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Chen et al.

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(54) **DIMMING CIRCUIT FOR A PHASE-CUT TRIAC DIMMER**

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H05B 33/08	(2006.01)
H05B 41/28	(2006.01)
B23H 1/02	(2006.01)

(52) **U.S. Cl.**

CPC ***H05B 33/0815*** (2013.01); ***H05B 33/0845*** (2013.01); ***H05B 33/0896*** (2013.01); *B23H 1/024* (2013.01)

(58) **Field of Classification Search**

CPC . H05B 41/2855; H05B 41/2851; B23H 1/024

USPC .... 315/127, 128, 200 R, 209 R, 291

See application file for complete search history.

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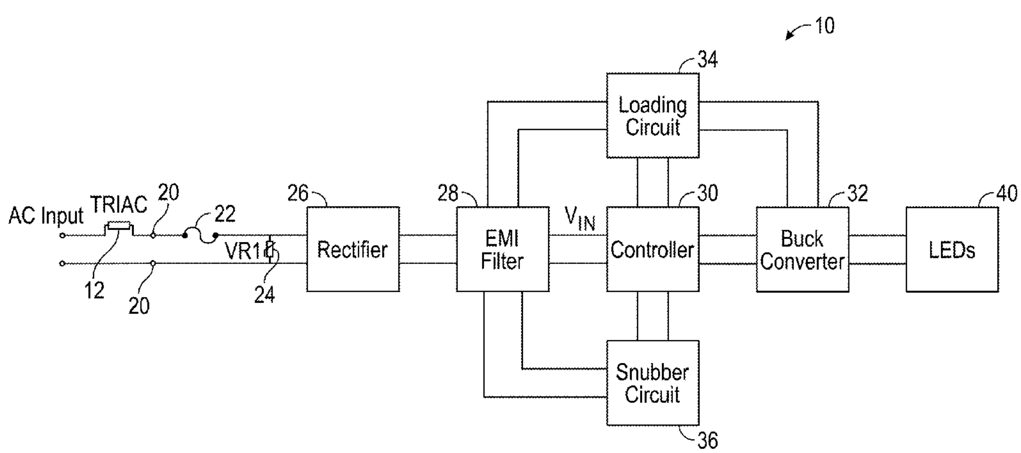
(57) **ABSTRACT**

A dimmer circuit for at least one LED is disclosed. The LED is controlled by a TRIAC dimmer. A leakage current flows through the TRIAC dimmer if the TRIAC dimmer is off. The dimmer circuit include inputs for receiving a source of incoming AC power, a rectifier for receiving the source of incoming AC power and producing a DC voltage, a controller for receiving the DC voltage from the rectifier and providing a switching signal, a first circuit, and a loading circuit. The first circuit receives the switching signal from the controller. The first circuit includes a first switching element that is selectively activated based on the switching signal. The loading circuit receives the switching signal from the controller. The loading circuit includes a second switching element that is activated if the first switching element is deactivated. The loading circuit selectively provides a minimum loading current.

