IN THE UNITED STATES DISTRICT COURT
DISTRICT OF MASSACHUSETTS

KONINKLIJKE PHILIPS N.V. AND PHILIPS LIGHTING NORTH AMERICA CORPORATION,	
Plaintiffs,	CIVIL ACTION NO. 1:15-cv-11053
v.	**DEMAND FOR JURY TRIAL**
TROY-CSL LIGHTING, INC.,	
Defendant.	

COMPLAINT

Plaintiffs Koninklijke Philips N.V. ("KPNV") and Philips Lighting North America Corporation ("PLNA") (collectively, "Philips") bring this complaint for patent infringement against Defendant Troy-CSL Lighting, Inc. ("Troy-CSL").

NATURE OF THE ACTION

1. This is an action for patent infringement under 35 U.S.C. § 271, *et seq.*, by Philips against Troy-CSL for infringement of United States Patent Nos. 6,013,988 ("the '988 patent"), 6,094,014 ("the '014 patent"), 6,250,774 ("the '774 patent"), 6,561,690 ("the '690 patent"), 7,038,399 ("the '399 patent"), 7,262,559 ("the '559 patent"), and 7,352,138 ("the '138 patent") (collectively, the "patents-in-suit").

THE PARTIES

2. Plaintiff Koninklijke Philips N.V., formerly known as Koninklijke Philips Electronics N.V., is a corporation organized and existing under the laws of the Netherlands, with a principal place of business at Breitner Center, Amstelplein 2, 1096 BC Amsterdam, The Netherlands.

3. Plaintiff Philips Lighting North America Corporation is a corporation organized and existing under the laws of Delaware, with a principal place of business at 200 Franklin Square Drive, Somerset, New Jersey 08873.

4. Upon information and belief, Defendant Troy-CSL Lighting, Inc. is a corporation organized and existing under the laws of California, with a principal place of business at 14508 Nelson Avenue, City of Industry, California 91744.

JURISDICTION AND VENUE

5. This Court has subject matter jurisdiction over this action pursuant to 28 U.S.C. §§ 1331 and 1338.

6. Upon information and belief, Defendant has made, used, provided, sold, offered to sell, imported, or distributed to others for such purposes, lighting products and systems employing light-emitting diodes ("LEDs") for illumination ("LED Lighting Devices") throughout the United States, including Massachusetts and this judicial district.

7. Upon information and belief, Defendant maintains or has maintained continuous and systematic contacts with Massachusetts and this judicial district and has committed tortious activity within the district.

8. Venue is proper in this judicial district under 28 U.S.C. §§ 1391(b), (c) and/or 1400(b), as *inter alia* the Defendant is subject to personal jurisdiction in this district.

FACTUAL BACKGROUND

9. Upon information and belief, Defendant's LED Lighting Devices include, without limitation, products under the Creative Systems Lighting (CSL) and Troy Lighting brands. Defendant's LED Lighting Devices include interior and exterior lighting products including hanging lights, downlights, linear and task lights, sconce lights, flush lighting fixtures, flood

lights, path lights, step lights, deck lights, wall lights, well lights, underwater lights, post fixtures, and other luminaire-type lighting products.

COUNT I: PATENT INFRINGEMENT OF U.S. PATENT NO. 6,013,988

10. Plaintiffs incorporate by reference paragraphs 1-9 as if fully set forth herein.

11. On January 11, 2000, the United States patent & Trademark Office ("Patent Office") duly and legally issued the '988 patent, entitled "Circuit Arrangement, and Signaling Light Provided with the Circuit Arrangement," to Marcel J. M. Bucks et al. Plaintiff KPNV is the assignee and owner of the '988 patent, a copy of which is attached hereto as Exhibit A.

12. Upon information and belief, Defendant is engaged in activities that infringe the '988 patent under 35. U.S.C. § 271 by making, using, offering to sell, selling and/or importing LED Lighting Devices, including without limitation its Eco-Downlight LED, Eco-Counter LED, and Dexter Exterior LED Wall Sconce products, in the United States.

13. Upon information and belief, Defendant is aware of the '988 patent and their infringement is deliberate, willful, and in reckless disregard of Plaintiffs' patent rights.

14. Plaintiffs have been and continue to be injured by the infringing activities of Defendant.

COUNT II: PATENT INFRINGEMENT OF U.S. PATENT NO. 6,094,014

15. Plaintiffs incorporate by reference paragraphs 1-9 as if fully set forth herein.

16. On July 25, 2000, the Patent Office duly and legally issued the '014 patent, entitled "Circuit Arrangement, and Signaling Light Provided with the Circuit Arrangement," to Marcel J. M. Bucks et al. Plaintiff KPNV is the assignee and owner of the '014 patent, a copy of which is attached hereto as Exhibit B.

17. Upon information and belief, Defendant is engaged in activities that infringe the ’014 patent under 35. U.S.C. § 271 by making, using, offering to sell, selling and/or importing LED Lighting Devices, including without limitation its Eco-Downlight LED products, Eco-Counter LED, and Dexter Exterior LED Wall Sconce, in the United States.

18. Upon information and belief, Defendant is aware of the ’014 patent and their infringement is deliberate, willful, and in reckless disregard of Plaintiffs’ patent rights.

19. Plaintiffs have been and continue to be injured by the infringing activities of Defendant.

COUNT III: PATENT INFRINGEMENT OF U.S. PATENT NO. 6,250,774

20. Plaintiffs incorporate by reference paragraphs 1-9 as if fully set forth herein.

21. On June 26, 2001, the Patent Office duly and legally issued the ’774 patent, entitled “Luminaire,” to Simon H. A. Begemann et al. Plaintiff KPNV is the assignee and owner of the ’774 patent, a copy of which is attached hereto as Exhibit C.

22. Upon information and belief, Defendant is engaged in activities that infringe the ’774 patent under 35. U.S.C. § 271 by making, using, offering to sell, selling and/or importing LED Lighting Devices, including without limitation its Eco-Downlight LED products, in the United States.

23. Upon information and belief, Defendant is aware of the ’774 patent and their infringement is deliberate, willful, and in reckless disregard of Plaintiffs’ patent rights.

24. Plaintiffs have been and continue to be injured by the infringing activities of Defendant.

COUNT IV: PATENT INFRINGEMENT OF U.S. PATENT NO. 6,561,690

25. Plaintiffs incorporate by reference paragraphs 1-9 as if fully set forth herein.

26. On May 13, 2003, the Patent Office duly and legally issued the ’690 patent, entitled “Luminaire Based on the Light Emission of Light-Emitting Diodes,” to Christophe Balestriero et al. Plaintiff KPNV is the assignee and owner of the ’690 patent, a copy of which is attached hereto as Exhibit D.

27. Upon information and belief, Defendant is engaged in activities that infringe the ’690 patent under 35. U.S.C. § 271 by making, using, offering to sell, selling and/or importing LED Lighting Devices, including without limitation its Eco-Downlight LED products, in the United States.

28. Upon information and belief, Defendant is aware of the ’690 patent and their infringement is deliberate, willful, and in reckless disregard of Plaintiffs’ patent rights.

29. Plaintiffs have been and continue to be injured by the infringing activities of Defendant.

COUNT V: PATENT INFRINGEMENT OF U.S. PATENT NO. 7,038,399

30. Plaintiffs incorporate by reference paragraphs 1-9 as if fully set forth herein.

31. On May 2, 2006, the Patent Office duly and legally issued the ’399 patent, entitled “Methods and Apparatus for Providing Power to Lighting Devices,” to Ihor A. Lys et al. Plaintiff PLNA is the assignee and owner of the ’399 patent, a copy of which is attached hereto as Exhibit E.

32. Upon information and belief, Defendant is engaged in activities that infringe the ’399 patent under 35. U.S.C. § 271 by making, using, offering to sell, selling and/or importing LED Lighting Devices, including without limitation its Eco-Downlight LED products, Eco-Counter LED, and Dexter Exterior LED Wall Sconce, in the United States.

33. Upon information and belief, Defendant is aware of the ’399 patent and their infringement is deliberate, willful, and in reckless disregard of Plaintiffs’ patent rights.

34. Plaintiffs have been and continue to be injured by the infringing activities of Defendant.

COUNT VI: PATENT INFRINGEMENT OF U.S. PATENT NO. 7,262,559

35. Plaintiffs incorporate by reference paragraphs 1-9 as if fully set forth herein.

36. On August 28, 2007, the Patent Office duly and legally issued the ’559 patent, entitled “LEDs Driver,” to Ajay Tripathi et al. Plaintiff KPNV is the assignee and owner of the ’559 patent, a copy of which is attached hereto as Exhibit F.

37. Upon information and belief, Defendant is engaged in activities that infringe the ’559 patent under 35. U.S.C. § 271 by making, using, offering to sell, selling and/or importing LED Lighting Devices, including without limitation its Eco-Downlight LED products, Eco-Counter LED, and Dexter Exterior LED Wall Sconce, in the United States.

38. Upon information and belief, Defendant is aware of the ’559 patent and their infringement is deliberate, willful, and in reckless disregard of Plaintiffs’ patent rights.

39. Plaintiffs have been and continue to be injured by the infringing activities of Defendant.

COUNT VII: PATENT INFRINGEMENT OF U.S. PATENT NO. 7,352,138

40. Plaintiffs incorporate by reference paragraphs 1-9 as if fully set forth herein.

41. On April 1, 2008, the Patent Office duly and legally issued the ’138 patent, entitled “Methods and Apparatus for Providing Power to Lighting Devices,” to Ihor A. Lys et al. Plaintiff PLNA is the assignee and owner of the ’138 patent, a copy of which is attached hereto as Exhibit G.

42. Upon information and belief, Defendant is engaged in activities that infringe the ’138 patent under 35. U.S.C. § 271 by making, using, offering to sell, selling and/or importing LED Lighting Devices, including without limitation its Eco-Downlight LED products, Eco-Counter LED, and Dexter Exterior LED Wall Sconce, in the United States.

43. Upon information and belief, Defendant is aware of the ’138 patent and their infringement is deliberate, willful, and in reckless disregard of Plaintiffs’ patent rights.

44. Plaintiffs have been and continue to be injured by the infringing activities of Defendant.

PRAYER FOR RELIEF

WHEREFORE, Plaintiffs respectfully request the following relief:

(a) a declaration that Defendant infringes the patents-in-suit and a final judgment incorporating same;

(b) entry of preliminary and/or permanent equitable relief, including but not limited to a preliminary and/or permanent injunction that enjoin Defendant and any of its officers, agents, employees, assigns, representatives, privies, successors, and those acting in concert or participation with it from infringing and/or inducing infringement of the patents-in-suit;

(c) an award of damages sufficient to compensate Plaintiffs for infringement of the patents-in-suit by Defendant, together with prejudgment and post-judgment interest;

(d) a declaration or order finding that Defendant’s infringement is willful and/or an order increasing damages under 35 U.S.C. § 284;

(e) a judgment holding that this is an exceptional case under 35 U.S.C. § 285 and awarding Plaintiffs their reasonable attorneys’ fees, costs, and expenses; and

(f) such other relief deemed just and proper.

JURY DEMAND

Under Rule 38 of the Federal Rules of Civil Procedure, Plaintiffs hereby demand trial by jury of all issues so triable by a jury in this action.

Dated: March 20, 2015

Respectfully submitted,

/s/ Denise W. DeFranco
Denise W. DeFranco (BBO No. 558859)
denise.defranco@finnegan.com
FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, LLP
Two Seaport Lane
Boston, MA 02210-2001
Telephone: (617) 646-1600
Facsimile: (617) 646-1666

Attorney for Plaintiffs
Koninklijke Philips N.V. and
Philips Lighting North America Corporation

Exhibit A

US006013988A

United States Patent [19]

Bucks et al.

[11] **Patent Number: 6,013,988**

[45] **Date of Patent: Jan. 11, 2000**

[54] **CIRCUIT ARRANGEMENT, AND SIGNALLING LIGHT PROVIDED WITH THE CIRCUIT ARRANGEMENT**

[75] Inventors: **Marcel J. M. Bucks**; **Engbert B. G. Nijhof**, both of Eindhoven, Netherlands

[73] Assignee: **U.S. Philips Corporation**, New York, N.Y.

[21] Appl. No.: **09/128,147**

[22] Filed: **Aug. 3, 1998**

[30] **Foreign Application Priority Data**

Aug. 1, 1997 [EP] European Pat. Off. 97202399

[51] **Int. Cl.**[7] **H05B 37/00**

[52] **U.S. Cl.** **315/307**; 315/291; 315/297

[58] **Field of Search** .... 315/291, 307, 315/306, 225, 224, 287, DIG. 5, 297

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,577,320 3/1986 Yoshikawa et al. 372/29

5,028,862 7/1991 Roth 315/291

5,612,596 3/1997 Wiese 315/291

FOREIGN PATENT DOCUMENTS

2172120 9/1986 United Kingdom .

Primary Examiner—Don Wong

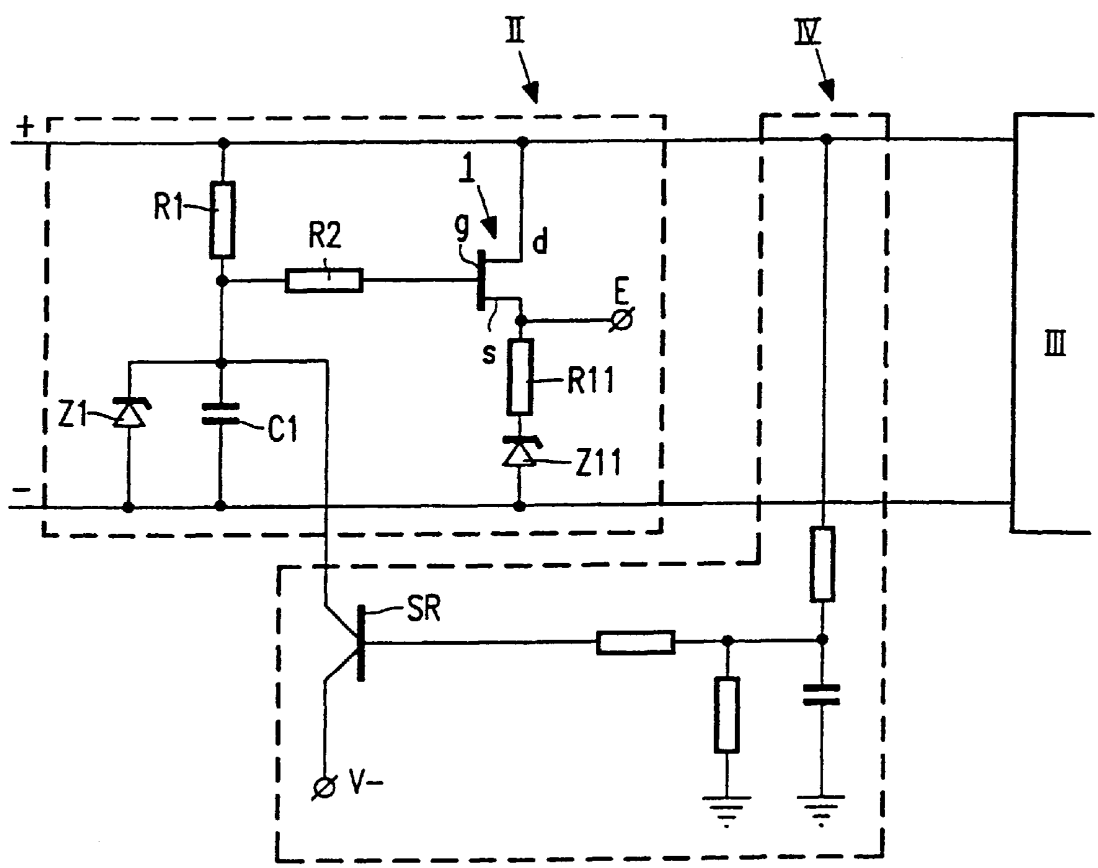
Assistant Examiner—Tuyet Vo

Attorney, Agent, or Firm—Edward W. Goodman

[57] **ABSTRACT**

A circuit arrangement for operating a semiconductor light source includes connection terminals for connection to a control unit, an input filter, a converter having a control circuit, and output terminals for connection to the semiconductor light source. The circuit arrangement is also provided with a self-regulating current-conducting network.

5 Claims, 3 Drawing Sheets



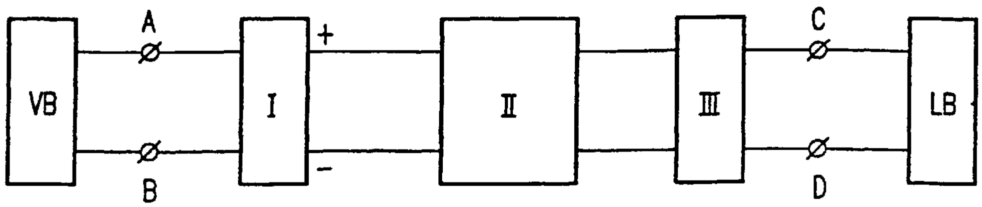


FIG. 1

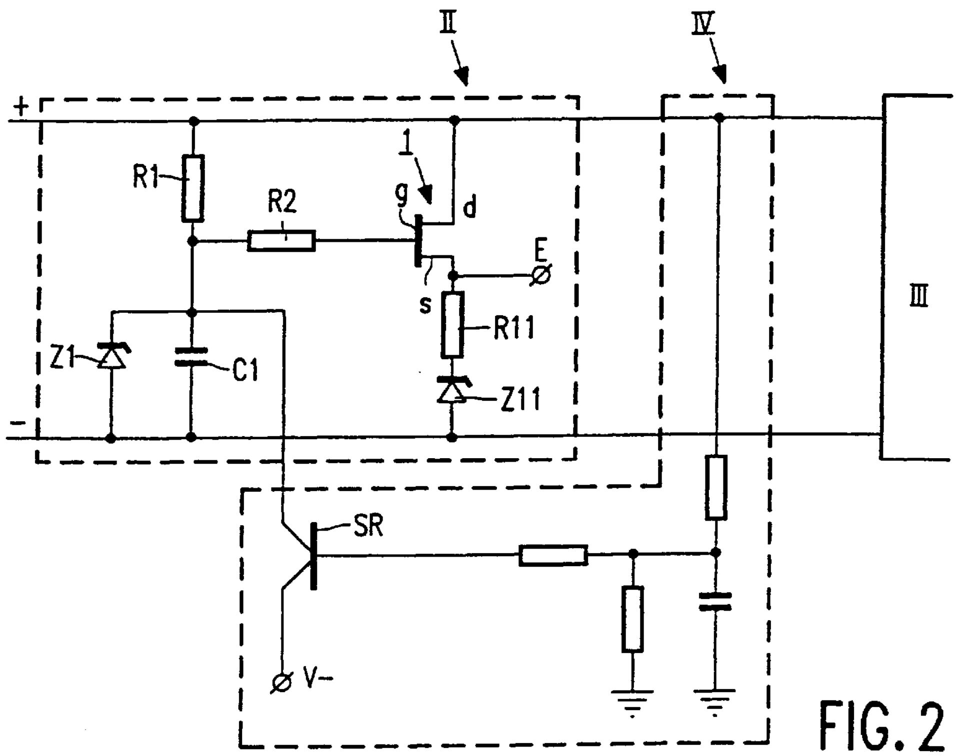


FIG. 2

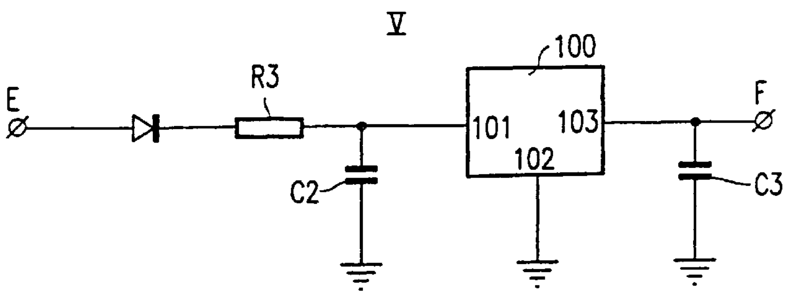


FIG. 3

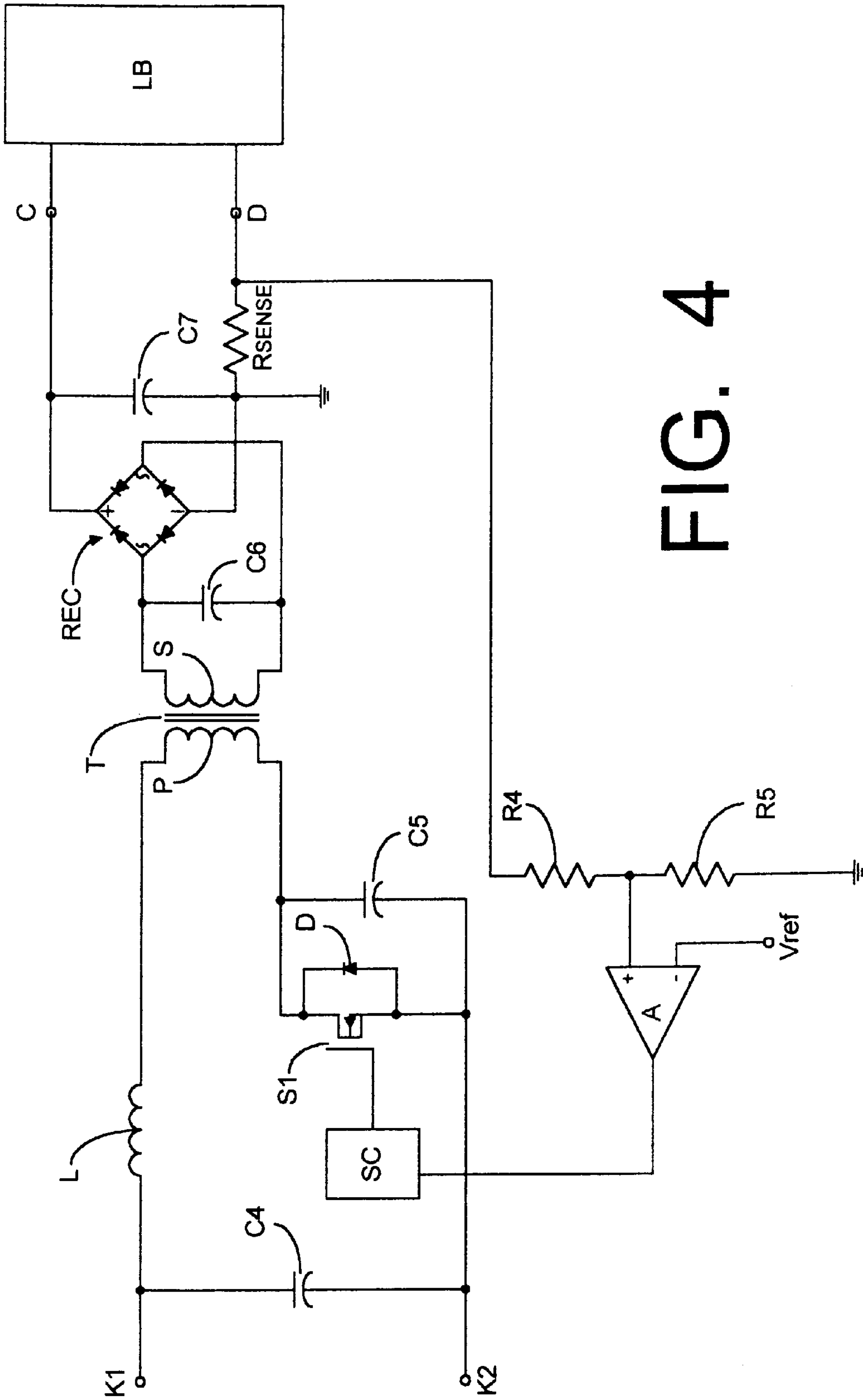


FIG. 4

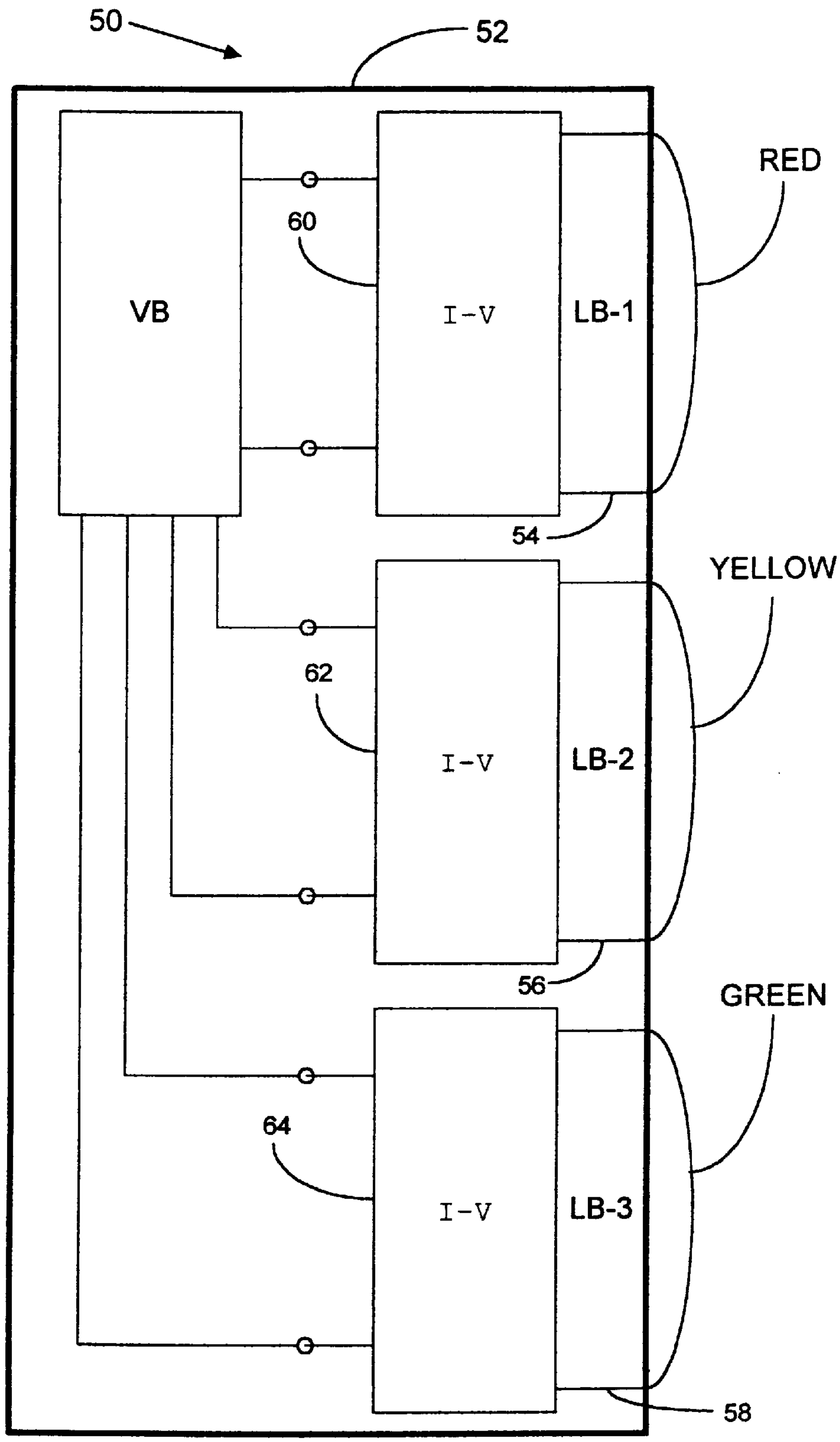


FIG. 5

CIRCUIT ARRANGEMENT, AND SIGNALLING LIGHT PROVIDED WITH THE CIRCUIT ARRANGEMENT

Circuit arrangement, and signalling light provided with the circuit arrangement.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a circuit arrangement for operating a semiconductor light source provided with:

connection terminals for connection to a control unit,

input filter means,

a converter comprising a control circuit, and

output terminals for connection to the semiconductor light source. The invention also relates to a signalling light provided with such a circuit arrangement.

2. Description of the Related Art

Semiconductor light sources are increasingly used as signalling lights. A semiconductor light source in such an application has the advantage over a usual incandescent lamp that it has a longer life and a considerably lower power consumption than the incandescent lamp. Signalling lights often form part of a complicated signalling system, for example, a traffic control system with traffic lights. It is necessary for the circuit arrangement to provide retrofit possibilities in respect of existing signalling systems if the above advantages of semiconductor light sources are to be realized on a wide scale.

A signalling light in an existing signalling system is often controlled by means of a control unit which includes a solid state relay, a status test of the relay and of the signalling light taking place at the connection terminals of the connected circuit arrangement. It is a general property of solid state relays that a leakage current occurs in the non-conducting state of the relay. The use of a semiconductor light source is apt to give rise to an incorrect outcome of the status test. This is a problem in the use of the semiconductor light source.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a measure by which the above problem is eliminated.

According to the invention, this object is achieved in that the circuit arrangement is, in addition, provided with a self-regulating current-conducting network. It is possible, thanks to the self-regulating current-conducting network, to drain off a leakage current occurring in the control unit while the control unit, for example, a solid state relay, is in the non-conducting state, and thus, to keep the voltage at the connection terminals of the circuit arrangement below a level required for a correct outcome of the status test. It is realized, thereby, in a simple and effective manner, that the circuit arrangement exhibits a characteristic at its connection terminals which corresponds, to a high degree, to the characteristic of an incandescent lamp.

An important feature of an incandescent lamp characteristic in this respect is a comparatively low impedance of the lamp in the extinguished state, with the result that the removal of the leakage current through the incandescent lamp leads to only a low voltage at the connection terminals of the control circuit.

Preferably, the circuit arrangement according to the invention comprises means for deactivating the self-regulating current-conducting network when the converter is switched on, which has the advantage that unnecessary power dissipation is counteracted. In an advantageous embodiment of the circuit arrangement according to the invention, the circuit arrangement is provided with a stabilized low-voltage supply, and the self-regulating current-conducting network in the activated state forms a supply source for said stabilized low-voltage supply. This embodiment has the major advantage that the stabilized low-voltage supply delivers the required low voltage very quickly upon switching-on of the converter by means of the control circuit, for example, the solid state relay, entering the conducting state, because the self-regulating current-conducting network has already been activated.

In the present description, the term "converter" is understood to mean an electrical circuit by means of which an electrical power supplied by the control circuit is converted into a current-voltage combination required for operating the semiconductor light source. Preferably, a switched-mode power supply fitted with one or several semiconductor switches is used for this purpose. Since modern switch-mode power supplies are often DC—DC converters, it is preferable for the input filter means to be also provided with rectifier means, which are known per se.

Preferably, a signalling light is provided with a housing containing a semiconductor light source according to the invention and also provided with the circuit arrangement according to the invention. The possibilities of using the signalling light as a retrofit unit for an existing signalling light are strongly increased thereby. The application possibilities as a retrofit signalling light are optimized when the circuit arrangement is provided with a housing which is integrated with the housing of the signalling light.

BRIEF DESCRIPTION OF THE DRAWING

The above and further aspects of the invention will be explained in more detail below with reference to a drawing of an embodiment of the circuit arrangement according to the invention, in which:

FIG. **1** is a block diagram of the circuit arrangement,

FIG. **2** is a circuit diagram showing a self-regulating current-conducting network in more detail;

FIG. **3** is a circuit diagram of a stabilized low-voltage supply; and

FIG. **4** is a circuit diagram showing a converter with a control circuit; and

FIG. **5** is a diagram of a traffic light having a semiconductor light source as a signalling light, and the circuit arrangement of the subject invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. **1**, A and B are connection terminals for connection to a control unit VB, for example, provided with a solid state relay. Reference I denotes input filter means, and III a converter with a control circuit. C and D are output terminals for connecting the semiconductor light source LB. II denotes a self-regulating current-conducting network. The input filter means I are provided with a positive pole + and a negative pole −.

The self-regulating current-conducting network II, of which the diagram is shown in more detail in FIG. **2**, comprises a MOSFET **1** with a gate g, a drain d, and a source s. The gate g of the MOSFET **1** is connected via a resistor R**2** to a voltage divider network, which is connected electrically in parallel to the input filter means I, which comprises a series arrangement of a resistor **R1** and a capacitor C**1**. The capacitor C**1** is shunted by a zener diode Z**1**. The drain d of the MOSFET **1** is directly connected to the positive pole + of the input filter means I. The source s is connected to the negative pole – of the input filter means I via a series arrangement of a resistor R**11** and a zener diode Z**11**. E denotes a connection point of the self-regulating current-conducting network for connection to a stabilized low-voltage supply which forms part of the circuit arrangement. The self-regulating current-conducting network II in the activated state forms, through the connection point E, a supply source for the stabilized low-voltage supply.

FIG. **2** also shows means IV included in the circuit arrangement for deactivating the self-regulating current-conducting network II when the converter III is switched on. A switch SR is, for this purpose, connected, on the one hand, to a common junction point of the resistor R**1** and the capacitor C**1**, and on the other hand, to an auxiliary voltage V–. A control electrode of the switch SR is connected to the positive pole + by means of a voltage divider. When the control unit is switched on, i.e., for switching on the converter III, the voltage at the positive pole + will rise, whereupon the switch SR becomes conducting and the MOSFET **1** is cut off, so that the self-regulating current-conducting network is deactivated.

In the embodiment shown, the auxiliary voltage V– is preferably modulated by a signal which is proportional to the current flowing through the connected semiconductor light source. This is advantageous in that there is avoided that the self-regulating current-conducting network with switched-on converter III is activated each time the voltage of the connected control unit has a zero-crossing. This is realized in a further embodiment in that the means IV is connected, for example, to output terminal C of the converter or to terminal F of the low-voltage supply and, besides, the auxiliary voltage V– has a constant voltage, for example, the voltage of the negative pole. In an advantageous manner, there is thus also realized that the self-regulating current-conducting network is deactivated by the means IV on the basis of current supplied by the semiconductor light source when the converter is switched on, without the hazard of the network being activated when the voltage of the control unit has a zero-crossing.

Although the means for deactivating the self-regulating current-conducting network is indicated as separate means IV in the drawing, the means IV preferably forms part of the control circuit of the converter III. FIG. **3** shows a stabilized low-voltage supply unit V which forms part of the circuit arrangement. The stabilized low-voltage supply V is connected with an input to connection point E of the self-regulating current-conducting network II, which thus forms, when in the activated state, a supply source for the stabilized low-voltage supply. The connection point E is connected to a pin **101** of an integrated circuit (IC) **100** via a diode D**1** and a network of a resistor R**3** and a capacitor C**2**. A pin **103** of the IC **100** forms an output pin carrying a stabilized low voltage which can be taken off by means of connector F. The pin **103** is connected to ground via a capacitor C**3**. A pin **102** of the IC **100** is also connected to ground.

In a practical realization of the embodiment of the circuit arrangement according to the invention as described above, this circuit arrangement is suitable for connection to a control unit supplying a voltage in the conducting state of at least 80 V, 60 Hz, and at most 135 V, 60 Hz, and which is suitable for operating a semiconductor light source comprising a matrix of 3×6 LEDs, made by Hewlett-Packard, with

a forward voltage V_F of between 2 V and 3 V, defined at 250 mA and at an ambient temperature of 25° C. A rectified voltage with an effective value of at least 80 V and, at most, 135 V is present at the positive pole + of the input filter means when the converter is in the activated state. The MOSFET **1** of the self-regulating current-conducting network II is of the IRF 820 type (made by IRF). The zener diode Z1 has a zener voltage of 15 V, the zener diode Z**11**, 5.6 V. The capacitor C1 has a value of 330 pF, and the resistors R**1**, R**2**, and R**3** have values of 240 kΩ, 10 kΩ, and 220 kΩ, respectively. When the control unit is disconnected, this results in a maximum current through the MOSFET **1** of 31 mA, which corresponds to a voltage at the input terminal A of at most 10 Vrms. This corresponds to the maximum admissible voltage level for the control unit in the disconnected state which will just lead to a correct outcome of a status test of the control unit.

The switch SR is of the BCX70 type (made by Philips). The IC **100** is of the 78L09 type (made by National Semiconductors) and supplies a stabilized low voltage of 9 V with an accuracy of 1%. The resistor R**3** has a value of 10 Ω and the capacitors C**2** and C**3** each have a capacitance value of 1 μF.

FIG. **4** shows a schematic diagram of the converter III with the control circuit. K1 and K**2** in this embodiment form input terminals for connection to a DC voltage source. K1 and K2 are interconnected by means of a capacitor C**4** which serves as a buffer capacitance. The input terminals K1 and K**2** are also interconnected by a series arrangement of a coil L, a primary winding P of a transformer T, and a capacitor C**5**. The capacitor C**5** is shunted by a switching element S**1** whose control electrode is connected to an output of a control circuit SC for rendering the switching element S1 conducting and non-conducting with high frequency. An input of the control circuit SC is connected to an output of an amplifier A. A first input of the amplifier A is connected to a reference voltage Vref which is present during operation of the circuit arrangement. A second input of the amplifier A is connected to a common junction point of a resistor R**4** and NTC R**5**. A first end of the series arrangement of resistor R**4** and NTC R**5** is connected to a terminal D. A second end of the series arrangement is connected to ground. A diode D forms part of the switching element S**1**. A secondary winding S of the transformer T is shunted by a capacitor C**6**. Ends of the secondary winding S are connected to respective input terminals of a diode rectifier bridge REC. Output terminals of the diode rectifier bridge REC are interconnected by a capacitor C**7** which acts as a buffer capacitance. The positive output terminal of the diode bridge is connected to the terminal C. The negative output terminal of the diode rectifier bridge REC is connected to ground and, through a resistor Rsense, to the terminal D. The terminal C and D form the output terminals of the converter. The semiconductor light source LB is connected to these output terminals C and D. In the "off" state of the converter, the control circuit SC keeps the switching element S**1** in its non-conducting condition, while in the "on" state of the converter, the control circuit SC cyclically switches the switching element S**1** between the conducting and non-conducting conditions at a high frequency.

FIG. **5** shows a diagram of a traffic light **50** for use in a traffic control system. The traffic light **50** includes a housing **52** which contains three signalling light lenses—RED, YELLOW, GREEN. Each of the lenses receives light from a respective signalling light in the form of semiconductor light sources LB-**1**, LB-**2** and LB-**3**, each arranged in respective housings **54**, **56** and **58** within the housing **52** of the traffic light **50**. Each of the semiconductor light sources LB-**1**, LB-**2** and LB-**3** has an associated circuit arrangement (I–V) which are each arranged in respective housings **60**, **62** and **64**, these housing being integrated with the housings **54**, **56** and **58**, respectively, of the semiconductor light sources LB-**1**, LB-**2** and LB-**3**. Each of the circuit arrangements (I–V) selectively receive power from the control unit VB.

What is claimed is:

1. A circuit arrangement for operating a semiconductor light source, said circuit arrangement comprising:

connection terminals for connecting the circuit arrangement to outputs from a control unit for controlling the semiconductor light source;

input filter means coupled to the connection terminals;

a converter comprising a control circuit, said converter being coupled to output means of the input filter means; and

output terminals for coupled to output means of said converter for connecting said circuit arrangement to the semiconductor light source,

characterized in that said converter comprises a switched-mode power supply for providing power to said semiconductor light source, said switched-mode power supply having a switching element which is cyclically switched on and off by said control circuit, and the circuit arrangement further comprises a self-regulating current-conducting network coupled between said filter means and said converter, said self-regulating current-conducting network draining off a leakage current in the control unit when said control unit is in a non-conducting state.

2. The circuit arrangement as claimed in claim **1**, characterized in that the circuit arrangement comprises means or deactivating the self-regulating current-conducting network hen the converter is switched on.

3. The circuit arrangement as claimed in claim **1**, characterized in that the circuit arrangement further comprises a stabilized low-voltage supply, the self-regulating current-conducting network, in an activated state, forming a supply source for said stabilized low-voltage supply.

4. A signalling light provided with a housing containing a semiconductor light source and a control unit for controlling the semiconductor light source, characterized in that the signalling light is provided with a circuit arrangement for operating the semiconductor light source, said circuit arrangement comprising:

connection terminals for connecting the circuit arrangement to outputs from the control unit;

input filter means coupled to the connection terminals;

a converter comprising a control circuit, said converter being coupled to output means of the input filter means; and

output terminals for coupled to output means of said converter for connecting said circuit arrangement to the semiconductor light source,

wherein said converter comprises a switched-mode power supply for providing power to said semiconductor light source, said switched-mode power supply having a switching element which is cyclically switched on and off by said control circuit, and wherein the circuit arrangement further comprises a self-regulating current-conducting network coupled between said filter means and said converter, said self-regulating current-conducting network draining off a leakage current in the control unit when said control unit is in a non-conducting state.

5. The signalling light as claimed in claim **4**, characterized in that the circuit arrangement is provided with a housing which is integrated with a housing of the signalling light.

* * * * *

Exhibit B

US006094014A

United States Patent [19]

Bucks et al.

[11] **Patent Number: 6,094,014**

[45] **Date of Patent: Jul. 25, 2000**

[54] **CIRCUIT ARRANGEMENT, AND SIGNALING LIGHT PROVIDED WITH THE CIRCUIT ARRANGEMENT**

[75] Inventors: **Marcel J. M. Bucks**; **Engbert B. G. Nijhof**, both of Eindhoven, Netherlands

[73] Assignee: **U.S. Philips Corporation**, New York, N.Y.

[21] Appl. No.: **09/128,148**

[22] Filed: **Aug. 3, 1998**

[30] **Foreign Application Priority Data**

Aug. 1, 1997 [EP] European Pat. Off. 97202400

[51] **Int. Cl.**[7] **G05F 1/00**

[52] **U.S. Cl.** **315/291**; 315/307; 315/169.3; 363/25; 363/89; 323/222; 323/282

[58] **Field of Search** 315/169.3, 291, 315/307, 290, 287; 323/222, 282, 351; 363/15, 25, 89, 80, 81, 126

[56] **References Cited**

U.S. PATENT DOCUMENTS

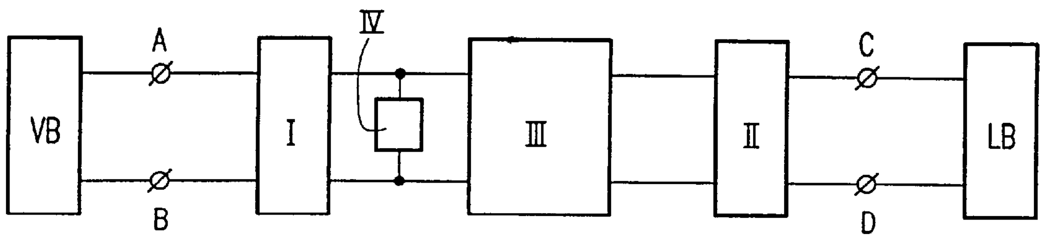
4,291,254	9/1981	Arlt et al.	315/240
4,403,157	9/1983	Guajardo et al.	327/520
4,595,861	6/1986	Simopoulos et al.	315/169.3
4,654,629	3/1987	Bezos et al.	246/473.3
5,656,925	8/1997	Schie et al.	323/222
5,661,645	8/1997	Hochstein	363/89

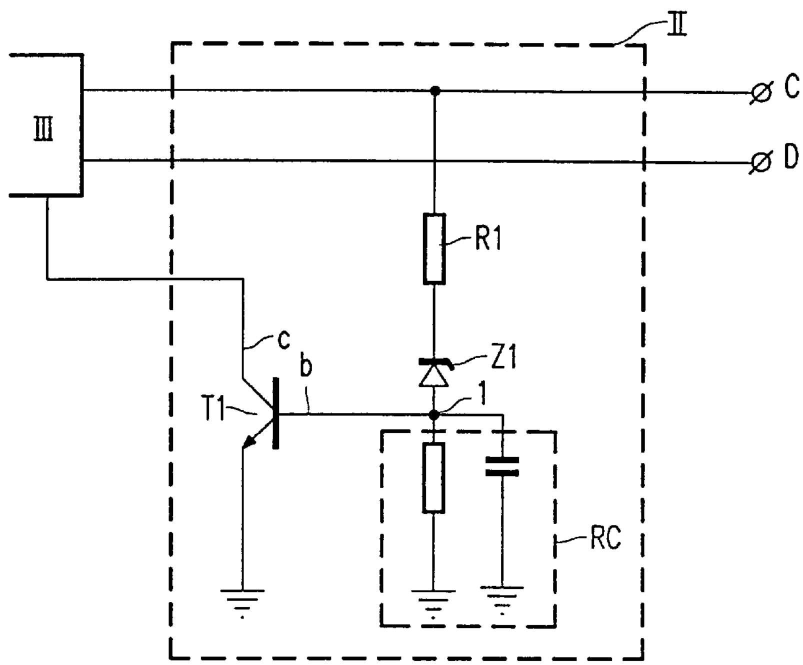
Primary Examiner—Haissa Philogene
Attorney, Agent, or Firm—Robert J. Kraus; Edward W. Goodman

[57] **ABSTRACT**

A circuit arrangement for operating a semiconductor light source, includes input terminals for connecting a supply voltage, an input filter, a converter having a control circuit, and output terminals for connecting the semiconductor light source. The circuit arrangement is provided with a voltage detector for detecting the output voltage at the output terminals.

