Shedding light
on control gear for LED lighting

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There are many types of control gear for lighting applications ranging from very specialised static induction lamp ballasts and sine wave dimmers to the familiar Triac dimmer.

In the past, electrical contractors mainly had to choose between 230 V AC and low voltage lamps and electronic or wire-wound transformers. There was good compatibility between different lamp, transformer and dimmer brands and just about any combination worked. Where more specialised controls, such as electronic ballasts, were required, these were usually specified and supplied with the lamps and pre-defined compatibility was ensured while magnetic ballasts worked with nearly any brand of lamp.

With the maturity and market dominance of LED lighting technology, a number of control gear options are now available, and the topologies can be confusing:

- Trailing edge, Leading edge and Universal dimmers,
- 1-10 V, 0-10 V and 10 V PWM dimming
- Constant current vs constant voltage vs PWM drivers,
- PWM or DC dimmers
- the various bus systems and automation options.

This article summarises the more common control gear technologies.

DIMMERS

A dimmer's function is to instruct a lamp to dim to a particular intensity and consists of two distinct building blocks to achieve this function: The power processing section and the user interface.

The power processing or power control section can have two different configurations:

- the full load current flows through the dimmer, such as phase cut leading or trailing edge dimmers, and the load reacts to the RMS voltage applied to it via the dimmer, hence the wattage rating of the dimmer.
- the dimmer supplies a control signal to the driver or similar control gear, for instance a 1-10 V dimmer. In this case, the driver 'reads' the signal and internally adjusts its intensity accordingly. The dimmer is thus not rated for the load wattage, but typically for the total number of drivers per dimmer.

1.1 Phase cut mains operated dimmers

- Any locally manufactured or imported mains operated dimmer must have a valid Letter of Approval (LOA) from the National Regulator for Compulsory Specifications (NRCS) as per SANS 10142-1 and the Occupational Health and Safety Act (OHSA) legal requirements.
- Phase cut dimmers are only compatible with an alternating current (AC) sine wave supply and have poor to little compatibility with, for instance, simulated- or quasi-sine inverters and uninterrupted power supply (UPS) backups.
- The dimmer is wired in series with the load and must thus be rated for the load power and is often de-rated for power factor and other lamp characteristics.
- The dimmer controls the load power by turning parts of the mains AC cycle on or off to reduce the root mean square (RMS) voltage to the load, thus only a true RMS voltmeter will display the correct voltage, a standard multi-meter will not provide an accurate reading.

'Triac' dimmers

- A Triac is an electronic switch, similar in concept to a transistor and is a variant of a thyristor or silicon controlled rectifier (SCR).
- This is the ideal component to use for the classical design of a leading edge dimmer and the majority of leading edge dimmers manufactured since the late 1970s to today employ a Triac component.
- The word 'Triac' has become synonymous with leading edge dimmers, the same as 'Google' is synonymous with 'search engine' and many suppliers refer to a Triac dimmer rather than the more descriptive 'leading edge' dimmer.

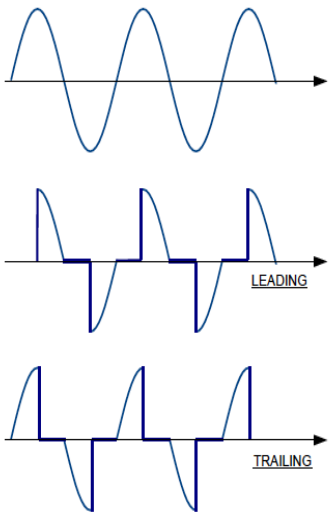
Leading edge dimmers

- After the AC mains crosses through zero, the dimmer will keep the load turned off for a time and turn the load on somewhere in the cycle.
- The load will thus always experience a step input voltage at 100 times a second which can produce a buzzing sound in the dimmer and/or the load.
- Due to the repetitive step input voltage, capacitive loads such as LED lamps will experience a large repetitive peak current, which may impact the lifetime of the electronic components or cause incompatibility problems.
- Leading edge dimmers are thus not well suited to capacitive loads and should only be used with resistive and inductive loads.
- Ringing of the voltage and/or current during the step voltage rise time may be possible, which increases the conducted and radiated electrical emissions.
- A leading edge dimmer that employs a Triac component and is electromagnetic compatibility (**EMC**) compliant, incorporates a mains filter inductor or choke and a capacitor, which may cause additional voltage and current ringing as well as impose a minimum load of typically around 10% of the full rated power, making this topology less suited to LED lamps
- Some leading edge dimmers employ Mosfets (Metal Oxide Semiconductor Field Effect Transistors) or IGBTs (insulated-gate

bipolar transistor) as the power switch and do not have a mains filter. This results in a minimum load of usually around 2 W, making this topology more suited to LED lamps that are designed specifically for leading edge dimmer compatibility

