- terminal for the R_{set} connection, the accuracy is not affected by the LED return current and the real output current can be calculated using the following formula:

$$(6) \quad I_{out\_real} = \left(\frac{5\,V}{R_{set} + R_{gpr}} \right) \times 1000$$

2.3.6 Insulation
The interface line terminals of the LED driver have the same grade of insulation to the mains supply voltage as the output circuits. The LEDset interface has no specific protection against electrostatic discharge (ESD), except where noted otherwise in the product specifications. Therefore, it is recommended that any circuit (e.g. accessible potentiometer) connected to the LEDset interface port has a corresponding insulation against touchable parts.

2.3.7 Cable length
The LEDset wire can be as long as the output supply wires to the LED modules. Further limitations to cable length generally derive from EMI emission or immunity issues or directly from product specification details. For detailed information, please refer to the datasheet or instruction sheet of the respective LED driver.

2.3.8 Marking
LED drivers and LED modules equipped with LEDset and compliant to LEDset specifications will be marked with the following logo:

The LEDset logo

2.3.9 Incorrect wiring

Missing LEDset control wire
LEDset is an interface meant for current setting and thermal management of an LED module. If the LEDset line is not connected to the setting and derating circuit of the LED module, the thermal protection of the module and its correct current setting will not work. This fault condition could result in an undetected overheating of the module.

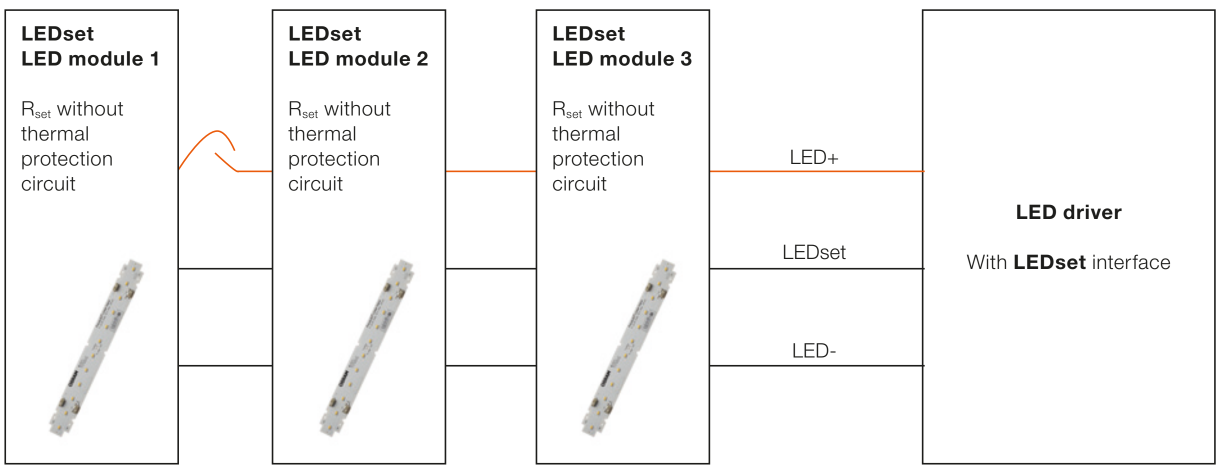
In order to protect the LED module in this condition, the absence of the control signal is recognized and the driver behavior then follows the description specified by the product specification.

LEDset short circuit
In case of short circuit (< 900 Ω) of LEDset (LEDset connected to LED-), the interface recognizes the fault condition and sets the LED output current as specified by the product specifications.

Miswiring of LED+, LED-, LEDset
The interface is protected against incorrect wiring connections of the three poles LED+, LED- and LEDset at power-up. Compliance with this requirement is mandatory for LED drivers and recommended but not mandatory for LED modules.

Incorrect wiring (not native) covered by LEDset interface:
In case of multi-LED module connection, if one or more LED+ module wires are disconnected from the LED driver but all R_{set} resistors remain connected to the PSU, the remaining connected modules receive from a higher LED current from the LED driver. In this case, the LED modules can overheat if they are not equipped with thermal protection circuits.

Figure 15: Critical condition not covered by LEDset interface



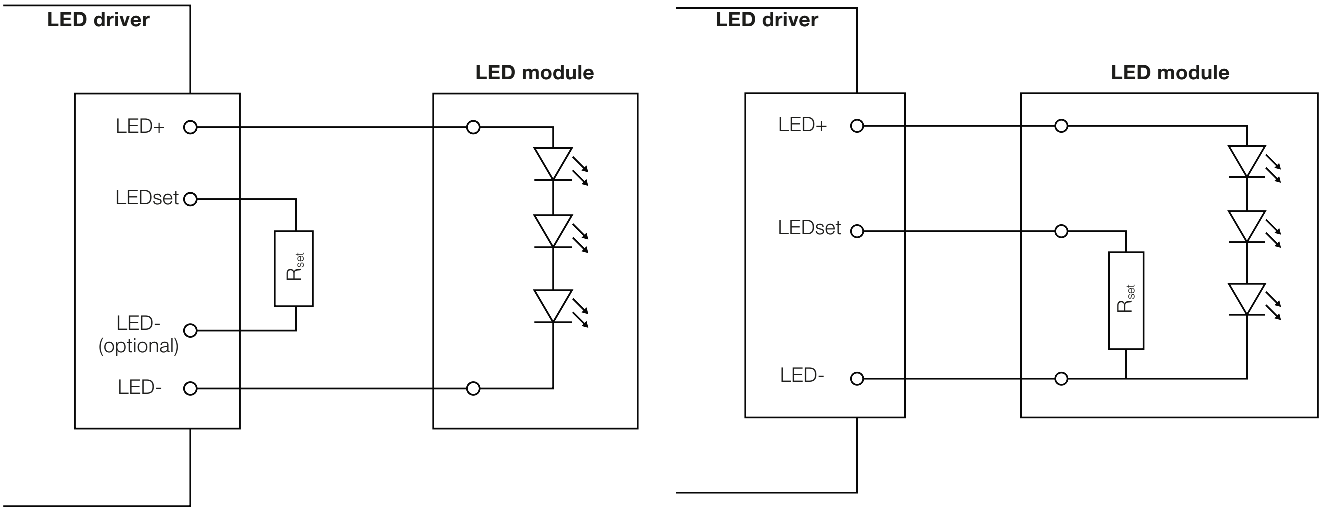
3 LEDset applications

3.1 Current setting by external resistor

If the application requires a specific fixed output current, the easiest way to set the output current is to apply a resistor between the LEDset and LED- terminals.

