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(54) **Title**: LED-BASED LIGHTING SYSTEM WITH HIGH POWER FACTOR

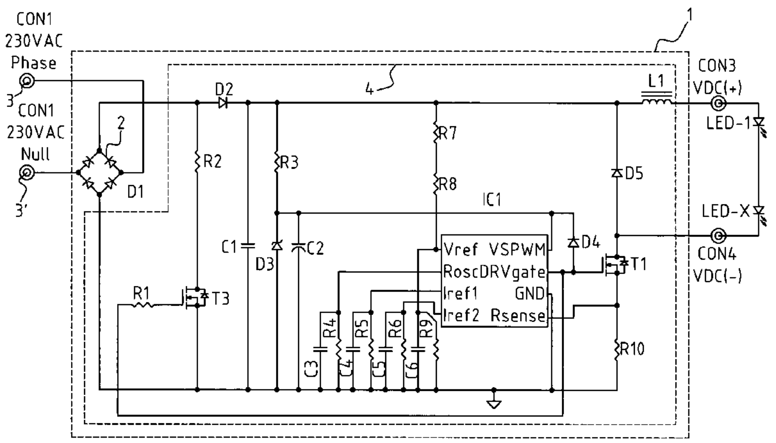

FIG. 2

(57) **Abstract**: The present invention relates to a light-emitting diode (LED) lighting system, and more in particular, to a LED lighting system for domestic use. According to the present invention a LED lighting system is provided that demonstrates a high power factor, low harmonic distortion and high power efficiency. It comprises a light-emitting diode (LED) and a LED driver to electrically drive said LED, wherein said LED driver comprises: - a rectifier having an input and an output, wherein said rectifier is arranged to convert an alternating electrical supply signal provided at its input into a rectified electrical supply signal emerging at its output, wherein said output is connected to said LED; - a switching element electrically connected to said LED and to the output of said rectifier, wherein said switching element is arranged to cause an alternating current through said LED, said alternating LED current having a switching frequency substantially larger than a frequency of said alternating rectified electrical supply signal. The lighting system of the present invention is characterized in that at least one of an average and a maximum of said alternating LED current is set proportional to an instantaneous voltage value of said rectified alternating electrical supply signal. The present invention further provides an electrical driver for use in such a lighting system and a method to electrically drive a LED.

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LED-based lighting system with high power factor

The present invention relates to a light-emitting diode (LED) lighting system, and more in particular, to a LED lighting system for domestic use.

Recently, LED-based lighting solutions have emerged on the market that can compete with the traditional incandescent or fluorescent lighting. LED-based lighting is more energy efficient and has a longer service life than traditional lighting products.

LED-based lighting typically comprises a plurality of LEDs controlled by a LED driver. Especially for domestic lighting solutions, the LED driver can normally be connected to the mains, e.g. 110V or 230V, of the home electricity network.

A typical circuit configuration of a known LED-based lighting device is schematically illustrated in figure 1A. The device comprises a LED driver 1 driving a plurality of LEDs, LED-1..LED-X. The driver comprises a rectifier 2 which performs a full-wave rectification on an alternating electrical supply signal at its input terminals 3, 3', e.g 230V @ 50Hz. The rectified signal is fed to LED-1..LED-X through switching element 4, which causes an alternating current through LED-1..LED-X. The frequency of the alternating LED current, i.e. the switching frequency, is substantially higher than the frequency of the rectified alternating electrical supply signal.

The switched-mode operation of the LEDs improves the power efficiency compared to the situation in which the LEDs are connected to the rectified signal directly albeit using a resistor connected in series to limit the current.

A problem with these known LED-based lighting devices, or LED drivers, is the low power factor and high harmonic distortion that is commonly associated with highly non-linear devices.

Low power factors indicate that a significant amount of the power delivered to the LED lighting system is reactive. Reactive power presents a challenge for the energy suppliers in that it does not contribute to the power dissipated/used by the consumer but it does increase the load on the electricity network, due to high currents and/or voltages which can occur in them.

Harmonic distortion introduces unwanted high frequency components in the network. These signals could interfere with other components connected to the network.

Typical I-V characteristics of a known LED-based lighting device are illustrated in figure 1B. As shown, the current is only drawn when the applied voltage is high. In addition, the waveform is non-sinusoidal and out of phase compared to the applied voltage. As a result of these factors, the power factor is low and the harmonic distortion is high.

Surprisingly, to the applicant's knowledge, there are no LED-based lighting systems available today for the consumer market that exhibit a high power factor (ideally very close to 1) and a low harmonic distortion.