Trailing edge dimmer

- The dimmer turns the load on immediately when the AC mains crosses through zero and turn the load off somewhere in the cycle.
- The load will thus always experience a natural soft start, a continuous 'soft start' as well as a 'soft off'.
- There is thus no step input voltage to the load resulting in perfectly silent operation of both the dimmers and lamps. The voltage waveforms are typically void of ringing, resulting in less electrical noise than leading edge dimmers and generally allowing more LED lamps per trailing edge dimmer than for a leading edge dimmer of the same wattage.
- An inductive load generates a 'back EMF (electromotive force)', thus a large voltage pulse when turning off. This 'back EMF' makes trailing edge dimmers unsuited for inductive loads since the dimmer may suffer permanent damage.
- Trailing edge control is however perfectly suited to resistive and capacitive loads and is the recommended dimming method by the majority of LED lamp and driver manufacturers. It is also the recommended dimming method for traditional halogen and incandescent lamps, carbon filament lamps and traditional electronic low voltage transformers.
- Due to the fundamental operating principle of a Triac component, this part cannot be used for trailing edge dimmer designs. Trailing edge dimmers use Mosfets or IGBTs. These nullify the requirement for a mains filter, resulting in a minimum load requirement of typically around 2 W.
- Many trailing edge dimmers include thermal regulation and short circuit and/or overload protection.
- Since low end flicker with some LED lamps is sometimes unavoidable and the dimming curve of LED lamps differ vastly between models and brands, it is recommended to install a dimmer that includes settings for adjusting the dimmer minimum and maximum intensities. Some universal dimmers offer additional advanced installer settings.



Lamp voltage waveforms with leading and trailing edge dimming

'Universal' mains operated dimmer

- A universal dimmer is a phase cut dimmer that can be set to leading or trailing edge.
- This is becoming the standard for high end professional dimmers worldwide.
- Some universal dimmers are factory default in trailing edge mode and automatically detect an inductive load and switch to leading edge mode to protect the dimmer.
- A universal dimmer provides all the outstanding features of a trailing edge dimmer, but can be a leading edge dimmer if required, providing a complete solution in one package

1.2 Pulse Width Modulation (PWM) dimmers

- PWM or DC dimmers were practically unknown before the age of LED lighting.
- A DC dimmer provides a 'digital' output voltage to a compatible LED lamp, mostly 12 V or 24 V LED strip lights.
- The 12 V DC or 24 V DC to the lamp is switched on and off, hence 'digital', at regular intervals, usually 200 Hz and higher: the longer the off time, the lower the intensity of the lamp due to a lower average lamp voltage.
- DC dimmers offer very deep, stable and flicker-free dimming, sometimes as low as 1% with digital accuracy.
- The input supply to a PWM dimmer can be AC mains, or in the case of a 'DC' dimmer, the input is a low voltage DC from a battery or suitable power supply.
- A 'non-dimmable' low voltage LED strip light can thus be dimmed by simply wiring a DC dimmer between the output of the specified DC transformer and the strip light. This is one of the few exceptions where a non-dimmable LED lamp can be dimmed perfectly. Generally non-dimmable lamps should not be dimmed since they may fail prematurely and void manufacturers' guarantees.
- Some PWM dimmers, especially the low voltage versions, can have 'master/slave' configurations that allow installation flexibility.

