



your solution – our innovation

*Energy
for life*

Basics of LED drivers

Functions • Requirements • Selection

Andreas Hagemeyer
Master of Science

05.2015

This article is meant to provide the reader with basic knowledge about the functional principle of LED luminaires, to explain the requirements for an LED driver and to help find an appropriate driver for a specific application. This requires basic knowledge of physical processes which describe the electroluminescence. In this respect different switching concepts for LED luminaires are described.

Henry Joseph Round, the electroluminescence and engineering of the current LED

In 1907 Henry Joseph Round investigated carborundum (SiC) for the use in a demodulator for RF signals. He observed that under certain conditions the SiC crystal emits light when voltage is applied. Round called his discovery a "curious phenomenon" (*H. J. Round, Electrical World 49, 309, 1907*). Later it was called electroluminescence. With his discovery Round laid the foundation for the development of today's light-emitting diodes (LEDs). The first LEDs which went into series production still had a rather low luminous efficacy and were therefore used as control lamps only. Continuous advancement increased the LED's efficiency to such an extent that they progressively supersede conventional luminaires. The high luminous efficacy and long service life are substantial arguments for the use of LEDs, the small size and low discharge heat allow completely new lighting concepts.

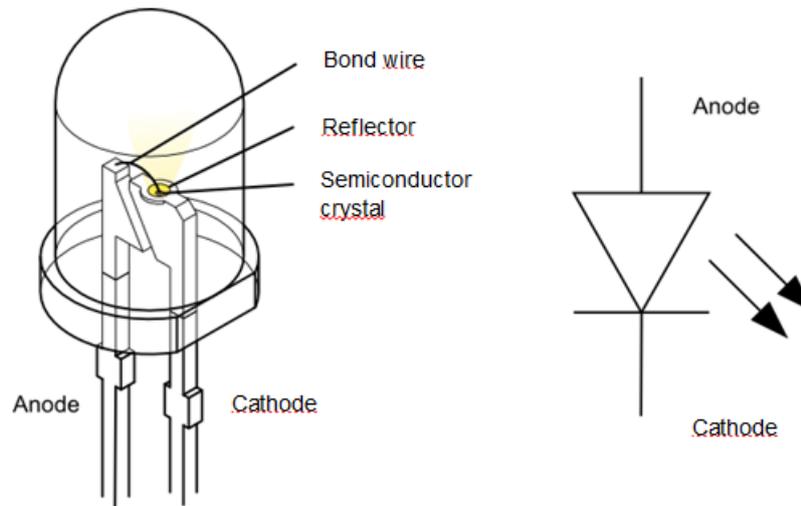
Operation of LEDs in the grid

In conventional luminaires, for instance light bulbs, light is generated by a tungsten wire. That way only a small part (less than 5 %) of the energy is converted into visible light. This pretty inefficient principle was unrivaled for many decades because of its simple structure and pleasant light. Although LEDs have a much higher luminous efficacy than light bulbs, luminaires were not regarded as a replacement for light bulbs for a long time: In comparison to light bulbs LEDs impose special demands on the power source. If the LED's aren't sufficiently supplied with energy the light flickers or is perceived as choppy.

To operate the advantageous LED lighting in the grid system, special circuits are necessary which convert the mains voltage to a precisely matching voltage for the connected LED luminaire. These circuits are power supplies optimized for LEDs and are commonly known as "LED drivers". As a leading manufacturer of switching power supplies FRIWO has taken on the challenge to engineer and manufacture LED drivers which solve the aforementioned problems. With the use of FRIWO drivers, LEDs can be used as luminaires without any compromises. Meanwhile FRIWO offers a wide range of LED drivers which allow many ways of dimming the luminaire application.

