ACADEMY

4. LED CONTROLS

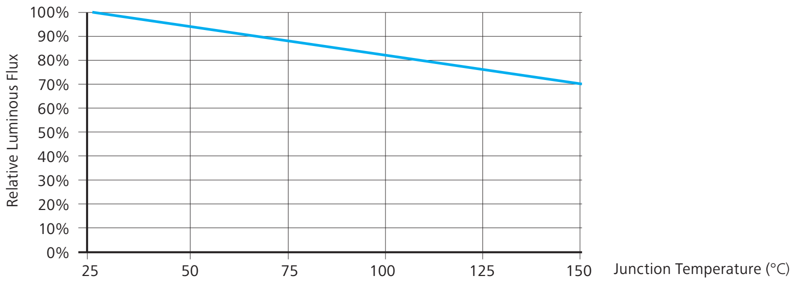
4.1. Cold lumens versus hot lumens

Luminous flux emitted by LED depends directly on forward current (I_f) magnitude. "Typical luminous flux" for nominal I_f (e.g. 350 mA) is listed in datasheets. Input power needed to reach typical luminous flux is expressed by following equation:

$$P = I_f \cdot V_f ,$$

where V_f is LED forward voltage (voltage drop) at nominal I_f. Then the LED efficacy is expressed as a ratio between the typical luminous flux and the input power. However, all these values (typical luminous flux, I_f, and V_f) are listed for junction temperature T_j = 25 °C. In this case we are talking about "cold lumens". But in real luminaire, junction (active area) of LED is heated up significantly by dissipative heat, which becomes from energy conversion within the LED die. Maximum allowed T_j ranges from 130 °C to 150 °C (depending on LED type). Higher temperatures will irreversibly damage LED chip.
Luminous flux decreases with increasing T_j (Figure 5.1.1). Therefore it is necessary to keep T_j on the lowest possible value. Term "hot lumens" is used when speaking about luminous flux emitted by LED at operational T_j (70 – 120 °C) after steady-state conditions were reached.

Figure 4.1.1: Relative luminous flux as a function of junction temperature.



On the other hand, with the increasing junction temperature decreases internal resistance of LED chip, thus LED efficacy increases. Decrease is expressed by "Temperature coefficient of voltage" (V_T), measured in mV/°C (Figure 4.1.2).

Figure 4.1.2: Characteristics of the LED Cree XP-E HEW.

Characteristics	Unit	Minimum	Typical	Maximum
Thermal Resistance, junction to solder point	°C/W		6	
Viewing Angle (FWHM) - white	degrees		120	
Temperature coefficient of voltage	mV/°C		-3	
ESD Classification (HBM per Mil-Std-883D)			Class2	
DC Forward Current	mA			1000
Reverse Voltage	V		5	
Forward Voltage (for 350 mA)	V		3.0	3.5
Forward voltage (for 700 mA)	V		3.15	
Forward Voltage (for 1000 mA)	V		3.25	
LED Junction Temperature	°C		150	

We have 100 % of relative luminous flux at T_j = 25 °C, but only 70 % at T_j = 150 °C (Figure 4.1.1).
According equation:
Efficacy = Relative luminous flux for T_j / (V_f + ΔV) · I_f),
where $\Delta V = (T_j - 25) \cdot V_T$,
we can calculate efficacy of LED Cree XP-E HEW with luminous flux = 114 lm at
T_j = 25°C when biased by nominal forward current of 350 mA (Figure 4.1.2) as follows:
ΔV = (25 – 25) · (-0.003) = 0 V, then
Efficacy = 114 / ((3 + 0) · 0.35) = **108.57 lm/W for I_f = 350 mA, T_j = 25 °C**.
Now calculate efficacy of the LED at T_j = 150°C, biased by the same current (from Figure 4.1.1 luminous flux = 79.8 lm at T_j = 150 °C):
ΔV = (150 – 25) · (-0.003) = -0.375 V, then
Efficacy = 79.8 / ((3 – 0.375) · 0.35) = **86.86 lm/W for I_f = 350 mA, T_j = 150 °C**.