1.3 0-10 V, 1-10 V and 10 V PWM dimmers

- 1-10 V is a simple and very mature uni-directional analogue communication protocol, initially developed in the late 1960s for industrial process control. If 10 V DC is supplied to the control port of the device, it operates at 100% output, if 1 V DC is supplied, it operates at 10% output, 5 V DC for 50% etc.
- The initial protocol was, however, adapted for commercial lighting so that the driver supplies the 10 V DC to simplify the dimmer design and size and reduce its cost.
- A 1-10 V dimmable driver has an internal isolated 10 V DC power supply, limited to a maximum of 2 mA and exclusively reserved for the dimmer control.
- If the driver's 1-10 V port is open circuit, hence 10 V DC present, the light output is 100%. When the dimmer 'pulls' the voltage down, the light output corresponds to the port voltage. If the dimmer pulls the port down to 6 V DC for instance, the light output is 60%, hence the light output % = port voltage x 10.
- A 1-10 V driver's minimum light output is 10% even if the port is shorted out and this driver must thus be turned on and off via a switch in the mains supply.
- Some 1-10 V dimmers do not have a built-in mains switch for turning the driver off and an external switch must be used. Dimmers with a built-in mains switch must have a valid NRCS LOA.

- If the control port of a 0-10 V driver is shorted, the light turns off, allowing the dimmer to control the on/off without requiring a mains switch. This is, however, not a clearly defined specification and there are variations, always check the product data sheet for clarity.
- 10 V PWM is a growing adaptation of the 0/1-10 V protocol. In this variant, the dimmer does not pull the port down to a specific voltage, but rather switches the port between open circuit and short circuit at regular intervals, just like the PWM dimmer above. This improves the dimmer efficiency significantly while providing digital accuracy.
- The advantage of the 1-10 V dimmer family is that the load power does not flow through the dimmer, besides the mains on/off switch. The dimmer is thus rated for the number of drivers, rather than load wattage (except for the mains switch). A further advantage of this dimmer is assurance of good compatibility between dimmer and control gear brands and models.

1.4 User interfaces

The user interface to a dimmer can have many different configurations, ranging from a mechanical bell-press or rotary option to mobile phone and digital interfaces. Digital interfaces can also have a number of configurations and protocols such as DALI, DMX, KNX and many proprietary communication protocols, often used for home and building automation.

However, irrespective of the user interface or communication protocol, the dimmer's 'engine' will be one of the fundamental types discussed above and must be selected to suit the lamp or driver requirements as per product data sheet.

LED DRIVERS

The fundamental purpose of a LED driver is to convert a power source, such as the mains supply, to match the requirements of a LED lamp. A driver may consist of many building blocks, such as:

- an isolated mains primary to secondary converter,
- an optional power factor correction circuit,
- various secondary side regulation methods,
- a user interface which may include any of the methods described in the dimmer section above,
- possible phase cut or 1-10 V control and input circuit,
- mains surge and filter section and often several protection methods such as short circuit, temperature, overload, etc.

To appreciate the complexity and options available in LED drivers, it's important to consider the electrical requirements of a Light Emitting Diode or LED, the actual component that produces visible light. As the name suggests, a LED component is fundamentally a diode, very similar to the diodes in, for instance, a bridge rectifier and it has similar electrical characteristics. The LED component is thus a DC constant current device and the voltage drop or forward voltage across it varies according to the component's age, temperature, etc. If the component's DC current is reduced from a specified maximum, its light intensity decreases, hence dimming is achieved.

There are a number of different LED lamp configurations and the driver must be selected to match the lamp requirements as follows:

- Some LED lamps, such as GU10, bulb replacement etc, have a suitable driver built into the lamp and will work correctly provided that the appropriate supply voltage is applied as per product label.
- Since the driver adds heat to the lamp or may impose restrictions on the physical lamp size (such as panel lamps), some LED lamps do not have a built-in driver and an external driver must be used. This is also sometimes the case when a lamp is designed for backwards compatibility with, for instance, low voltage transformers or for special automation or control purposes.

  The different configurations are thus:

Constant voltage driver (such as a mains to 12 V or 24 V power supply)

- The LED lamp has a DC voltage to unregulated DC current converter built into the lamp (DC current thus dependent on the DC voltage input), but no mains isolation.
- A good example of this lamp type is 12 V or 24 V LED strip lighting, AR111 rated for DC voltage input etc.
- The driver must thus be a constant voltage type with a fixed and well-regulated output voltage.
- The driver's output current can vary to match the load wattage requirement, ranging from 0 to the maximum that the power supply can deliver.
- With these lamp types, multiple lamps can be connected in parallel to the driver or power supply.

AC output driver or power supply (such as the very familiar 'halogen' low voltage wire-wound or electronic transformer).

