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Description

CURRENT COMPENSATION DEVICE AND LIGHTING APPARATUS WITH THE
SAME

5

FIELD

[0001] The present disclosure relates to the technical field of a lighting apparatus, and in particular to a current compensation device and a lighting apparatus with the same.

10

BACKGROUND

[0002] This section provides background information related to the present disclosure which is not necessarily prior art.

[0003] Color temperature is a characteristic of visible light
15 that has important applications in lighting field and the like. The color temperature of a light source is the temperature of an ideal black body radiator that radiates light of comparable hue to that of the light source. Different color temperatures will result in different influences on human
20 emotions or feelings. And, lighting with different color temperature may be needed in different occasions. When a color temperature of a lighting apparatus is controlled, an average current flowing through lighting units of the lighting apparatus will vary as the lighting units are switched in and by-
25 passed, thereby resulting in an unwanted color temperature of the lighting apparatus.

SUMMARY

[0004] This section provides a general summary of the present
30 disclosure, and is not a comprehensive disclosure of its full

scope or all of its features.

[0005] Some embodiments of the present disclosure provide a current compensation device and a lighting apparatus with the same which can have good response to dynamic load, to ensure consistency of an average current flowing through lighting units of the lighting apparatus, thereby obtaining a desirable lighting effect of the lighting apparatus.

[0006] According to an aspect of the present disclosure, there is provided a current compensation device of a lighting apparatus for controlling ON/OFF of a current control switch unit in the lighting apparatus based on a sensing voltage sensed by a voltage sensing unit in the lighting apparatus and an OFF duration of the current control switch unit, characterized by including: a mapping unit which maps an ON/OFF state of at least one lighting switch unit in the lighting apparatus to ON/OFF data corresponding to an ON/OFF condition of the current control switch unit; a control unit which obtains the ON/OFF data from the mapping unit when the ON/OFF state of any of the at least one lighting switch unit changes; and a current compensation driving unit which generates a driving signal according to the sensing voltage and the ON/OFF data to control ON/OFF of the current control switch unit.

[0007] Preferably, the ON/OFF data may be ON data corresponding to an ON condition of the current control switch unit, and the current compensation driving unit may include: a conversion unit which converts the ON data into a variable reference voltage; a comparison unit which compares the variable reference voltage with the sensing voltage to output a comparison signal; a constant OFF duration generation unit which outputs a constant OFF duration denotation signal; and a latch and driving unit which generates the driving signal based on the comparison signal and the constant OFF duration denotation signal.

[0008] Preferably, the conversion unit may include a conversion resistor and a conversion capacitor, one terminal of the conversion resistor is connected to the control unit, another terminal of the conversion resistor is connected to the one
5 terminal of the conversion capacitor, and another terminal of the conversion capacitor is grounded.

[0009] Preferably, the comparison unit may include a first op amplifier, the sensing voltage is connected to a positive input terminal of the first op amplifier, and a node between
10 the conversion resistor and the conversion capacitor is connected to a negative input terminal of the first op amplifier.

[0010] Preferably, the constant OFF duration generation unit may output the constant OFF duration denotation signal based
15 on a constant OFF duration set by the control unit.

[0011] Preferably, the constant OFF duration generation unit may output the constant OFF duration denotation signal based on the driving signal generated by the current compensation driving unit, and the constant OFF duration generation unit
20 may include: a timing circuit which is connected between a power supply voltage and a grounding and includes a timing resistor and a timing capacitor connected in series, wherein a terminal of the timing resistor is connected to the power supply voltage, and a terminal of the timing capacitor is
25 grounded; a discharge circuit which includes a discharge triode, a collector of the discharge triode is connected to a node between the timing resistor and the timing capacitor in the timing circuit, an emitter of the discharge triode is grounded, and a base of the discharge triode is controlled by
30 the driving signal generated by the current compensation driving unit; and a comparison circuit which includes a second op amplifier, the node between the timing resistor and the timing capacitor in the timing circuit is connected to a

positive input terminal of the second op amplifier, and a comparison reference voltage is connected to a negative input terminal of the second op amplifier.

[0012] Preferably, the latch and driving unit may include: a
5 latch circuit which includes a SR latch, the comparison signal is connected to a R input terminal of the SR latch, and the constant OFF duration denotation signal is connected to a S input terminal of the SR latch; and a driving circuit, an input terminal of which is connected to a Q output terminal
10 of the SR latch.

[0013] Preferably, the ON/OFF data may be OFF data corresponding to an OFF duration of the current control switch unit, and the current compensation driving unit may include: a timing unit which outputs a variable OFF duration denotation
15 signal based on the OFF data; a comparison unit which compares a constant reference voltage with the sensing voltage to input a comparison signal; and a latch and driving unit which generates the driving signal based on the comparison signal and the variable OFF duration denotation signal.

20 [0014] Preferably, the comparison unit may include an op amplifier, the sensing voltage is connected to a positive input terminal of the op amplifier, and a constant reference voltage is connected to a negative input terminal of the op amplifier.

25 [0015] Preferably, the latch and driving unit may include: a latch circuit which includes a SR latch, the comparison signal is connected to a R input terminal of the SR latch, the variable OFF duration denotation signal is connected to a S input terminal of the SR latch, and a Q output terminal of
30 the SR latch outputs an enable signal to the timing unit; and a driving circuit, an input terminal of which is connected to a Q output terminal of the SR latch.

[0016] According to another aspect of the present disclosure, there is provided a lighting apparatus including: a power supply unit; a plurality of lighting units connected in series with each other powered by the power supply unit; at least one lighting switch unit, each of which is connected in parallel with corresponding one of the plurality of lighting units; an energy storage unit which is connected in series to the plurality of lighting units; a current control switch unit which is connected in series to the energy storage unit; an unidirectional current conduction unit which is connected in parallel with the plurality of lighting units and the energy storage unit; and a voltage sensing unit which is connected in series to the current control switch unit to sense a sensing voltage corresponding to a current flowing through the plurality of lighting units when the current control switch unit is turned on, characterized in that the lighting apparatus further includes a current compensation device according to the present disclosure which controls ON/OFF of the current control switch unit based on the sensing voltage and an OFF duration of the current control switch unit.

[0017] Preferably, the driving signal generated by the current compensation driving unit may be a switching signal.

[0018] Preferably, the control unit may provide a control signal to each lighting switch unit to control ON/OFF of each lighting switch unit.

[0019] Preferably, the control signal may be a PWM (Pulse Width Modulation) signal, and the control unit may control the lighting effect of the lighting apparatus through the control signal.

[0020] Preferably, each of the plurality of lighting units may include one LED (Light Emitting Diode) or a plurality of LEDs connected in series.

[0021] Preferably, the lighting switch unit may include a switch device.

[0022] Preferably, the energy storage unit may include an inductor.

5 [0023] Preferably, the current control switch unit may include a MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) device.

[0024] Preferably, the unidirectional current conduction unit may include a diode, an anode of the diode is connected to
10 the energy storage unit, and a cathode of the diode is connected to the power supply unit.

[0025] Preferably, the voltage sensing unit may include a sensing resistor.

[0026] The current compensation device and a lighting apparatus
15 with the same according to the present disclosure may map the ON/OFF state of the lighting switch unit to the ON/OFF data corresponding to an ON/OFF condition of the current control switch unit and generate the driving signal based on the ON/OFF data to control ON/OFF of the current control switch
20 unit. Therefore, the lighting apparatus can have good response to dynamic load, to ensure consistency of an average current flowing through lighting units of the lighting apparatus, thereby obtaining a desirable lighting effect of the lighting apparatus.

25 [0027] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF DRAWINGS

[0028] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure. In the drawings:

Figure 1 is a circuit structural diagram of a lighting apparatus known by the inventors of the present disclosure;

Figure 2 is a timing chart of signals in the lighting apparatus shown in Figure 1;

Figure 3 is a graph of an average current flowing through lighting units in the lighting apparatus shown in Figure 1 versus load voltage;

Figure 4 is a circuit structural diagram of a lighting apparatus with a current compensation circuit known by the inventors of the present disclosure;

Figure 5 is a block diagram of a schematic structure of a lighting apparatus according to an embodiment of the present disclosure;

Figure 6 is a circuit structural diagram of a lighting apparatus according to the embodiment of the present disclosure;

Figure 7 is an example of a lookup table in the lighting apparatus according to the embodiment of the present disclosure shown in Figure 6;

Figure 8 is a timing chart of signals in the lighting apparatus according to the embodiment of the present disclosure shown in Figure 6; and

Figure 9 is a circuit structural diagram of a lighting apparatus according to a specific embodiment of the present disclosure.

[0029] While the present disclosure is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the present disclosure to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present disclosure. Note that corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DESCRIPTION OF EMBODIMENTS

[0030] Examples of the present disclosure will now be described more fully with reference to the accompanying drawings. The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

[0031] Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0032] As shown in Figure 1, a lighting apparatus 100 known by the inventors of the present disclosure may include a plural-

ity of lighting units 111, 112, and 113 connected in series, which are powered by an input voltage V_{in} . Each of the lighting units 111, 112, and 113 may include one LED or a plurality of LEDs connected in series. The number of the LEDs included in respective lighting units may be same or may be different.

