Title: RETROFIT LED LAMP

Abstract: A retrofit LED lamp (30) is disclosed, which can replace a fluorescent lamp in a luminaire provided with a magnetic ballast circuit or an electronic ballast circuit. The lamp (30) comprises a string (31) of serial arranged LEDs (32). The AC voltage from the ballast is supplied to power lines (38, 39). A rectifier (40) with an AC input (47, 48) coupled to the power lines (38, 39) has DC outputs (45, 46) which are coupled to the string (31) of LEDs (32). An AC/DC converter (23) has DC outputs (33, 34) coupled to the string (31) of LEDs (32). The AC/DC converter is coupled to the power lines (38, 39) via a filter (50) with a high pass frequency characteristic which substantially blocks the transport of electric energy for an AC voltage with a frequency below a first frequency value. For frequencies above a second frequency value the filter (50) let pass the high frequency currents, resulting in that the AC/DC converter provides a DC voltage at its DC outputs (33, 34) with a level above the amplitude of the AC voltage received on its inputs. Preferably voltage multipliers (61) are used for the AC/DC converter (23).
Retrofit LED lamp.

FIELD OF THE INVENTION
The application relates to a retrofit LED lamp which is suitable to be energized by different types of ballasts, in particular a magnetic ballast and an electronic ballast.

BACKGROUND OF THE INVENTION
Fluorescent lighting has been around for many years now. This form of lighting started out as a highly efficient alternative for incandescent light bulbs, but has recently been surpassed by LED lighting to some extent in terms of efficiency and power consumption, and also in other aspects as set out below.

Fluorescent lamps generally comprise a tube filled with an inert gas and a small amount of mercury, capped at both ends with double pinned end caps. The end caps contain a glow wire to preheat the gasses inside the tube and to vaporize the mercury in order to assist with ignition of the fluorescent lamp. Once the fluorescent lamp is ignited, heat generated by the conducted current keeps the fluorescent lamp in operational condition.

To facilitate these starting conditions and to limit current through the fluorescent lamp during operation, and thus limit the power consumed, an electrical ballast is connected between the mains power supply and the fluorescent lamp.

When first introduced, the only available ballasts were simple magnetic inductors, which limit consumed power by limiting the AC current as a result of the frequency dependent impedance of the inductor. An undesirable result is a relatively low power factor and relatively high reactive power.

More recently electronic ballasts have been introduced. Such electronic ballasts usually first convert AC mains power into DC power, and subsequently convert the DC power into high frequency AC power to drive the fluorescent lamp. The more recent electronic ballasts actively control
current through the fluorescent lamp and actively control AC power absorbed by the ballast itself. This allows the system to have a power factor close to a value of one. Even though power absorbed by the electronic ballast and fluorescent lamp combined is only slightly lower than a system with a magnetic ballast, reactive power is greatly reduced. The efficiency of the ballast itself is also improved.

Although LED lighting itself is only slightly more efficient than fluorescent lighting, it has many other advantages. For example, no mercury is required for LED lighting, LED lighting is more directional, LEDs require less effort to control or regulate power consumed, and the lifetime is greatly increased over fluorescent lighting.

Thus, replacing existing fluorescent lighting systems with LED lighting systems is often desirable. However, costs for such replacement are relatively high. Replacement LED lamps cannot be inserted in luminaires designed for fluorescent lamps due to the ballast, so the existing luminaire for fluorescent lamps needs to be replaced. As a consequence, many users simply replace failed fluorescent lamps with another fluorescent lamp, even in view of the evident advantages of LED lamps. The incentive to replace fluorescent lamps with LED lamps is further diminished when only a single fluorescent tube in a multi-tube luminaire has failed.

Replacing the luminaire would result in discarding fluorescent tubes still in functioning order.

Consequently, there is a need for an LED lamp that can be put into operation when mounted in an existing luminaire designed for a fluorescent lamp.

WO2015044311 discloses a retrofit LED lamp adapted to replace a fluorescent lamp in a luminaire having a magnetic or an electronic ballast. The arrangement comprises a plurality of LEDs switchable among a plurality of circuit configurations, first means for sensing a frequency of power supplied to the arrangement by the luminaire and generating an output, and second means for switching the circuit configuration of the
plurality of LEDs on the basis of the output of the first means for sensing frequency so that LED configurations are adapted to the type of ballast circuitry.

