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(54) **LIGHT TUBE AND POWER SUPPLY CIRCUIT**

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CPC .. F21V 19/003; F21V 23/023; F21V 23/0815; F21K 9/278; F21K 9/272; F21K 9/275
See application file for complete search history.

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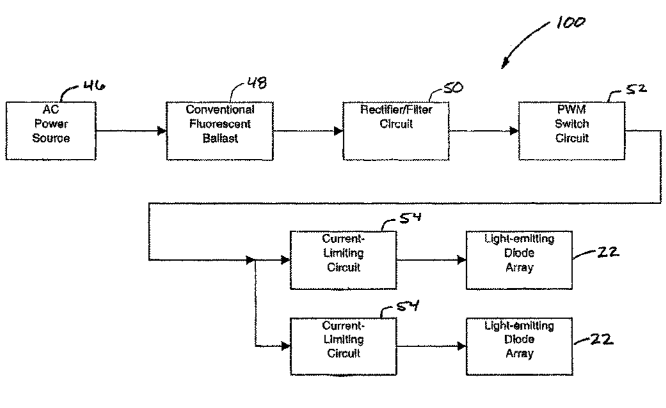
(57) **ABSTRACT**

A replacement light tube for replacing a fluorescent light tube includes a bulb portion extending between a first end and a second end, the bulb portion comprising a support structure, a plurality of white light emitting diodes (LEDs) and an elongate light-transmissive cover. The support structure has a first surface extending between the first end and the second end. The plurality of LEDs are supported by the first surface and arranged between the first end and the second end. The elongate light-transmissive cover extends between the first end and the second end and over the first surface of the support structure. A first end cap and a second end cap are disposed on the first end and the second end, respectively, each configured to fit with a socket for a fluorescent light tube. A power supply circuit is configured to provide power to the plurality of LEDs. The plurality of LEDs are arranged to emit light through the elongate light-transmissive cover and at least a portion of the power supply circuit is packaged inside at least one of the end caps.

23 Claims, 9 Drawing Sheets



Related U.S. Application Data

continuation of application No. 14/865,325, filed on Sep. 25, 2015, now Pat. No. 9,416,923, which is a continuation of application No. 14/669,963, filed on Mar. 26, 2015, now Pat. No. 9,222,626, which is a continuation of application No. 14/299,909, filed on Jun. 9, 2014, now Pat. No. 9,006,990, and a continuation of application No. 14/299,915, filed on Jun. 9, 2014, now Pat. No. 9,006,993, said application No. 14/299,909 is a continuation of application No. 13/777,331, filed on Feb. 26, 2013, now Pat. No. 8,866,396, and a continuation of application No. 12/965,019, filed on Dec. 10, 2010, now Pat. No. 8,382,327, which is a continuation of application No. 11/085,744, filed on Mar. 21, 2005, now Pat. No. 8,247,985, which is a continuation of application No. 09/782,375, filed on Feb. 12, 2001, now Pat. No. 7,049,761, said application No. 14/299,915 is a continuation of application No. 13/777,331, filed on Feb. 26, 2013, now Pat. No. 8,866,396.

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Defendant's Initial Invalidity and Unenforceability Contentions by Ilumisys, LLC d/b/a Toggled, United States District Court for the Eastern District of Michigan, Case No. 2:13-cv-14961, dated May 8, 2015, 39 pages.
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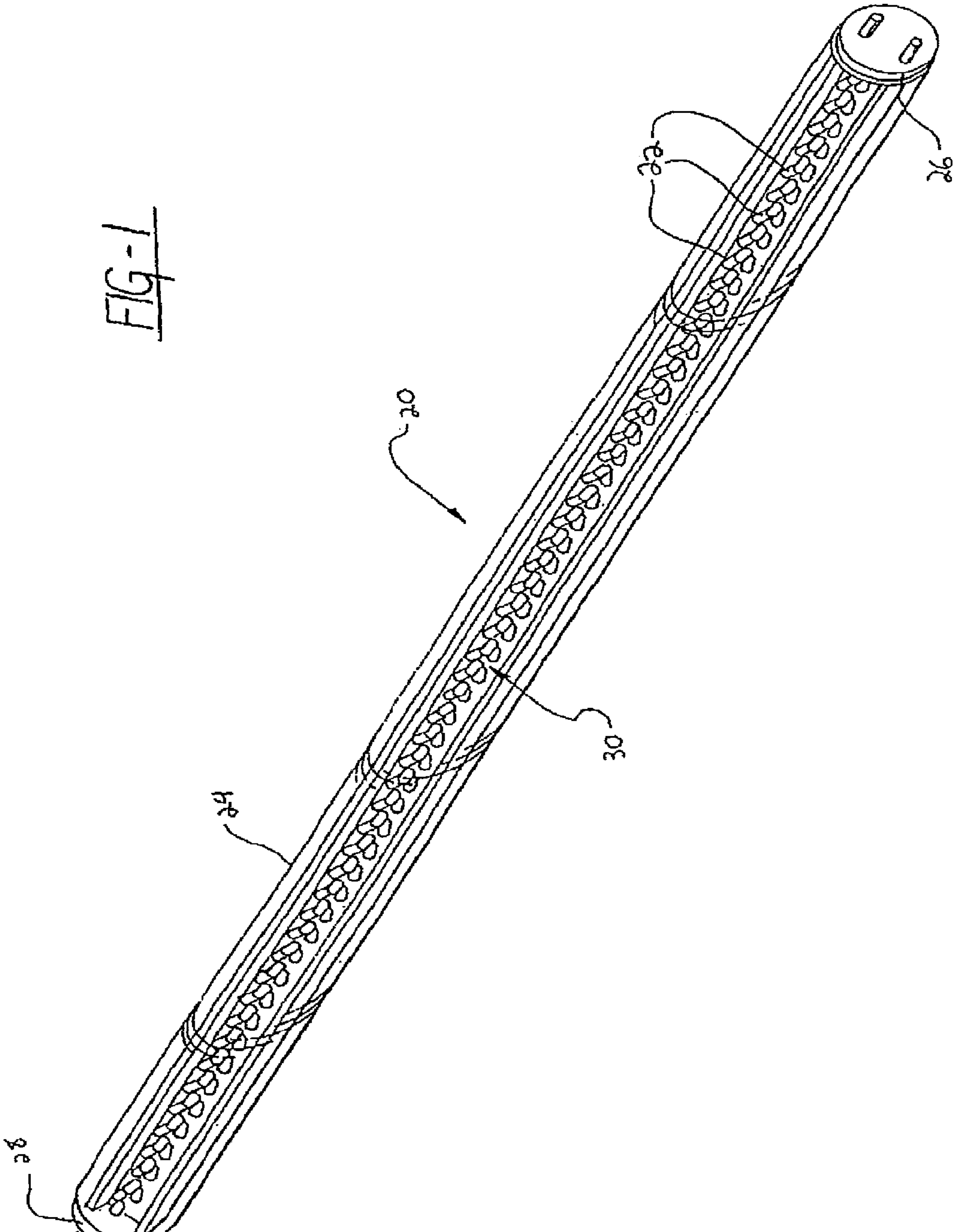
FIG-1