7 Claims, 1 Drawing Sheet





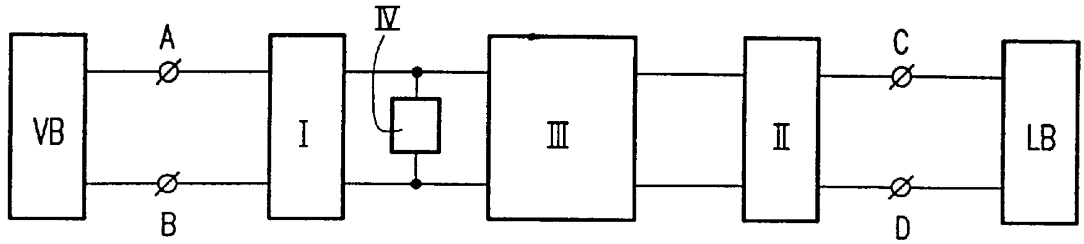


FIG. 1

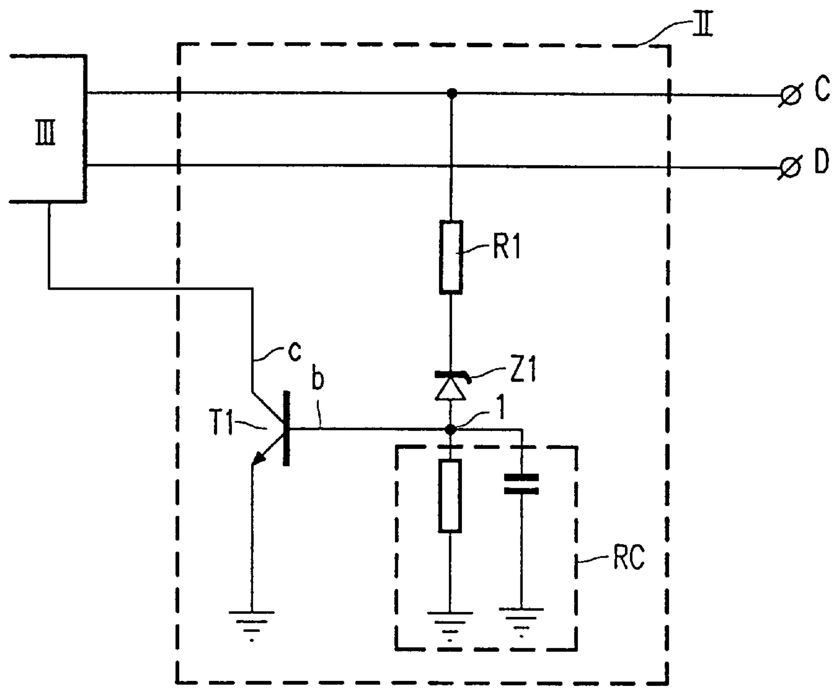


FIG. 2

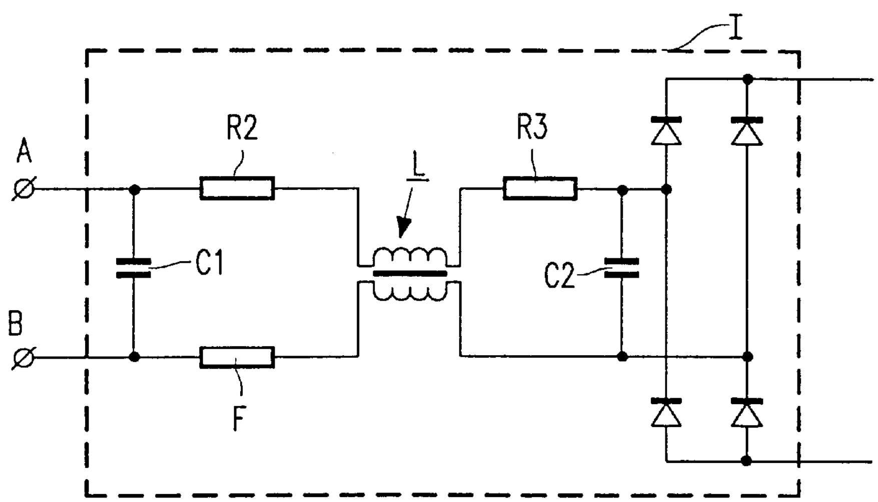


FIG. 3

CIRCUIT ARRANGEMENT, AND SIGNALING LIGHT PROVIDED WITH THE CIRCUIT ARRANGEMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a circuit arrangement suitable for operating a semiconductor light source and provided with:

input terminals for connecting a supply voltage,

input filter means,

a converter comprising a control circuit, and

output terminals for connecting the semiconductor light source.

2. Description of the Related Art

The invention also relates to a signaling light provided with such a circuit arrangement.

Semiconductor light sources are increasingly used for signaling lights. A semiconductor light source has the advantage over a usual incandescent lamp in such an application that it has a considerably longer life and a considerably lower power consumption than the incandescent lamp. Signaling lights often form part of a complicated signaling system, for example, a traffic control system with traffic lights. Semiconductor light sources, in general, have the property that the operation as a light source is determined by the value of the current supplied to the semiconductor. The converter should accordingly, act as a current generator. A disadvantage of this is that a very high voltage may arise at the output terminals in the case of a defective semiconductor light source. If operation continues for a long time in such a condition, there is a risk of breakdown in the circuit arrangement, so that it becomes defective. Neither is the probability of short-circuits occurring a negligible one, with all the risks this involves.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a circuit arrangement of the kind described in the opening paragraph in which the above disadvantage is avoided.

According to the invention, this object is achieved in a circuit arrangement of the kind mentioned in the opening paragraph in that the circuit arrangement is provided with voltage detection means for voltage detection at the output terminals. An advantage of the measure according to the invention is that a direct check of the voltage level occurring at the output terminals of the converter is possible. This renders possible not only a detection of a defective semiconductor light source, but indeed, any disturbance of a safe operation of the converter.

Preferably, the voltage detection means generates a signal S if a voltage Vu appears the output terminals which is higher than a threshold voltage Vud. This has the advantage that it can be detected whether the impedance of the connected semiconductor light source has risen. A semiconductor light source in general, comprises a matrix of semiconductors, for example, in the form of LEDs, which are electrically interconnected. A defect in one or a few of the semiconductors will already give rise to an increased impedance of the light source. Although the increase in the voltage at the output terminals in itself need not be detrimental to the operation of the converter, the lumen output of the light source may drop as a result of this to such an extent that it no longer forms a reliable signaling light. Given a suitable choice of the threshold voltage level Vud, this detection has the advantage that it is suitable as a detection

of whether the semiconductor light source is wholly or partly defective.

In an advantageous embodiment of the circuit arrangement according to the invention, the input filter means is provided with switching means for switching the converter into an operational state for which it is true that Vu<Vud. This renders it possible to prevent an overload on the converter in a simple and reliable manner. The reliability is in particular, safeguarded by the use of switching means which is separate from the converter. The reliability is further enhanced in a preferred embodiment in which the switching means comprises disconnecting means, and the signal S serves for operating the converter in an operational state for activating the disconnecting means. An advantage of this is that the control circuit may be comparatively simple while a full separation between the control circuit of the converter, on the one hand and the switching means of the input filter means, on the other hand, is realized, whereby a reliable and controlled disconnection of the converter is safeguarded. A further improvement in the reliability of the disconnection of the converter can be advantageously achieved in that the switching means is constructed as a fuse. It is necessary for the circuit arrangement to have retrofit possibilities with respect to existing signaling systems in order to realize the above advantages of semiconductor light sources on a wide scale. The use of the fuse advantageously realizes a condition at the connection terminals comparable to a defective incandescent lamp when the converter has been disconnected by the disconnecting means. The use of a semiconductor light source as a replacement for an incandescent lamp is further promoted thereby.

In an advantageous embodiment, the circuit arrangement according to the invention is suitable for connection to a solid state relay, and a self-regulating current limitation network is connected between the input filter means and the converter. The self-regulating current limitation network will also be disconnected when the converter is disconnected by the disconnecting means. An advantage of this is that a situation arises again under these circumstances comparable to a defective incandescent lamp. This may be explained as follows. Traffic control systems provided with traffic lights are usually fitted with a so-called conflict monitor which regularly measures the voltage between connection terminals of a relevant traffic light. The control of the traffic light usually takes place by means of a solid state relay. When the solid state relay is non-conducting, a small leakage current will usually flow. If the traffic light is an incandescent light, it will have a low impedance and accordingly, the leakage current flowing through the lamp will not lead to an appreciable rise in the voltage between the connection terminals. If the incandescent lamp is defective, on the other hand, its impedance is very high, which means that the occurrence of the leakage current leads to a considerable rise in the voltage between the connection terminals. The voltage between the connection terminals thus forms an indication for the conflict monitor as to whether the connected lamp is defective or not. In the present description, the term "converter" is understood to mean an electrical circuit with which an electrical power supplied by the supply source is converted into a current/voltage combination required for operating the semiconductor light source. Preferably, a switched mode power supply provided with one or several semiconductor switches is used as such. Since modern switch mode power supplies are usually DC—DC converters, it is preferable for the input filter means to be provided also with rectifying means which is known per se.

Preferably, a signaling light provided with a housing containing a semiconductor light source according to the invention is also provided with the circuit arrangement according to the invention. The possibilities of using the signaling light as a retrofit unit for an existing signaling light are strongly enhanced in this manner. The application possibilities as a retrofit signaling light are an optimum if the circuit arrangement is provided with a housing which is integrated with the housing of the signaling light.

BRIEF DESCRIPTION OF THE DRAWING

The above and further aspects of the invention will be explained in more detail below with reference to a drawing of an embodiment of the circuit arrangement according to the invention, in which:

FIG. **1** is a block diagram of the circuit arrangement;

FIG. **2** is a more detailed circuit diagram of voltage detection means for the detection of voltage; and

FIG. **3** shows the input filter means in detail.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. **1**, A and B are connection terminals for connecting a supply source VB, for example, provided with a solid state relay. Reference I denotes input filter means and III, a converter with a control circuit. C and D form output terminals for connecting the semiconductor light source LB. II denotes voltage detection means for the detection of the voltage at the output terminals. A self-regulating current limitation network IV is connected between the input filter means I and the converter III. The converter III, preferably, is a switch mode power supply fitted with one or several semiconductor switches.

FIG. **2** shows a more detailed diagram of the voltage detection means, which comprises a voltage divider branch consisting of a resistor R**1**, a zener diode Z**1**, and an RC network RC. Between the zener diode Z**1** and the RC network RC, there is a junction point **1** to which a base b of a transistor T**1** is connected for generating a signal S if a voltage Vu appears at the output terminals which is higher than a threshold voltage Vud. The threshold voltage here is defined by the zener voltage of the zener diode Z**1**. The moment the output voltage Vu becomes higher than the threshold voltage Vud, a signal S will appear at a collector c of the transistor T**1**. This signal S is conducted to the control circuit of the converter III.

The input filter means I is shown in detail in FIG. **3** and comprises two coupled self-inductances L which, together with capacitors C**1**, C**2** and resistors R**2**, R**3**, form a filter for suppressing electromagnetic interference. A fuse F also forms part of the input filter means, acting as a disconnecting means therein. The disconnecting means thus forms switching means for switching the converter into an operational state for which it is true that Vu<Vud. The signal S, which is conducted to the control circuit of the converter III, serves to operate the converter in an operational state which leads to an activation of the disconnecting means.

In a practical realization of the embodiment of the circuit arrangement according to the invention as described above, this circuit arrangement is suitable for connection to a supply source with a voltage of at least 80 V, 60 Hz, and at most 135 V, 60 Hz, and is suitable for operating a semiconductor light source comprising a matrix of 3×6 LEDs, made by Hewlett-Packard, with a forward voltage V_F of between 2 V and 3 V, defined at 250 mA and at an ambient temperature of 25° C. The embodiment described is highly suitable for use as a traffic light in a traffic control system.

The converter III is formed by a switched mode power supply provided with a semiconductor switch. The zener diode Z**1** of the voltage detection means II has a zener voltage of 27 V. The resistor R**1** has a value of 1 kΩ. The transistor T**1** is of the BCX70 type (made by Philips). The RC network RC comprises a parallel arrangement of a 10 kΩ resistor and a 10 nF capacitor. The transistor T**1** will become conducting and current will start to flow through the collector c as soon as the output voltage Vu is and remains higher than 27 V. This current through the collector c forms the signal S. In the embodiment described here, the collector c is connected to a trigger input of an IC of the TLP555 type (made by TI), which forms part of the control circuit of the switch mode power supply. This achieves that the semiconductor switch of the switched mode power supply is so switched that the switched mode power supply draws a continuous strong current from the supply source.

The two coupled self-inductances L of the input filter means I each has a value of 1.5 μH, the capacitors C**1** and C**2** each have a value of 100 nF, and the resistors R**2** and R**3**, a value of 5.6 Ω each. The fuse F, which forms part of the input filter means, is formed by a fusistor of 10 Ω, type NFR25H, made by Philips.

The circuit arrangement, provided with a housing, forms part of a signaling light which is provided with a housing containing a semiconductor light source, the housing of the circuit arrangement being integrated with the housing of the signaling light. The embodiment described is highly suitable for use as a traffic light in a traffic control system.

We claim:

1. A circuit arrangement suitable for operating a semiconductor light source, said circuit arrangement comprising:

input terminals for connecting a supply voltage;

input filter means;

a converter comprising a control circuit; and

output terminals for connecting the semiconductor light source, wherein said converter generates a current for application to said semiconductor light source, and said control circuit controls said converter to produce a predetermined value of said current at said output terminals, said predetermined value of said current corresponding to an output voltage which is less than a predetermined threshold voltage,

characterized in that the circuit arrangement further comprises voltage detection means for detecting the output voltage at the output terminals, said voltage detection means generating a detection signal when the output voltage exceeds said predetermined threshold voltage.

2. A circuit arrangement as claimed in claim **1**, characterized in that the input filter means includes switching means for switching the converter into an operational state in which the output voltage is made less than the threshold voltage.

3. A circuit arrangement as claimed in claim **2**, characterized in that the switching means comprises disconnecting means for disconnecting the converter from said supply voltage, and the detection signal causes the converter to operate in a state such that the disconnecting means is activated.

4. A circuit arrangement as claimed in claim **3**, characterized in that the disconnecting means is constructed as a fuse.

5. A circuit arrangement as claimed in claim **1**, characterized in that the circuit arrangement is suitable for connection to a solid state relay, and in that a self-regulating current limitation network is connected between the input filter means and the converter.

6. A signaling light provided with a housing containing a semiconductor light source, characterized in that the signaling light is provided with a circuit arrangement for operating the semiconductor light source, said circuit arrangement comprising:

input terminals for connecting a supply voltage;

input filter means;

a converter comprising a control circuit; and

output terminals for connecting the semiconductor light source, wherein said converter generates a current for application to said semiconductor light source, and said control circuit controls said converter to produce a predetermined value of said current at said output

terminals, said predetermined value of said current corresponding to an output voltage which is less than a predetermined threshold voltage,

characterized in that the circuit arrangement further comprises voltage detection means for detecting the output voltage at the output terminals, said voltage detection means generating a detection signal when the output voltage exceeds said predetermined threshold voltage.

7. A signaling light as claimed in claim **6**, characterized in that the circuit arrangement is provided with a housing which is integrated with the housing of the signaling light.

* * * * *

Exhibit C

US006250774B1

(12) **United States Patent**
Begemann et al.

(10) **Patent No.: US 6,250,774 B1**
(45) **Date of Patent: *Jun. 26, 2001**

(54) **LUMINAIRE**

(75) Inventors: **Simon H. A. Begemann**; **Albertus J. H. M. Kock**, both of Eindhoven (NL)

(73) Assignee: **U.S. Philips Corp.**, New York, NY (US)

(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/012,319**

(22) Filed: **Jan. 23, 1998**

(30) **Foreign Application Priority Data**

Jan. 23, 1997 (EP) 97200149

(51) **Int. Cl.**[7] **F21V 7/09**

(52) **U.S. Cl.** **362/231**; 362/240; 362/245; 362/800

(58) **Field of Search** 362/230, 231, 362/236, 237, 240, 241, 243, 244, 245, 251, 800

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,698,730 *	10/1987	Sakai et al.	362/800
5,105,179 *	4/1992	Smith	340/468
5,404,282	4/1995	Klinke et al.	362/249
5,580,156 *	12/1996	Suzuki et al.	362/240
5,893,633 *	4/1999	Uchio et al.	362/244

FOREIGN PATENT DOCUMENTS

3022974A1	1/1982	(DE) .
3806217A1	9/1989	(DE) .
4431750	3/1996	(DE) .
0748979A1	12/1996	(EP) .
WO9523313	8/1995	(WO) .

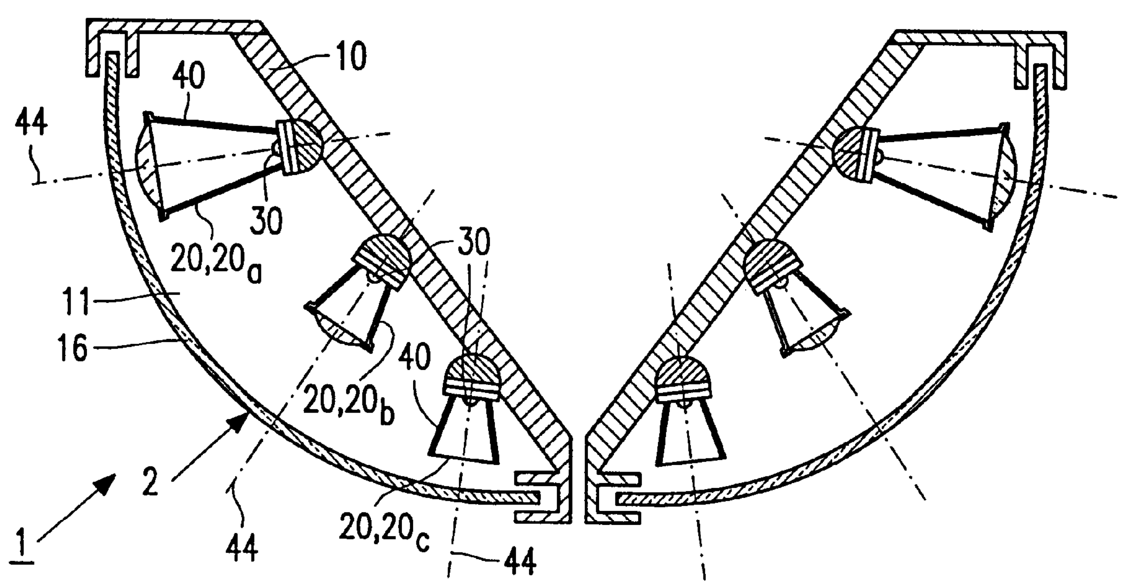
* cited by examiner

Primary Examiner—Y. Quach
(74) *Attorney, Agent, or Firm*—Dicran Halajian

(57) **ABSTRACT**

A luminaire **(1)** comprises a housing **(10)** with a light emission window **(11)**, and at least one lighting module **(2)** accommodated in the housing for illuminating an object. The lighting module comprises a set of lighting units **(20)** which each comprise at least an LED chip **(30)** and an optical system **(40)** coupled thereto. The lighting units illuminate respective portions of an object. The LED chips supply a luminous flux of at least 5 lm each.

15 Claims, 8 Drawing Sheets



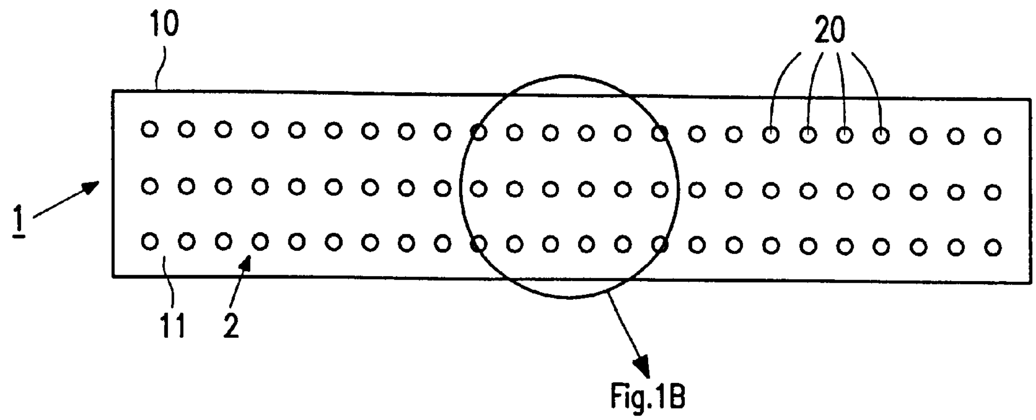


FIG. 1A

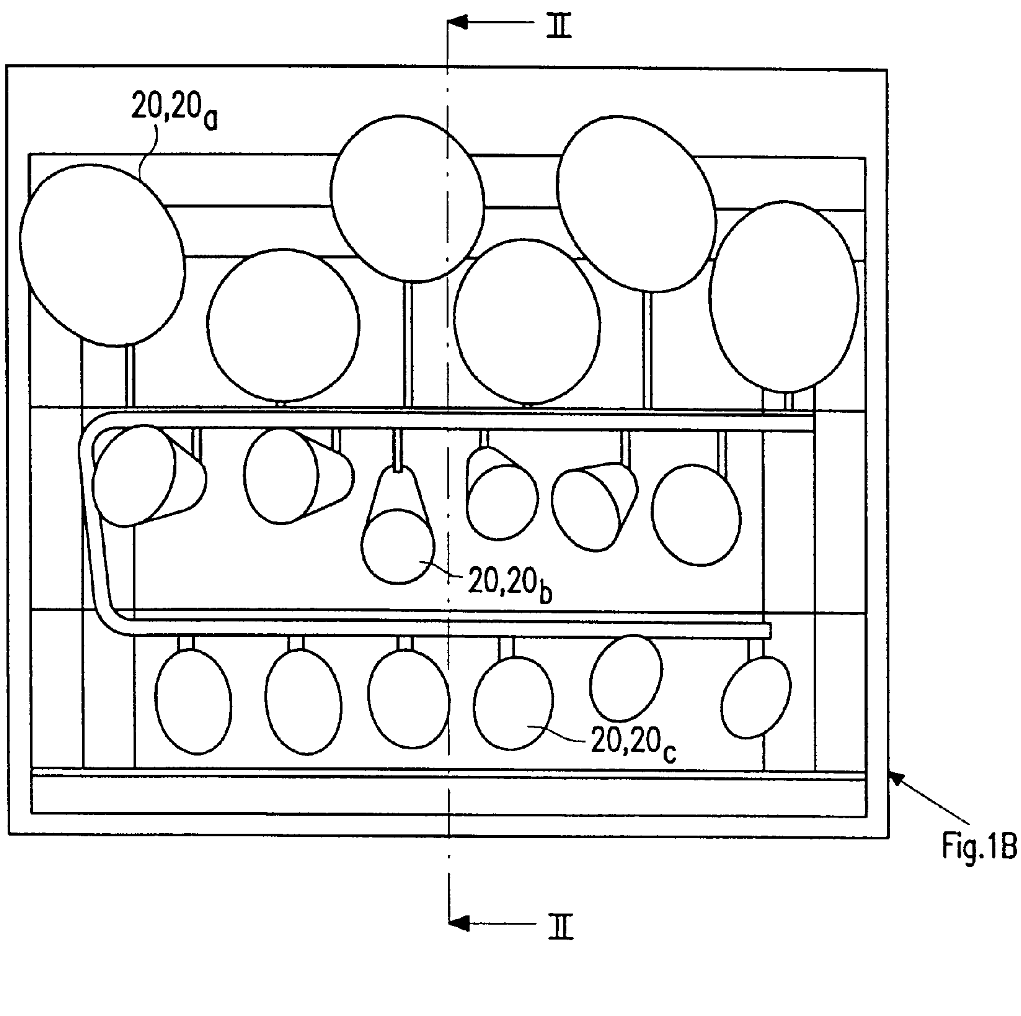


FIG. 1B

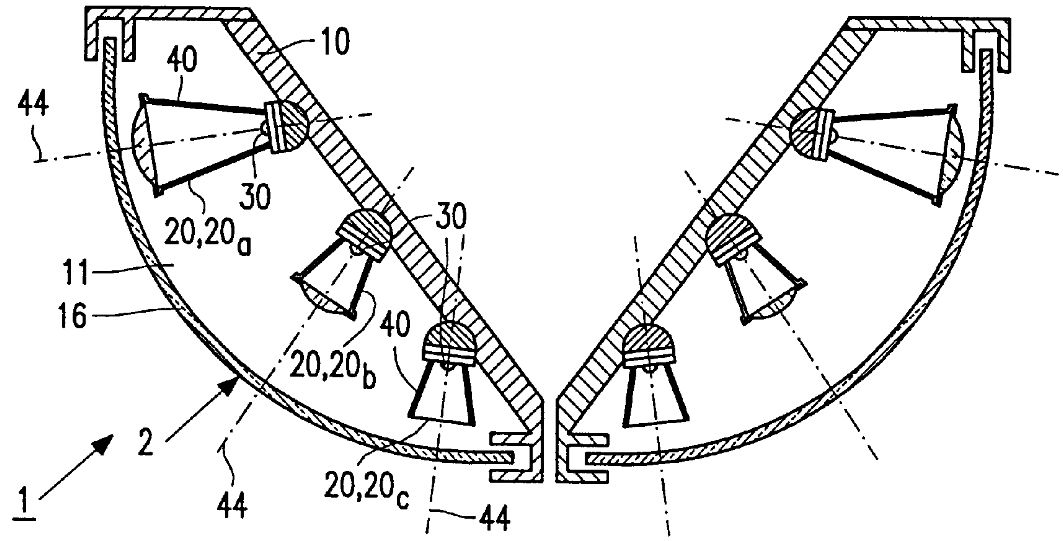

10
40
44
30
20,20a
30
11
16
40
20,20b
2
1
44
20,20c
44

FIG. 2

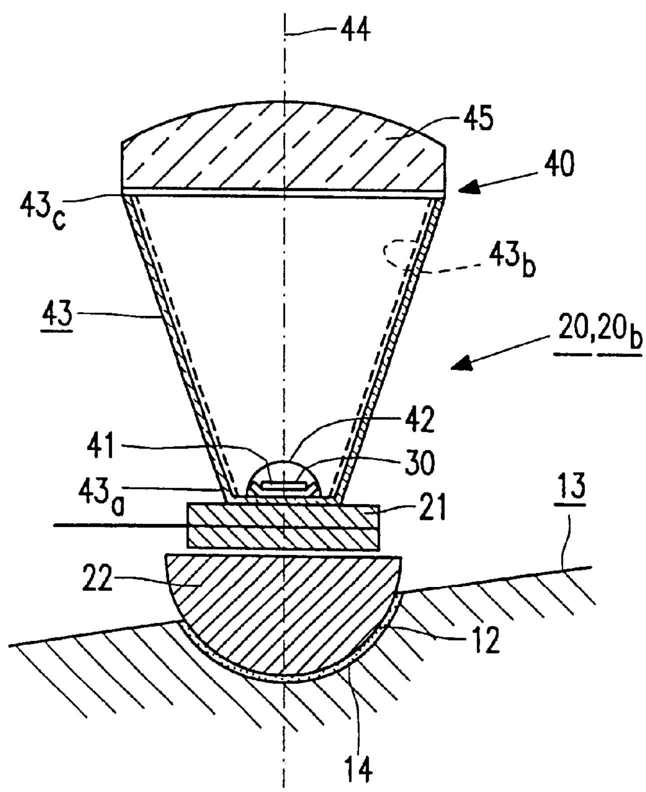

44
45
40
43c
43b
43
20,20b
42
41
30
43a
21
13
22
12
14

FIG. 3

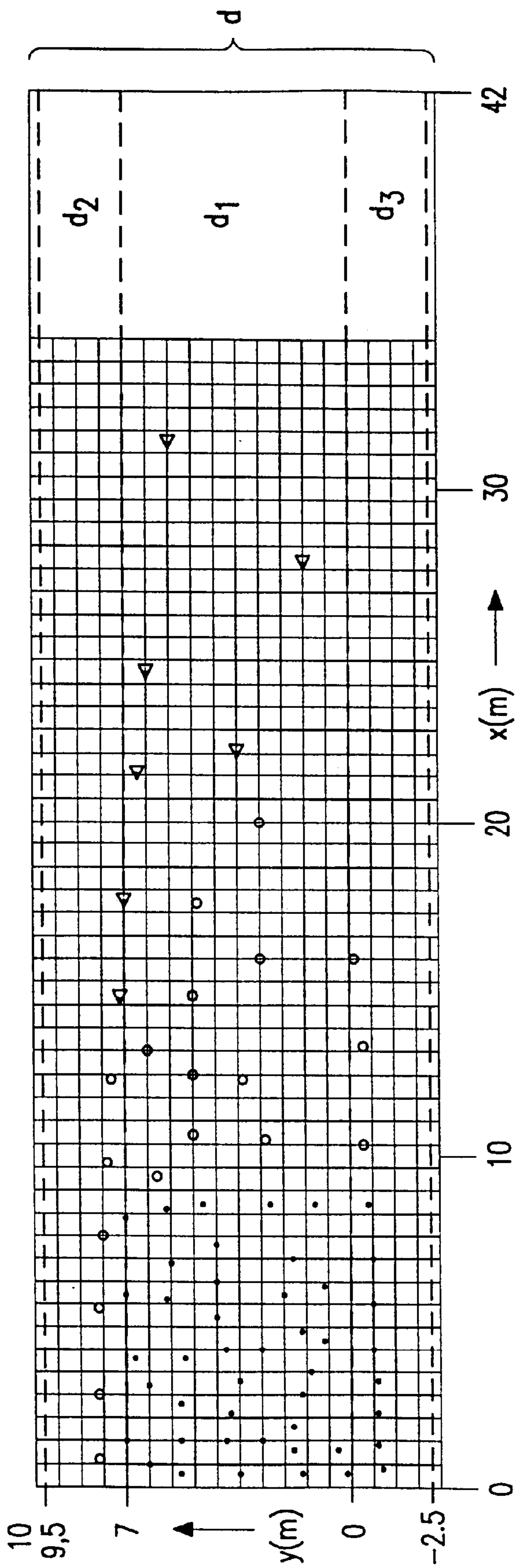


FIG. 4

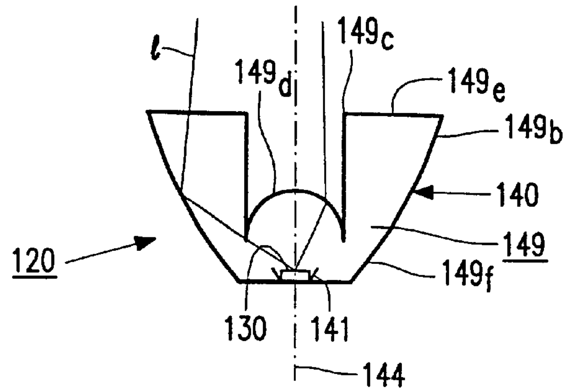


FIG. 5

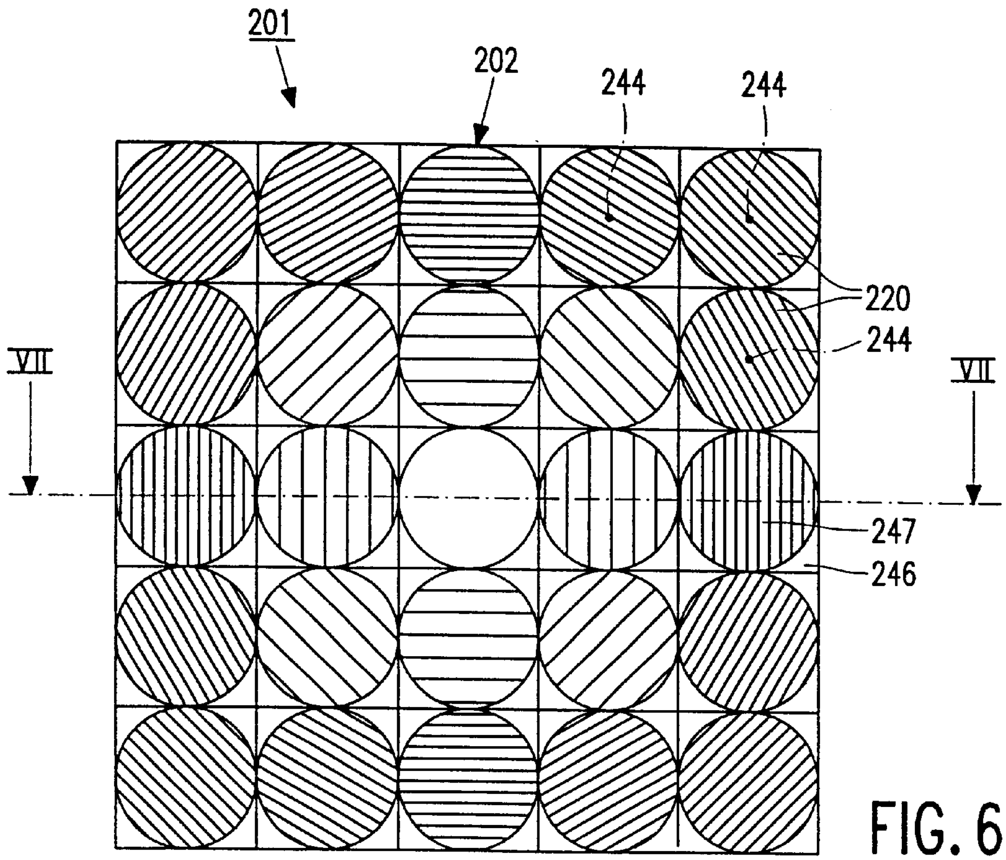


FIG. 6

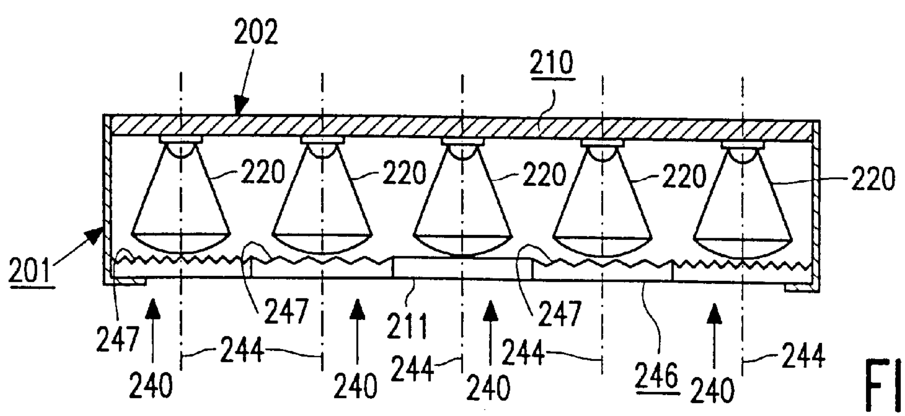


FIG. 7

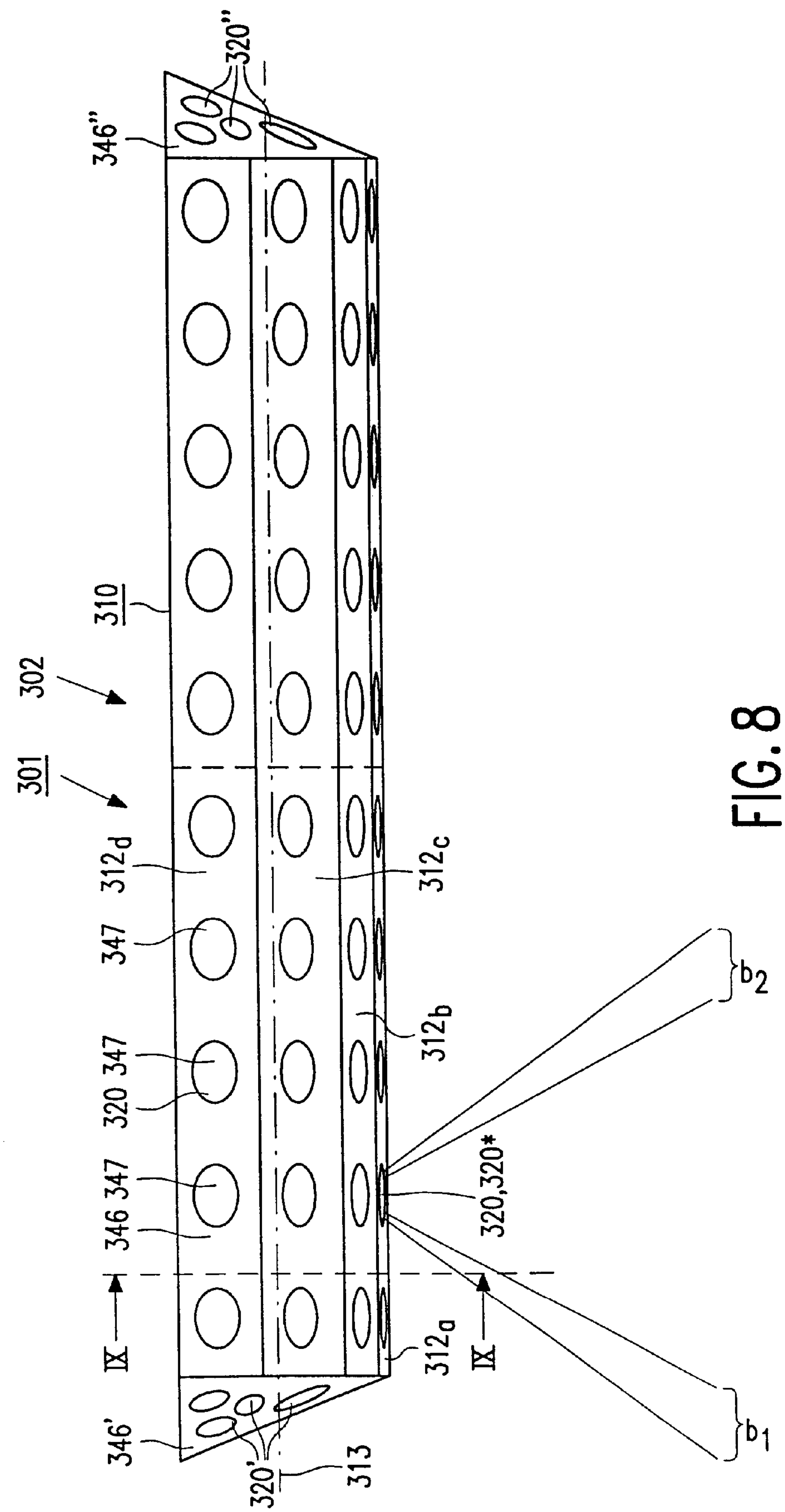

320"
346"
310
302
301
312d
312c
347
320 347
346 347
312b
320,320*
b2
b1
IX
IX
312a
346'
320'
313

FIG. 8

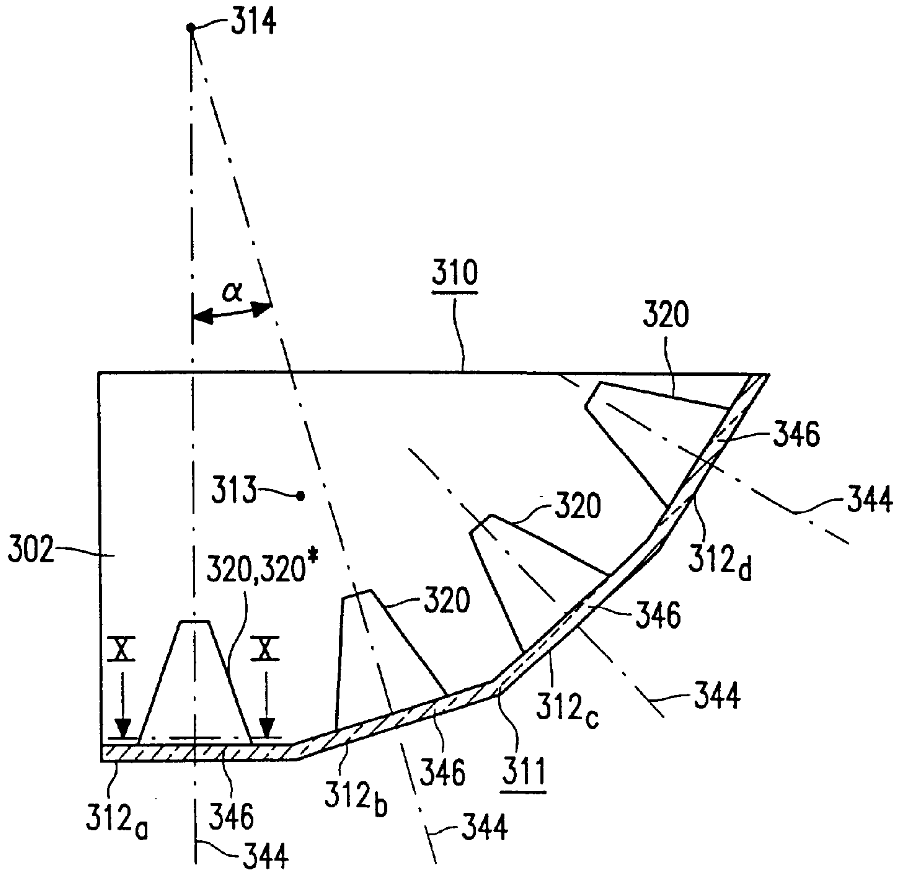


FIG. 9

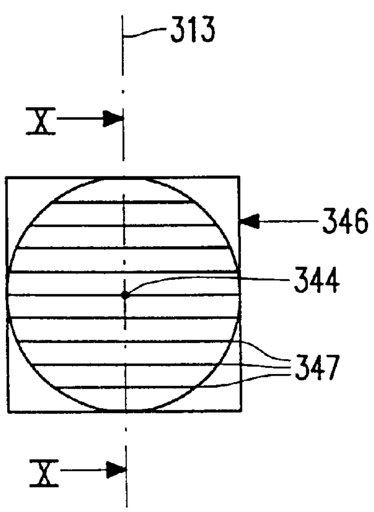


FIG. 10A

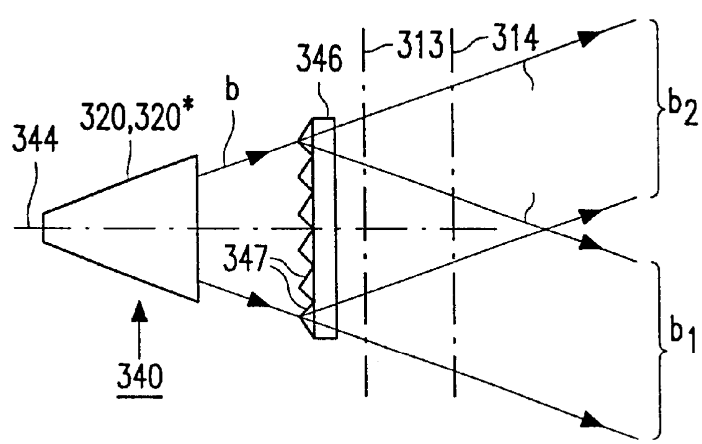


FIG. 10B

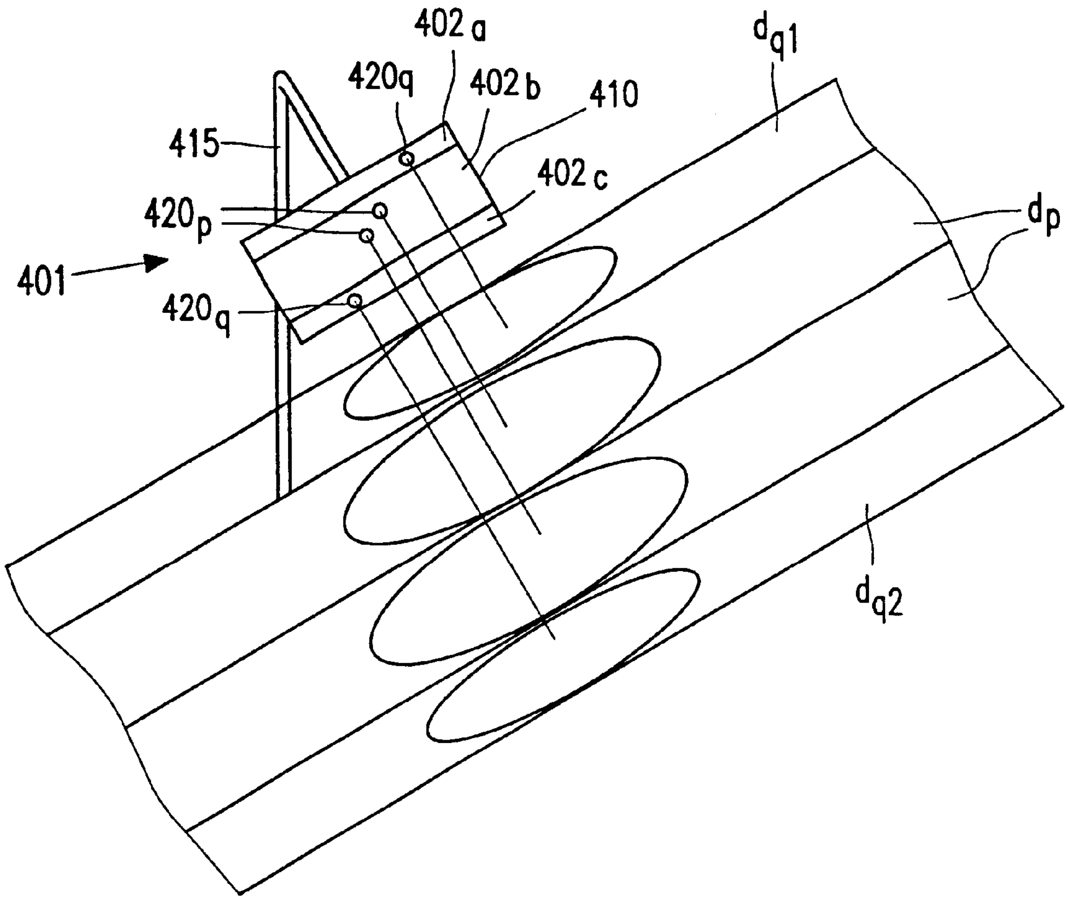
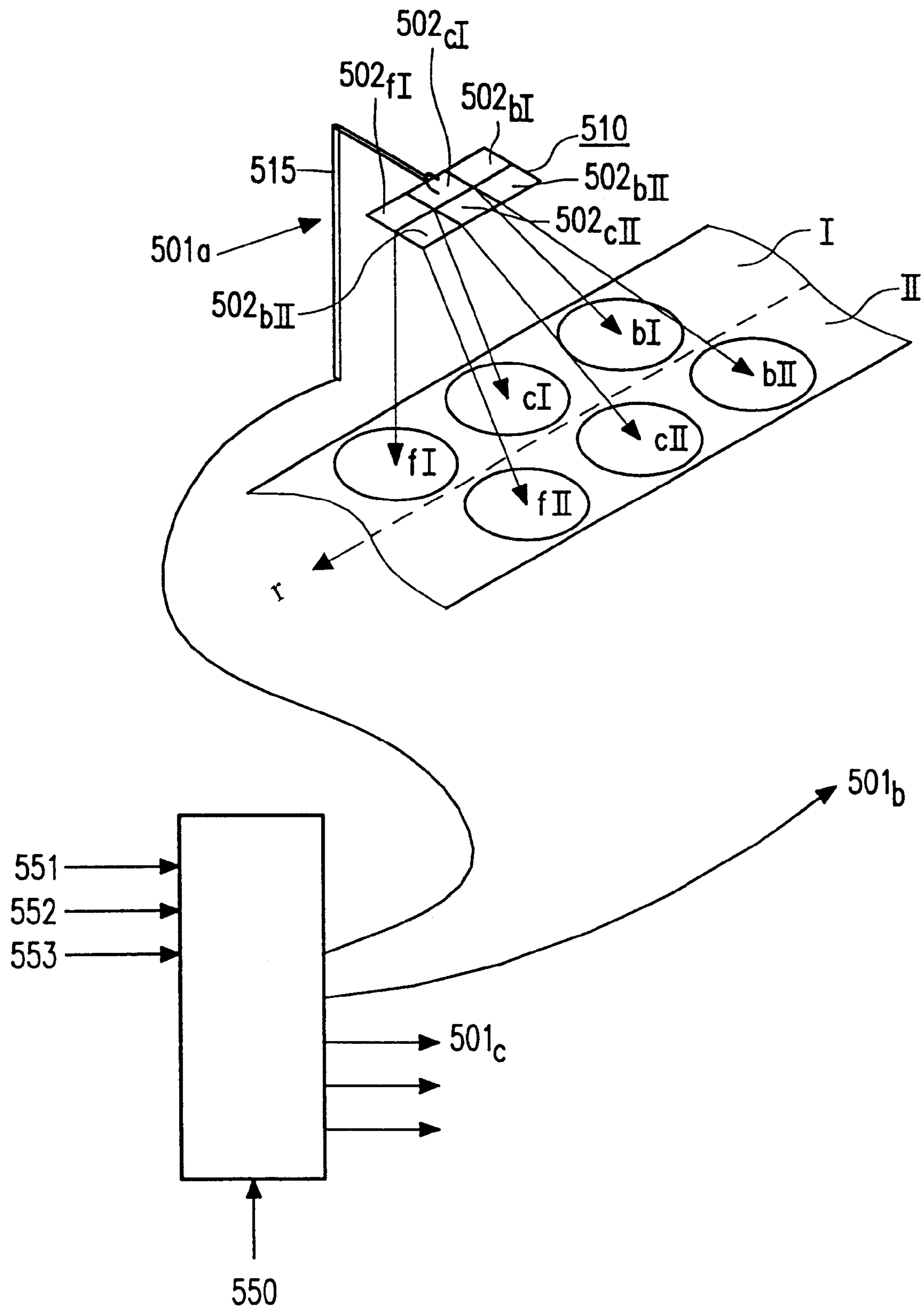


FIG. 11



502cI
502fI
502bI
510
515
502bII
501a
502cII
I
II
502bII
bI
bII
cI
cII
fI
fII
r
501b
551
552
553
501c
550

FIG. 12

LUMINAIRE

BACKGROUND OF THE INVENTION

The invention relates to a luminaire comprising a housing with a light emission window, and at least one lighting module for illuminating an object accommodated in the housing and comprising a light source and optical means.