Although this retrofit lamp is very well suitable for the different types of ballast circuits it requires switches to adapt the LED configuration to the type of ballast. These switches are relative expensive components.

SUMMARY OF INVENTION

It is an object of the invention to provide a LED retrofit lamp which is suitable to operate with different types of ballast circuits without switches for changing the LED configuration.

According to the invention this object is achieved by a retrofit LED lamp for replacing a fluorescent lamp in a luminaire provided with a magnetic ballast circuit or with an electronic ballast circuit for supplying an AC supply voltage to the retrofit lamp, which retrofit LED lamp comprises:

- power lines for receiving the AC supply voltage from the luminaire,
- a rectifier having a DC output side and having an AC input side coupled to the power lines, an AC/DC converter having a DC output side and having an input side coupled to the power lines via a filter with a high pass frequency characteristic for blocking AC currents below a first frequency value and letting pass AC currents above a second frequency value, and
- a string of serial arranged LEDs which is coupled the DC output sides of the rectifier and AC/DC converter to be energized with a DC current by either the rectifier or the AC/DC converter which has the highest DC output voltage level.

In this retrofit lamp advantageous use is made of the differences in the characteristics which are typical for a magnetic ballast and an electronic ballast. A magnetic ballast provides an AC voltage which is equal to the frequency of the mains voltage the mains voltage is typically 50 Hz (e.g. in Europe) or 60 Hz (e.g. the USA). The frequency of the output voltage of an electronic ballast has a frequency above the frequency spectrum for which the human ears are sensitive, typically this frequency is above 20
kHz. Further the operation voltage over the LED string in a retrofit LED lamp connected to a magnetic ballast is substantial higher than the operation voltage when connected to an electronic ballast.

The differences between the operation voltage and frequency of magnetic ballast and the electronic ballast results in that in case the retrofit lamp is connected to a magnetic ballast the energy transport to the AC/DC converter is blocked by the input impedance of the AC/DC converter, due to the low frequency of the AC voltage supplied by the magnetic ballast to the retrofit lamp. So the retrofit lamp is energized via the rectifier. In case the retrofit lamp is connected to an electronic ballast energy transport to the AC/DC converter is enabled, due to the high frequency of the AC voltage. Since the output voltage of the AC/DC converter is higher than the maximum output voltage that can be delivered by the rectifier the lamp will be energized via the AC/DC converter only. The up conversion of the DC voltage by the AC/DC converter provides a compensation for the differences in the operation voltages of the magnetic and electronic ballasts, so that the number of serial connected LEDs in the string of LEDs can be the same for both a magnetic ballast and an electronic ballast. This makes a ballast type dependent configuration of the LED circuit superfluous. So switches for changing the configuration are not required, which leads to a substantial saving of costs of material. Moreover detection circuitry for the detecting the type of ballast and controlling the switches are also not required.

In a preferred embodiment of the retrofit lamp the AC/DC converter comprises a voltage multiplier.

Such voltage multipliers can be can be realized without switching transistors or with passive components and diodes, which makes the retrofit lamp inexpensive, reliable and durable.

A further embodiment of the comprises a current control subsystem for controlling the current supplied by the rectifier to the string of LEDs, which control subsystem comprises a switch for bypassing in response to a
control signal at least a part of the string of LEDs and a control circuit for periodically providing the control signal in dependence on the current supplied.

This embodiment enables to control the current through the LEDs or power supplied to LEDs, such that the emitted light is substantially independent to variations in the amplitude of the mains voltage.

In a further embodiment of the retrofit LED lamp the control subsystem is arranged to bypass a variable number of LEDs, which variable number is dependent on the voltage over the string of LEDs and/or the current through the string of LEDs, so as to maintain the current through the string of LEDs within an operation range.

This embodiment enables an automatic adaption of the number of energized LEDs to the actual supply voltage, so that the retrofit lamp can be directly connected to the mains. In this way a retrofit lamp is created which is suitable to be directly energized via the mains, via a magnetic ballast or an electronic ballast.

