(54) Title: LIGHT UNIT AND METHOD FOR CONTROLLING A LIGHT UNIT COMPRISING ONE OR MORE LIGHTING DEVICES.

(57) Abstract: A light unit (10) including one or more lighting devices, in particular one or more solid state lighting devices, is disclosed. The light unit comprises input terminals (12, 14) for connecting the light unit to a variable external power supply (16, 18) and for receiving a variable input voltage (V10). A first lighting device (22) is electrically connected to the input terminals. A current path (30) is connected in parallel to the first lighting device, wherein the current path comprises a current control device (32) for controlling the current (IS1) in the current path. The current control device is adapted to control the current in the current path on the basis of light emitted by the first lighting device and detected by a light sensor (48) or a light sensitive portion. Wherein said current path (30) is adapted to connect said input terminals (12, 14) directly by bypassing all of the lighting devices when the input voltage (V10) is below the forward voltage of the first lighting device (22) thus no light emitted thereby.

FIG. 1
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Light unit and method for controlling a light unit comprising one or more lighting devices

FIELD OF THE INVENTION

The present invention relates to a light unit including one or more lighting devices, in particular one or more solid state lighting devices. Further, the present invention relates to a method for controlling a light unit comprising one or more lighting devices, in particular one or more solid state lighting devices.

BACKGROUND OF THE INVENTION

In the field of luminaires solid state light sources such as LEDs are more and more used as lighting devices which are connected directly to mains network. Since the solid state light sources are directly connected to the mains network, driver devices are necessary to adapt the solid state light sources to the mains voltage as input voltage in order to achieve a stable drive current. In the field of driver devices for solid state light sources for offline applications such as retrofit lamps it is essential that the driver devices which transform the mains voltage into the required drive current comply with present and future power mains regulations. In particular it is required that the driver devices comply with existing power adjusting means, e.g. dimmers or the like so that the drivers can be used universally as a retrofit driver device including the solid state lighting devices.

The driver devices should comply with all kinds of dimmers and especially the drivers should comply with phase-cut dimmers, which are preferably used to regulate the mains power with low power loss. Most dimmer devices utilize a low load impedance path for a timing circuit operating current to adjust the phase-cut timing, so that the driver devices have to provide a continuous current path to ensure the proper functionality of the dimmer device.

In order to comply with the alternating mains voltage a tapped linear driver may be utilized to drive a plurality of LEDs corresponding to the absolute value of the mains voltage. A corresponding driver device is e.g. known from US 2014/0292218 A1.

A disadvantage of the known driver device for connecting solid state light sources to the mains network is that the driver devices are technically complicated and have a
large physical volume so that the costs and the overall size of the lighting devices is increased.

A further disadvantage of the known driver devices is that no continuous low impedance current path is provided and that a current flow can only be established if the input voltage is higher than the forward voltage of the first solid state lighting device.

WO2013090252A2 discloses a tapped linear driver with optical control component, wherein there is an LED in the power loop and the light emitted by said LED is used for controlling the bypass switch of a next LED, and the light emitted by said next LED is used for controlling the bypass switching of an even next LED, and so on.

US20090057534A1 discloses a light source device for back light, wherein there is a shunt switch parallel with a LED, which shunt switch is controlled according to the light emitted by said LED in a negative feedback manner to regulate/maintain the light output of the LED.

**SUMMARY OF THE INVENTION**

It is an object of the present invention to provide a light unit including one or more lighting devices having an improved compatibility to different power supplies, in particular to phase cut dimmers, with low technical effort. It is a further object to provide a corresponding method for controlling a light unit.

According to a first aspect of the present invention, a light unit is provided including one or more lighting devices comprising:

- input terminals for connecting the light unit to a variable external power supply and for receiving a variable input voltage,
- a first lighting device electrically connected to the input terminals,
- a current path connected in parallel to the first lighting device,
wherein the current path comprises a current control device for controlling the current in the current path,

- wherein the current control device is adapted to control the current in the current path on the basis of light emitted by the first lighting device and detected by a light sensor or a light sensitive portion

wherein said current path is adapted to connect said input terminals directly by bypassing all of the lighting devices when the input voltage is below the forward voltage of the first lighting device thus no light emitted thereby.
According to another aspect of the present invention, a method for controlling a light unit comprising one or more lighting devices, in particular one or more solid state lighting devices is provided comprising the steps:

- receiving a variable input voltage at input terminals and providing the variable input voltage to first lighting device,
- providing a current path in parallel to the lighting device,
- detecting light emitted by the first lighting device by means of a light sensor or a light sensitive portion, and
- controlling a current in the current path on the basis of light emitted by the first lighting device wherein said current path is adapted to connect said input terminals directly by bypassing all of the lighting devices when the input voltage is below the forward voltage of the first lighting device thus no light emitted thereby.

