Dimming LED Lighting

LED lighting has the potential to offer many benefits to the user and to society as a whole. Very high efficiency together with extremely long life expectancy of the LEDs reduces the energy consumption and the use of resources, and can offer low lifecycle cost. In order to become widely accepted, LED lighting must provide dimming capability at least equivalent to that offered by traditional incandescent lighting. This White Paper examines the issues involved in designing LED lighting that can be dimmed.

Over the past few years there has been a dramatic surge of interest in LED lighting, driven by the advances in LED brightness, efficiency and colour-rendering index (CRI). Luminaires using high brightness white LEDs (HB-LEDs) are now able to rival or exceed traditional light sources based on incandescent, fluorescent, CFL and even metal halide technologies, with substantial reductions in energy consumption. What's more, they are now available in warm white or daylight as well as the cool, bluish white that many people associate with LEDs.

In many applications it is acceptable for the light output to have constant brightness – either it is on or it is off – and many early uses of LED lighting fall into this category. An illuminated sign above a store-front is either running continuously or perhaps may be switched off after hours, but in either case there is no need for it to be able to operate at reduced brightness. Similarly, an LED replacement for a fluorescent lamp inside a refrigerated grocery store cabinet is simply turned on when the store opens and turned off when it closes.

For other applications, the light does not always need to deliver full brightness and a dimming capability is highly desirable. On the one hand, dimmable lights may be used simply as “mood lighting” to vary the effect, such as in a restaurant or living room. Increasingly, dimming is also being used as a means to further reduce energy consumption by only providing the light level actually needed at that moment. For example, lights in a parking garage or residential street may be dimmed to a low level late at night and only brought up to full brightness if a motion sensor detects activity in the area. Lights over a wide area may be linked using wireless technology to form a local network, with sophisticated sensing, control and monitoring capability through software to optimize the light levels under all conditions.

The fact that LEDs react instantaneously to changes in power input allows this kind of control to be widely used, with the potential for dramatic improvements in energy consumption. In contrast, previous lighting technologies such as metal halide or high pressure sodium react extremely slowly and it is not feasible to control brightness in real time. Dimming capability can therefore be considered to be a key element in the general acceptance and use of LED lighting. This White Paper describes some of the techniques...
that can be used for dimming and discusses the advantages and disadvantages in various applications.

Introduction – LED Lighting

A luminaire using HB-LEDs is more complex than a typical incandescent or fluorescent fixture, and contains several elements that are specific to the LEDs. Firstly, the LEDs themselves cannot be used directly, but must be mounted onto a circuit board that provides physical support, interconnection and cooling. The complete assembly of LEDs onto the circuit board is commonly referred to as a *light engine*, which is cooled by a *heatsink*. Second, the LEDs must be supplied with a DC current that is accurately controlled to provide the required light level without exceeding the LED rating. The current control function is provided by a *driver*. Finally, in the case of LEDs operating from AC power, there must be a *power supply* (PSU) that converts the AC into DC for the driver, and provides safety isolation. Figure 1 shows an outline block diagram.

![Figure 1 – Luminaire using LEDs](image)

In a practical luminaire some of these functions may be combined to simplify the product. One common approach is to combine the driver and light engine, as shown in Figure 2.

![Figure 2 – Driver combined with light engine](image)

Another common approach is to combine the driver and power supply, as shown in Figure 3. In this case the combined power supply and driver effectively becomes an AC-input driver.
Each of these basic configurations has advantages and disadvantages which depend on the end application. The configuration chosen also has a direct effect on the options available for dimming.

**Driver combined with light engine**

This configuration has two main advantages: first and foremost, it allows a single power supply to feed multiple light engines, as shown in Figure 4. This possibility offers flexibility and is widely used in applications such as illuminated channel-letter signs, where each letter may need different numbers of light engines.
Another advantage is that features such as LED drive current level, on-off control, dimming and analog or digital interface are controlled directly on the light engine. The power supply can therefore be identical in a range of luminaires, some of which offer fixed light level while others offer various customer options for dimming, monitoring and control.

It is even possible to offer independent dimming control of each light engine, which can be useful in applications where a central power supply feeds several separate luminaires. This type of configuration is being promoted by the Emerge Alliance¹, using a power supply with 24Vdc output to feed multiple luminaires in environments such as offices and conference rooms.

One final advantage for this configuration is that the LEDs and the driver components are typically all small surface mount devices that can easily be assembled in a single process, and tested with no need for high voltages. In contrast the power supply uses a mixture of surface mount and through-hole components that require multiple assembly processes. Design, testing and certification are much more complex because of the high internal voltages and the need to meet safety regulations.