Such luminaires are generally known and are used, for example, for street lighting, for lighting a portion of a street, or in spotlighting, for example for lighting objects in shop windows.

A luminaire for street lighting of the kind described in the opening paragraph and fitted with two lighting modules is known from DE 44 31 750 A1. The first lighting module is designed for illuminating a surface portion of the road which extends to comparatively far away from the luminaire. The second lighting module is designed for illuminating a surface portion close to the luminaire. The light sources of the luminaire can be controlled independently of one another so as to illuminate a road section optimally both in wet and in dry weather. The lighting modules in the known luminaire each have a tubular discharge lamp as the light source and a reflector as the optical means. A disadvantage of such a luminaire is that the light from the light sources is difficult to concentrate into a beam. More than 50% is often incident outside the object to be illuminated in practice.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a luminaire in which the light generated by the light source is utilized more efficiently.

According to the invention, the lighting module comprises a set, for example a few dozen, of lighting units which each comprise at least one LED chip and an optical system cooperating therewith, the LED chips and optical systems forming the light source and the optical means, respectively, while the lighting units illuminate portions of the object during operation, and the LED chips each supply a luminous flux of at least 5 lm during operation.

An LED chip comprises an active layer of a semiconductor material, for example AlInGaP or InGaN, which emits light upon the passage of a current. Integrated units of an LED chip and a primary optical system are generally known under the name of LEDs (Light Emitting Diodes), also referred to as LED lamps. The surface area of the active layer of an LED chip is comparatively small, for example of the order of a few tenths of a mm^2 up to a few mm^2. An LED chip thus forms a good approximation of a point source, so that the light generated thereby can be easily and accurately concentrated into a beam. Since the LED chips jointly illuminate the object, each individual beam only hitting a portion of the object, the beams may be narrow, so that they can be aimed with high accuracy within the boundaries of the object and only little light is incident outside the object. The use of LED chips which each supply a luminous flux of at least 5 lm during operation results in a luminaire according to the invention which, in spite of a comparatively limited number of lighting units, yet offers wide application possibilities, for example for street lighting, spotlighting, or floodlighting. The light distribution may be adjusted in a flexible manner through a control of the luminous fluxes of lighting modules or of separate lighting units of a lighting module.

If so desired, the portions of the object to be illuminated may overlap one another so as to achieve a more homogeneous lighting result, for example illuminance or luminance. Overlaps of the portions to be illuminated may also be desirable for achieving an even light distribution. A measure for the overlaps is the overlap factor (O) defined as $O=(\Sigma\Omega_e-\Omega_a)/\Omega_a$ where $\Sigma\Omega_a$ is the sum of the beam angles of the lighting units, and Ω_a is the optical solid angle covered by the object to be illuminated with respect to the luminaire. The beam angle of a lighting unit is defined here as the solid angle of that portion of the beam generated by the lighting unit within which 65% of the luminous flux of the lighting unit is contained and within which the luminous intensity is greater than or equal to that outside it. A lighting unit may illuminate portions of the object remote from one another, for example as a result of components which split up the beam of the lighting unit. In that case the beam angle is the sum of the solid angles of those portions of the beam within which in total a 65 % fraction of the luminous flux of the lighting unit is contained and within which the luminous intensity is greater than or equal to that outside said portions. The overlap factor is preferably at most 10 in a fully illuminated object. The homogeneity of the lighting result increases only little when the overlap factor increases further. The ratio of the overlap factor (O) to the number of lighting units (N) is preferably below 0.2. At a higher ratio, comparatively strongly widening beams are necessary, so that the light generated by the luminaire can be aimed less efficiently within the boundaries of the envisaged object and the possibilities of varying the distribution of the illuminance are limited.

It is favourable when the LED chips generate light mainly in a wavelength range from approximately 520 nm to approximately 600 nm for applications where the luminous efficacy plays a major role and colour rendering is of lesser importance, for example for lighting of roads and garages. LED chips may be used for this purpose, for example comprising an active layer of AlInGaP with an emission maximum at 592 nm. A combination of red-, green-, and blue-emitting LED chips may be used in applications where on the contrary the colour rendering is important, such as lighting of domestic spaces, for example LED chips having an active layer of AlInGaP for emission in a wavelength range of 590–630 nm, and LED chips with an active layer of InGaN for emission in the wavelength ranges of 520–565 nm and 430–490 nm. The active layers of a red-, a green-, and a blue-emitting LED chip may then be provided on a common substrate, for example made of sapphire or silicon carbide, and these LED chips may have a common optical system. Alternatively, for example, lighting units may be used in which the LED chip emits UV radiation and the optical system of the lighting units comprises means for converting UV radiation into visible radiation. The means for converting UV radiation are formed, for example, by a luminescent layer provided on the LED chip.

An attractive embodiment of the luminaire according to the invention is characterized in that the set of lighting units comprises two or more varieties of lighting units for illuminating portions of the object with mutually differing spectra. The spectra of the lighting units may then be adapted to the optical properties, for example the reflectivity, of the individual portions of the object, so that an optimum visibility of these portions is realized. The different spectra in addition render it easy for an observer to orient himself.

The luminance often lies in the mesopic vision range in the case of outdoor lighting such as street lighting, safety lighting, and lighting of parking lots, i.e. between 0.001 and 3 cd/m^2. The eye sensitivity to light originating from the periphery of the field of vision under these circumstances is a maximum for a wavelength which is relatively short, approximately 510 nm, compared with a wavelength, approximately 555 nm, for which the eye sensitivity to light coming from the center of the field of vision is a maximum. A modification of the preceding embodiment which is particularly favorable for outdoor lighting is characterized in that the set of lighting units comprises a first variety of lighting units for illuminating central portions of the object with a spectrum having a maximum at a first wavelength and a second variety of lighting units for illuminating peripheral portions of the object with a spectrum having a maximum at a second wavelength which is smaller than the first wavelength. This modification is particularly suitable for road lighting, the first portion being, for example, a driving lane, and the second portion a lane lying alongside the former lane. A higher visibility of the surroundings, and a resulting shorter reaction time of drivers present in the driving lane are obtained thereby (given a certain energy consumption). The different spectra provide a clear demarcation of the driving lane, so that drivers can easily orient themselves. It is favorable when the first wavelength lies in a range from 550 to 610 nm and the second wavelength in a range from 500 to 530 nm. It is achieved thereby that the peripheral portions are illuminated with a spectrum to which the eye sensitivity is high. In addition, such a spectrum can be generated with a high luminous efficacy by means of LED chips having an active layer of the InGaN type.

A favourable embodiment of the luminaire according to the invention is characterized in that the set of lighting units comprises two or more types of lighting units for generating beams which widen more and less strongly. In this embodiment, the portions of the object to be illuminated may have approximately the same surface area and also approximately the same illuminance in that portions of the object situated close to the luminaire are illuminated with comparatively strongly widening beams and portions farther removed with comparatively less strongly widening beams. This renders it easier to subdivide the surface of the object to be illuminated into portions which are to be illuminated by specific lighting units.

The optical system of the lighting units may comprise, for example, reflecting, refracting, and/or diffracting optical elements. A practical embodiment of the luminaire according to the invention is characterized in that the optical system of the lighting units comprises a primary and a secondary optical system. The primary optical system is provided with a primary reflector on which the LED chip is provided and with a, for example hemispherical, transparent envelope in which the LED chip is embedded, and said secondary optical system being provided with a secondary, for example conical reflector in whose comparatively narrow end portion the LED chip is positioned. It is favourable for the generation of comparatively narrow beams when the secondary reflector supports a lens at an end opposite the comparatively narrow end portion.

An attractive embodiment is characterized in that the optical system of the lighting unit comprises a transparent body with a first optical part which deflects the light generated by the LED chip through refraction and a second optical part which deflects the light generated by the LED chip through reflection.

A favourable modification of the above embodiment is characterized in that the transparent body has a wide end and opposite thereto a comparatively narrow end portion, in which end portion the LED chip is embedded, while the side of the LED chip remote from the wide end of the transparent body is provided on a primary reflector. The transparent

body has a spherical portion which is centrally positioned relative to an axis, which is recessed into the wide end, and which forms the first optical part, while the body has a peripheral portion around the axis with a paraboloidal circumferential surface around the axis which forms the second optical part.

The lighting units may be provided with means for adjusting a predetermined beam direction. The light distribution of the luminaire may thus be readily adapted during manufacture to the conditions of use, for example, in the case of a street lighting luminaire the width of the road and the interspacings of the posts on which the luminaires are mounted.

A favourable embodiment is characterized in that components of the optical systems of different lighting units are mutually integrated. This simplifies the operation of assembling the luminaire. Depending on the application, the components may, for example, deflect, narrow, and/or split up the beams generated by the LED chips. In a practical modification of this embodiment, the integrated components of the optical systems are reliefs in a transparent plate in the light emission window. Preferably, the relief is formed by substantially mirror-symmetrical ridges. Such a relief is capable of forming two comparatively strongly deflected beams from the incident beam with little stray light.

In a favourable modification of the above embodiment, lighting units are arranged in rows which extend along a longitudinal axis, lighting units in one and the same row having optical axes which are directed substantially mutually parallel and transverse to the longitudinal axis, while optical axes of lighting units of different rows enclose an angle with one another each time around a further axis parallel to the longitudinal axis, and the integrated components form deflected beams, which are substantially symmetrically situated relative to a plane through the optical axis of the lighting unit and the further axis, from the beams formed by the lighting units. A comparatively large surface area to be illuminated can be covered at angles around the longitudinal axis thanks to the mutually differing orientations of the rows, and at angles transverse to the further axis and transverse to the optical axis thanks to the further optical means. Nevertheless, the luminaire is of a comparatively simple construction. The arrangement of the lighting units in rows, with the lighting units within one row having the same direction, renders possible a simple placement of the lighting units.

One or several luminaires according to the invention may form part of a lighting system according to the invention. An attractive embodiment of such a lighting system comprises one or several luminaires and a control system, the one or several luminaires together having at least two lighting modules which are controllable independently of one another by means of the control system. The control system may receive signals from sensors and other sources, so that the lighting situation, for example the light distribution, illuminance, or colour temperature, can be automatically adapted to the circumstances. The lighting system has the advantages here that the luminous flux of an LED chip is controllable over a wide range and that the LED chips generate light substantially immediately after switching-on. If the lighting system is used for street lighting, luminaires for street lighting may be connected to a common control system. To adapt the lighting conditions to the weather conditions, the control system may receive signals inter alia from a fog detector and from means which measure the reflection properties of the road surface. A system for interior lighting receives signals, for example, from a daylight sensor which measures the luminous flux of incident daylight and from a proximity detector which detects the presence of persons in the room to be illuminated.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A diagrammatically shows a first embodiment of the luminaire according to the invention in elevation,

FIG. **1**B shows a detail of this elevation,

FIG. **2** is a cross-section of the luminaire taken on the line II—II in FIG. **1**B,

FIG. **3** is a longitudinal sectional view of a lighting unit of the first embodiment of the luminaire,

FIG. **4** shows the subdivision of the object into spatial portions,

FIG. **5** is a longitudinal sectional view of a lighting unit in a modification

FIG. **6** shows a second embodiment,

FIG. **7** is a cross-section taken on the line VII—VII in FIG. **6**,

FIG. **8** shows a third embodiment,

FIG. **9** is a cross-section taken on the line IX—IX in FIG. **8**,

FIG. **10**A is a cross-section taken on the line X—X in FIG. **9**,

FIG. **10**B is a cross-section taken on the line X—X in FIG. **10**A,

FIG. **11** shows a fourth embodiment, and

FIG. **12** shows a lighting system according to the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A first embodiment of the luminaire **1** according to the invention is shown in FIGS. **1**A, **1**B and **2**. The luminaire forms part of a row of luminaires which are placed with a mutual interspacing of 42 m each time. The luminaire **1** shown comprises a housing **10** with a light emission window **11** in which a transparent plate **16** is accommodated. The luminaire, which is mounted to a post (not shown) with a height of 7 m, is designed for street lighting. A lighting module for illuminating an object d (see FIG. **4**) is accommodated in the housing. The object d to be illuminated here is a road section d**1** with a width of 7 m and two strips d**2**, d**3** on either side of the road section d**1** having a width of 2.5 m each. The road section d**1** and the two strips extend on either side of the post over a distance of 42 m. The lighting module comprises a light source and optical means.

The lighting module **2** comprises a set of, here **144** lighting units **20** which each comprise an LED chip **30** and an optical system **40** cooperating with said chip. The LED chips **30** and the optical systems **40** form the light source and the optical means, respectively. The lighting units **20** illuminate portions of the object. The LED chips **30** each supply a luminous flux of at least 5 lm, in this case 23 lm.

A lighting unit **20** is shown in more detail in FIG. **3**. The LED chip **30** is provided on a primary reflector **41** of metal which is fastened on a synthetic resin support **21**. The LED chip **30** is accommodated in a synthetic resin envelope **42** which together with the primary reflector **41** forms a primary optical system. LED chips **30** having an active layer of AlInGaP are used in the embodiment shown. The active layer has a surface of 0.5×0.5 mm perpendicular to an optical axis **44** and a thickness of 0.2 mm. The total light-emitting surface area is 0.65 mm^2.

The lighting units in the embodiment shown each have a hemispherical mounting member **22** which is accommodated in a mating recess **12** in an aluminum heat sink **13**. The mounting member **22** and the recess **12** together form means for adjusting a predetermined beam direction. When the luminaire is being assembled, the lighting units **20** are provided in the desired directions on the heat sink **13**, the mounting member **22** being fixed in the recess **12** by means of an adhesive agent **14**.

The LED chip **30** with its primary optical system **41**, **42** is arranged in a narrow end portion $\mathbf{43}_a$ of a secondary, conical reflector **43** which forms a secondary optical system. The secondary reflector **43**, here made of acrylate, is coated with a reflecting material $\mathbf{43}_b$, for example aluminum, on an internal surface thereof. The secondary reflector **43** may support a lens **45** at an end $\mathbf{43}_c$ opposite the narrow end portion $\mathbf{43}_a$. The lens **45** and the secondary reflector **43** then together form a secondary optical system. The beam angle may be chosen through a choice of the dimensions of the reflector and of the lens, if present.

In the embodiment shown, the set of **144** lighting units **20** comprises three types of lighting units $\mathbf{20}_a$, $\mathbf{20}_b$, $\mathbf{20}_c$ for generating beams which widen more and less strongly. The lighting module here comprises **14** lighting units of a first type $\mathbf{20}_a$, in which the beam widens at a beam angle of 0.012 sr. The secondary reflector **43** in each module $\mathbf{20}_a$ supports a lens **45** at its end $\mathbf{43}_c$ opposite the narrow end portion $\mathbf{43}_a$. The lighting module in addition comprises **38** lighting units of a second type $\mathbf{20}_b$, also carrying a lens, of which the beam widens at a beam angle of 0.043 sr. Finally, the lighting module comprises **92** lighting units of a third type **203**, without lenses, whose beam widens at a beam angle of 0.060 sr. The sum $\Sigma\Omega_c$ of the beam angles of the lighting units is 7.3 sr. The object to be illuminated occupies a spatial angle Ω_a of 2.6 sr relative to the luminaire. The overlap factor O accordingly is 1.82. The overlap factor (O) divided by the number of lighting units (N) is 0.012.

The object d is symmetrically illuminated with respect to a plane through the post and the y-axis. The illuminance realized by means of the luminaire decreases evenly with the absolute value of the x-coordinate with respect to the post. Two consecutive luminaires achieve an approximately homogeneous distribution of the illuminance between them.

FIG. **4** shows the subdivision of the road section into portions to be illuminated by the lighting units **20** by means of marks at one side of the post (position x=0, y=0). Portions to be illuminated by means of a lighting unit of the first (**20***a*), the second (**20***b*) and the third type (**20***c*) have been marked with a triangle (Δ), a circle (o), and a dot (●), respectively. The location of the mark indicates the point of intersection between the optical axis **44** of the relevant lighting unit **20** and the portion of the object d to be illuminated thereby. It was found that the light generated by the light source in the luminaire **1** according to the invention is utilized efficiently. More than 95% is incident within the boundaries of the object to be illuminated, while still the object is illuminated in its entirety.

A lighting unit **120** of a modification of the first embodiment of a lighting module according to the invention is shown in FIG. **5**. Components in this Figure corresponding to those in FIG. **3** have reference numerals which are 100 higher. The optical system **140** of the lighting units **120** in this embodiment comprises a transparent body **149** with an axis **144** and a paraboloidal circumferential outer surface $\mathbf{149}_b$ around the axis. The body **149** comprises, centrally relative to the axis, a recessed, spherical portion $\mathbf{149}_d$ at a wide end 149_c surrounded by a peripheral portion 149_c. The LED chip **130** is embedded in a narrow end portion 149_f of the body. The LED chip **130** is provided with its side remote from the wide end 149_c on a primary reflector **141**. The recessed portion 149_d forms a first optical part. The peripheral portion 149_c with the paraboloidal circumferential surface 149_b forms a second optical part. The first optical part 149_d operates as a positive lens which deflects the light generated by the LED chip **130** through refraction. Light **1** incident outside said portion 149_d is reflected at the circumferential outer surface 149_b and issues to the exterior at the peripheral portion 149_c.

A second embodiment of the lighting module according to the invention is shown in FIGS. **6** and **7**. Components in these Figures corresponding to those in FIGS. **1** to **3** have reference numerals which are 200 higher. The luminaire **201** in this embodiment comprises a single lighting module **202** with **25** lighting units **220**. The **25** lighting units lie in one plane in a regular arrangement and have mutually parallel optical axes **244**. In the embodiment shown, components **247**, here formed by reliefs, of optical systems **240** of individual lighting units **220** have been integrated into a transparent plate **246** provided in the light emission window **211**. The reliefs **247** split up the beams generated by the LED chips into two beams diverging from one another. In a modification, the light beams generated by the LED chips are split up into more, for example four beams. In another modification, the beams generated by the LED chips are not split up but, for example, deflected or widened. The luminaire shown is suitable, for example, for spotlighting.

A third embodiment of the luminaire **301** designed for street lighting is shown in FIGS. **8**, **9**, **10**A and **10**B. Components therein corresponding to those in FIGS. **1** to **3** have reference numerals which are 300 higher. In the embodiment shown, **40** lighting units **320** are arranged in four rows 312_a, 312_b, 312_c, 312_d of ten units each extending along a longitudinal axis **313** parallel to the street to be illuminated. In the embodiment shown, lighting units in one row are arranged at equal mutual interspacings parallel to the longitudinal axis. Alternatively, however, lighting units in a row may be arranged, for example, in a zigzag pattern along the longitudinal axis. Lighting units **320** in one and the same row have optical axes **344** which are directed mutually substantially parallel and which are transverse to the longitudinal axis **313**. Optical axes **344** of lighting units **320** of different rows 312_a, 312_b enclose an angle α with one another around a further axis **314** parallel to the longitudinal axis **313** (see FIG. **9**). In this case the angles enclosed by the optical axes of the lighting units of two consecutive rows are equal to α each time. This, however, is not necessarily the case. As in the second embodiment, components **347**, i.e. reliefs, of the optical systems **340** of different lighting units have been integrated into a transparent plate **346** which is mounted in the light emission window **311**. FIGS. **10**A and **10**B show that the relief **347** is formed by ridges of triangular cross-section which extend in a direction transverse to the longitudinal axis **313**. The ridges are substantially mirror-symmetrical. The reliefs **346** form deflected beams b**1** from the beams b generated by the LED chips **320**, said deflected beams lying substantially symmetrically relative to a plane through the optical axis **344** of the relevant lighting unit and through the further axis **314**. The reliefs **347** here split up the beams b into a first beam b**1** and a second beam b**2**. The beams b**1**, b**2** lie on either side of the optical axis **344**. This is shown for only one of the lighting units **320*** for the sake of clarity. The light emission window has a first and a second further transparent plate **346**', **346**" which extend transversely to the longitudinal axis and behind which further lighting units **320**', **320**" are positioned.

A fourth embodiment is shown in FIG. **11**. Components therein corresponding to components of FIGS. **1**A, **1**B, **2**, and **3** have reference numerals which are 400 higher.

In the luminaire **401** shown, the set of lighting units **420** comprise two or more varieties of lighting units **420***p*, **420***q* for illuminating portions of the object with mutually differing spectra.

The set of lighting units here comprises a first variety of lighting units **420***p* for illuminating central portions of the object, driving lanes of a road in this case, with a spectrum having a maximum in a wavelength range from 550 to 610 nm, i.e. at a first wavelength of 592 nm. The lighting units of the first variety are for this purpose equipped with LED chips with an active layer of AlInGaP. The set of lighting units **420** comprises a second variety of lighting units **420***q* equipped with LED chips with an active layer of InGaN for illuminating peripheral portions of the object with a spectrum having a maximum in a wavelength range from 500 to 530 nm, i.e. at a second wavelength of 510 nm, shorter than the first wavelength. The lighting units **420***p* of the first variety constitute a lighting module **402***b*. Lighting modules **402***a* and **402***c* comprise lighting units **420***q* of the second variety. The peripheral portions dq**1**, dq**2** of the object may be provided with vegetation. The comparatively high reflectivity thereof in the wavelength range from 500 to 530 nm contributes further to the visibility of any objects present in these locations.

In FIG. **12**, components corresponding to those of FIGS. **1**A, **1**B, **2**, and **3** have reference numerals which are 500 higher. FIG. **12** diagrammatically shows a lighting system according to the invention with a luminaire 501_a and a control system **550**. The luminaire 501_a forms part of a group of identical luminaires 501_a, 501_b, . . . according to the invention which are arranged at equal mutual interspacings on posts **515** along a street to be illuminated. The luminaire **501***a* comprises six lighting modules 502_{fI}, 502_{fII}, 502_{cI}, 502_{cII}, 502_{bI}, and 502_{bII}, each fitted with 24 lighting units. Lighting modules 502_{fI}, and 502_{fII} are designed for illuminating road sections f_I, f_{II} removed from the post **515** in a direction opposed to the driving direction r. Lighting modules 502_{bI} and 502_{bII} are designed for illuminating road sections b_I, b_{II} lying removed from the post **515** in the driving direction r. Lighting modules 502_{cI} and 502_{cII} are designed for illuminating a road section c_I, c_{II} lying between the other two. Lighting modules 502_{fII}, 502_{cII}, and 502_{bII}, illuminate a first driving lane I, and lighting modules 502_{fII}, 502_{cII} and 502_{bII}, illuminate a second driving lane II. The lighting modules are connected to a control system **550** and are controllable independently of one another by means of this control system. The control system receives signals **551** from a sensor for measuring the degree of wetness of the road surface, signals **552** from a sensor for detecting fog and possibly for ascertining the degree of light scattering caused thereby. The lighting system is activated by a central signal **553**. In the activated state, the lighting modules may be adjusted by the control system, for example, as follows.

Weather conditions	Lighting system setting
—	on: 502_{fI}, 502_{fII}, 502_{cI}, 502_{cII}, 502_{bI}, 502_{bII}
rain	on: 502_{fII}, 502_{cI}, 502_{cII}, 502_{bI}, 502_{bII} off: 502_{fI}
snow	dimmed: 502_{fI}, 502_{fII}, 502_{cI}, 502_{cII}, 502_{bI}, 502_{bII}
fog	on: 502_{cI}, 502_{cII}; dimmed: 502_{fI}, 502_{fII}, 502_{bI}, 502_{bII}

If water is present on the road surface, lighting module $\mathbf{502}_{fI}$ is dimmed or switched off entirely, so that disturbing reflections on the water surface are avoided. All lighting modules are dimmed in the case of a snow-covered road surface. A low illuminance is sufficient in that case for a good visibility. A normal light intensity may lead to glare under these circumstances. The best possible visibility is found to be obtained in the case of fog by means of a setting in which light originates mainly from the lighting modules $\mathbf{502}_{cI}$, $\mathbf{502}_{cII}$. The setting of the lighting modules may in addition depend on the traffic density. It is possible to save energy at a low traffic density in that the lighting system is used as a guiding lighting. This is realized, for example, in that only one out of every six lighting modules in each luminaire is operating. An even greater energy saving is possible in a control mode of the control system where modules are switched on temporarily when they are about to be passed by a vehicle.

What is claimed is:

1. A luminaire (**1**) comprising a housing (**10**) with a light emission window (**11**), at least one lighting module in said housing (**2**) for illuminating an object (d, d**1**, d**2**, d**3**) outside said housing, the lighting module comprising a set of lighting units (**20**), each lighting unit comprising at least one LED chip (**30**) and an optical system (**40**) cooperating therewith, the lighting units illuminating portions of the object (d, d**1**, d**2**, d**3**) during operation, each said LED chip supplying a luminous flux of at least 5 lm during operation.

2. A luminaire as claimed in claim **1**, wherein the set of lighting units (**20**) comprises at least two types (**20***a*, **20***b*, **20***c*) of lighting units for generating beams which widen more and less strongly.

3. A luminaire as claimed in claim **1** wherein the optical system (**40**) of the lighting units (**20**) comprises a primary (**41**, **42**) and a secondary optical system (**43**), said primary optical system being provided with a primary reflector (**41**) on which the LED chip (**30**) is provided and with a transparent envelope (**42**) in which the LED chip (**30**) is embedded, said secondary optical system (**43**) being provided with a secondary reflector (**43**) in whose comparatively narrow end portion ($\mathbf{43}_a$) the LED chip is positioned.

4. A luminaire as claimed in claim **3**, characterized in that the secondary reflector (**43**) supports a lens (**45**) at an end ($\mathbf{43}_c$) opposite the comparatively narrow end portion ($\mathbf{43}_a$).

5. A luminaire as claimed in claim **1** wherein the optical system (**140**) of the lighting unit (**120**) comprises a transparent body (**149**) with a first optical part ($\mathbf{149}_d$) which deflects the light generated by the LED chip (**130**) through refraction and a second optical part ($\mathbf{149}_c$) which deflects the light generated by the LED chip through reflection.

6. A luminaire as claimed in claim **5**, characterized in that the transparent body (**149**) has a wide end ($\mathbf{149}_c$) and opposite thereto a comparatively narrow end portion ($\mathbf{149}_f$), in which end portion the LED chip (**130**) is embedded, while the side of the LED chip remote from the wide end of the transparent body is provided on a primary reflector (**141**), said transparent body having a spherical portion ($\mathbf{149}_d$) which is centrally positioned relative to an axis (**144**), which is recessed into the wide end ($\mathbf{149}_c$), and which forms the first optical part, while the body has a peripheral portion ($\mathbf{149}_c$) around the axis (**144**) with a paraboloidal circumferential surface ($\mathbf{149}_b$) around the axis which forms the second optical part.

7. A luminaire as claimed in claim **1** wherein components (**247**; **347**) of the optical systems (**240**; **340**) of different lighting units (**220**; **320**) are mutually integrated.

8. A luminaire as claimed in claim **7**, characterized in that lighting units (**320**) are arranged in rows ($\mathbf{312}_a$, $\mathbf{312}_b$, $\mathbf{312}_c$, $\mathbf{312}_d$) which extend along a longitudinal axis (**313**), lighting units in one and the same row ($\mathbf{312}_a$) having optical axes (**344**) which are directed substantially mutually parallel and transverse to the longitudinal axis, while optical axes (**344**) of lighting units of different rows ($\mathbf{312}_a$, $\mathbf{312}_b$) enclose an angle (α) with one another each time around a further axis (**314**) parallel to the longitudinal axis, and the integrated components (**347**) of the optical systems (**340**) form deflected beams (b_1), which are substantially symmetrically situated relative to a plane through the optical axis of the lighting unit and the further axis, from the beams (b) formed by the lighting units.

9. A luminaire as claimed in claim **7** wherein the integrated components (**247**; **347**) of the optical systems (**240**; **340**) are reliefs in a transparent plate (**246**; **346**) in the light emission window (**211**; **311**).

10. A luminaire as claimed in claim **9**, characterized in that the relief (**347**) is formed by ridges.

11. A luminaire as claimed in claim **1** wherein the set of lighting units (**420**) comprises two or more varieties of lighting units (**420***p*, **420***q*) for illuminating portions (dp, dq**1**, dq**2**) of the object with mutually differing spectra.

12. A luminaire as claimed in claim **11**, characterized in that the set of lighting units (**420**) comprises a first variety of lighting units (**420***p*) for illuminating central portions (dp) of the object with a spectrum having a maximum at a first wavelength, and a second variety of lighting units (**420***q*) for illuminating peripheral portions (dq**1**, dq**2**) of the object with a spectrum having a maximum at a second wavelength which is smaller than the first wavelength.

13. A luminaire as claimed in claim **12**, characterized in that the first wavelength lies in a range from 550 to 610 nm and the second wavelength in a range from 500 to 530 nm.

14. A lighting system comprising at least one luminaire comprising a housing with a light emission window and a lighting module in said housing for illuminating an object outside of said housing said module comprising a plurality of lighting units each comprising at least one LED chip and an optical system, said LED chips each supplying a luminous flux of at least 5 lm during operation, said luminous flux being directed through a respective optical system toward respective portion of said object.

15. A lighting system as in claim **14** wherein each said luminaire comprises a plurality of said lighting modules in said housing, said lighting system further comprising means for controlling said lighting modules independently of each other.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,250,774 B1 Page 1 of 3
DATED : June 26, 2001
INVENTOR(S) : Simon H.A. Begemann et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 9,
Line 30, delete "(1)" and "(10)";
Line 31, delete "(11)";
Line 32, delete "(2)" and "(d, d1, d2, d3)";
Line 34, delete "(20)";
Line 34, after "each" insert -- of said --;
Line 34, change "unit" to -- units --;
Line 35, delete "(30)" and "(40) cooperating";
Line 36, change "therewith, the lighting units illuminating" to -- configured to illuminate --;
Line 37, delete "(d, d1, d2, d3)";
Line 40, delete "(20)" and "(20a, 20b,";
Line 41, delete "20c)";
Line 44, delete "(40)" and "(20)";
Line 45, delete "(41, 42)" and "(43)";
Line 46, delete "(41)";
Line 47, delete "(30)";
Line 48, delete "(42)" and "(30)";
Line 49, delete "(43)";
Line 50, delete "(43)";
Line 51, delete "(43a)";
Line 52, delete "characterized in that";
Line 53, before "the" insert -- wherein --;
Line 53, delete "(43)" and "(45)";
Line 54, delete "(43a)" and "(43a)";
Line 56, delete "(140)" and "(120)";
Line 57, delete "(149)" and "(149a)";
Line 58, delete "(130)";
Line 59, delete "(149c)".

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,250,774 B1 Page 2 of 3
DATED : June 26, 2001
INVENTOR(S) : Simon H.A. Begemann et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 10,
Line 1, delete "(130)" and "while";
Line 2, change "the" to -- and wherein a primary reflector is located on a --;
Line 3, delete "is provided on a primary reflector (141)";
Line 4, delete "(149d)";
Line 5, delete "(144)";
Line 6, delete "(149c)";
Line 8, delete "(149c)" and "(144)";
Line 9, delete "(149b)";
Line 12, delete "(247; 347)" and "(240; 340)";
Line 13, delete "(220; 320)";
Line 13, after "integrated" insert -- to illuminate said portions of the object --;
Line 14, change "characterized in that" to -- wherein the different --;
Line 15, delete "(320)" and "(312a, 312b, 312c)";
Line 16, delete "312d)" delete "(313)";
Line 17, delete "(312a)";
Line 18, delete "(344)";
Line 19, delete "(344)";
Line 21, delete "(α)";
Line 22, delete "(314)";
Line 23, delete "(347)" and "(340)";
Line 24, delete "(b_1)";
Line 26, delete "(b)";
Line 29, delete "(247; 347)" and "(240;";
Line 30, delete "340)" and "(246; 346)";
Line 31, delete "(211; 311)";
Line 32, delete "characterized in";
Line 33, change "that" to -- wherein one of --;
Line 33, delete "(347)";
Line 35, delete "(420)";
Line 36, delete "(420p, 420q)" and "(dp,";
Line 37, delete "dq1, dq2)";
Line 37, change "mutually differing" to -- different --;

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

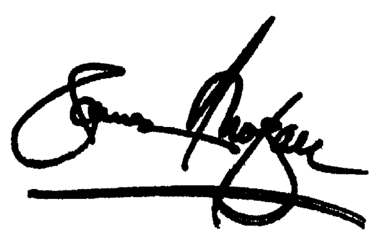
PATENT NO. : 6,250,774 B1
DATED : June 26, 2001
INVENTOR(S) : Simon H.A. Begemann et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 10, cont'd.
Line 38, delete "characterized in";
Line 39, change "that" to -- wherein --;
Line 39, delete "(420)";
Line 40, delete "(420p)" and "(dp)"
Liine 42, delete "(420q)";
Line 43, delete "(dq1, dq2)";
Line 46, delete "characterized in";
Line 47, change "that" to -- wherein --;
Line 53, after "each" insert -- of said plurality of lighting units --;
Line 58, after "each" insert -- at least one --.

Signed and Sealed this

Seventh Day of January, 2003



JAMES E. ROGAN
Director of the United States Patent and Trademark Office

Exhibit D

US006561690B2

(12) United States Patent
Balestriero et al.

(10) Patent No.: US 6,561,690 B2
(45) Date of Patent: May 13, 2003

(54) **LUMINAIRE BASED ON THE LIGHT EMISSION OF LIGHT-EMITTING DIODES**

(75) Inventors: **Christophe Balestriero**, Caluire (FR); **Marc Olivier Flaissier**, Lyon (FR)

(73) Assignee: **Koninklijke Philips Electronics N.V.**, Eindhoven (NL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/933,557**

(22) Filed: **Aug. 20, 2001**

(65) **Prior Publication Data**

US 2002/0044456 A1 Apr. 18, 2002

(30) **Foreign Application Priority Data**

Aug. 22, 2000 (FR) 0010804

(51) **Int. Cl.**[7] **F21V 7/04**

(52) **U.S. Cl.** **362/555**; 362/558; 362/544; 362/581; 362/240; 362/800; 362/455; 362/255

(58) **Field of Search** 362/555, 558, 362/544, 581, 240, 800, 455, 255, 235, 257, 241, 244, 245, 246, 247, 374

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,829,407 A		5/1989	Bushell et al.	362/29
5,335,151 A		8/1994	Dahlberg	362/153.1
6,076,950 A	*	6/2000	Topping et al.	362/245

FOREIGN PATENT DOCUMENTS

FR	0596782 A1	5/1994	B60Q/1/26
WO	WO 98/33007	7/1998	F21S/1/10

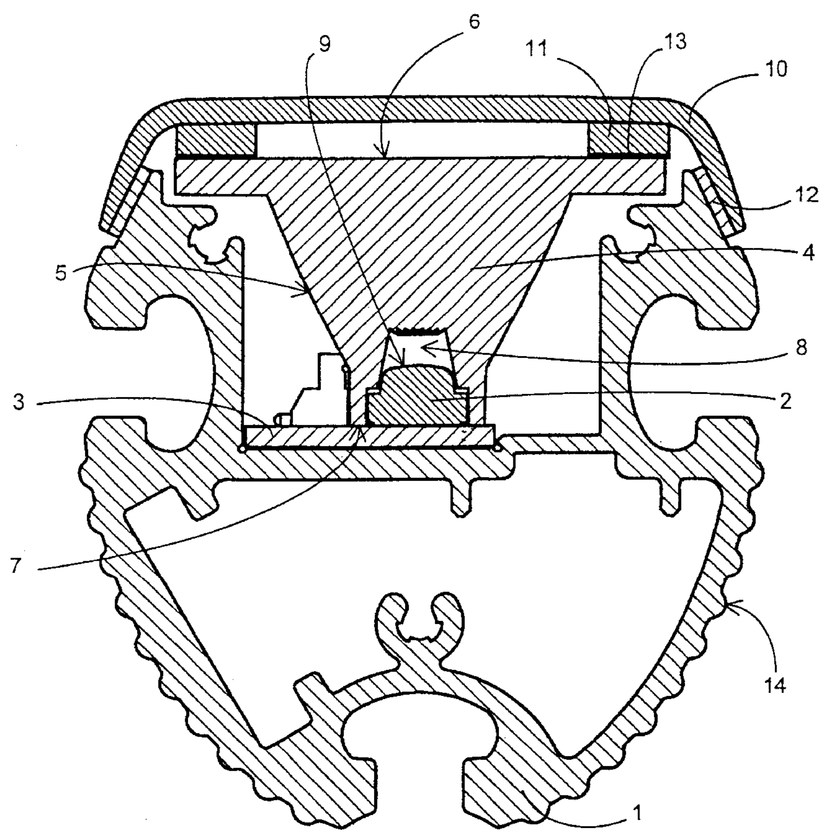
* cited by examiner

Primary Examiner—Sandra O'Shea
Assistant Examiner—Bertrand Zeade
(74) *Attorney, Agent, or Firm*—Frank Keegan

(57) **ABSTRACT**

The invention relates to a luminaire comprising a housing **(1)** which defines an internal space containing at least one light source formed by a light-emitting diode (LED) **(2)** and optical means **(4)** for guiding the light emitted by the LED **(2)** to the exterior of the housing **(1)**. The LED **(2)** is mounted to a support **(3)** connected to the housing **(1)**, and the optical means **(4)** are held between a retaining element **(10)** connected to the housing **(1)** and the support **(3)** of the LED **(2)**.