Preferred embodiment of the invention are defined in the dependent claims. It shall be understood that the claimed method has similar and/or identical preferred embodiments as the claimed device and as defined in the dependent claims.

The present invention is based on the idea to provide a current path in parallel to all lighting devices in order to provide a current path for low voltages or a low impedance path for the power supply. Since the current control device in the current path is adapted to control the current in the current path on the basis of the light emitted by the lighting device, the current path can be provided as a bypass for low voltages when the lighting device is deactivated, and the current path can be disable when the lighting device is activated so as to save power loss. Hence, the light unit can be connected to an external power supply which provides a variable input voltage and in particular a pulsating phase cut input voltage, wherein a current flow through the light unit can be achieved for any voltage level either through the current path or the lighting device. Since the current flow is either established in the current path or the lighting device, the energy loss during the on-stage of the lighting device can be reduced and since the current control device is controlled on the basis of the light emitted by the lighting device, a separate current or voltage detection unit can be omitted. Hence, the technical effort for providing the continuous current path for the external power supply can be achieved with low technical effort.

In a preferred embodiment, the light sensitive portion is integrated in the current control device. This is a possibility to utilize a light sensitive current control device such as a photo transistor, so that the technical effort for controlling the current in the current path can be further reduced.
In an alternative embodiment, the light sensor is coupled to the current control device. This is a possibility to separate the lighting device and the current control device.

In a preferred embodiment, said current path is adapted to: provide a low impedance path for a drive current if the first lighting device is switched off and deactivate if the first lighting device is switched on. In this embodiment, whether the first lighting device is emitting light or not is an indication of the low input voltage, as well as an indication of whether the first lighting device is conducting, even an indication of whether the current through the dimmer is necessary, the current path is automatically controlled according to whether the first lighting device is emitting light or not, and the current path can provide the dimmer current in proper occasion.

In a preferred embodiment, said current path comprises a resistor and said lighting unit is adapted to be used with a phase cut dimmer. A resistive current path is advantageous since the current through the current path is allowed as the input voltage increases near the zero crossing.

In a preferred embodiment, the current control device comprises a controllable switch. This is a possibility to activate and deactivate the current in the current path effectively with low technical effort.

In a preferred embodiment, the current control device further comprises a biasing element, for coupling the input voltage to a control terminal of the controllable switch, said biasing element comprising a control resistor for setting a first level of the input voltage that turns on the controllable switch. In this embodiment, the controllable switch is biased to be turned on by the input voltage above a first level, thus the current (bypass) path will be activated as long as the dimmer outputs is above the first level and in turn provides a dimmer-friendly solution. Preferably, the first level is rather small.

In a still further embodiment, said first level is smaller than a forward voltage of the first lighting device. In this embodiment, before the LED starts conducting current, the current pass can pass dimmer current so as to fire the dimmer properly.

In a further preferred embodiment, the current path comprises a current limiting device. This is a possibility to avoid a short circuit in the current path and to ensure that a maximum drive voltage drops across the lighting device so as to turn on the lighting device.

In a preferred embodiment, the current control device comprises a current source. This is a possibility to drive a current in the current path in order to assure a proper
functionality of the external power supply and in particular a dimmer device connected to the external power supply.

In a preferred embodiment, the light sensor comprises a light emitting diode for light detection electrically connected to the current control device. This is a possibility to utilize standard light emitting diodes for light detection so that the technical effort for light detection can be further reduced.

In a further preferred embodiment, the light emitting diode is connected to a control terminal of the current control device and reversely biased by the input voltage. This is a possibility to achieve a current control in the current path effectively with low technical effort, since the reversely biased light emitting diode can provide a control voltage to the control terminal with low technical effort.

In a further preferred embodiment, the current control device is adapted to allow a current in the current path when the detected light emitted by the first lighting device is below a predefined level. This is a possibility to activate the current path when the input voltage is below a threshold voltage for activating the lighting device so that a current path can be provided for low input voltages.

In a further preferred embodiment, the current control device is adapted to reduce the current in the current path when the detected light emitted by the first lighting device is above the predefined level. In this embodiment, after the lighting device is turned on, current can flow through the lighting device and there is less need for a current in the current bypass, thus the current through the current path is reduced to save power loss through the current path.

In a preferred embodiment, the light unit further comprises a second lighting device connected in series to the first lighting device and the current path, wherein a second current path including a second current control device is connected in parallel to the second lighting device, and wherein the second current control device is adapted to control a current in the second current path on the basis of light emitted by the first lighting device and detected by a second light sensor or a second light sensitive portion. In other words, the current in the second current path is also controlled by the light emitted by the first lighting device. This is a possibility to provide an optical tapped linear driver, wherein the lighting devices are switched step by step in a cascade corresponding to the variable input voltage so that an effective illumination can be achieved.