- The LED lamp has an AC voltage to a regulated DC current converter built into the lamp (DC current thus not dependent on the AC voltage input), but no mains isolation.
- For instance, MR16 low voltage LED lamps.
- A driver for this lamp thus has a regulated or unregulated AC output voltage which may be at 50 Hz mains frequency (wire-wound) or up to 35-40 kHz (electronic transformer).
- Classic 'halogen' electronic transformers often have a minimum load wattage, which may lead to compatibility problems, especially during dimming and it is recommended to consult with the suppliers to ensure a hassle-free installation.
- With these lamp types, multiple lamps can be connected in parallel to the driver or power supply.

Constant current driver (such as a mains to 350 mA or 700 mA driver)

- The most efficient lamp type and often also the highest overall system efficiency, is where the LED lamp consists only of the enclosure and the LED component There is no built-in regulation or conversion of the input to the required LED component DC current.
- In this case, a constant current driver must be used and the output current and voltage range of the driver must be matched to the lamp's requirements.
- The output voltage of a constant current driver can vary depending on the forward voltage of the LED lamp and, when dimming, the output voltage range of the driver must preferably be at least 10% higher than the lamp's maximum and 10% lower than the lamp minimum.
- There is usually very good compatibility between lamp and driver brands, but the output voltage range of the driver vs the lamp's requirements are often overlooked, causing installation problems.
- With these lamp types, only one lamp per driver must be used.
- The constant current lamp is usually preferred for higher wattage lamps; lamps where the smallest form factor is required (such as thin panel lamps); where increased system protection against adverse conditions is required; and where very consistent lamp output intensity is required, for optimal system lifetime, etc.

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Dimmers for LED, halogen and incandescent lighting