It is therefore an object of the present invention, to provide a LED-based lighting system with a high power factor, low harmonic distortion and a high power efficiency. It is a further object of the present invention, that the lighting system according to the present invention has very few components and can be fabricated at low cost.

According to the invention, these goals are at least partly achieved with a LED lighting system according to claim 1, in which at least one of an average and a maximum of the alternating current through the LED is set proportional to an instantaneous voltage value of the rectified alternating electrical supply signal.

Alternating current in the context of the present application should be construed as current that is time-varying. It should not be interpreted as excluding a time-varying current that is continuously positive.

It should further be noted that due to the periodic nature of the current through the LED(s), the average and maximum of this current are related. It is therefore possible to set the current through the LED using the maximum and/or average value of this current.

By choosing the current through the LED proportional to the instantaneous voltage of the rectified alternating electrical supply signal, a resistive loading of the mains network is thereby achieved.

In a preferred embodiment of the present invention, the switching element comprises a transistor that under working conditions has an "on" and "off" state. The transistor is electrically connected to the LED. The switching element further comprises an electromagnetic energy storage device for storing electromagnetic energy, and a transistor driver arranged to switch said transistor between the "on" and "off" states with the aforementioned switching frequency. Under working conditions, said electromagnetic energy storage device stores energy in the "on" state and releases energy in the "off" state thereby supplying electrical power to said LED.

Although capacitive elements could be used, it is advantageous if the electromagnetic energy storage device is an inductance. In a preferred embodiment, this inductance is connected in series with the LED. This series connection has a first node closest to the anode of the LED and a second node closest to the cathode of the LED. The LED driver further comprises a fly-back diode placed parallel to said series connection, wherein the cathode of the fly-back diode is connected to the first node and its anode to the second node. In addition, the second node is connected to said transistor.

To enhance the efficiency of the LED driver, and hence the LED lighting system, in the "off" state, which is predominantly determined by the on-voltage of the fly-back diode, the fly-back diode can be replaced by a second transistor. This transistor is controllable by said transistor driver through an inverter such that said first and said second transistor operate in opposite states. Hence, when the first transistor is in the "off" state, the current flows from the inductance through the LEDs and the second transistor, which in this case is in the "on" state.

It is advantageous if the transistor driver is capable of sensing the LED current and is arranged to switch the transistor into the "off" state if a predetermined current value is exceeded. According to the invention, this predetermined current value is set proportional to the instantaneous voltage value of the rectified alternating electrical supply signal. Sensing could for instance comprise monitoring the voltage drop over a resistor that is placed in the current path of the LEDs. Further or other advantages can be achieved if the transistor driver sets the predetermined current value in accordance with a resistive voltage division of the instantaneous voltage value of the rectified alternating electrical supply signal.

Dimming of LED-based lighting systems is difficult due to the relatively low powers that are needed by these systems. Usually, these powers are too low to enable appropriate dimming. This problem can be circumvented if the LED lighting system comprises a third transistor connected to the output of the rectifier. This transistor is placed in series with a resistive load and is controllable by the transistor driver, much like the first transistor. The third transistor and transistor driver are arranged to provide an internal resistive loading during the "on" state of said first transistor. If the duration of the "on" state is much shorter than the duration of the "off" state, the resistive loading will only occur during a limited amount of time. By choosing appropriate values for the resistor, appropriate dimming can therefore be realized with low energy loss.

The present invention also provides an electronic LED driver for use in a LED lighting system as discussed above.

In addition, the present invention also provides a method to electrically drive a LED comprising the steps of rectifying an alternating electrical supply signal, providing this rectified alternating electrical supply signal to the LED, controlling an alternating current through the LED with a frequency substantially larger than the frequency of said rectified alternating electrical supply signal. This method is characterized by setting at least one of the average and a maximum of said alternating LED current proportional to an instantaneous voltage value of said rectified alternating electrical supply signal.

Hereafter, embodiments of the present invention will be discussed in more detail under reference to the accompanied drawings, in which:

Figures 1A and 1B present a schematic illustration of a known LED lighting system, and typical I-V characteristics of such a system, respectively;

Figure 2 illustrates a preferred embodiment of the present invention;

Figure 3 illustrates the preferred embodiment from figure 2 adapted to improve the efficiency during the "off" state.

Figure 4 illustrates typical I-V characteristics obtained with a LED-based lighting system according to the present invention.