**Driver combined with power supply**

This configuration offers the advantage of simplicity for the luminaire designer, because the power supply provides all the functions needed and the light engine does not require any components other than the LEDs themselves. It is commonly used in applications such as street lights or high bay lights where the main focus is on achieving a high light output with good efficiency and high reliability, rather than a wide range of customer controls.

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¹ Emerge Alliance: A consortium of companies working on standards for LED lighting systems.
The combined power supply/driver can have two or more outputs to drive several light engines, allowing a standard light engine to be used in multiple different applications. For example, a 50W light engine could be used as a building block with one, two, three or more light engines in street lights with different light outputs. Figure 6 shows a dual output driver as an example.

**Figure 6 – Dual output driver**

With this configuration, all outputs will typically be identical and cannot be controlled independently. When dimming is required it can be easily implemented in the driver, but will affect all light engines equally.

**LED Dimming Methods**

It is important to distinguish between the mechanism used to feed the dimming information into the luminaire, and the technique used to actually reduce the brightness of the LEDs. There are a number of different mechanisms that can be used to convey the dimming information to the luminaire, from simple wall-mounted control to complex digital programming. These various options will be discussed in a later section of this white paper.

There are two basic alternatives that can be used to reduce the light output of the LEDs: analog dimming; and pulse-width modulation (PWM).

**Analog dimming**

Analog dimming simply controls the drive current fed to the LEDs. Full brightness uses the full drive current, and the current is linearly reduced to achieve dimming, reaching zero in the off condition. Analog dimming is illustrated in Figure 7.
**Figure 7 – Analog dimming**

This type of dimming is implemented in the driver, and directly controls the LED drive current. For example, if the LED drive current is 350mA for full brightness it is reduced to 175mA for half brightness or 87mA for one quarter brightness. At any given brightness the LED sees a constant DC, ideally with no AC component although in practice there is always a small amount of AC ripple.

This type of dimming can be simple to implement but may not be able to deliver the best overall performance, because the colour temperature of the light output may change as the drive current varies.

**Pulse-width modulation dimming**

In pulse-width modulation (PWM) dimming, the LEDs are driven with full amplitude pulses of current and (as the name implies) the width of the pulses is varied to control the apparent brightness. This type of dimming relies on the capability of the human eye to integrate the average amount of light in the pulses. Provided the pulse rate is high enough, the eye does not perceive the pulsing at all but only the overall average. PWM dimming may be implemented in the power supply or in the driver.

For example, at 50% brightness the LEDs are driven with pulses where the ON-time and OFF-time are equal, as shown in Figure 8. As mentioned above, the pulse rate must be high enough so that the eye perceives only the average light intensity. Typically a pulse rate of approximately 200Hz is high enough to achieve this objective, without any visible flickering. This corresponds to a period of 5ms per pulse, as indicated in Figure 8.
For 25% brightness, the LEDs are driven with pulses where the ON-time is equal to 25% of the pulse (Figure 9). For 75% brightness, the ON-time is increased to 75% of the pulse (Figure 10), and for 100% brightness the ON-time is 100% so that there is no pulsing, as shown in Figure 11.
PWM dimming requires the addition of a PWM controller and a MOSFET switch in the power supply and is generally more complex to implement than analog dimming. The benefit is that it maintains high efficiency and ensures the light output does not vary in colour. HB-LEDs are designed to offer optimum performance at their full rated drive current, and with PWM control the LEDs are always either off or fully on; there is no condition where they are driven at reduced current. Except at 100% brightness, the LEDs do not see a constant DC but instead see a continuous stream of current pulses.

In reality the LED current cannot be switched instantaneously between zero and maximum and there will be a slight slope on the waveform. However, at the typical PWM frequency of 200Hz the transition period is very short and can be ignored.

**Dimming Controls**

In order to vary the brightness, some form of signal is needed to convey the dimming information to the luminaire. This signal can be carried through the AC wiring, an analog input, a digital input or through a wireless interface. Each of these options has some advantages and some drawbacks, and different options are appropriate for different applications.
Phase control dimming is the most widely used, particularly in residential and small commercial buildings.