The LEDset interface is able to generate a constant voltage (V_{set} = 5 V) and thus allows the use of “passive” circuits (i.e. resistors) to achieve the setting current (I_{set}).

Figure 16: Current setting by external resistor placed on the LED driver terminal block (left) and by external resistor placed on the LED module (right)



The resistor can be placed either on the terminal block of the LED driver or on the LED module (see figure 16). If the first solution is adopted (resistor directly connected to the LED driver), the additional LED- terminal has to be used for the resistor connection.

The LED current can be easily set as an absolute value and in the correct LEDset range ($R_{set\_min} < R_{set} < R_{set\_max}$), choosing the correct resistor value through the following formula:

$$I_{LED} = \frac{5\,V}{R_{set}} \times 1000 \qquad (7)$$

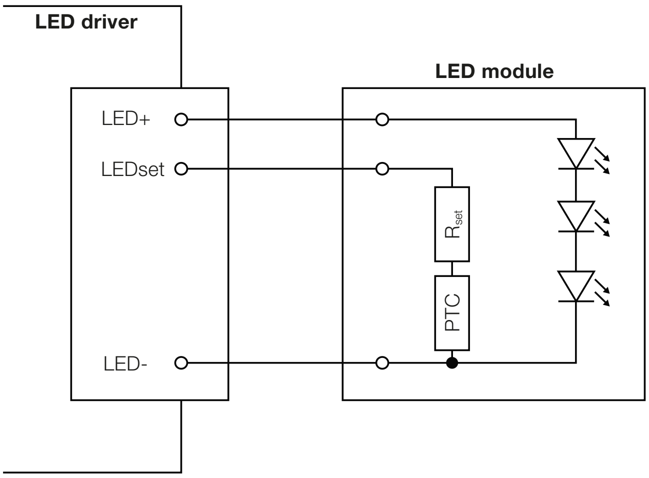
Note:
For resistor values out of the R_{set_min} to R_{set_max} range, please consult the product datasheet, the instruction sheet or the additional application guide.

3.2 Overtemperature protection

3.2.1 Application example 1

The easiest and cheaper way to implement the thermal derating on the LED module is to connect a series consisting of the PTC thermistor and the R_{set} resistor to the LEDset terminal. Figure 17 (below) shows this simple circuit.

Figure 17: Thermal derating circuit through a PTC thermistor



The LED current can be calculated using the following formula:

$$(8) \qquad I_{LED} = \frac{5\,V}{R_{set} + R_{PTC}} \times 1000$$

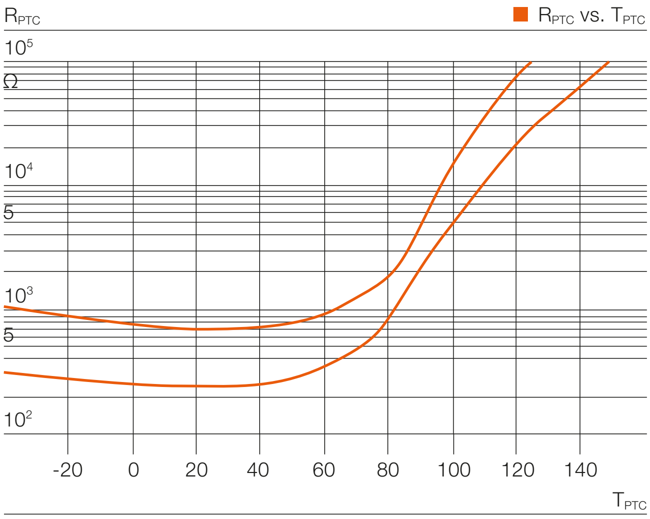
As the PTC resistance value R_{PTC} rises sharply with increasing temperature after its reference temperature has been exceeded, the LED current drops when the LED module temperature exceeds the selected temperature threshold T_{th}.

Example 1:

The circuit in figure 17 has been simulated using the following components:

- PTC EPCOS B59421A0095A062 (SMD_0402, $R_R = 470\,\Omega$, $t_{sense} = 95\,°C$)
- $R_{set} = 6800\,\Omega$

Figure 18: PTC resistance versus PTC temperature

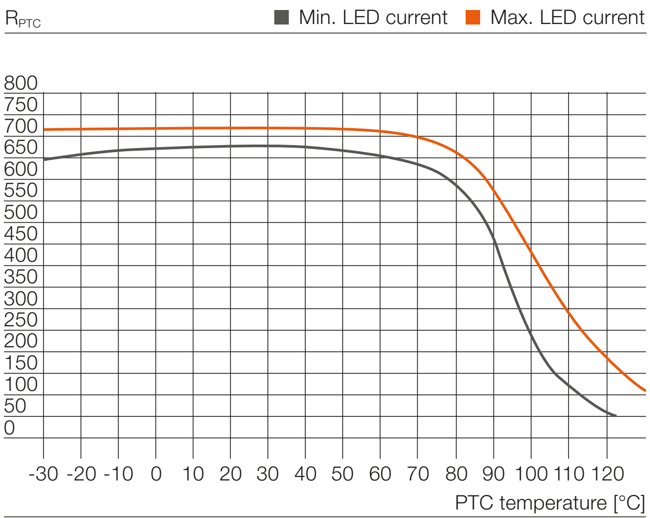


The typical LED current value at ambient temperature can be calculated using the typical PTC resistance value $R_R = 470\,\Omega$ as follows:

$$(9) \qquad I_{LED\ typ} = \frac{5\,V}{6800 + 470\,\Omega} \times 1000 = 687\,mA$$

