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Fang et al.

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(54) **LED DRIVER**

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H05B 37/02 (2006.01)
H05B 33/08 (2006.01)

(52) **U.S. Cl.**
CPC ***H05B 33/0815*** (2013.01); ***H05B 33/0812*** (2013.01); ***H05B 33/0824*** (2013.01); ***H05B 33/0845*** (2013.01); ***H05B 33/0887*** (2013.01); ***H05B 37/02*** (2013.01)

(58) **Field of Classification Search**
CPC H05B 33/08; H05B 37/02; H05B 33/0815; H05B 33/0824; H05B 33/0887; H05B 33/0812; H05B 33/0845
USPC 315/291, 294, 307, 308
See application file for complete search history.

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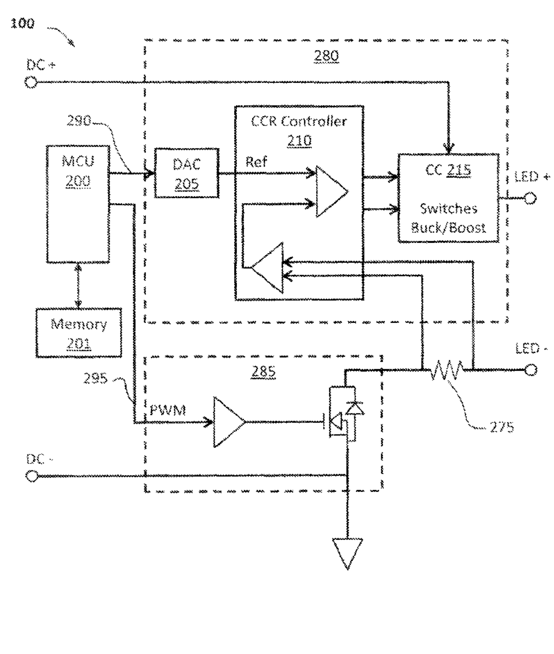
(57) **ABSTRACT**

Dimming or illumination control of an LED-based lighting fixture can utilize a combination of pulse width modulation and constant current reduction. A light emitting diode driver can implement pulse width modulation to control light over a first light intensity range and constant current reduction over a second light intensity range. The first light intensity range can be less intense than the second light intensity range. Thus, the driver can practice constant current reduction for dimming at higher light intensities and pulse width modulation for dimming at lower light intensities.

18 Claims, 5 Drawing Sheets



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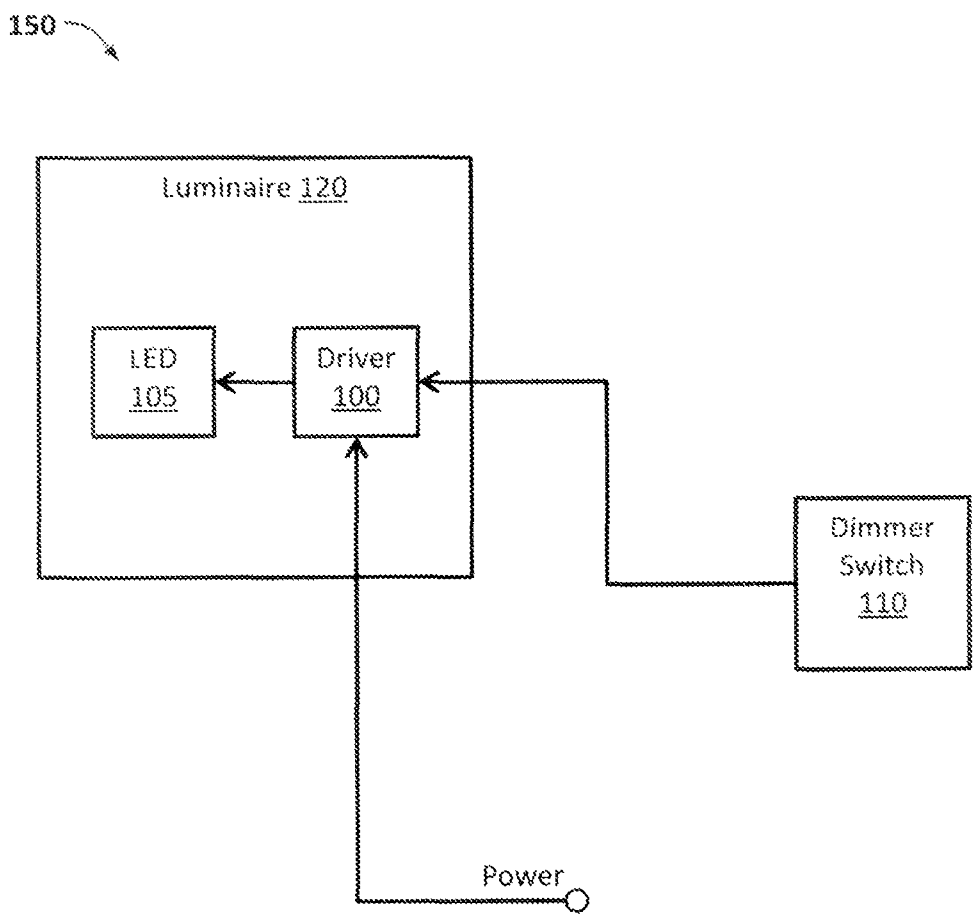
150
Luminaire 120
LED
105
Driver
100
Dimmer
Switch
110
Power