Some types of electronic ballast comprises an End Of Life (EOL)-detection, which detects whether a DC-offset in the supply voltage exceeds a threshold value which indicates that a fluorescent lamp has reached its end of life. In response to an EOL-detection the electronic ballast stops the energy supply to the lamp.

To prevent an erroneous switch-off an embodiment of the retrofit LED lamp the retrofit LED lamp is arranged to maintain the DC voltage component in the AC voltage between the power lines substantially equal to zero.

**BRIEF DESCRIPTION OF THE DRAWINGS**

These and other aspects of the invention will be apparent from and elucidated further with reference to the embodiments described by way of example in the following description and with reference to the accompanying drawings, in which

Fig. 1 depicts a characteristic curve for a typical electronic ballast,
Fig. 2 depicts a characteristic curve for a typical magnetic ballast,
Fig. 3 shows an embodiment of a retrofit lamp according to the invention,
Fig. 4 shows an embodiment of a retrofit lamp according to the invention using an AC/DC converter using a trafo,
Fig. 5 shows an embodiment of a retrofit lamp according to the invention using an AC/DC converter in the form of a voltage multiplier comprising a chain of voltage doublers,
Fig. 6a shows an embodiment of a retrofit lamp according to the invention using an AC/DC converter comprising a chain of voltage doublers in which a rectifier for the low frequency rectification is partly integrated in the chain,
Fig. 6b and 10 show embodiments of retrofit lamps according to the invention using an AC/DC converter comprising a chain of voltage doublers in which a rectifier for the low frequency rectification is fully integrated in the chain,
Fig. 7 and 8 show embodiments of retrofit lamps according to the invention in which the current through the LED string of the lamp is controlled by one or more switches which are connected in parallel over parts of the LED string, and
Fig. 9 shows an embodiments of retrofit LED lamps in which the current through the LED string is controlled by using a voltage multiplier with taps providing different voltages.

DETAILED DESCRIPTION OF EMBODIMENTS
An explanation with respect to features of embodiments of the invention with respect to technical properties and phenomena is provided, followed by exemplary embodiments of the present invention.
Both magnetic and electronic ballasts are designed to start, control and to limit current supplied to a fluorescent tube and regulate the power consumed by the tube.
Magnetic and electronic ballasts exhibit different behaviors with respect to different input power levels. Figure 1 depicts a characteristic curve for a
typical electronic ballast, with an approximately linear increase in power supplied by the ballast as output voltage is increased, demonstrating its applicability as current source. Note that electronic ballasts typically include over-power protection which automatically shifts down the current generated by the ballast once the power reaches a certain level.

Figure 2 depicts a characteristic curve for a typical magnetic ballast (not including over-power protection). As shown in Figure 2, power supplied by the ballast increases with output voltage to a maximum at point 10 and then decreases as voltage increases further. When the magnetic ballast is used to power a string of LEDs, an increase in the total forward voltage of the LED string relative to the situation at maximum point 10 will result in shifting the operating point to the right of maximum point 10 resulting in a decrease of power.

As can be seen in Figure 2, the characteristic curve exhibits the same power output at two different voltages when operating at below the maximum power 10. For example, a power output of 40 watts is achieved at operating voltages of approximately 50V and 200V, indicated at dashed lines 11 and 12 in Figure 2. At these two voltages, the luminaire will operate at two different current levels and two different power factors, with substantially the same output power. At the higher voltage operating point, though, the reactive power is decreased significantly, and resistive losses in the coil and the connecting wiring, and the magnetization and saturation losses of the ballast core are therefore also decreased, so that the luminaire, at the above-mentioned output power, has a lower input power and as a result it operates more efficiently.