Comparison of results shows slight decrease of power consumption at higher junction temperature, but relatively steep decrease of luminous flux. Combined together, LED efficacy decrease with increased junction temperature. In real conditions T_j will be always higher than 25 °C, thus "cold lumens" parameter is nice but useless. In practice LED light source efficacy is always lower and also depends on ambient temperature, thus "hot lumens" parameter has to be used during luminaire design.

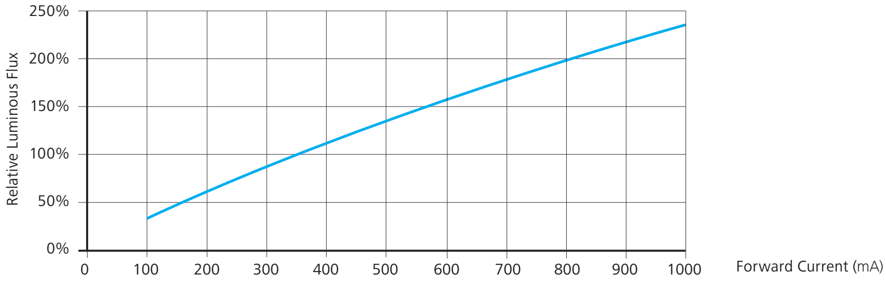
4.2. Driving LEDs

Forward current control

Since LED emits light depending on forward current magnitude, the easiest way how to control LED light source intensity is changing bias current value. Figure 4.2.1 depicts relative luminous flux as a function of forward current value. Change of luminous flux depends on forward-current change nearly linear; therefore control algorithm implementation is very easy.

Figure 4.2.1:

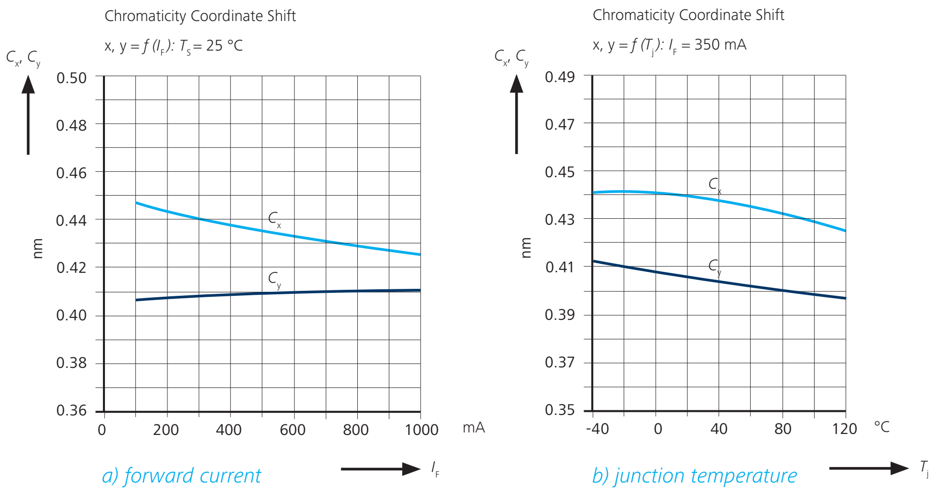
Relative luminous flux as a function of forward current.



However, altering of forward current value leads to a shift of chromaticity coordinates (Cx, Cy), what directly affects qualitative parameters (CCT, CRI) of emitted light (Figure 4.2.2).

Figure 4.2.2:

LED OSRAM LCW W5PM – chromaticity coordinates shift with:



We have C_x = 0.440 and C_y = 0.408 (corresponding to **CCT = 2985 K**) at I_F = 350 mA. If we decrease I_F to 100 mA, chromaticity coordinates will shift to C_x = 0.448 and C_y = 0.406 (corresponding to **CCT = 2838 K**), what is difference of **147 K** (Figure 4.2.2a).