In a further preferred embodiment, the light unit comprises a second lighting device connected in parallel to the first lighting device, wherein the current path is connected
in parallel to the first lighting device and the second lighting device, and wherein a threshold voltage for activating the first lighting device and the second lighting device have different voltage levels. In other words, the different lighting devices are connected in parallel to each other and in parallel to the current path, wherein the lighting devices have different activation voltage levels. This is a possibility to connect the lighting devices in a parallel connection and to activate the lighting devices in a cascade corresponding to the voltage level provided by the external power supply so that an effective illumination of the different lighting devices step by step can be achieved.

It is further preferred if the threshold voltage for activating the first lighting device is lower than the threshold voltage for activating the second lighting device. This is a possibility to first illuminate the first lighting device having the first current path and to activate the second lighting device when the input voltage is further increasing.

In a further preferred embodiment, the light unit further comprises a plurality of circuit segments connected in series to each other and in series to the first lighting device and each circuit segment comprising first second lighting device and a second current path connected in parallel to each other, wherein the second current path comprises a current control device adapted to control the current in the second current path on the basis of light detected by a second light sensor or a second light sensitive portion, and wherein the second light sensor or the second light sensitive portion of each of the plurality of circuit segments is optically coupled for light detection to a lighting device connected in series to the respective circuit segment. In other words, the current path of each of the circuit segments is controlled on the basis of a lighting device of a different or another circuit segment. This is a possibility to provide an optical tapped linear driver having a cascade of a plurality of lighting devices connected in series in the respective circuit segments so that an effective step by step illumination of the lighting devices corresponding to the voltage level of the input voltage can be achieved.

In a preferred embodiment, the second lighting devices and the second light sensor or the second light sensing portion of each circuit segment are disposed neighbored to each other and wherein the second light sensor or the second light sensing portion and the second lighting device of the respective circuit segment are optically isolated. This is a possibility to integrate the circuit segments as an integrated circuit and to manufacture the light sensor and the lighting device of each circuit segment in one piece, wherein the respective current control device is controlled by the light emitted by a lighting device of a different or another circuit segment.
As mentioned above, the light unit according to the present invention can provide a low current path when the variable input voltage is below a voltage level to activate the lighting device and to control the current in the current path when the input voltage is above the activation voltage of the lighting device so that a continuous low impedance path can be provided for any input voltage level and the power loss can be limited. Since the current in the current path is controlled on the basis of the light emitted by the lighting device, the technical effort of the light unit in general can be reduced.

Another aspect of the invention provides a structure for providing optical coupling, for example between the lighting device and the light sensors of the light unit according to the first aspect. This aspect uses a cavity in a PCB as light propagation path.

One embodiment of the above aspect provides:
- an electronic device comprising:
  - a light emitter;
  - a light receiver adapted to receive light emitted by said light emitter;
- and
  - a substrate on which said light emitter and said light receiver are mounted;

wherein said substrate comprises a hole and said light emitter is adapted to emit light into the hole and said light receiver is adapted to receive light from the hole.

In this embodiment, the hole can concentrate the light propagation between the light emitter and the light receiver, thus improves the optical coupling there between.

In a further embodiment, the hole is a through hole, and the light receiver and the light emitter are mounted on opposite side of the substrate and on a respective opening of the hole. In this embodiment, the light emitted by the light emitter passes through the hole to reach the light receiver.

In an alternative embodiment, the hole is a blind hole with one opening on one end and reflective material on the other end, the light receiver and the light emitter are mounted on the same side of the substrate and facing the opening of the hole. In this embodiment, the light emitted by the light emitter is reflected back to the light receiver by the reflective material. Since the light emitter and light receiver are on the same side, the thickness can be reduced.

In a further embodiment, first of the light emitter and the light receiver is placed within the hole. This embodiment can further reduce the distance between the light emitter and receiver thus improves optical coupling. To realize this embodiment, the
electronic device further comprises a gull wing bracket, wherein a wing portion of the
bracket is attached to the rim of the hole and a body portion is extending into the hole and
carrying the light emitter or the light receiver.

In a further embodiment, the inner wall of the hole comprises reflective
material, such as the hole comprises a through Via, adapted to redirect the light emitted from
the light emitter to the light receiver. In this embodiment, the emitted light that is not shining
perpendicular into the hole is reflected by the side walls of the Via and optical coupling is
improved.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will be apparent from and elucidated
with reference to the embodiment(s) described hereinafter. In the following drawings

Fig. 1 shows a schematic block diagram of a light unit comprising an optically
controlled current path,

Fig. 2 shows a detailed block diagram of the optically controlled current path
connected in parallel to a lighting device,

Fig. 3a, b show timing diagrams of a dimmed input voltage provided to the
light unit and an electrical current in the lighting device and the optically controlled current
path,

Fig. 4 shows a detailed block diagram of a circuit for optically controlling the
current in the current path,

Fig. 5 shows a schematic diagram of a geometric arrangement of an optically
tapped linear driver including an optically controlled current path,

Fig. 6 shows a schematic block diagram of an alternative embodiment of the
light unit of Fig. 1, and

Figs. 7 to 10 show different embodiments of an optical coupling structure
according to a second aspect of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a schematic illustration of an embodiment of a light unit which is
generally denoted by 10. The light unit 10 comprises input terminals 12, 14 for connecting
the light unit to an external power supply 16 which is preferably mains and for receiving a
 corresponding input voltage V10 which is preferably mains voltage. The input terminals 12,
14 are connected via a dimmer device 18 to the external power supply 16 in order to control
the input voltage V10 and to control the light emitted by the light unit 10 accordingly.