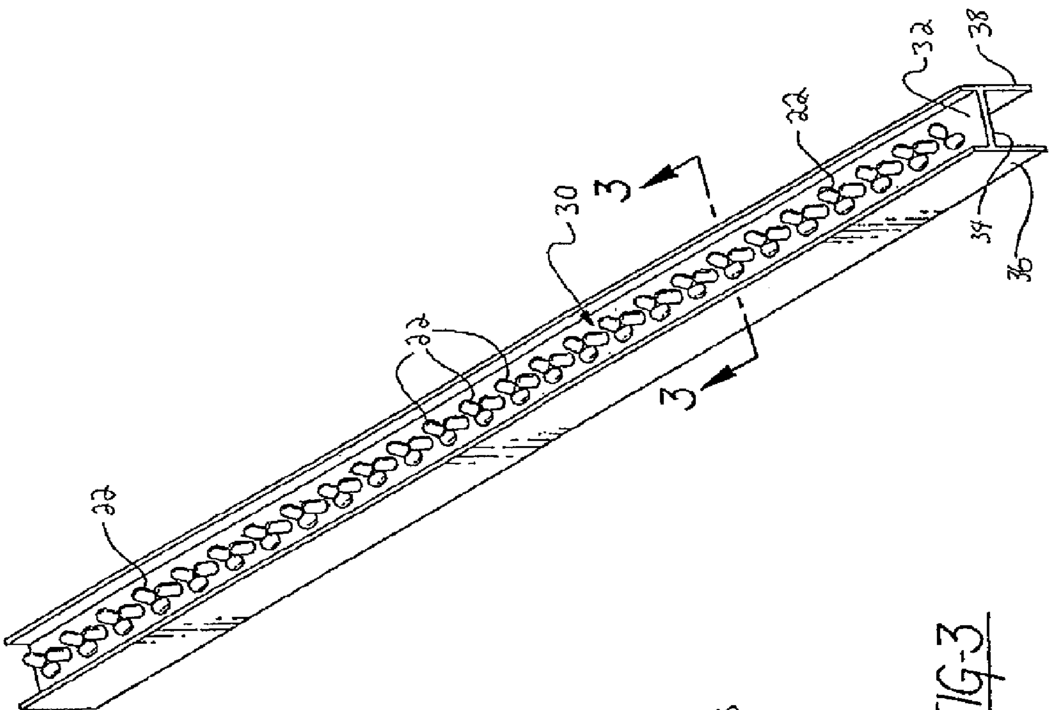


FIG-2

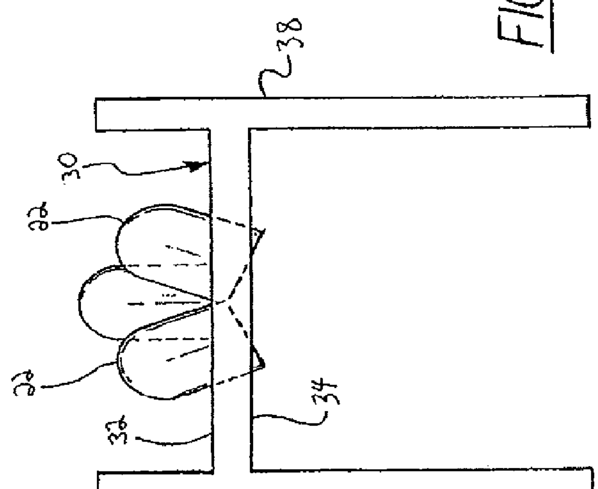


FIG-3

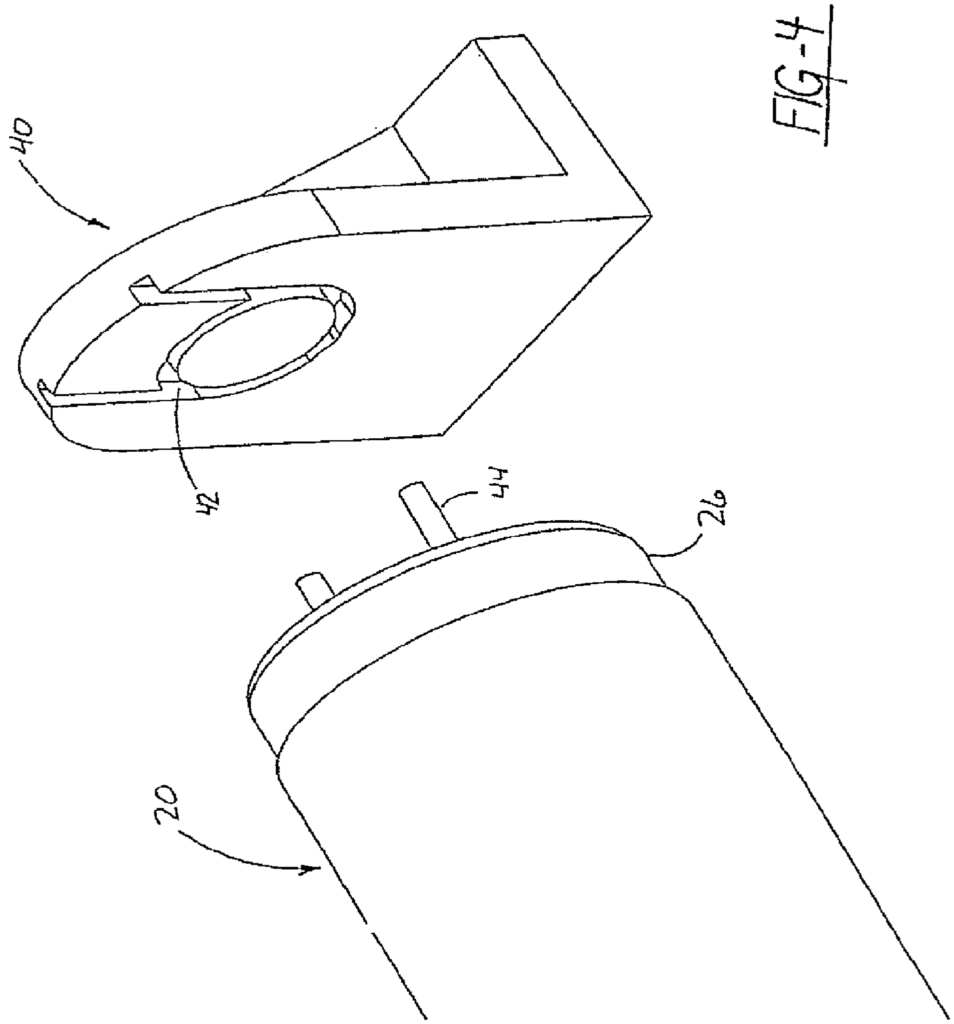


FIG-4

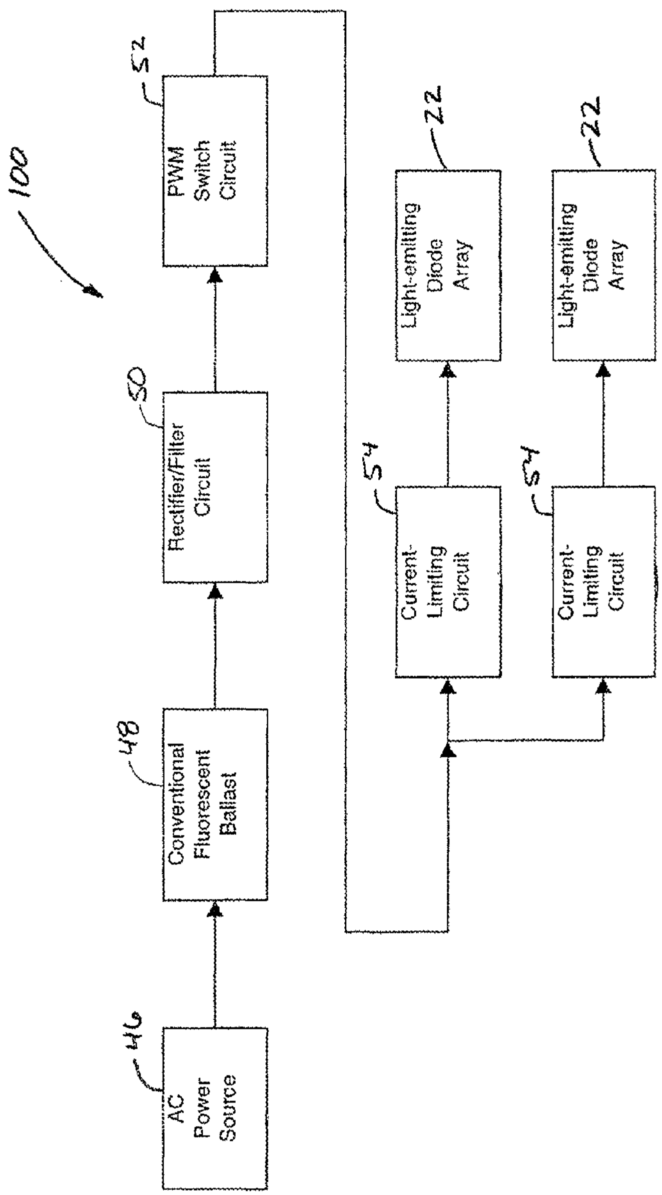

100
AC Power Source
46
Conventional Fluorescent Ballast
48
Rectifier/Filter Circuit
50
PWM Switch Circuit
52
Current-Limiting Circuit
54
Current-Limiting Circuit
54
Light-emitting Diode Array
22
Light-emitting Diode Array
22