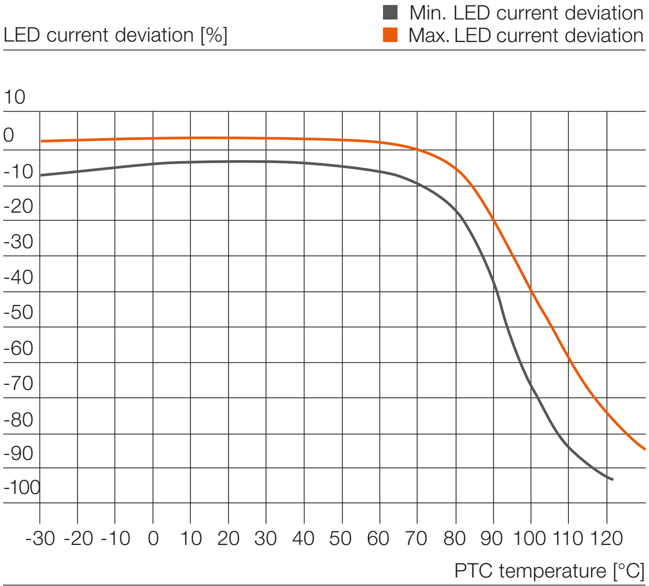
Using the PTC characterization from the EPCOS datasheet (see figure 18, above), the LED current can be calculated as a function of the PTC temperature. The diagram below (figure 19) shows the LED current versus the PTC temperature, the real LED current is a curve within the minimum and maximum of the calculated LED current.

Figure 19: LED current versus PTC temperature



The diagram below (figure 20) shows the deviation of the LED current with respect to the typical nominal value of 687 mA.

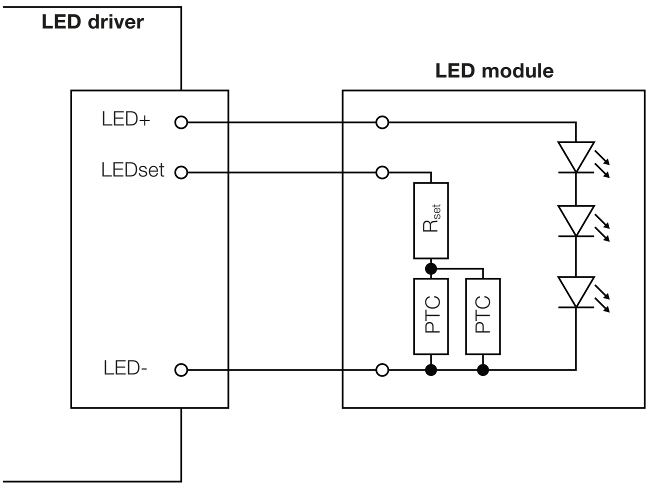
Figure 20: LED current deviation versus PTC temperature



3.2.2 Application example 2

The accuracy of the thermal derating solution presented in paragraph 3.2.1 can be increased by simply using two PTCs in parallel (see figure 21, below). In this case, in fact, the resistance tolerance due to the PTC components is reduced as the PTCs are connected in parallel, and is halved if two identical PTCs are used.

Figure 21: Thermal derating circuit through two PTC thermistors



If, as shown in figure 21, two identical PTCs are used in parallel connection, the LED current can be calculated using the following formula:

$$I_{LED} = \frac{5\,V}{R_{set} + \frac{R_{PTC}}{2}} \times 1000 \qquad (10)$$

Example 2:

The circuit in figure 21 has been simulated using the following components (the same components as in example 1):

- PTC EPCOS B59421A0095A062 (SMD_0402, $R_R = 470\ \Omega$, $t_{sense} = 95\ °C$)
- $R_{set} = 6800\ \Omega$

The typical LED current value at ambient temperature can be calculated using the typical PTC resistance value $R_R = 470\,\Omega$ as follows:

$$I_{LED\ typ}\,[A] = \frac{5\,V}{6800 + \frac{470}{2}} \times 1000 = 710\,mA \qquad (11)$$

Using the PTC characterization from the EPCOS datasheet (see figure 18 on page 11), the LED current can be calculated as a function of the PTC temperature. The diagram below (figure 22) shows the LED current versus the PTC temperature, the real LED current is a curve within the minimum and maximum of the calculated LED current.

The diagram below (figure 23) shows the deviation of the LED current with respect to the typical nominal value of 710 mA.