This difference is increased by chromaticity coordinates shift with varying junction temperature. We have C_x = 0.436 and C_y = 0.406 (corresponding to **CCT = 3036 K**) at
T_j = 20 °C, and C_x = 0.428 a C_y = 0.399 (**CCT=3121 K**) at T_j = 100 °C, what is difference of **85 K**. It can lead to visible (disturbing) difference of CCT mainly if several luminaires are dimmed-down simultaneously.

Advantages:

No flicker effect.

Disadvantages:

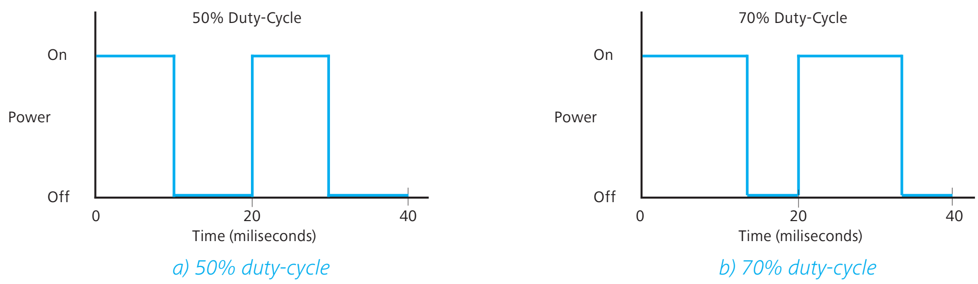
CCT changes when luminaire is dimmed-down.

PWM control

Another way how to control LED light source intensity is pulse-width modulation (PWM) method. Principle of PWM lies on biasing LED by constant nominal current which is periodically switched on and off. Ratio between on-state and off-state defines resulting intensity of the LED. Switching frequency is high enough thus human eye perceives light emitted by LED as continuous luminous flux with intensity depending on PWM duty-cycle. Figure 4.2.3 shows examples of PWM signal with 50 % and 70 % duty-cycle, respectively.

Figure 4.2.3:

Examples of PWM signal.



Advantages:
Stabilized CCT over whole dimming range.
Disadvantages:
Flicker effect can occur when luminaire is dimmed down.

4.3. LED connection

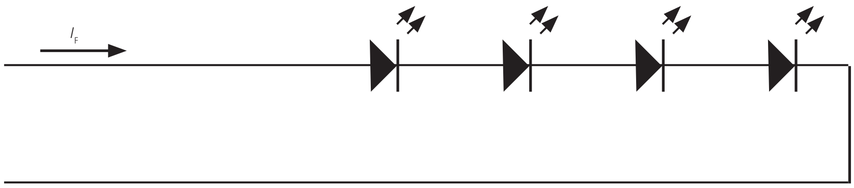
One LED does not deliver enough light. Therefore LED are connected together in order to reach desired lumen output. Exists four basic ways how to connect LEDs:

- LEDs in serial connection
- LEDs in parallel connection
- LEDs in serial/parallel connection
- LEDs in matrix connection

LEDs in serial connection

LEDs in serial connection (Figure 4.3.1) emit the same amount light regardless of forward voltage, which can vary because of uneven placement. This connection requires constant current LED driver and it is stable even in case of internal shortcut of one or more LEDs in string. Also serial connection is ideal both for forward current control and PWM control. It is used when stabilized CCT and CRI are requested.

Figure 4.3.1:
LEDs in serial connection.



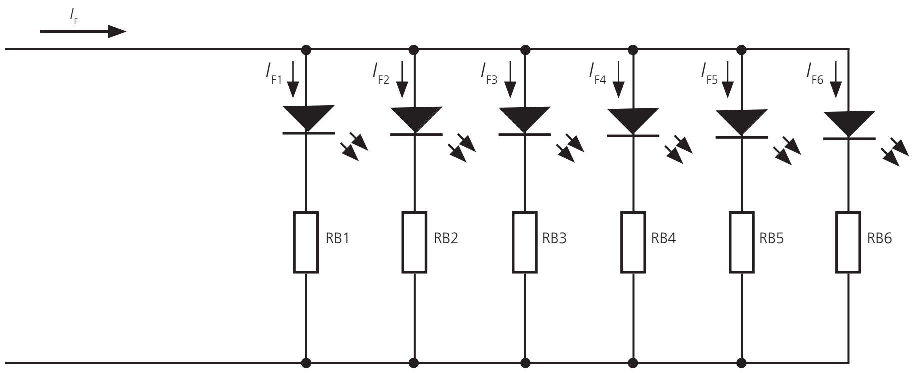
Advantages:
- each LED uses the same current – stabilized CCT and CRI
- high efficacy – no need of balance resistor
- LED short-circuit defect-proof connection
- ideal for forward current control and also PWM control