14 Claims, 3 Drawing Sheets



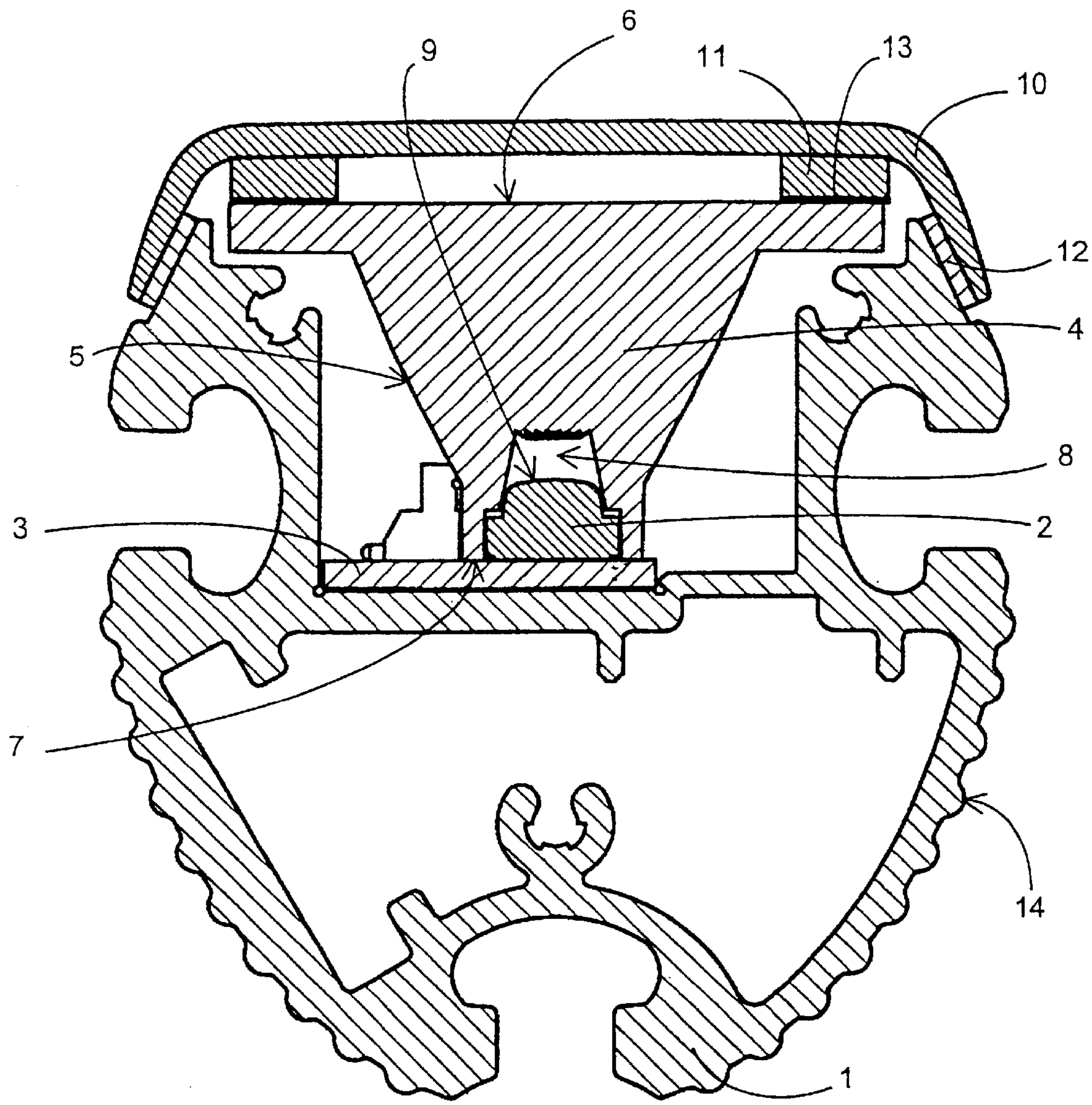


FIG. 1

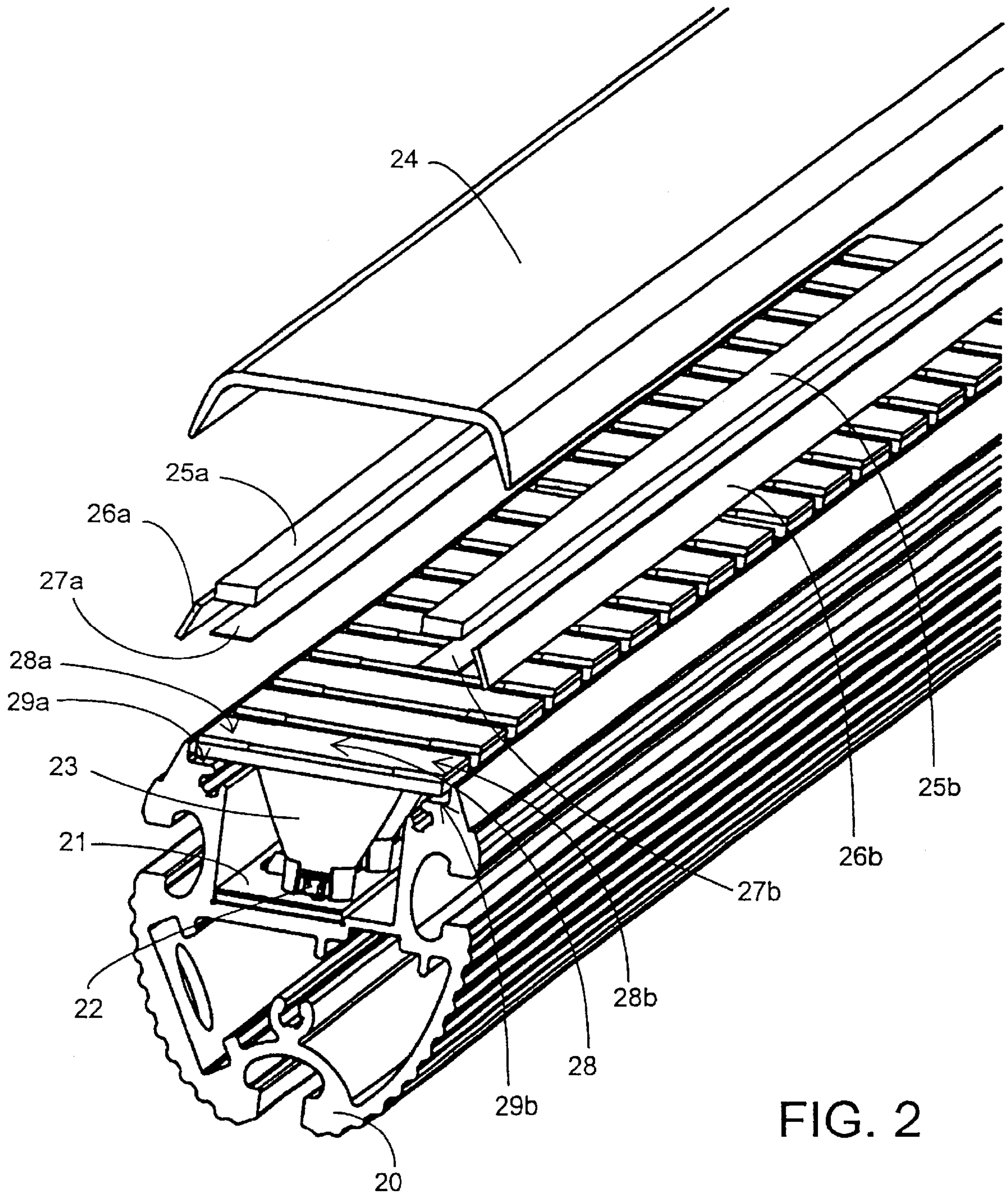


FIG. 2

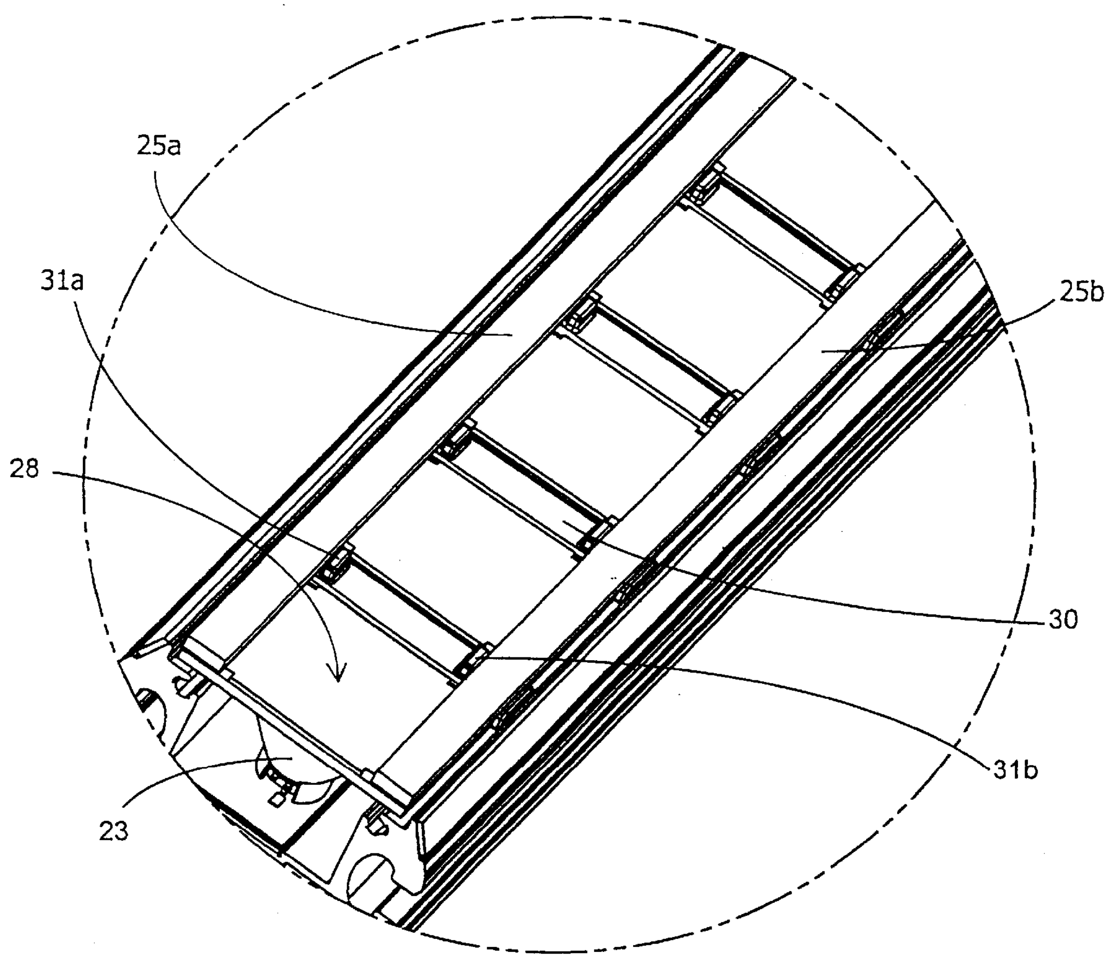


FIG. 3

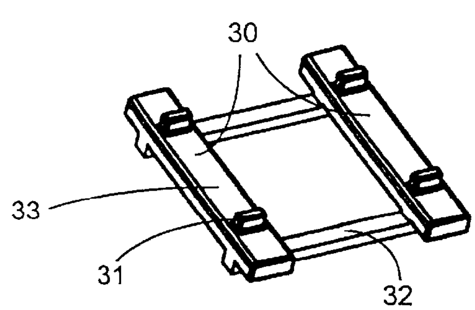


FIG. 4

LUMINAIRE BASED ON THE LIGHT EMISSION OF LIGHT-EMITTING DIODES

The invention relates to a luminaire comprising a housing which defines an internal space containing at least one light source formed by a light-emitting diode (LED) and optical means for guiding the light emitted by the LED to the exterior of the housing.

Such a luminaire is known from the document WO 98/33007. This luminaire, designed for street lighting, utilizes light emitted by LEDs: the optical guiding means used ensure on the one hand a concentration of the luminous intensity produced by the LED into a beam and on the other hand a defined direction of the beam.

The emission characteristic of a LED has a special shape. The optical means, which operate by principles of physical optics, have a geometry which renders it possible to obtain an optimum performance, provided the optical means occupy an accurate and constant position with respect to the emission characteristic of the LED. Since the luminaire is to be first transported and then installed, the robustness of the mounting of the optical means with respect to the LED must be guaranteed if the luminaires are to maintain the properties claimed by the manufacturer.

In the document WO 98/33007, the LED is fixed inside the optical means, which in their turn are fixed to the housing. The realization of this construction necessitates delicate manipulations of the LED. The LEDs, however, are highly sensitive to mechanical manipulations: their operational life and their light-emission performance depend on the care with which they are handled, especially during their mounting inside a luminaire as described in the opening paragraph. The LED comprises, among other things, a fragile dome on which no major forces are allowed to be exerted. A delicate mounting operation such as the one proposed in the document WO 98/33007 is accordingly to be avoided. In addition, this mounting is time-consuming and costly in terms of automated operations.

It is an object of the invention to resolve to a high extent the problem of mounting the optical means relative to the LED inside the luminaire.

According to the invention, a luminaire as described in the opening paragraph is for this purpose characterized in that the LED is mounted to a support connected to the housing, and in that the optical means are held between a retaining element connected to the housing and the support of the LED.

The mounting thus realized involves a placement of the optical means on the support of the LED and the use of the retaining element connected to the housing for keeping it fixed. This mounting provides the advantages that no delicate manipulations of the LED are necessary because the latter may be pre-installed on its support, that it is fast, and that it can be readily automated.

In an embodiment of the invention, the optical means are elastically held between the retaining element connected to the housing and the support of the LED by elastic retention means. Said elastic retention means in cooperation with the retaining element connected to the housing then exert a pressure on the optical means. As a result, the optical means exert a pressure on the support of the LED. Any mechanical play which may exist between the retaining element connected to the housing and the optical means and between the optical means and the support of the LED is eliminated, and this prevents relative movements of the optical means with respect to the support of the LED. The shapes of the optical means and those of the support of the LED are advantageously adapted such that, under pressure, the contact between the optical means and the support of the LED will serve to guarantee a precise and constant position which causes the assembly to provide an optimum performance.

In a preferred embodiment of the invention, the elastic retention means of the optical means are realized in the form of a block of elastic material placed in a position such that it is compressed between the retaining element connected to the housing and the optical means. Said elastic material may in particular be one of any number of foam types. This solution has the advantages that it is simple in its implementation and that it renders it possible to control the intensity of the pressure exerted by the optical means on the support of the LED through the choice of the characteristics of the elastic material used.

In an advantageous embodiment of the invention, a material having a low adhesion coefficient is placed between the optical means and the retaining element connected to the housing. This material achieves the contact between the optical means and either the retaining element of the optical means or the elastic retention means. The effect of this material of low adhesion coefficient, which may be polyethylene, is to facilitate relative translatory movements at the level of contact between the optical means and either the retaining element connected to the housing or the elastic retention means. Translatory movements of the retaining element connected to the housing or of the elastic retention means with respect to the housing on which the support of the LED is fixed may in fact carry the optical means along with them, which optical means in that case will be shifted from their position of optimum performance in relation to the emission characteristic of the LED. Said translatory movements resulting in shifts at the level of contact between objects may be the result of an external mechanical stress such as that caused by differences in thermal expansion between different materials. The differences in expansion are indeed the source of relative movements between certain objects in this environment, in which said objects made from different materials are present and in which the temperature is made to vary considerably, which movements may not be negligible.

In an advantageous embodiment of the invention, the retaining element connected to the housing is connected to the housing by gluing means. This solution avoids the necessity of using screws. Screws are habitually used in the field of luminaires, but they cause problems in relation to differences in expansion when the materials joined together are different, which is generally the case with a luminaire as described in the opening paragraph. An additional advantage is that a greater miniaturization of the luminaire is rendered possible than can be achieved with screws, because the use of gluing means requires a certain surface area but does not occupy a substantial volume of material.

In a special embodiment of the invention, the gluing means are formed by adhesive tapes.

In a particularly advantageous embodiment of the invention, the retaining element connected to the housing is a plate which transmits light. This arrangement is advantageously chosen when the light-transmitting plate is laid over the optical means, because in that case it fulfills two functions: it protects the optical means, which are usually fragile, and it keeps said optical means in place.

The invention will be better understood from the following description of a number of embodiments, given by way of example, with reference to the annexed drawings in which:

FIG. **1** is a cross-sectional view of an example of a luminaire according to the invention;

FIG. 2 is an exploded perspective view of another example of a luminaire in which the invention is implemented;

FIG. 3 is a bird's eye view of an improved embodiment of the luminaire of FIG. 2; and

FIG. 4 is a perspective view of an adjustment piece for mechanical play used in a special embodiment of the invention of the types shown in FIGS. 2 and 3.

FIG. 1 shows part of a luminaire in an advantageous embodiment of the invention. This Figure indicates only one embodiment.

This luminaire comprises a housing **1** containing a light source formed by a light-emitting diode or LED **2** mounted on a support **3** which is fixed to the housing **1**. The support **3** of the LED may be, for example, a printed circuit board, and the fixation of said support **3** may be realized, for example, by gluing means. The use of the gluing means, for example an adhesive tape, has the advantage that it takes part in a correct removal of heat. The gluing means in fact have good heat conduction properties and permit of a maximum contact surface area between the support **3** and the housing **1**. In the embodiment described here, the support **3** is planar, but this does not exclude other geometries of the support **3**.

The optical means here comprise a collimator **4** formed by a solid mass of a material which transmits light and is temperature-resistant, for example polymethylmethacrylate (PMMA). The optical means are formed by a "full-body" collimator **4** here, but they may alternatively be formed by, for example, a conical concave reflector. The collimator **4** has a symmetrical lateral surface **5** based on a parabolic or conical body of revolution, a planar front surface **6** here, and a base surface **7** geometrically opposed to the front surface **6**. The base **7** is planar here, but this characteristic does not exclude other geometries. The lateral surface **5** of the collimator **4** causes the light emitted by the LED **2** to be concentrated into a beam. The beam obtained here is a directional light beam consisting of parallel rays. This light beam leaves the collimator **4** by the front surface **6** and the direction of said beam is perpendicular to the plane defined by this front surface **6**. The emission characteristic of the system comprising the LED **2** and the collimator **4** thus has a maximum emission direction which in this example is perpendicular to the plane defined by the front surface **6** of the collimator **4**.

The collimator **4** in addition comprises a cavity **8** in its base **7**, provided for accommodating the LED **2**. The collimator **4** is placed over the LED **2**. Since the LED is sensitive to pressures which may be exerted on its dome **9**, the contacts which may arise between the LED **2** and the collimator **4** are minimized in that the inside of the cavity **8** is overdimensioned and the collimator **4** rests with its base **7** on the support **3** on which the LED **2** is mounted.

The optimum luminous performance of the collimator **4**, i.e. the control of the structure of the beam and its power, is obtained by means of a precise positioning of the collimator **4** with respect to the emission characteristic of the LED **2**. A lateral shift through translation of the base **7** of the collimator **4** with respect to the LED **2** by more than 4% of the diameter of the LED leads to a loss in efficiency of more than 10% here. The tolerances on the dimensions of the base **7** of the collimator **4** and on the dimensions of the cavity **8** are accordingly calculated here such that the lateral translations of the collimator **4** with respect to the LED **2** remain sufficiently small for guaranteeing a good luminous performance at the output of the collimator **4**. These dimensions also take into account the necessity of not applying major lateral stresses to the LED **2**.

The placement of the collimator **4** on the support **3** of the LED **2** renders it possible to ensure an initial positioning which will be maintained by the retaining element connected to the housing **1**. This retaining element in the present embodiment is a plate **10** which transmits light: the light-transmitting plate **10** is thus placed over the collimator **4** while compressing a block of elastic material **11**. The plate **10** is connected to the housing **1** by means of a two-sided adhesive tape **12**. The collimator **4**, being a fragile optical instrument, is thus protected by the light-transmitting plate **10** from external adverse influences which may damage it or impair its optical performance. The use of gluing means, such as the adhesive tape **12**, also has the advantage of promoting the sealing of the luminaire. Given the fact that in principle the housing **1** and the plate **10** are made from different materials and are accordingly subject to differences in expansion, the use of gluing means, such as the adhesive tape **12** whose shear resistance properties may be judiciously chosen, also provides a solution for allowing relative movements of the housing **1** and the plate **10**.

In this example, the block of elastic material **11** is placed on the front surface **6** of the collimator **4**. The elastic material may be chosen from any number of foam materials of different densities and different shapes as a function of the intensity of the pressure which one wishes to exert on the collimator **4** for keeping the latter in place. In an embodiment, for example, the block of elastic material **11** was formed from single-sided adhesive vinyl foam with a density of 225 kg/m^3, a thickness of 6 mm, and a width of 3 mm. Numerous modifications of the invention are possible as regards the elastic retention of the optical means as well as the positioning of the elastic retention means relative to other elements of the luminaire: for example, the use of springs is conceivable; and the placement of the elastic retention means between the support of the LED and a surface forming part of the housing itself, which would then constitute the retaining element connected to the housing, is another possible solution according to the invention.

The collimator **4** is here constructed such that it offers an optimum efficiency when the contact of the collimator **4** to the support **3** of the LED **2** is planar. A rotary movement about a family of axes perpendicular to the direction of maximum emission of the emission characteristic of the system comprising the LED **2** and the collimator **4** will result in a breaking of the planar contact between the collimator **4** and the support **3** of the LED **2**. In the case described here, a rotation of the collimator of more than 3° about one of these axes will lead to a loss of 10% of the maximum intensity. These rotary movements can only arise if there is a play in a direction close to the direction of maximum emission of the system comprising the LED **2** and the collimator **4**, between the various elements thereof such as the support **3** of the LED, the collimator **4**, and the plate **10** which transmits the light. The elastic material **11**, i.e. the elastic retention means, exerts a pressure on the collimator **4**, whereby the planar contact thereof to the support **3** of the LED is enforced. It is achieved in this manner that the elastic retention means of the collimator prevent the presence of said play, whereby said rotations are prevented.

A strip **13** of polyethylene, a material of low adhesion coefficient, is inserted between the elastic retention means formed by the block of elastic material **11** and the optical means formed by the collimator **4**, allowing translatory movements caused by differences in expansion between the various elements made from different materials. In particular, the pressure exerted on the collimator **4** by the block of elastic material **11** could impede said translatory movements if said material of low adhesion coefficient were absent and could thus generate a displacement of the collimator along with the light-transmitting plate **10** connected to the housing. The presence of the strip **13** of polyethylene, i.e. a material of low adhesion coefficient, disengages the translatory movements of the elastic material **11** from the collimator **4** and thus avoids movements of the collimator **4** relative to the support **3** of the LED **2**.

The housing is advantageously constructed from a heat-conducting material, for example anodized aluminum, and its outer surface comprises an undulating surface **14**. The LED **2** emits heat during its operation. If an optimum performance of a LED mainly in terms of its luminous flux is to be obtained, a controlled temperature is necessary: the heat generated by the LED **2** must accordingly be removed. The heat-conducting material of the housing renders it possible to remove the heat to the exterior, and the undulating surface enhances the efficacy of this radiator effect.

FIG. **2** depicts an embodiment of the invention inside a luminaire comprising a plurality of LEDs whose optical means are fixed in accordance with the invention. The increase in the number of LEDs leads to an increase in the length of the luminaire, and as a result thereof the movements caused by differences in expansion between different materials are greater. The invention finds a particularly interesting application in this case.

A support **21** carrying a number of LEDs **22** is fixed in a housing **20**. A collimator **23** is aligned and placed on the support **21** of each of the LEDs **22**. In a particular embodiment of the invention, several collimators **23** may alternatively be provided in a single component placed on the support **21** such that each collimator is centered on one LED **22**. A light-transmitting plate **24** is placed on top of the set of collimators **23**, compressing two strips **25***a* and **25***b* of elastic material. The plate **24** is connected to the housing **20** by means of two strips **26***a* and **26***b* of two-sided adhesive tape. Two strips **27***a* and **27***b* of polyethylene, i.e. a material with a low adhesion coefficient, are inserted between the collimators **23** and the strips **25***a* and **25***b* of elastic material, thus permitting translatory movements caused by differences in expansion between the various elements, such as the plate **24** and the housing **20**, which are made from different materials.

In this example, the use of several assemblies formed by a LED and its optical means requires that these assemblies formed by a LED and its optical means have a homogeneous lumen output. Differences in lumen output between individual assemblies will detract from the aesthetic effect and/or the efficacy of the overall performance. A fixation of the optical means in the optimum position with respect to the emission characteristic of the LEDs is indeed of particular importance for safeguarding the homogeneity of the light output of each of the assemblies formed by a LED and its optical means. By safeguarding an optimum, individual positioning of the optical means with respect to the emission characteristic of each of the LEDs the invention clears the way for uniform lighting arrangements of various shapes based on the emission of a plurality of LEDs.

In the present example, the collimators **23** have a rectangular, widened front surface **28** which exceeds the actual output surface of the light beam. This widened front surface **28** serves as a support surface for the two strips **25***a* and **25***b* of elastic material which are placed on the edges **28***a* and **28***b* of the front surface **28** such that they do not reduce the luminous flux.

Since the front surface **28** is rectangular, the collimators have no rotational symmetry. It might be desirable for aesthetic reasons to prevent a rotation about an axis perpendicular to the plane defined by the front surface **28** of the collimators **23**. This rotation is even more unpleasant if the optical means have no rotational symmetry for the purpose of providing an output beam which also has no rotational symmetry: said rotation would accordingly affect the photometric properties of the luminaire. This rotation may be limited by shoulders **29***a* and **29***b* provided on the housing **20**. In the embodiment shown in FIG. **2**, however, it is difficult to control the play present between the collimators **23** and the shoulders **29***a* and **29***b* in the housing **20**, which is made of extruded aluminum here, in view of industrial processes used for the manufacture of this housing. Said rotation is accordingly only roughly limited.

FIG. **3** shows part of an improved embodiment of the luminaire of FIG. **2** viewed from below, with components similar to those of FIG. **2** being given the same reference numerals. The improvement consists in a limitation of the extent of the rotary movement of the collimators **23** with respect to an axis perpendicular to the plane defined by the front surface **28** of the collimator **23**. Rigid pieces **30** are for this purpose inserted between the individual front surfaces **28** of the collimators **23**. These rigid pieces **30** have dimensions calculated such that there is a clearance between said rigid pieces **30** and the collimators **23**. The presence of said rigid pieces in fact renders it possible to limit the extent of the rotation of the collimators **23** without making the assembly of the collimators **23** rigid, the latter having to remain individually independent so as not to generate stresses on the LEDs **22**. In this example, the best adapted shape of these rigid pieces **30** is a parallelepiped shape which fills up the empty space present between two front surfaces **28** of two collimators **23**, but this shape is not exclusive and may be varied in many ways so as to adapt to the geometry of the luminaire and/or that of the optical means. Said rigid pieces **30** may be used in combination with the invention or independently of the invention.

Two projections **31***a* and **31***b* are advantageously situated on each of the rigid pieces **30** to serve as abutments for the strips **25***a* and **25***b* of elastic material and for the strips **26***a* and **26***b* of polyethylene shown in FIG. **2**. This prevents these elements from covering that portion of the front surface **28** of the collimator **23** through which the light beam is to issue to the exterior. Said projections **31***a* and **31***b* could be realized on the front surface **28** of the collimator **23** in an alternative embodiment.

FIG. **4** shows a particular example of an embodiment of the rigid piece **30**. Said rigid pieces **30** of parallelepiped shape and inserted between the individual front surfaces **28** of the collimators **23** are here grouped together, for example two-by-two, into a single play adjustment piece **33** each time by means of a connection element **32** which forms a whole with the two parallelepiped-shaped rigid pieces **30**. Said play adjustment piece **33** may be realized, for example, through molding/casting of any kind of rigid material. Molding and casting are particularly favorable because the projections **31** can be easily realized thereby.

The particular shape of this example of a play adjustment piece **33** renders it possible to limit the movements of the rigid pieces **30** between the collimators **23** which could arise in the case of independent rigid pieces **30**.

What is claimed is:

1. A luminaire comprising a housing which defines an internal space containing at least one light source formed by a light-emitting diode (LED) and optical means for guiding the light emitted by the LED towards outside of the housing, characterized in that the LED is mounted to a support connected to the housing, and the optical means is held between a retaining element connected to the housing and the support for the LED by pressure exerted by the retaining element and the support for the LED, wherein the optical means has first and second ends, the first end being proximate the support connected to the housing and the second end being proximate the retaining element.

2. A luminaire as claimed in claim **1**, characterized in that a material having a low adhesion coefficient is placed between the second end of the optical means and the retaining element connected to the housing.

3. A luminaire as claimed in claim **1**, characterized in that the retaining element connected to the housing is connected to the housing by gluing means.

4. A luminaire as claimed in claim **3**, characterized in that the gluing means are formed by adhesive tapes.

5. A luminaire as claimed in claim **1**, characterized in that the retaining element connected to the housing is a plate which transmits light.

6. A luminaire as claimed in claim **1**, characterized in that the first end of the optical means is in contact with the support connected to the housing.

7. A luminaire as claimed in claim **6** characterized in that there is elastic retention means between the second end of the optical means and the retaining element.

8. A luminaire as claimed in claim **7** characterized in that the elastic retention means are realized in the form of a block of elastic material placed in a position such that it is compressed between the retaining element connected to the housing and the second end of the optical means.

9. A luminaire as claimed in claim **7**, characterized in that both the support connected to the housing and the first end of the optical means are planar.

10. A luminaire as claimed **9**, wherein the optical means is a solid light conductor having a cavity for accommodating the LED.

11. A luminaire as claimed in claim **1** wherein the internal space includes a plurality of LED's and wherein the optical means comprises a plurality of light conductors, each being associated with a different LED, said luminaire further including a plurality of rigid members intermediate adjacent light conductors for limiting the range of rotation of said light conductors.

12. A luminaire as claimed in claim **11** wherein each rigid member has two projections thereon which aid in positioning said members.

13. A luminaire comprising a housing which defines an internal space containing at least one light source formed by a light-emitting diode (LED) and optical means for guiding the light emitted by the LED towards outside of the housing wherein the LED is mounted to a planar support connected to the housing and the optical means is held between a plate which transmits light which comprises a retaining element connected to the housing and the support for the LED by pressure exerted by the retaining element and the support, wherein the optical means has first and second ends, the first end being planar and being in direct contact against the planar support, the second end being proximate the retaining element, there being elastic retention means between the second end and the retaining element, and the optical means comprising a light conductor having a cavity near said first end for accommodating the LED.

14. A luminaire comprising a housing which defines an internal space containing at least one light source formed by a light-emitting diode (LED) and optical means for guiding the light emitted by the LED towards outside of the housing characterized in that the LED is mounted to a support connected to the housing, and the optical means are elastically held between a retaining element connected to the housing and the support for the LED by elastic retention means which comprises a block of elastic material placed in a position such that it is compressed between the retaining element and the optical means.

* * * * *

Exhibit E

US007038399B2

(12) United States Patent
Lys et al.

(10) **Patent No.: US 7,038,399 B2**
(45) **Date of Patent: May 2, 2006**

(54) **METHODS AND APPARATUS FOR PROVIDING POWER TO LIGHTING DEVICES**

(75) Inventors: **Ihor A. Lys**, Milton, MA (US); **Kevin J. Dowling**, Westford, MA (US); **Frederick M. Morgan**, Quincy, MA (US)

(73) Assignee: **Color Kinetics Incorporated**, Boston, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 118 days.

(21) Appl. No.: **10/435,687**

(22) Filed: **May 9, 2003**

(65) **Prior Publication Data**

US 2004/0212321 A1 Oct. 28, 2004

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/805,368, filed on Mar. 13, 2001, and a continuation-in-part of application No. 09/805,590, filed on Mar. 13, 2001.

(60) Provisional application No. 60/391,627, filed on Jun. 26, 2002, provisional application No. 60/379,079, filed on May 9, 2002.

(51) **Int. Cl.**
G05F 1/00 (2006.01)

(52) **U.S. Cl.** **315/291**; 315/307; 315/DIG. 4

(58) **Field of Classification Search** .... 315/200 R, 315/246–247, 291, 307, DIG. 4
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,909,097	A	10/1959	Alden et al.	353/31
3,318,185	A	5/1967	Kott	359/629
3,561,719	A	2/1971	Grindle	248/343
3,586,936	A	6/1971	McLeroy	318/118
3,601,621	A	8/1971	Ritchie	307/116
3,643,088	A	2/1972	Osteen et al.	362/280
3,746,918	A	7/1973	Drucker et al.	315/77

(Continued)

FOREIGN PATENT DOCUMENTS

AU	6 267 9	12/1996

(Continued)

OTHER PUBLICATIONS

"LM117/LM317A/LM317 3-Terminal Adjustable Regulator", National Semiconductor Corporation, May 1997, pp. 1-20.

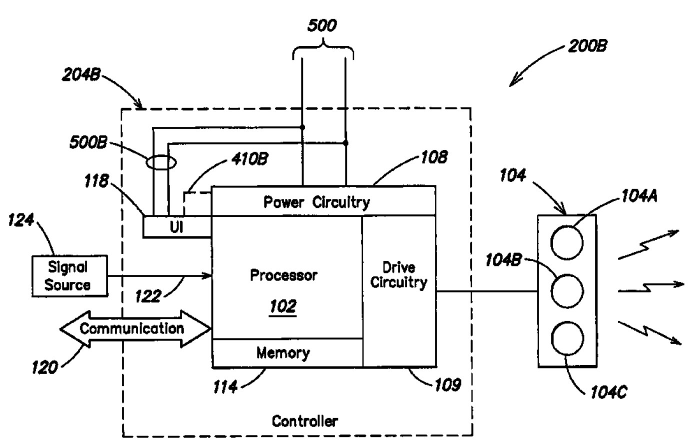
(Continued)

Primary Examiner—Thuy Vinh Tran
(74) *Attorney, Agent, or Firm*—Foley Hoag LLP

(57) **ABSTRACT**

Methods and apparatus for providing power to devices via an A.C. power source, and for facilitating the use of LED-based light sources on A.C. power circuits that provide signals other than standard line voltages. In one example, LED-based light sources may be coupled to A.C. power circuits that are controlled by conventional dimmers (i.e, "A.C. dimmer circuits"). Hence, LED-based light sources may be conveniently substituted for other light sources (e.g., incandescent lights) in lighting environments employing conventional A.C. dimming devices and/or other control signals present on the A.C. power circuit. In yet other aspects, one or more parameters relating to the light generated by LED-based light sources (e.g., intensity, color, color temperature, temporal characteristics, etc.) may be conveniently controlled via operation of a conventional A.C. dimmer and/or other signals present on the A.C. power circuit.

64 Claims, 10 Drawing Sheets



U.S. PATENT DOCUMENTS

3,818,216 A 6/1974 Larraburu 362/301
3,832,503 A 8/1974 Crane .... 200/51 R
3,858,086 A 12/1974 Anderson et al. 315/49
3,909,670 A 9/1975 Wakamatsu et al. 315/276
3,924,120 A 12/1975 Cox, III 398/98
3,958,885 A 5/1976 Stockinger et al. 356/139
3,974,637 A 8/1976 Bergey et al. 368/68
4,001,571 A 1/1977 Martin 315/189
4,054,814 A 10/1977 Fegley et al. 315/71
4,070,568 A 1/1978 Gala 362/311
4,082,395 A 4/1978 Donato et al. 439/115
4,096,349 A 6/1978 Donato 174/68.3
4,241,295 A 12/1980 Williams, Jr. 315/294
4,271,408 A 6/1981 Teshima et al. 345/83
4,272,689 A 6/1981 Crosby et al. 307/147
4,273,999 A 6/1981 Pierpoint 250/205
4,298,869 A 11/1981 Okuno 345/82
4,329,625 A 5/1982 Nishizawa et al. 315/158
4,339,788 A 7/1982 White et al. 362/157
4,342,947 A 8/1982 Bloyd 315/199
4,367,464 A 1/1983 Kurahashi et al. 345/22
4,388,567 A 6/1983 Yamazaki et al. 315/291
4,388,589 A 6/1983 Molldrem, Jr. 324/96
4,392,187 A 7/1983 Bornhorst 362/233
4,420,711 A 12/1983 Takahashi et al. 315/296
4,455,562 A 6/1984 Dolan et al. 347/130
4,500,796 A 2/1985 Quin 362/183
4,597,033 A 6/1986 Meggs et al. 362/183
4,622,881 A 11/1986 Rand .... 84/164 R
4,625,152 A 11/1986 Nakai 315/317
4,635,052 A 1/1987 Aoike et al. 345/211
4,647,217 A 3/1987 Havel 368/10
4,656,398 A 4/1987 Michael et al. 315/293
4,668,895 A 5/1987 Schneiter .... 315/185 S
4,675,575 A 6/1987 Smith et al. 315/186
4,682,079 A 7/1987 Sanders et al. 315/152
4,686,425 A 8/1987 Havel 368/10
4,687,340 A 8/1987 Havel 368/10
4,688,154 A 8/1987 Nilssen 362/147
4,688,869 A 8/1987 Kelly 439/209
4,695,769 A 9/1987 Schweickardt 315/155
4,701,669 A 10/1987 Head et al. 368/10
4,705,406 A 11/1987 Havel 368/11
4,707,141 A 11/1987 Havel 315/71
4,727,289 A 2/1988 Uchida 315/71
4,740,882 A 4/1988 Miller 700/3
4,753,148 A 6/1988 Johnson .... 84/464 R
4,771,274 A 9/1988 Havel 345/690
4,780,621 A 10/1988 Bartleucci et al. 307/11
4,794,383 A 12/1988 Havel 345/690
4,818,072 A 4/1989 Mohebban 349/199
4,824,269 A 4/1989 Havel 400/704
4,837,565 A 6/1989 White 345/46
4,843,627 A 6/1989 Stebbins 381/110
4,845,481 A 7/1989 Havel 345/46
4,845,745 A 7/1989 Havel 379/354
4,857,801 A 8/1989 Farrell 312/209
4,863,223 A 9/1989 Weissenbach et al. 439/115
4,870,325 A 9/1989 Kazar 315/178
4,874,320 A 10/1989 Freed et al. 439/115
4,887,074 A 12/1989 Simon et al. 345/82
4,922,154 A 5/1990 Cacoub 315/149
4,934,852 A 6/1990 Havel 400/704
4,962,687 A 10/1990 Belliveau et al. .... 84/464 R
4,965,561 A 10/1990 Havel 345/46
4,973,835 A 11/1990 Kurosu et al. .... 250/214 AL
4,979,081 A 12/1990 Leach et al. 362/219
4,980,806 A 12/1990 Taylor et al. 362/85
4,992,704 A 2/1991 Stinson 315/312
5,003,227 A 3/1991 Nilssen 315/161
5,008,595 A 4/1991 Kazar 315/178
5,008,788 A 4/1991 Palinkas 362/81
5,010,459 A 4/1991 Taylor et al. 362/85
5,027,262 A 6/1991 Freed 362/249
5,034,807 A 7/1991 Von Kohorn 725/5
5,036,248 A 7/1991 McEwan et al. 313/500
5,038,255 A 8/1991 Nishihashi et al. 362/547
5,072,216 A 12/1991 Grange 340/825.52
5,078,039 A 1/1992 Tulk et al. .... 84/464 R
5,083,063 A 1/1992 Brooks 315/294
5,089,748 A 2/1992 Ihms 315/151
5,122,733 A 6/1992 Havel 324/115
5,126,634 A 6/1992 Johnson 315/71
5,128,595 A 7/1992 Hara 315/312
5,130,909 A 7/1992 Gross 362/153
5,134,387 A 7/1992 Smith et al. 345/83
5,142,199 A 8/1992 Elwell 315/154
5,154,641 A 10/1992 McLaughlin 439/621
5,161,879 A 11/1992 McDermott 362/206
5,164,715 A 11/1992 Kashiwabara et al. 345/4
5,184,114 A 2/1993 Brown 345/83
5,194,854 A 3/1993 Havel 340/815.65
5,209,560 A 5/1993 Taylor et al. 362/85
5,225,765 A 7/1993 Callahan et al. 323/235
5,226,723 A 7/1993 Chen 362/241
5,254,910 A 10/1993 Yang 315/313
5,256,948 A 10/1993 Boldin et al. 315/313
5,278,542 A 1/1994 Smith et al. 345/690
5,282,121 A 1/1994 Bornhorst et al. 362/294
5,283,517 A 2/1994 Havel 324/115
5,287,352 A 2/1994 Jackson et al. 370/466
5,294,865 A 3/1994 Haraden 315/58
5,298,871 A 3/1994 Shimohara 332/109
5,301,090 A 4/1994 Hed 362/558
5,307,295 A 4/1994 Taylor et al. 703/1
5,329,431 A 7/1994 Taylor et al. 362/85
5,350,977 A 9/1994 Hamamoto et al. 315/291
5,357,170 A 10/1994 Luchaco et al. 315/159
5,371,618 A 12/1994 Tai et al. 349/78
5,374,876 A 12/1994 Horibata et al. 315/313
5,375,043 A 12/1994 Tokunaga 362/601
5,381,074 A 1/1995 Rudzewicz et al. 315/77
5,388,357 A 2/1995 Malita 40/570
5,402,702 A 4/1995 Hata .... 84/464 R
5,404,282 A 4/1995 Klinke et al. 362/249
5,406,176 A 4/1995 Sugden 315/292
5,410,328 A 4/1995 Yoksza et al. 345/82
5,412,284 A 5/1995 Moore et al. 315/155
5,412,552 A 5/1995 Fernandes 362/250
5,420,482 A 5/1995 Phares 315/292
5,421,059 A 6/1995 Leffers, Jr. .... 16/87.4 R
5,430,356 A * 7/1995 Ference et al. 315/291
5,432,408 A 7/1995 Matsuda et al. .... 315/200 R
5,436,535 A 7/1995 Yang 315/313
5,436,853 A 7/1995 Shimohara 702/79
5,450,301 A 9/1995 Waltz et al. 362/231
5,461,188 A 10/1995 Drago et al. 84/600
5,463,280 A 10/1995 Johnson 315/187
5,465,144 A 11/1995 Parker et al. 356/139.06
5,475,300 A 12/1995 Havel 315/294
5,489,827 A 2/1996 Xia 323/282
5,491,402 A 2/1996 Small 315/308
5,493,183 A 2/1996 Kimball 315/71
5,504,395 A 4/1996 Johnson et al. 356/394
5,519,496 A 5/1996 Borgert et al. 356/394
5,530,322 A 6/1996 Ference et al. 315/295
5,545,950 A 8/1996 Cho 315/56
5,559,681 A 9/1996 Duarte 362/252
5,561,346 A 10/1996 Byrne 313/512
5,575,459 A 11/1996 Anderson 362/240
5,575,554 A 11/1996 Guritz 362/103
5,592,051 A 1/1997 Korkala 315/210
5,614,788 A 3/1997 Mullins et al. 315/82
5,621,282 A 4/1997 Haskell 315/324