<table>
<thead>
<tr>
<th>Dimming interface</th>
<th>Advantages</th>
<th>Disadvantages</th>
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</table>
| AC wiring (phase-cut) | No additional wiring required  
Can use existing phase-cut dimmers | Added circuitry in power supply  
Cannot dim smoothly to zero  
May exhibit flickering |
| Analog input (0-10V) | Can use existing 0-10V lighting controls  
Can dim smoothly down to zero  
Simple implementation in driver | Requires additional control wiring  
Requires controller |
| Logic control | Very simple form of dimming | Only suitable for two-level brightness |
| Digital input (DALI) | Standard for control of multiple luminaires  
Can include luminaire monitoring capability | Requires additional control wiring  
Requires controller |
| Digital input (DMX) | Standard is focused on theatre/stage lighting  
Can offer comprehensive control – pan, tilt, zoom, colour, image effects | Requires additional control wiring  
Requires controller  
Noise sensitive, no monitoring capability |
| Wireless (Zigbee) | No additional wiring required  
Can offer comprehensive features  
Can use standard Zigbee protocol | Driver and controller are more complex  
Wireless signals have limited range |

In general the formats of the dimming signals are common to any lighting technology – they are not specific for LED lighting. The majority of LED luminaires will be retrofitted into existing buildings and they must be able to interact with the existing lighting controls.

**AC phase control**

The most widely used form of brightness control for lighting is the familiar triac-based dimmer that is found in residential buildings as well as many commercial buildings, restaurants, stores, etc. This type of dimmer operates by cutting out a portion of the AC waveform, with the degree of dimming proportional to the phase of the AC waveform where the cut occurs, hence the term phase-cut dimmer or phase control dimmer. The most common type cuts out a portion of the leading edge of the AC waveform, as shown in Figure 12 a). The controller senses each zero-crossing of the AC input, and waits for a variable delay period before turning on the triac switch and delivering the AC to the output. The AC delivered to the light therefore has a “bite” out of the leading edge of each half sinewave.

A second type of phase control dimmer operates in a very similar way, but includes circuitry to guarantee that the cut in the positive and negative portions of the AC sinewave is precisely symmetrical. This type of dimmer is designed primarily for use in Magnetic Low Voltage (MLV) applications.

A third type of dimmer operates in the reverse manner, by cutting a portion of the trailing edge of each half sinewave, as shown in Figure 12 b). This type of dimming is sometimes called reverse phase control, and is designed for use in Electronic Low Voltage (ELV) applications.
a) Triac phase control (forward phase control). The dimmer turns ON part-way through sinewave

b) ELV phase control (reverse phase control). The dimmer turns OFF part-way through sinewave

Figure 12 – Phase control dimming

Phase control dimmers were originally developed for traditional incandescent lighting, where the lamp brightness is directly dependent on the average power in the AC input. By cutting out a portion of either the leading edge or the trailing edge of the waveform, the power is reduced and the lamp becomes dimmer. However, this is not the case with LED lighting, and a different approach is necessary to support phase control dimming.

Phase control dimming of LEDs.

As shown in Figure 1, all LED luminaires contain a power supply and driver whose primary function is to maintain the LED current at a constant level regardless of the AC input voltage. Figure 13 shows a simplified block diagram of a typical constant-voltage power supply.

Figure 13 – Power supply block diagram

After the input filtering and protection, the power supply has two power conversion stages. The first stage provides control of the input power factor, to guarantee that the input current is closely in phase with the input voltage. This stage normally operates as a boost converter that raises the voltage coming from the AC input to an internal voltage of approximately 400Vdc. The power switching is controlled in such a way that the instantaneous input current is proportional to the voltage throughout the AC sinewave. An additional feedback loop maintains the PFC output at 400V over the full range of input voltage, typically 90-265V or 90-305V. Power factor control (PFC) is a regulatory requirement for LED lighting, as it is for most other electronic equipment.
Standard LED power supplies will not react to phase-control dimming because they are designed to maintain a constant output. A special AC detector circuit must be added in the PSU.

If this type of power supply is simply connected to the output of a phase control dimmer it will attempt to compensate for the missing portions of the AC waveform. As the amount of phase cut increases the power supply will maintain its output voltage by drawing higher input current, and the LEDs will remain at normal brightness. Eventually when the dimmer setting is very low, the power supply feedback circuits will no longer be able to compensate and its output will collapse. At this point the LED brightness will fall rapidly towards zero, with the exact response depending on the details of the power supply design.

In order to have an LED luminaire that can respond correctly to a phase-control dimmer, it is necessary to add several more functional blocks into the power supply, shown in orange in Figure 14.