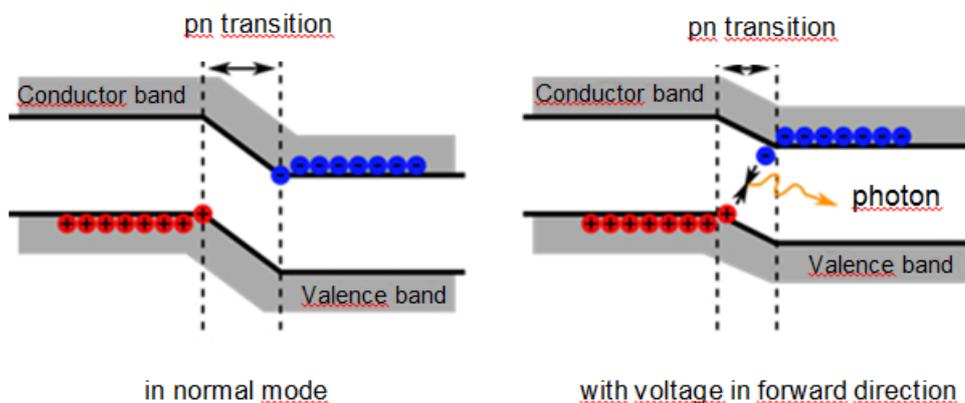
Basic structure of an LED

The main component of an LED is a small semiconductor crystal which is mounted in the reflector of the LED. This crystal encounters a targeted contamination with impurity atoms during production to influence the electrical conductivity of the material. This process is called doping and serves to ensure the availability of free charge carriers.



Structure of an LED and circuit symbol

With the selection of the impurity atoms it can be determined whether the charge carriers are electron imperfections (also known as positive charge carriers) and the crystal is p-doped or the charge carriers are electrons (also known as negative charge carriers) and the crystal is thus n-doped. In transition between a p-doped and an n-doped layer, the free charge carriers cancel each other - resulting in the so-called pn transition.



Recombination of electrons and electron imperfection at pn transition

Since there are no free charge carriers in the pn transition, no current can flow. However, if a DC voltage is applied to the pn transition, the distance between the free charge carriers can

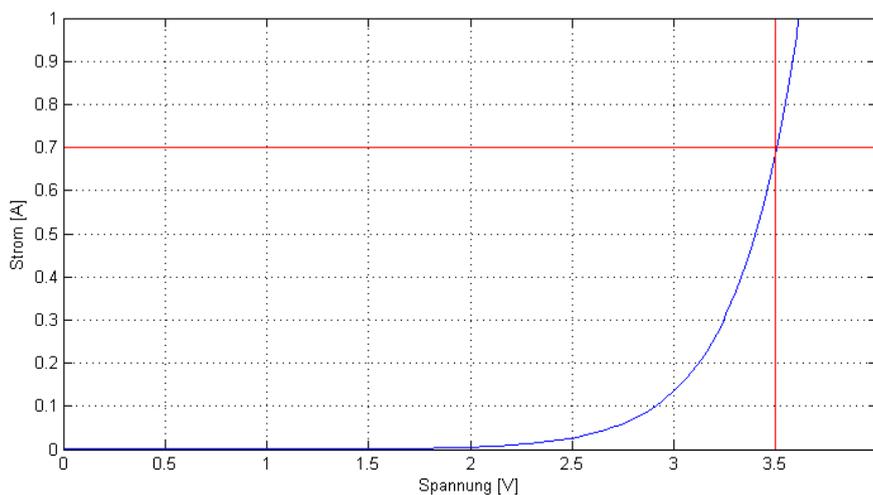
be influenced by polarity and voltage intensity. If the LED is operated in forward direction, i.e. with a positive voltage of the p-doped to n-doped layer, the distance between the charge carriers decreases. If the applied voltage exceeds a threshold value, it is likely that an electron will recombine with an electron imperfection and become conductive. This threshold voltage U_{th} is dependent on the LED's structure, i.e. on the semiconductor material and the doping, but it is also affected by temperature. The threshold voltage can be calculated with the concentration of donors N_D , the acceptors N_A and the intrinsic density n_i (material-specific):

$$U_{th} \approx \frac{k \cdot T}{e} \cdot \ln \frac{N_A \cdot N_D}{n_i^2}$$

So far this process does not differ much from that of conventional diodes. The special feature of LEDs, however, is that a photon emits during recombination and lights up the diode.