[0033] A MOSFET device Q2 is connected in parallel with the lighting unit 111, and a MOSFET device Q3 is connected in parallel with the lighting unit 112. Specifically, a drain and source of the MOSFET device Q2 are connected to both terminals of the lighting unit 111, respectively, and a drain and source of the MOSFET device Q3 are connected to both terminals of the lighting unit 112, respectively. Additionally, a gate of the MOSFET device Q2 is controlled by a PWM signal Q2_PWM, and a gate of the MOSFET device Q3 is controlled by a PWM signal Q3_PWM.

[0034] Each of the lighting units 111, 112, and 113 may have respective color temperature. The color temperature of LED refers to the color of the light emitted by the LED, which is generally classified into three types of warm white (2700k-4500k), pure white (4500k-6500k), and cool white (6500k or more). LED with different color temperature may be selected as necessary. After a LED is selected, the color temperature of the selected LED is unchanged. When the color temperature of the LED lighting device needs to be changed, it is necessary to provide at least two LED lighting units with different color temperatures. Herein, it is assumed that the lighting unit 111 has a first color temperature such as warm white, the lighting unit 112 has a second color temperature as pure white, and the lighting unit 113 has a third color temperature as cool white.

[0035] When the PWM signal Q2_PWM is of a low level such that the MOSFET device Q2 is turned off, the lighting unit 111 is

switched in and emits a light with the first color temperature. On the other hand, when the PWM signal Q2_PWM is of a high level such that the MOSFET device Q2 is turned on, the lighting unit 111 is bypassed and therefore emits no light.

5 Thus, the intensity of the light with the first color temperature may be controlled through the duty ratio of the PWM signal Q2_PWM.

[0036] Correspondingly, when the PWM signal Q3_PWM is of a low level such that the MOSFET device Q3 is turned off, the
10 lighting unit 112 is switched in and emits a light with the second color temperature. On the other hand, when the PWM signal Q3_PWM is of a high level such that the MOSFET device Q3 is turned on, the lighting unit 112 is bypassed and therefore emits no light. Thus, the intensity of the light with
15 the second color temperature may be controlled through the duty ratio of the PWM signal Q3_PWM.

[0037] When the intensity varying light with the first color temperature, the intensity varying light with the second color temperature, and the intensity constant light with the
20 third color temperature are mixed in a desirable proportion, a desirable color temperature of the lighting apparatus 100 will be achieved.

[0038] In Figure 1, an inductor L1 for energy storage, a MOSFET device Q1 for controlling a current I_L1 flowing through the
25 lighting units, and a resistor Rs for sensing the current I_L1 are connected in series to the lighting units 111, 112, and 113 in order. Specifically, one terminal of the inductor L1 is connected to the lighting unit 113, and the other terminal thereof is connected to a drain of the MOSFET device
30 Q1. A source of the MOSFET device Q1 is connected to one terminal of the resistor Rs, and the other terminal of the resistor Rs is grounded.

[0039] Additionally, it is noted that a diode D1 is connected in parallel with the lighting units 111, 112, and 113 and the inductor L1. Specifically, an anode of the diode D1 is connected to the inductor L1, and a cathode thereof is connected
5 to the lighting unit 111.

[0040] When the MOSFET device Q1 is turned on, the input voltage V_{in} powers the lighting units 111, 112, and 113, the inductor L1 stores energy, and the diode D1 is turned off. On the other hand, when the MOSFET device Q1 is turned off, the
10 diode D1 is turned on, and the inductor L1 releases energy to power the lighting units 111, 112, and 113. It is understood by those skilled in the art that the current I_{L1} flowing through the lighting units will fluctuate with turning on and off of the MOSFET device Q1. However, a desirable color tem-
15 perature of the lighting apparatus 100 may be achieved as long as an average value I_o of the current I_{L1} remains unchanged.

[0041] Control of the MOSFET device Q1 will be described in detail below. As shown in Figure 1, when the MOSFET device Q1
20 is turned on, the current I_{L1} flows through the resistor R_s , and therefore a sensing voltage V_{sense} is obtained. The sensing voltage V_{sense} corresponds to the current I_{L1} when the MOSFET device Q1 is turned on.

[0042] The sensing voltage V_{sense} is input to a positive input
25 terminal of an op amplifier X1 in a control module 120. Additionally, a reference voltage V_{ref} is input to a negative input terminal of the op amplifier X1. The reference voltage V_{ref} is obtained from a voltage dividing circuit including resistors R1 and R2 connected in series between a power supply
30 voltage V_{cc} and grounding, and therefore is constant.

[0043] The op amplifier X1 outputs a result of comparison of the sensing voltage V_{sense} with the reference voltage V_{ref} to

a signal generator 121 in the control module 120. The signal generator 121 generates a buck PWM signal BUCK_PWM based on the signal input by the op amplifier X1. The signal BUCK_PWM is input to a gate of the MOSFET device Q1 via a driver 130, thereby controlling ON/OFF of the MOSFET device Q1.

[0044] The operational principle of the lighting apparatus 100 will be further described in combination with Figure 2 below. Firstly, it is assumed that the signal Q2_PWM is always of a low level and the duty ratio of the signal Q3_PWM is limited to be 50% to simplify the analysis. Thus, the MOSFET device Q2 is always turned off, and the lighting unit 111 is always switched in.

[0045] During the period of t_1 , the signal Q3_PWM is of a low level, and therefore the MOSFET device Q3 is turned off and the lighting unit 112 is switched in. At this time, an output voltage V_{out} of the lighting units is the sum of voltages across the lighting units 111, 112, and 113.

[0046] During the period of t_2 , the signal Q3_PWM is of a high level, and therefore the MOSFET device Q3 is turned on and the lighting unit 112 is bypassed. At this time, the output voltage V_{out} of the lighting units is the sum of voltages across the lighting units 111 and 113. Compared to that during the period of t_1 , the output voltage V_{out} decreases during the period of t_2 .

[0047] The effect of changing in the output voltage V_{out} on the average current I_o flowing through the lighting units will be further described below. With reference to Figures 1 and 2, at the initial time, the signal BUCK_PWM is of a high level, and the MOSFET device Q1 is ON. At this time, the lighting units are powered by the input voltage V_{in} , the inductor L1 begins to store energy, and the current I_{L1} begins to increase.

[0048] As the current I_{L1} increases, the sensing voltage V_{sense} also increases. When the sensing voltage V_{sense} exceeds the reference voltage V_{ref} , the op amplifier X1 outputs a high level. The signal generator 121 which receives the input signal with high level from the op amplifier X1 generates the signal BUCK_PWM with low level. The signal BUCK_PWM with low level is input to the gate of the MOSFET device Q1 via the driver 130, resulting in OFF of the MOSFET device Q1.

[0049] When the MOSFET device Q1 is OFF, the diode D1 is ON. At this time, the inductor L1 begins to release energy and power the lighting units, and the current I_{L1} begins to decrease.

[0050] Next, when the cycle of the signal BUCK_PWM terminates, the signal BUCK_PWM changes to be the high level again, and the MOSFET device Q1 is ON again. Thus, the current I_{L1} increases again until the sensing voltage V_{sense} exceeds the reference voltage V_{ref} . It can be realized that a peak value I_{pk} of the current I_{L1} is decided by the reference voltage V_{ref} . In other words, the peak current I_{pk} will remain unchanged if the reference voltage V_{ref} is constant.

[0051] In Figure 2, it is assumed that the difference between the maximum and the minimum of the current I_{L1} is denoted as ΔI and the average current I_o is in the middle of the maximum and the minimum of the current I_{L1} . Whereby the following formula (1) may be obtained:

$$I_o = I_{pk} - \frac{1}{2} \cdot \Delta I \quad (1)$$

[0052] Further, those skilled in the art may readily obtain the formula (2) as follows:

$$\Delta I = \frac{(V_{in} - V_{out}) \cdot D}{F_s \cdot L} \quad (2)$$

[0053] where F_s denotes the frequency of the signal BUCK_PWM, L

denotes the inductance of the inductor L1, and D denotes the duty ratio of the signal BUCK_PWM.

[0054] Furthermore, those skilled in the art may obtain the formula (3) as follows:

$$D = \frac{V_{out}}{V_{in}} \quad (3)$$

[0055] In accordance with the formulas (1)-(3) as above, a graph of the average current I_o versus the load output voltage V_{out} as shown in Figure 3 may be obtained.

[0056] As can be seen from the combination of Figures 2 and 3, the output current I_{out} (i.e., the average current I_o flowing through the lighting units) increases as the output voltage V_{out} decreases. In this case, it is necessary to compensate for the output current I_{out}, so that the output current I_{out} always remains consistent to obtain the desirable color temperature of the lighting apparatus 100.

[0057] As shown in Figure 4, a lighting apparatus 200 with a current compensation circuit known by the inventors of the present disclosure provides an example in which the output current I_{out} is compensated for. The difference of the lighting apparatus 200 shown in Figure 4 from the lighting apparatus 100 shown in Figure 1 lies in that the lighting apparatus 200 provides a circuit consisting of resistors R_{c2} and R_{c3} and MOSFET devices Q_{c2} and Q_{c3} for compensating for the output current I_{out}.