5,621,603 A 4/1997 Adamec et al. 362/119
5,633,629 A 5/1997 Hochstein 340/907
5,634,711 A 6/1997 Kennedy et al. 362/119
5,640,061 A 6/1997 Bornhorst et al. 307/150
5,642,129 A 6/1997 Zavracky et al. 345/100
5,656,935 A 8/1997 Havel 324/115
5,673,059 A 9/1997 Zavracky et al. 345/8
5,688,042 A 11/1997 Madadi et al. 362/240
5,701,058 A 12/1997 Roth 315/58
5,712,650 A 1/1998 Barlow 345/55
5,721,471 A 2/1998 Begemann et al. 315/158
5,734,590 A 3/1998 Tebbe 700/94
5,751,118 A 5/1998 Mortimer 315/291
5,752,766 A 5/1998 Bailey et al. 362/250
5,769,527 A 6/1998 Taylor et al. 362/85
5,784,006 A 7/1998 Hockstein 340/905
5,790,329 A 8/1998 Klaus et al. 359/887
5,803,579 A 9/1998 Turnbull et al. 362/516
5,808,689 A 9/1998 Small 348/476
5,812,105 A 9/1998 Van de Ven 345/83
5,821,695 A 10/1998 Vilanilam et al. 315/58
5,828,178 A 10/1998 York et al. 315/151
5,836,676 A 11/1998 Ando et al. 362/244
5,848,837 A 12/1998 Gustafson 362/235
5,850,126 A 12/1998 Kanbar 362/231
5,851,063 A 12/1998 Doughty et al. 379/106.03
5,852,658 A 12/1998 Knight et al. 315/291
5,854,542 A 12/1998 Forbes 315/291
RE36,030 E 1/1999 Nadeau 439/115
5,859,508 A 1/1999 Ge et al. 315/366
5,896,010 A 4/1999 Mikolajczak et al. 315/77
5,907,742 A 5/1999 Johnson et al. 399/51
5,912,653 A 6/1999 Fitch 345/87
5,924,784 A 7/1999 Chliwnyj et al. 362/234
5,927,845 A 7/1999 Gustafson et al. 362/152
5,946,209 A 8/1999 Eckel et al. 700/14
5,952,680 A 9/1999 Strite 257/88
5,959,547 A 9/1999 Tubel et al. 340/853.2
5,963,185 A 10/1999 Havel 345/83
5,974,553 A 10/1999 Gandar 713/300
5,980,064 A 11/1999 Metroyanis 362/194
6,008,783 A 12/1999 Kitagawa et al. 345/39
6,016,038 A 1/2000 Mueller et al. 215/291
6,018,237 A 1/2000 Havel 324/115
6,020,825 A 2/2000 Chansky et al. 340/825.22
6,025,550 A 2/2000 Kato .... 84/464 A
6,031,343 A 2/2000 Recknagel et al. 315/292
6,068,383 A 5/2000 Robertson et al. 362/84
6,069,597 A 5/2000 Hansen 345/74.1
6,072,280 A 6/2000 Allen .... 315/185 S
6,092,915 A 7/2000 Rensch 362/471
6,095,661 A 8/2000 Lebens et al. 362/184
6,097,352 A 8/2000 Zavracky et al. 345/7
6,127,783 A 10/2000 Pashley et al. 315/149
6,132,072 A 10/2000 Turnbull et al. 362/494
6,135,604 A 10/2000 Lin 362/101
6,149,283 A * 11/2000 Conway et al. 362/236
6,150,774 A 11/2000 Mueller et al. 315/291
6,166,496 A 12/2000 Lys et al. 315/316
6,175,201 B1 1/2001 Sid 315/312
6,175,220 B1 * 1/2001 Billig et al. 323/239
6,181,126 B1 1/2001 Havel 324/115
6,183,086 B1 2/2001 Neubert 351/221
6,183,104 B1 2/2001 Ferrara 362/145
6,184,628 B1 2/2001 Ruthenberg .... 315/184 R
6,196,471 B1 3/2001 Ruthenberg 239/18
6,211,626 B1 4/2001 Lys et al. 315/291
6,215,409 B1 4/2001 Blach 340/815.4
6,250,774 B1 6/2001 Begemann et al. 362/231
6,252,358 B1 6/2001 Xydis et al. 315/295
6,273,338 B1 8/2001 White 235/462.42
6,292,901 B1 9/2001 Lys et al. 713/300
6,310,590 B1 10/2001 Havel 345/83
6,323,832 B1 11/2001 Nishizawa et al. ...... 315/185 S
6,340,868 B1 1/2002 Lys et al. .... 315/185 S
6,369,525 B1 4/2002 Chang et al. 315/300
6,379,022 B1 4/2002 Amerson et al. 362/231
6,445,139 B1 9/2002 Marshall et al. 315/291
6,448,550 B1 9/2002 Nishimura 250/226
6,459,919 B1 10/2002 Lys et al. 600/407
6,495,964 B1 * 12/2002 Muthu et al. 315/149
6,528,954 B1 3/2003 Lys et al. 315/291
6,548,967 B1 4/2003 Dowling et al. 315/318
6,577,080 B1 6/2003 Lys et al. 315/362
6,586,890 B1 7/2003 Min et al. 315/224
6,596,977 B1 7/2003 Muthu et al. 250/205
6,608,453 B1 8/2003 Morgan et al. 315/312
6,624,597 B1 9/2003 Dowling et al. 315/179
6,636,003 B1 10/2003 Rahm et al. 315/300
6,683,419 B1 1/2004 Kriparos 315/224
6,744,223 B1 6/2004 Laflamme et al. 315/291
2001/0033488 A1 10/2001 Chliwnyj et al. 362/231
2001/0045803 A1 * 11/2001 Cencur 315/291
2002/0038157 A1 3/2002 Dowling et al. 700/90
2002/0044066 A1 4/2002 Dowling et al. 340/815.46
2002/0047569 A1 4/2002 Dowling et al. 345/39
2002/0047624 A1 4/2002 Stam et al. 315/291
2002/0048169 A1 4/2002 Dowling et al. 315/291
2002/0057061 A1 5/2002 Mueller et al. 315/291
2002/0070688 A1 6/2002 Dowling et al. 315/312
2002/0074559 A1 6/2002 Dowling et al. 257/99
2002/0078221 A1 6/2002 Blackwell et al. 709/231
2002/0101197 A1 8/2002 Lys et al. 315/291
2002/0130627 A1 9/2002 Dowling et al. 315/291
2002/0145394 A1 10/2002 Morgan et al. 315/291
2002/0145869 A1 10/2002 Dowling 362/192
2002/0152045 A1 10/2002 Dowling et al. 702/107
2002/0153851 A1 10/2002 Dowling et al. 315/291
2002/0158583 A1 10/2002 Lys et al. 315/82
2002/0163316 A1 11/2002 Dowling et al. 315/291
2002/0171365 A1 11/2002 Morgan et al. 315/291
2002/0171377 A1 11/2002 Mueller et al. 315/291
2002/0171378 A1 11/2002 Morgan et al. 315/291
2002/0176259 A1 11/2002 Ducharme 362/545
2002/0195975 A1 12/2002 Dowling et al. 315/291
2003/0011538 A1 1/2003 Lys et al. 345/39
2003/0028260 A1 2/2003 Blackwell 315/291
2003/0057884 A1 3/2003 Dowling et al. 315/291
2003/0057886 A1 3/2003 Lys et al. 315/291
2003/0057887 A1 3/2003 Dowling et al. 315/291
2003/0057890 A1 3/2003 Lys et al. 315/295
2003/0076281 A1 4/2003 Morgan et al. 345/44
2003/0100837 A1 5/2003 Lys et al. 600/476
2003/0133292 A1 7/2003 Mueller et al. 362/231
2003/0137258 A1 7/2003 Piepgras et al. 315/291
2003/0189412 A1 10/2003 Cunningham 315/312

FOREIGN PATENT DOCUMENTS

CA 2 178 432 12/1996
CA 2 134 848 11/1998
DE 02315709 10/1974
DE 0205307 12/1983
DE 03438154 A1 4/1986
DE 3837313 5/1989
DE 3805998 9/1989
DE 3925767 A1 4/1990
DE 8902905 5/1990
DE 3917101 11/1990
DE 3916875 12/1990
DE 4041338 7/1992
DE 4130576 C1 3/1993
DE 9414688 U1 2/1995
DE 9414689 2/1995
DE 4419006 A1 12/1995
DE 29607270 U1 8/1996

DE	19525987		10/1996
DE	29620583	U1	3/1997
DE	19651140	A1	6/1997
DE	19602891	A1	7/1997
EP	0482680	A1	4/1992
EP	0495305	A2	7/1992
EP	0567280	B1	10/1993
EP	0534710	B1	1/1996
EP	0734082	A2	9/1996
EP	0752632	A2	1/1997
EP	0752632	A3	8/1997
EP	0823812	A2	2/1998
EP	0935234	A1	8/1999
EP	0942631	A2	9/1999
EP	1020352	A2	7/2000
EP	1113215	A2	7/2001
EP	1162400	A2	12/2001
FR	2 640 791		6/1990
FR	88 17359		12/1998
GB	2045098	A	10/1980
GB	2131589	A	11/1982
GB	2135536	A	8/1984
GB	2176042	A	12/1986
GB	2210720	A	6/1989
JP	2247688		3/1990
JP	03045166		2/1991
JP	06043830		2/1994
JP	7-39120		7/1995
JP	8-106264		4/1996
JP	09-139289		5/1997
KR	1019910009812		11/1991
WO	WO 89/05086		6/1989
WO	WO 94/18809		8/1994
WO	WO 95/13498		5/1995
WO	WO 96/41098		12/1996
WO	WO 99/06759		2/1999
WO	WO 02/061328	A1	8/2002

OTHER PUBLICATIONS

"DS96177 RS-485 / RS-422 Differential Bus Repeater", National Semiconductor Corporation, Feb. 1996, pp. 1-8.

"DS2003 / DA9667 / DS2004 High Current / Voltage Darlington Drivers", National Semiconductor Corporation, Dec. 1995, pp. 1-8.

"LM140A / LM140 / LM340A / LM7800C Series 3—Terminal Positive Regulators", National Semiconductor Corporation, Jan. 1995, pp. 1-14.

High End Systems, Inc., Trackspot User Manual, Aug. 1997, Excerpts (Cover, Title page, pp. ii through iii and 2-13 through 2-14).

Artistic License, AL4000 DMX512 Processors, Revision 3.4, Jun. 2000, Excerpts (Cover, pp. 7,92 through 102).

Artistic License, Miscellaneous Drawings (3 sheets) Jan. 12, 1995.

Artistic License, Miscellaneous Documents (2 sheets Feb. 1995 and Apr. 1996).

Newnes's Dictionary of Electronics, Fourth Edition, S.W. Amos, et al., Preface to First Edition, pp. 278-279.

"http://www.luminus.cx/projects/chaser", (Nov. 13, 2000), pp. 1-16.

Hewlett Packard Components, "Solid State Display and Optoelectronics Designer's Catalog," pp. 30-43, Jul. 1973.

INTEC Research, Trackspot, http://www.intec-research.com/trackspot.htm, pp. 1-4, Apr. 24, 2003.

Sharp, Optoelectronics Data Book, pp. 1096-1097, 1994/1995.

About DMX-512 Lighting Protocol—Pangolin Laser Systems, pp. 1-4, Apr. 7, 2003.

Avitec Licht Design '89-90, pp. 1-4.

Dr. Ing, Ulrich Tietze, Dr. Ing, Christoph Schenk, pp. 566-569.

Case No. 6:02-cv-270-ORL-19JGG in the United States District Court, Middle District of Florida, Orlando Division, Plaintiff's Amended Verified Complaint.

Case No. 6:02-cv-270-ORL-19JGG in the United States District Court, Middle District of Florida, Orlando Division, Defendant's Answer and Counterclaims.

Case No. 6:02-cv-270-ORL-19JGG in the United States District Court, Middle District of Florida, Orlando Division, Plaintiff's Answer to Conterclaims.

Case No. 6:02-cv-270-ORL-19JGG in the United States District Court, Middle District of Florida, Orlando Division, Plaintiff's Answers to Defendant's First Set of Interrogatories w/Exhibit 1.

Case No. 02 CV 11137MEL in the United States District Court, District of Massachusetts, Plaintiff's Complaint and Jury Demand.

Case No. 02 CV 11137MEL in the United States District Court, District of Massachusetts, Defendant's Answer and Affirmative Defenses.

Furry, Kevin and Somerville, Chuck, Affidavit, LED effects, Feb. 22, 2002, pp. 24-29.

Putman, Peter H., "The Allure of LED," www.sromagazine.biz, Jun./Jul. 2002, pp. 47-52.

Bremer, Darlene, "LED Advancements Increase Potential," www.ecmag.com, Apr. 2002, p. 115.

Longo, Linda, "LEDS Lead the Way," Home Lighting & Accessories, Jun. 2002, pp. 226-234.

* cited by examiner

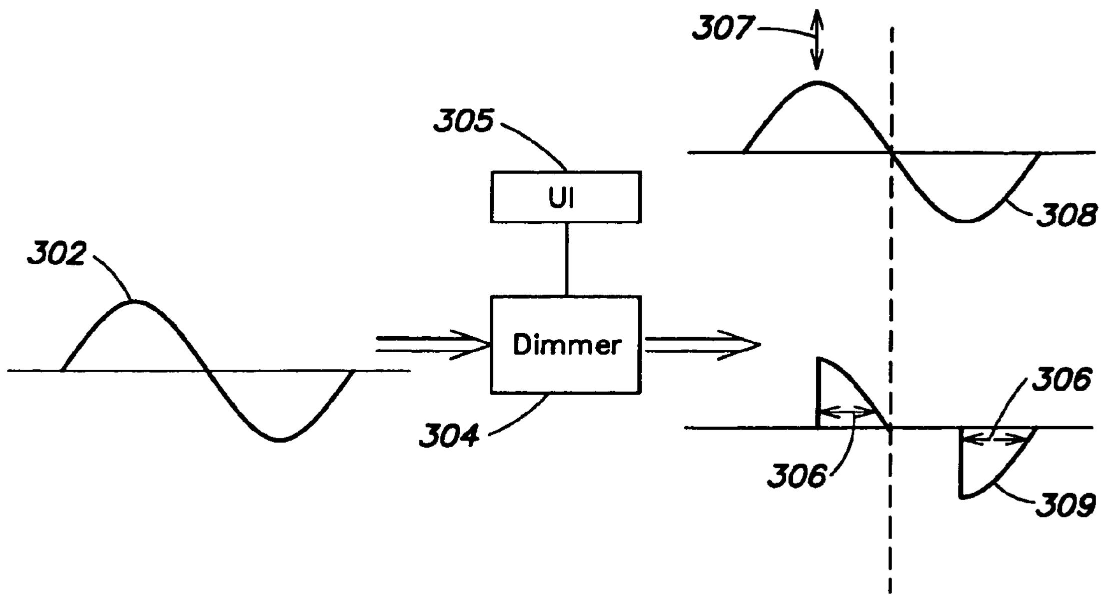


FIG. 1
(PRIOR ART)

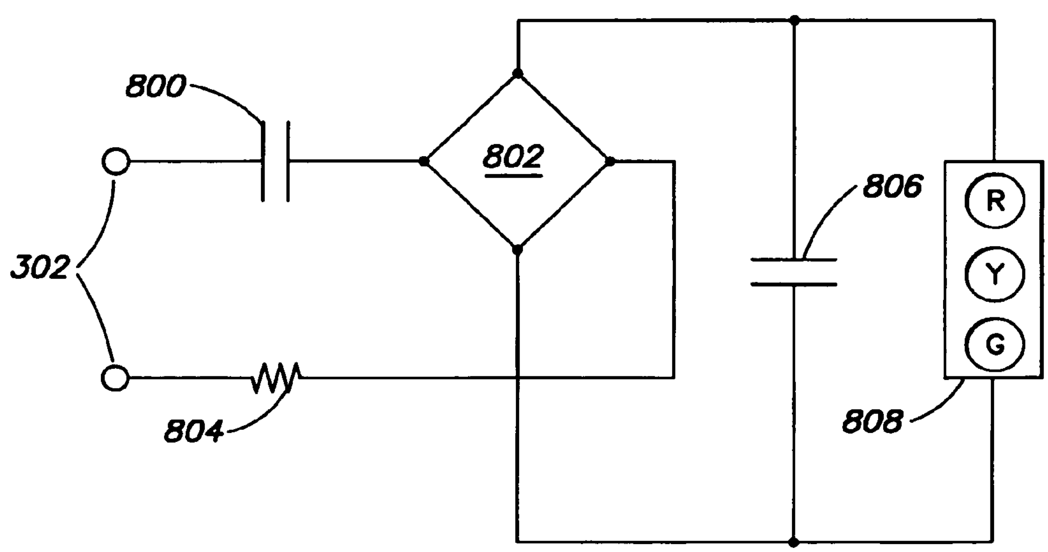


FIG. 2
(PRIOR ART)

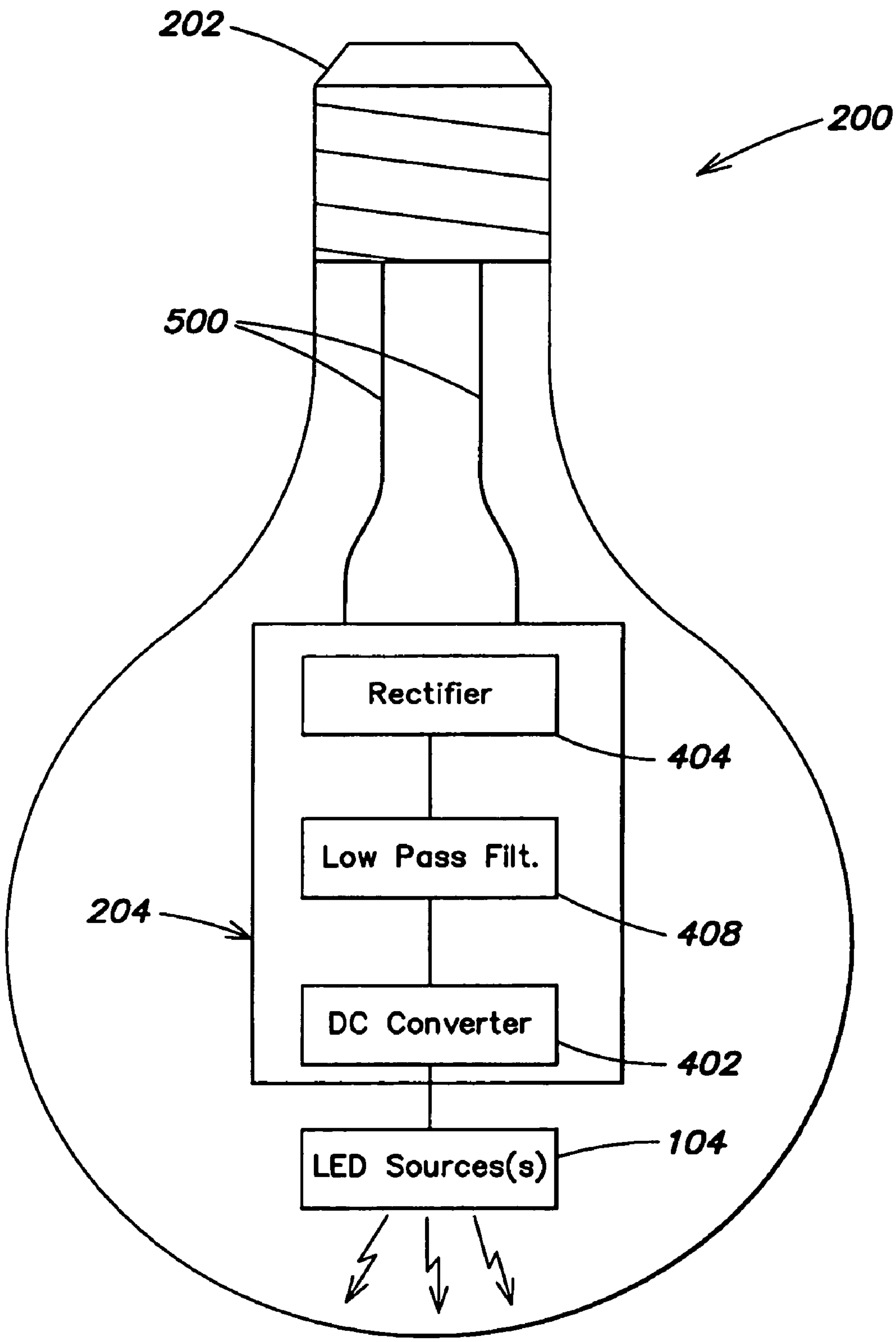

202
200
500
Rectifier
404
Low Pass Filt.
204
408
DC Converter
402
LED Sources(s)
104

FIG. 3

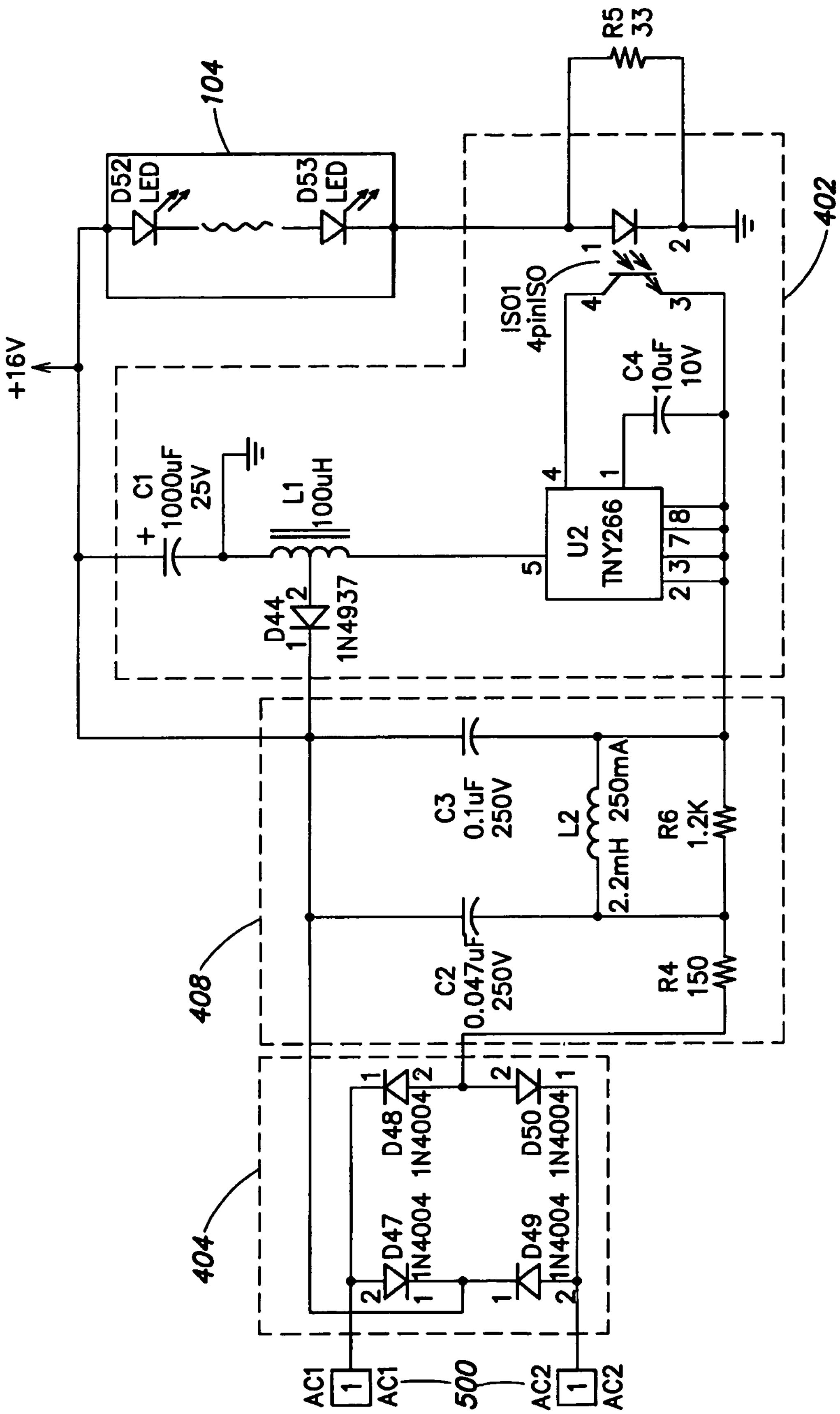

R5
33
104
D52
LED
D53
LED
402
1
2
ISO1
4pinISO
4
3
+16V
C4
10uF
10V
+
C1
1000uF
25V
L1
100uH
4
1
U2
TNY266
5
8
7
3
2
D44
1
2
1N4937
C3
0.1uF
250V
L2
2.2mH 250mA
R6
1.2K
408
C2
0.047uF
250V
R4
150
D48
1N4004
D50
1N4004
404
D47
1N4004
D49
1N4004
AC1
AC1
500
AC2
AC2

FIG. 4

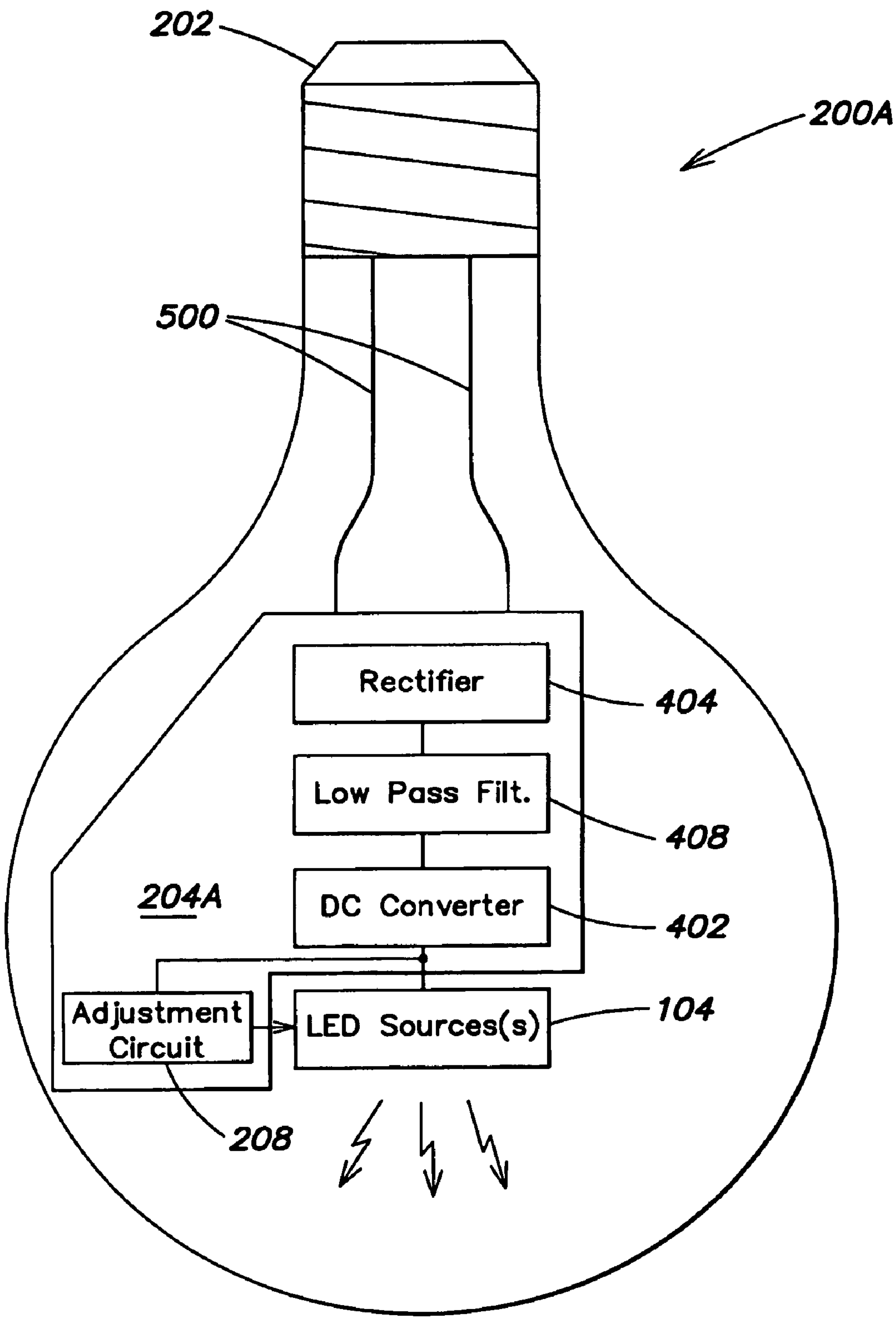

202
200A
500
Rectifier
404
Low Pass Filt.
408
204A
DC Converter
402
Adjustment Circuit
LED Sources(s)
104
208

FIG. 5

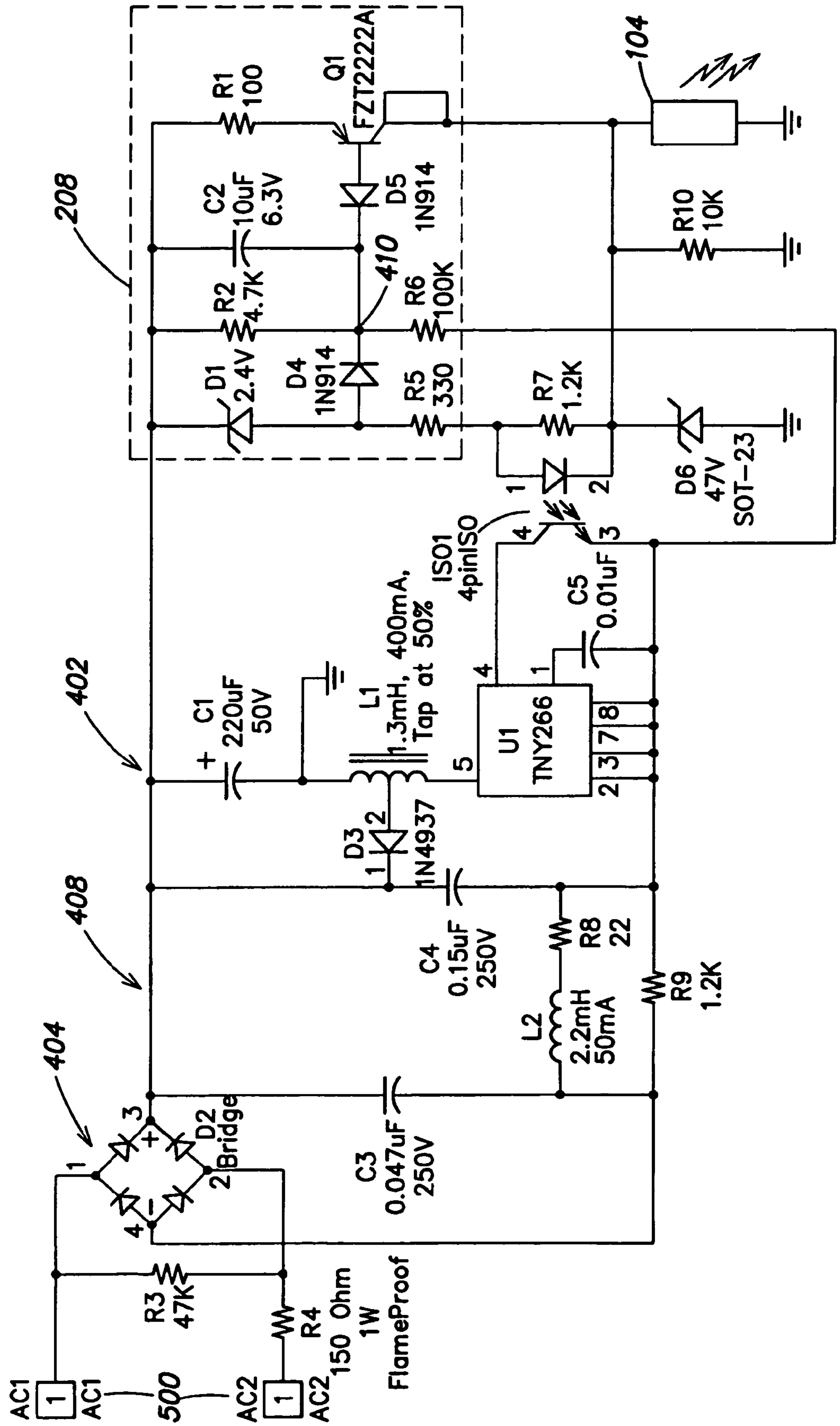

208
R1
100
Q1
FZT2222A
104
C2
10uF
6.3V
D5
1N914
R10
10K
410
R2
4.7K
R6
100K
D1
2.4V
D4
1N914
R5
330
R7
1.2K
D6
47V
SOT-23
ISO1
4pinISO
C5
0.01uF
402
C1
220uF
50V
L1
1.3mH, 400mA,
Tap at 50%
U1
TNY266
D3
1N4937
408
C4
0.15uF
250V
R8
22
L2
2.2mH
50mA
R9
1.2K
404
D2
Bridge
C3
0.047uF
250V
R3
47K
R4
150 Ohm
1W
FlameProof
AC1
AC2
500

FIG. 6

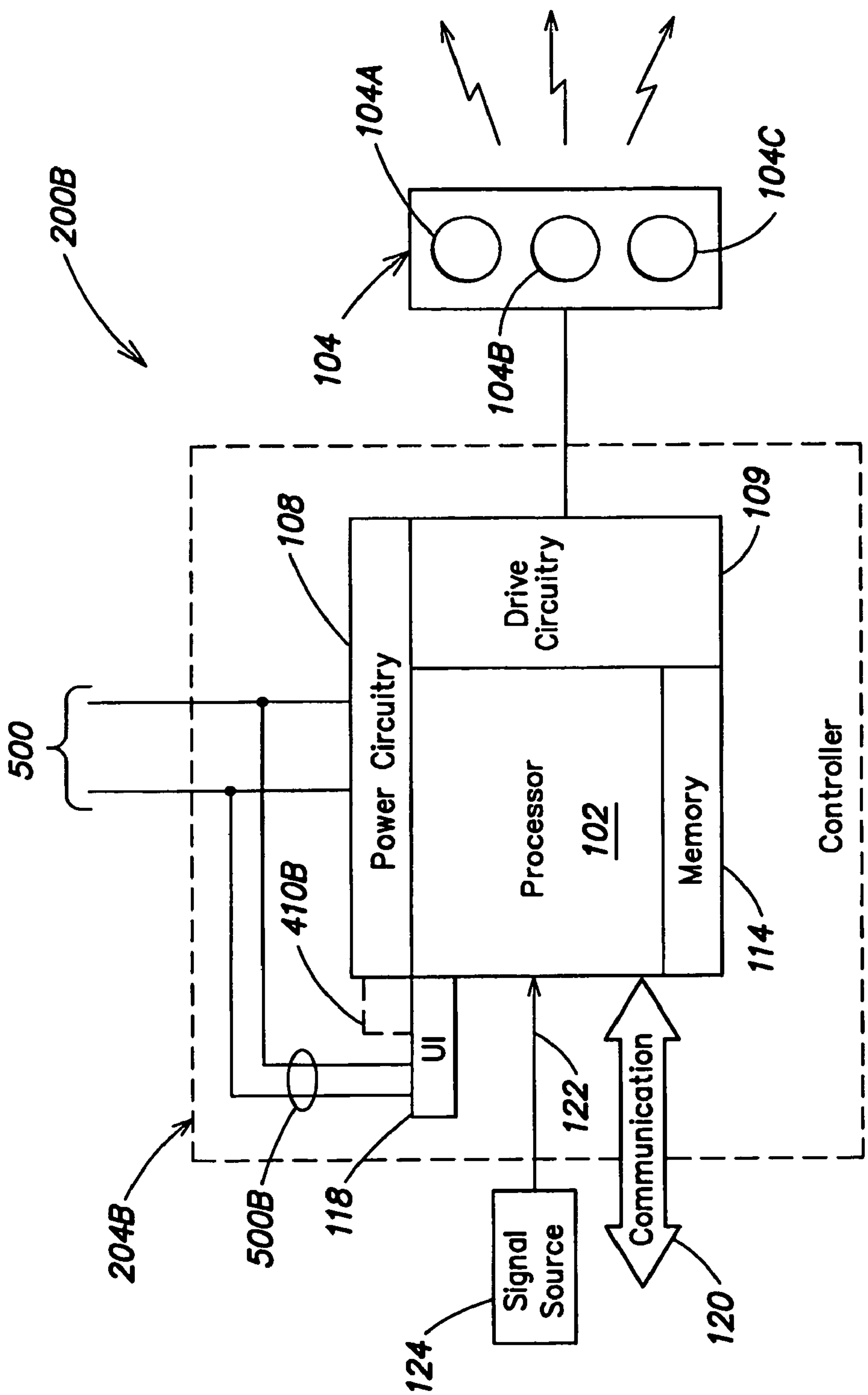

200B
104A
104C
104
104B
108
109
Drive Circuitry
Power Circuitry
Processor
102
Memory
Controller
500
410B
114
UI
122
Communication
204B
500B
118
Signal Source
120
124

FIG. 7

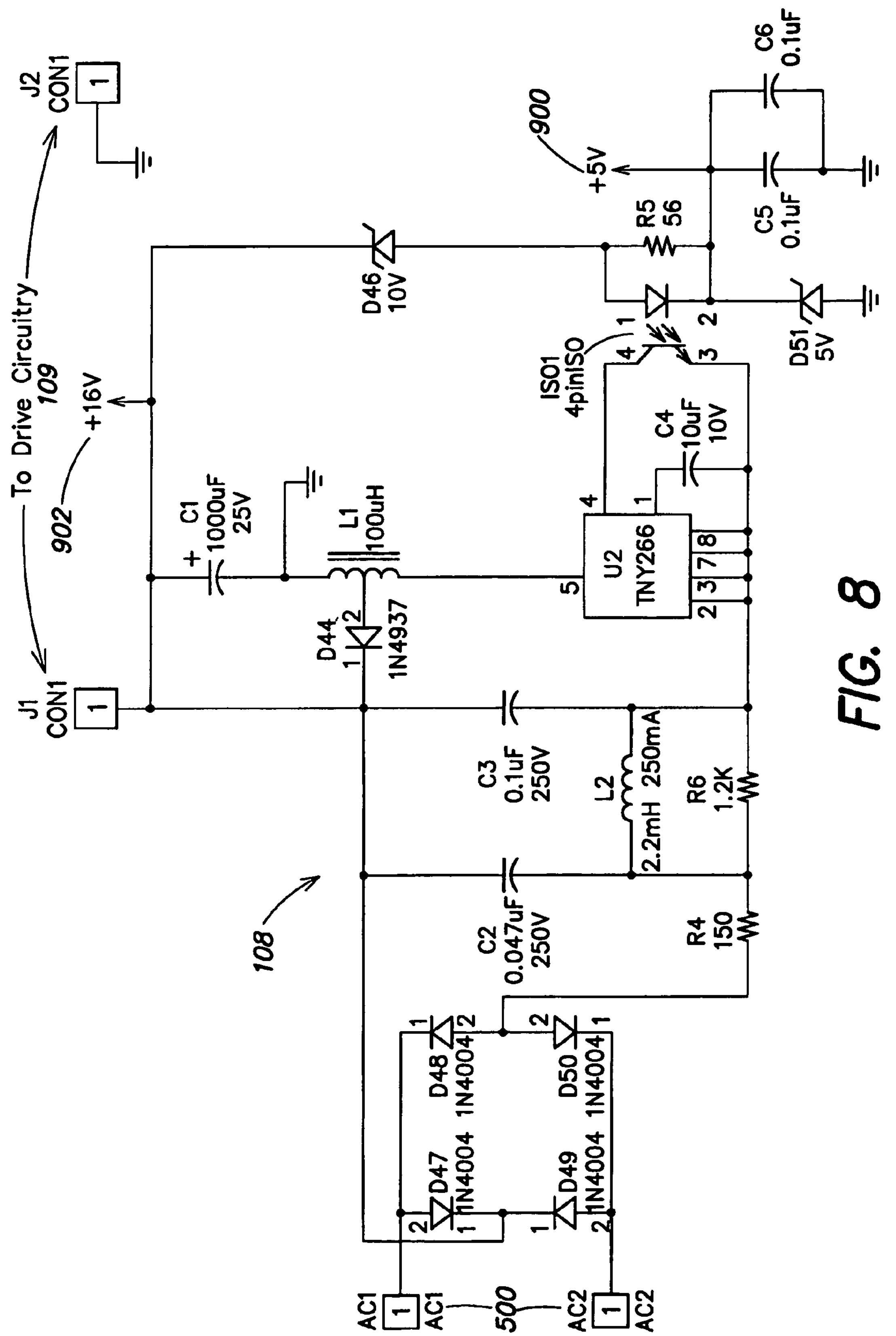
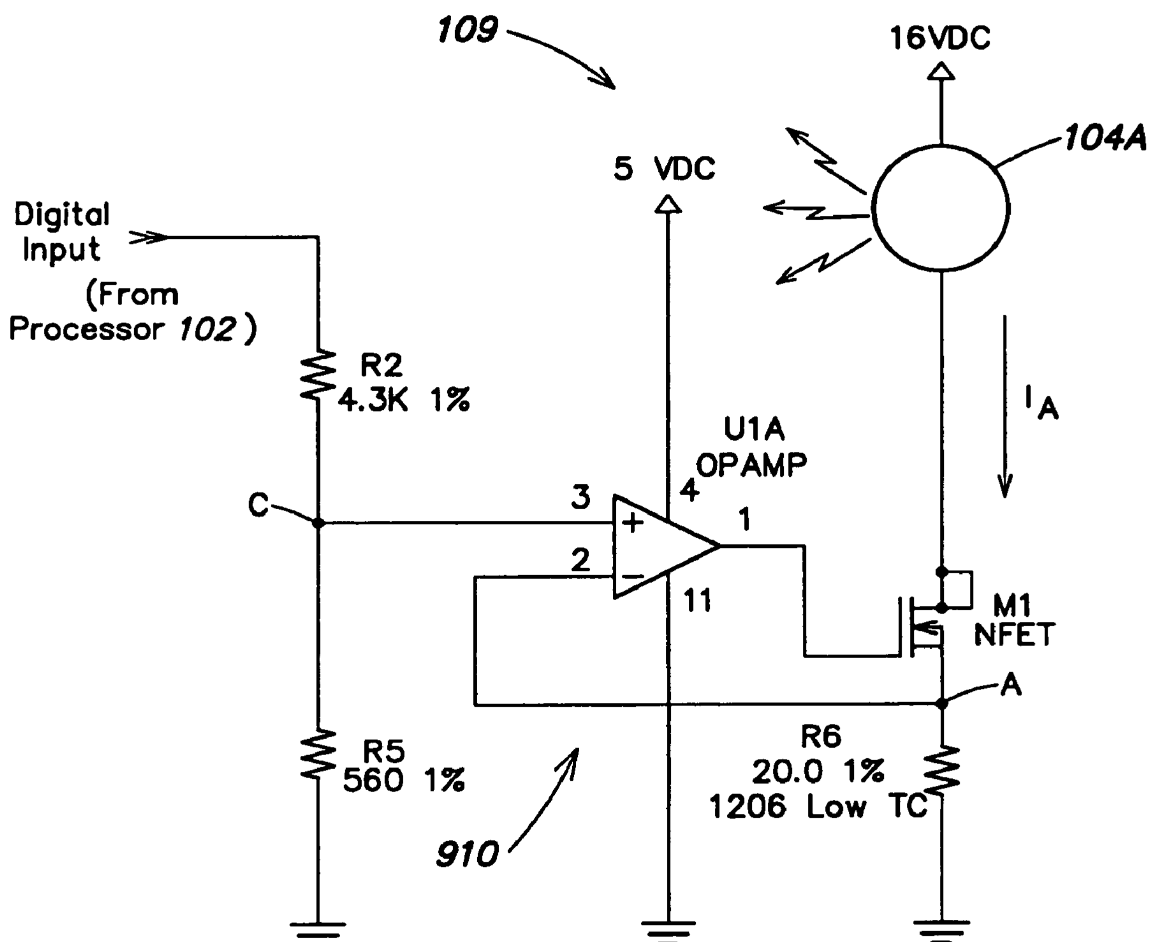

J2
CON1
To Drive Circuitry
109
902
+16V
900
+5V
C6
0.1uF
C5
0.1uF
R5
56
D46
10V
D51
5V
ISO1
4pinISO
C4
10uF
10V
C1
1000uF
25V
L1
100uH
U2
TNY266
D44
1N4937
J1
CON1
C3
0.1uF
250V
L2
2.2mH 250mA
R6
1.2K
C2
0.047uF
250V
R4
150
108
D47
1N4004
D48
1N4004
D49
1N4004
D50
1N4004
AC1
AC2
500

FIG. 8



109
16VDC
104A
5 VDC
Digital Input
(From Processor 102)
R2
4.3K 1%
I_A
U1A
OPAMP
C
3
4
1
2
11
M1
NFET
A
R6
20.0 1%
1206 Low TC
R5
560 1%
910

FIG. 9

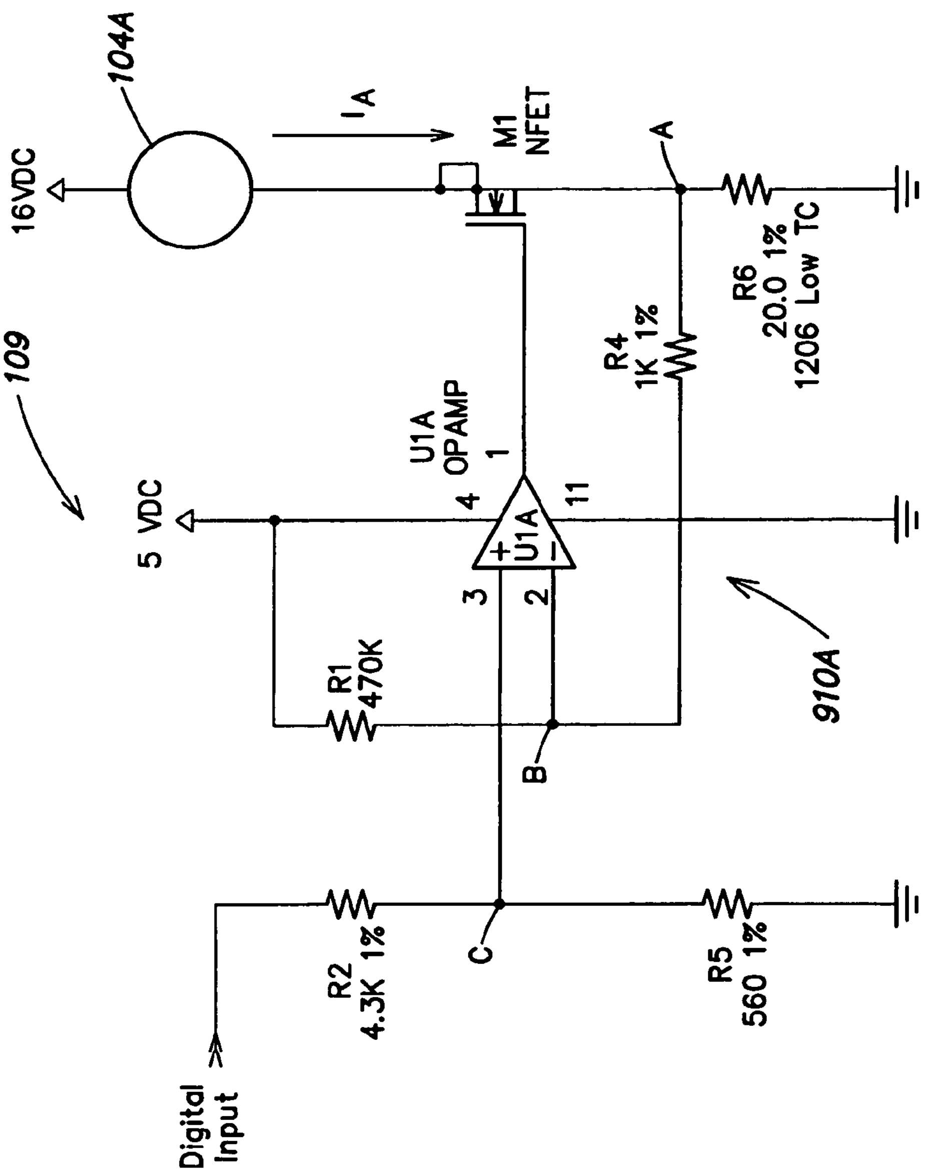
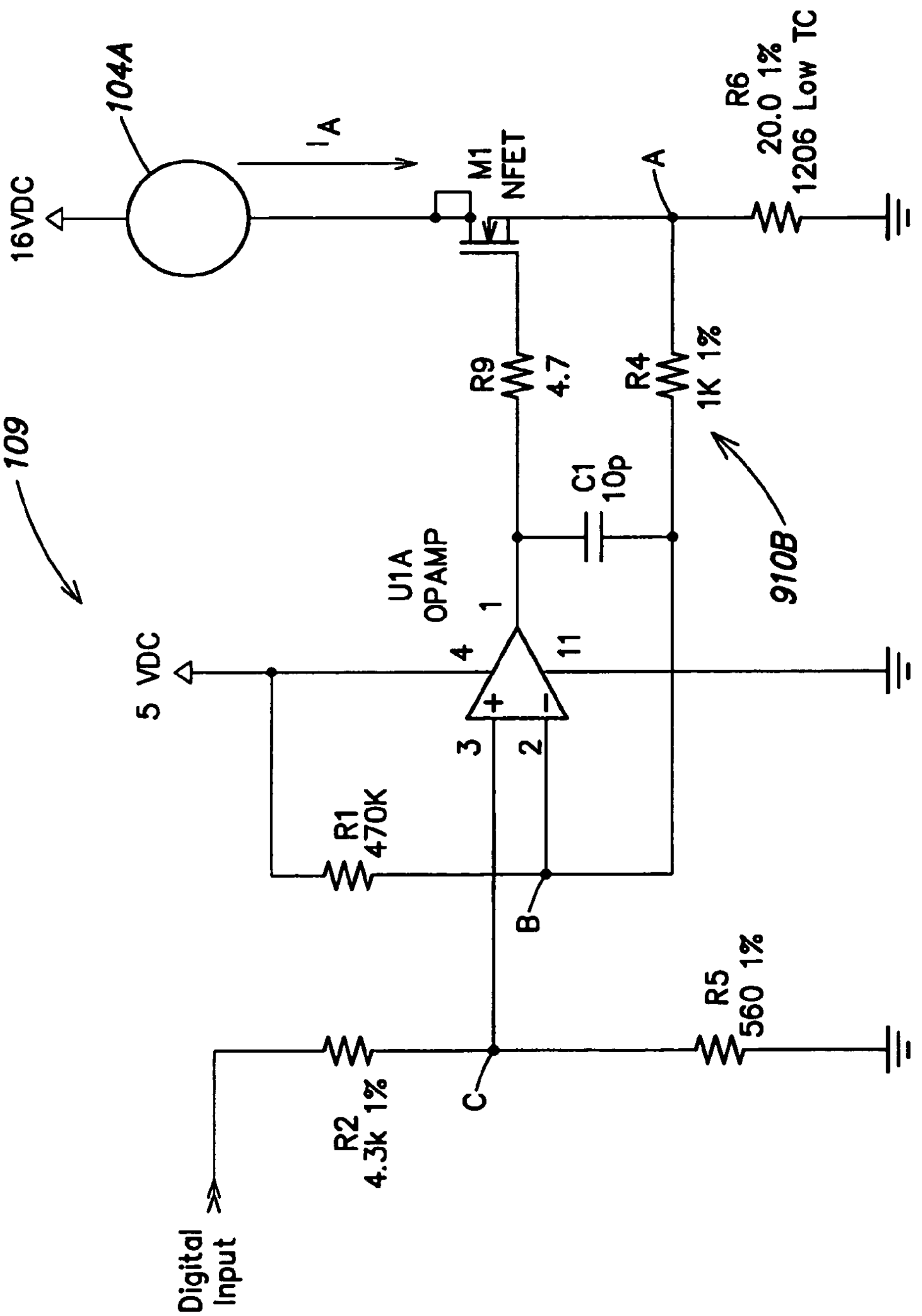

104A
16VDC
I_A
M1
NFET
A
R6
20.0 1%
1206 Low TC
109
R4
1K 1%
U1A
OPAMP
1
4
11
5 VDC
U1A
3
2
910A
R1
470K
B
C
R2
4.3K 1%
R5
560 1%
Digital
Input

FIG. 10



104A
16VDC
I_A
M1
NFET
A
R6
20.0 1%
1206 Low TC
109
R9
4.7
R4
1K 1%
C1
10p
910B
U1A
OPAMP
5 VDC
1
4
11
3
2
+
-
R1
470K
B
R5
560 1%
C
R2
4.3k 1%
Digital
Input

FIG. 11

METHODS AND APPARATUS FOR PROVIDING POWER TO LIGHTING DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit, under 35 U.S.C. §119(e), of U.S. Provisional Application Ser. No. 60/379,079, filed May 9, 2002, entitled "Systems and Methods for Controlling LED Based Lighting," and U.S. Provisional Application Ser. No. 60/391,627, filed Jun. 26, 2002, entitled "Switched Current Sink," which applications are hereby incorporated herein by reference.