![Figure 14 – Power supply block diagram for phase control dimming](image)

The first added block is an AC phase sensor which monitors the AC input waveform before the PFC stage. This block generates an output signal proportional to the amount of phase cut, which is transmitted to the output side of the power supply via an isolation function. Isolation at this point is necessary because the power supply output is Class 2 Safety Extra Low Voltage (SELV), and must be fully isolated from the AC input. As mentioned above, the DC-DC converter also provides isolation in the main power path. At the secondary side the phase-cut signal controls the PWM dimming of the output. When no AC phase-cut is detected the output is driven at 100% duty-cycle to give full brightness, as shown in Figure 11 on page 8.

Figure 15 shows how this power supply connects to the dimmer and provides a PWM output to drive the LEDs. An ELV dimmer is shown because it gives the best performance, but a standard triac dimmer can be used in the same way.
AC input voltage control
Another method of dimming that can be used with many lighting technologies including incandescent, metal halide and high pressure sodium is simply to reduce the AC input voltage. This system is particularly suitable for wide area applications such as street lighting, where it can be very effective in reducing energy consumption during off-peak hours. The normal AC voltage can be reduced by 10% in the late evening and by 20% after midnight, and then brought back to normal in the early morning. To minimize cost, a single voltage controller can be used at a central point where power is distributed to a number of lights in an area.

AC voltage control of LED lighting
This technique will not work with standard LED lighting, for the same reason as in the case of the AC phase control dimming. The power supply in the LED luminaire will compensate for the reduction in voltage and will maintain a constant power to the LEDs. For this application, an AC voltage sensor block could be used in the LED power supply to control the output duty-cycle, as shown in Figure 15.

Figure 16 – Power supply operation for AC voltage control dimming
With incandescent lighting, the bulb filament behaves approximately as a pure resistive load. Consequently, a drop in input voltage of 10% also results in a drop in current of about 10%, and therefore a drop in power (brightness) of approximately 20%. The AC voltage sensor in the LED power supply would therefore be designed to simulate this behavior, rather than providing a linear control of duty-cycle. Nominal input voltage would result in full duty-cycle; at an input of 90% of nominal the output duty-cycle would be 80%; at an input...
voltage of 80% of nominal, the output duty-cycle would be reduced to 60%. The exact values could be adjusted until the apparent variation of LED brightness matches that of an incandescent lamp.

**Analog (0-10V)**

With the two forms of dimming discussed above, the dimming information is part of the AC input itself and no additional wiring is needed. Analog dimming uses a separate control wire to provide the 0-10V dimming signal, and is defined in IEC60929 (Annex E). The dimmer acts as a current sink, allowing control of several luminaires in parallel. The dimming itself can be either a linear control of the output current or a variable PWM output.

When the dimming input is zero, the output is zero. When the dimming input is 10V the output is full brightness, with a linear variation in between as shown in Figure 17. If the dimming input is not used it can simply be left open-circuit. In this case it is internally pulled up to 10V and the output is again full brightness.

![Figure 17 – Analog Dimming using 0-10V control](image)

**Analog 0-10V control of LED lighting**

As mentioned above, the actual dimming of the LEDs themselves can be by a linear control of the LED drive current or by a PWM control of the power supply output. Figure 18 shows a block diagram of a power supply and driver with linear output dimming. Note that the 0-10V signal controls the LED driver current, not the power supply output voltage which remains constant (24V in this example).
Figure 18 – LED power supply/driver with 0-10V input and linear dimming

Figure 19 shows a block diagram of a power supply with analog control of PWM output dimming. In this case the 0-10V signal controls the power supply to provide a constant voltage, variable pulse-width output to the LED driver. The driver converts these voltage pulses into pulses of constant current to drive the LEDs.

Logic control
A simplified form of dimming control can be implemented where there are only a small number of fixed brightness levels (two, or possibly three), selected by input pins. As an example, this type of control can be used with a motion sensor so that the light output is at a low level until the motion sensor activates, when the light switches to full brightness.

Again, the dimming of the LEDs themselves can be achieved by either analog or PWM control. Since this type of dimming is intended to be as simple as possible, the most likely approach is to simply provide two (or three) output current set-points from the driver selected by one or more logic inputs, as shown in Figure 20.
The DALI digital interface is specifically designed for lighting control, and offers comprehensive dimming features. It is mainly intended for commercial and industrial applications.
Figure 21 – DALI Dimming

One of the features of DALI is that it provides comprehensive dimming capabilities based on stored information for different brightness configurations, referred to as scenes. The DALI protocol allows control of brightness and of dimming speed within each luminaire. When a command to go to a new scene (brightness level) is received, the ECG in the luminaire first determines how much difference there is from the current brightness, then calculates how rapidly it should change to the new level. This ensures that all luminaires in the network reach their new brightness level simultaneously.