The dimmer device 18 may be a phase-cut dimmer comprising a capacitor and
an adjustable resistor for determining a point in time, i.e. a phase angle during each half cycle
of the mains voltage V10 where the dimmer device connects its output to the mains voltage
V10 in order to provide a leading edge or a trailing edge phase-cut voltage as the input
voltage V10 to the input terminals 12, 14. The capacitor is charged by means of a current
provided to the input terminals 12, 14 and the phase angle is determined on the basis of a
voltage across the capacitor so that the dimmer device 18 works properly only if a continuous
low impedance path is provided by means of the light unit 10 during the whole half cycle of
the mains voltage V10. Hence, a continuous current path is necessary for the proper
functionality of the dimmer device 18.

The light unit 10 comprises a rectifier 20, which is connected to the input
terminals 12, 14 in order to rectify the input voltage V10 to a rectified pulsating voltage V20.
The light unit 10 comprises a plurality of light emitting diodes 22, 24, 26, 28, which are
connected in series to each other and which are connected to the rectifier 20 in order to
receive the rectified voltage V20.

A current path 30 is connected in parallel to a first of the light emitting diodes
22 including a controllable switch 32 and a resistor 34. Further current paths 36, 38, 40 are
respectively connected in parallel to the further light emitting diodes 24, 26, 28 each
including a controllable switch 42, 44, 46 for connecting and disconnecting the respective
light emitting diode 24, 26, 28 to which the respective current path 36, 38, 40 is connected to
the rectifier 20 in order to activate and deactivate the respective light emitting diode 24, 26,
28. Hence, by means of the current paths 36, 38, 40 and the controllable switches 42, 44, 46 a
tapped linear driver can be provided for activating the light emitting diode 24, 26, 28 step by
step in a cascade corresponding to a value of the rectified voltage V20 as described in the
following.

The light unit 10 further comprises a plurality of light sensors 48, 49, 50, 52,
which are each in general associated to one of the light emitting diodes 22, 24, 26 in order to
detect the emitted light and are adapted to control at least one of the controllable switches 32,
42, 44, 46 of the current paths 30, 36, 38, 40.

The first current path 30 is connected in parallel to the first of the light
emitting diodes 22 so that a drive current I20 provided by the rectifier 20 is divided to a diode
current ID1 provided to the first diode 22 and a bypass current IS1 in the current path 30. The
light sensor 48 is associated to the first light emitting diode 22 in order to detect the light emitted by the light emitting diode 22 and switches the controllable switch 32 off if light emitted by the light emitting diode 22 is detected. If no light is detected, the controllable switch 32 is switched on. Hence, the current path 30 provides a low impedance path for the drive current I20 if the light emitting diode 22 is switched off and the current path 30 is deactivated or disabled if the light emitting diode 22 is switched on so that in any case a current path for the drive current I20 is provided. Hence, the light unit 10 provides a behavior corresponding to a filament light unit so that the functionality of the dimmer device 18 can be ensured.

The current path 30 may be connected merely in parallel to the first light emitting diode 22 or may be connected in parallel to all of the light emitting diodes 22 in order to provide the low impedance path if the input V20 is below the threshold voltage for activating the first light emitting diode 22 i.e. the forward voltage of the light emitting diode 22 and the light emitting diode 22 has a high impedance. The resistor 34 of the current path 30 which is connected in series to the controllable switch 32 serves as a current limiter and achieves that a voltage drops across the light emitting diode 22 when the controllable switch 32 is closed.

The light sensor 49 is connected to the controllable switch 42 of the current path forming a bypass of the second light emitting diode 24 in order to connect the second light emitting diode 24 to the first light emitting diode 22 when the first light emitting diode 22 is switched on or the emitted light reaches a predefined level. Hence, the rectified voltage V20 is provided to the second light emitting diode 24 when the rectified voltage V20 reaches a predefined level so that the light emitting diodes 22-28 can be activated and illuminated step by step in a cascade corresponding to a voltage level of the input voltage V10 or the rectified voltage V20.

The light sensor 50 which is associated to the second light emitting diode 24 is connected to the controllable switch 34 of the current path 38 bypassing the third light emitting diode 26 in order to provide the rectified voltage V20 to the third light emitting diode 26 when the second light emitting diode 24 is switched on or the emitted light reaches a predefined level. Hence, the third light emitting diode 26 can be activated when the rectified voltage V20 reaches a predefined voltage level.