[0058] Specifically, as shown in Figure 4, one terminal of the resistor R_{c2} is connected to a node between the resistors R₁ and R₂, another terminal thereof is connected to a drain of the MOSFET device Q_{c2}, and a source of the MOSFET device Q_{c2} is grounded. One terminal of the resistor R_{c3} is connected to the node between the resistors R₁ and R₂, another terminal

thereof is connected to a drain of the MOSFET device Qc3, and a source of the MOSFET device Qc3 is grounded.

[0059] A gate of the MOSFET device Qc2 is controlled by the signal Q2_PWM. Thus, when the signal Q2_PWM is of a low

5 level, the MOSFET devices Q2 and Qc2 are both OFF. The lighting unit 111 is switched in, and the resistor Rc2 has no influence on the reference voltage Vref. On the other hand, when the signal Q2_PWM is of a high level, the MOSFET devices Q2 and Qc2 are both ON. The lighting unit 111 is bypassed,
10 the output voltage Vout is caused to decrease, and therefore the output current Iout has a tendency of increasing (see Figures 2 and 3). At the same time, since the MOSFET device Qc2 is ON, the resistors Rc2 and R2 are connected in parallel, resulting in decreasing of the reference voltage Vref.

15 As described above, the peak value Ipk of the current I_L1 is decided by the reference voltage Vref. It is understood by those skilled in the art that the peak value Ipk of the current I_L1 decreases as the reference voltage Vref decreases. As can be seen from Figure 2, while the output current Iout
20 has a tendency of increasing, the output current Iout has a tendency of decreasing if the peak value Ipk of the current I_L1 decreases. In a case where the resistance values of the resistors R1, R2, and Rc2 are set appropriately, the output current Iout at a time when the signal Q2_PWM is of the high
25 level may be caused to maintain consistent with the output current Iout at a time when the signal Q2_PWM is of the low level.

[0060] Likewise, a gate of the MOSFET device Qc3 is controlled by the signal Q3_PWM. Thus, when the signal Q3_PWM is of a

30 low level, the MOSFET devices Q3 and Qc3 are both OFF. On the other hand, when the signal Q3_PWM is of a high level, the MOSFET devices Q3 and Qc3 are both ON. In a case where the resistance values of the resistors R1, R2, and Rc3 are set

appropriately, the output current I_{out} at a time when the signal Q3_PWM is of the high level may be caused to maintain consistent with the output current I_{out} at a time when the signal Q3_PWM is of the low level.

5 [0061] Thus, the lighting apparatus 200 shown in Figure 4 may compensate for the output current I_{out} , so that the output current I_{out} is capable of always maintaining consistent in a case that the load varies dynamically.

[0062] However, it is noted that the lighting apparatus 200
10 shown in Figure 4 can only provide four compensations for the output current I_{out} , i.e., compensations for switching in of the lighting unit 111, bypassing of the lighting unit 111, switching in of the lighting unit 112, and bypassing of the lighting unit 112. If the load variations of the lighting
15 units in the lighting apparatus exceeds the four situations, for example, if three or more lighting units are required to be controlled for switching in or bypassing, at least six compensations for the output current I_{out} should be provided, which is difficult to be realized by employing resistor array
20 only.

[0063] In accordance with the formulas (1)-(3) as above, the inventors of the present disclosure has appreciated that the following formula (4) may be obtained:

$$I_{out}=I_{pk}-0.5(V_{in}-V_{out})\cdot T_{on}/L=I_{pk}-0.5\cdot V_{out}\cdot T_{off}/L \quad (4)$$

25 [0064] where T_{on} denotes a high level duration within a cycle of the signal BUCK_PWM (i.e., the ON duration of the MOSFET device Q1), and T_{off} denotes a low level duration within a cycle of the signal BUCK_PWM (i.e., the OFF duration of the MOSFET device Q1).

30 [0065] In the lighting apparatus for which the present disclosure may apply, the input voltage V_{in} the inductance L are generally constant values, and the load output voltage V_{out}

keeps changing. Additionally, it is noted that the ON duration T_{on} is related to the peak current I_{pk} .

[0066] As can be seen from the formula (4), in a case that the output voltage V_{out} changes, if it intends to cause the output current I_{out} to always maintain consistent, one of the following two methods may be adopted:

[0067] 1) changing the OFF duration T_{off} correspondingly according to the output voltage V_{out} , and keeping the other parameters unchanged; or

10 [0068] 2) changing the peak current I_{pk} correspondingly according to the output voltage V_{out} , and keeping the other parameters unchanged.

[0069] In other words, it is possible to cause the output current I_{out} to always maintain consistent by changing the ON/OFF condition of the MOSFET device Q1 correspondingly according to the output voltage V_{out} .

[0070] As shown in Figure 5, a lighting apparatus 300 according to a specific embodiment of the present disclosure may include a power supply unit 310, lighting units 321, 322, and 323, lighting switch units 331, 332, and 333, an energy storage unit 340, an unidirectional current conduction unit 350, a current control switch unit 360, a voltage sensing unit 370, and a current compensation unit 380. It is appreciated by those skilled in the art that the numbers of the lighting units and the lighting switch units shown in Figure 5 are only illustrative, and the number of the lighting switch units may less than that of the lighting units.

[0071] The lighting units 321, 322, and 323 are connected in series with each other, and are powered by the power supply unit 310. The lighting switch units 331, 332, and 333 are connected in parallel with the lighting units 321, 322, and 323, respectively. The energy storage unit 340 is connected

in series to the lighting units 321, 322, and 323, and the current control switch unit 360 is connected in series to the energy storage unit 340. The unidirectional current conduction unit 350 is connected in parallel with the lighting units 321, 322, and 323 and the energy storage unit 340, thereby forming a current loop. The voltage sensing unit 370 is connected in series to the current control switch unit 360, to sense a sensing voltage corresponding to a current flowing through the lighting units when the current control switch unit 360 is ON. The current compensation device 380 may control ON/OFF of the current control switch unit 360 based on the sensing voltage.

[0072] Specifically, the current compensation device 380 may include a mapping unit 381, a control unit 382, and a current compensation driving unit 383. The mapping unit 381 maps an ON/OFF state of the lighting switch units 331, 332, and 333 to ON/OFF data corresponding to an ON/OFF condition of the current control switch unit 360. The ON/OFF condition mentioned herein includes the ON condition of the current control switch unit 360 and the OFF duration of the current control switch unit 360. When the ON/OFF state of any of the lighting switch units 331, 332, and 333 changes, the control unit 382 obtains the ON/OFF data from the mapping unit 381. The current compensation driving unit 383 generates a driving signal according to the sensing voltage and the ON/OFF data to control ON/OFF of the current control switch unit 360.

[0073] In the lighting apparatus 300 shown in Figure 5, the ON/OFF state of the lighting switch units 331, 332, and 333 may be mapped to the ON/OFF data corresponding to an ON/OFF condition of the current control switch unit 360, and the driving signal may be generated based on the ON/OFF data to control ON/OFF of the current control switch unit 360. Therefore, the lighting apparatus 300 can have good response to

dynamic load, to ensure consistency of an average current flowing through the lighting units 321, 322, and 323 of the lighting apparatus 300, thereby obtaining a desirable color temperature of the lighting apparatus 300.

5 [0074] The present teachings are suitable for incorporation in many different types of lighting apparatus. Further, the present disclosure is not limited to controlling of the color temperature, but may be applied to various applications in which lighting effects are controlled. For exemplary purposes, descriptions are made below, taking a LED lighting apparatus in combination with controlling of the color temperature as an example.

[0075] With reference to Figure 6, a lighting apparatus 400 according to a specific embodiment of the present disclosure
15 may include a plurality of lighting units 421, 422, and 423 connected in series with each other, which are powered by a DC (Direct Current) power supply 410. The plurality of lighting units 421, 422, and 423 correspond to the lighting units 321, 322, and 323 shown in Figure 5, and the DC power supply
20 410 corresponds to the power supply unit 310 shown in Figure 5.

[0076] Each lighting unit may have respective color temperature. Each of the lighting units 421, 422, and 423 may include one LED or a plurality of LEDs connected in series. The
25 number of the LEDs included in respective lighting units may be same or may be different.

[0077] Switch devices such as MOSFET devices 431, 432, and 433 corresponding to the lighting switch units 331, 332, and 333 shown in Figure 5 are connected in parallel with the lighting
30 units 421, 422, and 423, respectively.

[0078] An inductor 440, a MOSFET device 460, and a resistor 470 shown in Figure 6 correspond to the energy storage unit 340,

the current control switch unit 360, and the voltage sensing unit 370, respectively, shown in Figure 5, which are connected in series to the lighting units 421, 422, and 423 in order.

5 [0079] Additionally, a diode 450 corresponding to the unidirectional current conduction unit 350 shown in Figure 5 is connected in parallel with the lighting units 421, 422, and 423 and the inductor 440.

