



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
07.12.2022 Bulletin 2022/49

(51) International Patent Classification (IPC):
H05B 45/20 ^(2020.01) **H05B 45/325** ^(2020.01)
H05B 45/34 ^(2020.01)

(21) Application number: **21177665.3**

(52) Cooperative Patent Classification (CPC):
H05B 45/20; H05B 45/325; H05B 45/34

(22) Date of filing: **04.06.2021**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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(54) **TUNABLE WHITE LED MODULE**

(57) Disclosed is a LED module (4), comprising input terminals (41) connectable to an LED driver (3); a plurality of LED lighting means (42, 43) having different color temperatures; an auxiliary load (44A, 44B, 44C) connected between the input terminals (41) and the plurality of LED lighting means (42, 43); and one or more first switches

(45A; 45B, 45C) configured to select, in dependence of one or more first PWM control signals (46A; 46B, 46C), one of the plurality of LED lighting means (42, 43) for feeding by the LED driver (3). This provides a smaller and less expensive tunable white LED module.

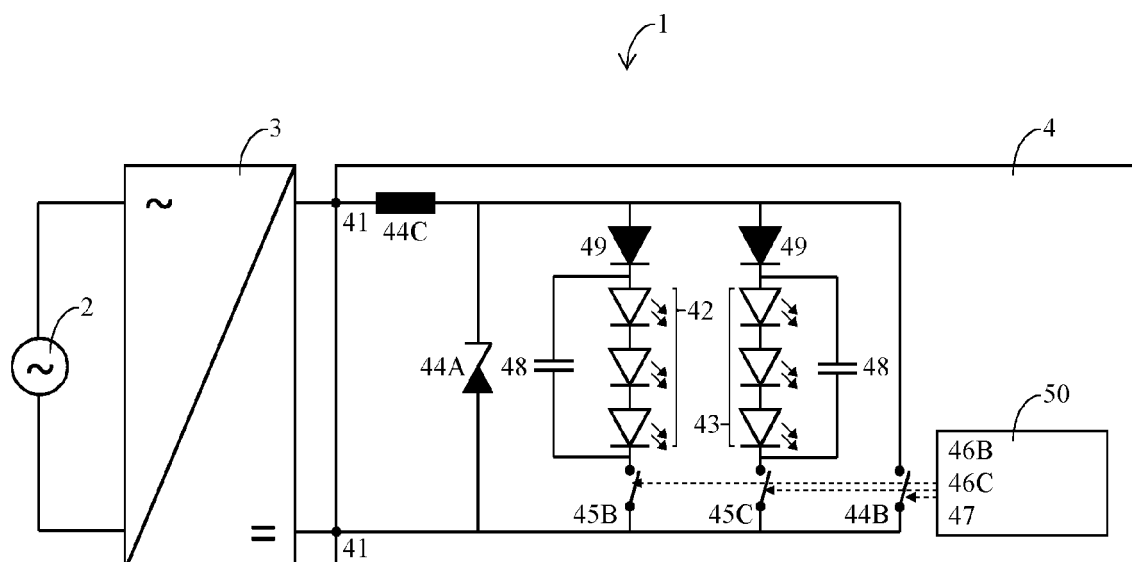


FIG. 6

Description

Technical Field

[0001] The present disclosure relates to lighting technology, and in particular to a tunable white LED module and a luminaire comprising the same.

Background Art

[0002] Tunable white describes a variable color temperature from warm white to cool white light, by mixing light from warm white and cool white LEDs.

[0003] Artificial light having an adequate color temperature and illuminance can promote human well-being in areas such as offices and educational institutions, as well as hospitals and care homes.

[0004] However, known tunable white illumination based on two-channel LED drivers for respective color temperatures is expensive in terms of both size and cost.

Summary

[0005] The object of the present disclosure is to provide a smaller and less expensive tunable white LED module and a corresponding luminaire comprising the same.

[0006] The invention is defined by the appended independent claims. Preferred embodiments are set forth in the dependent claims and in the following description and drawings.

[0007] A first aspect of the present disclosure relates to an LED module. The LED module comprises input terminals connectable to an LED driver; a plurality of LED lighting means having different color temperatures; an auxiliary load connected between the input terminals and the plurality of LED lighting means; and one or more first switches configured to select, in dependence of one or more first PWM control signals, one of the plurality of LED lighting means for feeding by the LED driver.

[0008] The auxiliary load may comprise a Zener diode connected in parallel to the plurality of LED lighting means.

[0009] The auxiliary load may comprise a second switch connected in parallel to the plurality of LED lighting means and configured to shunt, in dependence of a second control signal, the plurality of LED lighting means.

[0010] The auxiliary load may comprise an inductor connected in series between the input terminals and the plurality of LED lighting means.

[0011] A respective switching frequency of the one or more first PWM control signals may comprise an integer multiple of a minimum switching frequency.

[0012] The LED module may further comprise a respective capacitor connected in parallel to each of the plurality of LED lighting means and having a same capacitance that depends on the minimum switching frequency.