The light sensor 52, which is associated to the third light emitting diode 26 is connected to the controllable switch 46 of the current path 40 which bypasses the fourth light emitting diode 28 for activating the fourth light emitting diode 28 or connecting the fourth
light emitting diode 28 to an input voltage V10. The controllable switch 46 is switched off when the third light emitting diode 26 is switched on or when the light emitted by the third light emitting diode 26 reaches a predefined level.

Hence, the rectified voltage V20 is provided to the light emitting diodes 22-28 which are connected in series to each other are activated or switched on in a cascade or step by step corresponding to a voltage level of the rectified voltage V20 or the input voltage V10 so that the light unit 10 is formed as an optical tapped linear driver (OTLD) which can be implemented with low technical effort and integrated with a reduced overall physical size.

Since the first current path 30 is activated or deactivated corresponding to the light emitted by the first light emitting diode 22, i.e. the diode which is bypassed by the first current path 30, a low impedance current path can be provided continuously so that the behavior of a filament light unit can be simulated and the dimmer device 18 works properly independent of the used technology.

The light sensors 48, 49, 50, 52 may be formed as separate light sensors separately from the controllable switches 32, 42, 44, 46 and coupled electrically or via an optical wire to the respective controllable switch 32, 42, 44, 46. In an alternative embodiment, the controllable switches 32, 42, 44, 46 are formed as photosensitive controllable switches such as phototransistors comprising a photosensitive portion which replaces the light sensors 48, 49, 50, 52 so that the light of the light emitting diodes 22, 24, 26, 28 can be detected and the current in the respective current path 30, 36, 38, 40 can be controlled accordingly.

Fig. 2 shows a detailed partial view of the light unit 10 including the first light emitting diode 22 and the second light emitting diode 24 and the corresponding current paths 30, 36. The current path 30 may be formed by the controllable switch 32 and the resistor 34 connected in series to each other as shown in Fig. 1 or may comprise a controllable current source 54 controlled on the basis of a control signal received from the light sensor 48 associated to the first light emitting diode 22.

When the input voltage V10 or the rectified voltage V20 is below a threshold voltage for activating the first light emitting diode 22 i.e. the forward voltage, the light emitting diode 22 does not emit any light and the controllable switch 32 is closed on the basis of the light measured by the light sensor 48 so that the current IS1 in the current path 30 corresponds to the drive current I20 provided by the rectifier 20 or the external power supply 16. By means of the current path 30, a low impedance path is provided by the light unit 10 so that the light unit 10 simulates a behavior of a filament based light unit. The resistor 34 limits
the current IS1 and provides a corresponding voltage drops across the first light emitting diode 22. In this case when the light emitting diode 22 is switched off, the controllable switch 42 is closed so that the second light emitting diode 24 is bypassed and the input voltage V10 or the rectified voltage V20 dropping across the first light emitting diode 22 and corresponds to the voltage V1 shown in Fig. 2.

In the alternative embodiment shown in Fig. 2 including the current source 54, the current IS1 in the current path 30 is controlled by means of the current source 54 on the basis of a signal received from the light sensor 48. When the first light emitting diode 22 is switched on, the current source 54 reduces the current IS1 to zero so that the current ID1 in the first light emitting diode 22 corresponds to the input or drive current I20.

When the first light emitting diode 22 is switched on or the light emitted by the first light emitting diode 22 reaches a predefined level, the controllable switch 42 of the current path 36 bypassing the second light emitting diode 24 is switched off so that the second light emitting diode 24 is connected to the input voltage V10 or the rectified voltage V20. In this case, the input voltage V10 or the rectified voltage V20 corresponds to a sum of the voltage V1 dropping across the first light emitting diode 20 and the voltage V2 dropping across the second light emitting diode 24. When the voltage V2 reaches the threshold voltage of the second light emitting diode 24, the second light emitting diode 24 is switched on and the light sensor 50 detects the emitted light and controls correspondingly the controllable switch bypassing the following light emitting diode as shown in Fig. 1.

Fig. 3a shows a timing diagram of a phase cut voltage of one half cycle of the input voltage V10 or the rectified voltage V20. The phase cut voltage shown in Fig. 3a shows a trailing edge phase cut voltage (solid line) and a leading edge phase cut voltage (dotted line) and the full half cycle (dashed line) of the input voltage V10 provided by the external power supply 10. The trailing edge input voltage V10 has a phase angle at \( t_{TE} \) wherein the leading edge input voltage has a phase angle at \( t_{LE} \) as shown in Fig. 3a. By means of this phase cut input voltage, a dimming of the light unit 10 is possible with low power loss.

In Fig. 3b a detailed timing diagram of the trailing edge phase cut voltage V10 is schematically shown including the bypass current IS1 and the diode current ID1.