Disadvantages:
- unstable when one LED goes to open-circuit (whole string will switch-off)
- more expensive LED Driver

LEDs in parallel connection

Advantage of parallel connection of LEDs (Figure 4.3.2) is its resistance against single LED damage. This connection requires constant voltage LED driver. It is used when stabilized CCT and CRI are not requested, mainly for decorative lighting.

Figure 4.3.2:
LEDs in parallel connection.



Advantages:
- cheaper LED driver
- LED open-circuit proof

Disadvantages:
- low efficacy
- unstable when one LED goes to short-circuit
- unusable for forward current control

LEDs in serial/parallel connection

Slight degradation of defect-proof feature of parallel connection is outweighed by increase of efficacy of overall connection. Also CCT and CRI parameters are more stabilized as in case of pure parallel connection and it is possible to use constant voltage driver (lower price). Serial/parallel connection (Figure 4.3.3) is suitable for high numbers of LEDs connected such as long decorative stripes.

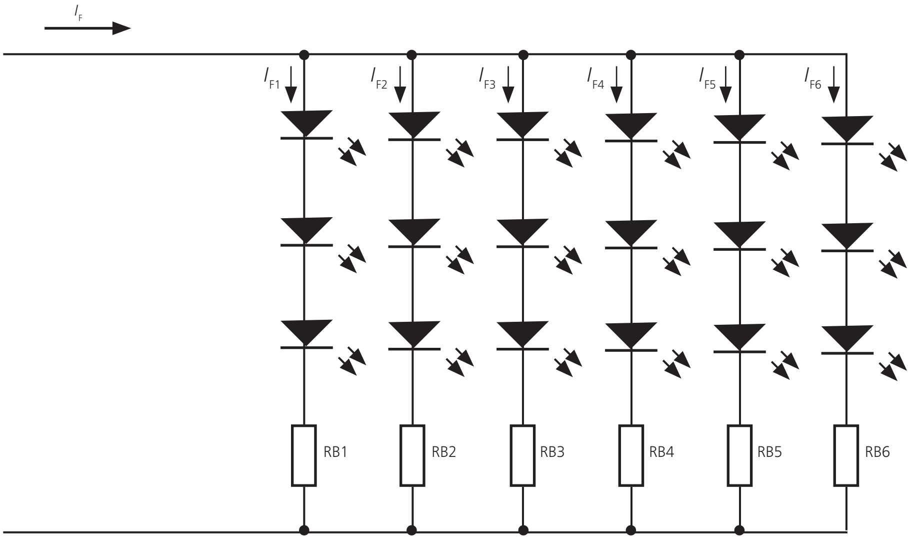


Figure 4.3.3:
LEDs in serial/parallel connection.

Advantages:

- ability to drive very high number of LEDs
- LED open/short-circuit proof

Disadvantages:

- lower efficacy
- unusable for forward current control

LEDs in matrix connection

When LEDs are connected in matrix (Figure 4.3.4), we can achieve very high number of LED used while maintaining stabilized CCT (also in case of any failure of any of the LED chips). LEDs in matrix connection can be driven by both constant current and constant voltage driver.