In figure 2 a preferred embodiment of the present invention is shown. According to this embodiment, the lighting system comprises a diode bridge-rectifier 2. The rectified signal is fed to inductance L1 which is connected in series to a plurality of LEDs (LED-1 ... LED-X). A fly-back diode D5 is placed in parallel to this series connection such that the corresponding diodes, e.g. LED-1 and D5, are anti-paralllel. At the cathode side of the LED-X, indicated by CON4, the series-parallel combination is connected to n-channel MOSFET T1. Resistor R10 is in series with T1 and is used during the "on" state of T1 to measure the current through LED-1, as will be discussed later.

The gate of T1 is driven by a transistor-driver IC1, e.g. the MLX10803 from Melexis or the HV9910 from Supertex. In the embodiment shown in figure 2, the MLX10803 is used and therefore only the relevant pin names of the MLX10803 are shown. Next, the operation of the lighting system will be discussed in detail.

As a starting condition it is assumed that T1 is open, e.g. low ohmic. A current will flow through L1, LED-1..LED-X, T1 and R10 to ground. Due to the nature of L1, this current will gradually increase thereby storing magnetic energy in the inductance. The current through LED-1 is sensed using the voltage over R10. This voltage is fed to the Rsense pin of IC1. Once the current has exceeded a certain predetermined limit, which is adjustable using a voltage applied to the Vref pin, the transistor driver switches off

T1. Consequently, the inductance will start to release its magnetic energy using a current that will flow through LED-1..LED-x, D5 back to L1.

The maximum current as well as the time that T1 is put in the "off" state can be adjusted using components external to IC1 and/or the voltage applied to pin Vref.

In this embodiment, the Vref pin is connected to resistive divider composed of R7, R8 and R9. Consequently, the maximum current through LED-1 is set proportional to the instantaneous value of the rectified alternating electrical supply signal. As a result, the current drawn by the lighting system is proportional to the instantaneous voltage applied to that system, leading to the desired high power factor and low harmonic distortion. Capacitor C6 is included to short any high-frequency distortion that may be present.

In figure 2, Zener diode D3, capacitor C2 and resistor R3 provide a 12V supply voltage for IC1. The external components C4, R5 and C5, R6 connected to Iref1 and Iref2, respectively, can be adjusted to optimize the temperature behavior of the lighting system. With components C3, R4 the oscillation frequency of IC1 can be chosen. In addition, diode D4 is used to discharge the gate of T1. More details can be found in the application note of IC1 and a more detailed description is therefore deemed unnecessary.

In addition, the embodiment in figure 2 comprises a n-channel MOSFET T3 connected to the gate of T1 by resistor R1. T3 is connected to the rectified alternating electrical supply signal by resistor R2. The purpose of T3 and R2 is to provide ohmic loading of the rectifier such that the lighting system can be dimmed using conventional triac-based dimmers. These dimmers usually are activated very quickly but require a minimum amount of current to keep them activated. A problem with LED-based circuits is that the current that is drawn by the system is relatively low compared to for instance incandescent lighting. These systems are therefore difficult to dim especially in the low voltage region of the supply signal. T3 and R2 improve this behavior in that a ohmic load is presented which draws a current when T1 (and T3) is in the "on" state. In general, the duration of the "on" state is much shorter than the duration of the "off" state so that the energy that is lost through R2 is marginal. Due to the fact that the switching frequency of IC1 is much higher (e.g. 30kHz) than the rectified alternating electrical supply signal (e.g. 120Hz) and due to the fact that the triac-based dimmers activate quickly but extinguish much more slowly, the dimmer remains activated during a large portion of the cycle of the alternating electrical supply signal.

Diode D2 and capacitor C1 are incorporated to reduce the impact on harmonic distortion by the current pulses caused by R2 and T3.

In figure 3, a further development of the circuit from figure 2 is depicted. In this embodiment, the fly-back diode D5 is replaced by a n-channel MOSFET T2. The gate of T2 is connected to the gate of T1 by an invertor comprised of PNP transistor T5 and NPN transistor T4. A Zener diode D6 is used to limit the voltage drop over T5. The operation of T2 is opposite to T1, i.e. if T1 is in the "on" state, T2 is in the "off" state and vice versa. If T1 is in the "off" state, the current from L1 flows through T2 instead of the fly-back diode D5. The advantage of using the n-channel MOSFET is that is presents a low ohmic path and does not suffer from the on-voltage of the fly-back diode D5. Consequently, the losses during the "off" state of T1 can be reduced significantly.

With the embodiments shown in figures 2 and 3, a power factor can be achieved better than 0.95 combined with a total harmonic distortion better than 15%. Typical I-V characteristics of such a system are illustrated in figure 4. The total power efficiency is better than 85%. It is highly surprising that these figures can be obtained with this amount of components. The costs involved in fabrication and maintenance are therefore greatly reduced compared to more complex systems in which the power factor is improved by providing additional complex circuitry. To the applicant's knowledge, these circuits do not employ the same principle as is used in the present invention.