The bypass current IS1 starts to flow in the current path 30 at \( t_0 \) due to the resistive current limiting characteristic of the current path 30 because of the resistor 34 as soon as a minimum dropout voltage \( V_0 \) is reached by the input voltage V10 or the rectified voltage V20. The minimum dropout voltage \( V_0 \) can be selected to be significantly smaller than e.g. the voltage V1 dropping across the first light emitting diode. Hence, a low voltage
compatible path is formed by the current path 30 for the dimmer current. The current path 30 allows the voltage across the first light emitting diode to rise so that the threshold voltage of the first light emitting diode 22 can be reached. As shown in Fig. 3b, the bypass current IS1 increases corresponding to the increase of the phase cut input voltage V10 or the phase cut rectified voltage V20 until the phase cut voltage V10 reaches the threshold voltage $V_d$ of the first light emitting diode 22 and the diode current ID1 starts to flow and the first light emitting diode starts to emit light at t1. At the same time, the controllable switch 32 is switched off so that the bypass current IS1 is reduced to zero.

Hence, a low impedance current path can be provided by the light unit 10 even if the input voltage V10 close to the zero crossing is below the threshold voltage of the first light emitting diode 22 when no forward current can be driven.

Fig. 4 shows a schematic block diagram of an embodiment of the light sensor 48 and the controllable switch 32 of the current path 30 to control the bypass current IS1 in the current path 30.

The controllable switch 32 is formed as a transistor and in this case as an FET comprising a collector terminal connected to the resistor 34, an emitter terminal connected to a cathode side of the first light emitting diode 22 and a gate electrode control terminal connected to a node 56 between a control resistor 58 and a diode 60, which is formed as a photodiode 60 or a light emitting diode 60. The control resistor 58 and the diode 60 are connected in series to each other and connected in parallel to the first light emitting diode 22. The diode 60 is associated to the first light emitting diode 22 and optically coupled via an optical path 62 so that the diode 60 can detect the light emitted by the first light emitting diode 22. The diode 60 is connected in a reverse direction to the first light emitting diode 22.

If the first light emitting diode 22 is deactivated, the diode 60 blocks a current through the control resistor 58 so that a voltage is provided via the control resistor 58 to the control terminal of the transistor 32 and the transistor 32 is switched on. When the first light emitting diode 22 is switched on or activated, the diode 60 draws a current so that the voltage at the node 56 provided to the control terminal of the controllable switch 32 is reduced and the controllable switch 32 is switched off. Hence, the current path 30 can be deactivated by means of the light emitted by the first light emitting diode 22.

After the controllable switch 32 is switched off the bypass current IS1 is merely determined by a leakage current of the controllable switch 32 and a current in the control resistor 58. The sensitivity of the diode 60 is set to be smaller than the nominal light level emitted by the first emitting diode 22.
When the input voltage V10 rises further, the diode ID1 increases and the light emission of the first light emitting diode 22 increases. At a certain drive current, the emitted light reaches a threshold level so that the controllable switch 42 bypassing the second light emitting diode 24 is opened and the corresponding second light emitting diode 24 is connected to the input voltage V10.

Fig. 5 shows a schematic diagram of three of the light emitting diodes 22, 24, 26 and the light sensors 48, 50, 52 associated to the respective light emitting diodes 22, 24, 26 for controlling the controllable switches 32, 42, 44. The light emitting diode 22, 24, 26 comprises a light emitting element and the light sensors 48, 49, 50 comprises a light sensitive element, wherein the light emitting elements may be covered by a phosphor layer for color conversion. The light emitting element of the first light emitting diode 22 is optically connected to the light sensor 48 via the optical path 62 and, further, connected to the light sensor 49 via another optical path 64. Hence, the light emitted by the first light emitting diode 22 can be detected by the light sensor 48 switching the controllable switch 32 of the current path 30 and can be detected by the light sensor 49 for switching the controllable switch 42 of the current path 36. The light sensor 49 is disposed close to the second light emitting diode 24 and optically disconnected by an optical barrier 66. Hence, the light sensor 49 is not influenced by the light emitted by the light emitting diode 24. The light emitting diode 24 is optically connected to the light sensor 50 by means of an optical path 68 for switching the controllable switch 44 of the current path 38 by passing the third light emitting diode 26. The light sensor 50 is optically disconnected or separated from the third light emitting diode 26 by means of an optical barrier 69.

The light emitting diodes 22-28 and the light sensor 48-52 can be monolithically integrated e.g. in a silicon substrate, wherein the respective optical paths 62, 64, 68 can be formed as an optical connection and the respective optical barriers 66, 69 may be formed as a trench filled with a light blocking material so that an optical separation can be achieved even if the light emitting diodes 22-28 and the light sensors 48-52 are integrated in a substrate.

Hence, an optical tapped linear driver for the light unit 10 can be achieved with low technical effort and with a reduced overall size and a low impedance path can be provided with low technical effort.