26 Claims, 4 Drawing Sheets



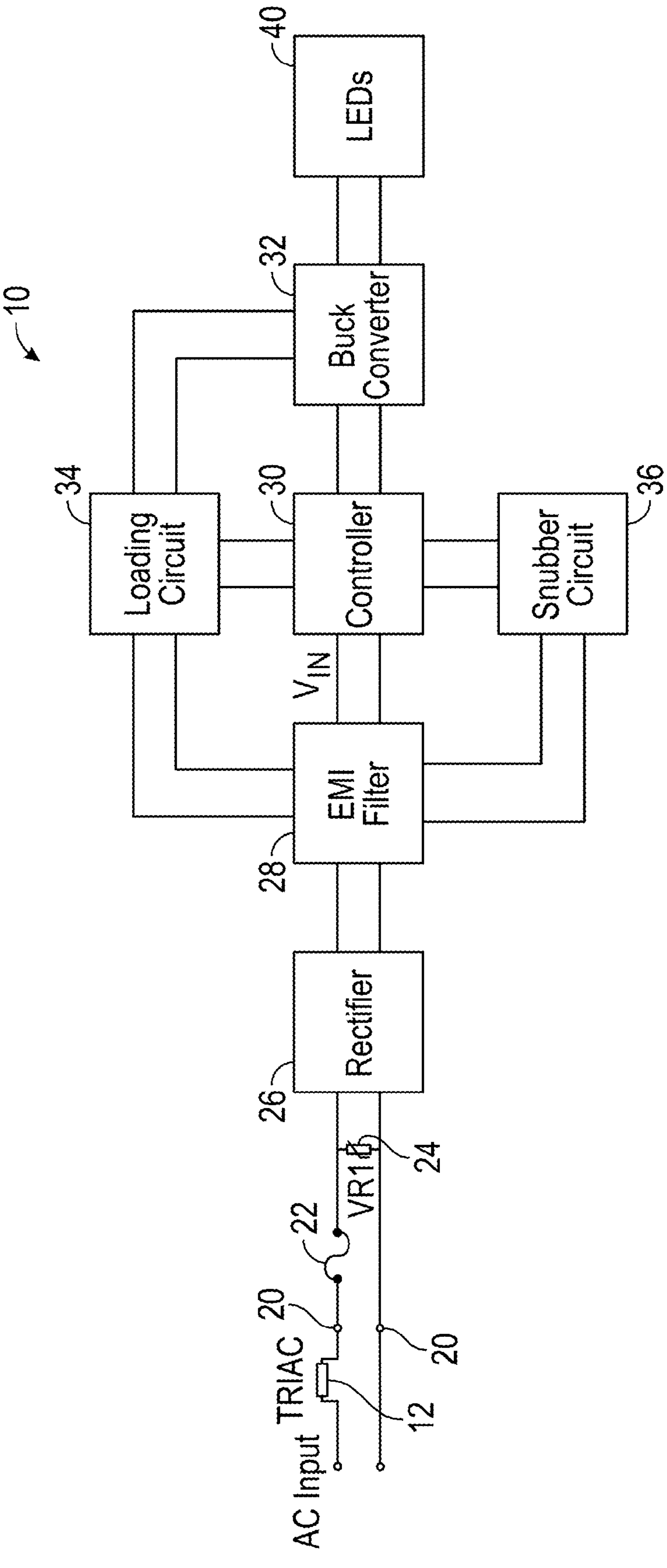

10
LEDs
40
Buck Converter
32
Loading Circuit
34
Controller
30
Snubber Circuit
36
V_{IN}
EMI Filter
28
Rectifier
26
24
VR1
22
20
20
TRIAC
12
AC Input

FIG. 1

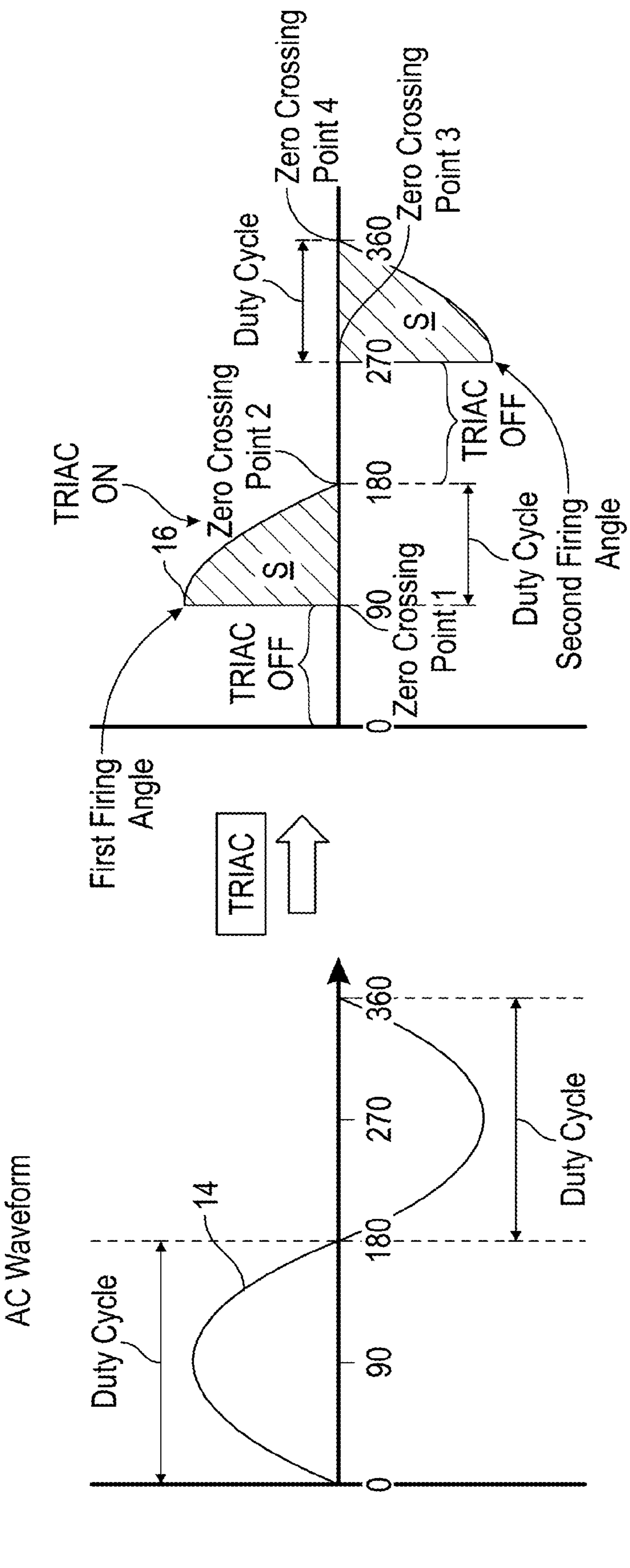

AC Waveform
Duty Cycle
14
0
90
180
270
360
Duty Cycle
TRIAC
First Firing Angle
TRIAC OFF
16
TRIAC ON
S
Zero Crossing Point 1
Zero Crossing Point 2
Duty Cycle
Second Firing Angle
TRIAC OFF
Duty Cycle
Zero Crossing Point 3
Zero Crossing Point 4