FIG. 5

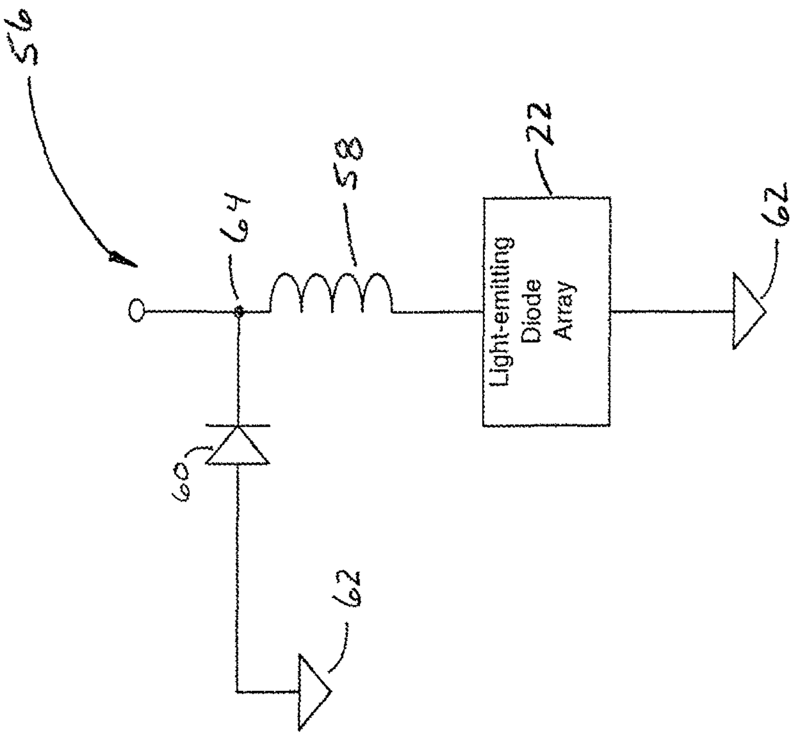


FIG. 6

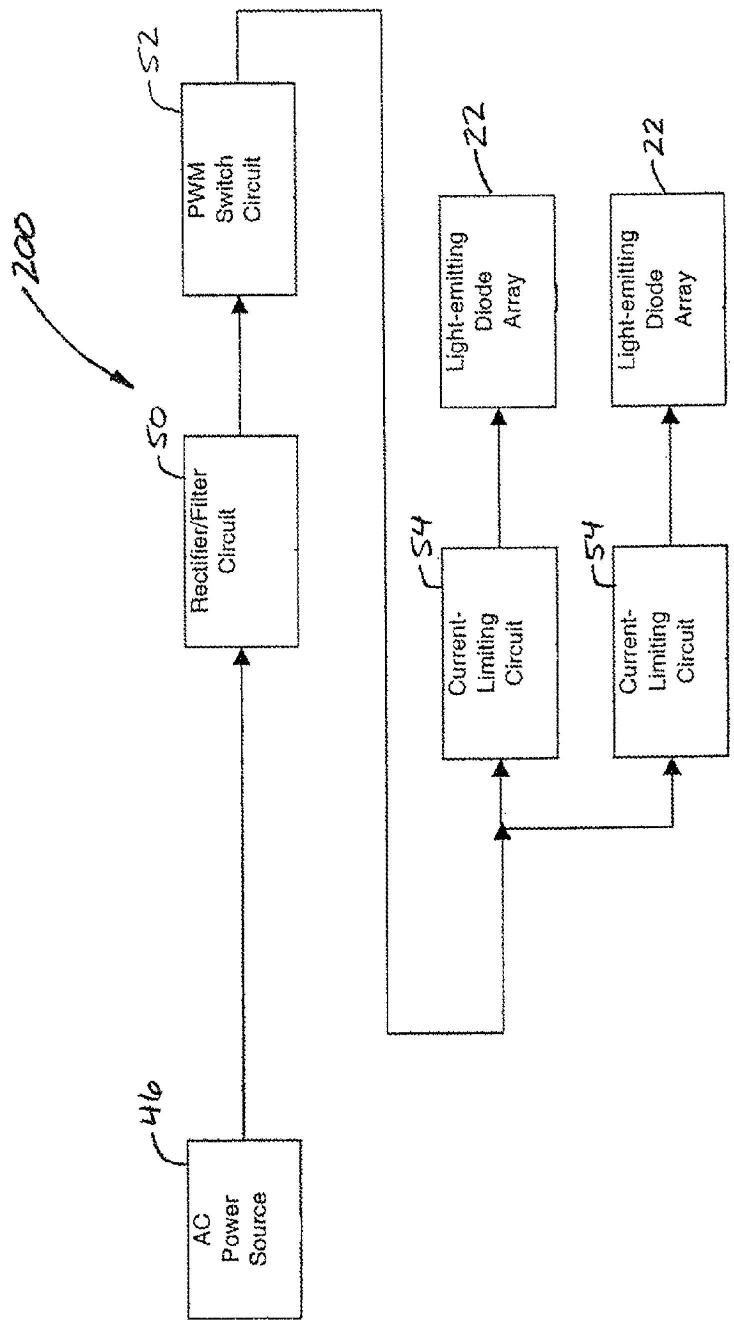

200
AC Power Source
46
Rectifier/Filter Circuit
50
PWM Switch Circuit
52
Current-Limiting Circuit
54
Current-Limiting Circuit
54
Light-emitting Diode Array
22
Light-emitting Diode Array
22

FIG. 7

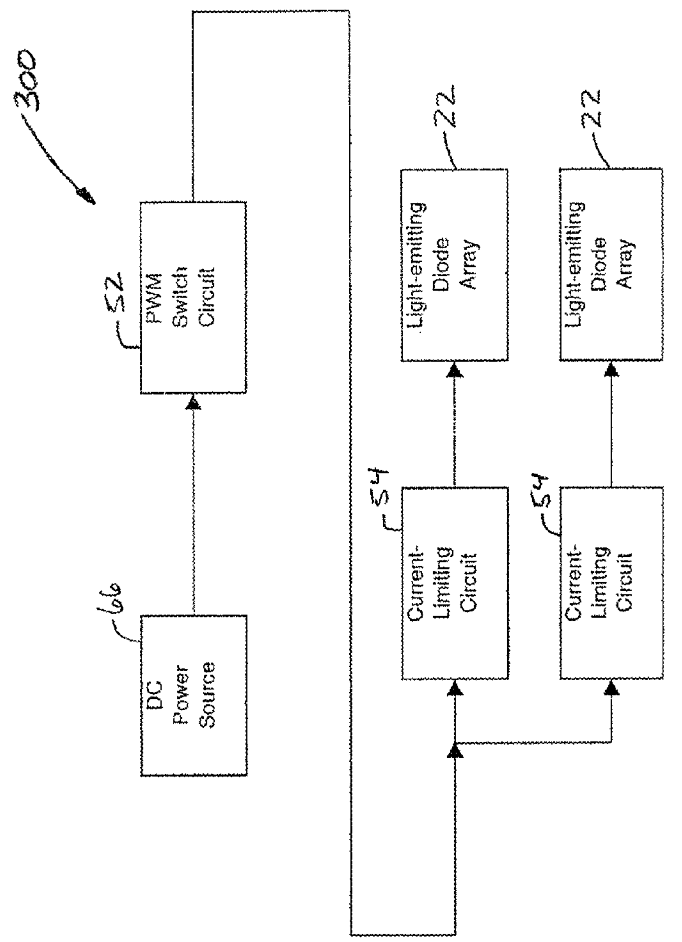

300
52
PWM Switch Circuit
66
DC Power Source
22
Light-emitting Diode Array
22
Light-emitting Diode Array
54
Current-Limiting Circuit
54
Current-Limiting Circuit