LEDs generally produce light (slightly) more efficiently than fluorescent tubes, and because LED lighting is directional the losses from redirecting light in the desired direction are lower, so that the required power for LED lighting is generally considerably lower than fluorescent lighting at the same light levels. The power for a LED-lamp connected to electronic ballast and producing a similar amount of light as a 40 Watt fluorescent
lamp is about 28 Watt, indicated by reference number 7 in Figure 1. The corresponding operation voltage is about 75 Volt.
If a LED lamp is connected to an magnetic ballast the lamp has to be energized at a higher voltage level, indicated by reference number 13 in Figure 2. The corresponding operation voltage is about 210 Volt.
Fig. 3 shows an embodiment of a retrofit lamp 30 according to the invention which is suitable to be energized via an electronic ballast and via a magnetic ballast. The retrofit lamp 30 comprises at least one string 31 of serial arranged LEDs 32. The string of LEDs 31 is connected to DC-outputs 33 and 34 of a circuit 35 having AC inputs 36 and 37. The AC inputs 36 and 37 are connected to power lines 38 and 39 for receiving an AC supply voltage from a ballast in a luminaire (not shown) for a fluorescent lamp. The retrofit lamp 30 further comprises a rectifier 40 of a usual type, for example a diode bridge rectifier or another type of rectifier.
The AC inputs 45 and 46 of rectifier 40 are connected to the power lines 38 and 39. The string of LEDs 31 is connected to DC outputs 47 and 48 of the rectifier 40.
The AC/DC converter 32 in Fig 3 is configured to be used in combination with luminaires which are connected to a mains voltage of 240 Volt AC and 50 Hz. In case the luminaire is provided with an electronic ballast it will supply an AC voltage with a frequency higher than 20 kHz to powerlines 38 and 39.
In case the luminaire is provided with a magnetic ballast the supply voltage has a frequency of 50 Hz or 60 Hz. The operation voltage of the magnetic ballast depends on the total front voltage over the LED string, which is equal to the number of LEDs multiplied by the forward voltage of an individual LED. The number LEDs in the string is chosen such that the required light emission is achieved by a current for which the string 31 of LEDs produce an amount of light which is substantially equal to the light emission of a conventional fluorescent lamp which is designed to be used in the luminaire. Circuit 35 comprises AC/DC converter 23 which is
supplied by an AC current via a filter 50 with a high pass frequency characteristic. The high pass frequency characteristic of the filter 50 is such that the transfer of energy to the AC/DC converter 23 is blocked for the frequency of the main voltage, which is typically 50 Hz or 60 Hz. So in case the retrofit lamp is energized via the a magnetic ballast the AC/DC converter is inactive and the string 31 of LEDs will be energized via the bridge rectifier 40, whereby the current path from the rectifier 40 into the DC output 33 AC/DC converter 23 is blocked by diode 21 placed between output 33 and supply line 70 of the LED string 31.

In case the retrofit lamp 30 is energized via an electronic ballast the frequency of the AC voltage is that high that energy transport into the AC/DC converter 23 will take place, which results that a DC voltage is available at the DC outputs 33 and 34 of the AC/DC converter. The AC/DC converter 23 is of a so-called up converting type for which the ratio between the DC level at is output and the amplitude of the AC input is higher than the corresponding ration for the rectifier 40. Preferably AC/DC converter comprises a so-called voltage multiplier, but also other types of up converting AC/DC converters can be used, as will be described later on in the description. In case the retrofit lamp 30 is connected to an electronic ballast the AC/DC converter 23 becomes active due to the fact that the filter 50 let pass the energy transport to the AC/DC converter 23. The DC output of the up converting AC/DC converter 23 is higher than the DC output of rectifier 40. The current path from the AC/DC converter 23 into the DC output 47 of rectifier 40 is blocked by the diode 22 which is placed between output 47 and the supply line 70 of the LED string 31. Now the LED string is energized by the higher voltage supplied by the AC/DC converter 23.

Electronic ballasts usually are designed to supply an AC current of constant level required to energize a fluorescent lamp to produce a specified amount of light. The AC/DC-converter is configured to produce
a DC voltage which results in a current through the string of LEDs which corresponds with the light emission which is substantially equal to the light emission of a fluorescent lamp which is designed to be used in the luminaire. As explained with reference to Fig. 1 and Fig. 2 the operation voltage of an electronic ballast (This is the voltage at which the electronic ballast supplies electric power required for the LED lamp) is substantially lower than the operation voltage of a magnetic ballast. For that reason the output voltage at the DC outputs 33 and 34 of the AC converter is chosen higher than the DC voltage which can be delivered by the bridge rectifier 40 for the operation voltage supplied by the electronic ballast. When energized by the electronic ballast the voltage over the string of LEDs is substantially determined by the total forward voltage over the LED string 31. When the lamp is energized by an electronic ballast it is important that the string 31 of LEDs is only energized via the AC/DC converter 35 and not via the bridge rectifier. In practice this is achieved to configure the LED lamp such that the total forward voltage over the string of LEDs is at least 1.5 times the amplitude of the voltage over the AC inputs 45 and 46, in casu 1.5 times the amplitude of voltage supplied by the electronic ballast to the powerlines 38 and 39.