Figure 22: LED current versus PTC temperature

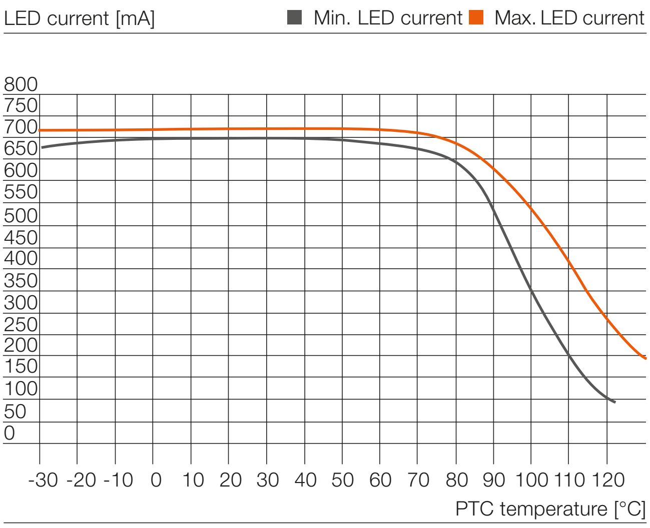
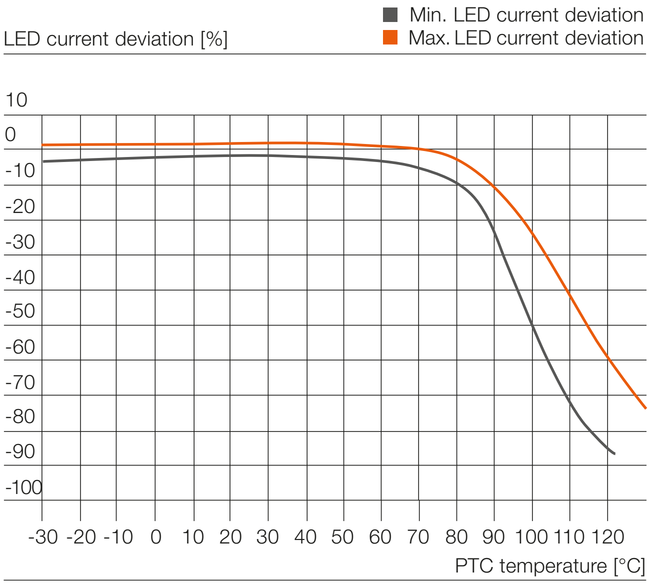


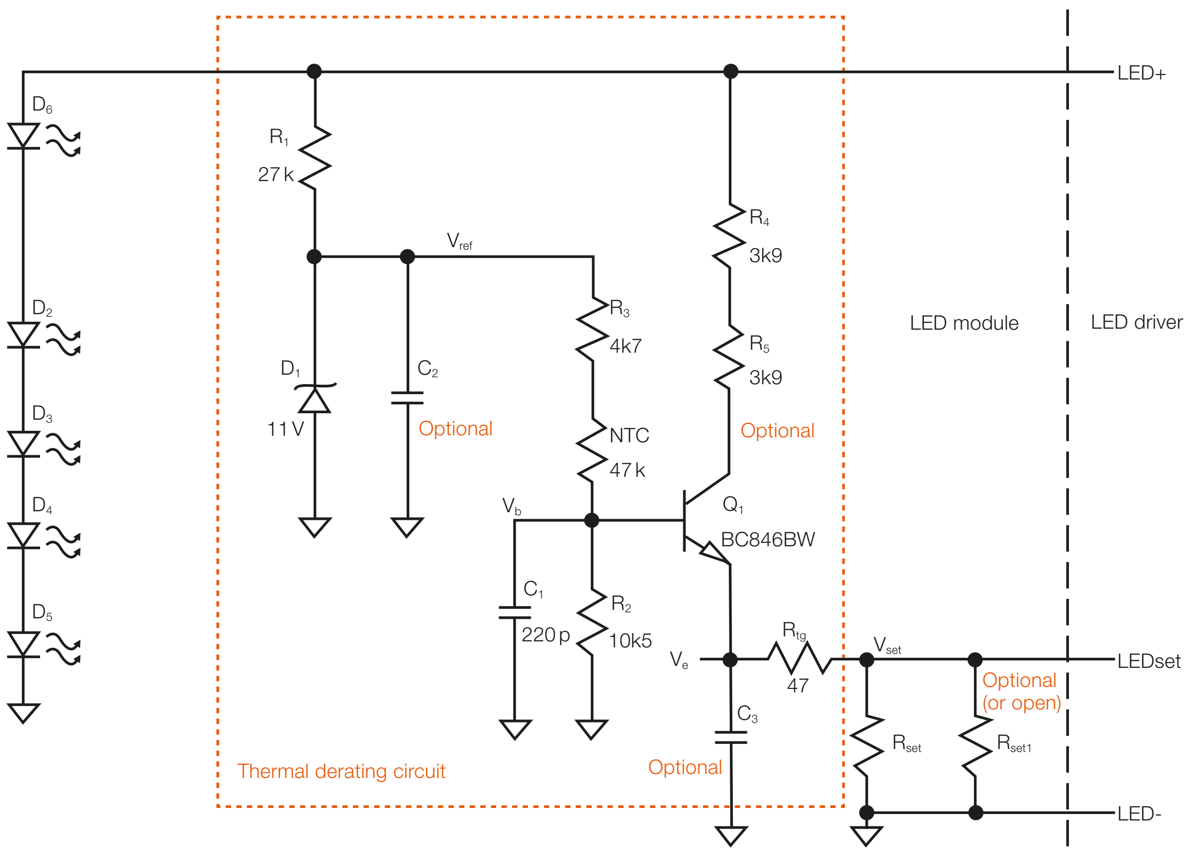
Figure 23: LED current deviation versus PTC temperature



3.2.3 Application example 3

The standard LED module temperature control and current setting circuit is shown in figure 24. It consists of the R_{set} resistor (in this example two resistors are used in order to obtain a better accuracy of the current set point) and the thermal derating circuit. This example refers to an LED module with an operating voltage of 50 V (±8 %) and a maximum operating temperature of 76 °C.

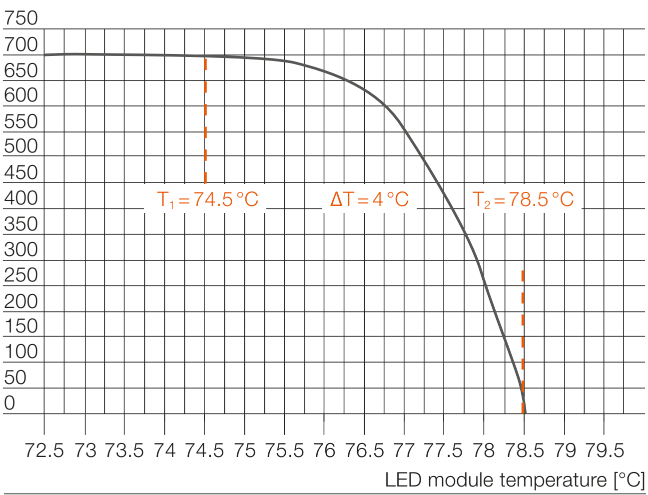
Figure 24: Example of a circuit for temperature control – LED module side (VLED = 50 V ±8 %)



The resistors R_1 and R_4 have been selected in order to provide enough bias current to the thermal derating circuit (see figure 24). In order to decrease power dissipation, R_1 and R_4 may be connected to a lower voltage source (for instance an intermediate LED tap of the total LED string), provided that the minimum tap voltage is higher than the D_1 Zener diode voltage (cf. the following notes). C_2 and C_3 are optional capacitors for ESD/immunity filtering, which can be tuned in the final application.