Fig. 6 shows a schematic block diagram of a sectional view of an embodiment of the light unit 10. The light unit 10 comprises the light emitting diodes 22', 24', 26' connected in parallel to each other and comprises the current path 30' including the resistor
34' and the controllable switch 32', wherein the light sensor 48' is associated to the light
emitting diode 22' for light detection and controls the controllable switch 32' on the basis of
the detected light.

The light emitting diode 22' and the current path 30' are identical with the light
emitting diode 22 and the current path 30 shown in Fig. 1 and 2. The further light emitting
diodes 24', 26' are connected in parallel to the light emitting diode 22' and the current path
30'. In order to activate the light emitting diode 22', 24', 26' step by step in a cascade with the
increasing input voltage V10 or the rectified voltage V20, the respective light emitting diodes
22', 24', 26' have different forward voltages. Preferably the light emitting diode 22' has the
lowest forward voltage so that this light emitting diode 22' is activated as first light emitting
diode of the light unit 10. The light emitting diode 24' has a forward voltage higher than the
light emitting diode 22' and lower than the light emitting diode 26', so that this light emitting
diode 24' is activated as second light emitting diode and the light emitting diode 26' is
activated as last of the light emitting diodes.

Consequently, the parallel connection of the light emitting diodes 22', 24', 26'
shown in Fig. 6 can provide a continuous low current path for the dimmer device 18 and can
illuminate the light emitting diodes step by step according to an optical tapped linear driver.

Another aspect of the invention provides a structure for providing optical
coupling, for example between the lighting device or the light emitting diodes 22-28 and the
light sensors 48-52. This aspect uses a cavity in a PCB as light propagation path.

Fig. 7 shows the cross section / side view of an embodiment according to the
above aspect. An electronic device 7 comprises a light emitter 70; a light receiver 72 adapted
to receive light emitted by said light emitter 70; and a substrate 74 on which said light emitter
70 and said light receiver 72 are mounted; wherein said substrate 74 comprises a hole 76 and
said light emitter 70 is adapted to emit light into the hole 76 and said light receiver 74 is
adapted to receive light from the hole 76.

In the shown embodiment, the hole 76 is a through hole, and the light receiver
72 and the light emitter 70 are mounted on opposite side of the substrate 74 and on a
respective opening of the hole 76. More specifically, the substrate 74 is a PCB. Reference
sign 78 denotes copper layer/trace on the PCB. More specifically, the proposed optical
coupling is created using a drilled hole in the PCB with e.g. on the top-side the high voltage
components, including the LED-load Surface Mounted Devices (SMD), including the light
emitter LED. On the bottom side are the low voltage components including the detector LED
as the light receiver.
In an alternative embodiment as shown in fig. 8, the hole 76’ is a blind hole with one opening on one end and reflective material on the other end. In this embodiment the other end of the hole 76’ is the copper layer 78. The light receiver 72 and the light emitter 70 are mounted on the same upper side of the substrate 74 and facing the opening of the hole 76’.

In a further embodiment, at least one of the light emitter and the light receiver are placed within the hole. As shown in fig. 9, the light emitter is mounted within the hole. This embodiment can further reduce the distance between the light emitter and receiver thus improves optical coupling. To realize this embodiment, the electronic device further comprises a gull wing bracket 90, wherein a wing portion of the bracket is attached to the rim of the hole 76 and a body portion is extending into the hole and carrying the light emitter 70. It should be understood that, alternatively or additionally, the light receiver could also be mounted on a similar gull wing bracket and placed within the hole.

In a further embodiment as shown in fig. 10, the inner wall of the hole comprises reflective material such as a through Via 100 adapted to redirect the light emitted from the light emitter 70 to the light receiver 72. In this embodiment, the emitted light that is not shining perpendicular into the hole is reflected by the side walls of the Via and optical coupling is improved. It should be understood that other kind of technology of coating reflective material on the inner wall of the hole is also applicable.

The proposed optical coupling structure can be used with the above optical tapped linear driver. It can also be used independent from the optical tapped linear driver, and used in a context where isolation between high voltage and low voltage circuitry is required and optical coupling should be as high as possible, while not making the PCB area too large. With this new implementation extra encapsulation material is not needed anymore.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single element or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.
Any reference signs in the claims should not be construed as limiting the scope.
CLAIMS:

1. Light unit (10) including one or more lighting devices, in particular one or more solid state lighting devices, comprising:
   - input terminals (12, 14) for connecting the light unit to a variable external power supply (16, 18) and for receiving a variable input voltage (V10),
   - a first lighting device (22) electrically connected to the input terminals,
   - a current path (30) connected in parallel to the first lighting device, wherein the current path comprises a current control device (32) for controlling the current (IS1) in the current path,
   - wherein the current control device is adapted to control the current in the current path on the basis of light emitted by the first lighting device and detected by a light sensor (48) or a light sensitive portion;
      wherein said current path (30) is adapted to connect said input terminals (12, 14) directly by bypassing all of the lighting devices when the input voltage (V10) is below the forward voltage of the first lighting device (22) thus no light emitted thereby.