FIG. 2

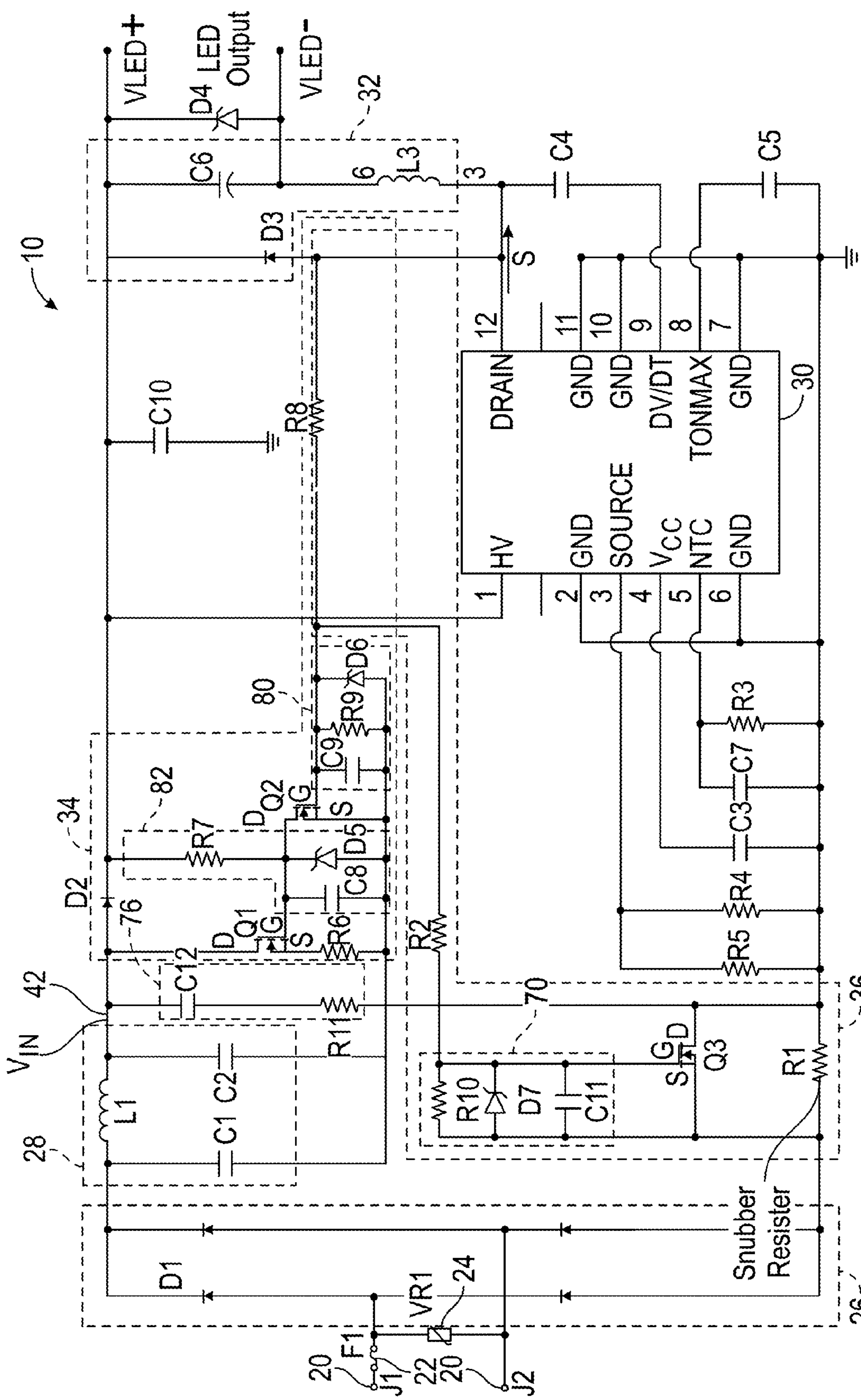

10
VLED+
D4 LED Output
VLED-
32
C6
6
L3
3
C4
C5
D3
S
C10
R8
12
11
10
9
8
7
DRAIN
GND
GND
DV/DT
TONMAX
GND
30
HV
GND
SOURCE
VCC
NTC
GND
1
2
3
4
5
6
80
D6
R9
C9
G
Q2
D
S
82
R7
D5
C8
34
D2
76
Q1
G
D
S
R6
C12
R2
42
VIN
R11
R3
C7
C3
R4
R5
70
36
R10
D7
C11
G
D
S
Q3
R1
L1
C1
C2
28
Snubber Resister
D1
VR1
24
F1
20
J1
22
20
J2
26