FIG. 8

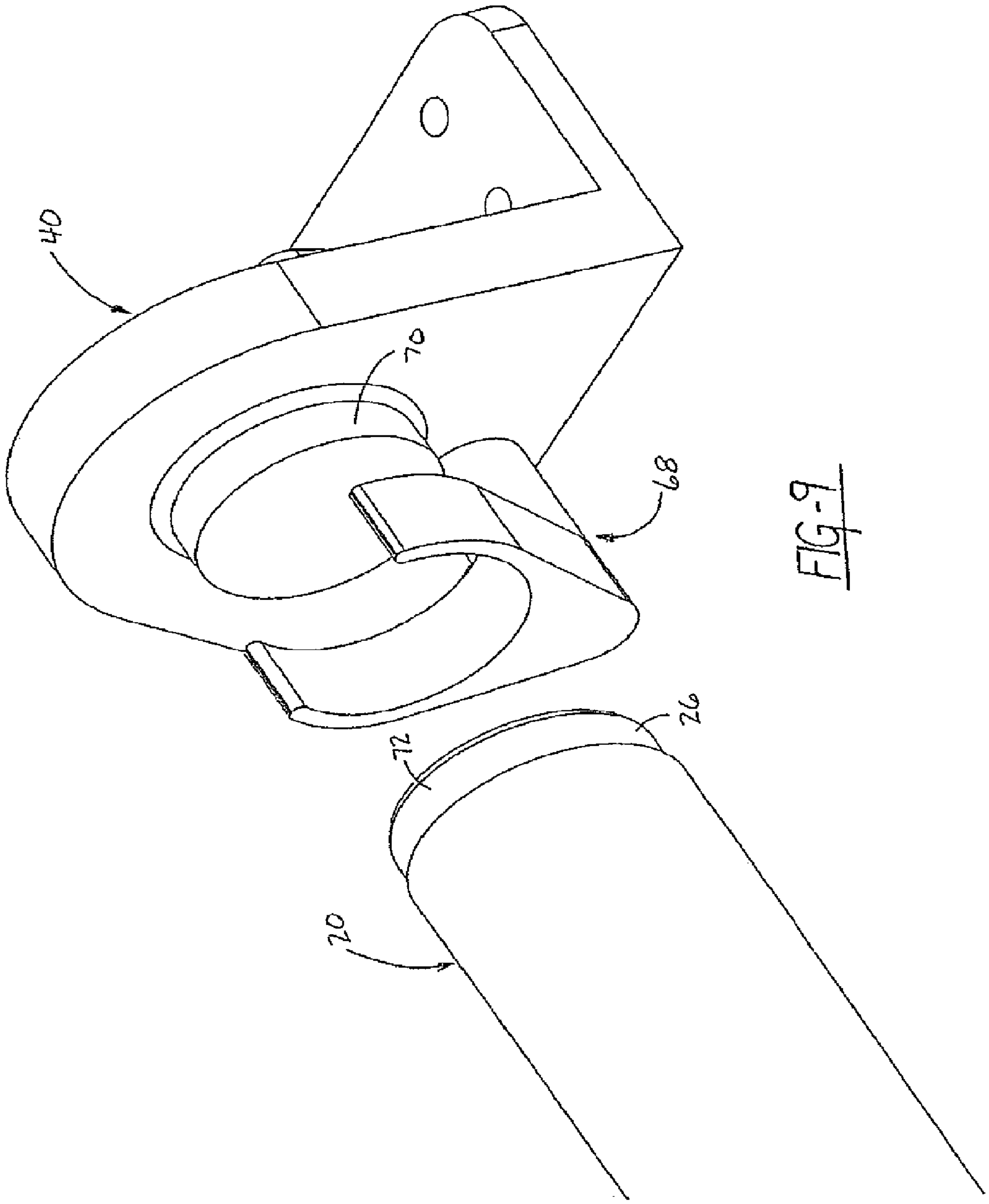


FIG-9

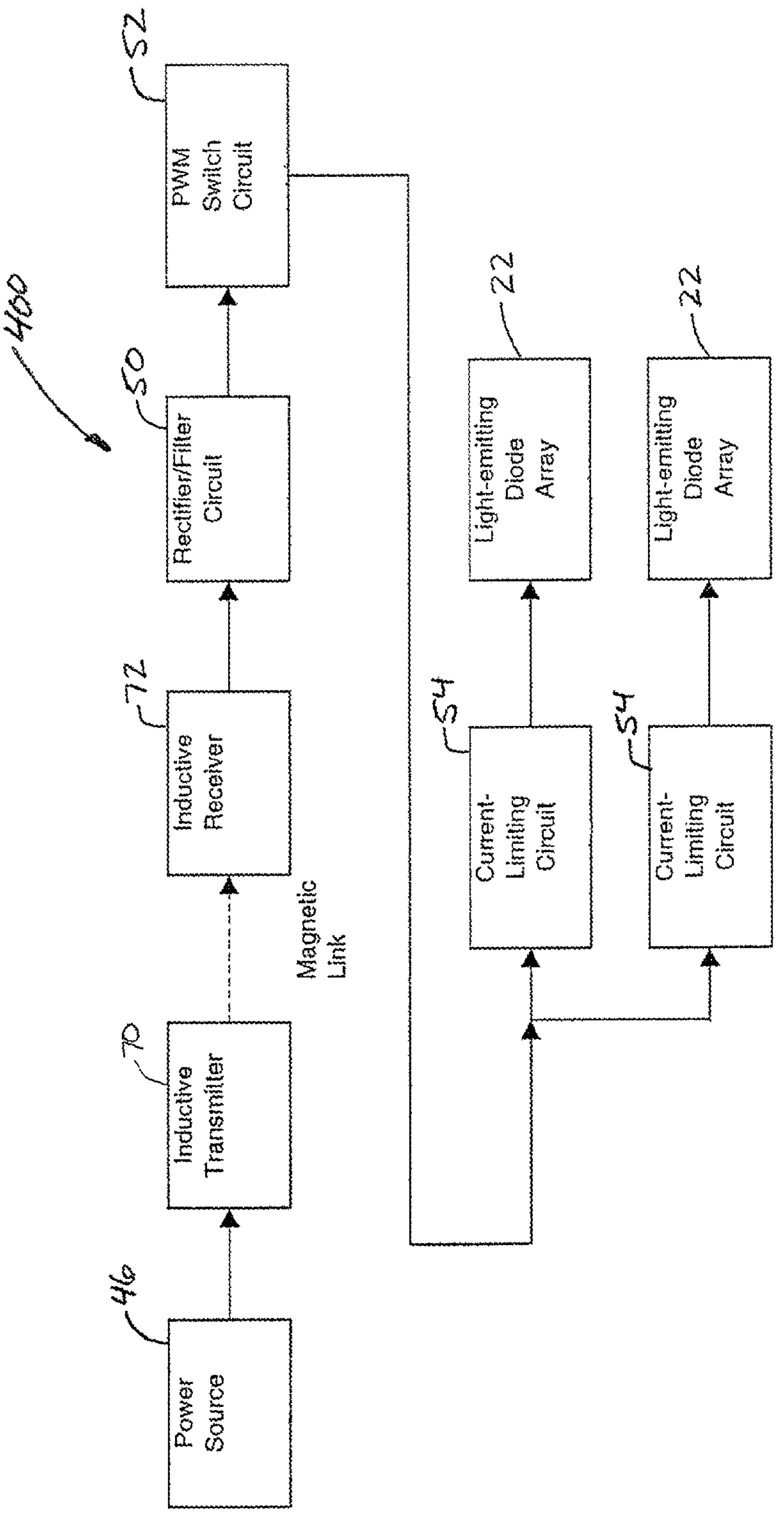

400
Power Source
46
Inductive Transmitter
70
Magnetic Link
Inductive Receiver
72
Rectifier/Filter Circuit
50
PWM Switch Circuit
52
Current-Limiting Circuit
54
Current-Limiting Circuit
54
Light-emitting Diode Array
22
Light-emitting Diode Array
22

FIG. 10

LIGHT TUBE AND POWER SUPPLY CIRCUIT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 15/187,456, filed Jun. 20, 2016, which is a continuation of U.S. patent application Ser. No. 14/865,325, filed Sep. 25, 2015 and issued as U.S. Pat. No. 9,416,923 on Aug. 16, 2016, which is a continuation of U.S. patent application Ser. No. 14/669,963, filed on Mar. 26, 2015 and issued as U.S. Pat. No. 9,222,626 on Dec. 29, 2015, which is a continuation of U.S. patent application Ser. No. 14/299,909, filed on Jun. 9, 2014 and issued as U.S. Pat. No. 9,006,990 on Apr. 14, 2015 and a continuation of U.S. patent application Ser. No. 14/299,915, filed Jun. 9, 2014 and issued as U.S. Pat. No. 9,006,993 on Apr. 14, 2015, which are continuations of U.S. patent application Ser. No. 13/777,331, filed Feb. 26, 2013 and issued as U.S. Pat. No. 8,866,396 on Oct. 21, 2014, which is a continuation of U.S. patent application Ser. No. 12/965,019, filed Dec. 10, 2010 and issued as U.S. Pat. No. 8,382,327 on Feb. 26, 2013, which is a continuation of U.S. patent application Ser. No. 11/085,744, filed Mar. 21, 2005 and issued as U.S. Pat. No. 8,247,985 on Aug. 21, 2012, which is a continuation of U.S. patent application Ser. No. 09/782,375, filed Feb. 12, 2001 and issued as U.S. Pat. No. 7,049,761 on May 23, 2006, which claims the benefit of U.S. Provisional Application No. 60/181,744 filed Feb. 11, 2000.