In that case the retrofit lamp 30 will be energized by the AC/DC converter 35 only.

In the embodiment of the retrofit lamp shown in Fig. 3 advantageous use is made of the differences in the operation frequency of the magnetic ballasts and those of electronic ballasts, such that depending on these properties the energizing of the string of LEDs is automatically done via the bridge rectifier 40 when a magnetic ballast is used or via the AC/DC converter 23 when an electronic ballast is used, whereby the AC/DC converter and rectifier 40 are preferably configured such that both the rectifier 40 and the AC/DC converter 23 provide currents with substantially the same current level to the string 31 of LEDs when they are energizing
the string. With this configuration it is achieved that string 31 of LEDs produce the same amount of light for both types of ballasts.

As state hereinbefore preferably voltage multipliers are used for the AC/DC converter, but in principle also other types of AC/DC converters can be used, as long as for the AC/DC converter 23 the ratio between the DC output and the amplitude of the AC voltage at its input is higher than the corresponding ratio for the rectifier 40.

Fig. 4 shows an embodiment of the retrofit lamp provided with an up converting AC/DC-converter with the above mentioned characteristics in the form of a trafo 55 and a bridge rectifier 57. AC inputs 51 and 52 of a primary winding of the trafo 55 are connected to the power lines 38 and 39 via a high pass filter in the form of a capacitor 56. The capacity of the capacitor 56 is chosen such that energy transport is blocked for AC frequencies below 60 Hz and enabled for frequencies above 20 kHz. A secondary winding of the trafo 55 is connected to the bridge rectifier 55 for rectifying the voltage available over the secondary winding of the trafo 55. The string 31 of LEDs is connected to DC outputs 53 and 54 of the rectifier 57.

The secondary windings of the trafo 55 are connected to a bridge rectifier 57. The DC voltage available on the outputs of the bridge rectifier 57 is supplied to the DC outputs 53 and 54.

Preferably the ratio between the primary and secondary windings of the trafo 55 has a value for which the rectifier 40 and the AC/DC converter 50 provide the same voltage to the string 31 of LEDs when they are energizing the string 31.

The rectifier 40 used in the embodiment shown in Fig. 4 comprises a diode bridge.

The trafo 55 can be provided with a control windings 58 with which the ratio between the voltage at secondary and the voltage at the primary winding can be controlled by changing the saturation of the kernel of the trafo 55, so as to control the current through the LED string 31.
Fig. 5 shows an embodiment of the retrofit lamp with an AC/DC-converter 60 of a preferred type. The AC/DC converter is a voltage multiplier preferably of a passive type, which only comprises passive components, such as capacitors and diodes. The voltage multiplier shown in Fig. 5 comprises as cascade circuit (chain) of a plurality of voltage doublers 61a, 61b, 61c and 61d. Each voltage doubler 61a, 61b, 61c and 61d comprises a diode 62 and 63 which are connected in series. A capacitor 64 is connected in parallel over the series connection of diodes 62 and 63. A junction 65 between the two diodes 63 and 64 is connected to the powerline 39 via a capacitor 66. The power line 38 is connected to a junction 67 between the diode 63 of voltage doubler 61b and diode 62 of voltage doubler 61c. The capacitor 64 of the voltage doublers 61a, 61b, 61c and 61d are connected in series between the DC outputs 68 and 69. The voltage multiplier is of a usual type whereby each of the capacitor is loaded to voltage which is equal to two times the amplitude of the AC voltage at the input of the voltage multiplier 60. The DC voltage between the DC outputs 68 and 69 is the sum of the voltages over the capacitors 64 of the voltage doublers 61a, 61b, 61c and 61d.