Power source and flickering of LEDs

Since the number of recombination's and the current passing through the LED are in a proportional relationship to each other, the emitted light is almost proportional to the current. The relationship between voltage and light output, however, is highly nonlinear. This becomes apparent by looking at the voltage current characteristic:



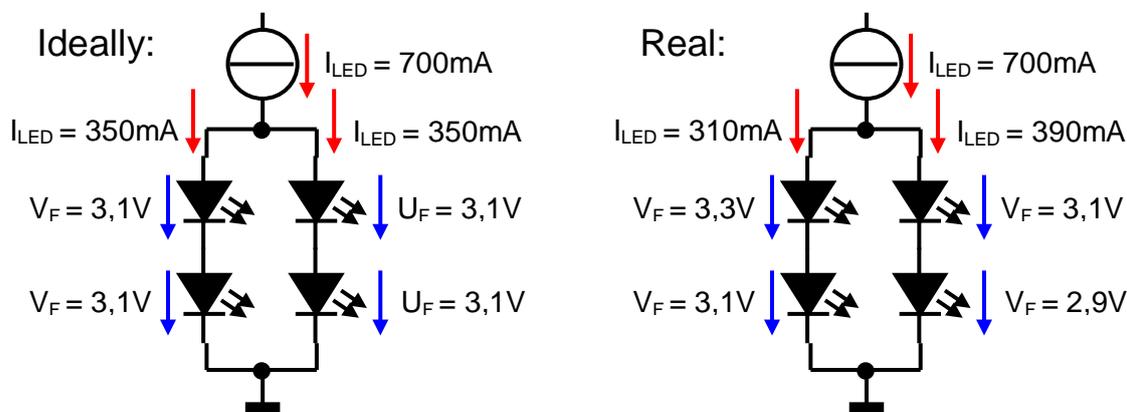
Voltage - current characteristic of a white LED

The measured LED has a rated voltage of 3.5 V and a rated current of 700 mA. The threshold voltage is approximately 2 V. At voltages below this value no current occurs. Once the applied voltage exceeds this value, the current rises exponentially with the increasing voltage. At nominal voltage, the characteristic experiences a big gradient. This means that a

small change of voltage can lead to a significant change of current and therefore to a considerable change of the emitted light. To avoid any flickering, LEDs need a source that supplies a constant current. To achieve this, there are two approaches which can be chosen in accordance with the corresponding application. The first approach is based on the fact that the driver provides a constant voltage, and that the LED luminaire (mostly a PCB with several LEDs) undergoes a treatment to suppress the impact of the nonlinear characteristic. The second approach has the driver supply a constant current which requires no further action for the LED. These concepts differ in terms of light output and flexibility. Each application therefore requires a decision which principle is to be chosen.

Operation of LEDs: Constant current or constant voltage?

An LED luminaire usually consists of several LEDs, the number of which depends on the required light output. The LEDs are connected to a PCB in series or parallel circuits. When connecting the LEDs, series circuits are to be prioritized to ensure that the same current is applied to all LEDs. In a parallel circuit the same voltage is applied to each LED. Theoretically the same current would pass through each LED if they do not have any production tolerances and if a constant temperature of all LEDs is guaranteed. Since this is very difficult to achieve, it may happen that some LEDs succumb to a higher current and will therefore be destroyed.



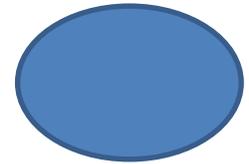
Parallel circuitry of LEDs (ideally and real)

A luminaire with LEDs connected in series may best be operated with a constant current driver. LEDs and drivers for this mode are usually marked "CC" (constant current).

There are, however, applications for which a parallel circuitry is required, for example if the maximum voltage is limited by the protection class (Safety Extra Low Voltage [SELV]). Even if the LED luminaire can be expanded modularly, a parallel circuitry would be the best choice. In this case a good example would be an LED strip which can be cut by the user as desired, or a system which allows single modules to be turned into a larger panel by pins. Such a structure consists of small, equal-sized groups of uniform, series-connected LEDs. Since all groups contain the same quantity of LEDs, they can be operated with the same voltage.