This application also claims the benefit under 35 U.S.C. §120 as a continuation-in-part (CIP) of the following U.S. non-provisional applications:

Ser. No. 09/805,368, filed Mar. 13, 2001, entitled LIGHT-EMITTING DIODE BASED PRODUCTS; and

Ser. No. 09/805,590, filed Mar. 13, 2001, entitled LIGHT-EMITTING DIODE BASED PRODUCTS.

FIELD OF THE INVENTION

The present invention is directed generally to methods and apparatus for providing power to devices on A.C. power circuits. More particularly, the invention relates to methods and apparatus for providing power to light emitting diode (LED) based devices, primarily for illumination purposes.

BACKGROUND

In various lighting applications (e.g., home, commercial, industrial, etc.), there are instances in which it is desirable to adjust the amount of light generated by one or more conventional light sources (e.g., incandescent light bulbs, fluorescent light fixtures, etc.). In many cases, this is accomplished via a user-operated device, commonly referred to as a "dimmer," that adjusts the power delivered to the light source(s). Many types of conventional dimmers are known that allow a user to adjust the light output of one or more light sources via some type of user interface (e.g., by turning a knob, moving a slider, etc., often mounted on a wall in proximity to an area in which it is desirable to adjust the light level). The user interface of some dimmers also may be equipped with a switching/adjustment mechanism that allows one or more light sources to be switched off and on instantaneously, and also have their light output gradually varied when switched on.

Many lighting systems for general interior or exterior illumination often are powered by an A.C. source, commonly referred to as a "line voltage" (e.g., 120 Volts RMS at 60 Hz, 220 Volts RMS at 50 Hz). A conventional A.C. dimmer typically receives the A.C. line voltage as an input, and provides an A.C. signal output having one or more variable parameters that have the effect of adjusting the average voltage of the output signal (and hence the capability of the A.C. output signal to deliver power) in response to user operation of the dimmer. This dimmer output signal generally is applied, for example, to one or more light sources that are mounted in conventional sockets or fixtures coupled to the dimmer output (such sockets or fixtures sometimes are referred to as being on a "dimmer circuit").

Conventional A.C. dimmers may be configured to control power delivered to one or more light sources in one of a few different ways. For example, in one implementation, the adjustment of the user interface causes the dimmer to

increase or decrease a voltage amplitude of the A.C. dimmer output signal. More commonly, however, in other implementations, the adjustment of the user interface causes the dimmer to adjust the duty cycle of the A.C. dimmer output signal (e.g., by "chopping-out" portions of A.C. voltage cycles). This technique sometimes is referred to as "angle modulation" (based on the adjustable phase angle of the output signal). Perhaps the most commonly used dimmers of this type employ a triac that is selectively operated to adjust the duty cycle (i.e., modulate the phase angle) of the dimmer output signal by chopping-off rising portions of A.C. voltage half-cycles (i.e., after zero-crossings and before peaks). Other types of dimmers that adjust duty cycles may employ gate turn-off (GTO) thyristors that are selectively operated to chop-off falling portions of A.C. voltage half-cycles (i.e., after peaks and before zero-crossings).

FIG. **1** generally illustrates some conventional A.C. dimmer implementations. In particular, FIG. **1** shows an example of an A.C. voltage waveform **302** (e.g., representing a standard line voltage) that may provide power to one or more conventional light sources. FIG. **1** also shows a generalized A.C. dimmer **304** responsive to a user interface **305**. In the first implementation discussed above, the dimmer **304** is configured to output the waveform **308**, in which the amplitude **307** of the dimmer output signal may be adjusted via the user interface **305**. In the second implementation discussed above, the dimmer **304** is configured to output the waveform **309**, in which the duty cycle **306** of the waveform **309** may be adjusted via the user interface **305**.

As discussed above, both of the foregoing techniques have the effect of adjusting the average voltage applied to the light source(s), which in turn adjusts the intensity of light generated by the source(s). Incandescent sources are particularly well-suited for this type of operation, as they produce light when there is current flowing through a filament in either direction; as the average voltage of an A.C. signal applied to the source(s) is adjusted (e.g., either by an adjustment of voltage amplitude or duty cycle), the current (and hence the power) delivered to the light source also is changed and the corresponding light output changes. With respect to the duty cycle technique, the filament of an incandescent source has thermal inertia and does not stop emitting light completely during short periods of voltage interruption. Accordingly, the generated light as perceived by the human eye does not appear to flicker when the voltage is "chopped," but rather appears to gradually change.

SUMMARY

The present invention is directed generally to methods and apparatus for providing power to devices on A.C. power circuits. More particularly, methods and apparatus according to various embodiments of the present invention facilitate the use of LED-based light sources on A.C. power circuits that provide either a standard line voltage or signals other than standard line voltages.

In one embodiment, methods and apparatus of the invention particularly facilitate the use of LED-based light sources on A.C. power circuits that are controlled by conventional dimmers (i.e, "A.C. dimmer circuits"). In one aspect, methods and apparatus of the present invention facilitate convenient substitution of LED-based light sources in lighting environments employing A.C. dimming devices and conventional light sources. In yet other aspects, methods and apparatus according to the present invention facilitate the control of one or more parameters relating to the light generated by LED-based light sources (e.g., intensity, color,

color temperature, temporal characteristics, etc.) via operation of a conventional A.C. dimmer and/or other signals present on the A.C. power circuit.

More generally, one embodiment of the invention is directed to an illumination apparatus, comprising at least one LED and at least one controller coupled to the at least one LED. The controller is configured to receive a power-related signal from an A.C. power source that provides signals other than a standard A.C. line voltage. The controller further is configured to provide power to the at least one LED based on the power-related signal.

Another embodiment of the invention is directed to an illumination method, comprising an act of providing power to at least one LED based on a power-related signal from an A.C. power source that provides signals other than a standard A.C. line voltage.

Another embodiment of the invention is directed to an illumination apparatus, comprising at least one LED, and at least one controller coupled to the at least one LED and configured to receive a power-related signal from an alternating current (A.C.) dimmer circuit and provide power to the at least one LED based on the power-related signal.

Another embodiment of the invention is directed to an illumination method, comprising an act of providing power to at least one LED based on a power-related signal from an alternating current (A.C.) dimmer circuit.

Another embodiment of the invention is directed to an illumination apparatus, comprising at least one LED adapted to generate an essentially white light, and at least one controller coupled to the at least one LED and configured to receive a power-related signal from an alternating current (A.C.) dimmer circuit and provide power to the at least one LED based on the power-related signal. The A.C. dimmer circuit is controller by a user interface to vary the power-related signal. The controller is configured to variably control at least one parameter of the essentially white light in response to operation of the user interface so as to approximate light generation characteristics of an incandescent light source.

Another embodiment of the invention is directed to a lighting system, comprising at least one LED, a power connector, and a power converter associated with the power connector and adapted to convert A.C. dimmer circuit power received by the power connector to form a converted power. The system also includes an adjustment circuit associated with the power converter adapted to adjust power delivered to the at least one LED.

Another embodiment of the invention is directed to a method of providing illumination, comprising the steps of providing an AC dimmer circuit, connecting an LED lighting system to the AC dimmer circuit, generating light from the LED lighting system by energizing the AC dimmer circuit, and adjusting the light generated by the LED lighting system by adjusting the AC dimmer circuit.

Another embodiment of the invention is directed to method for controlling at least one device powered via an A.C. line voltage. The method comprises an act of generating a power signal based on the A.C. line voltage, wherein the power signal provides an essentially constant power to the at least one device and includes at least one communication channel carrying control information for the at least one device, the at least one communication channel occupying a portion of a duty cycle over a period of cycles of the A.C. line voltage.

Another embodiment of the invention is directed to an apparatus for controlling at least one device powered via an A.C. line voltage. The apparatus comprises a supply voltage

controller configured to generate a power signal based on the A.C. line voltage, wherein the power signal provides an essentially constant power to the at least one device and includes at least one communication channel carrying control information for the at least one device, the at least one communication channel occupying a portion of a duty cycle over a period of cycles of the A.C. line voltage. In one aspect of this embodiment, the supply voltage controller includes at least one user interface to provide variable control information in the at least one communication channel.

As used herein for purposes of the present disclosure, the term “LED” should be understood to include any electroluminescent diode or other type of carrier injection/junction-based system that is capable of generating radiation in response to an electric signal. Thus, the term LED includes, but is not limited to, various semiconductor-based structures that emit light in response to current, light emitting polymers, electroluminescent strips, and the like.

In particular, the term LED refers to light emitting diodes of all types (including semi-conductor and organic light emitting diodes) that may be configured to generate radiation in one or more of the infrared spectrum, ultraviolet spectrum, and various portions of the visible spectrum (generally including radiation wavelengths from approximately 400 nanometers to approximately 700 nanometers). Some examples of LEDs include, but are not limited to, various types of infrared LEDs, ultraviolet LEDs, red LEDs, blue LEDs, green LEDs, yellow LEDs, amber LEDs, orange LEDs, and white LEDs (discussed further below). It also should be appreciated that LEDs may be configured to generate radiation having various bandwidths for a given spectrum (e.g., narrow bandwidth, broad bandwidth).

For example, one implementation of an LED configured to generate essentially white light (e.g., a white LED) may include a number of dies which respectively emit different spectra of electroluminescence that, in combination, mix to form essentially white light. In another implementation, a white light LED may be associated with a phosphor material that converts electroluminescence having a first spectrum to a different second spectrum. In one example of this implementation, electroluminescence having a relatively short wavelength and narrow bandwidth spectrum “pumps” the phosphor material, which in turn radiates longer wavelength radiation having a somewhat broader spectrum.

It should also be understood that the term LED does not limit the physical and/or electrical package type of an LED. For example, as discussed above, an LED may refer to a single light emitting device having multiple dies that are configured to respectively emit different spectra of radiation (e.g., that may or may not be individually controllable). Also, an LED may be associated with a phosphor that is considered as an integral part of the LED (e.g., some types of white LEDs). In general, the term LED may refer to packaged LEDs, non-packaged LEDs, surface mount LEDs, chip-on-board LEDs, T-package mount LEDs, radial package LEDs, power package LEDs, LEDs including some type of encasement and/or optical element (e.g., a diffusing lens), etc.

The term “light source” should be understood to refer to any one or more of a variety of radiation sources, including, but not limited to, LED-based sources (employing one or more LEDs as defined above), incandescent sources (e.g., filament lamps, halogen lamps), fluorescent sources, phosphorescent sources, high-intensity discharge sources (e.g., sodium vapor, mercury vapor, and metal halide lamps), lasers, other types of electroluminescent sources, pyro-luminescent sources (e.g., flames), candle-luminescent sources (e.g., gas mantles, carbon arc radiation sources), photo-luminescent sources (e.g., gaseous discharge sources), cathode luminescent sources using electronic satiation, galvano-luminescent sources, crystallo-luminescent sources, kine-luminescent sources, thermo-luminescent sources, triboluminescent sources, sonoluminescent sources, radioluminescent sources, and luminescent polymers.

A given light source may be configured to generate electromagnetic radiation within the visible spectrum, outside the visible spectrum, or a combination of both. Hence, the terms "light" and "radiation" are used interchangeably herein. Additionally, a light source may include as an integral component one or more filters (e.g., color filters), lenses, or other optical components. Also, it should be understood that light sources may be configured for a variety of applications, including, but not limited to, indication and/or illumination. An "illumination source" is a light source that is particularly configured to generate radiation having a sufficient intensity to effectively illuminate an interior or exterior space.

The term "spectrum" should be understood to refer to any one or more frequencies (or wavelengths) of radiation produced by one or more light sources. Accordingly, the term "spectrum" refers to frequencies (or wavelengths) not only in the visible range, but also frequencies (or wavelengths) in the infrared, ultraviolet, and other areas of the overall electromagnetic spectrum. Also, a given spectrum may have a relatively narrow bandwidth (essentially few frequency or wavelength components) or a relatively wide bandwidth (several frequency or wavelength components having various relative strengths). It should also be appreciated that a given spectrum may be the result of a mixing of two or more other spectra (e.g., mixing radiation respectively emitted from multiple light sources).

For purposes of this disclosure, the term "color" is used interchangeably with the term "spectrum." However, the term "color" generally is used to refer primarily to a property of radiation that is perceivable by an observer (although this usage is not intended to limit the scope of this term). Accordingly, the terms "different colors" implicitly refer to multiple spectra having different wavelength components and/or bandwidths. It also should be appreciated that the term "color" may be used in connection with both white and non-white light.

The term "color temperature" generally is used herein in connection with white light, although this usage is not intended to limit the scope of this term. Color temperature essentially refers to a particular color content or shade (e.g., reddish, bluish) of white light. The color temperature of a given radiation sample conventionally is characterized according to the temperature in degrees Kelvin (K) of a black body radiator that radiates essentially the same spectrum as the radiation sample in question. The color temperature of white light generally falls within a range of from approximately 700 degrees K (generally considered the first visible to the human eye) to over 10,000 degrees K.

Lower color temperatures generally indicate white light having a more significant red component or a "warmer feel," while higher color temperatures generally indicate white light having a more significant blue component or a "cooler feel." By way of example, fire has a color temperature of approximately 1,800 degrees K, a conventional incandescent bulb has a color temperature of approximately 2848 degrees K, early morning daylight has a color temperature of approximately 3,000 degrees K, and overcast midday skies have a color temperature of approximately 10,000 degrees K. A color image viewed under white light having a color temperature of approximately 3,000 degree K has a relatively reddish tone, whereas the same color image viewed under white light having a color temperature of approximately 10,000 degrees K has a relatively bluish tone.

The terms "lighting unit" and "lighting fixture" are used interchangeably herein to refer to an apparatus including one or more light sources of same or different types. A given lighting unit may have any one of a variety of mounting arrangements for the light source(s), enclosure/housing arrangements and shapes, and/or electrical and mechanical connection configurations. Additionally, a given lighting unit optionally may be associated with (e.g., include, be coupled to and/or packaged together with) various other components (e.g., control circuitry) relating to the operation of the light source(s). An "LED-based lighting unit" refers to a lighting unit that includes one or more LED-based light sources as discussed above, alone or in combination with other non LED-based light sources.

The terms "processor" or "controller" are used herein interchangeably to describe various apparatus relating to the operation of one or more light sources. A processor or controller can be implemented in numerous ways, such as with dedicated hardware, using one or more microprocessors that are programmed using software (e.g., microcode) to perform the various functions discussed herein, or as a combination of dedicated hardware to perform some functions and programmed microprocessors and associated circuitry to perform other functions.

In various implementations, a processor or controller may be associated with one or more storage media (generically referred to herein as "memory," e.g., volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM, floppy disks, compact disks, optical disks, magnetic tape, etc.). In some implementations, the storage media may be encoded with one or more programs that, when executed on one or more processors and/or controllers, perform at least some of the functions discussed herein. Various storage media may be fixed within a processor or controller or may be transportable, such that the one or more programs stored thereon can be loaded into a processor or controller so as to implement various aspects of the present invention discussed herein. The terms "program" or "computer program" are used herein in a generic sense to refer to any type of computer code (e.g., software or microcode) that can be employed to program one or more processors or controllers.

The term "addressable" is used herein to refer to a device (e.g., a light source in general, a lighting unit or fixture, a controller or processor associated with one or more light sources or lighting units, other non-lighting related devices, etc.) that is configured to receive information (e.g., data) intended for multiple devices, including itself, and to selectively respond to particular information intended for it. The term "addressable" often is used in connection with a networked environment (or a "network," discussed further below), in which multiple devices are coupled together via some communications medium or media.

In one network implementation, one or more devices coupled to a network may serve as a controller for one or more other devices coupled to the network (e.g., in a master/slave relationship). In another implementation, a networked environment may include one or more dedicated controllers that are configured to control one or more of the devices coupled to the network. Generally, multiple devices coupled to the network each may have access to data that is present on the communications medium or media; however, a given device may be "addressable" in that it is configured to selectively exchange data with (i.e., receive data from and/or transmit data to) the network, based, for example, on one or more particular identifiers (e.g., "addresses") assigned to it.

The term "network" as used herein refers to any interconnection of two or more devices (including controllers or processors) that facilitates the transport of information (e.g. for device control, data storage, data exchange, etc.) between any two or more devices and/or among multiple devices coupled to the network. As should be readily appreciated, various implementations of networks suitable for interconnecting multiple devices may include any of a variety of network topologies and employ any of a variety of communication protocols. Additionally, in various networks according to the present invention, any one connection between two devices may represent a dedicated connection between the two systems, or alternatively a non-dedicated connection. In addition to carrying information intended for the two devices, such a non-dedicated connection may carry information not necessarily intended for either of the two devices (e.g., an open network connection). Furthermore, it should be readily appreciated that various networks of devices as discussed herein may employ one or more wireless, wire/cable, and/or fiber optic links to facilitate information transport throughout the network.

The term "user interface" as used herein refers to an interface between a human user or operator and one or more devices that enables communication between the user and the device(s). Examples of user interfaces that may be employed in various implementations of the present invention include, but are not limited to, switches, potentiometers, buttons, dials, sliders, a mouse, keyboard, keypad, various types of game controllers (e.g., joysticks), track balls, display screens, various types of graphical user interfaces (GUIs), touch screens, microphones and other types of sensors that may receive some form of human-generated stimulus and generate a signal in response thereto.

It should be appreciated the all combinations of the foregoing concepts and additional concepts discussed in greater detail below are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter appearing at the end of this disclosure are contemplated as being part of the inventive subject matter.

The following patents and patent applications are hereby incorporated herein by reference:

U.S. Pat. No. 6,016,038, issued Jan. 18, 2000, entitled "Multicolored LED Lighting Method and Apparatus;"

U.S. Pat. No. 6,211,626, issued Apr. 3, 2001 to Lys et al, entitled "Illumination Components,"

U.S. patent application Ser. No. 09/870,193, filed May 30, 2001, entitled "Methods and Apparatus for Controlling Devices in a Networked Lighting System;"

U.S. patent application Ser. No. 09/344,699, filed Jun. 25, 1999, entitled "Method for Software Driven Generation of Multiple Simultaneous High Speed Pulse Width Modulated Signals;"

U.S. patent application Ser. No. 09/805,368, filed Mar. 13, 2001, entitled "Light-Emitting Diode Based Products;"

U.S. patent application Ser. No. 09/663,969, filed Sep. 19, 2000, entitled "Universal Lighting Network Methods and Systems;"

U.S. patent application Ser. No. 09/716,819, filed Nov. 20, 2000, entitled "Systems and Methods for Generating and Modulating Illumination Conditions;"

U.S. patent application Ser. No. 09/675,419, filed Sep. 29, 2000, entitled "Systems and Methods for Calibrating Light Output by Light-Emitting Diodes;"

U.S. patent application Ser. No. 09/870,418, filed May 30, 2001, entitled "A Method and Apparatus for Authoring and Playing Back Lighting Sequences;"

U.S. patent application Ser. No. 10/045,629, filed Oct. 25, 2001, entitled "Methods and Apparatus for Controlling Illumination;"

U.S. patent application Ser. No. 10/143,549, filed May 10, 2002, entitled "Systems and Methods for Synchronizing Lighting Effects;"

U.S. patent application Ser. No. 10/158,579, filed May 30, 2002, entitled "Methods and Apparatus for Controlling Devices in a Networked Lighting System;"

U.S. patent application Ser. No. 10/325,635, filed Dec. 19, 2002, entitled "Controlled Lighting Methods and Apparatus;" and

U.S. patent application Ser. No. 10/360,594, filed Feb. 6, 2003, entitled "Controlled Lighting Methods and Apparatus."

BRIEF DESCRIPTION OF THE FIGURES

The following figures depict certain illustrative embodiments of the invention in which like reference numerals refer to like elements. These depicted embodiments are to be understood as illustrative of the invention and not as limiting in any way.

FIG. **1** illustrates exemplary operation of conventional A.C. dimming devices;

FIG. **2** illustrates a conventional implementation for providing power to an LED-based light source from an A.C. line voltage;

FIG. **3** illustrates a lighting unit including an LED-based light source according to one embodiment of the invention;

FIG. **4** is a circuit diagram illustrating various components of the lighting unit of FIG. **3**, according to one embodiment of the invention;

FIG. **5** illustrates a lighting unit including an LED-based light source according to another embodiment of the invention;

FIG. **6** is a circuit diagram illustrating various components of the lighting unit of FIG. **5**, according to one embodiment of the invention;

FIG. **7** is a block diagram of a processor-based lighting unit including an LED-based light source according to another embodiment of the invention;

FIG. **8** is a circuit diagram illustrating various components of the power circuitry for the lighting unit of FIG. **7**;

FIG. **9** is a circuit diagram illustrating a conventional current sink employed in driving circuitry for an LED-based light source, according to one embodiment of the invention;

FIG. **10** is a circuit diagram illustrating an improved current sink, according to one embodiment of the invention; and

FIG. **11** is a circuit diagram illustrating an improved current sink, according to another embodiment of the invention.

DETAILED DESCRIPTION

1. Overview

Light Emitting Diode (LED) based illumination sources are becoming more popular in applications where general, task, accent, or other lighting is desired. LED efficiencies, high intensities, low cost, and high level of controllability are driving demand for LED-based light sources as replacements for conventional non LED-based light sources.

While conventional A.C. dimming devices as discussed above often are employed to control conventional light sources such as incandescent lights using an A.C. power source, Applicants have recognized and appreciated that generally such dimmers are not acceptable for use with solid-state light sources such as LED-based light sources. Stated differently, Applicants have identified that LED-based light sources, which operate based on substantially D.C. power sources, generally are incompatible with dimmer circuits that provide A.C. output signals. This situation impedes convenient substitution of LED-based light sources into pre-existing lighting systems in which conventional light sources are operated via A.C. dimmer circuits.

There are some solutions currently for providing power to LED-based lighting systems via an A.C. line voltage, but these solutions suffer from significant drawbacks if applied to A.C. dimmer circuits. FIG. **2** illustrates one such generalized scenario, in which a standard A.C. line voltage **302** (e.g., 120 Vrms, 220 Vrms, etc.) is used to power an LED-based lighting system, such as a traffic light **808** (the traffic light includes three modules of LED arrays, one red, one yellow and one green, with associated circuitry). In the arrangement of FIG. **2**, a full-wave rectifier **802**, together with capacitors **800** and **806** and resistor **804**, filter the applied A.C. line voltage so as to supply a substantially D.C. source of power for the traffic light **808**. In particular, the capacitor **800** may be specifically selected, depending on the impedance of other circuit components, such that energy is passed to the traffic light based primarily on the expected frequency of the A.C. line voltage (e.g., 60 Hz).

One problem with the arrangement shown in FIG. **2** if the applied A.C. signal is provided by a dimmer circuit rather than as a line voltage is that the applied signal may include frequency components that are significantly different from the frequency of the line voltage for which the circuit was designed. For example, consider a dimmer circuit that provides a duty cycle-controlled (i.e., angle modulated) A.C. signal **309** such as that shown in FIG. **1**; by virtue of the abrupt signal excursions due to the "chopping-off" of portions of voltage cycles, signals of this type include significantly higher frequency components than a typical line voltage. Were such an angle modulated A.C. signal to be applied to the arrangement of FIG. **2**, the capacitor **800** would allow excess energy associated with these higher frequency components to pass through to the traffic light, in most cases causing fatal damage to the light sources.

In view of the foregoing, one embodiment of the present invention is directed generally to methods and apparatus for facilitating the use of LED-based light sources on A.C. power circuits that provide either a standard line voltage or that are controlled by conventional dimmers (i.e, "A.C. dimmer circuits"). In one aspect, methods and apparatus of the present invention facilitate convenient substitution of LED-based light sources in lighting environments employing conventional dimming devices and conventional light sources. In yet other aspects, methods and apparatus according to the present invention facilitate the control of one or more parameters relating to the light generated by LED-based light sources (e.g., intensity, color, color temperature, temporal characteristics, etc.) via operation of a conventional dimmer and/or other control signals that may be present in connection with an A.C. line voltage.

Lighting units and systems employing various concepts according to the principles of the present invention may be used in a residential setting, commercial setting, industrial setting or any other setting where conventional A.C. dimmers are found or are desirable. Furthermore, the various concepts disclosed herein may be applied in lighting units according to the present invention to ensure compatibility of the lighting units with a variety of lighting control protocols that provide various control signals via an A.C. power circuit.

One example of such a control protocol is given by the X10 communications language, which allows X10-compatible products to communicate with each other via existing electrical wiring in a home (i.e., wiring that supplies a standard A.C. line voltage). In a typical X10 implementation, an appliance to be controlled (e.g., lights, thermostats, jacuzzi/hot tub, etc.) is plugged into an X10 receiver, which in turn plugs into a conventional wall socket coupled to the A.C. line voltage. The appliance to be controlled can be assigned with a particular address. An X10 transmitter/controller is plugged into another wall socket coupled to the line voltage, and communicates control commands (e.g., on, off, dim, bright, etc.), via the same wiring providing the line voltage, to one or more X10 receivers based at least in part on the assigned address(es) (further information regarding X10 implementations may be found at the website "www.smarthome.com"). According to one embodiment, methods and apparatus of the present invention facilitate compatibility of various LED-based light sources and lighting units with X10 and other communication protocols that communicate control information in connection with an A.C. line voltage.

In general, methods and apparatus according to the present invention allow a substantially complete retrofitting of a lighting environment with solid state LED-based light sources; in particular, pursuant to the present invention, the use of LED-based light sources as substitutes for incandescent light sources is not limited to only those A.C. power circuits that are supplied directly from a line voltage (e.g., via a switch); rather, methods and apparatus of the present invention allow LED-based light sources to be used in most any conventional (e.g., incandescent) socket, including those coupled to an A.C. dimmer circuit and/or receiving signals other than a standard line voltage.

In various embodiments, an LED-based lighting unit or fixture according to the invention may include a controller to appropriately condition an A.C. signal provided by a dimmer circuit so as to provide power to (i.e., "drive") one or more LEDs of the lighting unit. The controller may drive the LED(s) using any of a variety of techniques, including analog control techniques, pulse width modulation (PWM) techniques or other power regulation techniques. Although not an essential feature of the present invention, in some embodiments the circuitry of the LED-based lighting unit may include one or more microprocessors that are programmed to carry out various signal conditioning and/or light control functions. In various implementations of both processor and non-processor based embodiments, an LED-based lighting unit according to the invention may be configured for operation on an A.C. dimmer circuit with or without provisions for allowing one or more parameters of generated light to be adjusted via user operation of the dimmer.

More specifically, in one embodiment, an LED-based lighting unit may include a controller wherein at least a portion of the power delivered to the controller, as derived from an A.C. dimmer circuit, is regulated at a substantially constant value over a significant range of dimmer operation so as to provide an essentially stable power source for the controller and other circuitry associated with the lighting unit. In one aspect of this embodiment, the controller also may be configured to monitor the adjustable power provided by the dimmer circuit so as to permit adjustment of one or more parameters of the light generated by the lighting unit in response to operation of the dimmer.

In particular, there are several parameters of light generated by an LED-based light source (other than, or in addition to, intensity or brightness, for example) that may be controlled in response to dimmer operation according to the present invention. For example, in various embodiments, an LED-based lighting unit may be configured such that one or more properties of the generated light such as color (e.g., hue, saturation or brightness), or the correlated color temperature of white light, as well as temporal parameters (e.g., rate of color variation or strobing of one or more colors) are adjustable via dimmer operation.

As discussed above, in one embodiment, an LED-based lighting unit may include one or more processor-based controllers, including one or more memory storage devices, to facilitate the foregoing and other examples of adjustable light generation via dimmer operation. In particular, in one embodiment, such a lighting unit may be configured to selectively execute, via dimmer operation, one or more lighting programs stored in controller memory. Such lighting programs may represent various static or time-varying lighting effects involving multiple colors, color temperatures, and intensities of generated light, for example. In one aspect of this embodiment, the processor-based controller of the lighting unit may be configured to monitor the A.C. signal provided by the dimmer circuit so as to select different programs and/or program parameters based on one or more changes in the monitored dimmer signal having a particular characteristic (e.g., a particular instantaneous value relating to the dimmer signal, a particular time averaged value relating to the dimmer signal, an interruption of power provided by the dimmer for a predetermined duration, a particular rate of change of the dimmer signal, etc). Upon the selection of a new program or parameter, further operation of the dimmer may adjust the selected parameter or program.

In another exemplary embodiment, an LED-based lighting unit according to the present invention may be configured to be coupled to an A.C. dimmer circuit and essentially recreate the lighting characteristics of a conventional incandescent light as a dimmer is operated to increase or decrease the intensity of the generated light. In one aspect of this embodiment, this simulation may be accomplished by simultaneously varying the intensity and the color of the light generated by the LED-based source in response to dimmer operation, so as to approximate the variable lighting characteristics of an incandescent source whose intensity is varied. In another aspect of this embodiment, such a simulation is facilitated by a processor-based controller particularly programmed to monitor an A.C. signal provided by the dimmer circuit and respectively control differently colored LEDs of the lighting unit in response to dimmer operation so as to simultaneously vary both the overall color and intensity of the light generated by the lighting unit.

While many of the lighting effects discussed herein are associated with dimmer compatible control, several effects may be generated according to the present invention using other control systems as well. For example, the color temperature of an LED-based light source may be programmed to reduce as the intensity is reduced and these lighting changes may be controlled by a system other than a dimmer system (e.g. wireless communication, wired communication and the like) according to various embodiments of the invention.

Another embodiment of the present invention is directed to a method for selling, marketing, and advertising of LED-based light sources and lighting systems. The method may include advertising an LED lighting system compatible with conventional A.C. dimmers or dimming systems. The method may also include advertising an LED light that is compatible with both dimmable and non-dimmable lighting control systems.

Following below are more detailed descriptions of various concepts related to, and embodiments of, methods and apparatus for providing power to LED-based lighting according to the present invention. It should be appreciated that various aspects of the invention, as discussed above and outlined further below, may be implemented in any of numerous ways, as the invention is not limited to any particular manner of implementation. Examples of specific implementations are provided for illustrative purposes only.

2. Non-processor Based Exemplary Embodiments

As discussed above, according to various embodiments, LED-based light sources capable of operation via A.C. dimmer circuits may be implemented with or without microprocessor-based circuitry. In this section, some examples are given of lighting units that include circuitry configured to appropriately condition A.C. signals provided by a dimmer circuit without the aid of a microprocessor or microcontroller. In the sections that follow, a number of processor-based examples are discussed.

FIG. **3** illustrates an LED-based lighting unit **200** according to one embodiment of the present invention. For purposes of illustration, the lighting unit **200** is depicted generally to resemble a conventional incandescent light bulb having a screw-type base connector **202** to engage mechanically and electrically with a conventional light socket. It should be appreciated, however, that the invention is not limited in this respect, as a number of other configurations including other housing shapes and/or connector types are possible according to other embodiments. Various examples of power connector configurations include, but are not limited to, screw-type connectors, wedge-type connectors, multi-pin type connectors, and the like, to facilitate engagement with conventional incandescent, halogen, fluorescent or high intensity discharge (HID) type sockets. Such sockets, in turn, may be connected directly to a source of A.C. power (e.g., line voltage), or via a switch and/or dimmer to the source of A.C. power.

The lighting unit **200** of FIG. **3** includes an LED-based light source **104** having one or more LEDs. The lighting unit also includes a controller **204** that is configured to receive an A.C. signal **500** via the connector **202** and provide operating power to the LED-based light source **104**. According to one aspect of this embodiment, the controller **204** includes various components to ensure proper operation of the lighting unit for A.C. signals **500** that are provided by a dimmer circuit and, more specifically, by a dimmer circuit that outputs duty cycle-controlled (i.e., angle modulated) A.C. signals as discussed above.

To this end, according to the embodiment of FIG. **3**, the controller **204** includes a rectifier **404**, a low pass (i.e., high frequency) filter **408** and a DC converter **402**. In one aspect of this embodiment, the output of the DC converter **402** provides an essentially stable DC voltage as a power supply for the LED-based light source **104**, regardless of user adjustments of the dimmer that provides the A.C. signal **500**.

More specifically, in this embodiment, the various components of the controller **204** facilitate operation of the lighting unit **200** on a dimmer circuit without providing for adjustment of the generated light based on dimmer operation; rather, the primary function of the controller **204** in the embodiment of FIG. **3** is to ensure that no damage is done to the LED-based light source based on deriving power from an A.C. dimmer circuit.

In particular, according to one aspect of this embodiment, an essentially constant DC power is provided to the LED-based light source as long as the dimmer circuit outputs an A.C. signal **500** that provides sufficient power to operate the controller **204**. In one implementation, the dimmer circuit may output an A.C. signal **500** having a duty cycle of as low as 50% "on" (i.e., conducting) that provides sufficient power to cause light to be generated by the LED-based light source **104**. In yet another implementation, the dimmer circuit may provide an A.C. signal **500** having a duty cycle of as low as 25% or less "on" that provides sufficient power to the light source **104**. In this manner, user adjustment of the dimmer over a significantly wide range does not substantially affect the light output of the lighting unit **200**. Again, the foregoing examples are provided primarily for purposes of illustration, as the invention is not necessarily limited in these respects.

FIG. **4** is an exemplary circuit diagram that illustrates some of the details of the various components shown in FIG. **3**, according to one embodiment of the invention. Again, one of the primary functions of the circuitry depicted in FIG. **4** is to ensure safe operation of the LED-based light source **104** based on an A.C. signal **500** provided to the lighting unit **200** via a conventional A.C. dimmer circuit. As shown in FIG. **4**, the rectifier **404** may be realized by a diode bridge (D**47**, D**48**, D**49** and D**50**), while the low pass filter is realized from the various passive components (capacitors C**2** and C**3**, inductor L**2**, and resistors R**4** and R**6**) shown in the figure. In this embodiment, the DC converter **402** is realized in part using the integrated circuit model number TNY264/266 manufactured by Power Integrations, Inc., 5245 Hellyer Avenue, San Jose, Calif. 95138 (www.powerint.com), and is configured to provide a 16 VDC supply voltage to power the LED-based light source **104**.

It should be appreciated that filter parameters (e.g., of the low pass filter shown in FIG. **4**) are significantly important to ensure proper operation of the controller **204**. In particular, the cutoff frequencies of the filter must be substantially less than a switching frequency of the DC converter, but substantially greater than the typical several cycle cutoff frequency employed in ordinary switch-mode power supplies. According to one implementation, the total input capacitance of the controller circuit is such that little energy remains in the capacitors at the conclusion of each half cycle of the AC waveform. The inductance similarly should be chosen to provide adequate isolation of the high frequency components created by the DC converter to meet regulatory requirements (under certain conditions this value may be zero). In yet other implementations, it may be advantageous to place all or part of the filter components ahead of the bridge rectifier **404**.

The light source **104** of FIG. **4** may include one or more LEDs (as shown for example as the LEDs D**52** and D**53** in FIG. **4**) having any of a variety of colors, and multiple LEDs may be configured in a variety of serial or parallel arrangements. Additionally, based on the particular configuration of the LED source **104**, one or more resistors or other components may be used in serial and/or parallel arrangements with the LED source **104** to appropriately couple the source to the DC supply voltage.

According to another embodiment of the invention, an LED-based light source not only may be safely powered by an A.C. dimmer circuit, but additionally the intensity of light generated by the light source may be adjusted via user operation of a dimmer that controls the A.C. signal provided by the dimmer circuit. FIG. **5** shows another example of a lighting unit **200**A, similar to the lighting unit shown in FIG. **3**, that is suitable for operation via a dimmer circuit. Unlike the lighting unit shown in FIG. **3**, however, the lighting unit **200**A of FIG. **5** is configured to have an adjustable light output that may be controlled via a dimmer. To this end, the controller **204**A shown in FIG. **5** includes an additional adjustment circuit **208** that further conditions a signal output from the DC converter **402**. The adjustment circuit **208** in turn provides a variable drive signal to the LED-based light source **104**, based on variations in the A.C. signal **500** (e.g., variations in the average voltage of the signal) in response to user operation of the dimmer.

FIG. **6** is an exemplary circuit diagram that illustrates some of the details of the various components shown in FIG. **5**, according to one embodiment of the invention. Many of the circuit elements shown in FIG. **6** are similar or identical to those shown in FIG. **4**. The additional adjustment circuit **208** is implemented in FIG. **6** in part by the resistors R**2** and R**6** which form a voltage divider in the feedback loop of the integrated circuit U**1**. A control voltage **410** is derived at the junction of the resistors R**2** and R**6**, which control voltage varies in response to variations in the A.C. signal **500** due to dimmer operation. The control voltage **410** is applied via diode D**5** to a voltage-to-current converter implemented by resistor R**1** and transistor Q**1**, which provide a variable drive current to the LED-based light source **104** that tracks adjustments of the dimmer's user interface. In this manner, the intensity of the light generated by the light source **104** may be varied via the dimmer over a significant range of dimmer operation. Of course, it should be appreciated that if the dimmer is adjusted such that the A.C. signal **500** is no longer capable of providing adequate power to the associated circuitry, the light source **104** merely ceases to produce light.

It should be appreciated that in the circuit of FIG. **6**, the control voltage **410** is essentially a filtered, scaled, maximum limited version of average DC voltage fed to the DC converter. This circuit relies on the DC converter to substantially discharge the input capacitors each half cycle. In practice this is easily achieved because input current to the controller stays fairly constant or increases as the duty cycle of the signal **500** is reduced, so long as device output does not decrease faster than the control voltage.

3. Processor-based Exemplary Embodiments

According to other embodiments of the invention, an LED-based lighting unit suitable for operation via an A.C. dimmer circuit may be implemented using a processor-based controller. Below, an embodiment of an LED-based lighting unit including a processor is presented, including a discussion of how such a lighting unit may be particularly configured for operation via an A.C. dimmer circuit. For example, in addition to a microprocessor, such a processor-based lighting unit also may include, and/or receive signal(s) from, one or more other components associated with the microprocessor to facilitate the control of the generated light based at least in part on user adjustment of a conventional A.C. dimmer. Once a processor-based control scheme is implemented in a lighting unit according to the present invention, a virtually limitless number of configurations are possible for controlling the generated light.

FIG. **7** shows a portion of an LED-based lighting unit **200**B that includes a processor-based controller **204**B according to one embodiment of the invention. Various examples of processor controlled LED-based lighting units similar to that described below in connection with FIG. **7** may be found, for example, in U.S. Pat. No. 6,016,038, issued Jan. 18, 2000 to Mueller et al., entitled "Multicolored LED Lighting Method and Apparatus," and U.S. Pat. No. 6,211,626, issued Apr. 3, 2001 to Lys et al, entitled "Illumination Components," which patents are both hereby incorporated herein by reference.