FIG. 1

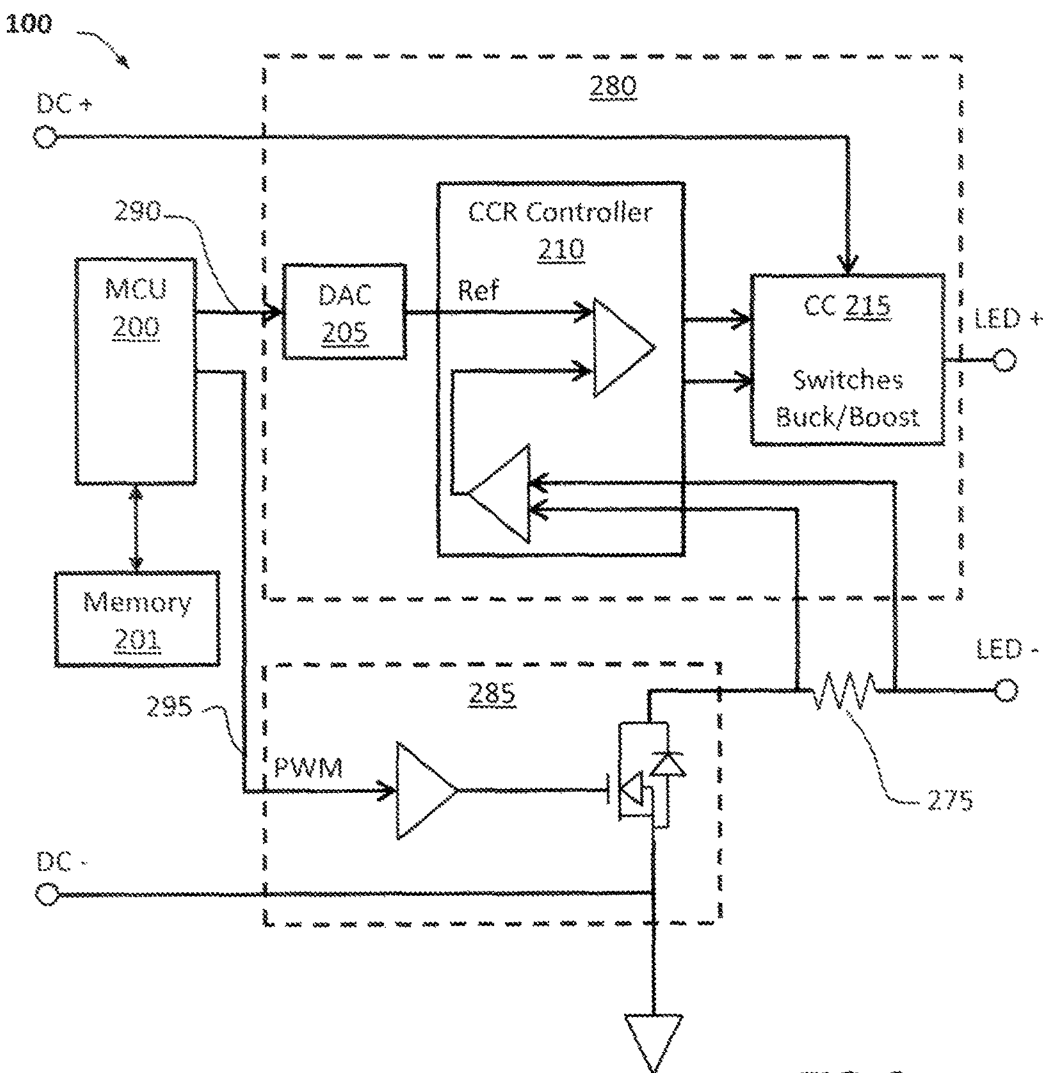
100
280
DC +
290
MCU
200
DAC
205
CCR Controller
210
Ref
CC 215
Switches
Buck/Boost
LED +
Memory
201
LED -
295
285
PWM
275
DC -