FIELD OF THE INVENTION

The present invention relates to a light tube illuminated by LEDs (light emitting diodes) which are packaged inside the light tube and powered by a power supply circuit.

BACKGROUND OF THE INVENTION

Conventional fluorescent lighting systems include fluorescent light tubes and ballasts. Such lighting systems are used in a variety of locations, such as buildings and transit buses, for a variety of lighting purposes, such as area lighting or backlighting. Although conventional fluorescent lighting systems have some advantages over known lighting options, such as incandescent lighting systems, conventional fluorescent light tubes and ballasts have several shortcomings. Conventional fluorescent light tubes have a short life expectancy, are prone to fail when subjected to excessive vibration, consume high amounts of power, require a high operating voltage, and include several electrical connections which reduce reliability. Conventional ballasts are highly prone to fail when subjected to excessive vibration. Accordingly, there is a desire to provide a light tube and power supply circuit which overcome the shortcomings of conventional fluorescent lighting systems. That is, there is a desire to provide a light tube and power supply circuit which have a long life expectancy, are resistant to vibration failure, consume low amounts of power, operate on a low voltage, and are highly reliable. It would also be desirable for such a light tube to mount within a conventional fluorescent light tube socket.

SUMMARY OF THE INVENTION

Embodiments of a replacement light tube for replacing a fluorescent light tube are disclosed herein. In one embodiment, the replacement light tube for replacing a fluorescent light tube includes a bulb portion extending between a first end and a second end, the bulb portion comprising a support structure, a plurality of white light emitting diodes (LEDs) and an elongate light-transmissive cover. The support structure has a first surface extending between the first end and the second end. The plurality of LEDs are supported by the first surface and arranged between the first end and the second end. The elongate light-transmissive cover extends between the first end and the second end and over the first surface of the support structure. A first end cap and a second end cap are disposed on the first end and the second end, respectively, each configured to fit with a socket for a fluorescent light tube. A power supply circuit is configured to provide power to the plurality of LEDs. The plurality of LEDs are arranged to emit light through the elongate light-transmissive cover and at least a portion of the power supply circuit is packaged inside at least one of the end caps.

In another embodiment, the replacement light tube includes a bulb portion extending between a first end and a second end, the bulb portion comprising a support structure, a plurality of white light emitting diodes (LEDs) and an elongate light-transmissive cover. The support structure has a first surface extending between the first end and the second end. The plurality of LEDs are supported by the first surface and arranged between the first end and the second end, the LEDs being disposed along a base of a channel defined by the support structure. The elongate light-transmissive cover extends between the first end and the second end and over the first surface of the support structure. A first end cap and a second end cap are disposed on the first end and the second end, respectively, each configured to fit with a socket for a fluorescent light tube. A power supply circuit is configured to provide power to the plurality of LEDs, the power supply circuit comprising a rectifier configured to receive alternating current (AC) input from a ballast and to provide direct current (DC) output. The plurality of LEDs are arranged to emit light through the elongate light-transmissive cover and at least a portion of the power supply circuit is packaged inside at least one of the end caps.

These and other embodiments will be discussed in additional detail hereafter.

BRIEF DESCRIPTION OF THE DRAWINGS

The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views, and wherein:

FIG. **1** is a line drawing showing a light tube, in perspective view, which in accordance with the present invention is illuminated by LEDs packaged inside the light tube;

FIG. **2** is a perspective view of the LEDs mounted on a circuit board;

FIG. **3** is a cross-sectional view of FIG. **2** taken along lines **3-3**;

FIG. **4** is a fragmentary, perspective view of one embodiment of the present invention showing one end of the light tube disconnected from one end of a light tube socket;

FIG. **5** is an electrical block diagram of a first power supply circuit for supplying power to the light tube;

FIG. **6** is an electrical schematic of a switching power supply type current limiter;

FIG. **7** is an electrical block diagram of a second power supply circuit for supplying power to the light tube;

FIG. **8** is an electrical block diagram of a third power supply circuit for supplying power to the light tube;

FIG. **9** is a fragmentary, perspective view of another embodiment of the present invention showing one end of the light tube disconnected from one end of the light tube socket; and

FIG. **10** is an electrical block diagram of a fourth power supply circuit for supplying power to the light tube.

DETAILED DESCRIPTION

FIG. **1** is a line drawing showing a light tube **20** in perspective view. In accordance with the present invention, the light tube **20** is illuminated by LEDs **22** packaged inside the light tube **20**. The light tube **20** includes a cylindrically shaped bulb portion **24** having a pair of end caps **26** and **28** disposed at opposite ends of the bulb portion. Preferably, the bulb portion **24** is made from a transparent or translucent material such as glass, plastic, or the like. As such, the bulb material may be either clear or frosted.

In a preferred embodiment of the present invention, the light tube **20** has the same dimensions and end caps **26** and **28** (e.g. electrical male bi-pin connectors, type G13) as a conventional fluorescent light tube. As such, the present invention can be mounted in a conventional fluorescent light tube socket.

The line drawing of FIG. **1** also reveals the internal components of the light tube **20**. The light tube **20** further includes a circuit board **30** with the LEDs **22** mounted thereon. The circuit board **30** and LEDs **22** are enclosed inside the bulb portion **24** and the end caps **26** and **28**.

FIG. **2** is a perspective view of the LEDs **22** mounted on the circuit board **30**. A group of LEDs **22**, as shown in FIG. **2**, is commonly referred to as a bank or array of LEDs. Within the scope of the present invention, the light tube **20** may include one or more banks or arrays of LEDs **22** mounted on one or more circuit boards **30**. In a preferred embodiment of the present invention, the LEDs **22** emit white light and, thus, are commonly referred to in the art as white LEDs. In FIGS. **1** and **2**, the LEDs **22** are mounted to one surface **32** of the circuit board **30**. In a preferred embodiment of the present invention, the LEDs **22** are arranged to emit or shine white light through only one side of the bulb portion **24**, thus directing the white light to a predetermined point of use. This arrangement reduces light losses due to imperfect reflection in a conventional lighting fixture. In alternative embodiments of the present invention, LEDs **22** may also be mounted, in any combination, to the other surfaces **34**, **36**, and/or **38** of the circuit board **30**.