Finally, it should be noted that it is apparent for a skilled person in the art that various modifications and changes can be applied to the embodiments described in conjunction with the present invention without deviation from the scope of the invention as set forth in the appended claims.

Claims

1. LED lighting system comprising a light-emitting diode (LED) and a LED driver to electrically drive said LED, wherein said LED driver comprises:

a rectifier having an input and an output, wherein said rectifier is arranged to convert an alternating electrical supply signal provided at its input into a rectified electrical supply signal emerging at its output, wherein said output is connected to said LED;

a switching element electrically connected to said LED and to the output of said rectifier, wherein said switching element is arranged to cause an alternating current through said LED, said alternating LED current having a switching frequency substantially larger than a frequency of said alternating rectified electrical supply signal;

characterized in that

at least one of an average and a maximum of said alternating LED current is set proportional to an instantaneous voltage value of said rectified alternating electrical supply signal.

2. LED lighting system according to claim 1, wherein said switching element comprises:

a first transistor under working conditions having an "on" and "off" state, said transistor being electrically connected to said LED;

an electromagnetic energy storage device for storing electromagnetic energy;

a transistor driver arranged to switch said first transistor between said "on" and "off" states with said switching frequency;

wherein under working conditions, said electromagnetic energy storage device stores energy in the "on" state and releases energy in the "off" state thereby supplying electrical power to said LED.

3. LED lighting system according to claim 2, wherein said electromagnetic energy storage device is an inductance connected in series with said LED, said series connection having a first node closest to the anode of said LED and a second node closest to the cathode of said LED, said LED driver further comprising a fly-back diode placed parallel to said series connection, said fly-back diode having its cathode connected to said first node and its anode connected to said second node, and wherein said second node is connected to said first transistor.

4. LED lighting system according to claim 2, wherein said electromagnetic energy storage device is an inductance connected in series with said LED, said series connection having a first node closest to the anode of said LED and a second node closest to the cathode of said LED, said LED driver further comprising a second transistor placed parallel to said series connection, wherein said second transistor is controllable by said transistor driver through an inverter such that said first and said second transistor operate in opposite states, and wherein said second node is connected to said first transistor.

5. LED lighting system according to any of the claims 2-4, wherein said transistor driver is capable of sensing said LED current and is arranged to switch said first transistor into said "off" state if a predetermined current value is exceeded, wherein said predetermined current value is set proportional to said instantaneous voltage value of said rectified alternating electrical supply signal.

6. LED lighting system according to claim 5, wherein said transistor driver sets said predetermined current value in accordance with a resistive voltage division of said instantaneous voltage value of said rectified alternating electrical supply signal.

7. LED lighting system according to any of the claims 2-6, further comprising a third transistor connected to the output of said rectifier, said third transistor placed in series with a resistive load and being controllable by said transistor driver, wherein said third transistor and said transistor driver are arranged to provide an internal resistive loading during the "on" state of said first transistor.

8. An electronic LED driver for use in a lighting system as defined in any of the claims 1-7.

9. A method to electrically drive a LED comprising the steps of:

rectifying an alternating electrical supply signal;

providing said rectified alternating electrical supply signal to said LED;

controlling an alternating current through said LED with a frequency substantially larger than the frequency of said rectified alternating electrical supply signal; **characterized by** setting at least one of the average and a maximum of said alternating LED current proportional to an instantaneous voltage value of said rectified alternating electrical supply signal.