[0013] The LED module may further comprise a re-

spective diode connected in series with each of the plurality of LED lighting means.

[0014] A respective duty cycle of the one or more first PWM control signals may depend on the respective switching frequency of the one or more first PWM control signals and on a proportion of the feeding of the plurality of LED lighting means relative to one another.

[0015] The plurality of LED lighting means may respectively comprise an LED string.

[0016] The plurality of LED lighting means may comprise first LED lighting means having a color temperature greater than or equal to 5.000 K; and second LED lighting means having a color temperature greater than or equal to 2.700 K and less than or equal to 3.000 K.

[0017] A second aspect of the present disclosure relates to a luminaire. The luminaire comprises an LED module according to the first aspect or any of its implementations; and an LED driver connected to input terminals of the LED module and configured to feed the LED module off a mains grid.

[0018] The LED driver may be configured to feed a constant current.

Advantageous Effects

[0019] The present disclosure provides tunable white illumination having high color consistency, i.e., a broad dimming range without a change of color temperature.

[0020] A ratio of cold white to warm white illumination is maintained with high accuracy without any A/D converters or feedback regulation loops.

[0021] A structural setup of the tunable white illumination is simplified and miniaturized, a number of components is small, and cost is reduced.

Brief Description of Drawings

[0022] The above-described aspects and implementations will now be explained with reference to the accompanying drawings, in which the same or similar reference numerals designate the same or similar elements.

[0023] The features of these aspects and implementations may be combined with each other unless specifically stated otherwise.

[0024] The drawings are to be regarded as being schematic representations, and elements illustrated in the drawings are not necessarily shown to scale. Rather, the various elements are represented such that their function and general purpose become apparent to those skilled in the art.

FIGs. 1 - 3 respectively illustrate a luminaire 1 comprising an LED module 4 in accordance with the present disclosure;

FIG. 4 illustrates time-dependent feed currents of the LED module 4 of FIG. 3;

- FIGs. 5 - 6 respectively illustrate a luminaire 1 comprising an LED module 4 in accordance with the present disclosure;
- FIG. 7 illustrates a multi-pulse feed of the LED module 4 of FIG. 6; and
- FIG. 8 illustrates a ripple of the branch current of the first LED lighting means 42 of FIG. 6 for capacitors 48 of different capacitance.

Detailed Descriptions of Drawings

[0025] FIG. 1 illustrates a luminaire 1 comprising an LED module 4 in accordance with the present disclosure.

[0026] The LED module 4 comprises input terminals 41 which are generally connectable to an LED driver 3. In accordance with FIG. 1, the LED driver 3 is connected to the input terminals 41 of the LED module 4 and configured to feed the LED module 4 off a mains grid 2.

[0027] In particular, the LED driver 3 may be configured to feed a constant current (CC).

[0028] The LED module 4 further comprises a plurality of LED lighting means 42, 43 having different color temperatures.

[0029] In particular, the plurality of LED lighting means 42, 43 may respectively comprise an LED string. In accordance with FIG. 1, the plurality of LED lighting means 42, 43 may comprise first LED lighting means 42 having a color temperature greater than or equal to 5.000 K ("cool white") and second LED lighting means 43 having a color temperature greater than or equal to 2.700 K and less than or equal to 3.000 K ("warm white").

[0030] The LED module 4 generally comprises one or more first switches 45A; 45B, 45C configured to select, in dependence of one or more first PWM control signals 46A; 46B, 46C, one of the plurality of LED lighting means 42, 43 for feeding by the LED driver 3. The one or more first PWM control signals 46A; 46B, 46C may be provided by a control unit 50 such as a microcontroller. A 16-bit resolution of the one or more first PWM control signals 46A; 46B, 46C may attain an accuracy sufficient for state-of-art color consistency.

[0031] In accordance with FIG. 1, the LED module 4 comprises a single first switch 45A configured to select, in dependence of a single first PWM control signal 46A, one of the plurality of LED lighting means 42, 43 for feeding by the LED driver 3. In other words, the first switch 45A is configured to toggle between the two branches of the first LED lighting means 42 and the second LED lighting means 43. As such, a PWM duty cycle of the first PWM control signal 46A determines a ratio of cool white and warm white illumination by the plurality of LED lighting means 42, 43.

[0032] Each of the two branches has one PWM pulse per switching period $T = 1/f$. Conclusively, the switching frequency f is the same for all branches, and the PWM duty cycles of the branches add up to 1.

[0033] In connection with the single first switch 45A, a single-channel CC LED driver 3 may suffice to drive the plurality of LED lighting means 42, 43 of the LED module 4, which may in turn reduce a form factor and a cost with respect to a two-channel LED driver.

[0034] In addition, the single-channel CC LED driver 3 may have a feed / output current tolerance relaxed beyond $\pm 5\%$ up to $\pm 10\%$, which may facilitate further cost savings and miniaturization.

[0035] The LED module 4 further comprises an auxiliary load 44A, 44B, 44C connected between the input terminals 41 and the plurality of LED lighting means 42, 43.