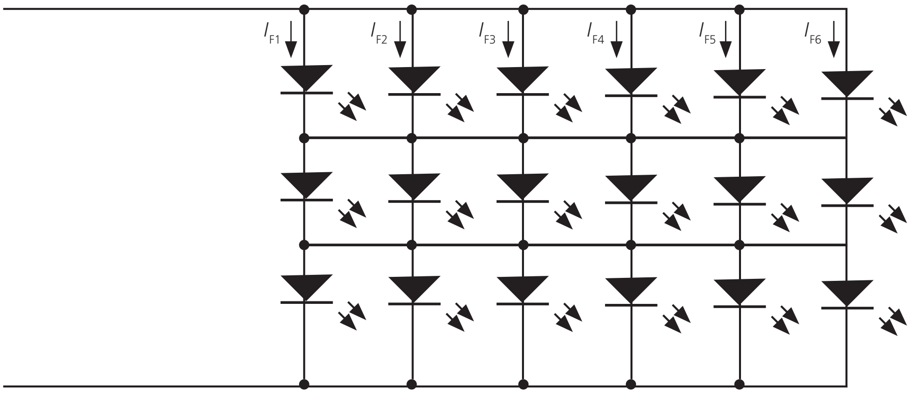


Figure 4.3.4:
LEDs in matrix connection.

Advantages:

- ability to drive very high number of LEDs
- high efficacy
- forward current control and PWM dimming (when constant current LED driver is used)
- LED open/short-circuit proof

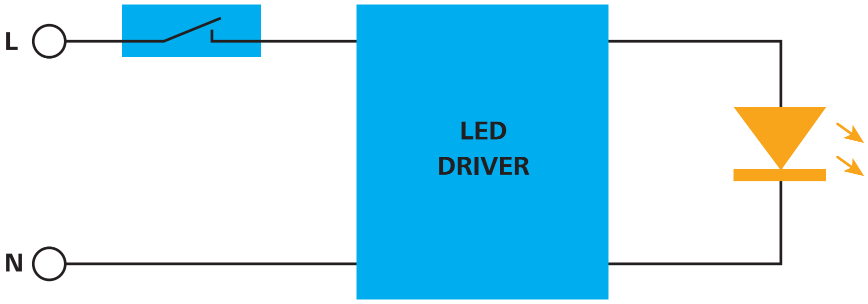
Disadvantages:

- quite complex design of printed-circuit board

4.4. LED driver

LED driver is simple electronic circuit which serves as an energy source for LEDs (Figure 4.4.1). The driver changes AC (grid) voltage to DC while optimizing driving current for LEDs. Modern luminaires with added value (dimming possibility, emergency unit, presence sensor, remote control, etc.) require more complex electronic circuitry.

Figure 4.4.1:
Basic connection scheme of LED light source.



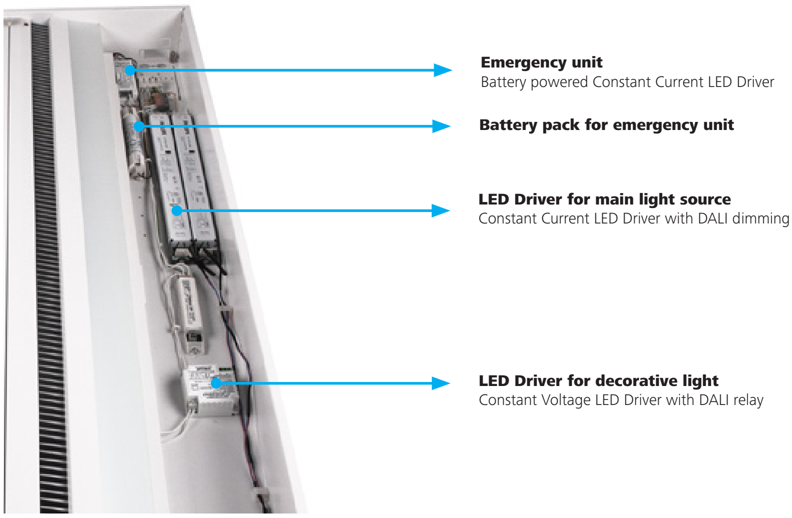
LED driver types and important parameters

According to type of output signal, we have three groups of LED drivers:

- **Constant current (CC)** - LEDs are mostly in serial connection, driver delivers precise current value. Ideal for dimming.
- **Constant voltage (CV)** - LEDs are mostly in parallel connection, ideal for decorative LED strips. Various numbers of LEDs can be connected. Not recommended for dimming.
- **Special (CC+CV)** - Both serial and parallel connections of LEDs can be used. Quite expensive solution.