FIG. 2

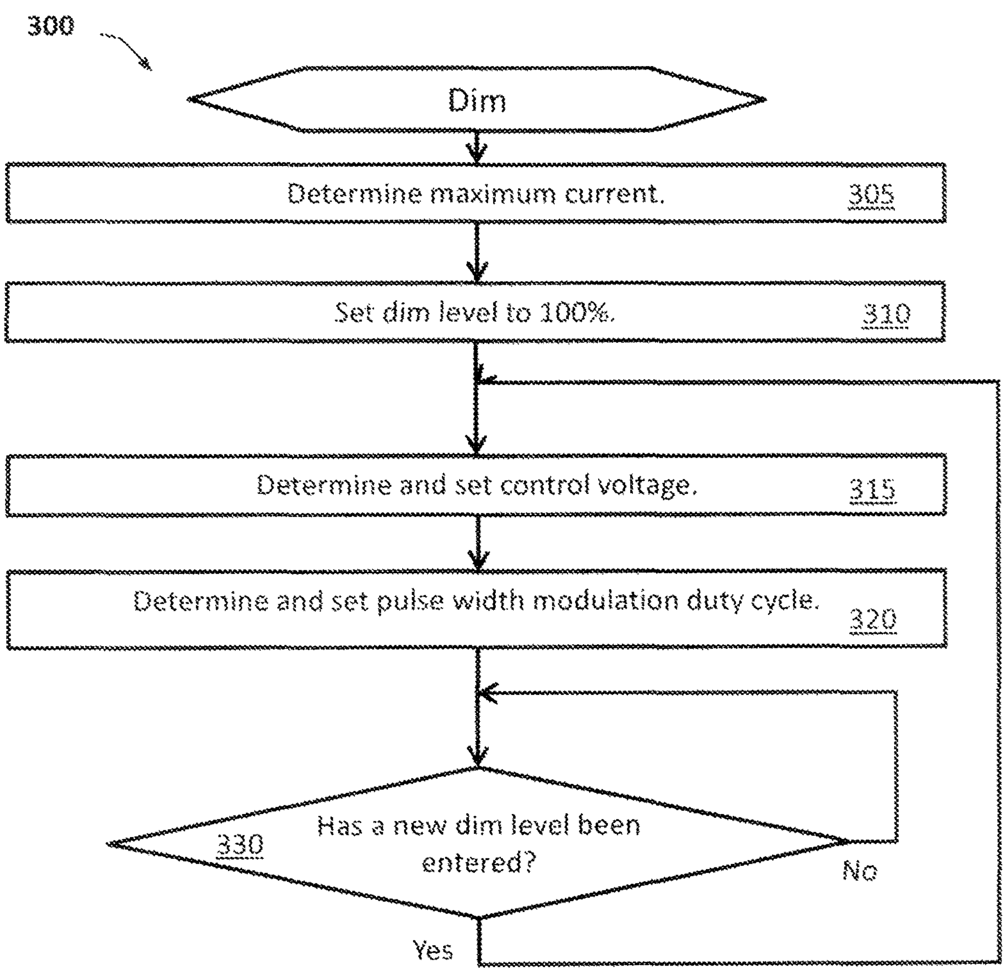
300
Dim
Determine maximum current.
305
Set dim level to 100%.
310
Determine and set control voltage.
315
Determine and set pulse width modulation duty cycle.
320
330
Has a new dim level been entered?
No
Yes

FIG. 3

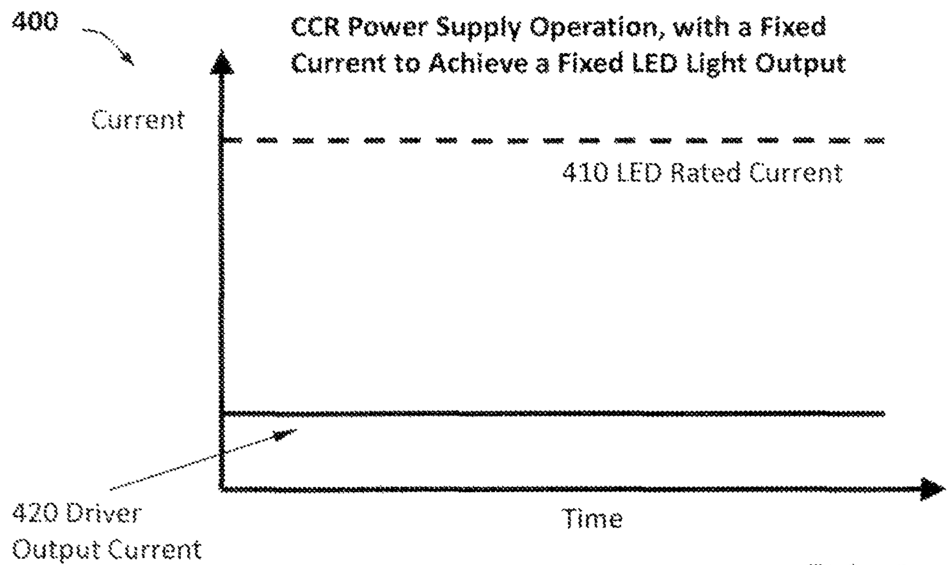
400
CCR Power Supply Operation, with a Fixed Current to Achieve a Fixed LED Light Output
Current
410 LED Rated Current
420 Driver Output Current
Time

FIG. 4

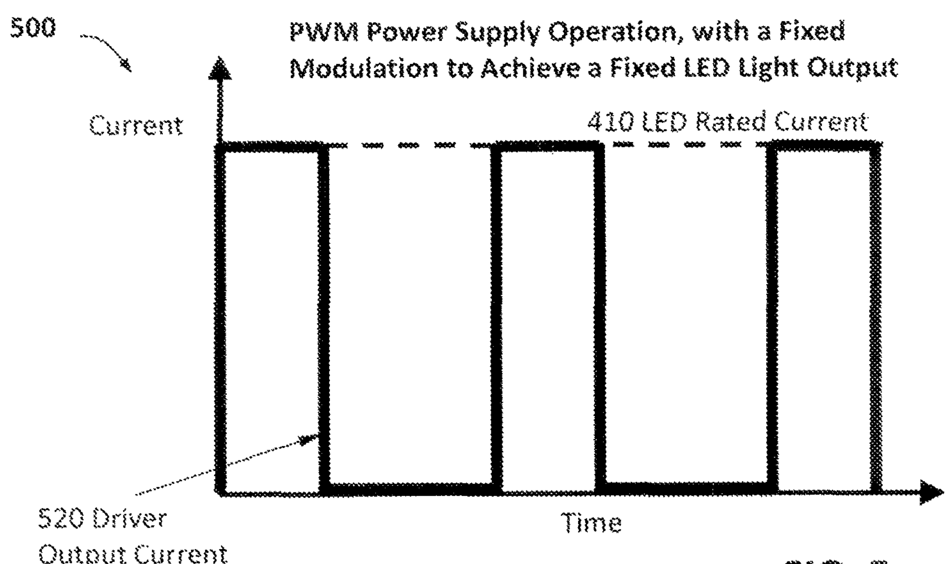
500
PWM Power Supply Operation, with a Fixed Modulation to Achieve a Fixed LED Light Output
Current
410 LED Rated Current
520 Driver Output Current
Time