[0036] The auxiliary load 44A, 44B, 44C may mitigate switching disturbances.

[0037] In the implementation of FIG. 1, the auxiliary load 44A, 44B, 44C may comprise a Zener diode 44A connected in parallel to the plurality of LED lighting means 42, 43.

[0038] A Zener diode is a special type of diode designed to allow a reversed current to flow when the diode is reverse-biased beyond a certain voltage, known as the Zener voltage, and to allow the reverse current to keep the voltage drop across the Zener diode close to the Zener voltage across a wide range of reverse currents.

[0039] The Zener diode 44A acts as a shunt regulator by maintaining a nearly constant voltage across itself and across the plurality of LED lighting means 42, 43 when the reverse current through it is sufficient to take it into the Zener breakdown region.

[0040] FIG. 2 illustrates a luminaire 1 comprising an LED module 4 in accordance with the present disclosure.

[0041] Alternatively or additionally to the implementation of FIG. 1, the auxiliary load 44A, 44B, 44C may comprise a second switch 44B ("dump switch") connected in parallel to the plurality of LED lighting means 42, 43 and configured to shunt, in dependence of a second control signal 47, the plurality of LED lighting means 42, 43. The second control signal 47 may be provided by the control unit 50, too.

[0042] The second switch 44B thus actively allows current to bypass the plurality of LED lighting means 42, 43 when none of the plurality of LED lighting means 42, 43 is selected for feeding by the LED driver 3.

[0043] FIG. 3 illustrates a luminaire 1 comprising an LED module 4 in accordance with the present disclosure, and FIG. 4 illustrates time-dependent feed currents of the LED module 4 of FIG. 3.

[0044] Some of the commercially available CC LED drivers include capacitors at their output for construction reasons (for power factor correction, PFC, for example). In such circumstances, current amplitudes of different branches may differ from each other, so that a non-constant feed current may be observed.

[0045] A top of FIG. 4 indicates an exemplary first PWM control signal 46A. A "high" level of the first PWM control signal 46A selects the "cool white" first LED lighting means 42 (CW channel) for feeding by the LED driver 3,

and a "high" level of the first PWM control signal 46A selects the "warm white" second LED lighting means 43 (WW channel). The first PWM control signal 46A has an 80% duty cycle for the CW channel and a 20% duty cycle for the WW channel.

[0046] A center of FIG. 4 shows an exemplary feed current provided by a CC LED driver 3 including output capacitors. In the particular example, average currents of 159mA and 414mA are fed into the CW channel and the WW channel, respectively. In other words, the CC LED driver 3 fails to provide a constant current and thus over-emphasizes the WW channel.

[0047] Thus, alternatively or additionally to the implementations of FIGs. 1 and 2, the auxiliary load 44A, 44B, 44C may comprise an inductor 44C ("choke") connected in series between the input terminals 41 and the plurality of LED lighting means 42, 43.

[0048] The inductor 44C mitigates the effect of the output capacitor inside the CC LED driver 3 by a change in a strength of a magnetic field in response to a change in current amplitude through the inductor.

[0049] A bottom of FIG. 4 depicts an exemplary feed current provided by the same CC LED driver 3 including output capacitors to the LED module 4 including the inductor 44C. As can be seen, a same average current for the CW channel and the WW channel results in a color temperature in accordance with the PWM duty cycles.

[0050] FIG. 5 illustrates a luminaire 1 comprising an LED module 4 in accordance with the present disclosure.

[0051] The LED module 4 comprises all the circuit elements of FIGs. 1 - 3 to indicate that these implementations may be combined with one other. Beyond the drawn versions, combinations of two circuit elements are also possible, i.e., 44A and 44C, 44B and 44C, as well as 44A and 44B.

[0052] Additionally, the LED module 4 may further comprise a respective capacitor 48 ("branch capacitor") connected in parallel to each of the plurality of LED lighting means 42, 43 and having a same capacitance value that depends on a switching frequency of the first PWM control signal 46A. As will be explained in more detail in connection with FIG. 6, this switching frequency may be termed minimum switching frequency f_0 .

[0053] The respective capacitor 48 maintains a current flow and continuous emission of light from LED branch 42 during the off-state of switch 45B. Similarly, "branch capacitor" 48 maintains a current flow and continuous emission of light from LED branch 43 during the off-state of switch 45C. Continuous emission of light is beneficial against TLA (Temporal Light Artefact) like for example visible flicker of a luminaire.

[0054] Additionally, the LED module 4 may further comprise a respective diode 49 ("branch diode") connected in series with each of the plurality of LED lighting means 42, 43.

[0055] The respective diode 49 may mitigate reverse bias condition on off-state switches 45A, 45B, 45C. Power MOSFET types of switches may not tolerate reverse

bias voltage across Drain-Source during off state.

[0056] Such unwanted reverse bias condition may result in for example at an on-state of dump switch 44B: In the absence of diode 49 the voltage of "branch capacitor" 48 would have appeared on the MOSFET switch 45A, 45B, 45C. The presence of diode 49 mitigates this failure-scenario.