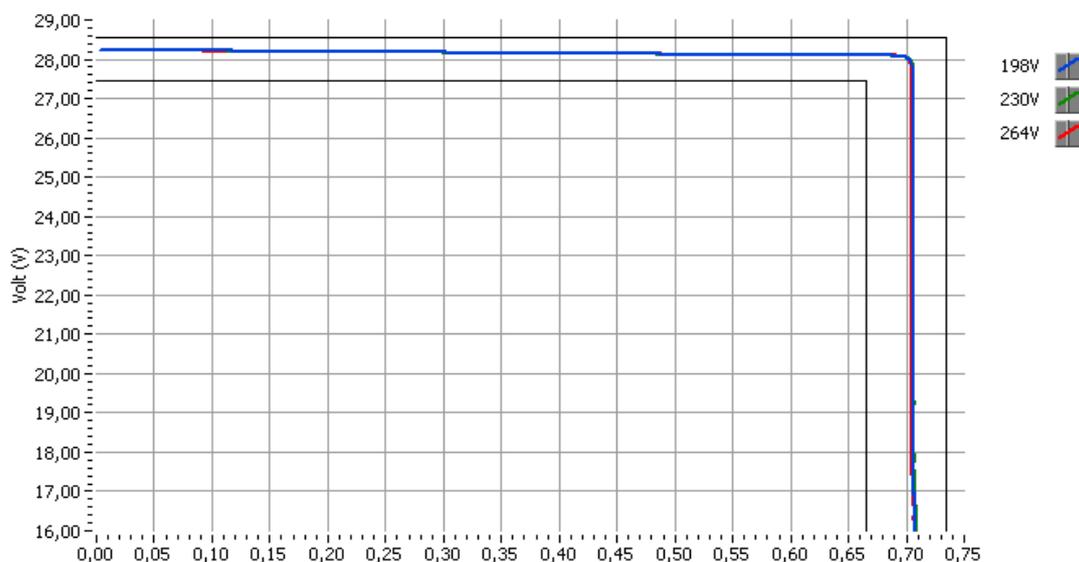
Considering the fact that the threshold voltages of the individual groups may vary in terms of production tolerances and temperature differences, applied currents may also vary significantly. Action must therefore be taken to compensate this unequal load. For this purpose, an element is added to each group which counteracts the impact of tolerances. In the simplest case this would be a resistor, connected in series to the LED group. If the forward voltage of a group is smaller than the calculated value, a distinctly higher current would pass through this group. Current and voltage are proportionally linked together within the resistor so that a higher current reduces the voltage available with the LEDs. It must be noted, however, that such a resistor converts some of the energy into heat, thus reducing the luminaire's efficiency. These luminaires need to be operated at a constant voltage to ensure an even current for all LEDs, which is why they are marked "CV" (constant voltage).

Structure of luminaires and selection of drivers



If several panels are to be operated with an LED, only LED luminaires of the same type should be used. It is therefore not possible to mix CC and CV luminaires. If CC luminaires are chosen, they will be connected in series by ensuring that all panels are designed for the same current. There is, however, a risk that all panels connected to the driver remain dark if a single LED fails. If several CV panels are operated by a single driver, they will be connected in parallel. It must be observed that all panels are designed for the same current. In case an LED fails, this will only affect part of the system's LEDs.

If the structure of the luminaire is identified, a driver can be chosen. With the drivers of the LT line, FRIWO can provide suitable power supplies for almost any application: All LED drivers of the FRIWO standard portfolio are suitable for both the CC and CV mode. This is made possible by the special voltage/current characteristic:



Voltage/current characteristic of a FRIWO LED driver (LT20-28)

This exemplary figure shows a measurement on LT20-28 (20W, 28V, 700 mA), where various hot spots were passed. If a CC luminaire is connected, the driver automatically sets the voltage at which the output current is reached (in this case 28 V). If a CV luminaire is connected to the driver, the rated voltage of the driver is applied to the luminaire (in this case 28 V). The quality of the FRIWO LED driver is confirmed particularly by the stability of the output current in CV mode and the stability of the output current in CC mode. Both output parameters are nearly constant in each mode over a wide load range. The measurement of output voltage and output current at various input voltages shows that the parameters are not affected by power fluctuations. Another important feature of the FRIWO LED drivers is the suppression of the output voltage's AC parts. These AC parts are particularly strong in the mains frequency and would cause flickering light. Special circuit techniques are used in FRIWO drivers to suppress this effect.



The author

M.Sc. Andreas Hagemeyer has been working for FRIWO since 2008. He studied electrical engineering at the Advanced Technical College Oldenburg FHWT (B.Eng.) and at Duisburg-Essen University (M.Sc.) Since 2015 he is in charge of LED driver engineering.