The capacities of the capacitors 66 act as the high pass filter and are dimensioned such that energy transport to the multiplier 60 is substantially blocked for the frequencies of the AC-voltage provided by magnetic ballast. For the high frequencies (above 20 kHz) the impedance of the capacitors 66 is sufficient low to power the string of LEDs to emit the required amount of light.

In the embodiment of Fig. 5 four voltage doublers are connected in cascade. At will be clear for the skilled man that the number of voltage doublers which are connected in cascade is a design feature. Depending the required operation voltage for the LED string 31 more or less voltage doublers can be connected in cascade.
Fig. 6a shows another embodiment of the retrofit lamp 30 according to the invention. In this embodiment the AC/DC converter and high filter are embedded in voltage multiplier comprising chain 108 of voltage doublers 61 and 61' (with total multiplication factor equal to 6). The capacitors 66 of the multipliers 61 are connected to the power lines 38 and 39 and act as high pass filter which blocks low frequency AC currents to the voltage multipliers 61. In case the power lines 38 and 39 are connected to a magnet ballast the retrofit lamp is supplied with a low frequency AC current. The current path to the voltage multipliers 61 is then blocked by the capacitors 66. The diodes 100 and 101 together with the diodes 102, 103, 62 and 68 of the chain 108 forms a diode bridge rectifier which takes care for the rectification when a low frequency AC voltage from a magnet ballast is received via the power lines 38 and 39. The DC voltage at the outputs of this diode bridge is supplied to the LED string 31 via the supply lines 70 and 71.

In case the retrofit lamp 30 is connected to an electronic ballast the lamp 30 is fed with an high frequency AC voltage which converted into a high voltage DC voltage by the voltage multiplier, due to the fact that now the current paths through the diodes 66 are not blocked for these high frequencies.

Note that voltage multiplier comprising long chains of voltage doublers will have a higher output impedance, which as such is favorable for supplying current through the LEDs. However the voltage drop over the output impedance will be higher which has to be taken into account in the design of the lamp 30.

Fig. 6b shows another embodiment of the retrofit lamp in which all components for the low frequency rectification are integrated in a voltage multiplier consisting of a chain 120 of voltage doublers 61 and a middle stage 61". The middle stage 61" comprises a standard Graetz diode bridge rectifier, formed by the diodes 102, 103, 111 and 112, which takes care for the rectification of the low frequency AC current in case the lamp
30 is connected to a magnet ballast. The rectified DC voltage at the outputs of the bridge is then supplied to the LED string 31 via the diodes of inactive voltage multipliers 61 and the supply lines 70 and 71. The coupling capacitors 66 of the voltage multipliers 61 determine a cross over frequency which is chosen well above 50 Hz and well below the operation frequency of an electronic ballast which is typical between 4.5 and 70 kHz. So in case the retrofit lamp 30 is connected to an electronic ballast the voltage multipliers become active, which result in a supply of a high level DC voltage over the LED string 31.

The embodiment shown in Fig 6b has the additional advantage that small currents of the electronic ballasts cannot load the coupling capacitors 66 to an undefined voltage level. This is in particular beneficial when the lamp is energized by a type of electronic ballast which contains supervisor circuitry monitoring the DC level on its output for EOL (End Of Life)-detection. A detection of a high DC voltage would then lead to a false triggering of the EOL-detection.

Often there exists a need to control the current through the LEDs of the lamp. An exemplary embodiment in which the current through the LED string 31 can be controlled is depicted in Figure 7. In this embodiment, the string 31 of LEDs is divided into two groups 82 and 83. A switch 81 is connected parallel to group 83 to bypass the group 83 when the switch 81 is closed. By periodically opening and closing the switch 81 the current through the string can be controlled. This is done by a control circuit 80 which senses current flowing through the LEDs and controls switch 81 on the basis of this current. In this embodiment, control circuit 80 senses current flowing through group 82 by sensing the voltage across impedance 84 through which the LED current flows.