FIG. 5

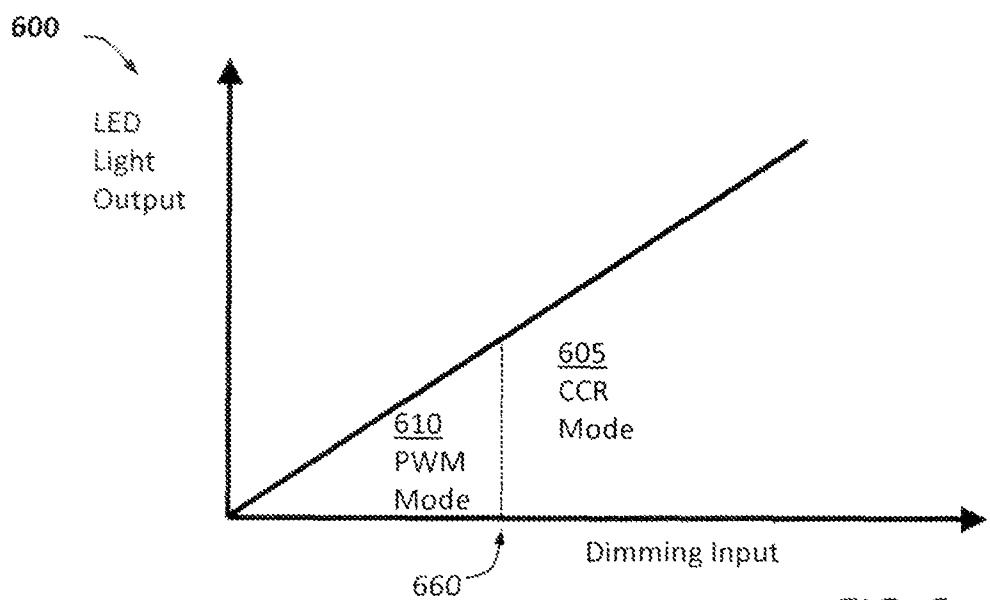
600
LED
Light
Output
605
CCR
Mode
610
PWM
Mode
Dimming Input
660

FIG. 6

LED DRIVER

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application No. 62/045,584 filed Sep. 4, 2014 in the name of Liang Fang, William Lee Shiley, James Moan, and James Christopher Andrews and entitled "LED Driver," the entire contents of which are hereby incorporated herein by reference.

TECHNICAL FIELD

Embodiments of the technology relate generally to a system for powering one or more light emitting diodes (LEDs), and more specifically to utilizing a combination of pulse width modulation (PWM) and constant current reduction (CCR) for dimming across a range of intensities.

BACKGROUND

For illumination applications, light emitting diodes (LEDs) offer substantial potential benefit associated with their energy efficiency, light quality, and compact size. However, to realize the full potential benefits offered by light emitting diodes, new technologies are needed. For instance, relative to incandescent lights, light emitting diodes typically have different electrical characteristics that warrant different dimming approaches.

Accordingly, there are needs in the art for technology to manage illumination produced by one or more light emitting diodes. Need exists for technology to dim a light emitting diode, so that a user can adjust output of a light emitting diode to provide a desired level of illumination. Need further exists for fine adjustment of a light emitting diode's light output across a wide range of intensities. A capability addressing one or more such needs, or some other related deficiency in the art, would support improved illumination systems and more widespread utilization of light emitting diodes in lighting applications.

SUMMARY

In one aspect of the disclosure, a lighting system can comprise a luminaire and a dimmer switch that controls the luminaire. The luminaire can comprise at least one light emitting diode and a driver for the light emitting diode. The driver can utilize a combination of pulse width modulation and constant current reduction to control the level of illumination emitted by the light emitting diode according to input from the dimmer switch. For example, pulse width modulation can control a lower intensity range of the light emitting diode and constant current reduction can control an upper intensity range of the light emitting diode.

The foregoing discussion of certain aspects of the disclosure is for illustrative purposes only. Various aspects of the technology may be more clearly understood and appreciated from a review of the following text and by reference to the associated drawings and the claims that follow. Other aspects, systems, methods, features, advantages, and objects of the present technology will become apparent to one with skill in the art upon examination of the following drawings and text. It is intended that all such aspects, systems, methods, features, advantages, and objects are to be included within this description and covered by this application and by the appended claims of the application.

BRIEF DESCRIPTION OF THE FIGURES

Reference will be made below to the accompanying drawings.

FIG. **1** illustrates an example lighting system in accordance some embodiments of the disclosure.

FIG. **2** illustrates a functional block diagram for an example of a light emitting diode driver in accordance with some embodiments of the disclosure.