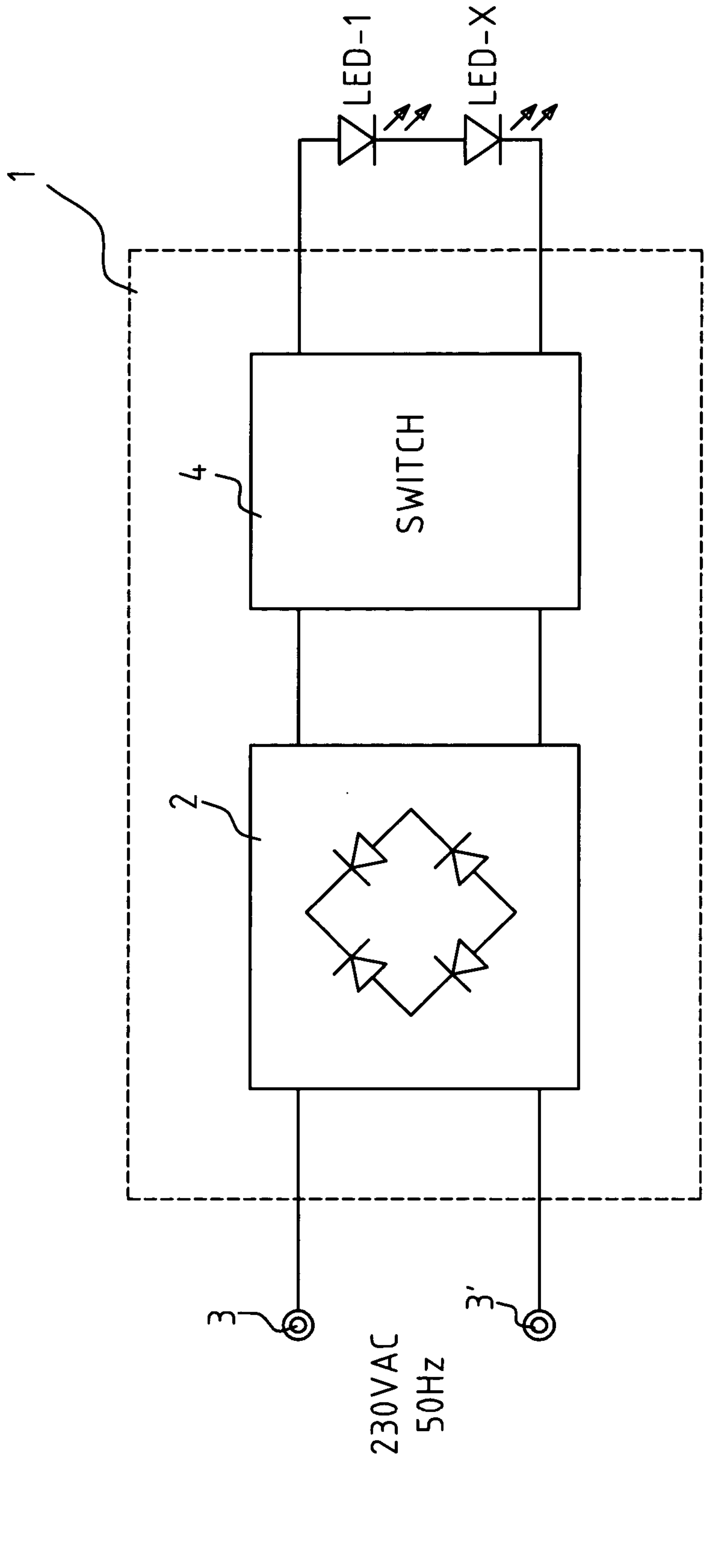


FIG. 1A