[0080] The connection manner of respective devices as described
10 above is similar to that shown in Figures 1 and 4, and therefore will not be repeated herein.

[0081] A current compensation device 480 shown in Figure 6 corresponds to the current compensation device 380 shown in Figure 5. The current compensation device 480 may include at
15 least part of a lookup table 481, a CPU (Central Processing Unit) 482, a TOFF timer 483, a reference voltage generator 484, a comparator 485, a SR latch 486, and a driver 487.

[0082] The operational principle of the current compensation device 480 will be described in detail below. As described
20 above, in a case that the output voltage V_{out} of the lighting units 421, 422, and 423 changes, if it intends to cause the output current I_{out} of the lighting units 421, 422, and 423 to always maintain consistent, one may change the OFF duration T_{off} of the MOSFET device 460 correspondingly according
25 to the output voltage V_{out} while keeping the other parameters unchanged, or may change the peak current I_{pk} of the output current correspondingly according to the output voltage V_{out} while keeping the other parameters unchanged. Descriptions will be made below for the former case firstly.

30 [0083] When the output current I_{out} is caused to always maintain consistent by changing the OFF duration T_{off} of the MOSFET device 460, the ON/OFF data for mapping is OFF data

corresponding to the OFF duration Toff. The lookup table 481 shown in Figure 6 corresponds to the mapping unit 381 shown in Figure 5. The lookup table 481 may be implemented by a register, a memory and the like, for example. The lookup table 481 may indicate a relationship between the ON/OFF state of the MOSFET devices 431, 432, and 433 and the OFF duration Toff, as shown in Figure 7. It is understood that the specific data for the OFF duration Toff corresponding to the ON/OFF state of the MOSFET devices 431, 432, and 433 is illustrative and can be calculated in advance to be stored in the lookup table 481.

[0084] In the example shown in Figure 7, the first column denotes the ON/OFF state of the MOSFET devices 431, 432, and 433, and the second column denotes the corresponding OFF duration Toff of the MOSFET device 460. String1, String2, and String3 denote switching in of the lighting units 421, 422, and 423, respectively. Data for the first row is taken as an example. String1+String2+String3 denotes that the lighting units 421, 422, and 423 are all switched in. At this time, the OFF duration Toff of the MOSFET device 460 is set to 131.

[0085] When the lighting units 421, 422, and 423 are all switched in, the CPU 482 corresponding to the control unit 382 shown in Figure 5 obtains the value of 131 for the OFF data from the lookup table 481, i.e., the OFF duration Toff of the MOSFET device 460.

[0086] The CPU 482 transmits the OFF data to the TOFF timer 483. The TOFF timer 483 may output a variable OFF duration denotation signal based on the OFF data. For example, the TOFF timer 483 may perform decrement count upon receiving the value of 131 for the OFF data. As the value for the OFF data is decreased to be zero, the TOFF timer 483 may output a high level as the variable OFF duration denotation signal.

[0087] Meanwhile, the comparator 485 may compare a constant reference voltage with the sensing voltage sensed via the resistor 470 to input a comparison signal. It is noted that the constant reference voltage may be implemented in the manner shown in Figure 1 instead of by means of the reference voltage generator 484.

[0088] Specifically, the comparator 485 may be an op amplifier. The sensing voltage V_{sense} is connected to a positive input terminal of the op amplifier 485, and the constant reference voltage is connected to a negative input terminal of the op amplifier 485.

[0089] Further, the comparison signal output by the comparator 485 and the variable OFF duration denotation signal output by the TOFF timer 483 are connected to R and S input terminals of the SR latch 486, respectively. Furthermore, a $\underline{Q}$ output terminal of the SR latch 486 outputs an enable signal EN to the TOFF timer 483, and a $\underline{Q}$ output terminal thereof is connected to an input terminal of the driver 487, so that the driver 487 outputs a driving signal to drive ON/OFF of the MOSFET device 460. This driving signal may be a switching signal such as a PWM signal.

[0090] At the initial time, when the ON/OFF state of the lighting switch units 431, 432, and 433 changes, the CPU 482 obtains the OFF data from the lookup table 481 and transmits the OFF data to the TOFF timer 483. At this time, it is assumed that the MOSFET device 460 is in an ON state. The sensing voltage V_{sense} increases with time. When V_{sense} exceeds the constant reference voltage, the comparator 485 outputs a comparison signal with high level. This comparison signal sets the $\underline{Q}$ output terminal to 0 and sets the $\underline{Q}$ output terminal to 1. Thus, the driver 487 outputs a driving signal with low level, causing the MOSFET device 460 to be OFF. At the same time, the $\underline{Q}$ output terminal inputs the enable signal EN

to the TOFF timer 483, causing the TOFF timer 483 to start timing.

[0091] As the TOFF timer 483 accomplishes the timing for the OFF data, the variable OFF duration denotation signal is input to the S input terminal of the SR latch 486. This variable OFF duration denotation signal sets the Q output terminal to 1 and sets the $\bar{Q}$ output terminal to 0. Thus, the driver 487 outputs a driving signal with high level, causing the MOSFET device 460 to be ON again. At the same time, the $\bar{Q}$ output terminal disables the TOFF timer 483 for timing.

[0092] As shown in Figure 8, when the ON/OFF state of the lighting switch units 431, 432, and 433 changes, the OFF duration Toff of the MOSFET device 460 are changed correspondingly while the other parameters are kept unchanged. Thus, while the peak current Ipk of the output current keeps unchanged, the duration and amplitude of decreasing of the output current change, and therefore it is still possible to cause the average current of the output current to maintain consistent.

[0093] With reference to Figure 9, description will be made below for the case where the output current Iout is caused to always maintain consistent by changing the peak current Ipk of the output current. The circuit structure of a lighting apparatus 400' shown in Figure 9 is similar to that of the lighting apparatus 400 shown in Figure 6, and descriptions for the same parts thereof will not be repeated herein.

[0094] When the output current Iout is caused to always maintain consistent by changing the peak current Ipk of the output current, the ON/OFF data for mapping is ON data corresponding to the peak current Ipk. When the ON/OFF state of the lighting switch units 431, 432, and 433 changes, the CPU 482 obtains the ON data from the lookup table 481.

[0095] The CPU 482 transmits the ON data to a conversion unit to convert the ON data into a reference voltage V_{ref} . In Figure 9, the conversion unit includes a conversion resistor R_{ref} and a conversion capacitor C_{ref} . One terminal of the conversion resistor R_{ref} is connected to the CPU 482, another terminal of the conversion resistor R_{ref} is connected to the one terminal of the conversion capacitor C_{ref} , and another terminal of the conversion capacitor C_{ref} is grounded.

[0096] Meanwhile, the comparator 485 may compare the variable reference voltage V_{ref} with the sensing voltage V_{sense} sensed via the resistor 470 to input a comparison signal.

[0097] Specifically, the comparator 485 may be an op amplifier. The sensing voltage V_{sense} is connected to a positive input terminal of the op amplifier 485, and the reference voltage V_{ref} is connected to a negative input terminal of the op amplifier 485.

[0098] Additionally, a constant OFF duration generation unit 483' corresponding to the TOFF timer 483 shown in Figure 6 may output a constant OFF duration denotation signal based on the driving signal PWM_MOS generated by the driver 487.

[0099] Specifically, the constant OFF duration generation unit 483' may include a timing circuit which is connected between a power supply voltage (e.g., 5V) and a grounding, a discharge circuit, and a comparison circuit. The timing circuit includes a timing resistor R' and a timing capacitor C' connected in series. A terminal of the timing resistor R' is connected to the power supply voltage, and a terminal of the timing capacitor C' is grounded. The discharge circuit includes a discharge triode Q' . A collector of the discharge triode Q' is connected to a node between the timing resistor R' and the timing capacitor C' , an emitter of the discharge triode Q' is grounded, and a base of the discharge triode Q'

is controlled by the driving signal PWM_MOS. The comparison circuit includes an op amplifier X'. The node between the timing resistor R' and the timing capacitor C' is connected to a positive input terminal of the op amplifier X', and a
5 comparison reference voltage (e.g., 2.5V) is connected to a negative input terminal of the op amplifier X'.

[00100] Further, the comparison signal output by the comparator 485 and the constant OFF duration denotation signal output by the constant OFF duration generation unit 483' are connected
10 to R and S input terminals of the SR latch 486, respectively. Furthermore, a Q output terminal of the SR latch 486 is connected to an input terminal of the driver 487, so that the driver 487 outputs the driving signal PWM_MOS to drive ON/OFF of the MOSFET device 460.

15[00101] At the initial time, when the ON/OFF state of the lighting switch units 431, 432, and 433 changes, the CPU 482 obtains the ON data from the lookup table 481 and transmits the ON data to the conversion resistor Rref in the conversion unit in a manner of PWM signal, thereby obtaining the refer-
20 ence voltage Vref corresponding to the ON data. This reference voltage Vref decides the magnitude of the peak current Ipk. At this time, it is assumed that the MOSFET device 460 is in an ON state. The sensing voltage Vsense increases with time. When Vsense exceeds the reference voltage Vref, the
25 comparator 485 outputs a comparison signal with high level. This comparison signal sets the Q output terminal to 0. Thus, the driver 487 outputs a driving signal PWM_MOS with low level, causing the MOSFET device 460 to be OFF.