FIG. **3** illustrates an example of a process for controlling electricity for a light emitting diode in connection with dimming in accordance some embodiments of the disclosure.

FIG. **4** illustrates an example plot for operating a light emitting diode under a constant current reduction mode in connection with dimming in accordance some embodiments of the disclosure.

FIG. **5** illustrates an example plot for operating a light emitting diode under a pulse width modulation mode in connection with dimming in accordance some embodiments of the disclosure.

FIG. **6** illustrates an example plot for operating a light emitting diode under a combination of pulse width modulation and constant current reduction modes in accordance some embodiments of the disclosure.

The drawings illustrate only example embodiments and are therefore not to be considered limiting of the embodiments described, as other equally effective embodiments are within the scope and spirit of this disclosure. The elements and features shown in the drawings are not necessarily drawn to scale, emphasis instead being placed upon clearly illustrating principles of the embodiments. Additionally, certain dimensions or positionings may be exaggerated to help visually convey certain principles. In the drawings, similar reference numerals among different figures designate like or corresponding, but not necessarily identical, elements.

DESCRIPTION OF EXAMPLE EMBODIMENTS

As will be discussed in further detail below, dimming an LED-based lighting fixture utilizing a combination of pulse width modulation and constant current reduction can support fine control of light intensity over a broad intensity range. Additionally, the pulse width modulation and constant current reduction can be implemented utilizing instructions stored in memory, such as firmware, and executed by a microprocessor or other controller.

In certain embodiments of the disclosure, driver current for one or more light emitting diodes can be set over a wide range via firmware, for example between 0.2 amps to 2.5 amps. Further, one or more light emitting diodes can be driven smoothly and/or continuously across a dimming range, for example between 100 percent and 1 percent.

In some example embodiments, a point of load (POL) DC-to-DC controller can increase or decrease direct current (DC) voltage to match a light emitting diode's forward voltage and overcome any line losses. The term "point of load DC-to-DC controller," as used herein, generally refers to a DC-to-DC voltage controller that is regulated according to feedback at the load, for example according to a sense resistor.

The term "forward voltage," as used herein in reference to a light emitting diode, refers to a threshold voltage applied between the light emitting diode's anode and cathode (with the anode voltage at a higher potential than the cathode voltage) that causes the light emitting diode to conduct current (and thus typically emit light).

In some embodiments of the disclosure, a DC/DC buck/boost circuit can implement the DC voltage adjustments. The circuit can function under (and switch among) buck mode, boost mode, and buck/boost mode according to input voltage, for example. A buck/boost converter is a type of DC-to-DC converter that exhibits an output voltage magnitude that is either greater than or less than its input voltage magnitude.

In some embodiments, the driver can utilize constant current reduction in higher current ranges in order to limit acoustic noise from the fixture. In some embodiments, constant current reduction can be utilized between 2.5 amps and 0.8 amps of current, for example.

The term constant current reduction (CCR), as used herein in reference to a light emitting diode, generally refers to gradually reducing output of the light emitting diode by making corresponding gradual reduction in the current flowing into the light emitting diode. In example embodiments, analog or linear dimming are within the scope of the term 'constant current reduction.' In some example embodiments, constant current reduction may be implemented using a current profile that comprises voltage or current steps.

In some embodiments of the disclosure, the driver may further utilize pulse width modulation (PWM) for dimming at lower intensities, thereby achieving smooth and accurate control of light level. For example, in one embodiment, pulse width modulation initiates for current below 0.8 amps.

The term "pulse width modulation," as used herein in reference to a light emitting diode, generally refers to controlling the intensity of light that the light emitting diode emits by feeding the light emitting diode pulses of electricity, where the light emitting diode generates light during each pulse and is off between pulses. Thus, light output can be increased by extending the duration of each pulse or by shortening the time between each pulse. And, light output can be decreased by shortening the duration of each pulse or by extending the time between each pulse.

In some example embodiments, a process executed from firmware-based instructions selects and sets driver output current that feeds a light emitting diode. In some such embodiments, the driver operates between 2.5 amps and 0.2 amps without any hardware changes. In other words, instructions executing on a controller or microprocessor can control the output of a commercially available light emitting diode driver so that the driver supplies pulse width modulated power at certain times and constant current power at other times. For example, a microprocessor and a digital-to-analog converter (DAC) can vary the voltage so that the hardware remains fixed while controlling light emitting diode current throughout a target range. Accordingly, accuracy and resolution of the microprocessor and the digital-to-analog converter can provide precise light intensity control and fine intensity adjustment.

For example, in accordance with the data shown in Table 1 below, a light emitting diode current (I_{LED}) can be programmed by the sense resistor **275** ($R_{LEDsense}$), in series with the LED strings. The Ref in CCR Controller **210** (Vctrl) would typically be higher than a threshold (here we use the example value of 1.3 Volts) to get the full-scale 100 mV threshold across the sense resistor. Vctrl can also be used to adjust the I_{LED}. When the Vctrl voltage is less than the threshold, I_{LED}=(Vctrl−200 mV)/(10×$R_{LEDsense}$). When the Vctrl voltage is higher than the threshold, the I_{LED} is regulated to I_{LED}=100 mV/$R_{LEDsense}$. In the Table 1, $R_{LEDsense}$ is 40 mΩ, which is an example value.