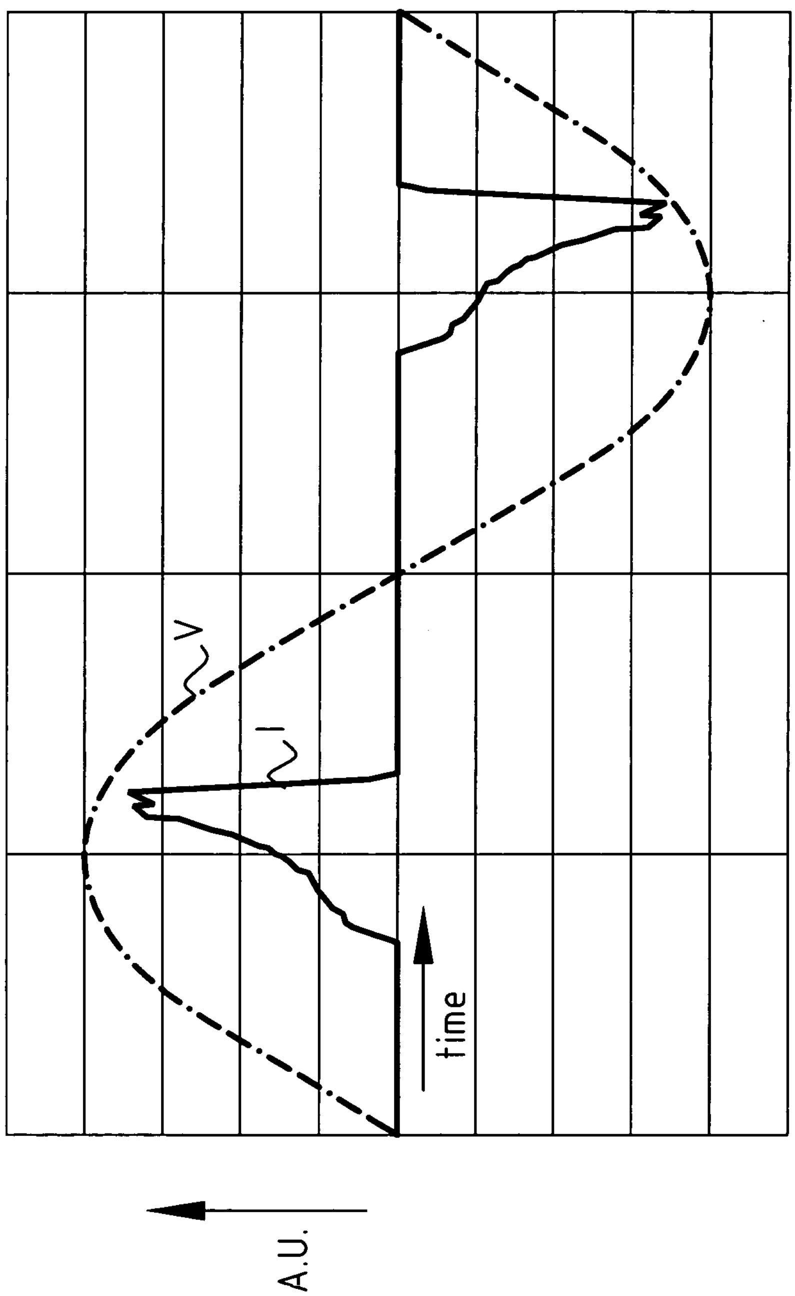
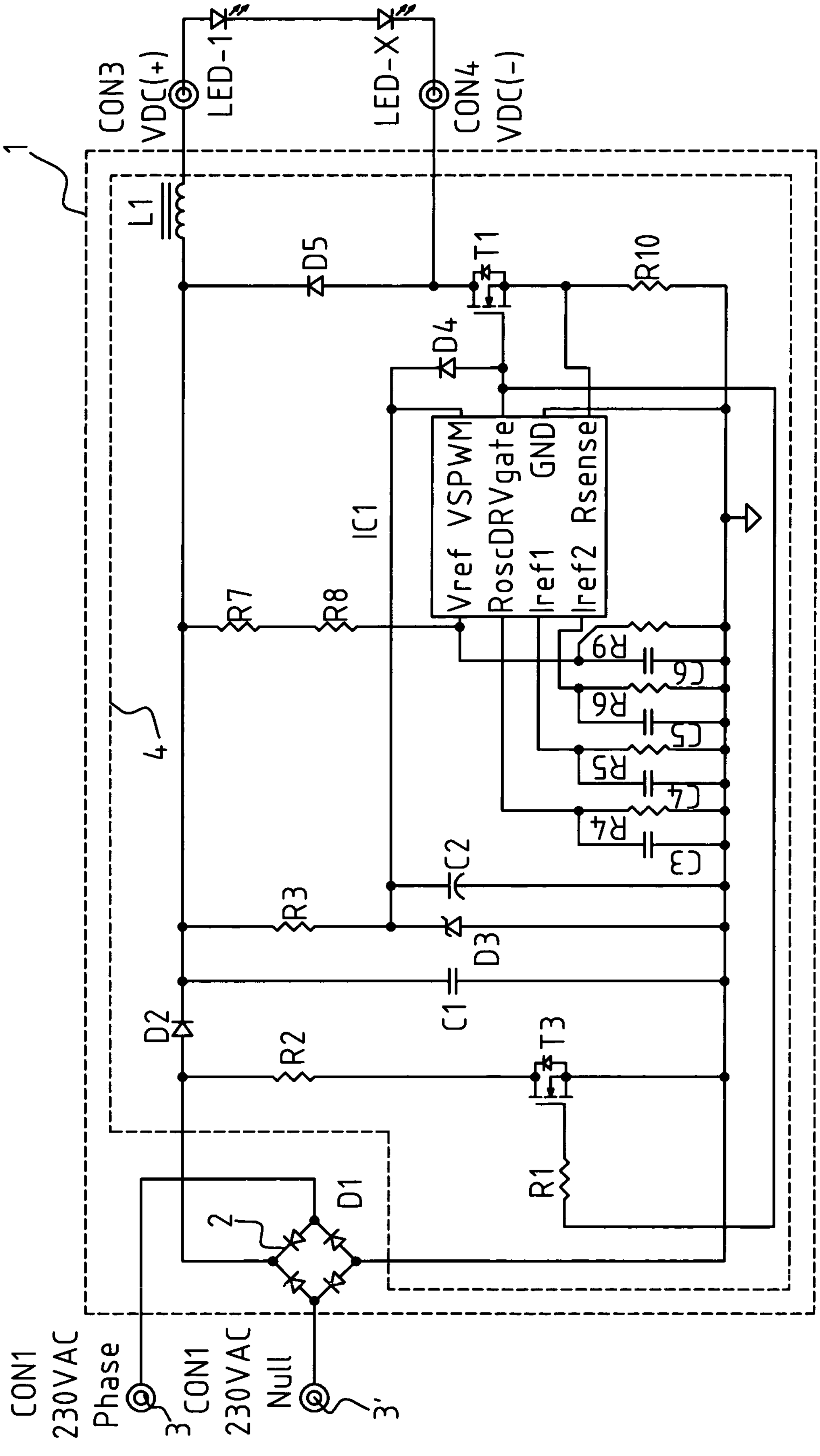