R_{set1} is an optional resistor available for fine tuning of the LED current. R_5 is also an optional resistor which can be used for reducing the power dissipation of the R_4 resistor during thermal derating (in the example of figure 24 on page 14, the R_5 resistor is necessary in order to use a 1206 R_4 case size).

Figure 25: Current derating simulation – I_{out} [mA] vs. LED module temperature [°C]*



*Based on the circuit shown in figure 14 on page 8

Design step 1 – calculation of the temperature-dependent parameters

After having selected the temperature threshold T_{th}, we can calculate all the system parameters influenced by the temperature:

R_{NTC} value at T_{th}:

(12) $$R_{NTC\_th} = 47\,k \times e^{B \times \left(\frac{1}{273.15 + T_{th}} - \frac{1}{298.15}\right)}$$

$V_{be\_BC846BW}$ value at T_{th}:

(13) $$V_{be\_BC846BW\_th} = 0.55 - 2.3\,mV/°C \times (T_{th} - 25\,°C)^{1)}$$

V_{ref} value (using BZX384-B11) at T_{th}:

(14) $$V_{ref\_th} = 11 + 7.4\,mV/°C \times (T_{th} - 25\,°C)^{2)}$$

where T_{th} = threshold temperature derating, B = NTC B parameter (B = 4000 for NTC EPCOS B57423V2473H062). At the temperature threshold, the current through R_{tg} is very low; therefore, the voltage drop can be neglected.

1) -2.3 mV/°C is the typical temperature coefficient of the BC846BW base-emitter junction – 0.55 V determined using Ebers-Moll equation calculated at working point T_{amb} = 25 °C at I_c = 30 µA.
2) 7.4 mV/°C is the typical temperature coefficient of the BZX384-B11.

R_3 calculation

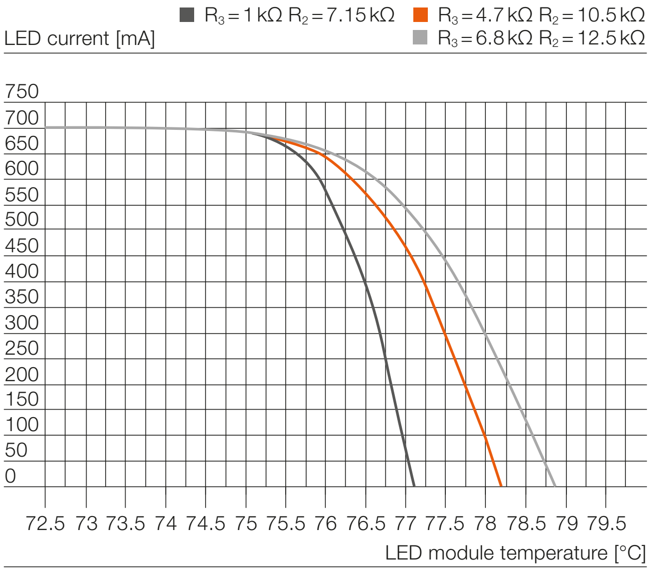
The value for R_3 must be selected lower than the R_{NTC_th} value calculated at the T_{th} temperature in order to preserve the system temperature sensitivity. This resistor is used to decrease the sensitivity of the thermal derating as indicated in figure 26.

R_2 calculation

(15) $$R_2 = \frac{V_{set} + V_{be\_BC846W\_th}}{V_{ref\_th} - V_{set} - V_{be\_BC846BW\_th}} \times (R_{NTC\_th} + R_3)$$

where V_{set} = 5 V

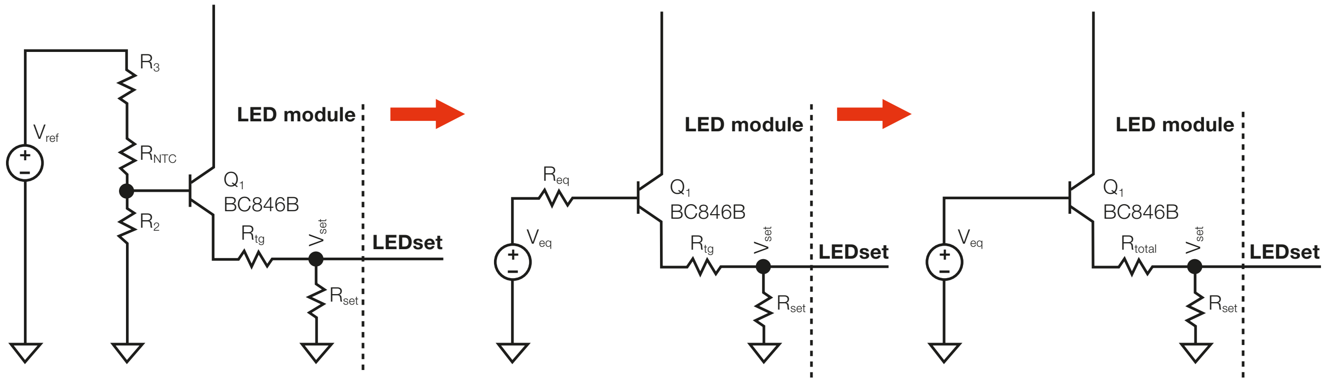
Figure 26: Current derating simulation – I_{out} [mA] vs. LED module temperature [°C] – with different R_3 and R_2 value combinations*