FIG. **3** is a cross-sectional view of FIG. **2** taken along lines **3-3**. To provide structural strength along the length of the light tube **20**, the circuit board **30** is designed with a H-shaped cross-section. To produce a predetermined radiation pattern or dispersion of light from the light tube **20**, each LED **22** is mounted at an angle relative to adjacent LEDs and/or the mounting surface **32**. The total radiation pattern of light from the light tube **20** is effected by (1) the mounting angle of the LEDs **22** and (2) the radiation pattern of light from each LED. Currently, white LEDs having a viewing range between 6° and 45° are commercially available.

FIG. **4** is a fragmentary, perspective view of one embodiment of the present invention showing one end of the light tube **20** disconnected from one end of a light tube socket **40**. Similar to conventional fluorescent lighting systems and in this embodiment of the present invention, the light tube socket **40** includes a pair of electrical female connectors **42** and the light tube **20** includes a pair of mating electrical male connectors **44**.

Within the scope of the present invention, the light tube **20** may be powered by one of four power supply circuits **100**, **200**, **300**, and **400**. A first power supply circuit includes a power source and a conventional fluorescent ballast. A second power supply circuit includes a power source and a rectifier/filter circuit. A third power supply circuit includes a DC power source and a PWM (Pulse Width Modulation) circuit. A fourth power supply circuit powers the light tube **20** inductively.

FIG. **5** is an electrical block diagram of a first power supply circuit **100** for supplying power to the light tube **20**. The first power supply circuit **100** is particularly adapted to operate within an existing, conventional fluorescent lighting system. As such, the first power supply circuit **100** includes a conventional fluorescent light tube socket **40** having two electrical female connectors **42** disposed at opposite ends of the socket. Accordingly, a light tube **20** particularly adapted for use with the first power supply circuit **100** includes two end caps **26** and **28**, each end cap having the form of an electrical male connector **44** which mates with a corresponding electrical female connector **42** in the socket **40**.

The first power supply circuit **100** also includes a power source **46** and a conventional magnetic or electronic fluorescent ballast **48**. The power source **46** supplies power to the conventional fluorescent ballast **48**.

The first power supply circuit **100** further includes a rectifier/filter circuit **50**, a PWM circuit **52**, and one or more current-limiting circuits **54**. The rectifier/filter circuit **50**, the PWM circuit **52**, and the one or more current-limiting circuits **54** of the first power supply circuit **100** are packaged inside one of the two end caps **26** or **28** of the light tube **20**.

The rectifier/filter circuit **50** receives AC power from the ballast **48** and converts the AC power to DC power. The PWM circuit **52** receives the DC power from the rectifier/filter circuit **50** and pulse-width modulates the DC power to the one or more current-limiting circuits **54**. In a preferred embodiment of the present invention, the PWM circuit **52** receives the DC power from the rectifier/filter circuit **50** and cyclically switches the DC power on and off to the one or more current-limiting circuits **54**. The DC power is switched on and off by the PWM circuit **52** at a frequency which causes the white light emitted from the LEDs **22** to appear, when viewed with a "naked" human eye, to shine continuously. The PWM duty cycle can be adjusted or varied by control circuitry (not shown) to maintain the power consumption of the LEDs **22** at safe levels.

The DC power is modulated for several reasons. First, the DC power is modulated to adjust the brightness or intensity of the white light emitted from the LEDs **22** and, in turn, adjust the brightness or intensity of the white light emitted from the light tube **20**. Optionally, the brightness or intensity of the white light emitted from the light tube **20** may be adjusted by a user. Second, the DC power is modulated to improve the illumination efficiency of the light tube **20** by capitalizing upon a phenomenon in which short pulses of light at high brightness or intensity to appear brighter than a continuous, lower brightness or intensity of light having the same average power. Third, the DC power is modulated to regulate the intensity of light emitted from the light tube **20** to compensate for supply voltage fluctuations, ambient temperature changes, and other such factors that affect the intensity of white light emitted by the LEDs **22**. Fourth, the DC power is modulated to raise the variations of the frequency of light above the nominal variation of 120 to 100 Hz thereby reducing illumination artifacts caused by low frequency light variations, including interactions with video screens. Fifth, the DC power may optionally be modulated to provide an alarm function wherein light from the light tube **20** cyclically flashes on and off.

The one or more current-limiting circuits **54** receive the pulse-width modulated or switched DC power from the PWM circuit **52** and transmit a regulated amount of power to one or more arrays of LEDs **22**. Each current-limiting circuit **54** powers a bank of one or more white LEDs **22**. If a bank of LEDs **22** consists of more than one LED, the LEDs are electrically connected in series in an anode to cathode arrangement. If brightness or intensity variation between the LEDs **22** can be tolerated, the LEDs can be electrically connected in parallel.

The one or more current-limiting circuits **54** may include (1) a resistor, (2) a current-limiting semiconductor circuit, or (3) a switching power supply type current limiter.

FIG. **6** is an electrical schematic of a switching power supply type current limiter **56**. The limiter **56** includes an inductor **58**, electrically connected in series between the PWM circuit **52** and the array of LEDs **22**, and a power diode **60**, electrically connected between ground **62** and a PWM circuit/inductor node **64**. The diode **60** is designed to begin conduction after the PWM circuit **52** is switched off. In this case, the value of the inductor **58** is adjusted in conjunction with the PWM duty cycle to provide the benefits described above. The switching power supply type current limiter **56** provides higher power efficiency than the other types of current-limiting circuits listed above.

FIG. **7** is an electrical block diagram of a second power supply circuit **200** for supplying power to the light tube **20**. Similar to the first power supply circuit **100**, the second power supply circuit **200** includes a conventional fluorescent light tube socket **40** having two electrical female connectors **42** disposed at opposite ends of the socket **40**. Accordingly, a light tube **20** particularly adapted for use with the second power supply circuit **200** includes two end caps **26** and **28**, each end cap having the form of an electrical male connector **44** which mates with a corresponding electrical female connector **42** in the socket **40**.

In the second power supply circuit **200**, the power source **46** supplies power directly to the rectifier/filter circuit **50**. The rectifier/filter circuit **50**, the PWM circuit **52**, and the one or more current-limiting circuits **54** operate as described above to power the one or more arrays of LEDs **22**. The rectifier/filter circuit **50**, the PWM circuit **52**, and the one or more current-limiting circuits **54** of the second power supply circuit **200** are preferably packaged inside the end caps **26** and **28** or the bulb portion **24** of the light tube **20** or inside the light tube socket **40**.

FIG. **8** is an electrical block diagram of a third power supply circuit **300** for supplying power to the light tube **20**. Similar to the first and second power supply circuits **100** and **200**, the third power supply circuit **300** includes a conventional fluorescent light tube socket **40** having two electrical female connectors **42** disposed at opposite ends of the socket **40**. Accordingly, a light tube **20** particularly adapted for use with the third power supply circuit **300** includes two end caps **26** and **28**, each end cap having the form of an electrical male connector **44** which mates with a corresponding electrical female connector **42** in the socket **40**.