The term "sense resistor," as used herein in reference to a light emitting diode, generally refers to a resistor that is in a path of current flowing through the light emitting diode, where voltage across the sense resistor correlates to current flowing through the sense resistor.

Accordingly, a circuit (which can comprise a hardware implementation with accompanying code) can control light emitting diode current throughout a broad target range of intensities. For example, if $R_{Ledsense}$=40 mΩ, when V_{CTRL}≥1.3 Vdc, then I_{LED} (amp)=100 mV/40 mΩ=2.50 amps.

TABLE 1

V_{CTRL} vs. I_{Led}

V_{CTRL} (mV)	I_{LED} (amp)
≥1300	2.5
1160	2.4
1120	2.3
1080	2.2
1040	2.1
1000	2.0
960	1.9
920	1.8
880	1.7
840	1.6
800	1.5
760	1.4
720	1.3
680	1.2
640	1.1
600	1.0
560	0.9
520	0.8
480	0.7
440	0.6
400	0.5
360	0.4
320	0.3
280	0.2

Continuing with the example, the microprocessor operating voltage is 3.3 V DC. Since 10 bit resolution of a 3.3 V DC rail is 3300 mV/1024=3.2 mv/bit, 280 mV control voltage can be provided within 1.1% (3.2 mv/280 mV=1.1%) accuracy.

Representative embodiments can support a hybrid dimming approach. In other words, the driver circuit can utilize constant current reduction and pulse width modulation in combination, either sequentially or concurrently.

For example, constant current reduction can initiate above 0.8 amps of drive current (or some other appropriate threshold set in firmware), and pulse width dimming can be utilized below 0.8 amps of drive current. As discussed above, the microprocessor and associated digital-to-analog converter can set the control voltage.

Some example parameters for one representative embodiment of a driver circuit follow immediately below, without limitation:

- DC/DC switching frequency is 300 KHz. Minimum PWM pulse is at least 6 switching cycles (that is 300 KHz/6=50 KHz), and the period of 50 KHz is 20 μs.
- Assume PWM frequency is 200 Hz, the waveform has a period of 5,000 μs.
- If I_{LED} (the current flowing through the light emitting diode) is 0.825 amps, through PWM, the minimum I_{LED} is 825 mA*20/5000=3.3 mA. Dimming depth is 3.3/825=0.4%.

If I_{LED} is 0.2 amps, through PWM, the minimum I_{LED} is 200 mA*20/5000=0.8 mA. Dimming depth is 0.8/200=0.4%.

Accordingly, a combination of constant current reduction and pulse width modulation can achieve sufficient dimming depth.

Some representative embodiments will be further described hereinafter with example reference to the accompanying drawings that describe representative embodiments of the present technology. The technology may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the technology to those appropriately skilled in the art.

Referring now to FIG. **1**, this figure illustrates an example lighting system **150** in accordance some embodiments of the disclosure. A luminaire **120** of the lighting system **150** comprises at least one light emitting diode **105** and a driver **100**. In some example embodiments, the luminaire **120** comprises a single light emitting diode **105**, for example a chip-on-board (CIB) light emitting diode. In some other embodiments, the luminaire **120** comprises two or more light emitting diodes **105**, which may be configured in an array or other appropriate arrangement.

The driver **100** receives a dimming signal from a dimmer switch **110** and controls the electrical feed to the light emitting diode **105** according to the dimming signal. In some embodiments, the driver **100** receives and is powered by DC electricity. In some other embodiments, the driver **100** receives and is powered by alternating current (AC) electricity.

As discussed above, the driver **100** controls the level of light emitted by the light emitting diode **105** using a combination of pulse width modulation and constant current reduction. For dimming across an upper portion of the light emitting diode's intensity range, the driver **100** can dim using constant current reduction. For diming across a lower portion of the light emitting diode's intensity range, the driver **100** can dim using pulse width reduction.

Accordingly, when the dimmer switch **110** prompts the driver **100** to control the light emitting diode **105** to emit light lower a threshold level, the driver **100** can output pulse width modulated current. And when the dimmer switch **110** prompts the driver **100** to control the light emitting diode **105** to emit light above the threshold level, the driver **100** can output constant current reduction current. In an example embodiment, the threshold level represents a point at which the driver switches between using constant current reduction to control the light emitted from the light emitting diode **105** and using pulse width modulation to control the light emitted from the light emitting diode **105**.

Referring now to FIG. **2**, this figure illustrates a functional block diagram for an example of the driver **100** illustrated in FIG. **1** in accordance with some embodiments of the disclosure. As illustrated, the driver **100** comprises a microcontroller **200** that can execute a dimming process for the light emitting diode(s) **105** via implementing a combination of pulse width modulation and constant current reduction as discussed above and below. As further discussed below, the dimming process can be represented by executable code or software stored in firmware or other appropriate memory **201** associated with the microcontroller **200**, so that the microcontroller **200** can readily access and execute the code.

The microcontroller **200** has two outputs **290**, **295**. The output **295** of the microcontroller **200** feeds a pulse width modulation branch **285** of the driver **100**. Meanwhile, the output **290** of the microcontroller **200** feeds a constant current reduction branch **280** of the driver **100**.