Up to 16 scenes can be stored, and can correspond to different uses of the room. One scene might be for introduction to a meeting, one for lecturing, one for slide presentation, one for coffee break, etc. Each individual light in the room can store the data relating to these scenes so that a single DALI command can simultaneously set all the lights to the required setting for that scene.

DALI also allows for status reporting from each device to the controller on request. Status information can include current brightness setting as well as power status, fault information, etc.

**DALI control of LED lighting**

For LED lighting in a DALI network, the dimming itself can be achieved through normal PWM control of the LED drive current. The same microcontroller that provides the ECG functions for the DALI interface can also provide the PWM interface function to the LED driver. An example is the 78K0/Ix2 Lighting Controller made by Renesas⁶, which supports DALI communication as well as LED dimming using the Renesas µPD168804 LED driver. Figure 22 shows a block diagram of the 78K0/Ix2 used to drive an LED light engine.
DMX512 (Digital Multiplex)

The DMX standard was developed in 1990 and standardized by ANSI in 2004 (ANSI E1.11-2004). Its main use is in control of theater stage lighting, and it can support multiple control functions such as pan, tilt, zoom, color and image effects in addition to dimming. A maximum of 32 devices can be connected on one DMX512 line. All devices must be connected in series, with a termination resistor at the far end. The protocol is based on RS485 and operates at 250kbit/s, and the set-point data for all devices are retransmitted continuously allowing near-instantaneous recovery from any transmission errors. DMX data flow is uni-directional and does not include provision for status reporting.

Dimming is normally implemented in one of two ways. The first method uses a specific DMX dimmer unit (called a dimmer pack) that provides several AC outputs for lights to be plugged into. Each of the outputs is controlled by an internal phase-cut dimmer, with the dimmer settings under independent control through the DMX signals. The dimmer pack includes switches to set the DMX address for each light.

The DMX512 digital interface is primarily intended for control of stage lighting. It supports dimming as well as a wide range of other lighting effects.

Figure 22 – Renesas 78K0/Ix2 DALI Interface
The second method uses a multi-channel DMX-to-analog converter that provides analog 0-10V outputs for each channel rather than AC outlets. These analog outputs are used to control lighting that can accept a 0-10V dimming input, as described in “Analog (0-10V)” on page 13.

Control of LED lighting through DMX could use either method for dimming, but the 0-10V analog method is simpler and allows more complete control.

**Zigbee**

Zigbee® is a digital wireless mesh networking standard based on IEEE 802.15.4-2003. It operates on a frequency band of 868Mhz, 915MHz or 2.4GHz, and is intended for applications such as building automation, smart energy and lighting control. The mesh network between devices in established automatically, making it robust and easy to install. Figure 24 shows an overview of potential applications within a building environment.
There are three types of Zigbee devices: the ZigBee Coordinator (ZC) acts as network hub, and can link to other hubs; the ZigBee Router (ZR) can act as a router and can link to other devices; and the ZigBee End Device (ZED) can link but cannot act as a router. The radio and microcontroller may be integrated into a single chip, such as the CC2530 2.4 GHz ZigBee transceiver/CPU made by Texas Instruments (TI)\(^7\).

One of the advantages of using Zigbee to control lighting is that no additional wiring is needed apart from the AC power. This can be particularly attractive for LED street lighting applications where the intention is to retrofit existing luminaires. Zigbee allows the retrofit to be carried out with no need for rewiring, and can support value-added features such as dimming during off-peak hours, multi-level dimming integrated with motion sensors, etc. It can also support status monitoring to provide warning of damage or failure, indication of brightness level, etc.

Zigbee control is also a key part of the new Emerge Alliance\(^1\) standard for low voltage (24V) DC building power, as a technique for controlling the low voltage DC lighting systems.

The actual dimming of the LEDs can be through PWM control or through analog variation of the LED drive current. As mentioned earlier, PWM dimming is generally preferred as it can achieve a higher efficiency than analog control. The CC2530 device mentioned above includes a PWM output that can interface to the LED driver.