FIG. 3

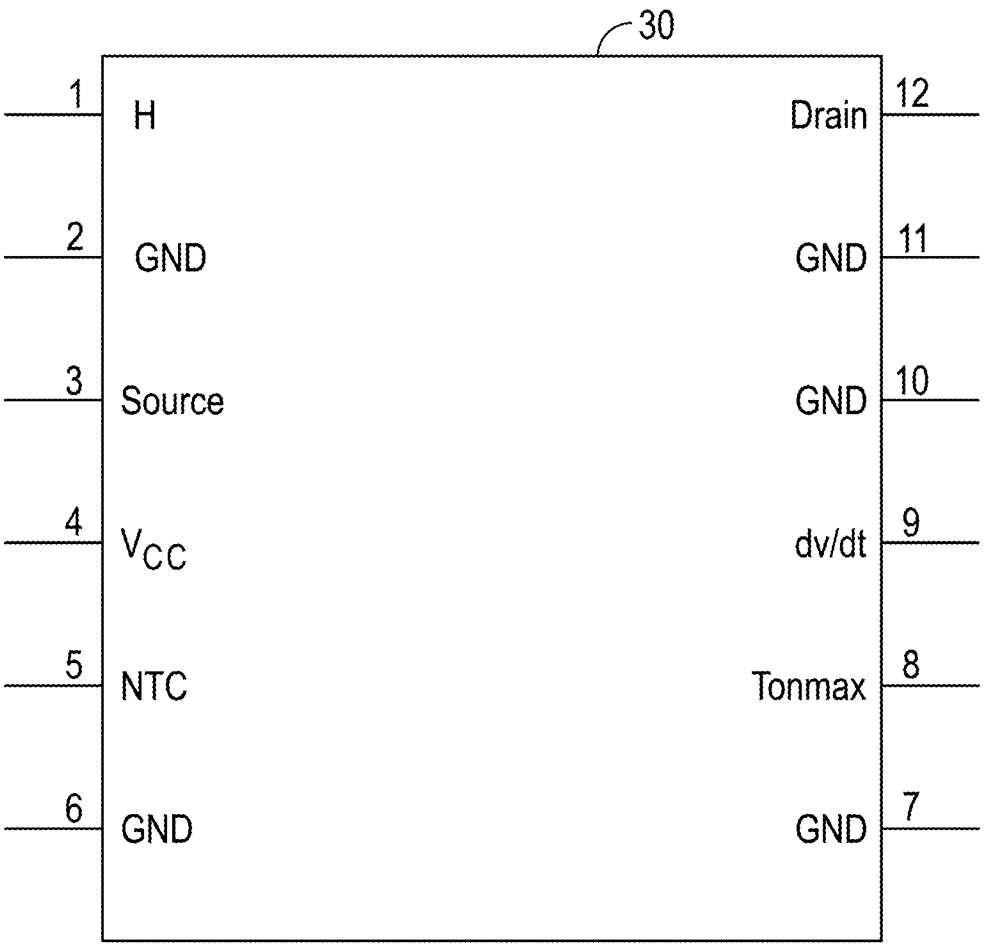

30
1
H
2
GND
3
Source
4
V_{CC}
5
NTC
6
GND
12
Drain
11
GND
10
GND
9
dv/dt
8
Tonmax
7
GND

FIG. 4

DIMMING CIRCUIT FOR A PHASE-CUT TRIAC DIMMER

RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/004,998, filed on May 30, 2014.

TECHNICAL FIELD

The present disclosure relates generally to a dimming circuit for at least one light emitting diode (LED), and more particularly to a dimming circuit selectively providing a minimum loading current back to a TRIAC dimmer.

BACKGROUND

Light emitting diode (LED) based lighting systems may offer several energy and reliability advantages over other types of lighting systems such as, for example, incandescent or fluorescent lighting. Thus, LED based lighting systems may be widely used to replace other existing lighting technologies. It should also be noted that dimming devices have also been developed that may be used to dynamically adjust the level of brightness in a lighting fixture. However, some types of dimming devices available today do not always work well with LED based lighting fixtures. For example, a phase-cut TRIAC dimmer is one commonly known and widely used dimming device. TRIAC dimmers were originally intended to handle the wattage induced by incandescent bulbs. In contrast, LED bulbs consume much less power than an incandescent bulb.

For an LED bulb to be dimmable, the bulb's power supply should interpret a variable phase angle output from the TRIAC and adjust the constant current drive to the LEDs accordingly. However, this may prove to be difficult while keeping the TRIAC working correctly, and may result in performance issues. For example, sometimes the LED bulb may flicker or blink as the dimming level is adjusted.

SUMMARY

In one embodiment, a dimmer circuit for at least one LED is disclosed. The LED is controlled by a TRIAC dimmer. A leakage current flows through the TRIAC dimmer when the TRIAC dimmer is off. The dimmer circuit includes inputs for receiving a source of incoming AC power, a rectifier for receiving the source of incoming AC power and producing a DC voltage, a controller for receiving the DC voltage from the rectifier and providing a switching signal, a first circuit, and a loading circuit. The first circuit receives the switching signal from the controller. The first circuit includes a first switching element that is selectively activated based on the switching signal. The loading circuit receives the switching signal from the controller. The loading circuit includes a second switching element that is activated if the first switching element is deactivated. The loading circuit selectively provides a minimum loading current that substantially dissipates the leakage current flowing through the TRIAC dimmer if the second switching element is activated.

In another embodiment, a dimmer circuit for at least one LED is disclosed. The LED is controlled by a TRIAC dimmer. A leakage current flows through the TRIAC dimmer when the TRIAC dimmer is off. The dimmer circuit includes inputs for receiving a source of incoming AC power, a rectifier for receiving the source of incoming AC power and producing a DC voltage, a controller for receiving the DC voltage from the rectifier and providing a switching signal, a snubber circuit and a loading circuit. The snubber circuit receives the switching signal from the controller. The snubber circuit includes a first switching element and a snubber resistor, where the first switching element is selectively activated based on the switching signal. The loading circuit receives the switching signal from the controller. The loading circuit comprises a second switching element that is activated if the first switching element is deactivated, and a third switching element that inverts the switching signal before being sent to the second switching element. The loading circuit is configured to selectively provide a minimum loading current that substantially dissipates the leakage current flowing through the TRIAC dimmer if the second switching element is activated.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exemplary block diagram of a driver circuit;

FIG. **2** is an illustration of an AC waveform being sent through a triode alternating current (TRIAC) dimmer shown in FIG. **1**;

FIG. **3** is a circuit diagram of the driver circuit shown in FIG. **1**; and

FIG. **4** is an illustration of a controller shown in FIG. **3**.