The constant current reduction branch **280** includes a digital-to-analog converter **205** that feeds a target reference signal to a constant current reduction controller **210**. More specifically, the microcontroller **200** sends a digital signal to the digital-to-analog converter **205** over the output **290**. The digital-to-analog converter **205** then transforms that digital signal into a corresponding analog signal, typically a voltage that represents a target current flowing through the light emitting diode **105**.

The constant current reduction controller **210** receives a voltage from a sense resistor **275** indicative of the current flowing through the light emitting diode **105**. The constant current reduction controller **210** compares the voltage produced by the digital-to-analog converter **205** to the voltage across the sense resistor **275**. The constant current reduction controller **210** then uses the buck/boost switches **215** to adjust the current flowing the light emitting diode **105** (which flows through the sense resistor **275**) until the voltages match. When the voltages match, the light emitting diode **105** is receiving the target amount of current and thus produces the target level of light as set by the dimmer switch **100**. Thus, the sense resistor **275** provides a feedback control signal.

Turning now to FIG. **3**, this figure illustrates an example of a process **300** for controlling electricity for a light emitting diode **105** in connection with dimming in accordance some embodiments of the disclosure. As discussed above, process **300** can implement a combination of constant current reduction and pulse width modulation. Instructions for the process **300** can be stored in firmware **201** or other memory associated with the microcontroller **200** and executed by a microprocessor of the microcontroller **200**.

At block **305** of process **300**, maximum current is determined. Maximum current may be determined from a specification sheet provided by a manufacturer of the light emitting diode **105** or via laboratory testing, for example. In an example embodiment, the maximum current equates to a rated current **410**, as illustrated in FIGS. **4** and **5** and discussed below.

At block **310**, the dim level for the light emitting diode(s) **105** is set to a predetermined value, which is illustrated as 100 percent. Execution of block **310** can be viewed as initializing process **300**.

At block **315**, the microcontroller **200** determines and sets a control voltage according to diming input from the dimmer switch **110**, as discussed above. For example, a person may manually manipulate the dimmer switch **110**, causing the dimmer switch to provide a command dimming input to the microcontroller. The input is initialized as 100 percent per block **310**, and is updated based on inquiry step **330**, discussed below.

At block **320**, the microcontroller **200** sets an appropriate pulse width modulation duty cycle in order to achieve the desired illumination as discussed above. The pulse width modulation duty cycle can set a pulse width to achieve a target light output, for example.

Inquiry block **330** determines if the dimming level has been changed, for example by a new manual entry at the dimmer switch **110**. If the dimming setting remains unchanged, process **300** iterates the inquiry. When a new diming setting is detected, process **300** loops back to block **315** and executes blocks **315** and **320** to implement constant current reduction and/or pulse width modulation for precise dimming of the luminaire **120**.

Turning now to FIG. **4**, this figure illustrates an example plot **400** for operating the light emitting diode **105** under a constant current reduction mode in connection with dimming in accordance some embodiments of the disclosure. As discussed above, the lighting system **150** can practice constant current reduction to control intensity above a threshold, for example.

As illustrated in plot **400**, the light emitting diode **105** has a maximum or rated current **410**, at or below which the constant current is supplied. In the plot **400**, the driver output current **420** is set to a specific value that causes the light emitting diode **105** to produce a corresponding level of light. As illustrated, the driver maintains the driver output current **420** at this value for the time span illustrated in FIG. **4**. To change the light output from the light emitting diode **105**, the driver **100** will increase or decrease the driver output current **420**. The changes to the driver output current **420** may be ramped either in a smooth or linear fashion, or stepwise, for example.

Turning now to FIG. **5**, this figure illustrates an example plot **500** for operating the light emitting diode **105** under a pulse width modulation mode in connection with dimming in accordance some embodiments of the disclosure. As discussed above, the lighting system **150** can practice pulse width modulation to control intensity below a threshold, for example.

As illustrated in plot **500**, the light emitting diode **105** has a maximum or rated current **410**, at which the driver **100** pulses the driver output current **520**. In the illustrated embodiment, the driver output current **520** steps or switches between an off state and an on state at the rated current **401**. Accordingly, the light emitting diode **105** is effectively switching or cycling off and on. The fraction of time that the light emitting diode **105** is in the on state during a given period of time determines the average intensity for that period of time and thus perceived intensity.

In the plot **500**, the pulse width modulation of the driver output current **520** is set to a specific value that causes the light emitting diode **105** to produce a corresponding level of light. As illustrated, the driver maintains the driver output current **420** at this value for the time span illustrated in FIG. **5**. To change the light output from the light emitting diode **105**, the driver **100** increases or decreases the amount of time that the driver output current **420** is in the on state relative to the off state. The driver **100** may increase or decrease the duration of each pulse to increase or decrease average light intensity from the light emitting diode **105**, for example.

Turning now to FIG. **6**, this figure illustrates an example plot **600** for operating the light emitting diode **105** under a combination of pulse width modulation and constant current reduction modes **605**, **610** in accordance some embodiments of the disclosure. As illustrated in the plot **600**, the driver **100** operates the light emitting diode **105** under the pulse width modulation mode **610** for lower intensities and under the constant current reduction mode **605** for higher intensities.

In one example embodiment, the transition **660** between the pulse width modulation mode **610** and the constant current reduction mode **605** can occur at a light level below 10 percent of maximum light output, such as in a range of approximately 0.25 percent of maximum to approximately 5 percent of maximum. Various other ranges and values may be utilized in some applications. Input from the dimmer switch **110** may trigger the transition **660**, for example.