2. Light unit as claimed in claim 1, wherein the light sensitive portion is integrated in the current control device, and wherein said current path (30) is adapted to:
   provide a low impedance path for a drive current (I20) if the first lighting device (22) is emitting light and
deactivate if the first lighting device (22) is not emitting light.

3. Light unit as claimed in claim 1, wherein the light sensor is coupled to the current control device, and
   said current path (30) comprises a resistor (34) and said lighting unit (10) is adapted to be used with a phase cut dimmer (18).

4. Light unit as claimed in claim 1, wherein the current control device comprises:
a controllable switch, and
a biasing element, for coupling the input voltage to a control terminal of the controllable switch, said biasing element comprising a control resistor for setting a first level of the input voltage that turns on the controllable switch, and said first level being smaller than a forward voltage of the first lighting device (22).

5. Light unit as claimed in claim 1, wherein the current control device comprises a current source (54).

6. Light unit as claimed in claim 1, wherein the light sensor comprises a light emitting diode (60) for light detection electrically connected to the current control device.

7. Light unit as claimed in claim 6, wherein the light emitting diode is connected to a control terminal of the current control device and reversely biased by the input voltage.

8. Light unit as claimed in claim 1, wherein the current control device is adapted to allow a current in the current path when the detected light emitted by the first lighting device is below a predefined level.

9. Light unit as claimed in claim 8, wherein the current control device is adapted to reduce the current in the current path when the detected light emitted by the first lighting device is above the predefined level.

10. Light unit as claimed in claim 1, wherein the light unit further comprises a second lighting device (24) connected in series to the first lighting device and the current path, wherein a second current path (36) including a second current control device (42) is connected in parallel to the second lighting device, and wherein the second current control device is adapted to control a current in the second current path on the basis of light emitted by the first lighting device and detected by a second light sensor (49) or a second light sensitive portion, and wherein said current path (30) and said second current path (36) are adapted to connect said input terminals (12, 14) directly by bypassing all of the lighting devices.

11. Light unit as claimed in claim 1, wherein the light unit comprises a second lighting device connected in parallel the first lighting device, wherein the current path is
connected in parallel to the first lighting device and the second lighting device, and wherein a threshold voltage for activating the first lighting device and the second lighting device have different voltage levels.

12. Light unit as claimed in claim 11, wherein the threshold voltage for activating the first lighting device is lower than the threshold voltage for activating the second lighting device.

13. Light unit as claimed in claim 1, wherein the light unit further comprises a plurality of circuit segments connected in series to each other and in series to the first lighting device, each circuit segment comprising a second lighting device and a second current path connected in parallel to each other, wherein the second current path comprises a current control device adapted to control the current in the second current path on the basis of light detected by a second light sensor or a second light sensitive portion, and wherein the second light sensor or the second light sensitive portion of each of the plurality of circuit segments is optically coupled for light detection to a lighting device connected in series to the respective circuit segment.

14. Light unit as claimed in claim 13, wherein the second lighting device and the second light sensor or second light sensing portion of each circuit segment are disposed neighboured to each other, and wherein the second light sensor or the second light sensing portion and the second lighting device of the respective circuit segment are optically isolated.

15. Method for controlling a light unit (10) comprising one or more lighting devices, in particular one or more solid state lighting devices, comprising the steps of:
   - receiving a variable input voltage (V10) at input terminals (12, 14) and providing the variable input voltage to a first lighting device (22),
   - providing a current path (30) in parallel to the first lighting device,
   - detecting light emitted by the first lighting device by means of a light sensor (48) or a light sensitive portion, and
   - controlling a current (IS1) in the current path on the basis of light emitted by the first lighting device, wherein said current path (30) is adapted to connect said input terminals (12, 14) directly by bypassing all of the lighting devices when the input
voltage (V10) is below the forward voltage of the first lighting device (22) thus no light emitted thereby.
### INTERNATIONAL SEARCH REPORT

**PCT/EP2016/063568**

#### A. CLASSIFICATION OF SUBJECT MATTER

**INV.**  H05B33/08  
**ADD.**

According to International Patent Classification (IPC) or to both national classification and IPC

#### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

**H05B**

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**EPO-Internal, WPI Data**

#### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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**Further documents are listed in the continuation of Box C.**  
**See patent family annex.**

* Special categories of cited documents:  
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  * "O" document referring to an oral disclosure, use, exhibition or other means  
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**Date of the actual completion of the international search**  
15 September 2016  
**Date of mailing of the international search report**  
22/09/2016  
**Name and mailing address of the ISA/  
European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040,  
Fax. (+31-70) 340-3016**  
**Authorized officer**  
Maicas, Jesús
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