*Based on the circuit shown in figure 26 – fixed temperature threshold point – R_{NTC} = 6844 Ω at 75 °C

R_{tg} calculation
In order to select the resistor value R_{tg}, it is necessary to calculate the total equivalent series resistance R_{tot}:

Figure 27: Equivalent circuit analysis – based on circuit of figure 24



V_{eq} and R_{eq} are the model parameters viewed from the base of Q_1 and calculated as:

$$(16)\quad R_{eq} = \frac{(R_3 + R_{NTC\_th}) \times R_2}{R_3 + R_{NTC\_th} + R_2}$$

$$(17)\quad V_{eq} = \frac{V_{ref} \times R_2}{R_3 + R_{NTC\_th} + R_2}$$

R_{total} can be calculated as follows:

$$(18)\quad R_{total} = R_{tg} + \frac{R_{eq}}{1 + h_{FE\_min}}$$

where h_{FE_min} is the minimum static current gain of the transistor Q_1.

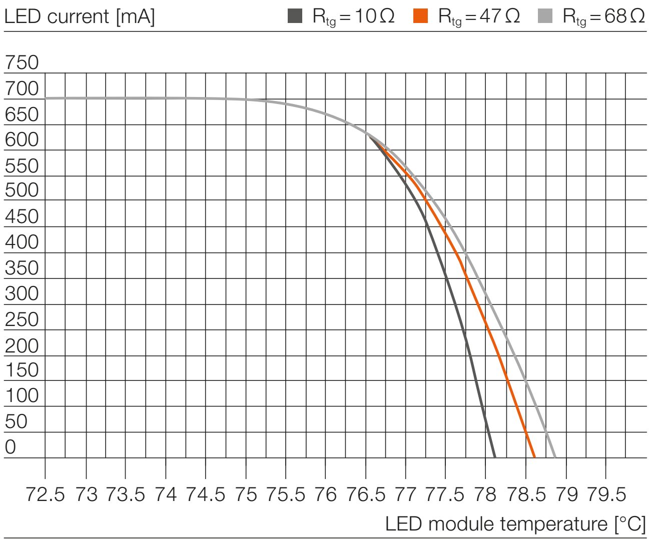
In order to preserve the thermal derating behavior in case of multi-module parallel connections or low R_{set} value, a value for R_{total} must be selected which is below 100 Ω.

Figure 28 (below) shows the thermal derating behaviour with different R_{tg} values; the slope of the derating curve is lower at higher values of R_{tg}.

A disadvantage of using high R_{tg} values is the influence of this parameter on the final shutdown temperature T_2. If high values of R_{tg} are used, the slope of the thermal derating curve increases when the R_{set} value is reduced. For this reason, it is recommended to select the lowest R_{tg} value that ensures the thermal derating stability (to be verified in the corresponding application). A rule of thumb for R_{tg} selection is shown below:

$$(19)\quad R_{tg} \geq \frac{R_{eq}}{(1 + h_{FE\_min})}$$

Figure 28: Current derating simulation – I_{out} [mA] vs. LED module temperature [°C] at different R_{tg} values*



* Based on the circuit shown in figure 14 on page 8 (with fixed R_2 and R_3)

In order to facilitate R_2 and R_3 selection, a simplified table is shown below:

Table 6: R_2 , R_3 and R_{tg_max} values according to T_{th} temperature threshold*

T_{th} [°C]	R_{NTC_th} [Ω]	R_3 [Ω]	R_2 [Ω]	R_{tg_max} [Ω]
45	20 222	13 975	33 349	16
50	16 647	11 505	27 163	31
55	13 786	9527	22 257	43
60	11 481	7973	18 342	53
65	9613	6644	15 199	61
70	8091	5592	12 660	67
75	6844	4730	10 599	72
80	5817	4020	8916	77
85	4966	3432	7535	80
90	4258	2943	6395	83
95	3666	2534	5452	86
100	3170	2191	4666	88
105	2751	1901	4009	89
110	2396	1656	3458	91
115	2095	1448	2993	92
120	1837	1270	2600	93
125	1617	1117	2266	94

*Table based on the circuit shown in figure 14 on page 8

Design step 2 – R_1 selection:
R_1 has to be selected in a way that ensures that the minimum required current of the circuit is provided while its power dissipation is minimized.

Design example:

Input data

Maximum module temperature (T_{max}): 80 °C
Maximum LED module voltage (V_{LED+_max}) [3]: 54 V [4]
Minimum LED module voltage (V_{LED+_min}): 46 V [5]
Minimum LEDset voltage (V_{set_min}): 4.75 V
Maximum LEDset voltage (V_{set_max}): 5.25 V
Zener diode nominal voltage (V_{Zener_nom}): 11 V (BZX384-B11)
Zener diode voltage tolerance (tol%): 2 % (BZX384-B11)
Zener diode temperature coefficient max (K_{temp}): 9 mV/K (BZX384-B11)
Zener diode maximum power dissipation ($P_{D1\_Zener\_max}$): 300 mW (BZX384-B11)

Other fixed data

Minimum Zener diode bias current (I_{bias_z}): 0.5 mA
Maximum interface current ($I_{interface\_max}$): 5 mA at I_{out} = 5 A
Q1 - BC846BW min static current gain ($h_{FE\_min} = I_c/i_b$): 200 at I_c = 2 mA

R_1 calculation
Using the equations (20) and (21), it is possible to find the minimum and the maximum Zener diode voltage (V_{ref_max}, V_{ref_min}):

$$V_{ref\_max} = V_{Zener\_nom} + V_{Zener\_nom} \times tol\,\% + K_{temp} \times (T_{max} - 25\,°C) \quad (20)$$

$$V_{ref\_min} = V_{Zener\_nom} - V_{Zener\_nom} \times tol\,\% + K_{temp} \times (T_{max} - 25\,°C) \quad (21)$$