DETAILED DESCRIPTION

The following detailed description will illustrate the general principles of the invention, examples of which are additionally illustrated in the accompanying drawings. In the drawings, like reference numbers indicate identical or functionally similar elements.

FIG. **1** is an exemplary block diagram of a dimming circuit **10** that may be used with a phase cut TRIAC dimmer **12**. In one non-limiting embodiment, the dimming circuit **10** may be used to provide power to one or more light emitting diodes (LEDs). In an embodiment, the LEDs **40** may be organic LEDs (OLEDs). The TRIAC dimmer **12** may be electrically connected to a source (not shown) of AC power such as, for example, main power lines at a nominal 120 volts AC. The TRIAC dimmer **12** may be used to cut out or chop a portion of the AC power, allowing only a portion of the supplied power to pass to the dimming circuit **10**. For example, FIG. **2** illustrates an exemplary standard AC voltage waveform **14**. The TRIAC dimmer **12** is configured to output waveform **16**, which is a chopped up version of the standard AC voltage waveform **14**. Specifically, the TRIAC dimmer **12** may be used to adjust a duty cycle of the standard AC voltage waveform **14**.

Continuing to refer to FIG. **2**, the TRIAC dimmer **12** is on or activated if the waveform **16** is either above or below a zero-crossing. Specifically, the shaded regions S bounded by the waveform **16** represent when the TRIAC dimmer **12** is activated. Similarly, the TRIAC dimmer **12** is off if the waveform **16** is at zero-crossing. The exemplary waveform **16** as shown in FIG. **2** includes four zero-crossing points which are labelled as zero-crossing point **1**, zero-crossing point **2**, zero-crossing point **3**, and zero-crossing point **4**. The exemplary waveform **16** also includes two firing angles. Specifically, a first firing angle has a phase angle between about zero to one hundred and eighty degrees and a second firing angle has a phase angle between about one hundred and eighty and three hundred and sixty degrees. The firing angle of a TRIAC dimmer is generally defined as the phase angle of a voltage waveform at which the TRIAC dimmer turns on. Thus, in the embodiment as shown in FIG. **2**, the TRIAC dimmer **12** turns on when the phase angle of the waveform **16** is at about ninety degrees (i.e., zero-crossing point **1**), and turns off when the phase angle of the waveform **16** is at about one hundred and eighty degrees (i.e., zero-crossing point **2**). The TRIAC dimmer **12** turns back on when the phase angle of the waveform **16** is at about two hundred and seventy degrees (i.e., zero-crossing point **3**), and turns off when the phase angle of the waveform **16** is at about three hundred and sixty degrees (i.e., zero-crossing point **4**).

Turning back to FIG. **1**, the dimmer circuit **10** may include a pair of power input lines **20** for connection to the TRIAC dimmer **12** and the AC power. The driver circuit **10** may also include a fuse **22**, a varistor **24**, a rectifier **26**, an electromagnetic interference (EMI) filter **28**, a controller **30**, a buck converter **32**, a loading circuit **34**, a snubber circuit **36**, and one or more LEDs **40**. The input lines **20** may be connected to the rectifier **26**, which converts incoming AC power to a pulsing DC power. Referring to FIGS. **1** and **3**, in one embodiment the rectifier **26** may be a full wave diode bridge rectifier, however those skilled in the art will readily appreciate that any type full wave rectifier may be used as well. The output of the rectifier **26** is connected to the EMI filter **28**.

In one non-limiting embodiment the EMI filter **28** may include an inductor L**1** as well as two capacitors C**1** and C**2** in parallel with one another. The output of the EMI filter **28** may be referred to as an input voltage V_{IN}. The input voltage V_{IN} may be provided to the controller **30**. The controller **30** may refer to, be part of, or include an electronic circuit, a combinational logic circuit, a field programmable gate array (FPGA), a processor (shared, dedicated, or group) that executes code, other suitable components that provide the described functionality, or a combination of some or all of the above, such as in a system-on-chip. The term module may include memory (shared, dedicated, or group) that stores code executed by the processor. The term code, as used above, may include software, firmware, or microcode, and may refer to programs, routines, functions, classes, or objects.

Referring to both FIGS. **3** and **4**, one commercially available example of the controller **30** is integrated circuit (IC) model number SSL21082 which is commonly used for LED dimming control, and is available from NXP B.V., of Eindhoven, the Netherlands. The controller **50** may include twelve pins or input/outputs. Specifically, pin **1** is high voltage, pin **2** is ground, pin **3** is source, pin **4** is power supply (V_{CC}), pin **5** is temperature protection input, pin **6** is ground, pin **7** is ground, pin **8** is on-time modulation input, pin **9** is dV/dT or change in voltage, pin **10** is ground, pin **11** is ground, and pin **12** is an internal switch. As seen in FIG. **3**, an energy storage or EMI capacitor C**10** may be connected to the high voltage pin **1** of the controller **30**. The source pin **3** is connected to resistors R**3** and R**4** that are in parallel with one another. The power supply pin **4** is connected to C**3**. The temperature protection input pin **5** is connected to capacitor C**7** and resistor R**3** in series. The on-time modulation input pin **8** is connected to capacitor **5**. The change in voltage pin **9** is connected to the buck converter **32** through capacitor C**4**.