Figure 4.4.2:
Control gear of LED luminaire Vega (OMS Elite).

Various LED drivers implemented into LED luminaire Vega (OMS Elite).



LED driver most important parameters:

- **Rated Current/Voltage** - Predefined output current or voltage.
- **Rated power** - Output power of driver.
- **Efficacy** - Ratio between output power and input power in per cents - higher number means better driver.

4.5. LED driver additional features

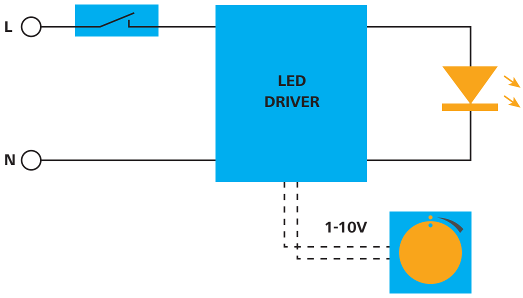
Analog interface - the easiest way to control brightness of a luminaire

Analog interfaces are used in lighting industry only for dimming. It is the most used dimming system for retail (e.g. spot lights in shops). Drawback is that it is not possible to switch off luminaire via analog dimming.

There are two basics analog interfaces:

- **TE/LE** - trailing/leading edge (thyristor regulation) – only one luminaire can be dimmed.
- **0-10 V, 1-10 V dimming** – supports more than one controlled luminaire (Figure 4.5.1).

Figure 4.5.1:
1-10V dimming.



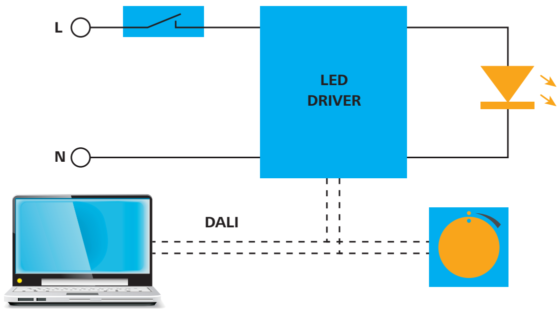
Digital interface – sophisticated communication with luminaire

Digital interface offers possibility to connect more LED drivers via digital interface, and control them independently. It also supports reading the status of each luminaire. Digital interface supports dimming, presence sensor, remote control, tunable white, scenic light schemes, etc. It is ideal solution for installations/projects with high numbers and various types of luminaires.

Digital interfaces used in lighting industry:

- DALI-Digital Addressable Lighting Interface – most used (Figure 4.5.2)
- DSI-Digital Signal Interface
- DMX-Digital Multiplex
- KNX-Worldwide standard for all applications in home and building control

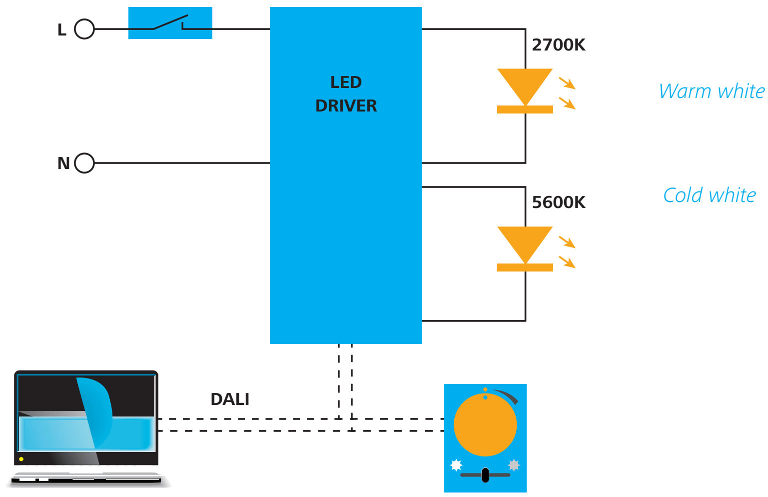
Figure 4.5.2:
DALI interface.