Maximum Zener diode voltage (BZX384-B11):
V_{ref_max} = 11 V + 11 V*2 % + 9 mV/K * (80 °C-25 °C) = 11.715 V

Minimum Zener diode voltage (BZX384-B11):
V_{ref_min} = 11 V - 11 V*2 % + 9 mV/K * (80 °C-25 °C) = 11.275 V

Now it is necessary to calculate the current I_{R1} (24) as a sum of three currents: BC846BW base current (22), maximum NTC current (23) and the minimum Zener diode bias current I_{bias_z}.

$$I_{b\_max\_BC846BW} = \frac{I_{interface\_max}}{h_{FE\_min}} \quad (22)$$

$$I_{NTC\_max} = \frac{V_{ref\_max}}{R_2 + R_3} \quad (23)$$

$$I_{R1\_min} = I_{b\_max\_BC846BW} + I_{NTC\_max} + I_{bias\_z} \quad (24)$$

Maximum BC846BW base current ($I_{b\_max\_BC846BW}$): 25 μA
Maximum NTC current (I_{NTC_max}): 746 μA
I_{R1min} ≈ 1.3 mA

3) V_{LED+} is the voltage between the LED+ and LED- poles.
4) In case of intermediate LED voltage source connection, use its maximum value.
5) In case of intermediate LED voltage source connection, use its minimum value.

Under the condition of $V_{LED+\_min} > V_{ref\_max}$:

$$(25) \quad R_{1\_max} = \frac{V_{LED+\_min} - V_{ref\_max}}{I_{R_{1\_min}}}$$

R_1 has to be selected fulfilling the two conditions (26) and (27); in order to save power dissipation, R_1 has to be selected as close as possible to the R_{1_max} value:

$$(26) \quad R_1 < R_{1\_max}$$

$$(27) \quad P_{R_1} = \frac{(V_{LED+\_max} - V_{ref\_min})^2}{R_1} < P_{R_{1\_max}}$$

where $P_{R_{1\_max}}$ is the maximum permitted power dissipation indicated by the selected R_1 resistor according to its package size (cf. resistor datasheet) and P_{R1} is its calculated maximum power.

If these conditions cannot be fulfilled, please select a bigger R_1 case in order to increase the $P_{R_{1\_max}}$ value.

After the R_1 selection, it is necessary to verify the Zener diode power dissipation constraint (28):

$$(28) \quad P_{D1\_Zener} = \frac{(V_{LED+\_max} - V_{ref\_min})}{R_1} \times V_{ref} \leq P_{D1\_Zener\_max}$$

where $P_{D1\_Zener\_max}$ is the maximum power dissipation allowable by D_1.

The user has to verify the maximum power dissipation by D_1 using equation (28), according to its maximum allowed power dissipation (cf. Zener diode datasheet). If this condition isn't met, please select a bigger D_1 package size in order to increase the $P_{D1\_Zener\_max}$ value.

Design step 3 – R_4 and R_5 selection:
Considering the following equation:

$$(29) \quad R_{eq} = R_4 + R_5$$

R_{eq} has to be selected in order to maintain the maximum interface current ($I_{interface\_max} = 5\,mA$) with the voltage V_{LED+_min}, the BC846BW collector-emitter saturation voltage $V_{CEsat\_BC846BW}$ and the R_{tg} voltage drop. The maximum R_{eq} resistor value has to be calculated as indicated in equation (30):

$$(30) \quad R_{eq\_max} = \frac{V_{LED+\_min} - V_{set\_max} - V_{CEsat\_BC846BW} - R_{tg} \times I_{interface\_max}}{I_{interface\_max}}$$

R_{eq} has to be selected fulfilling the two conditions (31) and (32): In order to save power dissipation, R_{eq} has to be selected as close as possible to the R_{eq_max} value:

$$(31) \quad R_{eq} < R_{eq\_max}$$

$$(32) \quad P_{R_{eq}} = \frac{(V_{LED+\_max} - V_{CEsat\_BC846BW} - V_{ref\_min})^2}{R_{eq}} \leq P_{R_{eq\_max}}$$

$P_{R_{eq}}$ is the total calculated power dissipation of $R_4 + R_5$ and $P_{R_{eq\_max}}$ is the maximum power dissipation allowed by the two resistors. In order to save components, it is possible to consider $R_5 = 0\,\Omega$ and so $P_{R_{eq\_max}} = P_{R_{4\_max}}$. The R_4 package has to be selected in order to fulfill condition (32). If this condition is not fulfilled, please select a bigger R_4 case in order to increase the $P_{R_{4\_max}}$ value or use the series R_5 resistor in order to share the power dissipation (selecting R_5 and R_4 according to equation (29) as shown in the following example).

Example:

Thermal protection design example
$T_{th} = 75\,°C$
$R_{NTC@75\,°C} = 6844\,\Omega$
$V_{be\_BC846BW@75\,°C} = 0.435\,V$
$V_{ref\_nom@75\,°C} = 11.37\,V$
$V_{CEsat\_BC846BW} = 90\,mV$

$R_1 = 27\,k\Omega$ – SMD case: 0805 – $P_{max} = 125\,mW$ [6)]
$R_2 = 10.5\,k\Omega$ – SMD case: 0805 – $P_{max} = 125\,mW$
$R_3 = 4.7\,k\Omega$ – SMD case: 0805 – $P_{max} = 125\,mW$
$R_4 = 3.9\,k\Omega$ – SMD case: 1206 – $P_{max} = 250\,mW$
$R_5 = 3.9\,k\Omega$ – SMD case: 1206 – $P_{max} = 250\,mW$