In one aspect, while not shown explicitly in FIG. **7**, the lighting unit **200**B may include a housing structure that is configured similarly to the other lighting units shown in FIGS. **3** and **5** (i.e., as a replacement for an incandescent bulb having a conventional screw-type connector). Again, however, it should be appreciated that the invention is not limited in this respect; more generally, the lighting unit **200**B may be implemented using any one of a variety of mounting arrangements for the light source(s), enclosure/housing arrangements and shapes to partially or fully enclose the light sources, and/or electrical and mechanical connection configurations.

As shown in FIG. **7**, the lighting unit **200**B includes one or more light sources **104**A, **104**B, and **104**C (shown collectively as **104**), wherein one or more of the light sources may be an LED-based light source that includes one or more light emitting diodes (LEDs). In one aspect of this embodiment, any two or more of the light sources **104**A, **104**B, and **104**C may be adapted to generate radiation of different colors (e.g. red, green, and blue, respectively). Although FIG. **7** shows three light sources **104**A, **104**B, and **104**C, it should be appreciated that the lighting unit is not limited in this respect, as different numbers and various types of light sources (all LED-based light sources, LED-based and non-LED-based light sources in combination, etc.) adapted to generate radiation of a variety of different colors, including essentially white light, may be employed in the lighting unit **200**B, as discussed further below.

As shown in FIG. **7**, the lighting unit **200**B also may include a processor **102** that configured to control drive circuitry **109** to drive the light sources **104**A, **104**B, and **104**C so as to generate various intensities of light from the light sources. For example, in one implementation, the processor **102** may be configured to output via the drive circuitry **109** at least one control signal for each light source so as to independently control the intensity of light generated by each light source. Some examples of control signals that may be generated by the processor and drive circuitry to control the light sources include, but are not limited to, pulse modulated signals, pulse width modulated signals (PWM), pulse amplitude modulated signals (PAM), pulse code modulated signals (PCM) analog control signals (e.g., current control signals, voltage control signals), combinations and/or modulations of the foregoing signals, or other control signals.

In one implementation of the lighting unit **200**B, one or more of the light sources **104**A, **104**B, and **104**C shown in FIG. **7** may include a group of multiple LEDs or other types of light sources (e.g., various parallel and/or serial connections of LEDs or other types of light sources) that are controlled together by the processor **102**. Additionally, it should be appreciated that one or more of the light sources **104**A, **104**B, and **104**C may include one or more LEDs that are adapted to generate radiation having any of a variety of spectra (i.e., wavelengths or wavelength bands), including, but not limited to, various visible colors (including essentially white light), various color temperatures of white light, ultraviolet, or infrared. LEDs having a variety of spectral bandwidths (e.g., narrow band, broader band) may be employed in various implementations of the lighting unit **200**B.

In another aspect of the lighting unit **200**B shown in FIG. **7**, the lighting unit may be constructed and arranged to produce a wide range of variable color radiation. For example, the lighting unit **200**B may be particularly arranged such that the processor-controlled variable intensity light generated by two or more of the light sources combines to produce a mixed colored light (including essentially white light having a variety of color temperatures). In particular, the color (or color temperature) of the mixed colored light may be varied by varying one or more of the respective intensities of the light sources (e.g., in response to one or more control signals output by the processor and drive circuitry). Furthermore, the processor **102** may be particularly configured (e.g., programmed) to provide control signals to one or more of the light sources so as to generate a variety of static or time-varying (dynamic) multi-color (or multi-color temperature) lighting effects.

Thus, the lighting unit **200**B may include a wide variety of colors of LEDs in various combinations, including two or more of red, green, and blue LEDs to produce a color mix, as well as one or more other LEDs to create varying colors and color temperatures of white light. For example, red, green and blue can be mixed with amber, white, UV, orange, IR or other colors of LEDs. Such combinations of differently colored LEDs in the lighting unit **200**B can facilitate accurate reproduction of a host of desirable spectrums of lighting conditions, examples of which includes, but are not limited to, a variety of outside daylight equivalents at different times of the day, various interior lighting conditions, lighting conditions to simulate a complex multicolored background, and the like. Other desirable lighting conditions can be created by removing particular pieces of spectrum that may be specifically absorbed, attenuated or reflected in certain environments.

As shown in FIG. **7**, the lighting unit **200**B also may include a memory **114** to store various information. For example, the memory **114** may be employed to store one or more lighting programs for execution by the processor **102** (e.g., to generate one or more control signals for the light sources), as well as various types of data useful for generating variable color radiation (e.g., calibration information). The memory **114** also may store one or more particular identifiers (e.g., a serial number, an address, etc.) that may be used either locally or on a system level to identify the lighting unit **200**B. In various embodiments, such identifiers may be pre-programmed by a manufacturer, for example, and may be either alterable or non-alterable thereafter (e.g., via some type of user interface located on the lighting unit, via one or more data or control signals received by the lighting unit, etc.). Alternatively, such identifiers may be determined at the time of initial use of the lighting unit in the field, and again may be alterable or non-alterable thereafter.

In another aspect, as also shown in FIG. **7**, the lighting unit **200**B optionally may be configured to receive a user interface signal **118** that is provided to facilitate any of a number of user-selectable settings or functions (e.g., generally controlling the light output of the lighting unit **200**B, changing and/or selecting various pre-programmed lighting effects to be generated by the lighting unit, changing and/or selecting various parameters of selected lighting effects, setting particular identifiers such as addresses or serial numbers for the lighting unit, etc.). In one embodiment of the invention discussed further below, the user interface signal **118** may be derived from an A.C. signal provided by a dimmer circuit and/or other control signal(s) on an A.C. power circuit, so that the light generated by the light source **104** may be controlled in response to dimmer operation and/or the other control signal(s).

More generally, in one aspect of the embodiment shown in FIG. **7**, the processor **102** of the lighting unit **200**B is configured to monitor the user interface signal **118** and control one or more of the light sources **104**A, **104**B, and **104**C based at least in part on the user interface signal. For example, the processor **102** may be configured to respond to the user interface signal by originating one or more control signals (e.g., via the drive circuitry **109**) for controlling one or more of the light sources. Alternatively, the processor **102** may be configured to respond by selecting one or more pre-programmed control signals stored in memory, modifying control signals generated by executing a lighting program, selecting and executing a new lighting program from memory, or otherwise affecting the radiation generated by one or more of the light sources.

To this end, the processor **102** may be configured to use any one or more of several criteria to "evaluate" the user interface signal **118** and perform one or more functions in response to the user interface signal. For example, the processor **102** may be configured to take some action based on a particular instantaneous value of the user interface signal, a change of some characteristic of the user interface signal, a rate of change of some characteristic of the user interface signal, a time averaged value of some characteristic of the user interface signal, periodic patterns or interruptions of the user interface signal having particular durations, zero-crossings of an A.C. user interface signal, etc.

In one embodiment, the processor is configured to digitally sample the user interface signal **118** and process the samples according to some predetermined criteria to determine if one or more functions need to be performed. In yet another embodiment, the memory **114** associated with the processor **102** may include one or more tables or, more generally, a database, that provides a mapping of values relating to the user interface signal to values for various control signals used to control the LED-based light source **104** (e.g., a particular value or condition associated with the user interface signal may correspond to particular duty cycles of PWM signals respectively applied to differently colored LEDs of the light source). In this manner, a wide variety of lighting control functions may be performed based on the user interface signal.

FIG. **7** also illustrates that the lighting unit **200**B may be configured to receive one or more signals **122** from one or more other signal sources **124**. In one implementation, the processor **102** of the lighting unit may use the signal(s) **122**, either alone or in combination with other control signals (e.g., signals generated by executing a lighting program, user interface signals, etc.), so as to control one or more of the light sources **104**A, **104**B and **104**C in a manner similar to that discussed above in connection with the user interface. Some examples of a signal source **124** that may be employed in, or used in connection with, the lighting unit **200**B of FIG. **7** include any of a variety of sensors or transducers that generate one or more signals **122** in response to some stimulus. Examples of such sensors include, but are not limited to, various types of environmental condition sensors, such as thermally sensitive (e.g., temperature, infrared) sensors, humidity sensors, motion sensors, photosensors/light sensors (e.g., sensors that are sensitive to one or more particular spectra of electromagnetic radiation), various types of cameras, sound or vibration sensors or other pressure/force transducers (e.g., microphones, piezoelectric devices), and the like.

As also shown in FIG. **7**, the lighting unit **200**B may include one or more communication ports **120** to facilitate coupling of the lighting unit to any of a variety of other devices. For example, one or more communication ports **120** may facilitate coupling multiple lighting units together as a networked lighting system, in which at least some of the lighting units are addressable (e.g., have particular identifiers or addresses) and are responsive to particular data transported across the network.

In particular, in a networked lighting system environment, as data is communicated via the network, the processor **102** of each lighting unit coupled to the network may be configured to be responsive to particular data (e.g., lighting control commands) that pertain to it (e.g., in some cases, as dictated by the respective identifiers of the networked lighting units). Once a given processor identifies particular data intended for it, it may read the data and, for example, change the lighting conditions produced by its light sources according to the received data (e.g., by generating appropriate control signals to the light sources). In one aspect, the memory **114** of each lighting unit coupled to the network may be loaded, for example, with a table of lighting control signals that correspond with data the processor **102** receives. Once the processor **102** receives data from the network, the processor may consult the table to select the control signals that correspond to the received data, and control the light sources of the lighting unit accordingly.

In one aspect of this embodiment, the processor **102** of a given lighting unit, whether or not coupled to a network, may be configured to interpret lighting instructions/data that are received in a DMX protocol (as discussed, for example, in U.S. Pat. Nos. 6,016,038 and 6,211,626), which is a lighting command protocol conventionally employed in the lighting industry for some programmable lighting applications. However, it should be appreciated that lighting units suitable for purposes of the present invention are not limited in this respect, as lighting units according to various embodiments may be configured to be responsive to other types of communication protocols so as to control their respective light sources.

The lighting unit **200**B of FIG. **7** also includes power circuitry **108** that is configured to derive power for the lighting unit based on an A.C. signal **500** (e.g., a line voltage, a signal provided by a dimmer circuit, etc.). In one implementation of the lighting unit **200**B, the power circuitry **108** may be configured similarly to portions of the circuits shown in FIGS. **4** and **6**, for example. In particular, FIG. **8** illustrates one exemplary circuit arrangement for the power circuitry **108**, based on several of the elements shown in FIGS. **4** and **6**, that may be employed in one implementation of the lighting unit **200**B. In the circuit shown in FIG. **8**, a 5 Volt DC output **900** is provided for at least the processor **102**, whereas a 16 Volt DC output **902** is provided for the drive circuitry **109**, which ultimately provides power to the LED-based light source **104**. Like the circuits shown in FIGS. **4** and **6**, it should be appreciated that as the overall power provided by the A.C. signal **500** is reduced due to operation of a dimmer, for example, at some point the power circuitry **108** will be unable to provide sufficient power to the various components of the lighting unit **200**B and it will cease to generate light. Nonetheless, in one aspect, the power circuitry **108** is configured to provide sufficient power to the lighting unit over a significant range of dimmer operation.

According to another embodiment of the invention, the power circuitry **108** shown in FIG. **8** may be modified to also provide a control signal that reflects variations in the A.C. signal **500** (e.g., changes in the average voltage) in response to dimmer operation. For example, the circuit of FIG. **8** may be modified to include additional components similar to those shown in connection with the adjustment circuit **208** of FIG. **6** which provide the control voltage **410** (e.g., a resistor divider network in the opto-isolator feedback loop). A control signal similarly derived from the circuit of FIG. **8** may serve as the user interface signal **118** applied to the processor **102**, as indicated by the dashed line **410**B shown in FIG. **7**. In other embodiments, the circuit of FIG. **8** may be modified so as to derive a control/user interface signal from other portions of the circuitry, such as an output of the rectifier or low pass filter, for example.

In yet another embodiment, the user interface signal **118** provided to the processor **102** may be the A.C. signal **500** itself, as indicated in FIG. **7** by the connections **500**B. In this embodiment, the processor **102** may be particularly programmed to digitally sample the A.C. signal **500** and detect changes in one or more characteristics of the A.C. signal (e.g., amplitude variations, degree of angle modulation, etc.). In this manner, rather than respond to a control signal that is derived based on variations of an average voltage of the A.C. signal **500** due to dimmer operation, the processor may respond to dimmer operation by "more directly" monitoring some characteristic (e.g., the degree of angle modulation) of the A.C. dimmer output signal. A number of techniques readily apparent to those skilled in the art, some of which were discussed above in connection with the user interface signal **1118**, may be similarly implemented by the processor to sample and process the A.C. signal **500**.

Once a user interface signal **118** that represents dimmer operation is derived using any of the techniques discussed above (or other techniques), the processor **102** may be programmed to implement any of a virtually limitless variety of light control functions based on user adjustment of the dimmer. For example, user adjustment of a dimmer may cause the processor to change one or more of the intensity, color, correlated color temperature, or temporal qualities of the light generated by the lighting unit **200**B.

To more specifically illustrate the foregoing, consider the lighting unit **200**B configured with two lighting programs stored in the memory **114**; the first lighting program is configured to allow adjustment of the overall color of the generated light in response to dimmer operation, and the second lighting program is configured to allow adjustment of the overall intensity of the generated light, at a given color, in response to dimmer operation. Moreover, the processor is programmed such that a particular type of dimmer operation toggles between the two programs, and such that on initial power-up, one of the two programs (e.g., the first program) is automatically executed as a default.

In this example, on power up, the first program (e.g., adjustable color) begins executing, and a user may change the overall color of the generated light by operating the dimmer user interface in a "normal" fashion over some range of adjustment (e.g., the color may be varied through a rainbow of colors from red to blue with gradual adjustment of the dimmer's user interface).

Once arriving at a desirable color, the user may then select the second program (e.g., adjustable intensity) for execution by operating the dimmer user interface in some particular predetermined manner (e.g., instantaneously interrupting the power for a predetermined period via an on/off switch incorporated with the dimmer, adjusting the dimmer's user

interface at a quick rate, etc.). As discussed above in connection with user interface signal concepts, any number of criteria may be used to evaluate dimmer operation and determine if a new program selection is desired, or if adjustment of a currently executing program is desired. Various examples of program or mode selection via a user interface, as well as parameter adjustment within a selected program or mode, are discussed in U.S. Non-provisional application Ser. No. 09/805,368 and U.S. Non-provisional application Ser. No. 10/045,629, incorporated herein by reference.

In this example, once the second program begins to execute, the user may change the intensity of the generated light (at the previously adjusted color) by subsequent "normal" operation (e.g., gradual adjustment) of the dimmer's user interface. Using the foregoing exemplary procedure, the user may adjust both the intensity and the color of the light emitted from the lighting unit via a conventional A.C. dimmer.

It should be appreciated that the foregoing example is provided primarily for purposes of illustration, and that the invention is not limited in these respects. In general, according to various embodiments of the invention, multiple parameters relating to the generated light may be changed in sequence, or simultaneously in combination. Also, via selection and execution of a lighting program, temporal characteristics of the generated light also may be adjusted (e.g., rate of strobing of a given color, rate of change of a rainbow wash of colors, etc.).

For example, in one embodiment, an LED-based light source coupled to an A.C. dimmer circuit may be configured to essentially recreate the lighting characteristics of a conventional incandescent light as a dimmer is operated to increase or decrease the intensity of the generated light. In one aspect of this embodiment, this simulation may be accomplished by simultaneously varying the intensity and the color of the light generated by the LED-based source via dimmer operation.

More specifically, in conventional incandescent light sources, the color temperature of the light emitted generally reduces as the power dissipated by the light source is reduced (e.g., at lower intensity levels, the correlated color temperature of the light produced may be near 2000K, while the correlated color temperature of the light at higher intensities may be near 3200K). This is why an incandescent light tends to appear redder as the power to the light source is reduced. Accordingly, in one embodiment, an LED-based lighting unit may be configured such that a single dimmer adjustment may be used to simultaneously change both the intensity and color of the light source so as to produce a relatively high correlated color temperature at higher intensities (e.g. when the dimmer provides essentially "full" power) and produce lower correlated color temperatures at lower intensities, so as to mimic an incandescent source.

Another embodiment of the present invention is directed to a flame simulation control system, or other simulation control system. The system may include an LED-based light source or lighting unit arranged to produce flame effects or simulations. Such a flame simulation system may be used to replace more conventional flame simulation systems (e.g. incandescent or neon). The flame simulation lighting device may be configured (e.g., include a lighting program) for altering the appearance of the generated light to simulate wind blowing through the flame or random flickering effects to make the simulation more realistic. Such a simulation system may be associated with a user interface to control the effects, and also may be configured to be adapted for use and/or controlled via an A.C. dimmer circuit (e.g., a dimmer control system may be used to change the effects of the simulation system). In other implementations, the user interface may communicate to the simulation device through wired or wireless communication and a user may be able to alter the effects of the device through the user interface. The simulation device may include an effect that can be modified for rate of change, intensity, color, flicker rate, to simulate windy conditions, still conditions, moderate conditions or any other desirable modification.

Many lighting control systems do not include dimmer circuits where dimming and other alterable lighting effects would be desirable. Accordingly, yet another embodiment of the present invention is directed to a lighting effect control system including a wireless control system. According to this embodiment, an LED-based light source or lighting unit may be adapted to receive wireless communications to effect lighting changes in the lighting system (e.g., see FIG. **7** in connection with communication link **120**). A wireless transmitter may be used by a user to change the lighting effects generated by the lighting system. In one implementation, the transmitter is associated with a power switch for the control system. For example, the power switch may be a wall mounted power switch and a user interface may be associated with the wall-mounted switch. The user interface may be used to generate wireless communication signals that are communicated to the lighting system to cause a change in the light emitted. In another embodiment, the signals are communicated to the lighting system over the power wires in a multiplexed fashion where the light decodes the data from the power.

Yet another embodiment of the invention is directed to methods and apparatus for communicating control information to one or more lighting devices, as well as other devices that typically are powered via a standard A.C. line voltage, by using a portion of the duty cycle of the line voltage to communicate the control information. For example, according to one embodiment, a supply voltage controller is configured to receive a standard A.C. line voltage as an input, and provide as an output a power signal including control information. The power signal provides an essentially constant A.C. power source; however, according to one aspect of this embodiment, the signal periodically is "interrupted" (e.g., a portion of the AC duty cycle over a period of cycles is removed) to provide one or more communication channels over which control information (e.g., digitally encoded information) may be transmitted to one or more devices coupled to the power signal. The device(s) coupled to the power signal may be particularly configured to be responsive in some way to such control information.

For example, it should be appreciated that the various LED-based lighting units disclosed herein, having the capability to provide power to LED-based light sources from a standard A.C. line voltage, an A.C. dimmer circuit (e.g., providing an angle modulated power source), or from a power source in which other control signals may be present in connection with an A.C. line voltage, may be particularly configured to be compatible with the power signal described above and responsive to the control information transmitted over the communication channel.

According to one aspect of this embodiment, a supply voltage controller to provide a power signal as discussed above may be implemented as a processor-based user interface, including any number of features (e.g., buttons, dials, sliders, etc.) to facilitate user operation of the controller. In particular, in one implementation, the supply voltage controller may be implemented to resemble a conventional dimmer (e.g., having a knob or a slider as a user interface), in which an associated processor is particularly programmed to monitor operation of the user interface and generate control information in response to such operation. The processor also is programmed to transmit the control information via one or more communication channels of the power signal, as discussed above.

In other aspects of this embodiment, unlike currently available home control networks/systems such as X10, the device(s) being controlled by the power signal essentially are defined by the electrical wiring that provides the power signal, rather than by programming or addresses assigned to the device(s). Additionally, other "non-controllable" devices (i.e., not configured to be responsive to the control information transported on the power signal) may be coupled to the power signal without any detrimental effect, and allow for a mix of controllable and non-controllable devices on the same power circuit (i.e., delivering the same power signal to all devices on the circuit). Moreover, devices in different wiring domains (i.e., on different power circuits) are guaranteed through topology not to interfere with, or be responsive to, the power signal on a particular power circuit. In yet another aspect, the power signal of this embodiment is essentially "transparent" to (i.e., does not interfere with) other protocols such as X10.

In one exemplary implementation based on a supply voltage controller providing a power signal as discussed above on a given power circuit, a number of lighting devices (e.g., conventional lighting devices, LED-based lighting units, etc) may be coupled to the power circuit and configured such that they are essentially non-responsive to any control information transmitted on the power circuit. For example, the "non-responsive" lighting devices may be conventional incandescent light sources or other devices that receive power via the portion of the power signal that does not include the communication channel. These lighting devices may serve in a given environment to provide general illumination in the environment.

In addition to the non-responsive lighting devices in this example, one or more other controllable lighting devices (e.g., particularly configured LED-based lighting units) also may be coupled to the same power circuit and configured to be responsive to the control information in the communication channel of the power signal (i.e., responsive to user operation of the supply voltage controller). In this manner, the controllable lighting device(s) may provide various types of accent/special effects lighting to complement the general illumination provided by the other "non-responsive" devices on the same power circuit.

4. Exemplary Drive Circuit Embodiments

With reference again to FIG. **7**, the drive circuitry **109** of the lighting unit **200**B may be implemented in numerous ways, one of which employs one or more current drivers respectively corresponding to the one or more light sources **104**A, **104**B and **104**C (collectively **104**). In particular, according to one embodiment, the drive circuitry **109** is configured such that each differently colored light source is associated with a voltage to current converter that receives a voltage control signal (e.g., a digital PWM signal) from the processor **102** and provides a corresponding current to energize the light source. Such a driver circuit is not limited to implementations of lighting units that are particularly configured for operation via an A.C. dimmer circuit; more generally, lighting units similar to the lighting unit **200**B and configured for use with various types of power sources (e.g, A.C. line voltages, A.C. dimmer circuits, D.C. power sources) may employ driver circuitry including one or more voltage to current converters.

FIG. **9** illustrates one example of a portion of the driver circuitry **109** employing a conventional voltage to current converter, also referred to as a "current sink" **910**. As shown in FIG. **9**, the current sink **910** receives a digital input control signal from the processor **102** and provides a current I_A to drive the light source **104**A. It should be appreciated that, according to one embodiment, multiple light sources are included in the lighting unit, and that the driver circuitry **109** includes circuitry similar to that shown in FIG. **9** for each light source (wherein the processor provides one control signal for each current sink).

The current sink **910** illustrated in FIG. **9** is widely used for control of current in various applications, and is discussed in many popular textbooks (e.g., see Intuitive IC OPAMPS, Thomas M. Frederiksen, 1984, pages 186–189). The operational amplifier based current sink of FIG. **9** functions to maintain the voltage at the node "A" (i.e., across the resistor R**6**) and the "reference" voltage at the node "C" (at the non-inverting input of the operational amplifier U**1**A) at the same value. In this manner, the light source current I_A is related to (i.e., tracks) the digital control signal provided by the processor **102**.

The reference voltage at the point "C" in FIG. **9** may be developed in a variety of ways, and the Frederiksen text referenced above suggests that a resistor divider (e.g., R**2** and R**5**) is a good method of creating this voltage. Generally, the reference voltage is chosen by a designer of the circuit as a compromise; on one hand, the voltage should be as low as possible, to reduce the burden voltage (i.e. the lowest voltage at which the current I_A is maintained) of the current sink. On the other hand, lowering the reference voltage increases the circuit error, due to various sources, including: 1) the offset voltage of the op-amp; 2) differences in the input bias currents of the op-amp; 3) poor tolerances of low value resistors; and 4) errors in sensing small voltages due to voltage drops across component interconnections. Lowering the reference voltage also decreases the speed of the circuit, because feedback to the op-amp is reduced. This situation can also lead to instabilities in the circuit.

The reference voltage at the point "C" in FIG. **9** need not be constant, and it may be switched between any desired voltages to generate different currents. In particular, a pulse width modulated (PWM) digital control voltage may be applied to the circuit from the processor **102**, to generate a switched current I_A. Through careful selection of resistor values for the voltage divider formed by resistors R**2** and R**5**, various circuit goals may be achieved, including the matching of op-amp bias currents.

One issue with the circuit shown in FIG. **9** is that when the digital control signal from the processor is not present or off (e.g., at zero volts), the operational amplifier U**1**A may not turn the transistor M**1** fully off. As a result, some current I_A may still flow through the light source **104**A, even though the light source is intended to be off. In view of the foregoing, one embodiment of the present invention is directed to drive circuitry for LED-based light sources that incorporates an improved current sink design to ensure more accurate control of the light sources.

FIG. **10** illustrates one example of such an improved current sink **910**A according to one embodiment of the invention. The current sink **910**A is configured such that there is a known "error voltage" at the node "B" (e.g., the inverting input of the operational amplifier U**1**A), through the use of resistors R**4** and R**1**. In particular, the values of resistors R**4** and R**1** are selected so as to slightly increase the voltage at the node "B" as compared to the arrangement shown in FIG. **9**. As a result, when the reference voltage at the node "C" is zero (i.e., when the digital control signal is such that the light source **104**A is intended to be off), the voltage at the node "B" is slightly above that at the node "C". This voltage difference forces the op-amp to drive its output low, which hence drives transistor M**1** well into its "off" region and avoids any inadvertent flow of the current I_A.

The small known error voltage introduced at the node "B" does not necessarily result in any increase in current error. In one embodiment, the values of resistors R**2** and R**5** may be adjusted to compensate for the effects of the error voltage. For example, resistors R**4** and R**1** may be selected to result in 20 mV at the node "B" when the node "C" is at zero volts (such that the OP AMP is in the "off" state). In the "on" state, the circuit may be configured such that there is approximately 5 mV of sense voltage at the node "A" (across the resistor R**6**). The error voltage is added to the desired sense resistor voltage, and the values of resistors R**2** and R**5** are appropriately selected to result in a 25 mV reference voltage at the node "C" in the presence of a digital control signal indicating an "on" state. In one embodiment, the circuit may be configured such that the output current I_A and sense voltage at node "A" may be much greater than the minimums, for various reasons, but most notably because lower cost op-amps may be used to achieve 1% accuracy if the sense voltage is increased to the 300–700 mV range.

FIG. **11** shows yet another embodiment of a current sink **910**B, in which several optional components are added to the circuit of FIG. **10**, which increase the speed and current capability of the circuit. In particular, as the size of transistor M**1** is increased towards larger currents, capacitor C**1** and resistor R**3** may be added to compensate for the larger capacitance of M**1**. This capacitance presents a large load to the op-amp, and for many op-amp designs, this can cause instability. Resistor R**3** lowers the apparent load presented by M**1**, and C**1** provides a high frequency feedback path for the op-amp, which bypasses M**1**. In one aspect of this embodiment, the circuit impedance at nodes "B" and "C" may be matched, to reduce the effects of op-amp bias current. In another embodiment this matching may be avoided by using modern FET input op-amps.

Having thus described several illustrative embodiments of the invention, various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be within the spirit and scope of the invention. While some examples presented herein involve specific combinations of functions or structural elements, it should be understood that those functions and elements may be combined in other ways according to the present invention to accomplish the same or different objectives. In particular, acts, elements and features discussed in connection with one embodiment are not intended to be excluded from a similar or other roles in other embodiments. Accordingly, the foregoing description is by way of example only, and is not intended as limiting.

The invention claimed is:

1. An illumination apparatus, comprising:

at least one LED; and

at least one controller coupled to the at least one LED and configured to receive a power-related signal from an alternating current (A.C.) power source that provides signals other than a standard A.C. line voltage, the at least one controller further configured to provide power to the at least one LED based on the power-related signal,

wherein the A.C. power source is an A.C. dimmer circuit, and

wherein the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal, and wherein the at least one controller is configured to provide an essentially non-varying power to the at least one LED over a significant range of operation of the user interface.

2. The apparatus of claim **1**, wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the at least one controller is configured to provide the essentially non-varying power to the at least one LED over a significant range of operation of the user interface notwithstanding variations in the duty cycle of the power-related signal.

3. The apparatus of claim **1**, wherein the at least one controller comprises:

a rectifier to receive the power-related signal and provide a rectified power-related signal;

a low pass filter to filter the rectified power-related signal; and

a DC converter to provide the essentially non-varying power based on the filtered rectified power-related signal.

4. The apparatus of claim **1**, further comprising:

a screw-type power connector configured to engage mechanically and electrically with a conventional incandescent light socket so as to couple the apparatus to the A.C. dimmer circuit.

5. The apparatus of claim **4**, further comprising:

a housing, coupled to the screw-type power connector, to enclose the at least one LED and the at least one controller, the housing being structurally configured to resemble an incandescent light bulb.

6. The apparatus of claim **5**, wherein the at least one LED includes a plurality of differently colored LEDs.

7. An illumination apparatus, comprising:

at least one LED; and

at least one controller coupled to the at least one LED and configured to receive a power-related signal from an alternating current (A.C.) power source that provides signals other than a standard A.C. line voltage, the at least one controller further configured to provide power to the at least one LED based on the power-related signal,

wherein the A.C. power source is an A.C. dimmer circuit,

wherein the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal, and wherein the at least one controller is configured to variably control at least one parameter of light generated by the at least one LED in response to operation of the user interface, and

wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the at least one controller is configured to variably control the at least one parameter of the light based at least on the variable duty cycle of the power-related signal.

8. The apparatus of claim **7**, wherein the at least one parameter of the light that is variably controlled by the at least one controller in response to operation of the user interface includes at least one of an intensity of the light, a color of the light, a color temperature of the light, and a temporal characteristic of the light.

9. The apparatus of claim **7**, wherein the at least one controller is configured to variably control at least two different parameters of the light generated by the at least one LED in response to operation of the user interface.

10. The apparatus of claim **9**, wherein the at least one controller is configured to variably control at least an intensity and a color of the light simultaneously in response to operation of the user interface.

11. The apparatus of claim **9**, wherein the at least one LED is configured to generate an essentially white light, and wherein the at least one controller is configured to variably control at least an intensity and a color temperature of the white light simultaneously in response to operation of the user interface.

12. The apparatus of claim **11**, wherein the at least one controller is configured to variably control at least the intensity and the color temperature of the essentially white light in response to operation of the user interface so as to approximate light generation characteristics of an incandescent light source.

13. The apparatus of claim **12**, wherein the at least one controller is configured to variably control the color temperature of the essentially white light over a range from approximately 2000 degrees K at a minimum intensity to 3200 degrees K at a maximum intensity.

14. The apparatus of claim **12**, further comprising:

a screw-type power connector configured to engage mechanically and electrically with a conventional incandescent light socket so as to couple the apparatus to the A.C. dimmer circuit.

15. The apparatus of claim **14**, further comprising:

a housing, coupled to the screw-type power connector, to enclose the at least one LED and the at least one controller, the housing being structurally configured to resemble an incandescent light bulb.

16. The apparatus of claim **12**, wherein the at least one LED includes a plurality of differently colored LEDs.

17. An illumination apparatus, comprising:

at least one LED; and

at least one controller coupled to the at least one LED and configured to receive a power-related signal from an alternating current (A.C.) power source that provides signals other than a standard A.C. line voltage, the at least one controller further configured to provide power to the at least one LED based on the power-related signal,

wherein the A.C. power source is an A.C. dimmer circuit,

wherein the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal, and wherein the at least one controller is configured to variably control at least one parameter of light generated by the at least one LED in response to operation of the user interface, and

wherein the at least one controller includes:

an adjustment circuit to variably control the at least one parameter of light based on the varying power-related signal; and

power circuitry to provide at least the power to the at least one LED based on the varying power-related signal.

18. The apparatus of claim **17**, wherein the power circuitry includes: a rectifier to receive the power-related signal and provide a rectified power-related signal;

a low pass filter to filter the rectified power-related signal; and

a DC converter to provide the power to at least the at least one LED based on the filtered rectified power-related signal.

19. The apparatus of claim **18**, wherein the adjustment circuit is coupled to the DC converter and is configured to variably control the at least one LED based on the filtered rectified power-related signal.

20. The apparatus of claim **18**, wherein the adjustment circuit includes at least one processor configured to monitor at least one of the power-related signal, the rectified power-related signal, and the filtered rectified power-related signal so as to variably control the at least one LED.

21. The apparatus of claim **20**, wherein the power circuitry is configured to provide at least the power to the at least one LED and power to the at least one processor based on the varying power-related signal.

22. The apparatus of claim **20**, wherein the at least one processor is configured to sample the varying power-related signal and determine at least one varying characteristic of the varying power-related signal.

23. The apparatus of claim **20**, wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the at least one processor is configured to variably control the at least one parameter of the light based at least on the varying duty cycle of the power-related signal.

24. The apparatus of claim **23**, wherein the at least one LED includes a plurality of differently colored LEDs.

25. The apparatus of claim **24**, wherein:

the plurality of differently colored LEDs includes:

at least one first LED adapted to output at least first radiation having a first spectrum; and

at least one second LED adapted to output second radiation having a second spectrum different than the first spectrum; and

the at least one processor is configured to independently control at least a first intensity of the first radiation and a second intensity of the second radiation in response to operation of the user interface.

26. The apparatus of claim **25**, wherein the at least one processor is programmed to implement a pulse width modulation (PWM) technique to control at least the first intensity of the first radiation and the second intensity of the second radiation.

27. The apparatus of claim **26**, wherein the at least one processor further is programmed to:

generate at least a first PWM signal to control the first intensity of the first radiation and a second PWM signal to control the second intensity of the second radiation; and

determine duty cycles of the respective first and second PWM signals based at least in part on variations in the power-related signal due to operation of the user interface.

28. The apparatus of claim **17**, wherein the adjustment circuit includes drive circuitry including at least one voltage-to-current converter to provide at least one drive current to the at least one LED so as to control the at least one parameter of the generated light.

29. The apparatus of claim **28**, wherein the at least one voltage-to-current converter includes an operational amplifier configured so as to have a predetermined error voltage applied across its non-inverting and inverting inputs during operation to essentially reduce to zero a current output of the at least one voltage-to-current converter when a voltage applied to the at least one voltage-to-current converter is essentially zero.

30. An illumination method, comprising an act of:

A) providing power to at least one LED based on a power-related signal from an alternating current (A.C.) power source that provides signals other than a standard A.C. line voltage, wherein the act A) includes an act of:

providing power to the at least one LED based on a power-related signal from an alternating current (A.C.) dimmer circuit,

wherein the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal, and wherein the act A) comprises an act of:

B) providing an essentially non-varying power to the at least one LED over a significant range of operation of the user interface.

31. The method of claim **30**, wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the act B) includes an act of:

providing the essentially non-varying power to the at least one LED over a significant range of operation of the user interface notwithstanding variations in the duty cycle of the power-related signal.

32. The method of claim **30**, wherein the act B) includes acts of:

rectifying the power-related signal to provide a rectified power-related signal;

filtering the rectified power-related signal; and

providing the essentially non-varying power based on the filtered rectified power-related signal.

33. The method of claim **30**, wherein the at least one LED includes a plurality of differently colored LEDs.

34. An illumination method, comprising an act of:

A) providing power to at least one LED based on a power-related signal from an alternating current (A.C.) power source that provides signals other than a standard A.C. line voltage, wherein the act A) includes an act of:

providing power to the at least one LED based on a power-related signal from an alternating current (A.C.) dimmer circuit,

wherein the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal, and wherein the act A) includes an act of:

C) variably controlling at least one parameter of light generated by the at least one LED in response to operation of the user interface,

wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the act C) includes an act of:

D) variably controlling the at least one parameter of the light based at least on the variable duty cycle of the power-related signal.

35. The method of claim **34**, wherein the act D) includes an act of:

variably controlling at least one of an intensity of the light, a color of the light, a color temperature of the light, and a temporal characteristic of the light in response to operation of the user interface.

36. The method of claim **34**, wherein the act D) includes an act of:

E) variably controlling at least two different parameters of the light generated by the at least one LED in response to operation of the user interface.

37. The method of claim **36**, wherein the act E) includes an act of:

variably controlling at least an intensity and a color of the light simultaneously in response to operation of the user interface.

38. The method of claim **36**, wherein the at least one LED is configured to generate an essentially white light, and wherein the act E) includes an act of:

F) variably controlling at least an intensity and a color temperature of the white light simultaneously in response to operation of the user interface.

39. The method of claim **38**, wherein the act F) includes an act of:

G) variably controlling at least the intensity and the color temperature of the essentially white light in response to operation of the user interface so as to approximate light generation characteristics of an incandescent light source.

40. The method of claim **39**, wherein the act G) includes an act of:

variably controlling the color temperature of the essentially white light over a range from approximately 2000 degrees K at a minimum intensity to 3200 degrees K at a maximum intensity.

41. The method of claim **40**, wherein the at least one LED includes a plurality of differently colored LEDs.

42. An illumination method, comprising an act of:

A) providing power to at least one LED based on a power-related signal from an alternating current (A.C.) power source that provides signals other than a standard A.C. line voltage, wherein the act A) includes an act of:

providing power to the at least one LED based on a power-related signal from an alternating current (A.C.) dimmer circuit,

wherein the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal, and wherein the act A) includes an act of:

C) variably controlling at least one parameter of light generated by the at least one LED in response to operation of the user interface,

wherein the act C) includes an act of:

H) digitally sampling the varying power-related signal so as to determine at least one varying characteristic of the varying power-related signal.

43. The method of claim **42**, wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the act H) includes an act of:

variably controlling the at least one parameter of the light based at least on the varying duty cycle of the sampled power-related signal.

44. An illumination method, comprising an act of:

A) providing power to at least one LED based on a power-related signal from an alternating current (A.C.) power source that provides signals other than a standard A.C. line voltage, wherein the act A) includes an act of:

providing power to the at least one LED based on a power-related signal from an alternating current (A.C.) dimmer circuit,

wherein the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal, and wherein the act A) includes an act of:

C) variably controlling at least one parameter of light generated by the at least one LED in response to operation of the user interface,

wherein:

the at least one LED includes:

at least one first LED adapted to output at least first radiation having a first spectrum; and

at least one second LED adapted to output second radiation having a second spectrum different than the first spectrum; and

the act C) includes an act of:

I) independently controlling at least a first intensity of the first radiation and a second intensity of the second radiation in response to operation of the user interface.

45. The method of claim **44**, wherein the act I) includes an act of:

J) implementing a pulse width modulation (PWM) technique to control at least the first intensity of the first radiation and the second intensity of the second radiation.

46. The method of claim **45**, wherein the act J) includes acts of:

generating at least a first PWM signal to control the first intensity of the first radiation and a second PWM signal to control the second intensity of the second radiation; and

determining duty cycles of the respective first and second PWM signals based at least in part on variations in the power-related signal due to operation of the user interface.

47. An illumination apparatus, comprising:

at least one LED adapted to generate an essentially white light; and

at least one controller coupled to the at least one LED and confianred to receive a power-related signal from an alternating current (A.C.) dimmer circuit and provide power to the at least one LED based on the power-related signal,

wherein:

the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal; and

the at least one controller is configured to variably control at least one parameter of the essentially white light in response to operation of the user interface so as to approximate light generation characteristics of an incandescent light source,

wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the at least one controller is configured to variably control the at least one parameter of the essentially white light based at least on the variable duty cycle of the power-related signal.

48. The apparatus of claim **47**, further comprising:

a screw-type power connector configured to engage mechanically and electrically with a conventional incandescent light socket so as to couple the apparatus to the A.C. dimmer circuit; and

a housing, coupled to the screw-type power connector, to enclose the at least one LED and the at least one controller, the housing being structurally configured to resemble an incandescent light bulb.

49. The apparatus of claim **47**, wherein the at least one controller is configured to variably control at least an intensity and a color temperature of the essentially white light simultaneously in response to operation of the user interface.

50. The apparatus of claim **49**, wherein the at least one controller is configured to variably control the color temperature of the essentially white light over a range from approximately 2000 degrees K at a minimum intensity to 3200 degrees K at a maximum intensity.

51. The apparatus of claim **50**, wherein the at least one LED includes a plurality of differently colored LEDs.

52. The apparatus of claim **51**, wherein:

the plurality of differently colored LEDs includes:

at least one first LED adapted to output at least first radiation having a first spectrum; and

at least one second LED adapted to output second radiation having a second spectrum different than the first spectrum; and

the at least one controller is configured to independently control at least a first intensity of the first radiation and a second intensity of the second radiation in response to operation of the user interface.

53. The apparatus of claim **52**, wherein the at least one controller includes at least one microprocessor programmed to implement a pulse width modulation (PWM) technique to control at least the first intensity of the first radiation and the second intensity of the second radiation.

54. The apparatus of claim **52**, wherein the microprocessor further is programmed to:

generate at least a first PWM signal to control the first intensity of the first radiation and a second PWM signal to control the second intensity of the second radiation; and

determine duty cycles of the respective first and second PWM signals based at least in part on variations in the power-related signal due to operation of the user interface.

55. The apparatus of claim **54**, wherein the microprocessor further is programmed to monitor at least one signal representative of the variations in the power-related signal.

56. The apparatus of claim **54**, wherein the microprocessor further is programmed to directly sample the power-related signal so as to measure variations in the power-related signal.

57. An illumination apparatus, comprising:

at least one LED; and

at least one controller coupled to the at least one LED and configured to receive first power from an alternating current (A.C.) dimmer circuit, the A.C. dimmer circuit being controlled by a user interface to vary the first power, the at least one controller further configured to provide second power to the at least one LED based on the first power,

wherein:

the A.C. dimmer circuit includes a triac responsive to the user interface so as to variably control a duty cycle of an A.C. signal and thereby vary the first power; and

the at least one controller is configured to provide the second power as an essentially stable non-varying power to the at least one LED notwithstanding significant variations of the first power.

58. An illumination apparatus, comprising:

at least one LED; and

at least one controller coupled to the at least one LED and configured to receive first power from an alternating current (A.C.) dimmer circuit, the A.C. dimmer circuit being controlled by a user interface to vary the first power, the at least one controller further configured to provide second power to the at least one LED based on the first power,

wherein:

the A.C. dimmer circuit includes a triac responsive to the user interface so as to variably control a duty cycle of an A.C. signal and thereby vary the first power; and

the at least one controller is configured to provide the second power as a varying power to the at least one LED based on variations of the first power.

59. An illumination apparatus, compnsing:

at least one LED; and

at least one controller coupled to the at least one LED and configured to receive first power from an alternating current (A.C.) dimmer circuit, the A.C. dimmer circuit being controlled by a user interface to vary the first power, the at least one controller further configured to provide second power to the at least one LED based on the first power,

wherein:

the A.C. dimmer circuit includes a triac responsive to the user interface so as to variably control a duty cycle of an A.C. signal and thereby vary the first power; and

the at least one controller is configured to variably control at least one parameter of light generated by the at least one LED in response to operation of the user interface.

60. The illumination apparatus of claim **59**, wherein the at least one parameter of the light that is variably controlled by the at least one controller in response to operation of the user interface includes at least one of an intensity of the light, a color of the light, a color temperature of the light, and a temporal characteristic of the light.

61. The illumination apparatus of claim **60**, wherein the at least one LED includes a plurality of differently colored LEDs.

62. The illumination apparatus of claim **60**, wherein the at least one controller is configured to variably control at least an intensity and a color of the light simultaneously in response to operation of the user interface.

63. The illumination apparatus of claim **60**, wherein the at least one LED is configured to generate an essentially white light, and wherein the at least one controller is configured to variably control at least an intensity and a color temperature of the white light simultaneously in response to operation of the user interface.

64. The illumination apparatus of claim **63**, wherein the at least one LED includes a plurality of differently colored LEDs.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,038,399 B2 Page 1 of 1
APPLICATION NO. : 10/435687
DATED : May 2, 2006
INVENTOR(S) : Lys et al.

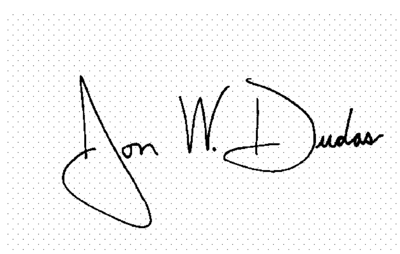
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In column 30, line 29, delete "confianed" and insert –configured--.

In column 32, line 14, delete "compnsing" and insert –comprising--.

Signed and Sealed this

Twenty-second Day of August, 2006



JON W. DUDAS
Director of the United States Patent and Trademark Office

Exhibit F

US007262559B2

(12) **United States Patent**
Tripathi et al.

(10) **Patent No.:** **US 7,262,559 B2**
(45) **Date of Patent:** **Aug. 28, 2007**

(54) **LEDS DRIVER**

(75) Inventors: **Ajay Tripathi**, Schaumburg, IL (US); **Bernd Clauberg**, Schaumburg, IL (US); **Young-Kee Min**, Elm Grove, WI (US); **Raghuram Narasimhan**, Lubbock, TX (US); **Rohit Khetarpal**, Lisle, IL (US)

(73) Assignee: **Koninklijke Philips Electronics N.V.**, Eindhoven (NL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 35 days.