**Summary**

Lighting technology using HB-LEDs can fully support dimming control through the AC wiring, through an analog or digital input or through a wireless mesh network. The virtually instantaneous response of LEDs to changes in drive current allows great flexibility in the end application and will support ongoing and future initiatives to reduce the amount of energy used for lighting. As a leader in LED power supplies, AEG Power Solutions offers products with or without integrated LED drivers that are compatible with the various forms of dimming discussed in this White Paper.
### Appendix I – Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
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<tr>
<td>CFL</td>
<td>Compact Fluorescent Lamp</td>
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<td>CRI</td>
<td>Color Rendering Index</td>
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<td>DALI</td>
<td>Digital Addressable Lighting Interface</td>
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<td>DMX</td>
<td>Digital Multiplex</td>
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<tr>
<td>ECD</td>
<td>Electronic Control Device</td>
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<tr>
<td>ECG</td>
<td>Electronic Control Gear</td>
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<tr>
<td>ELV</td>
<td>Electronic Low Voltage$^4$</td>
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<tr>
<td>EMI</td>
<td>Electromagnetic Interference</td>
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<tr>
<td>FET</td>
<td>Field-Effect Transistor</td>
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<tr>
<td>HB-LED</td>
<td>High-Brightness LED</td>
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<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
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<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronic Engineers</td>
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<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
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<tr>
<td>MLV</td>
<td>Magnetic Low Voltage$^3$</td>
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<tr>
<td>MOSFET</td>
<td>Metal Oxide Semiconductor Field Effect Transistor</td>
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<tr>
<td>PFC</td>
<td>Power Factor Correction</td>
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<tr>
<td>PSU</td>
<td>Power Supply Unit</td>
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<tr>
<td>PWM</td>
<td>Pulse-width Modulation</td>
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<tr>
<td>SELV</td>
<td>Safety Extra Low Voltage</td>
</tr>
<tr>
<td>TRIAC</td>
<td>Triode for Alternating Current Switch$^2$</td>
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<tr>
<td>ZC</td>
<td>Zigbee Coordinator</td>
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<td>ZED</td>
<td>Zigbee End Device</td>
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<td>ZR</td>
<td>Zigbee Router</td>
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</table>
## Appendix II – Terms and Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Driver</td>
<td>The driver provides a regulated current to the LEDs, and may provide added features such as dimming. It operates from the output of the power supply.</td>
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<tr>
<td>Emerge Alliance(^1)</td>
<td>An open industry association promoting the adoption of safe, low voltage DC power distribution and use in commercial building interiors.</td>
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<tr>
<td>Heatsink</td>
<td>A piece of metal, usually aluminum, whose function is to absorb heat from an LED (or other semiconductor) and dissipate it into the air.</td>
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<tr>
<td>Light Engine</td>
<td>An assembly of HB-LEDs onto a substrate which provides physical support and electrical interconnection. A light engine may include a driver.</td>
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<tr>
<td>Luminaire</td>
<td>A complete lighting fixture including light source, lens and external housing. A luminaire using HB-LEDs includes the power supply and driver.</td>
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<tr>
<td>Power Supply</td>
<td>The power supply converts the incoming AC into a low voltage output suitable for the LED driver. A power supply may include a driver.</td>
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<tr>
<td>Scene</td>
<td>A pre-set combination of brightness settings for a group of luminaires connected to a DALI network. A single DALI command can change from one scene to another, simultaneously changing the brightness of multiple luminaires.</td>
</tr>
<tr>
<td>Zigbee Alliance(^6)</td>
<td>An association of companies working together to enable reliable, cost-effective, low power, wirelessly networked, monitoring and control products based on an open global standard.</td>
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</tbody>
</table>

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1 Refer to [www.emergealliance.org](http://www.emergealliance.org) for details.

2 A triac is a bidirectional semiconductor switch that can be turned on by a short pulse on its gate, and then remains on until the voltage drops to zero. In a dimmer application, it automatically shuts off at the end of each cycle making it ideal for forward phase control.

3 An MLV dimmer is designed for use with inductive loads, and the symmetrical waveform avoids any DC imbalance. MLV dimmers are suitable for use with low voltage incandescent lighting such as 12V halogen type MR-16 lamps driven from magnetic transformers. However, an ELV dimmer should be used for MR-16 lamps driven by an electronic transformer (refer to note 4 below).

4 An ELV dimmer is more suitable for controlling capacitive electronic loads because the AC voltage does not have a sudden step increase as it does with a triac dimmer. ELV dimmers use a MOSFET switch rather than a triac. They are more complex internally and are usually more expensive.

5 More information on Renesas products is available at [www.renesas.com](http://www.renesas.com).

6 Refer to [www.zigbee.org](http://www.zigbee.org) for more information on the Zigbee Alliance.

7 Refer to [www.ti.com](http://www.ti.com) for details.