An input line **42** from the EMI filter **26** is connected to and delivers the input voltage V_{IN} to high voltage pin **1** through diode D**2**. The input voltage V_{IN} is sufficient to activate or turn on the controller **30**. Once the controller **30** is activated, a binary (on/off) or switching signal S may be sent though the external switch pin **12**. The switching signal S may be sent to the buck converter **32**, as well as to both the loading circuit **34** and the snubber circuit **36**. In the embodiment as shown in FIG. **3**, the buck circuit **44** may include an inductor L**3**, an electrolytic capacitor C**6**, and a buck diode D**3**. The buck converter **32** may be used to provide current to the LED **40** (shown in FIG. **1**). A zener diode D**4** may be placed in parallel with the buck converter **32** in order to provide over-voltage protection to the LED **40** (FIG. **1**).

The switching signal S from the internal switch pin **12** of the controller **30** may be sent to the snubber circuit **36** through resistors R**1** and R**2**. In the embodiment as shown in FIG. **3**, the snubber circuit **36** may include gate drive circuitry **70**, a switching element Q**3**, and a snubber resistor R**1**. The gate drive circuitry **70** may include a resistor R**10**, a zener diode D**7**, and a capacitor C**11**. The switching element Q**3** may be selectively activated based on the switching signal S. Specifically, the gate drive circuitry **70** may be used to determine a time delay of the switching signal S from the internal switch pin **12** of the controller **30** before the switching signal S is sent to a gate G of the switching element Q**3**. The time delay may be used to determine on and off switching times of the switching element Q**3**.

In the exemplary embodiment as shown in FIG. **3**, the switching element Q**3** is a metal-oxide-semiconductor field-effect transistor (MOSFET), however it is to be understood that other types of switching elements may be used as well. When the switching element Q**3** is activated, the snubber resistor R**1** is not supplied voltage and is not part of the dimming circuit **10**. Likewise, when the switching element Q**3** is not activated, then the snubber resistor R**1** is supplied voltage, and therefore is part of the dimming circuit **10**. Referring to both FIGS. **2** and **3**, since the switching signal S is aligned with the voltage that is sent to the buck converter **32**, the snubber resistor R**1** is only part of the dimming circuit **10** when the TRIAC **12** is triggered on. In other words, as seen in FIG. **2**, the snubber resistor R**1** is only activated if the waveform **16** from the TRIAC dimmer **12** is turned on and either above or below zero-crossing (i.e., at the zero crossing point **1** and zero crossing point **3**).

Referring to FIGS. **1**-**3**, the snubber resistor R**1** is activated by the switching element Q**3** when the switching signal S is on in order to reduce or substantially eliminate circuit resonance, which in turn decreases or substantially eliminates any flickering in the LEDs **40**. The snubber resistor R**1** is deactivated by the switching element Q**3** when the switching signal S from the controller **30** is off in order to enhance or improve the overall efficiency of the dimming circuit **10**. In additional to the snubber resistor R**1**, the dimming circuit **10** may also include a second snubber circuit **76**, which includes a capacitor C**12** and a resistor R**11** that are connected in series with one another. The second snubber circuit **76** is an RC type snubber circuit. The second snubber circuit **76** may be connected in parallel with the EMI filter **28**. Unlike the snubber resistor R**1**, the second snubber circuit **76** remains part of the dimming circuit **10** continuously during operation of the TRIAC **12**.

The switching signal S from the internal switch pin **12** of the controller **30** may be sent to the loading circuit **34** through the resistor R**8**. In the embodiment as shown in FIG. **3**, the loading circuit **34** may include gate drive circuitry **80**, an inverting switching element Q**2**, gate drive circuitry **82**, a switching element Q**3**, and a resistor R**6** that is arranged in series with the switching element Q**3**. The gate drive circuitry **80** may include a zener diode D**6**, a resistor R**9**, and a capacitor C**9**. The gate drive circuitry **80** may be used to condition the switching signal S from the internal switch pin **12** of the controller **30** before the switching signal S is sent to a gate G of the inverting switching element Q**2**. The gate drive circuitry **80** may also be used to determine on and off switching times of the inverting switching element Q**2**.

The inverting switching element Q**2** may be used to invert the switching signal S sent from the internal switch pin **12** of the controller **30**, before the switching signal S is sent to the switching element Q1. Thus, when the switching element Q1 is on or activated, the switching element Q3 is off or deactivated. Likewise, when the switching element Q1 is off or deactivated, the switching element Q3 is on or activated.

The gate drive circuitry **82** may include a resistor R**7**, a zener diode D**5**, and a capacitor C**8**. The gate drive circuitry **82** may be used to condition the switching signal S from the inverting switching element Q2 before the switching signal S is sent to a gate G of the switching element Q**1**. The gate drive circuitry **82** may also be used to determine on and off switching times of the inverting switching element Q**1**.