FIG. 1B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2
3
3'
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Phase
CON1
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CON4
VDC(-)
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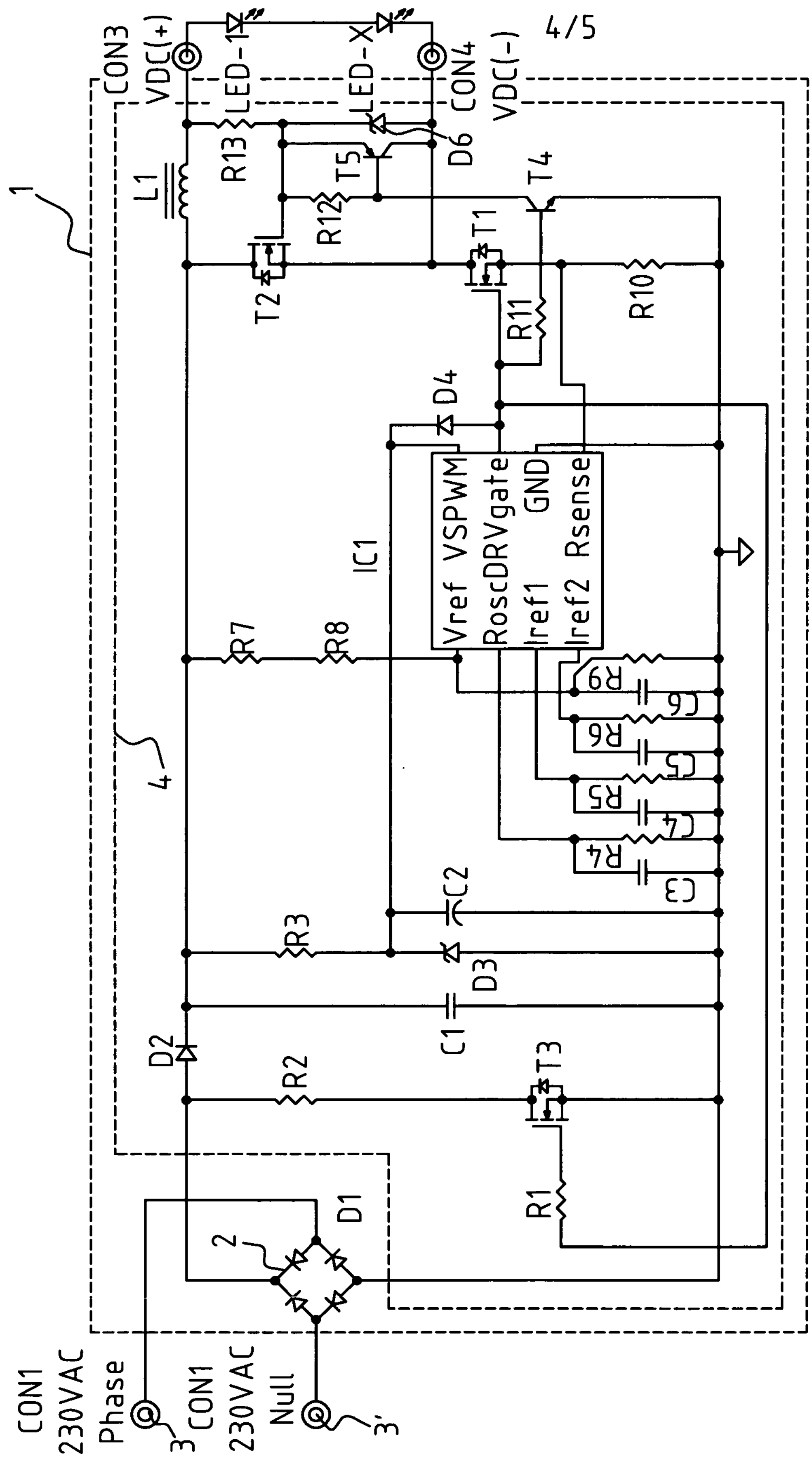
LED-X
L1
D1
D2
D3
D4
D5
T1
T3
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
C1
C2
C3
C4
C5
C6
IC1
Vref
VSPWM
RoscDRVgate
GND
Iref1
Iref2
Rsense