The third power supply circuit **300** includes a DC power source **66**, such as a vehicle battery. In the third power supply circuit **300**, the DC power source **66** supplies DC power directly to the PWM circuit **52**. The PWM circuit **52** and the one or more current-limiting circuits **54** operate as described above to power the one or more arrays of LEDs **22**. In the third power supply circuit **300**, the PWM circuit **52** is preferably packaged in physical location typically occupied by the ballast of a conventional fluorescent lighting system while the one or more current-limiting circuits **54** and LEDs **22** are preferably packaged inside the light tube **20**, in either one of the two end caps **26** or **28** or the bulb portion **24**.

FIG. **9** is a fragmentary, perspective view of another embodiment of the present invention showing one end of the light tube **20** disconnected from one end of the light tube socket **40**. In this embodiment of the present invention, the light tube socket **40** includes a pair of brackets **68** and the light tube **20** includes a pair of end caps **26** and **28** which mate with the brackets **68**.

FIG. **10** is an electrical block diagram of a fourth power supply circuit **400** for supplying power to the light tube **20**. Unlike the first, second, and third power supply circuits **100**, **200**, and **300** which are powered through direct electrical male and female connectors **44** and **42**, the fourth power supply circuit **400** is powered inductively. As such, the fourth power supply circuit **400** includes a light tube socket **40** having two brackets **68** disposed at opposite ends of the socket **40**. At least one bracket **68** includes an inductive transmitter **70**. Accordingly, a light tube **20** particularly adapted for use with the fourth power supply circuit **400** has two end caps **26** and **28** with at least one end cap including an inductive receiver or antenna **72**. When the light tube **20** is mounted in the light tube socket **40**, the at least one inductive receiver **72** in the light tube **20** is disposed adjacent to the at least one inductive transmitter **70** in the light tube socket **40**.

The fourth power supply circuit **400** includes the power source **46** which supplies power to the at least one inductive transmitter **70** in the light tube socket **40**. The at least one transmitter **70** inductively supplies power to the at least one receiver **72** in one of the end caps **26** and/or **28** of the light tube **20**. The at least one inductive receiver **72** supplies power to the rectifier/filter circuit **50**. The rectifier/filter circuit **50**, PWM circuit **52**, and the one or more current-limiting circuits **54** operate as described above to power the one or more arrays of LEDs **22**. In this manner, the light tube **20** is powered without direct electrical connection.

What is claimed is:

1. A method for providing a light tube for mounting within a conventional fluorescent light tube socket, the method comprising:

disposing the plurality of light emitting diodes on a rigid support structure;

disposing the support structure and plurality of light emitting diodes within an tubular housing comprising a transmissive cover for the light emitting diodes;

connecting a power supply circuit to the plurality of light emitting diodes, the power supply circuit being configured to receive power from a power source and provide power to the plurality of light emitting diodes during operation of the light tube;

disposing a pair of end caps at opposite ends of the bulb portion, each end cap configured to fit with the conventional fluorescent light tube socket; and

packaging at least a portion of the power supply circuit inside at least one of the end caps.

2. The method of claim **1**, wherein the power supply circuit is configured to regulate the intensity of light emitted from the plurality of light emitting diodes to compensate for voltage fluctuations from the power source during operation of the light tube.

3. The method of claim **1**, wherein the power supply circuit is configured to regulate the intensity of light emitted from the plurality of light emitting diodes to compensate for ambient temperature changes during operation of the light tube.

4. The method of claim **1**, wherein the power supply circuit comprises a pulse width modulator configured to receive the power from the power source and provide regulated power to the light emitting diodes by pulse-width modulating the received power during operation of the light tube.

5. The method of claim **4**, wherein the power supply circuit comprises a current limiter having an inductive element electrically coupled between the pulse width modulator and at least some of the plurality of light emitting diodes, the current limiter configured to receive power from the pulse width modulator and to transmit power to the at least some of the plurality of light emitting diodes during operation of the light tube.

6. The method of claim **1**, wherein the power supply circuitry is configured to switch power to the plurality of light emitting diodes on and off at a frequency and to cause the light emitted from the plurality of light emitting diodes to appear, when viewed by a human eye, to shine continuously during operation of the light tube.

7. The method of claim **1**, wherein the power supply circuit comprises a rectifier configured to receive alternating current (AC) input and to provide direct current (DC) output during operation of the light tube.

8. The method of claim **7**, wherein the rectifier is arranged to provide the DC output to a pulse width modulator during operation of the light tube.

9. The method of claim **1**, wherein each end cap comprises a bi-pin connector for connecting with the conventional fluorescent light tube socket.

10. The method of claim **9**, further comprising electrically connecting the power supply circuit to the bi-pin connector of at least one end cap.

11. The method of claim **1**, wherein disposing the plurality of light emitting diodes relative to the light transmissive cover comprises disposing the plurality of light emitting diodes on a rigid support structure and covering the light emitting diodes with the light transmissive cover of the tubular housing.

12. The method of claim **11**, wherein covering the rigid support structure comprises disposing the support structure within the tubular housing comprising the transmissive cover for the light emitting diodes.

13. The method of claim **12**, wherein the rigid support structure comprises spaced-apart sidewalls defining a channel and a planar portion having a first surface extending in the channel formed by the sidewalls, the light emitting diodes being disposed on the first surface.

14. The method of claim **13**, wherein at least a portion of the sidewalls contact an interior surface of the tubular housing when the support structure is disposed within the tubular housing.

15. The method of claim **13**, wherein, when disposed within the tubular housing, the support structure divides the tubular housing into a first space in which the plurality of light emitting diodes are housed and a second space defined by the planar portion, the sidewalls and the interior surface of the tubular housing.

16. The method of claim **13**, wherein the planar portion is integral with the sidewalls.

17. The method of claim **13**, wherein the sidewalls are generally perpendicular to the planar portion.

18. The method of claim **11**, wherein the support structure comprises a circuit board and the light emitting diodes are mounted on a surface of the circuit board.

19. The method of claim **1**, wherein the light emitting diodes are arranged along an axis extending between the end caps.

20. The method of claim **1**, wherein the light emitting diodes are white light emitting diodes.

21. The method of claim **1**, wherein the light transmissive cover is a tube formed from a transparent or translucent material.

22. The method of claim **1**, wherein the tubular housing is a cylindrical tube.

23. The method of claim **1**, wherein the light emitting diodes comprises a first light emitting diode and a second light emitting diode, the first light emitting diode being the light emitting diode closest to an end of the rigid support structure and the second light emitting diode being the next closest to the end of the rigid support structure, the first and second light emitting diodes being are disposed such that a shortest distance between the first light emitting diode and the second light emitting diode is less than a shortest distance between the first light emitting diode and the end of the rigid support structure.

* * * * *