[00102] At the same time, the driving signal PWM_MOS with low
30 level causes the discharge triode Q' to be OFF, so that the timing capacitor C' starts charging. When a certain charging time elapses, the voltage at the positive input terminal of the op amplifier X' will be higher than the reference volt-

age. At this time, the op amplifier X' outputs a comparison signal with high level as the constant OFF duration denotation signal.

[00103] The constant OFF duration denotation signal is input to the S input terminal of the SR latch 486. This constant OFF duration denotation signal sets the Q output terminal to 1. Thus, the driver 487 outputs a driving signal PWM_MOS with high level, causing the MOSFET device 460 to be ON again. At the same time, the driving signal PWM_MOS with high level causes the discharge triode Q' to be ON, thereby releasing the charge accumulated in the timing capacitor C'. Therefore, the voltage at the positive input terminal of the op amplifier X' will be lower than the reference voltage. At this time, the op amplifier X' outputs a comparison signal with low level, which has no influence on the SR latch 486.

[00104] As described above, the output current Iout may be caused to always maintain consistent either by changing the OFF duration Toff of the MOSFET device 460 or by changing the peak current Ipk of the output current. Since the ON/OFF data is stored in the lookup table and can be acquired readily, provision of compensation for the output current Iout for each case can be facilitated even if the load variations of the lighting units in the lighting apparatus exceeds the four situations as described above.

[00105] Additionally, in Figures 6 and 9, the MOSFET devices 431, 432, and 433 are driven by drivers 491, 492, and 493, respectively, which in turns are controlled by the CPU 482. In other words, the CPU 482 may provide a control signal to the MOSFET devices 431, 432, and 433 to control ON/OFF of MOSFET devices 431, 432, and 433. The control signal may be a PWM signal and may be determined by the user in advance. The CPU 482 may control the lighting effect of the lighting apparatus through the control signal.

[00106] It can be appreciated by those skilled in the art that, if a CPU for providing the control signal exists in the prior art lighting apparatus, the existing CPU can be employed to provide the ON/OFF data corresponding to the ON/OFF condition of the current control switch unit without additional circuit. Accordingly, the cost for the lighting apparatus may be reduced.

[00107] Further, the constant OFF duration generation unit 483' composed of respective specific devices is provided in Figure 9. However, the present disclosure has not specific limitation thereto. For example, the constant OFF duration generation unit may also be realized by the TOFF timer 483 shown in Figure 6. In this case, the CPU 482 may set a constant OFF duration, and transmit constant OFF data corresponding to the set constant OFF duration to the TOFF timer 483. The TOFF timer 483 which is the constant OFF duration generation unit may output the constant OFF duration denotation signal based on the constant OFF duration set by the CPU 482.

The particular embodiments disclosed above are illustrative only, as the disclosure may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the disclosure.

Claims

1. A current compensation device of a lighting apparatus for controlling ON/OFF of a current control switch unit in the lighting apparatus based on a sensing voltage sensed by a voltage sensing unit in the lighting apparatus and an OFF duration of the current control switch unit, characterized by comprising:

a mapping unit which maps an ON/OFF state of at least one lighting switch unit in the lighting apparatus to ON/OFF data corresponding to an ON/OFF condition of the current control switch unit;

a control unit which obtains the ON/OFF data from the mapping unit when the ON/OFF state of any of the at least one lighting switch unit changes; and

a current compensation driving unit which generates a driving signal according to the sensing voltage and the ON/OFF data to control ON/OFF of the current control switch unit.

2. The current compensation device according to claim 1, wherein the ON/OFF data is ON data corresponding to an ON condition of the current control switch unit, and the current compensation driving unit includes:

a conversion unit which converts the ON data into a variable reference voltage;

a comparison unit which compares the variable reference voltage with the sensing voltage to output a comparison signal;

a constant OFF duration generation unit which outputs a constant OFF duration denotation signal; and

a latch and driving unit which generates the driving signal based on the comparison signal and the constant

OFF duration denotation signal.

3. The current compensation device according to claim 2,
wherein the conversion unit includes a conversion resistor and a conversion capacitor, one terminal of the conversion resistor being connected to the control unit, another terminal of the conversion resistor being connected to the one terminal of the conversion capacitor, and another terminal of the conversion capacitor being grounded.
4. The current compensation device according to claim 3,
wherein the comparison unit includes a first op amplifier, the sensing voltage being connected to a positive input terminal of the first op amplifier, and a node between the conversion resistor and the conversion capacitor being connected to a negative input terminal of the first op amplifier.
5. The current compensation device according to claim 2,
wherein the constant OFF duration generation unit outputs the constant OFF duration denotation signal based on a constant OFF duration set by the control unit.
6. The current compensation device according to claim 2,
wherein the constant OFF duration generation unit outputs the constant OFF duration denotation signal based on the driving signal generated by the current compensation driving unit, and the constant OFF duration generation unit includes:

a timing circuit which is connected between a power supply voltage and a grounding and includes a timing resistor and a timing capacitor connected in series, wherein a terminal of the timing resistor is connected to the power supply voltage, and a terminal of the timing capacitor is grounded;

a discharge circuit which includes a discharge triode, a collector of the discharge triode being connected to a node between the timing resistor and the timing capacitor in the timing circuit, an emitter of the discharge triode being grounded, and a base of the discharge triode being controlled by the driving signal generated by the current compensation driving unit; and

a comparison circuit which includes a second op amplifier, the node between the timing resistor and the timing capacitor in the timing circuit being connected to a positive input terminal of the second op amplifier, and a comparison reference voltage being connected to a negative input terminal of the second op amplifier.

7. The current compensation device according to claim 2, wherein the latch and driving unit includes:

a latch circuit which includes a SR latch, the comparison signal being connected to a R input terminal of the SR latch, and the constant OFF duration denotation signal being connected to a S input terminal of the SR latch; and

a driving circuit, an input terminal of which is connected to a Q output terminal of the SR latch.

8. The current compensation device according to claim 1, wherein the ON/OFF data is OFF data corresponding to an OFF duration of the current control switch unit, and the current compensation driving unit includes:

a timing unit which outputs a variable OFF duration denotation signal based on the OFF data;

a comparison unit which compares a constant reference voltage with the sensing voltage to input a comparison signal; and

a latch and driving unit which generates the driving signal based on the comparison signal and the variable OFF duration denotation signal.

9. The current compensation device according to claim 8,
5 wherein the comparison unit includes an op amplifier, the sensing voltage being connected to a positive input terminal of the op amplifier, and a constant reference voltage being connected to a negative input terminal of the op amplifier.

10 10. The current compensation device according to claim 8,
wherein the latch and driving unit includes:

a latch circuit which includes a SR latch, the comparison signal being connected to a R input terminal of the SR latch, the variable OFF duration denotation signal being
15 connected to a S input terminal of the SR latch, and a Q output terminal of the SR latch outputting an enable signal to the timing unit; and

a driving circuit, an input terminal of which is connected to a Q output terminal of the SR latch.

20 11. A lighting apparatus comprising:

a power supply unit;

a plurality of lighting units connected in series with each other powered by the power supply unit;

at least one lighting switch unit, each of which is connected in parallel with corresponding one of the plurality
25 of lighting units;

an energy storage unit which is connected in series to the plurality of lighting units;

a current control switch unit which is connected in series
30 to the energy storage unit;

an unidirectional current conduction unit which is connected in parallel with the plurality of lighting units and the energy storage unit; and

a voltage sensing unit which is connected in series to the current control switch unit to sense a sensing voltage corresponding to a current flowing through the plurality of lighting units when the current control switch unit is turned on,

characterized in that the lighting apparatus further comprises:

a current compensation device according to any of claims 1-10 which controls ON/OFF of the current control switch unit based on the sensing voltage and an OFF duration of the current control switch unit.

12. The lighting apparatus according to claim 11, wherein the driving signal generated by the current compensation driving unit is a switching signal.

13. The lighting apparatus according to claim 11, wherein the control unit provides a control signal to each lighting switch unit to control ON/OFF of each lighting switch unit.

14. The lighting apparatus according to claim 13, wherein the control signal is a Pulse Width Modulation signal, and the control unit controls the lighting effect of the lighting apparatus through the control signal.

15. The lighting apparatus according to claim 11, wherein each of the plurality of lighting units includes one LED or a plurality LEDs connected in series.

16. The lighting apparatus according to claim 11, wherein the lighting switch unit includes a switch device.

17. The lighting apparatus according to claim 11, wherein the

energy storage unit includes an inductor.

18. The lighting apparatus according to claim 11, wherein the current control switch unit includes a MOSFET device.

19. The lighting apparatus according to claim 11, wherein the
5 unidirectional current conduction unit includes a diode,
an anode of the diode being connected to the energy storage unit, and a cathode of the diode being connected to the power supply unit.