Many modifications and other embodiments of the disclosures set forth herein will come to mind to one skilled in the art to which these disclosures pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the disclosures are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of this application. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

What is claimed is:

1. A system comprising:

an input configured to receive a first signal indicating desired intensity;

an output configured to emit a second signal that conveys electricity for powering a light source according to the desired intensity; and

a circuit for producing the second signal, the circuit connected to the input and the output and comprising:

a processor; and

memory storing a program for execution by the processor, the program comprising instructions for performing the steps of:

comparing the desired intensity to a threshold;

responsive to obtaining a first result for the comparison, selecting for the second signal a non-zero level of pulse width modulation without constant current reduction; and

responsive to obtaining a second result for the comparison that is different from the first result, selecting for the second signal a non-zero level of constant current reduction without pulse width modulation.

2. The system of claim **1**, wherein for the first result, the desired intensity is below the threshold, and

wherein for the second result, the desired intensity is above the threshold.

3. The system of claim **1**, wherein the circuit further comprises a pulse width modulation branch and a constant current reduction branch.

4. The system of claim **1**, wherein the light source comprises a light emitting diode.

5. The system of claim **1**, wherein the light source comprises a luminaire that comprises at least one light emitting diode.

6. The system of claim **1**, wherein the input is configured for connecting to a dimmer switch.

7. A driver comprising:

an input configured to receive a dimming signal;

an output configured to emit electricity for powering a light emitting diode according to the dimming signal; and

a circuit for producing the electricity, the circuit connected to the input and the output and comprising:

a processor; and

memory storing a program for execution by the processor, the program comprising instructions for performing the steps of:

determining a level of constant current reduction and a level of pulse width modulation according to the received dimming signal; and

producing the electricity utilizing the determined levels of constant current reduction and pulse width modulation,

wherein determining the level of constant current reduction and the level of pulse width modulation according to the received dimming signal comprises:

if the received dimming signal is below a threshold, setting the level of constant current reduction to zero and setting the level of pulse width modulation to a value other than zero; and

if the received dimming signal is above the threshold, setting the level of pulse width modulation to zero and setting the level of constant current reduction to a value other than zero.

8. The driver of claim **7**, wherein the circuit comprises a pulse width modulation branch electrically coupled between the input and the output.

9. The driver of claim **7**, wherein the circuit comprises a constant current reduction branch electrically coupled between the input and the output.

10. The driver of claim **7**, wherein the driver comprises a luminaire.

11. The driver of claim **7**, wherein producing the electricity utilizing the determined levels of constant current reduction and pulse width modulation comprises feeding current to the light emitting diode to cause the light emitting diode to produce a target level of illumination.

12. A driver comprising:

an input configured to receive a dimming signal;

an output configured to emit electricity for powering a light emitting diode according to the dimming signal; and

a circuit for producing the electricity, the circuit connected to the input and the output and comprising:

a processor; and

memory storing a program for execution by the processor, the program comprising instructions for performing the steps of:

determining a level of constant current reduction and a level of pulse width modulation according to the received dimming signal; and

producing the electricity utilizing the determined levels of constant current reduction and pulse width modulation,

wherein the output comprises:

a first port configured for coupling to a positive side of at least one light emitting diode; and

a second port configured for coupling to a negative side of at the least one light emitting diode, and

wherein the circuit further comprises:

a pulse width modulation branch electrically coupled between the processor and the second port; and

a constant current reduction branch electrically coupled between the processor and the first port.

13. A driver comprising:

an input configured to receive a dimming signal;

an output configured to emit electricity for powering a light emitting diode according to the dimming signal; and

a circuit for producing the electricity, the circuit connected to the input and the output and comprising:

a processor; and

memory storing a program for execution by the processor, the program comprising instructions for performing the steps of:

determining a level of constant current reduction and a level of pulse width modulation according to the received dimming signal; and

producing the electricity utilizing the determined levels of constant current reduction and pulse width modulation,

wherein the circuit further comprises:

a digital-to-analog converter connected to an output of the processor;

a constant current reduction controller connected to an output of the digital-to-analog converter; and

buck/boost switches connected to an output of the constant current reduction controller.

14. The driver of claim **13**, wherein the constant current reduction controller is connected to a sense resistor.

15. A driver comprising:

an input configured to receive a dimming signal;

an output configured to emit electricity for powering at least one light emitting diode according to the dimming signal; and

a circuit for producing the electricity, the circuit connected to the input and the output and comprising:

a pulse width modulation branch electrically coupled to a first side of the output;

a constant current reduction branch electrically coupled to a second side of the output; and

a controller that is electrically connected to the pulse width modulation branch and to the constant current reduction branch and that is operable:

to use the pulse width modulation branch if the dimming signal is below a value; and

to use the constant current reduction branch if the dimming signal is above the value,

wherein the constant current reduction branch comprises:

a digital-to-analog converter connected to an output of the controller;

a constant current reduction controller connected to an output of the digital-to-analog converter; and

buck/boost switches connected to an output of the constant current reduction controller.

16. The driver of claim **15**, wherein the value comprises a threshold.

17. The driver of claim **15**, wherein the circuit further comprises:

a sense resistor connected between the sense resistor and the constant current reduction controller.

18. The driver of claim **15**, wherein the driver comprises a luminaire.

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