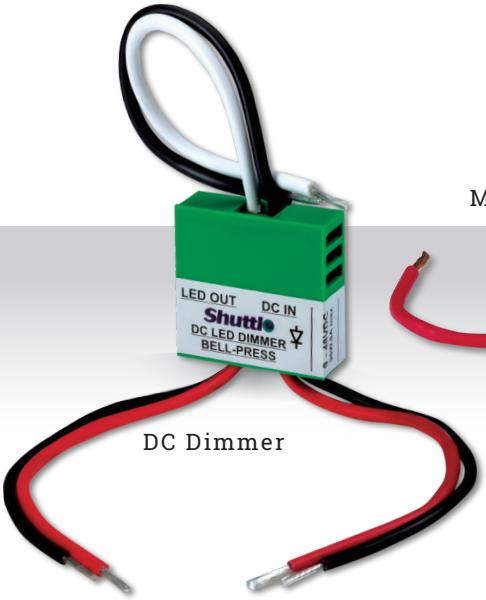
800W

500W

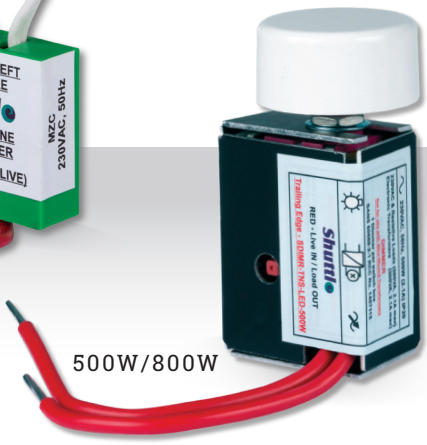
250W

125W

MZC

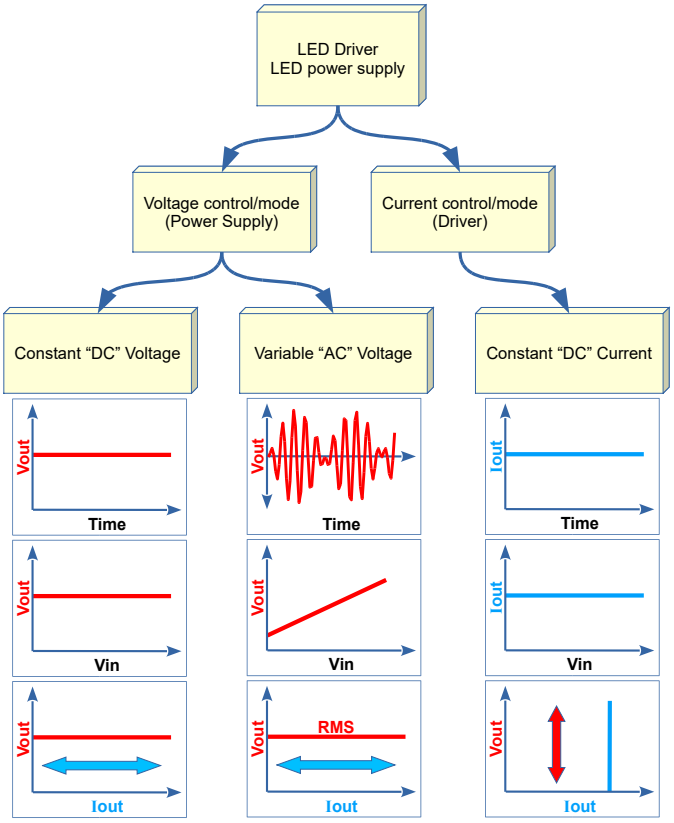


DC Dimmer



500W/800W

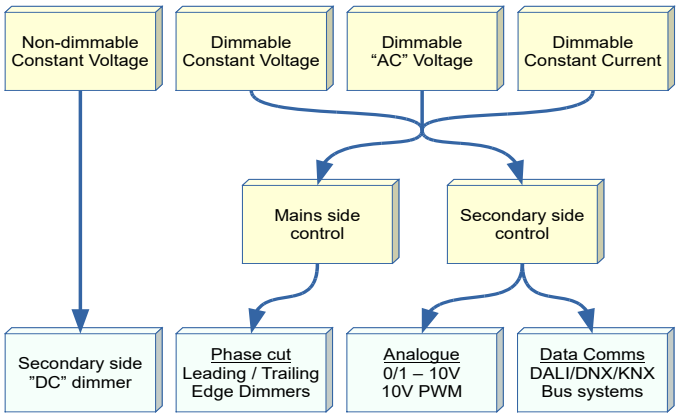
225W Rotary



Vin = Input voltage, Vout = Output voltage, Iout = Output current

All three of the LED driver or power supply types discussed above are available in dimmable options which involves two system blocks, the driver's dimmer compatibility or input and the driver's output section.

- **Dimmable driver's input**
  - As was described in the dimmer section, a driver may be mains phase cut, 1-10 V or digital input dimmer compatible and is selected upon client or installation requirements.
  - Mains side leading or trailing edge compatible drivers are the simplest to install since no additional control or communications wires are required, but it's best to confirm compatibility of the various items before installation.
  - Some drivers do not require an external dimmer and have an internal dimming capability which is addressed via a bell-press (such as 'DALI DIM'); or a secondary side communications protocol such as DALI, DMX, etc; or a proprietary communications method, often employed by automation products.
  - A non-dimmable driver should never be dimmed, just like non-dimmable LED lamps with the exception of the 12 V or 24 V LED strip discussed previously.
- **Dimmable driver's output**
  - It is important to consider the way that the dimmable constant current and constant voltage driver changes its output to achieve the dimming. There are usually three different methods and selecting the incorrect method for the lamp can lead to installation difficulties.



Dimmable constant current driver output

- The driver decreases the constant output current to a lower level to achieve dimming (for instance a 700 mA driver will output 350 mA for 50% intensity).
- Some drivers may switch to digital PWM current output at low intensity to achieve stable and very deep dimming.
- These methods usually present no problem, provided that the driver's output voltage range and current match the lamp requirements.

Dimmable constant voltage driver output

- The driver may decrease the constant voltage output to a lower level to achieve dimming (for instance a 12 V driver will output 6 V for 50% intensity).
- The driver may provide a PWM output whereby the output voltage amplitude remains at for instance 12 V, but is switched on and off with regular intervals, same as the DC or PWM dimmer does.
- It is very important to select the correct output method to match the lamp's requirements and this often leads to installation difficulties. For instance, a 12 V or 24 V strip LED lamp will not dim properly with a driver that decreases its output voltage, a dimming range of around only 100% - 70% will be achieved. A PWM output driver must be selected for this lamp type.

Summary

There are many dimmer, driver and lamp configurations and options available and selecting the correct combination can be daunting. It's safest to consult with dimmer, lamp and driver compatibility charts and suppliers before installation and where possible, do a mock-up installation before going to site.

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