20. The lighting apparatus according to claim 11, wherein the
10 voltage sensing unit includes a sensing resistor.

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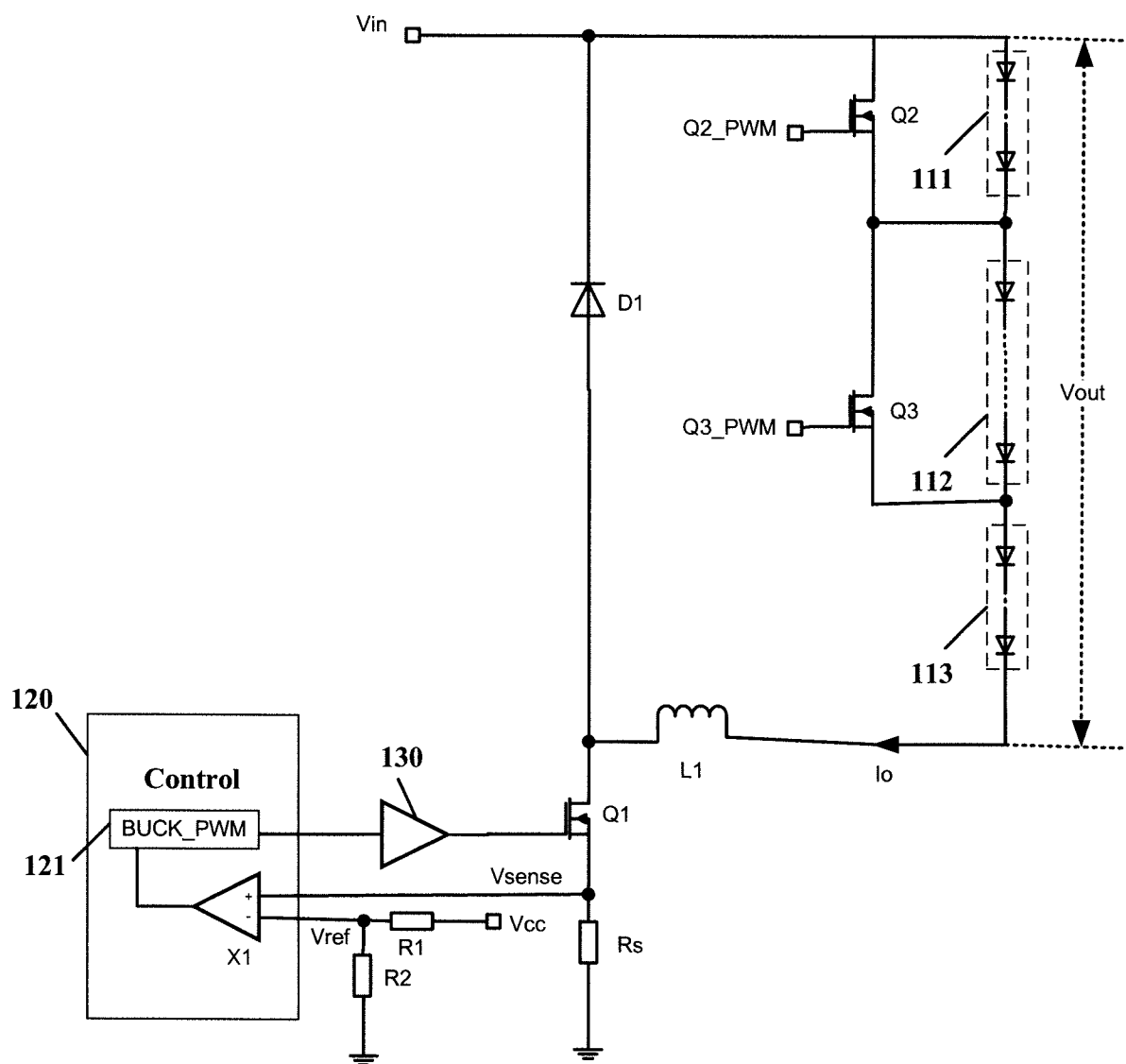