FIG. 2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LED-1
LED-X
CON4
VDC(-)
D6
R13
T5
L1
R12
T4
T2
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R10
D4
IC1
Vref
VSPWM
RoscDRVgate
GND
Iref1
Iref2
Rsense
R7
R8
R9
C6
R6
C5
R5
C4
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C3
C2
R3
D3
C1
D2
R2
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Phase
CON1
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FIG. 3

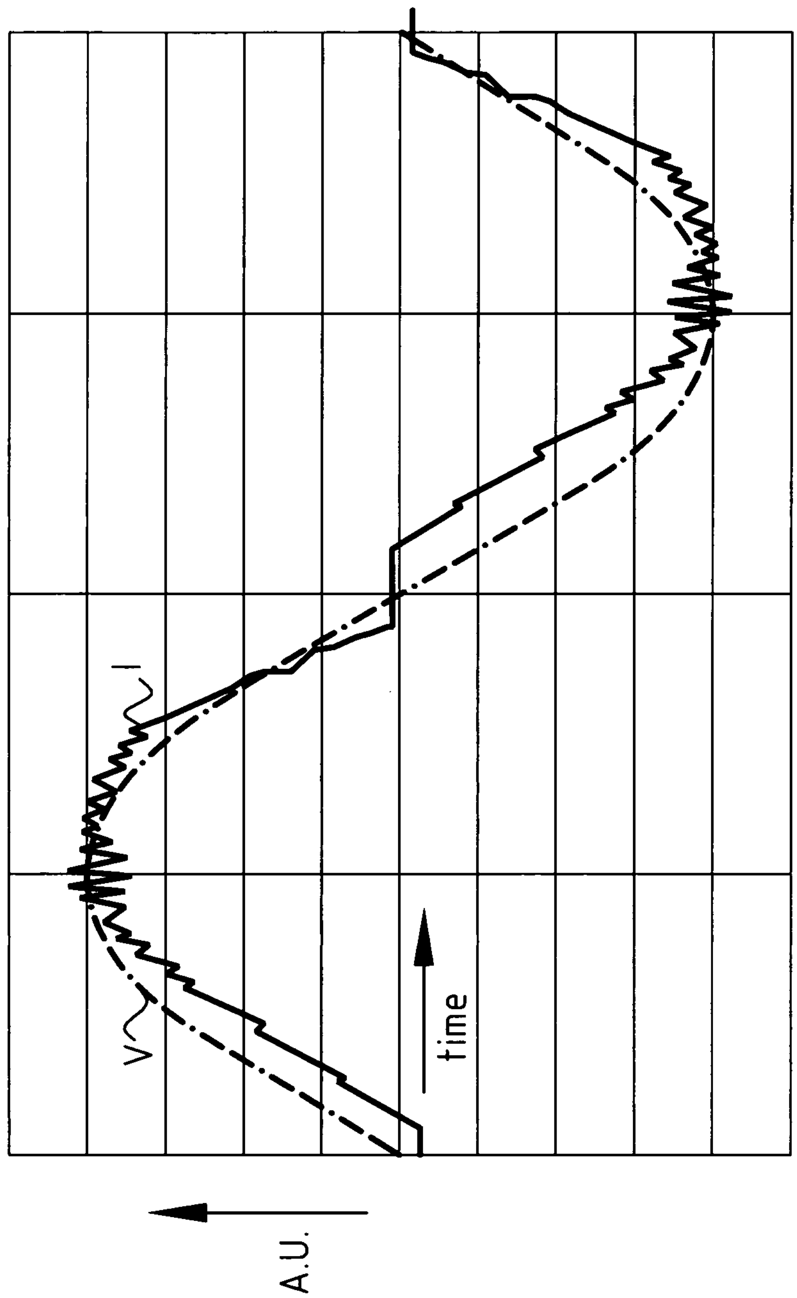

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/003842

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/042908 A1 (ST-GERMAIN NICOLAS [CA]) 6 March 2003 (2003-03-06) page 4; figure 1	1-9
X	US 2007/108916 A1 (WANG JI [CN] ET AL) 17 May 2007 (2007-05-17) pages 3-4; figure 5	1-9
X	US 2007/152604 A1 (TATSUMI NAOKI [JP]) 5 July 2007 (2007-07-05) page 5; figure 5	1-9

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 October 2008	29/10/2008

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2008/003842

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