Tunable white

If we duplicate some electronic parts inside the driver, we can connect and control two types of LEDs with different CCT – cool white and warm white (Figure 4.5.3). This allows for "tuning" CCT of light emitted by a luminaire and use it in various well-being applications.

Figure 4.5.3:
Tunable white.



Thermal feedback

LED driver Based on actual temperature of LEDs (Figure 4.5.4), driving current can be decreased in order to avoid overheating of LEDs in case of excessive ambient temperature. Lifetime of LED light source can be easily maintained by this way.

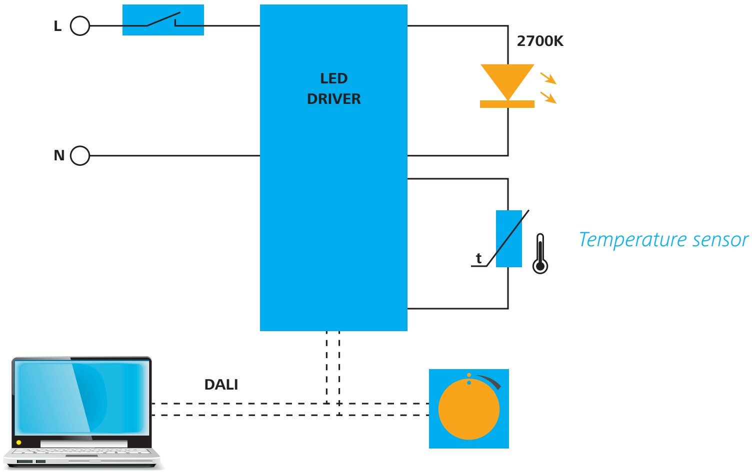


Figure 4.5.4:
Thermal feedback.

Remote control

LED driver can easily have implemented remote control function for wireless control of luminaire (Figure 4.5.5).

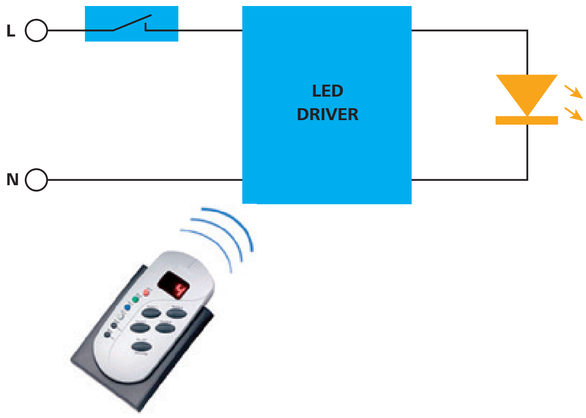


Figure 4.5.5:
Remote control.

Emergency unit

LED driver with emergency feature continuously monitor permanent power line (Figure 4.5.6) and in case of black out, driver starts to bias light source from battery pack. Commonly are used emergency units with batteries which can supply luminaire in emergency mode for 1 or 3 hours. It is one of the most important features required by law for all public installations.

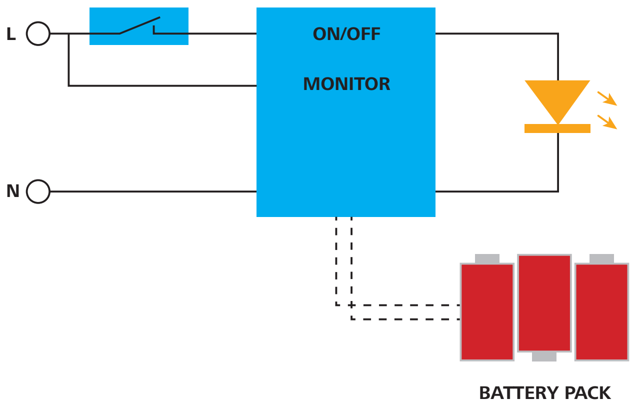


Figure 4.5.6:
Emergency unit.


STATUS DISPLAY
OUTPUT POWER
0%
100%
BRIGHTNESS
0%
100%
DOWN
UP