Fig. 8 shows an embodiment of the retrofit LED lamp in which the string of LEDs is divided in eight subgroups of 90, ..., 97 of LEDs, each comprising a number of serial arranged LEDs. With a line regulation circuit 100 one
or more of the subgroups 90, ..., 97 can be bypassed by means of a switches (not shown) integrated in the line regulation circuit 100 for bypassing one or more of the subgroups 90, ..., 97. These switches are controlled in dependence on the current through the string of LEDs. The line regulation circuit control 100 changes the number of bypassed LEDs in dependence on the current through impedance 84, so as to keep the current within its operation range, having an upper threshold value and a lower threshold value. In case the current reaches a value below the lower threshold the number of bypassed LEDs is decreased. In case the current reaches a value above the upper threshold value the number of bypassed LEDs is decreased. In this way the current is kept within its operation range over a broad range of supply voltages, which even enables to connect the power lines 38 and 39 directly to the mains, without using a ballast circuit.

In an interesting alternative solution for the control of the current through the LED string 31 makes use of a voltage multiplier with at least three taps with different output voltages. In case the voltage multiplier is realized as a chain of voltage doublers, such as for example is shown in Fig. 5 one tap Vn is the positive output of the voltage doubler N on the upper side of the chain of voltage doublers forming the voltage multiplier. At least one tap corresponds with the intersection between two successive voltage doublers in the chain, e.g. Vn-1 which is the intersection between the voltage doubler N and the voltage doubler N-1 directly below voltage doubler N. One tap Vo is connected to the negative output of the voltage doubler on the low side of the chain. Depending on the current through the LED string 31, the LED string 31 is connected between V0 and VN or between Vo and Vn-1. Since the voltage on tap Vn-1 is lower than the voltage on tap Vn a change of the connection form VN to VN-1 results in a decrease of the current through the LED string 31. So by switching the connection of the LED string 31 between Vn and VN-1 in dependence on the current through the LED string the current through the
LED string 31 can be controlled. Fig. 9 shows a modification of the embodiment of Fig. 5 in which the current control is controlled, using such voltage multiplier with three taps. The taps Vn, VN-1 and V0 correspond with outputs 68a, 68b and 69 of the voltage doublers in circuit 35. A switch 133 is placed between the tap VN-1 and the supply line 70 of the LED string 31. The tap VN-1 is connected to the supply line 70 via a diode 134. When the switch is open the LED string 31 is energized via tap VN-1. When the switch 133 is closed, then the LED string 31 is energized via tap VN-1. A current sensor 130 senses the current through the LED string 31. The sensor 130 is connected to a controller 131 which controls the opening and closing of the switch 133 in dependence on the sensed current through the LED string.

In Fig 9 the switch 133 is placed at the high voltage side. It will be clear for the skilled person that alternatively the switch can also be placed at low voltage side.

The embodiment shown in Fig. 9 has three taps with different voltages between which the LED string 31 can be connected in a controlled manner. However it is to be noted that the number of taps with different voltages is not limited to three. Voltage multipliers with current control using more than three taps and whereby the LED string is connected between different pairs of taps in a controlled manner are possible.

As already stated hereinbefore certain types of electronic ballast comprises an End Of Life (EOL) detection circuit for detecting that a fluorescent lamp has reaches its end of life. Such EOL detection circuit detects the DC offset between the AC power lines. In case this offset voltage exceeds a predetermined EOL threshold value this is an indication that the end of life of the lamp is reached and the electronic ballast is switched off.
To prevent that the electronic ballast is switched off when it is connected
to a retrofit LED lamp, it is crucial that the retrofit LED lamp is designed
such that the DC offset voltage remains below the EOL threshold value.
Several configurations of AC/DC converters with low DC offset between
its powerlines are possible.

Fig 10 shows an embodiment of a retrofit lamp with low DC offset which
achieves the low DC offset with low costs in a similar way as in the
embodiment shown in Fig. 6b. The voltage multiplier shown in Fig. 9 has
a symmetrical structure and has 5 stages $61d, 61e, 61f, 61g$. AC
inputs 116 and 117 of a bridge rectifier, comprising diodes 112, 113, 114
and 115, are connected to the AC power lines 38 and 39. A capacitor 118
is connected between DC outputs 119 and 120. The bridge rectifier
provides a positive DC voltage between DC output 120 and DC output
119.