[0057] FIG. 6 illustrates a luminaire 1 comprising an LED module 4 in accordance with the present disclosure.

[0058] The LED module of FIG. 6 differs from the implementation of FIG. 5 in that the single first PWM switch 45A is replaced by a plural of first switches 45B, 45C configured to select, in dependence of a corresponding plural of first PWM control signals 46B, 46C, one of the plurality of LED lighting means 42, 43 for feeding by the LED driver 3.

[0059] By contrast to the LED module of FIG. 5, the switching frequency f is not necessarily the same for the CW channel and the WW channel, and the PWM duty cycles of these branches do not necessarily add up to 1. In other words, this implementation enables a dimming operation.

[0060] Besides that, decoupling the CW channel and the WW channel from one another serves the following purpose:

Even in the presence of the ripple filters 48, 49, still some small non-zero flicker remains. Its magnitude depends on the capacitance value of the capacitors 48, which in turn relates to the switching frequency of the CW channel and the WW channel.

[0061] Ripple as used herein may refer to rapid fluctuations of an electrical quantity, such as a current, and may be measured as a ratio of deviations from an average value to this average value.

[0062] Flicker as used herein may refer to a visible change in brightness of a lighting means due to ripple in its power feed.

[0063] Smaller capacitance values are generally more desirable for miniaturization. However, smaller capacitance values result in higher ripple, as may be taken from FIG. 8 below. In addition, the magnitude of the flicker further depends on the PWM duty cycle, too, as is also depicted in FIG. 8.

[0064] Especially in the region of high PWM duty cycle to the right of FIG. 6, the use of one PWM pulse per base cycle period $1/f_0$ increases ripple significantly. Here, a use of multiple PWM pulses per base cycle period may reduce ripple/flicker as this effectively increases switching frequencies.

[0065] Accordingly, a respective switching frequency of the two first PWM control signals 46B, 46C may comprise an integer multiple of a minimum switching frequency f_0 (see above) which is common for all first switches 45B, 45C, and which provides an accurate ratio of cool white and warm white illumination.

[0066] FIG. 7 illustrates a multi-pulse feed of the LED module 4 of FIG. 6.

[0067] In this example, the CW channel comprising the

first LED lighting means 42 is fed $N=5$ times more often than the WW channel comprising the second LED lighting means 43.

[0068] A respective duty cycle of the two first PWM control signals 46B, 46C may depend on the respective switching frequency of the two first PWM control signals 46B, 46C and on a proportion of the feeding of the plurality of LED lighting means 42, 43 relative to one another.

[0069] For example, PWM pulse widths of 0,2% and 1% and switching frequencies of $f_0=732\text{Hz}$ and $5 \cdot f_0=3,66\text{kHz}$ for the WW/CW channels results in PWM duty cycles of 0,2% and 5% for the WW/CW channels.

[0070] FIG. 8 illustrates a ripple of the branch current of the first LED 42 of FIG. 6 for capacitors 48 of different capacitance.

[0071] Especially in the region of high PWM duty cycle (i.e., higher light intensity), where maintaining a use of one PWM pulse per switching period increases ripple considerably, it is desirable to use multiple PWM pulses per base cycle period. There is an advantage of using multiple pulses per base cycle period for a higher intensity branch while keeping a single pulse per cycle for a lower intensity branch. Thus multi-pulse feed reduces a ripple of the feed current significantly and enables deployment of smaller branch capacitors 48 at the same time.

Claims

1. An LED module (4), comprising

input terminals (41) connectable to an LED driver (3);
a plurality of LED lighting means (42, 43) having different color temperatures;
an auxiliary load (44A, 44B, 44C) connected between the input terminals (41) and the plurality of LED lighting means (42, 43); and
one or more first switches (45A; 45B, 45C) configured to select, in dependence of one or more first PWM control signals (46A; 46B, 46C), one of the plurality of LED lighting means (42, 43) for feeding by the LED driver (3).

2. The LED module (4) of claim 1, wherein the auxiliary load (44A, 44B, 44C) comprises a Zener diode (44A) connected in parallel to the plurality of LED lighting means (42, 43).

3. The LED module (4) of claim 1 or claim 2, wherein the auxiliary load (44A, 44B, 44C) comprises a second switch (44B) connected in parallel to the plurality of LED lighting means (42, 43) and configured to shunt, in dependence of a second control signal (47), the plurality of LED lighting means (42, 43).

4. The LED module (4) of any one of the preceding

claims,

wherein the auxiliary load (44A, 44B, 44C) comprises an inductor (44C) connected in series between the input terminals (41) and the plurality of LED lighting means (42, 43).

5. The LED module (4) of any one of the preceding claims,

wherein a respective switching frequency of the one or more first PWM control signals (46A; 46B, 46C) comprises an integer multiple of a minimum switching frequency (f_0).

6. The LED module (4) of claim 5, further comprising a respective capacitor (48) connected in parallel to each of the plurality of LED lighting means (42, 43) and having a same capacitance that depends on the minimum switching frequency (f_0).