The switching element Q1 may be used to selectively supply an additional or minimum loading current back to the TRIAC **12** when turned on or activated. The dimmer circuit **10** may already provide some loading current to the TRIAC dimmer **12**. However the switching element Q1 is used to provide the additional or minimum loading current back to the TRIAC dimmer **12**. The additional loading current may be used to maintain the firing angle (shown in FIG. **2**) of the TRIAC dimmer **12**, which is described in greater detail below.

Referring to FIGS. **2**-**3**, the loading circuit **34** provides the minimum loading current to the TRIAC dimmer **12** if the switching element Q**3** is turned on or activated. The minimum loading current may be used to substantially dissipate a leakage current flowing through the TRIAC dimmer **12** when the TRIAC dimmer **12** is off. TRIAC dimmers are not ideal devices. This means that even if the TRIAC dimmer **12** is off, leakage current may still flow through. If left unchecked, the leakage current may interact with the dimmer circuit **10**, thereby causing LED flickering. Specifically, if left unchecked the leakage current from the TRIAC dimmer **12** may interact with the components in the EMI filter (e.g., the capacitors C**1** and C**2** and inductor L**1**), the second snubber circuit **76** (e.g., capacitor C**12** and resistor R**11**), and the EMI capacitor **10**, thereby creating resonance. The resonance may create unwanted oscillations in the dimming circuit **10**, which contain stray inductances and/or capacitances. These oscillations may create LED flickering. Dissipating the leakage current in the TRIAC dimmer **12** reduces or substantially eliminates the instances of LED flickering.

Continuing to refer to FIGS. **2**-**3**, when the TRIAC dimmer **12** is off (i.e., between 0 and the zero crossing point **1**, and between zero crossing point **2** and zero crossing point **3**), the minimum loading current is provided by the dimmer circuit **10**. In one embodiment, the minimum loading current from the switching element Q1 is determined by the following equation:

$$\text{Minimum loading current} = \frac{\text{voltage of } D5 - \text{Gate to source voltage } (V_{GS}) \text{ of } Q1}{\text{resistance of resistor } R6}$$

A source S of the switching element Q1 is connected to resistor R**6**. Thus, the minimum loading current flows from the resistor R**6** and back through to the TRIAC dimmer **12**. Therefore, if the switching signal S sent by the controller **30** is on, the loading circuit **34** may provide the minimum loading current back to the TRIAC **12**.

Referring generally to FIGS. **1**-**4**, the dimmer circuit **10** may be used to provide a relatively cost-effective and simple approach for dimming an LED. Specifically, the disclosed dimmer circuit **10** includes a simpler design using fewer electrical components when compared to some other types of dimming circuits currently available. In addition to a relatively cost-effective design, the disclosed dimmer circuit **10** may also generally prevent flickering of one or more LEDs.

While the forms of apparatus and methods herein described constitute preferred embodiments of this invention, it is to be understood that the invention is not limited to these precise forms of apparatus and methods, and the changes may be made therein without departing from the scope of the invention.

What is claimed is:

1. A dimmer circuit for at least one LED that is controlled by a TRIAC dimmer, wherein a leakage current flows through the TRIAC dimmer if the TRIAC dimmer is off, comprising:
- inputs for receiving a source of incoming AC power;
- a rectifier for receiving the source of incoming AC power, the rectifier producing a DC voltage;
- a controller for receiving the DC voltage from the rectifier and providing a switching signal;
- a first circuit for receiving the switching signal from the controller, the first circuit including a first switching element that is selectively activated based on the switching signal;
- a loading circuit for receiving the switching signal from the controller, wherein the loading circuit includes a second switching element that is activated if the first switching element is deactivated, the loading circuit selectively providing a minimum loading current that substantially dissipates the leakage current flowing through the TRIAC dimmer if the second switching element is activated, and wherein the loading circuit further includes a third switching element that inverts the switching signal before being sent to the second switching element.

2. The dimmer circuit as recited in claim **1**, wherein the first circuit is a snubber circuit including a snubber resistor.

3. The dimmer circuit as recited in claim **2**, wherein the snubber resistor is part of the dimming circuit if the first switching element is deactivated.

4. The dimmer circuit as recited in claim **2**, wherein the snubber resistor is activated if the TRIAC dimmer is on.

5. The dimmer circuit as recited in claim **1**, wherein the first switching element and the second switching element are metal-oxide-semiconductor field-effect transistors (MOSFETs).

6. The dimmer circuit as recited in claim **1**, comprising a buck converter that provides current to the LED.

7. The dimmer circuit as recited in claim **6**, wherein the buck converter receives the switching signal from the controller.

8. The dimmer circuit as recited in claim **1**, wherein the loading circuit comprises a resistor, a zener diode, and a capacitor that define gate drive circuitry that conditions the switching signal before being sent to the second switching element.

9. The dimmer circuit as recited in claim **8**, wherein the loading circuit comprises a second resistor that is arranged in series with the second switching element.