The voltage multiplier 110 comprise four voltage doubles $61d, ..., 61g$, of
the same type as shown in Fig. 5 and described with reference to
reference numbers $61a, ..., 61c$.

The voltage doubiers $61d$ and $61e$ are connected in cascade to the
positive output 120 of the bridge rectifier. The voltage doubiers $61f$ and
$61g$ are connected in cascade to the negative output 119 of the bridge
rectifier 111. The capacitors 66 of voltage doubler $61d$ and $61f$ are
connected to AC powerline 39. The capacitors 66 of voltage doubiers $61e$
and $61g$ are connected to power line 38. The capacitors 64 of the voltage
doubles $61d, ..., 61g$ are connected in series with capacitor 118. This
series connection of capacitors is loaded to a DC voltage which is a
multiple of the amplitude of the AC voltage received on the power lines 38
and 39. This DC voltage is used to power the string of 31 of LEDs. The
use of the bridge rectifier in stage 61" results in a very low DC offset
voltage between the powerlines 38 and 39.

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 and 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 processor or controller or other unit can fulfil 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 symbol in the claims should not be construed as limiting the scope.
Claims

1. Retrofit LED lamp for replacing a fluorescent lamp in a luminaire provided with a magnetic ballast circuit or with an electronic ballast circuit for supplying an AC supply voltage to the retrofit lamp, which retrofit LED lamp comprises
   • power lines for receiving the AC supply voltage from the luminaire,
   • a rectifier having a DC output side and having an AC input side coupled to the power lines,
   • an AC/DC converter having a DC output side and having an input side coupled to the power lines via a filter with a high pass frequency characteristic for blocking AC currents below a first frequency value and letting pass AC currents above a second frequency value, and
   • a string of serial arranged LEDs which is coupled the DC output sides of the rectifier and the AC/DC converter to be energized with a DC current by either the rectifier or the AC/DC converter which has the highest DC output voltage level.

2. Retrofit LED lamp as claimed in claim 1, whereby the AC/DC converter comprises a voltage multiplier, preferably comprising only passive components, such as capacitors and diodes..

3. Retrofit lamp as claimed in claim 1 or 2, whereby the first frequency value is 100 Hz and the second frequency value is 20 kHz.

4. Retrofit lamp as claimed in any of the preceding claims whereby the ratio between the amplitude of the second DC voltage and the amplitude of the AC-voltage is within the range between 2 and 6.
5. Retrofit LED lamp as claimed in any of the 2 to 4, wherein the rectifier and the AC/DC converter comprise at least partly the same components.

6. Retrofit LED lamp as claimed in claim 5, wherein the rectifier is fully integrated in the AC/DC converter.

7. Retrofit LED lamp as claimed in any of the preceding claims, comprising a current control subsystem for controlling the current supplied by the rectifier to the string of LEDs, which control subsystem comprises a switch for by passing in response to a control signal at least a part of the string of LEDs and a control circuit for periodically providing the control signal in dependence on the current supplied.

8. Retrofit LED lamp as claimed in claim 7, whereby the control subsystem is arranged to shortcut a variable number of LEDs, which variable number is dependent on the voltage over the string of LEDs and/or the current through the string of LEDs, so as to maintain the current through the string of LEDs within an operation range.

9. Retrofit LED lamp as claimed in any of the preceding claims, whereby the retrofit LED lamp is arranged to maintain the a DC voltage component in the AC voltage between the power lines substantially equal to zero.

10. Retrofit LED lamp as claimed in any one of the claims 2 to 6, whereby the AC/DC converter comprises a plurality of taps with different output voltages, and whereby the lamp comprises a controller including switch circuitry for connecting the string of
LEDs between two of the plurality of taps in dependence on the current through the string of LEDs.

11. Retrofit LED lamp as claimed in any of the preceding claims, whereby the LED lamp is a tube lamp.
### A. CLASSIFICATION OF SUBJECT MATTER
**INV.** H05B33/08

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.

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Date of the actual completion of the international search
8 February 2017

Date of mailing of the international search report
15/02/2017

Name and mailing address of the ISA:
European Patent Office, P.B. 5818 Patentlaan 2
NL-2280 HJ Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer
Henderson, Richard
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