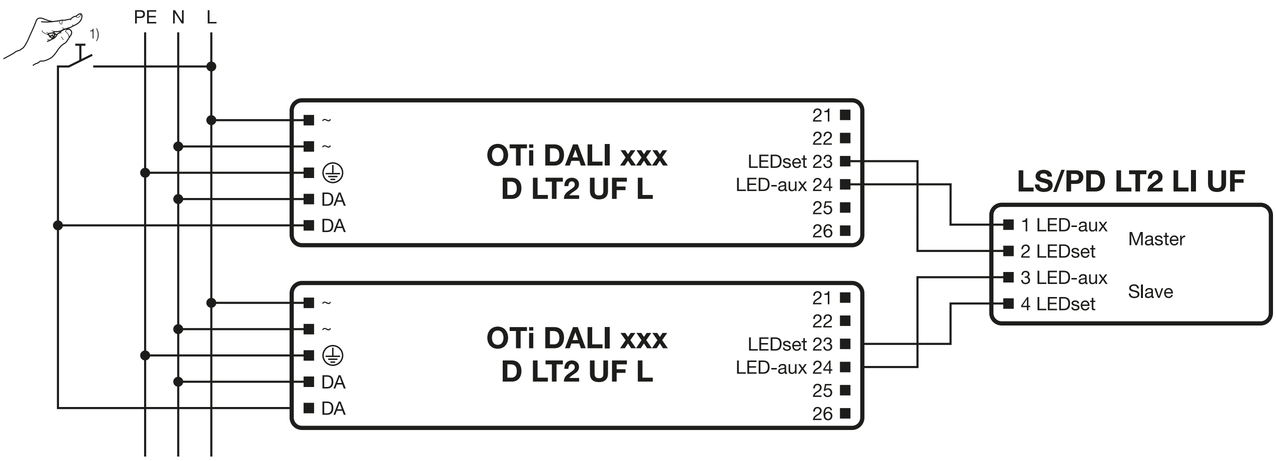
6) P_{max} is the maximum power dissipation allowable by the resistor, relating to its power thermal derating.

4 Additional functions LEDset in Ultraflat LED drivers

4.1 Motion detection and daylight-dependent control with LS/PD LT2 LI UF and Ultraflat LED drivers
The LS PD LT2 LI UF sensor can be used with up to two OTi DALI xxx D LT2 UF L LED drivers as a stand-alone solution for daylight-dependent lighting control with motion/presence detection. The sensor is connected to the LED drivers via the LEDset interface, so that additional push-buttons can be integrated into the system via Touch DIM® and the DALI interface.

Figure 29: Wiring scheme with one LED driver

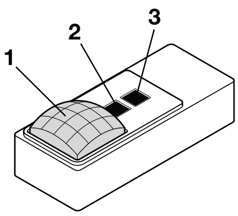
Figure 30: Wiring scheme with two LED drivers



1) External pushbutton

Table 7: Sensor for OTi DALI Ultraflat LED drivers

Connection (Master/Slave)	LEDset/LED-aux
Operating voltage	5 V_{DC}
Power consumption	30 mW
Sensor connection	≤ 1 m
External pushbutton connection total wire length	≤ 25 m
External pushbutton	230 V_{AC}
Light sensing range	10…1000 lx
t_a	0…+50 °C
t_c	55 °C
Type of protection	IP20



4.1.1 Application and function
The LS/PD LT2 LI UF sensor measures brightness reflected by a reference surface below (e.g. a working desk) and detects motions from persons or other objects with heat dissipation (1: Presence and motion detector). Brightness and motion information is transmitted to the connected LED drivers. The LED drivers take over the role of the control unit. The light switched on if presence is detected and regulated according to the incoming daylight (2: Light sensor and indication LED) and the stored set point. Each detected motion is indicated by the integrated green LED if no presence is detected and the delay time has expired the light will be switched off. The switch off delay time is stored in the drivers (ex factory setting: 15 min) and can be modified by the Tuner4TRONIC® software. The presence detection and light regulation can be disabled temporarily or permanently on demand. In addition, the light can be dimmed/switched manually and a set point can be stored by the button integrated in the sensor (3: Pushbutton) or with an external TouchDIM® pushbutton connected to the LED drivers. If not otherwise stated, all subsequently described user operations can be performed with both buttons.

4.1.2 Manual dimming and switching
By a short push on a button the light can be switched on and off. If the light is switched on and a set point is stored, the daylight-dependent regulation is active. If the light is switched off by a short push and the presence detection is enabled, the light will switch on with the next motion after the inhibit time of 30 s (ex factory setting, the inhibit time can be modified by the Tuner4TRONIC® software) has expired. The inhibit timer is retriggered with every detected motion.

The light can be dimmed by a long push on the button. Dimming direction toggles with every long push. Manual dimming stops the daylight-dependent regulation, the regulation will be reactivated if the light is switched on again either by a short push or by presence detection.

4.1.3 Storing and deleting a daylight-dependent regulation set point
To store a new regulation set point and enable the daylight-dependent regulation, the light has to be dimmed to the desired brightness level. Subsequently the brightness level has to be stored by a double click. The double click is confirmed by a two times blinking of the light. The new brightness level is stored ~10 s after the double click, within that period no persons or objects should be in between the sensor and the reference surface below.

To delete the set point and disable the daylight regulation, switch off the light by a short push and then double click on the button. The light will switch on and dim to maximum to confirm that the set point is deleted.

4.1.4 Disable presence detection temporarily (holiday mode)
To disable the presence and motion detection temporarily (e.g. to avoid switch-on during a longer absence period of the workplace owner), double click on the button when light is switched on and light was not dimmed manually within the last 30 s. The detection will still be indicated by the sensor LED, but not lead to a switch-on of the light.
To enable the presence and motion detection again, shortly push the button.

4.1.5 Disable presence detection permanently
Press the button integrated in the sensor for ~20 s until the LED of the sensor flashes one time to indicate that the presence detection is disabled. If the detection is disabled, the sensor LED will not blink anymore if persons or objects enter the detection area. To enable the detection again, press the button integrated in the sensor for ~20 s until the LED of the sensor flashes two times to indicate that the presence detection is re-enabled.

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For more product-specific information, please go to:

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- Light management systems: www.osram.com/lms
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