10. The dimmer circuit as recited in claim **9**, wherein the minimum loading current is determined by the following equation:

$$\frac{\text{a voltage of the zener diode} - \text{a gate to source voltage } (V_{GS}) \text{ of the second switching element}}{\text{a resistance of the second resistor}}.$$

11. The dimmer circuit as recited in claim **1**, wherein the LED is an organic LED (OLED).

12. A dimmer circuit for at least one LED that is controlled by a TRIAC dimmer, wherein a leakage current flows through the TRIAC dimmer if the TRIAC dimmer is off, comprising:

inputs for receiving a source of incoming AC power;

a rectifier for receiving the source of incoming AC power, the rectifier producing a DC voltage;

a controller for receiving the DC voltage from the rectifier and providing a switching signal;

a snubber circuit for receiving the switching signal from the controller, the snubber circuit including a first switching element and a snubber resistor, the first switching element selectively activated based on the switching signal; and

a loading circuit for receiving the switching signal from the controller, wherein the loading circuit comprises:

a second switching element that is activated if the first switching element is deactivated; and

a third switching element that inverts the switching signal before being sent to the second switching element,

wherein the loading circuit selectively provides a minimum loading current that substantially dissipates the leakage current flowing through the TRIAC dimmer if the second switching element is activated.

13. The dimmer circuit as recited in claim 12, wherein the snubber resistor is part of the dimming circuit if the first switching element is deactivated.

14. The dimmer circuit as recited in claim 12, wherein the snubber resistor is activated if the TRIAC dimmer is on.

15. The dimmer circuit as recited in claim 12, wherein the first switching element, the second switching element, and the third switching element are metal-oxide-semiconductor field-effect transistors (MOSFETs).

16. The dimmer circuit as recited in claim 12, comprising a buck converter that provides current to the LED.

17. The dimmer circuit as recited in claim 12, wherein the loading circuit comprises a resistor, a zener diode, and a capacitor that define gate drive circuitry that conditions the switching signal before being sent to the second switching element.

18. The dimmer circuit as recited in claim 17, wherein the loading circuit comprises a second resistor that is arranged in series with the second switching element.

19. The dimmer circuit as recited in claim 18, wherein the minimum loading current is determined by the following equation:

$$\frac{\text{a voltage of the zener diode} - \text{a gate to source voltage } (V_{GS}) \text{ of the second switching element}}{\text{a resistance of the second resistor}}.$$

20. A dimmer circuit for at least one LED that is controlled by a TRIAC dimmer, wherein a leakage current flows through the TRIAC dimmer if the TRIAC dimmer is off, comprising:

inputs for receiving a source of incoming AC power;

a rectifier for receiving the source of incoming AC power, the rectifier producing a DC voltage;

a controller for receiving the DC voltage from the rectifier and providing a switching signal;

a first circuit for receiving the switching signal from the controller, the first circuit including a first switching element that is selectively activated based on the switching signal, wherein the first circuit is a snubber circuit including a snubber resistor; and

a loading circuit for receiving the switching signal from the controller, wherein the loading circuit includes a second switching element that is activated if the first switching element is deactivated, the loading circuit selectively provides a minimum loading current that substantially dissipates the leakage current flowing through the TRIAC dimmer if the second switching element is activated.

21. The dimmer circuit as recited in claim 20, wherein the snubber resistor is part of the dimming circuit if the first switching element is deactivated.

22. The dimmer circuit as recited in claim 20, wherein the snubber resistor is activated if the TRIAC dimmer is on.

23. A dimmer circuit for at least one LED that is controlled by a TRIAC dimmer, wherein a leakage current flows through the TRIAC dimmer if the TRIAC dimmer is off, comprising:

inputs for receiving a source of incoming AC power;

a rectifier for receiving the source of incoming AC power, the rectifier producing a DC voltage;

a controller for receiving the DC voltage from the rectifier and providing a switching signal;

a first circuit for receiving the switching signal from the controller, the first circuit including a first switching element that is selectively activated based on the switching signal;

a loading circuit for receiving the switching signal from the controller, wherein the loading circuit includes a second switching element that is activated if the first switching element is deactivated, the loading circuit selectively provides a minimum loading current that substantially dissipates the leakage current flowing through the TRIAC dimmer if the second switching element is activated; and

a buck converter that provides current to the LED, wherein the buck converter receives the switching signal from the controller.

24. A dimmer circuit for at least one LED that is controlled by a TRIAC dimmer, wherein a leakage current flows through the TRIAC dimmer if the TRIAC dimmer is off, comprising:

inputs for receiving a source of incoming AC power;

a rectifier for receiving the source of incoming AC power, the rectifier producing a DC voltage;

a controller for receiving the DC voltage from the rectifier and providing a switching signal;

a first circuit for receiving the switching signal from the controller, the first circuit including a first switching element that is selectively activated based on the switching signal;

a loading circuit for receiving the switching signal from the controller, wherein the loading circuit includes a second switching element that is activated if the first switching element is deactivated, the loading circuit selectively provides a minimum loading current that substantially dissipates the leakage current flowing through the TRIAC dimmer if the second switching element is activated, and wherein the loading circuit comprises a resistor, a zener diode, and a capacitor that define gate drive circuitry that conditions the switching signal before being sent to the second switching element.

25. The dimmer circuit as recited in claim 24, wherein the loading circuit comprises a second resistor that is arranged in series with the second switching element.

26. The dimmer circuit as recited in claim 25, wherein the minimum loading current is determined by the following equation:

$$\frac{\text{a voltage of the zener diode} - \text{a gate to source voltage } (V_{GS}) \text{ of the second switching element}}{\text{a resistance of the second resistor}}.$$

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