7. The LED module (4) of claim 6, further comprising a respective diode (49) connected in series with each of the plurality of LED lighting means (42, 43).

8. The LED module (4) of any one of the claims 5 to 7, wherein a respective duty cycle of the one or more first PWM control signals (46A; 46B, 46C) depends on the respective switching frequency of the one or more first PWM control signals (46A; 46B, 46C) and on a proportion of the feeding of the plurality of LED lighting means (42, 43) relative to one another.

9. The LED module (4) of any one of the preceding claims, wherein the plurality of LED lighting means (42, 43) respectively comprises an LED string.

10. The LED module (4) of any one of the preceding claims, wherein the plurality of LED lighting means (42, 43) comprises first LED lighting means (42) having a color temperature greater than or equal to 5.000 K; and second LED lighting means (43) having a color temperature greater than or equal to 2.700 K and less than or equal to 3.000 K.

11. A luminaire (1), comprising

an LED module (4) of any one of the preceding claims; and
an LED driver (3) connected to input terminals (41) of the LED module (4) and configured to feed the LED module (4) off a mains grid (2).

12. The luminaire (1) of claim 11, wherein the LED driver (3) is configured to feed a constant current.

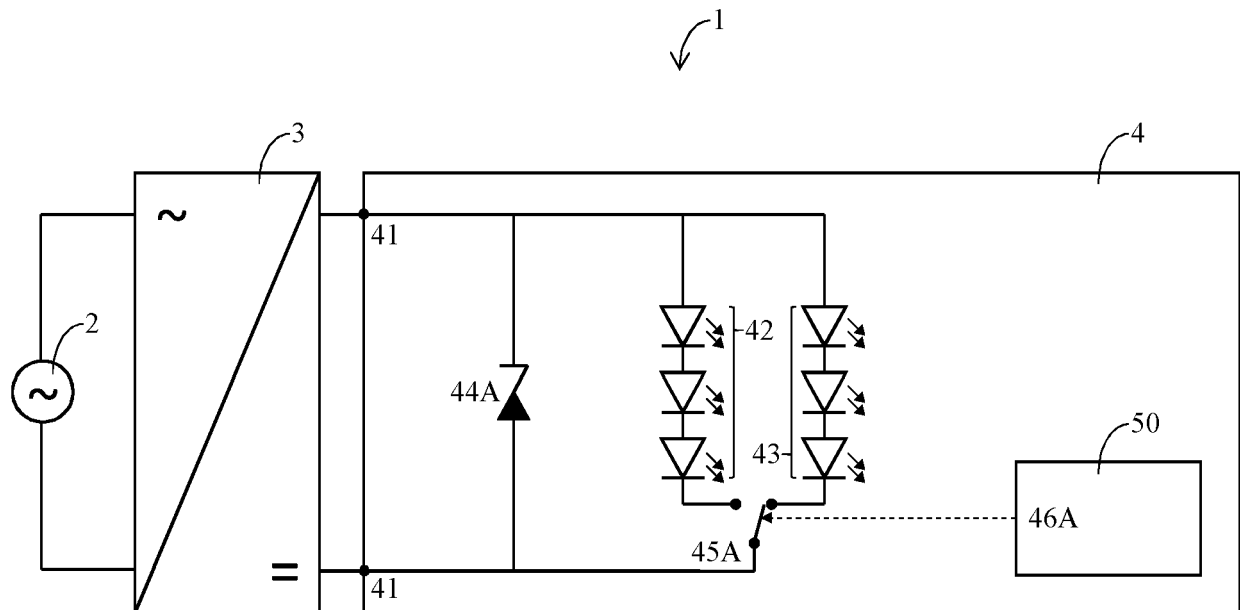


FIG. 1

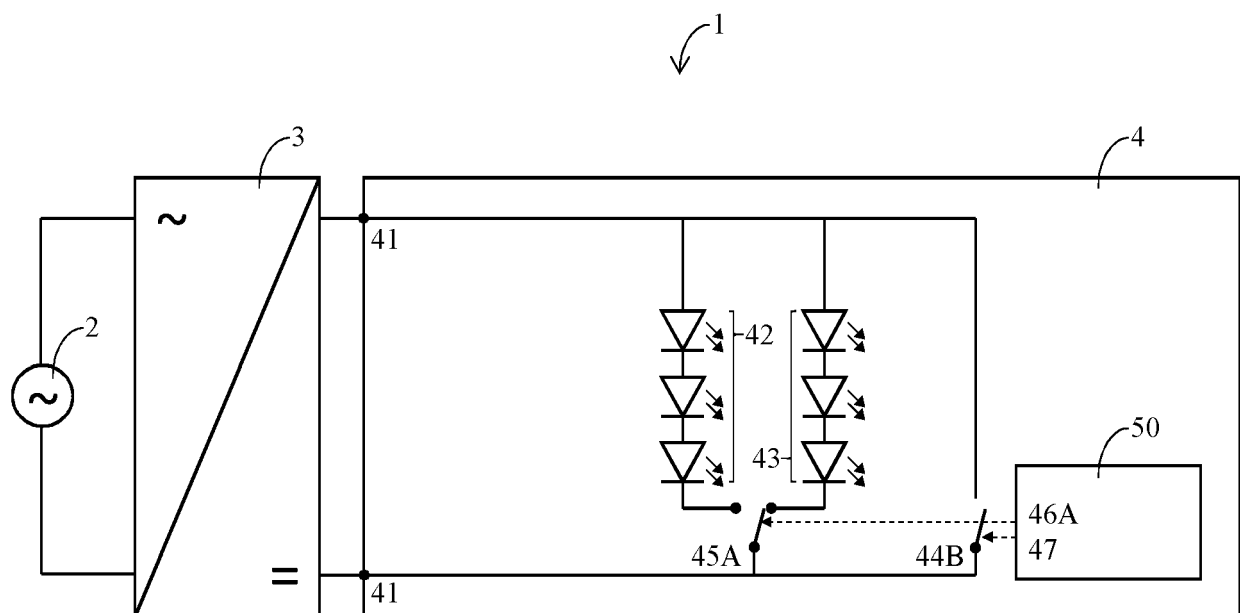


FIG. 2