FIGURE 1

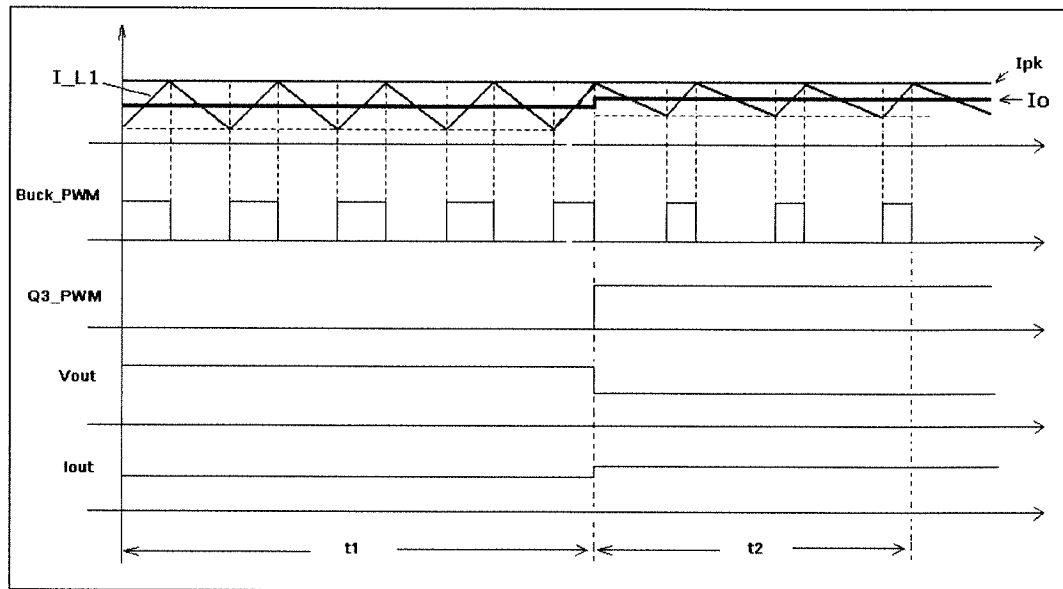


FIGURE 2

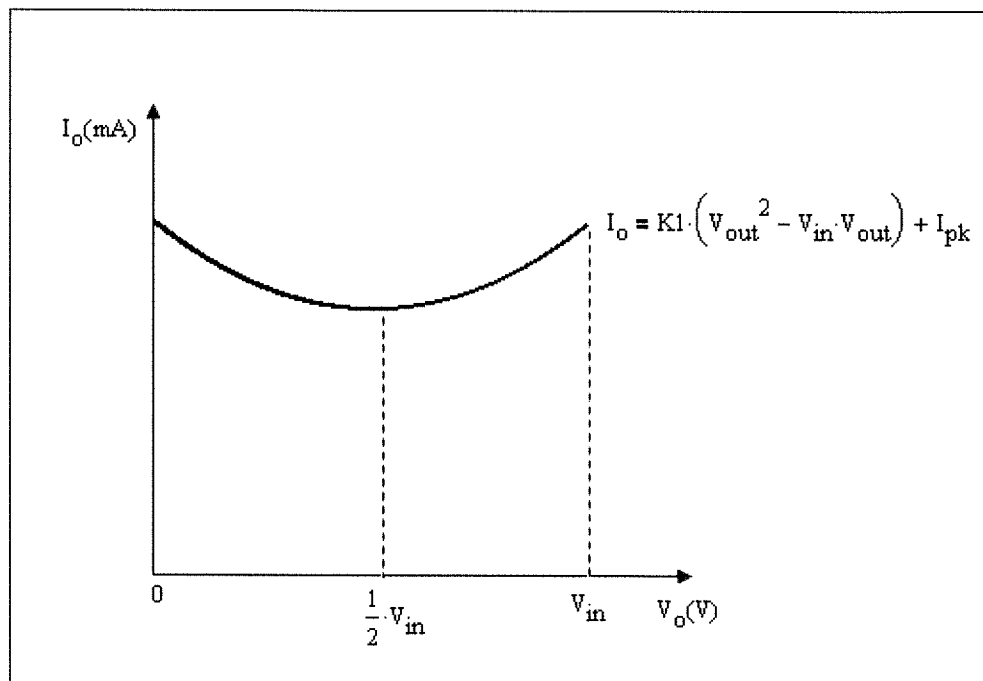


FIGURE 3

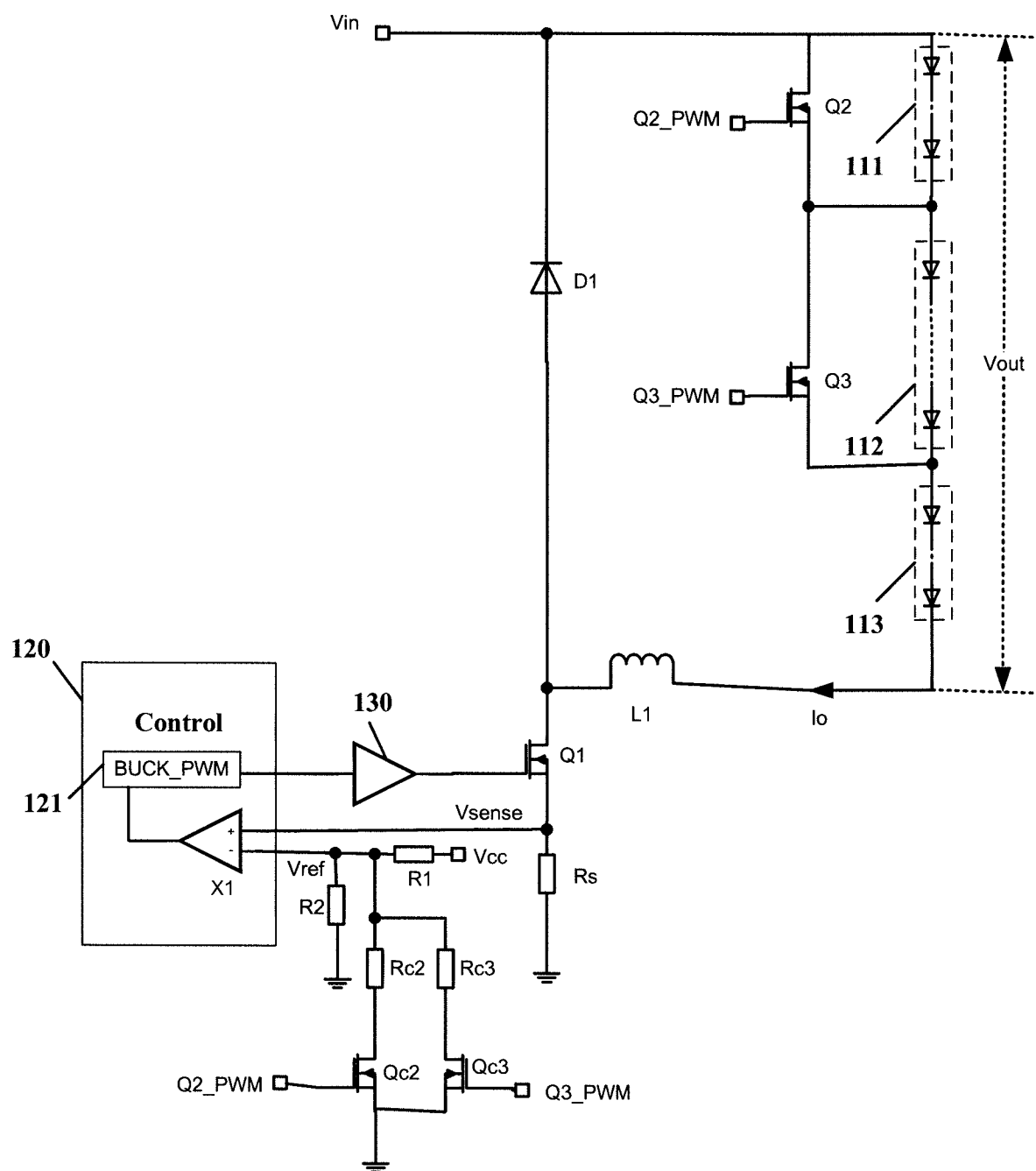
200

FIGURE 4

300

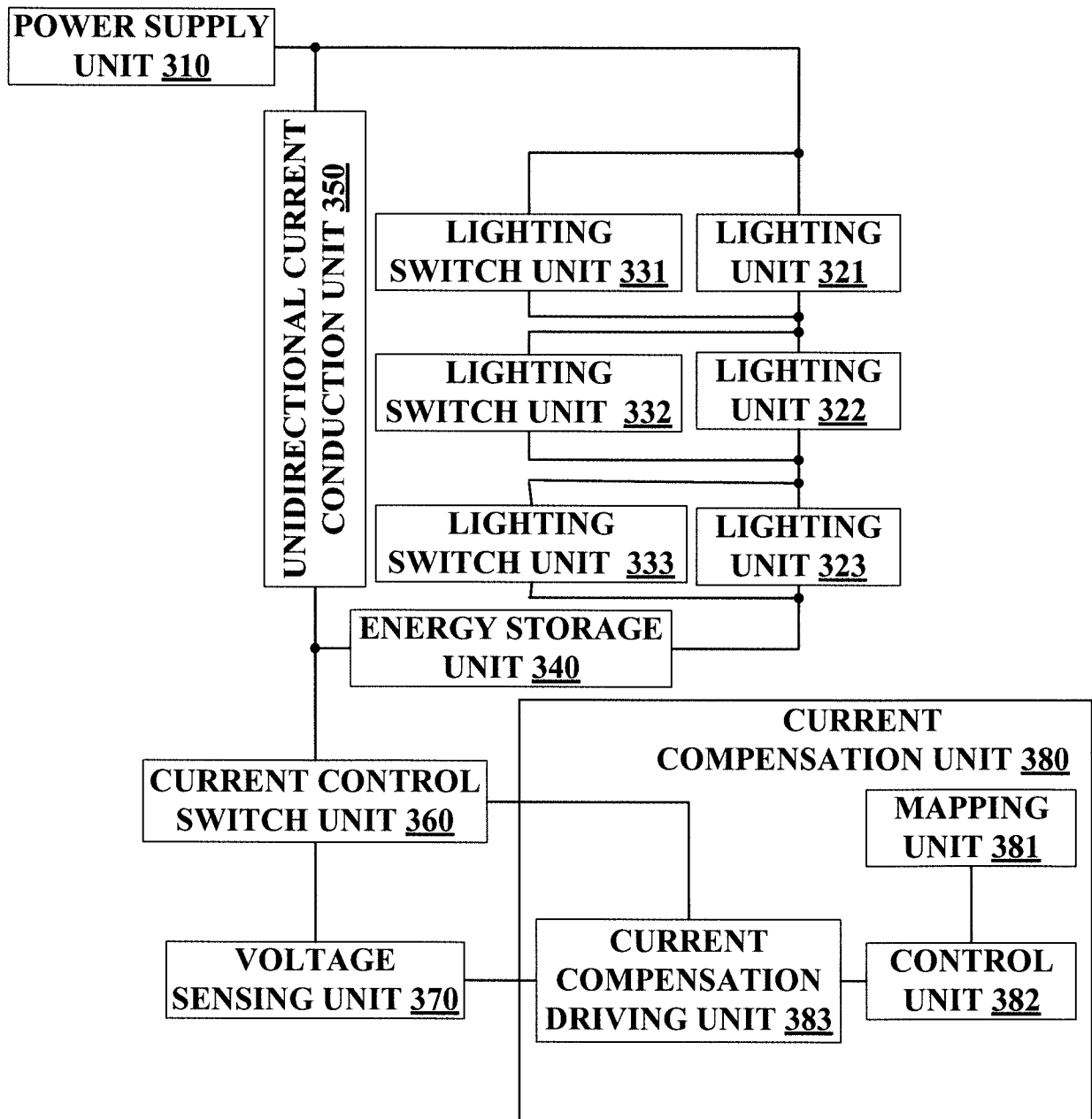


FIGURE 5

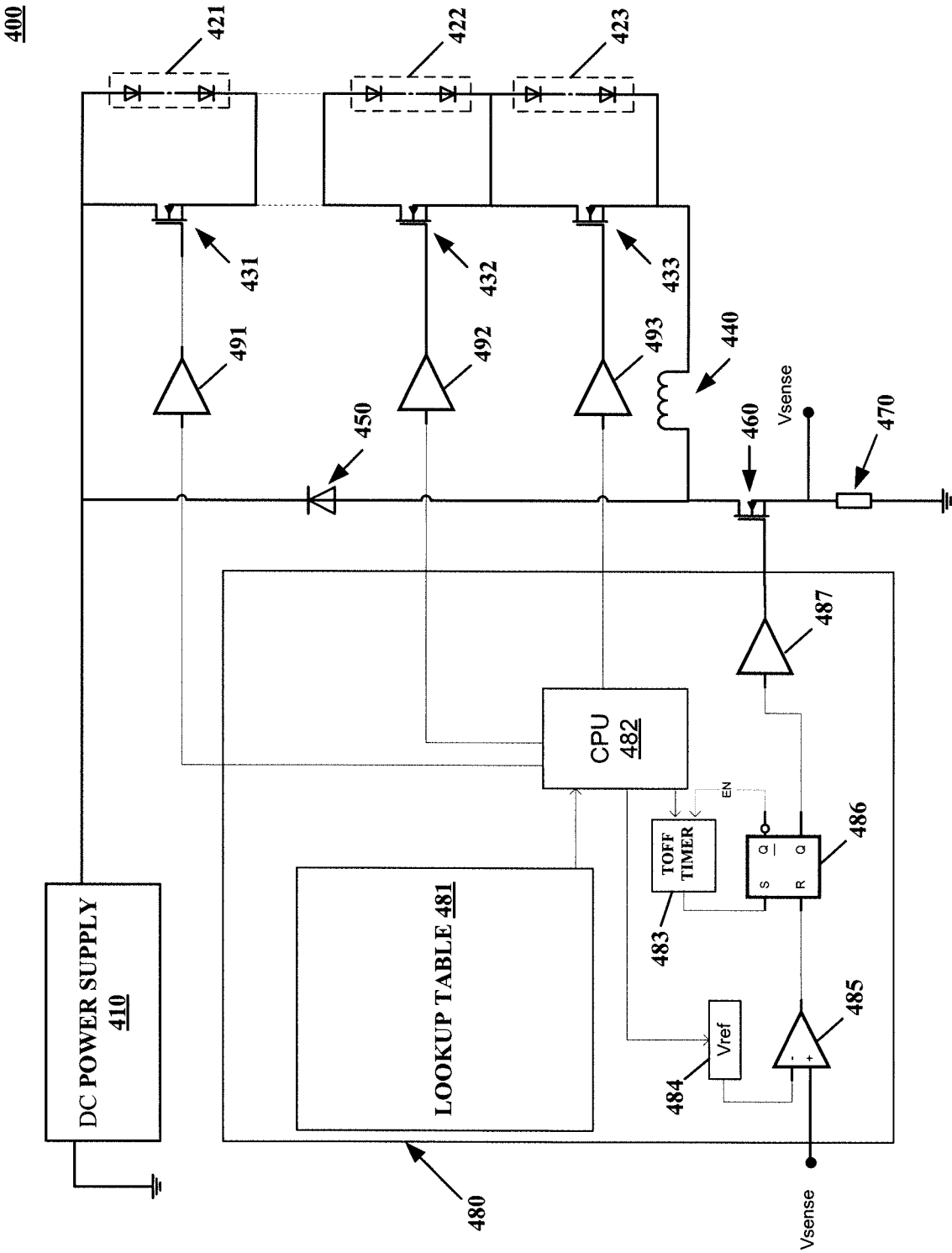


FIGURE 6

V_LED	Toff
String1+String2+string_3	131
String1+String2	180
String2+string_3	175
String1+string_3	152
String1	220
String 2	200
String 3	230

FIGURE 7

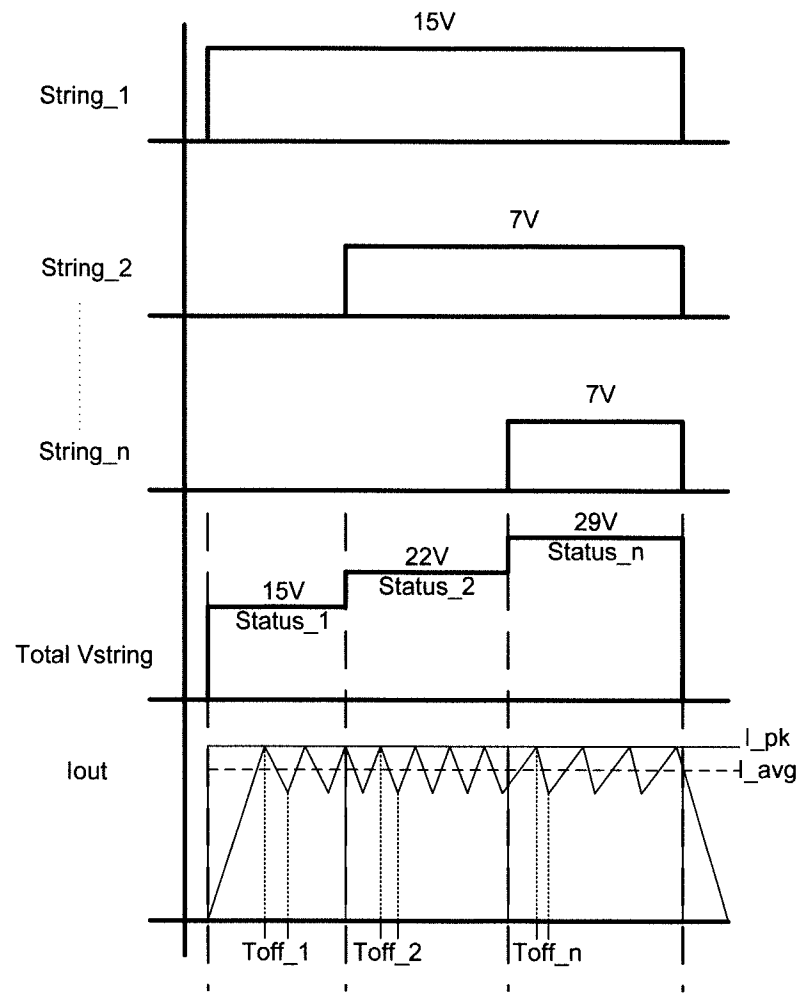


FIGURE 8

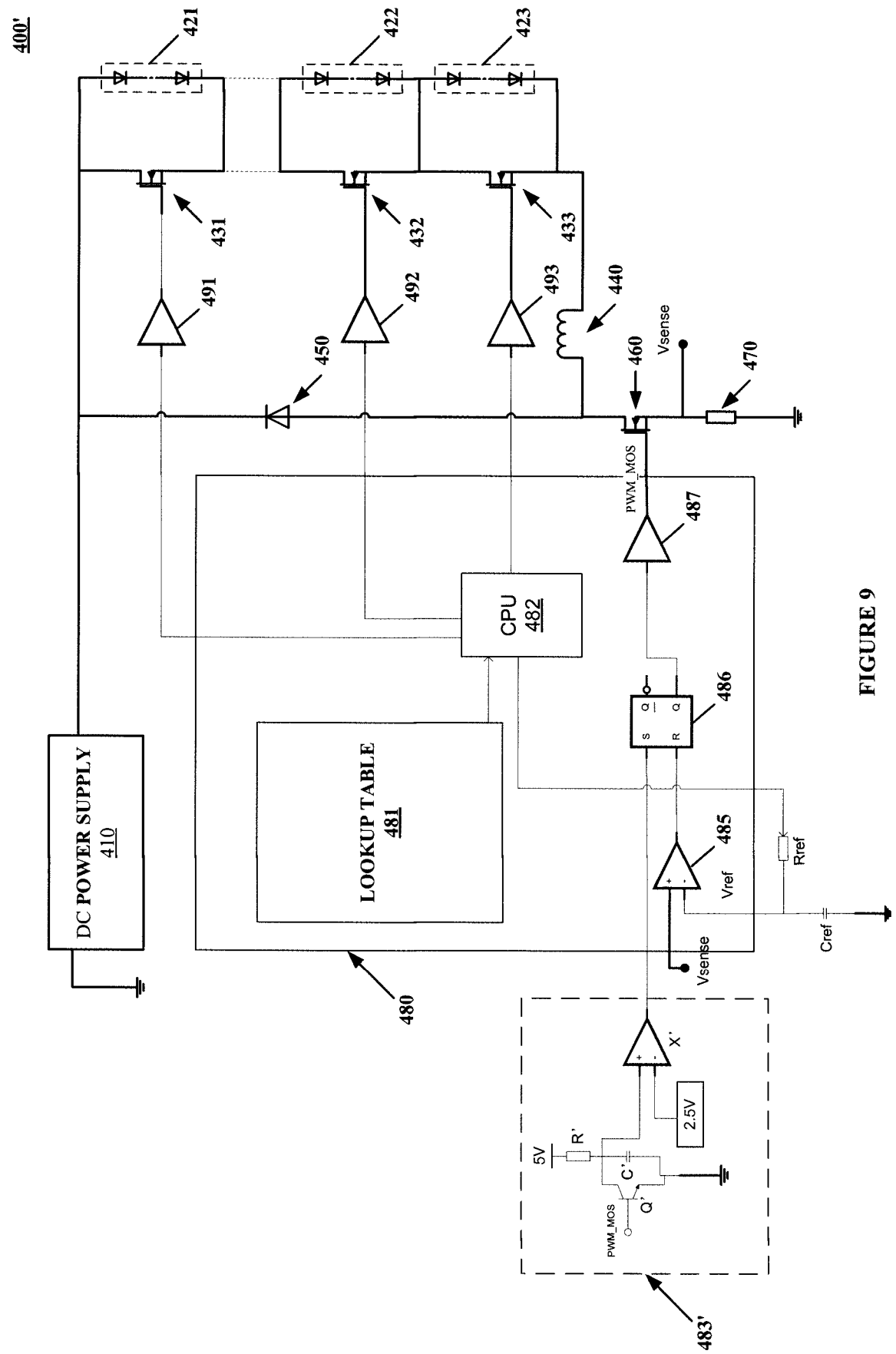


FIGURE 9

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2013/075420

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)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/095865 A2 (NXP BV [NL]; HOOGZAAD GIAN [NL]) 6 August 2009 (2009-08-06) abstract page 3, line 19 - page 17, line 2; figures 1-16 page 21, line 8 - page 49, line 32 -----	1-20
X	WO 2009/157763 A2 (ELDOLAB HOLDING BV [NL]; WELTEN PETRUS JOHANNES MARIA [NL]) 30 December 2009 (2009-12-30) the whole document -----	1-20
X	WO 2007/069200 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; VAN ERP JOSEPHUS A M [NL]) 21 June 2007 (2007-06-21) the whole document ----- -/--	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

28 February 2014

Date of mailing of the international search report

12/03/2014

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2013/075420

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

International application No

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