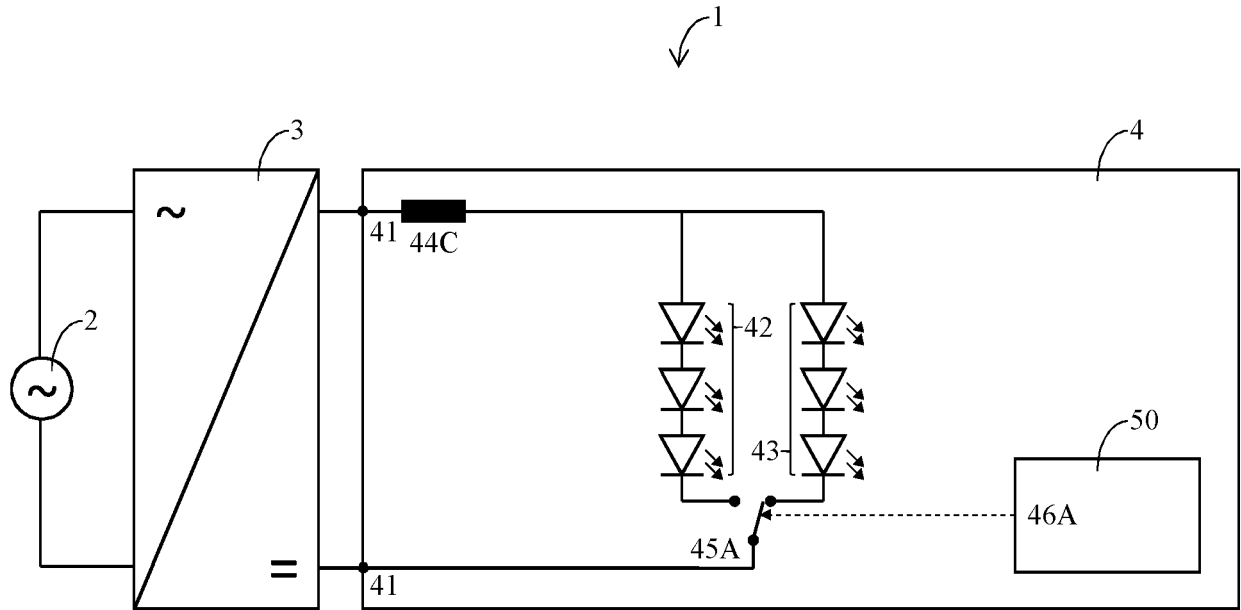


FIG. 3

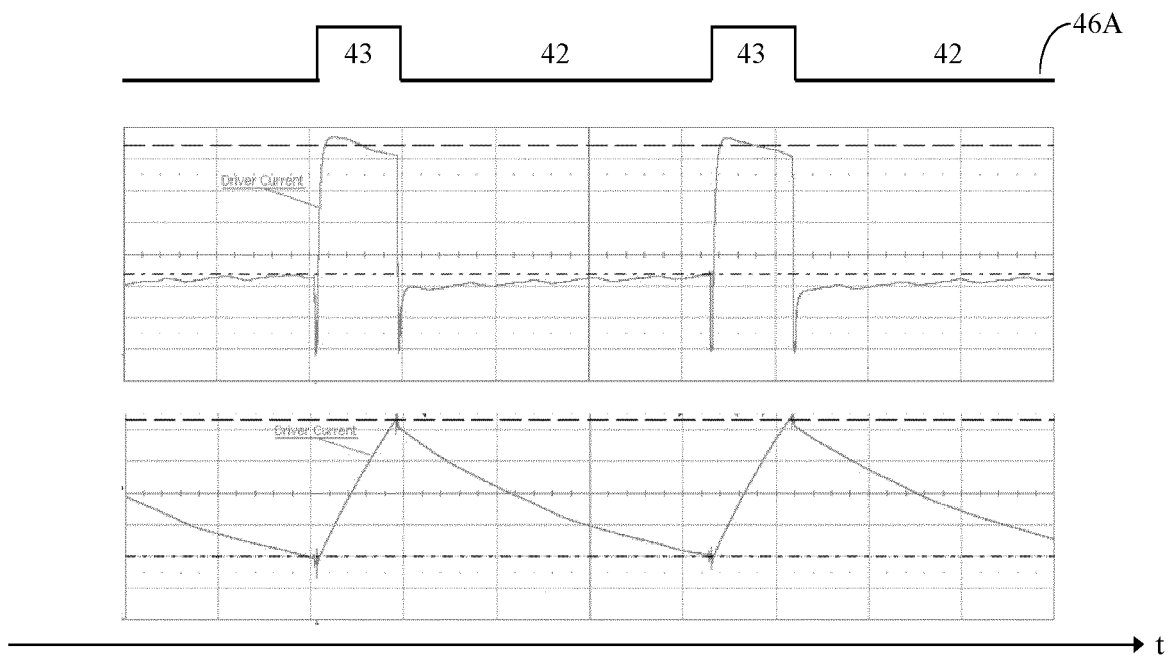


FIG. 4

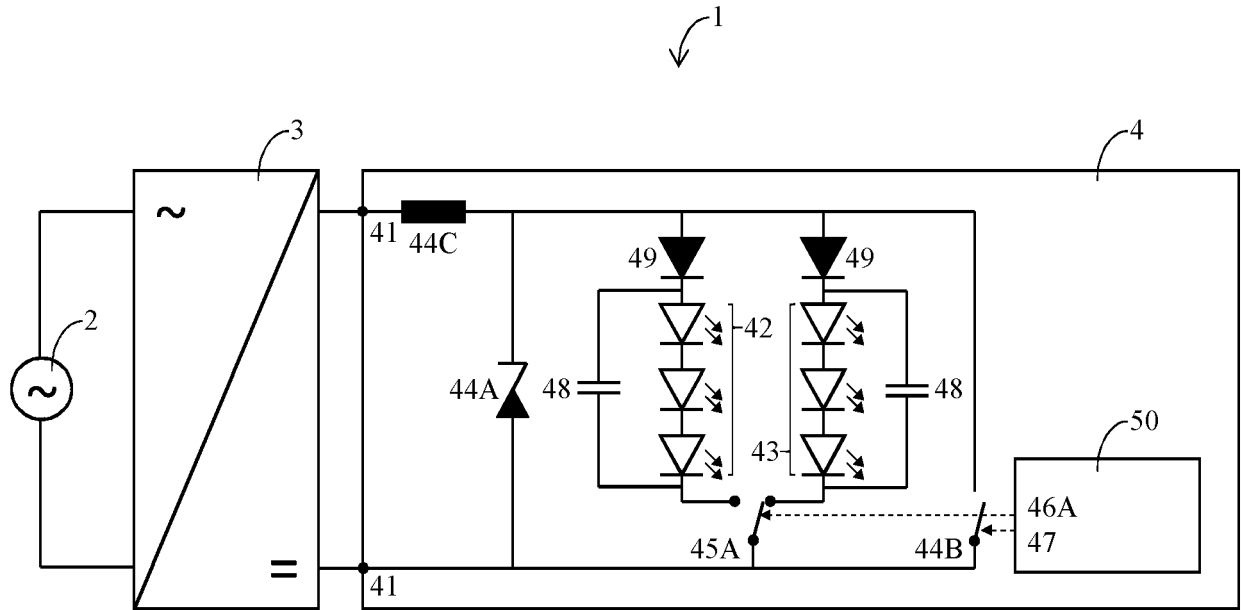


FIG. 5

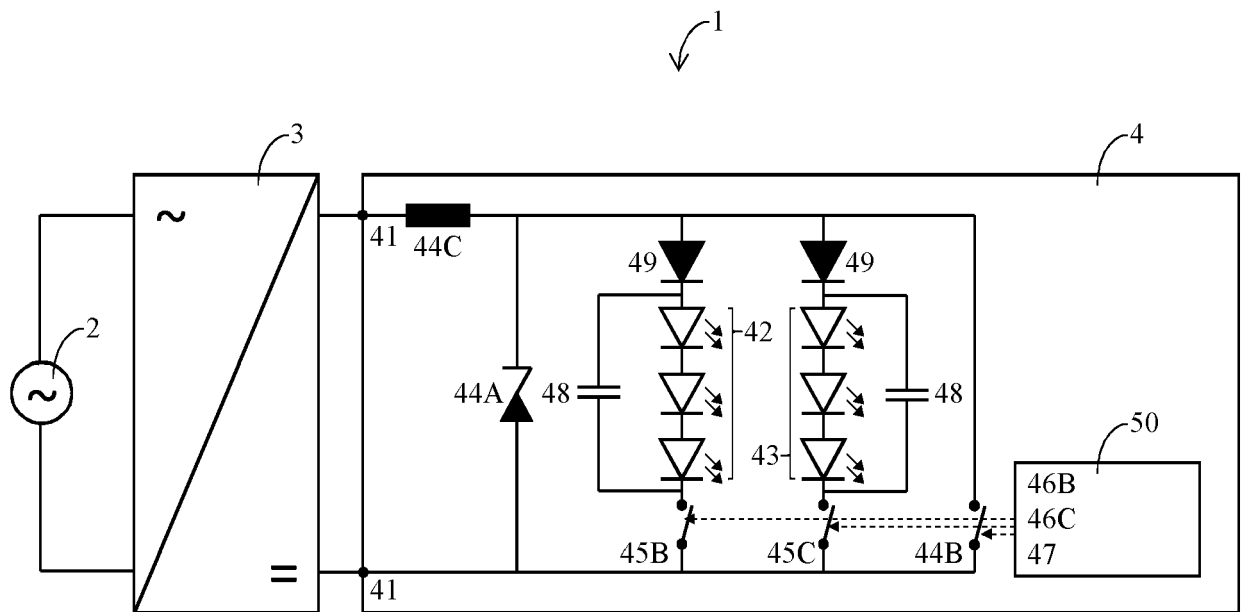


FIG. 6

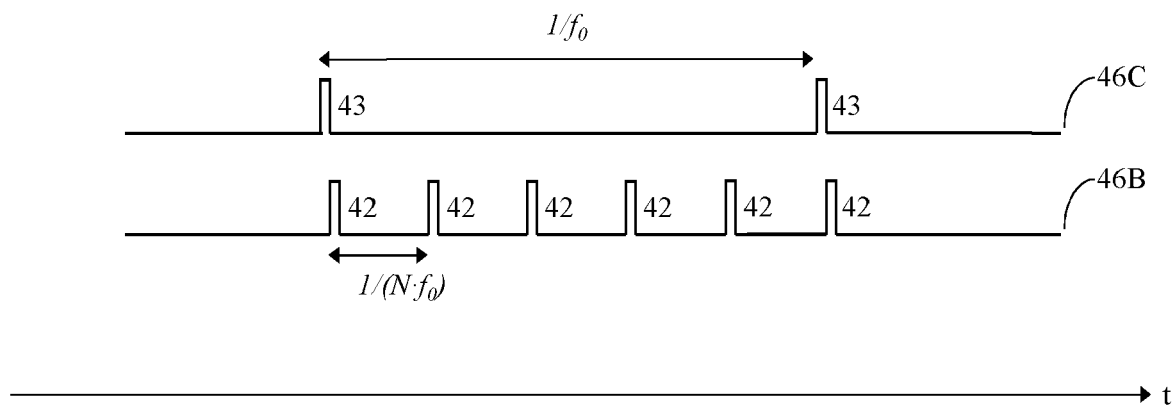


FIG. 7

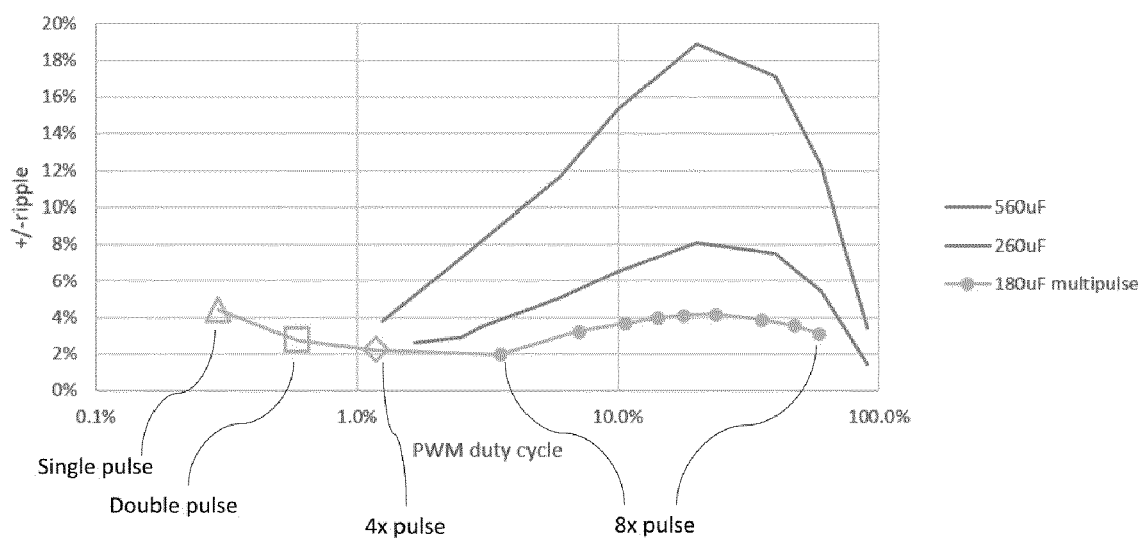


FIG. 8



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Application Number
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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