(21) Appl. No.: **10/539,981**

(22) PCT Filed: **Dec. 11, 2003**

(86) PCT No.: **PCT/IB03/05992**

§ 371 (c)(1),
(2), (4) Date: **Jun. 19, 2005**

(87) PCT Pub. No.: **WO2004/057924**

PCT Pub. Date: **Jul. 8, 2004**

(65) **Prior Publication Data**

US 2006/0071614 A1 Apr. 6, 2006

Related U.S. Application Data

(60) Provisional application No. 60/434,550, filed on Dec. 19, 2002.

(51) **Int. Cl.**
H01B 37/02 (2006.01)

(52) **U.S. Cl.** .... **315/291**; 315/290 R

(58) **Field of Classification Search** .... 315/185 R, 315/291, 209 R
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,496,939	A *	1/1985	Moberg	340/636.13
6,500,101	B1	12/2002	Chen	
6,577,072	B2 *	6/2003	Saito et al.	315/185 R
2002/0158590	A1	10/2002	Saito et al.	
2004/0032754	A1 *	2/2004	Yang	363/56.09
2006/0012349	A1 *	1/2006	Allen	323/265

FOREIGN PATENT DOCUMENTS

WO WO02/069839 A1 9/2002

OTHER PUBLICATIONS

Datasheet: "LT1932—Constant-Current DC/DC LED DRiver in Thin SOT", 2001, LInear Technology, pp. 1-16.

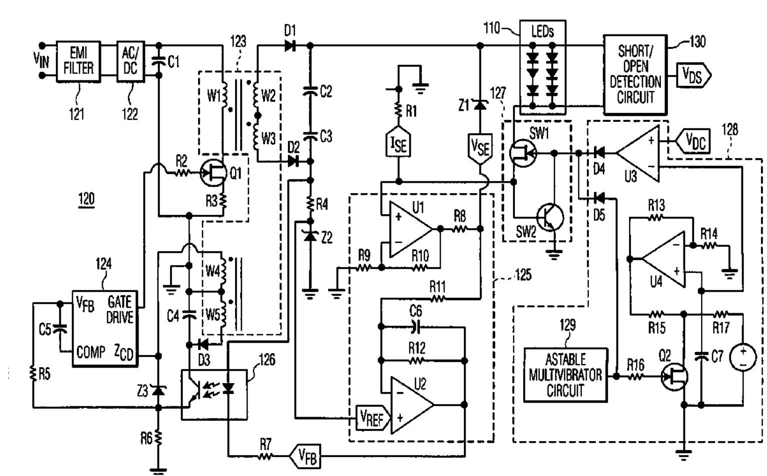
* cited by examiner

Primary Examiner—Trinh Vo Dinh

(57) **ABSTRACT**

The power supply (**20**) for LEDs provides power to a LED light source (**10**) having a variable number of LEDs wired in series and/or in parallel. The power supply (**20**) uses current and voltage feedback to adjust power to the LEDs and provides protection to the LED light source (**10**). A feedback controller (**27**) compares sensed current and sensed voltage to a reference signal and generates a feedback signal, which is processed by a power factor corrector (**124**) to adjust the current flow through the transformer supplying current to the LEDs. A LED control switch (**24**) clamps a peak of the current to the LEDs to provide further protection to the LED light source (**10**). A short/open detection circuit (**30**) indicates any detection of a "LED outage" of the LED light source (**10**).

12 Claims, 4 Drawing Sheets



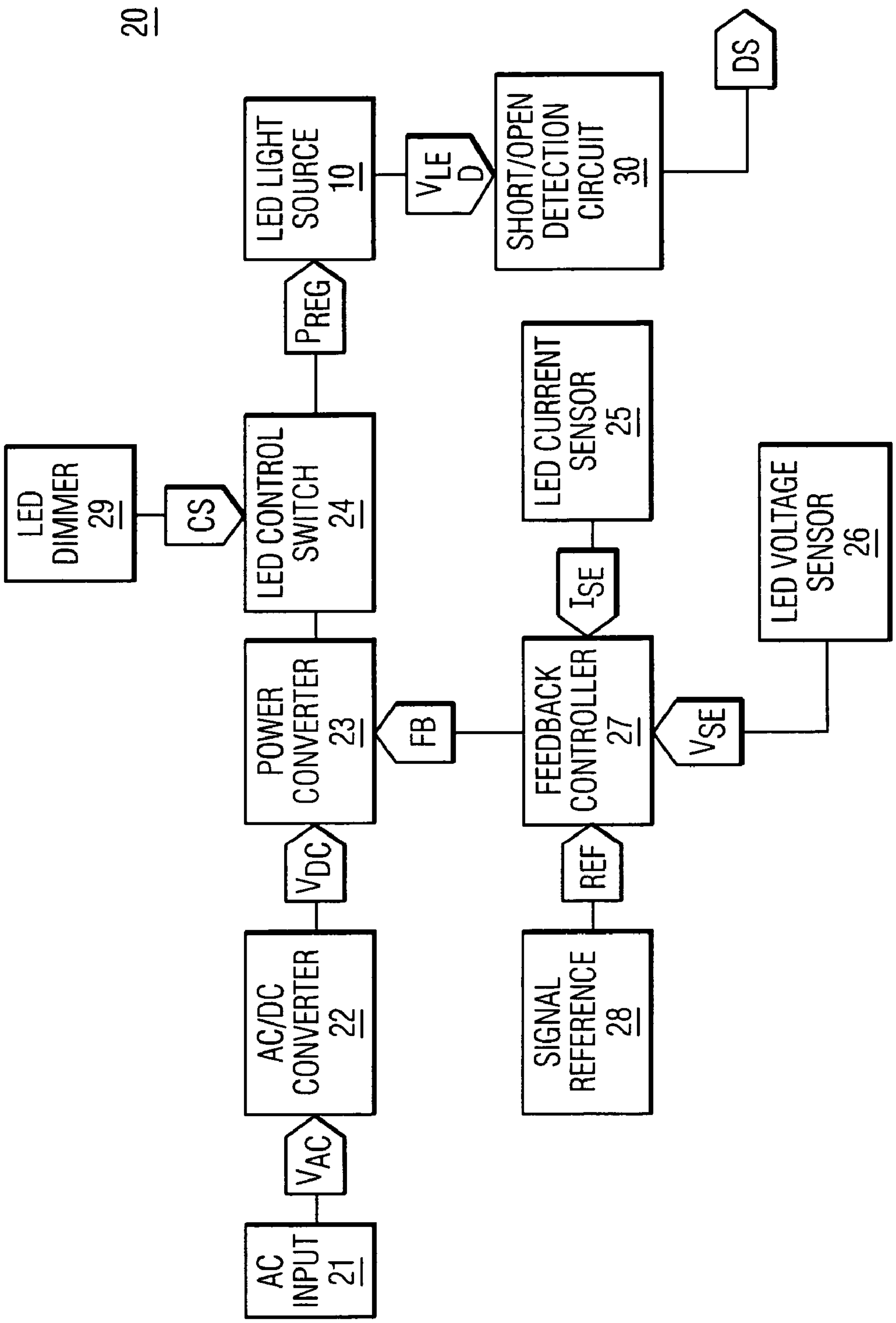

20
AC INPUT 21
V_{AC}
AC/DC CONVERTER 22
V_{DC}
POWER CONVERTER 23
LED CONTROL SWITCH 24
LED DIMMER 29
CS
P_{REG}
LED LIGHT SOURCE 10
V_{LED}
SHORT/OPEN DETECTION CIRCUIT 30
DS
FB
FEEDBACK CONTROLLER 27
REF
SIGNAL REFERENCE 28
I_{SE}
LED CURRENT SENSOR 25
V_{SE}
LED VOLTAGE SENSOR 26

FIG. 1

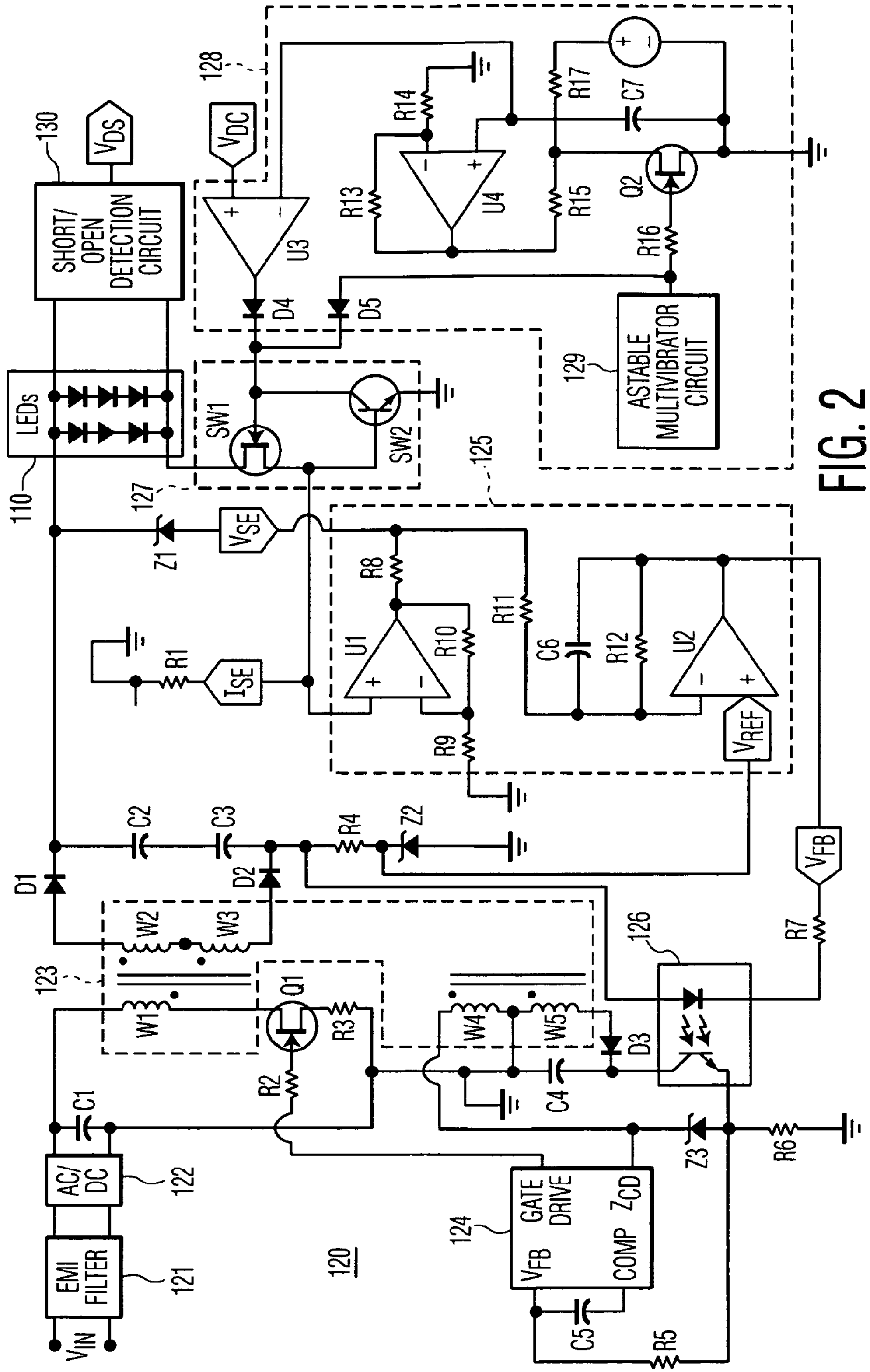

120
VIN
EMI FILTER
121
AC/DC
122
C1
123
W1
W2
W3
Q1
R2
R3
D1
D2
C2
C3
R4
Z2
124
GATE DRIVE
VFB
COMP
ZCD
C5
R5
W4
W5
C4
D3
Z3
R6
126
R7
VFB
110
LEDs
130
SHORT/OPEN DETECTION CIRCUIT
VDS
127
Z1
VSE
SW1
SW2
R1
ISE
125
U1
R8
R9
R10
R11
C6
R12
U2
VREF
128
VDC
U3
D4
D5
R13
R14
U4
R15
R17
C7
Q2
R16
129
ASTABLE MULTIVIBRATOR CIRCUIT

FIG. 2

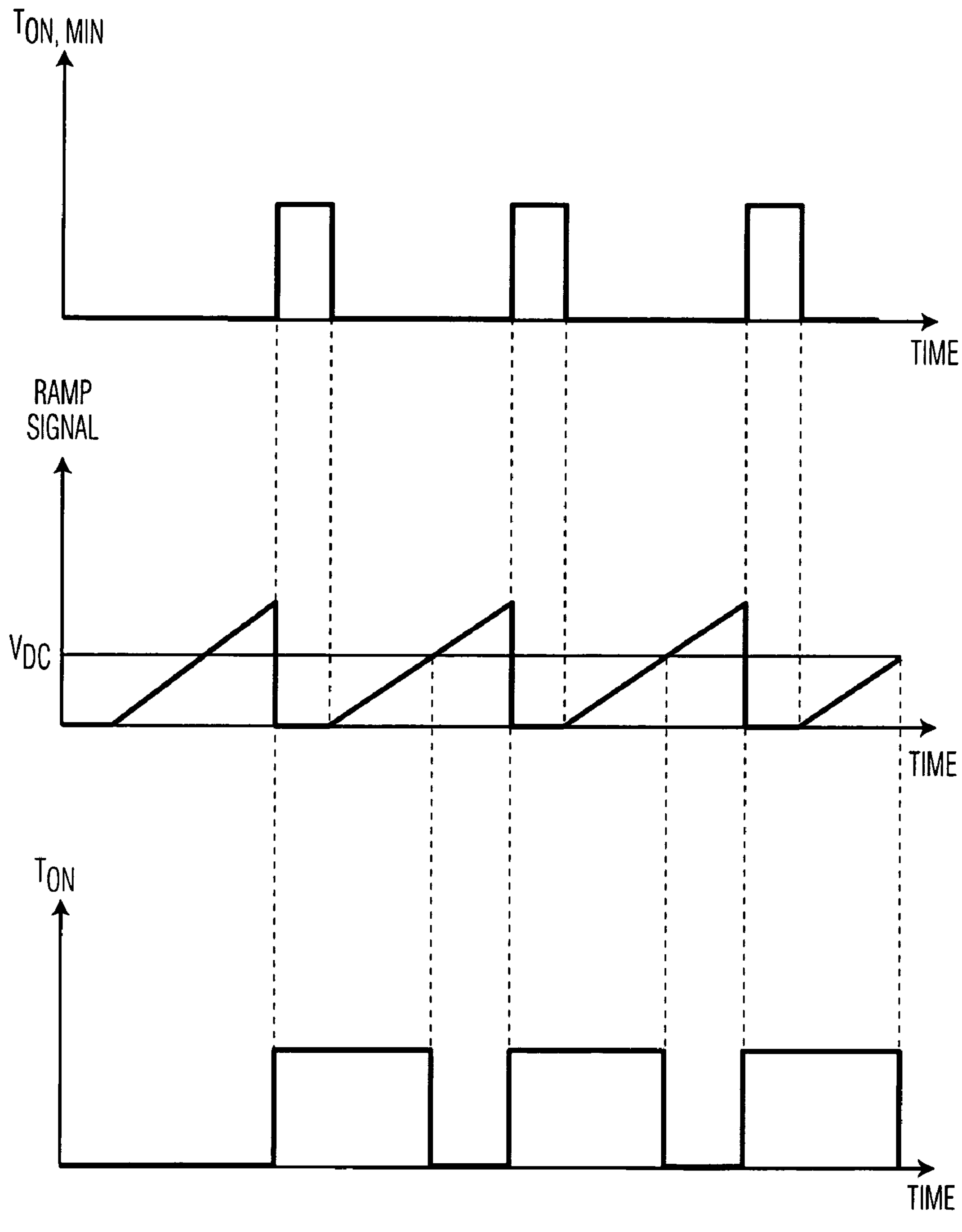
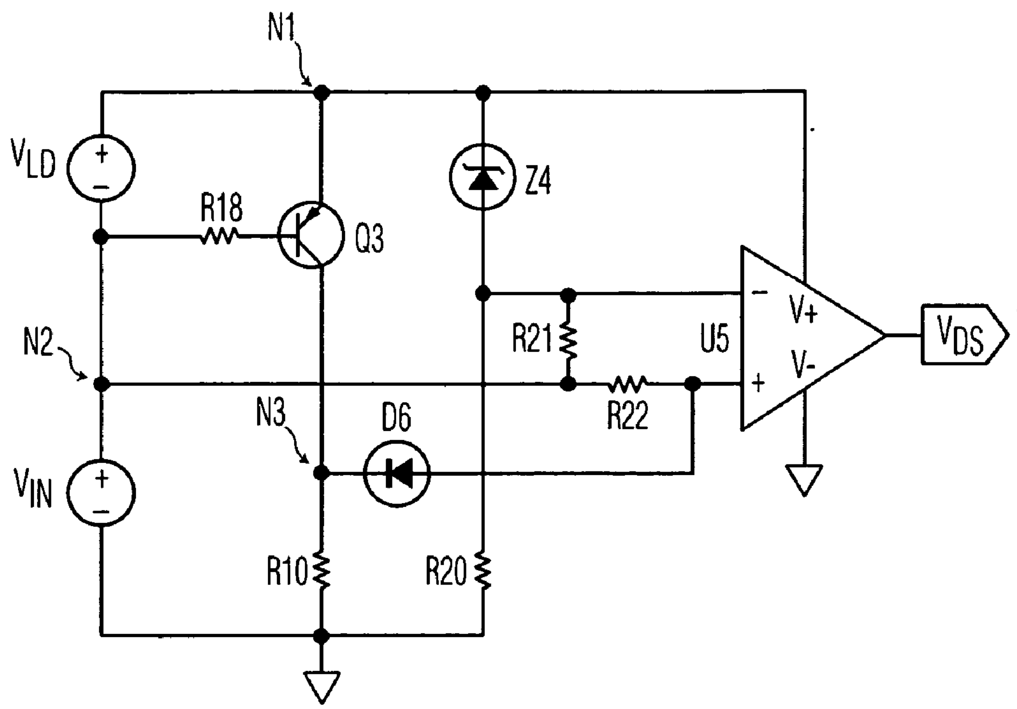
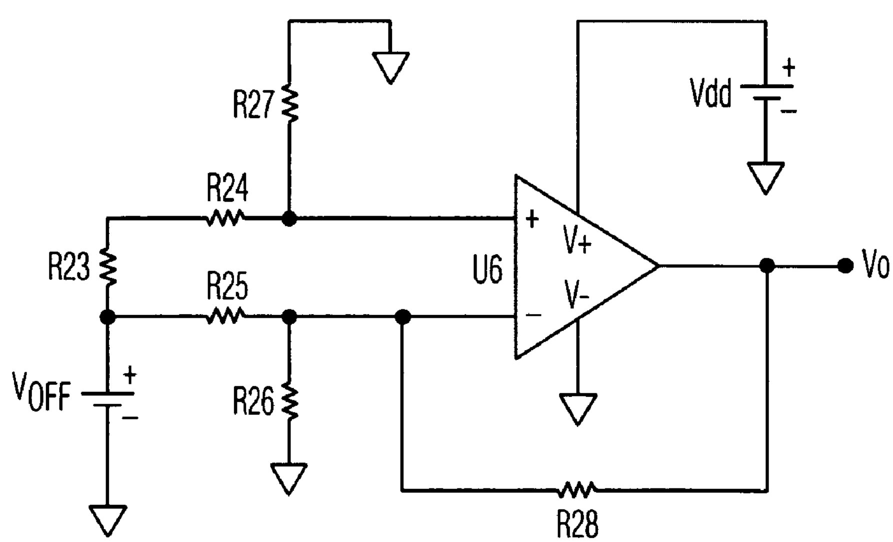


FIG. 3



N1
VLD
R18
Q3
Z4
N2
R21
U5
V+
V-
VDS
R22
N3
D6
VIN
R10
R20

FIG. 4



R27
Vdd
R24
R23
R25
U6
V+
V-
Vo
VOFF
R26
R28

FIG. 5

LEDS DRIVER

CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. provisional application Ser. No. 60/434,550, filed Dec. 19, 2002, which the entire subject matter is incorporated herein by reference.

The technical field of this disclosure is power supplies, particularly, a power supply for LEDs.

Significant advances have been made in the technology of white light emitting diodes (LEDs). White light LEDs are commercially available which generate 10-15 lumens/watt. This is comparable to the performance of incandescent bulbs. In addition, LEDs offer other advantages such as longer operating life, shock/vibration resistance and design flexibility because of their small size. As a result, white light LEDs are replacing traditional incandescent sources for illumination applications such as signage, accenting, and pathway lighting. The white LEDs can be used alone or in conjunction with colored LEDs for a particular effect.

The electrical characteristics of LEDs are such that small changes in the voltage applied to the LED lamp will cause appreciable current changes. In addition, ambient temperature changes will also result in LED current changes by changing the forward drop across the LEDs. Furthermore, the lumen output of LEDs depends on the LED current. The existing electrical power supplies for LED light sources are not designed to precisely regulate the LED current to prevent luminous intensity variations due to input ac voltage variations and ambient temperature. Operation of LED lamps at excessive forward current for a long period can cause unacceptable luminous intensity variations and even catastrophic failure. In addition, current electrical power supplies do not minimize power consumption to maximize energy savings.

It would be desirable to have a power supply for LEDs that would overcome the above disadvantages.

One form of the present invention is a power supply for a LED light source that comprises a power converter and a LED control switch. The power converter operates to provide a regulated power including a LED current and a LED voltage. The LED control switch further operates to control a flow of the LED current through the LED light source. The LED control switch further operates to clamp a peak of the LED current during an initial loading stage of the LED light source. This prevents damage to the LED light source due to a field misapplication.

A second form of the present invention is a power supply for a LED light source further comprising a detection circuit operating to provide a detection signal indicative of an operating condition of the LED light source associated with the LED voltage. The detection signal has a first level representative of a load condition of the LED light source. The detection signal has a second level representative of a short condition or an open condition indicative of the LED light source.

A third form of the present invention is a power supply for a LED light source further comprising a LED current sensor or a LED voltage sensor. Each sensor includes a differential amplifier and means for adjusting a gain of the differential amplifier.

The foregoing forms as well as other forms, features and advantages of the present invention will become further apparent from the following detailed description of the presently preferred embodiments, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the present invention rather than limiting, the scope of the present invention being defined by the appended claims and equivalents thereof.

FIG. **1** illustrates a block diagram of a power supply for an LED light source in accordance with the present invention;

FIG. **2** illustrates a schematic diagram of one embodiment of the FIG. **1** power supply in accordance with the present invention;

FIG. **3** illustrates a timing diagram of one embodiment of a control circuit in accordance with the present invention;

FIG. **4** illustrates a schematic diagram of one embodiment of a short/open detection circuit in accordance with the present invention; and

FIG. **5** illustrates a schematic diagram of one embodiment of a differential amplification circuit in accordance with the present invention.

FIG. **1** illustrates a block diagram of a power supply **20** for powering an LED light source **10** including a variable number of LEDs wired in series and/or in parallel. A single-phase ac input **21** of power supply **20** provides a voltage V_{AC} to an AC/DC converter **22** of power supply **20** whereby AC/DC converter **22** converts voltage V_{AC} into a voltage V_{DC}. AC/DC converter **22** provides voltage V_{DC} to a power converter **23** of power supply **20** whereby power converter **23** generates a regulated power P_{REG} including a LED current and a LED voltage V_{LED}.

Power converter **23** provides regulated power P_{REG} to LED light source **10**. In operation, LED control switch **24** controls a flow of the LED current through the LED light source **10**. A LED current sensor **25** of power supply **20** provides a sensed current I_{SE} indicative of a magnitude of the LED current flowing through LED light source **10**. A LED voltage sensor **26** of power supply **20** provides a sensed voltage V_{SE} indicative of a magnitude of the LED voltage V_{LED} applied to LED light source **10**. Sensed current I_{SE} and sensed voltage V_{SE} are fed to a feedback controller **27** of power supply **20**. A signal reference **28** of power supply **20** provides a reference signal REF to a feedback controller **27**, whereby feedback controller **27** provides a feedback signal FB to power converter **23** based on sensed current I_{SE}, sensed voltage V_{SE} and reference signal REF.

LED control switch **24** further operates to clamp a peak of LED current flowing through LED light source **10** to thereby protect the LED light source **10** from electrical damage. LED control switch **24** is particularly useful when LED light source **10** transitions from an open operating state to a load operating state (i.e., an initial loading), such as, for example, a connection of LED light source **10** to power supply **20** subsequent to an energizing of power supply **20**. An LED dimmer **29** of power supply **20** operates to control a desired dimming of LED light source **10** by providing a control signal CS to LED control switch **24**. Control signal CS can be in one of many conventional forms, such as, for example, a pulse width modulation signal ("PWM").

A short/open detection circuit **30** provides a detection signal DS as an indication of a short condition or an open condition of LED light source **10** based on the LED voltage V_{LED} applied to LED light source **10**.

The configuration of each component **21-30** of power supply **20** is without limit. Additionally, coupling among the components **21-30** of power supply **20** can be achieved in numerous ways (e.g., electrically, optically, acoustically, and/or magnetically). The number of embodiments of power supply **20** is therefore essentially limitless.

FIG. **2** illustrates a schematic diagram of one embodiment **120** of power supply **20** (FIG. **1**) for one embodiment **110** of

LED light source **10** (FIG. **1**) made in accordance with the present invention. Power supply **120** employs a flyback transformer with current feedback through a power factor corrector ("PFC") IC to supply power to LED light source **110**. To this end, power supply **120** includes an EMI filter **121**, an AC/DC converter ("AC/DC") **122**, a transformer **123**, a power factor corrector **124**, a feedback controller **125**, an optocoupler **126**, a LED control switch **127**, a LED PWM dimmer **128** resistors R**1**-R**7**, capacitors C**1**-C**5**, diodes D**1**-D**3**, zener diodes Z**1**-Z**3** and a MOSFET Q**1** as illustrated in FIG. **2**.

Voltage is supplied to power supply **120** at V_{IN} to EMI filter **121**. The voltage can be an ac input and is typically 50/60 Hertz at 120/230 V_{RMS}. EMI filter **121** blocks electromagnetic interference on the input. AC/DC **122** can be a bridge rectifier and converts the ac output of EMI filter **120** to dc. Transformer **123** includes a primary winding W**1**, W**4** and W**5**, and a plurality of secondary windings W**2** and W**3**. The windings W**1**/W**2** constitute the flyback transformer to power the LED light source **110**. The flyback transformer is controlled by PFC **124**, which is a power factor corrector integrated circuit, such as model L6561 manufactured by ST Microelectronics, Inc.

The flyback transformer transfers power to LED light source **110** where the LED current and the LED voltage are controlled by feedback control. The forward converter operation of windings W**1**/W**3** charge a capacitor C**3** and a reference current signal is generated between a series resistor R**4** and a zener Z**2**. The peak voltage across capacitor C**3** depends on the W**1**/W**3** turns ratio. The output dc voltage from flyback operation of windings W**1**/W**2** cannot be used to generate the reference current signal since the output dc voltage across LED light source **110** can have a wide range—from 2.6 Volts dc for one LED lamp to about 32 Volts dc for 8 LEDs in series. The forward converter operation of windings W**1**/W**3** can be used instead. The forward converter operation of the W**1**/W**5** windings can also be used to supply power to the integrated circuits, such as PFC **124**.

A sensed LED current I_{SE} flows through resistor R**1**, which is in series with the LED light source **110** via LED control switch **127**. A voltage representative of sensed LED current I_{SE} is applied to a non-inverting input of a comparator U**1**. A sensed LED voltage V_{SE} is generated by zener diode Z**1**. Sensed LED current I_{SE} and sensed LED voltage V_{SE} as well as a voltage reference V_{REF} are fed to feedback controller **125**, whereby a voltage feedback V_{FB} from feedback controller **125** drives an optocoupler **126** via resistor R**7**. In generating voltage feedback V_{FB}, feedback controller **125** employs a pair of comparators U**1** and U**2**, resistors R**8**-R**12**, and a capacitor C**6** as illustrated in FIG. **2**.

Feedback controller **125** is necessary since optocouplers have a wide range of current transfer ratio (CTR). Feedback controller **125** maintains an accurate voltage feedback V_{FB} to thereby avoid large errors in LED current flowing through LED light source **110**. Optocoupler **126** isolates the dc circuit supplying the LED light source **110** from the ac circuit power supply at EMI filter **120**, the two circuits being on the opposite sides of the transformer **123**.

The output of the optocoupler **126** is connected to PFC **124**, which supplies a gate drive signal to MOSFET Q**1**. Control of MOSFET Q**1** adjusts the current flow through winding W**1** of transformer **123** to match the LED light source **110** power demand. The internal 2.5 V reference signal and an internal compensation circuit of PFC **124** maintains the voltage drop across a resistor R**6** at 2.5V. Although this example uses MOSFET Q**1** for adjusting the transformer current, alternate embodiments can use other types of transistors to adjust the current, such as an insulated gate bipolar transistor ("IGBT") or a bipolar transistor. The input to PFC **124** at Z_{CD} provides a reset signal powered from windings W**2**/W**4**.

Zener diode Z**1** also provides overvoltage protection for LED light source **110**. Specifically, zener diode Z**1** connects across the output connection to the LED light source **110** and clamps the output voltage to a specified maximum value. The nominal zener operating voltage is selected to be just over the maximum specified output voltage. In case of an output open circuit, the flyback operation of windings W**1**/W**2** of transformer **123** would continue to build the output voltage. The increasing output voltage turns on the zener diode Z**1** to thereby increase the amount of feedback to resistor R**6** from feedback controller **125** via resistor R**7** and optocoupler **126**. This limits the gate drive signal to MOSFET Q**1**, preventing the flyback converter from building the output voltage to the LED light source **110** beyond a specified maximum voltage. Similarly, zener diode Z**3** connected from the reset winding W**4** to resistor R**6** will prevent output overvoltage due to a malfunction of feedback controller **125**. In alternate embodiments, either zener diode Z**1** or zener diode Z**3**, or both zener diode Z**1** and zener diode Z**3** can be omitted depending on the degree of control protection required for a particular application.

LED control switch **127** includes a switch SW**1** in the form of a MOSFET and a switch SW**2** in the form of a bipolar transistor. Switches SW**1** and SW**2** can be in other conventional forms, such as, for example, an IGBT. As illustrated, a drain of MOSFET switch SW**1** is connected to LED light source **110**. A gate of MOSFET switch SW**1** is connected to a collector of bipolar switch SW**2**. A source of MOSFET switch SW**1** and a base of bipolar switch SW**2** are connected to zener diode Z**1**, resistor R**1**, and feedback controller **125**. An emitter of bipolar switch SW**2** is connected to ground. In operation, switch SW**1** is turned on and switch SW**2** is turned off when the LED current is below the desired peak. This mode permits a normal operation of the front-end components of power supply **120**. Conversely, switch SW**1** is turned off and switch SW**2** is turned on when the LED current exceeds the desired peak. This limits the peak of the LED current to a safe level whereby damage to LED light source **110** is prevented. As will be appreciated by one having skill in the art, LED control switch **127** is particularly useful upon a connection of LED light source **110** to an energized power supply **120** whereby capacitor C**2** discharges stored energy to LED light source **110** with a current having a peak clamped to thereby prevent damage to LED light source **110**.

MOSFET switch SW**1** can be operated by a conventional gate driver (not shown) or by an illustrated LED PWM dimmer **128**.

LED PWM dimmer **128** provides a PWM signal (not shown) to MOSFET switch SW**1** in response to an external dim command V_{DC}. LED PWM dimmer **128** adjusts the duty cycle of the PWM signal to thereby produce a desired light output from LED light source **110**. LED PWM dimmer **128** is particularly useful in producing a precise and temperature sensitive minimum dim level for LED light source **110**.

LED PWM dimmer **128** includes a diode D**4** and a diode D**5** connected to the gate of MOSFET switch SW**1**. A comparator U**3** of LED PWM dimmer **128** is in the form of an operational amplifier having an output connected to diode D**4** and a non-inverting input for receiving a dimming command V_{DC}. A conventional astable multivibrator circuit

129 of LED PWM dimmer **128** is connected to diode D**5**. A ramp generator of LED PWM dimmer **128** includes a resistor R**16** connected to diode D**5** and a gate of transistor Q**2** in the form of a MOSFET. Transistor Q**2** can be in other forms, such as, for example, an IGBT. The ramp generator further includes an operational amplifier U**4**. A resistor R**15**, a resistor R**17**, a drain of bipolar transistor Q**2**, a capacitor C**7**, and an inverting input of comparator U**3** are connected to a non-inverting input of operational amplifier U**4**. Resistor R**15** is further connected to an output of operational amplifier U**4**. A resistor R**13** is connected to the output and an inverting input of operational amplifier U**4**. A resistor R**14** is connected to the inverting input of operational amplifier U**4** and ground. The source of MOSFET transistor Q**2** and capacitor C**7** are connected to ground. Resistor R**17** is further connected to a DC voltage source.

In operation, LED PWM dimmer **128** achieves a precise and temperature insensitive minimum dim level for LED light source **110**. Specifically, astable multivibrator circuit **129** produces a minimum pulse width (e.g., $T_{ON,MIN}$ illustrated in FIG. **3**). The duration of the minimum pulse width is a function of a resistance and capacitance of astable multivibrator circuit **129**. Thus, the minimum pulse width is accurate and temperature insensitive. The ramp generator produces a ramp signal (e.g., RS illustrated in FIG. **3**), which is periodically reset by the minimum pulse width. The ramp signal is supplied to the inverting input of comparator U**3** whereby a comparison of the ramp signal and dim command V_{DC} yields a target pulse width at the output of comparator U**3** (e.g., T_{ON} illustrated in FIG. **3**). The minimum pulse width and the target pulse width are combined to provide the PWM signal at the gate of MOSFET switch SW**1**. As such, the PWM signal consists of the target pulse width overlapping the minimum pulse width when the dim command V_{DC} exceeds or is equal to the ramp signal. Conversely, the PWM signal exclusively consists of the minimum pulse width when the ramp signal exceeds the voltage dim command V_{DC}.

In practice, a suitable range for voltage dim command V_{DC} is 0 to 10 volts.

Short/Open Circuit Detection

FIG. **4** illustrates one embodiment of short/open detection circuit **130**. A LED voltage drop V_{LD} across the LED light source **110** applied between a node N**1** and a node N**2**, and an input voltage V_{IN} is applied between node N**2** and a common reference. The LED voltage drop V_{LD} approximates zero (0) volts when LED light source **110** (FIG. **2**) is shorted, and approximates the LED voltage V_{LED} of regulated power P_{REG} (FIG. **1**) when LED light source **110** is an open circuit. The input voltage V_{IN} is typically in the range of six (6) volts to sixteen (16) volts. A comparator U**5** in the form of an operational amplifier provides a detection signal V_{DS} at a high level to indicate a "LED outage" condition of LED light source **110** and at a low level to indicate a normal operation of LED light source **110**. The "LED outage" condition is either indicative of a short or open of LED light source **110**.

Input voltage V_{IN} in the illustrated embodiment is a dc voltage. A dc-dc type power converter can therefore be used to supply power to LED light source **110** (FIG. **2**). In alternative embodiments, detection circuit **130** can be adapted for use in ac to dc type power converters.

An emitter of a transistor Q**3** in the form of a bipolar transistor, and a zener diode Z**4** are also connected to node N**1**. Transistor Q**3** can be in other conventional forms, such as, for example, an IGBT. A resistor R**18**, a resistor R**21**, and a resistor R**22** are also connected to node N**2**. A base of bipolar transistor Q**3** is connected to resistor R**18**. Zener diode Z**4**, a resistor R**20** and resistor R**21** are connected to an inverting input of comparator U**5**. A collector of bipolar transistor Q**3**, a diode D**6**, and a resistor R**19** are connected to a node N**3**. Resistor R**19** and resistor R**20** are further connected to the common reference. Diode D**6** and resistor R**22** are connected to a non-inverting input of comparator U**5**.

For a normal operation of LED light source **110**, the LED voltage drop V_{LD} is greater than the base-emitter junction voltage of transistor Q**3** whereby transistor Q**3** is on, diode D**6** is in a non-conductive state, and the voltage at the collector of transistor Q**3** exceeds the input voltage V_{IN}. As a result, the input voltage V_{IN} is applied to the inverting input of comparator U**3**. The conducting voltage of zener diode Z**4** is chosen to be above the LED voltage drop V_{LD} and therefore zener diode Z**4** is in a non-conductive state. As a result, a voltage applied to the non-inverting input of comparator U**2** will equate the input voltage V_{IN} reduced by a voltage divider factor established by resistor R**20** and resistor R**21**. The output of comparator U**5** will be low (e.g., close to ground) since the voltage applied to the inverting input exceeds the voltage applied to the non-inverting input.

For an open array condition of LED light source **110**, the LED voltage drop V_{LD} approximates the LED voltage V_{LED} of regulated power P_{REG}, which is chosen to be higher than the voltage of zener diode Z**4**. The LED voltage drop V_{LD} is greater than the base-emitter junction voltage of transistor Q**3** whereby transistor Q**3** is on and the voltage at the collector transistor Q**3** exceeds the input voltage V_{IN}. As a result, the input voltage V_{IN} is applied to the inverting input of comparator U**3**. The conducting voltage of zener diode Z**4** is lower than the LED voltage drop V_{LD} and zener diode Z**4** is therefore in a conductive state. As a result, a voltage applied to the non-inverting input of comparator US will equate a summation of the input voltage V_{IN} and the LED voltage drop V_{LD} minus the conducting voltage of diode D**6**. The output of comparator US will be high (e.g., close to the input voltage V_{IN}) since the voltage applied to the non-inverting input exceeds the voltage applied to the inverting input.

For a short array condition of LED light source **110**, the LED voltage drop V_{LD} approximates zero (0) volts. The LED voltage drop V_{LD} is therefore less than the base-emitter junction voltage of transistor Q**3** whereby transistor Q**3** is off, the voltage at the collector transistor is pulled down by resistor R**19** and diode D**6** is conducting. As a result, a voltage applied to the inverting input of comparator US will equate the input voltage V_{IN} reduced by a voltage divider factor established by resistor R**19** and resistor R**22**. The conducting voltage of zener diode Z**4** exceeds the LED voltage drop V_{LD} and zener diode Z**4** is therefore in a non-conductive state. The output of comparator US will be high (e.g., close to the input voltage V_{IN}) since the voltage applied to the non-inverting input exceeds the voltage applied to the inverting input.

In an alternate embodiment, an additional zener diode or a voltage reference can be inserted in the emitter path of transistor Q**3** to detect a voltage level other than less that one base-emitter junction of transistor Q**3**.

FIG. **5** illustrates a differential amplification circuit having a voltage output V_O that can be employed in LED current sensor **25** (FIG. **1**) or LED current sensor **26** (FIG. **1**). A resistor R**23** and a resistor R**25** are connected to an offset voltage source V_{OFF}. Resistor R**25**, a resistor R**26**, and a resistor R**28** are connected to an inverting input of an operational amplifier U**6**. A resistor R**24** and a resistor R**27** are connected to a non-inverting input of operational amplifier U**6**. Resistor R**23** and resistor R**24** are connected. Resistor R**28** is further connected to an output of operational amplifier U**6**.

In operation, the voltages applied to the inputs of the operational amplifier U**6** are lower than the supply voltage V_{dd} irrespective of the size of resistor R**23**. In one embodiment, resistors R**25** and R**26** are chosen to apply half of the offset voltage V_{OFF} to the inverting input of operational amplifier U**6**, and resistors R**24** and R**27** are chosen to obtain a proper common mode rejection (e.g., resistor R**28** equaling a parallel combination of resistor R**26** and R**28**). As a result, the gain of operational amplifier U**6** can be adjusted as desired.

It is important to note that FIGS. **2-5** illustrates specific applications and embodiments of the present invention, and is not intended to limit the scope of the present disclosure or claims to that which is presented therein. Upon reading the specification and reviewing the drawings hereof, it will become immediately obvious to those skilled in the art that myriad other embodiments of the present invention are possible, and that such embodiments are contemplated and fall within the scope of the presently claimed invention.

While the embodiments of the invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the spirit and scope of the invention. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.

The invention claimed is:

1. A power supply for an LED light source, said power supply comprising:

a power converter operable to provide a regulated power including a LED current and a LED voltage;

a LED control switch operable to control a flow of the LED current through the LED light source

wherein said LED control switch is further operable to clamp a peak of the LED current during an initial loading stage of the LED light source;

a switch operable to establish a current path from the LED light source to said power converter when the LED current is below the peak threshold, said switch further operable to eradicate the current path when the LED current is above the peak threshold

an LED PWM dimmer operable to provide a pulse width modulation signal to said LED control switch in response to an external dim command,

wherein said pulse width modulation signal has a target pulse width in response to the dim command exceeding a ramp signal, and

wherein said pulse width modulation signal has a minimum pulse width in response to the ramp signal exceeding the dim command.

2. The power supply of claim **1**, wherein said LED PWM dimmer includes:

an astable multivibrator circuit operable to establish the minimum pulse width in a precise and temperature insensitive manner.

3. The power supply claim **1**, wherein said LED PWM dimmer includes:

a comparator operable to establish the target pulse width in response to a reception of the dim command and the ramp signal.

4. The power supply of claim **3**, wherein said LED PWM dimmer further includes:

a ramp generator operable to provide the ramp signal to said comparator indicative of the minimum pulse width.

5. The power supply of claim **4**, wherein said LED PWM dimmer further includes:

an astable multivibrator circuit operable to establish the minimum pulse width in a precise and temperature insensitive manner.

6. A power supply for an LED light source, said power supply comprising:

a power converter operable to provide a regulated power including a LED current and a LED voltage;

an LED control switch operable to control a flow of the LED current through the LED light source; and

a detection circuit operable to provide a detection signal indicative of an operating condition of the LED light source associated with the LED voltage,

wherein said LED control switch is further operable to clamp a peak of the LED current during an initial loading stage of the LED light source,

wherein the detection signal has a first level representative of a load condition of the LED light source, and

wherein the detection signal has a second level representative of either a short condition or an open condition of the LED light source.

7. The power supply of claim **6**, wherein the load operating condition indicates a magnitude of a LED voltage drop across the LED light source is between zero volts and the LED voltage.

8. The power supply of claim **6**, wherein the short operating condition indicates a magnitude of a LED voltage drop across the LED light source approximates zero volts.

9. The power supply of claim **6**, wherein the open operating condition indicates a magnitude of a LED voltage drop across the LED light source approximates the LED voltage.

10. A power supply for an LED light source, said power supply comprising:

a power converter operable to provide a regulated power including a LED current and a LED voltage;

an LED control switch operable to control a flow of the LED current through the LED light source; and

a current sensor operable to sense the LED current flowing through the LED light source, said current sensor including

an differential amplifier, and

means for adjusting a gain of said differential amplifier,

wherein said LED control switch is further operable to clamp a peak of the LED current during an initial loading stage of the LED light source.

11. A power supply for an LED light source, said power supply comprising:

a power converter operable to provide a regulated power including a LED current and a LED voltage;

an LED control switch operable to control a flow of the LED current through the LED light source; and

a voltage sensor operable to sense the LED voltage applied to the LED light source, said voltage sensor including

an differential amplifier, and

means for adjusting a gain of said differential amplifier, wherein said LED control switch is further operable to clamp a peak of the LED current during an initial loading stage of the LED light source.

12. A method of operating an LED light source, said method comprising:

providing a regulated power to the LED light source, the regulated power including an LED current and an LED voltage;

controlling a flow of the LED current through the LED light source;

clamping a peak of the LED current during an initial loading stage of the LED light source; and

generating a detection signal indicative of an operating condition of the LED light source associated with the LED voltage,

wherein the detection signal has a first level representative of a normal operating condition of the LED light source, and wherein the detection signal has a second level representative of either a short operating condition or an open operating condition of the LED light source.

* * * * *

Exhibit G

US007352138B2

(12) **United States Patent**
Lys et al.

(10) **Patent No.: US 7,352,138 B2**
(45) **Date of Patent: *Apr. 1, 2008**

(54) **METHODS AND APPARATUS FOR PROVIDING POWER TO LIGHTING DEVICES**

(75) Inventors: **Ihor A. Lys**, Milton, MA (US); **Kevin J. Dowling**, Westford, MA (US); **Frederick M. Morgan**, Quincy, MA (US)

(73) Assignee: **Philips Solid-State Lighting Solutions, Inc.**, Burlington, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **11/379,191**

(22) Filed: **Apr. 18, 2006**

(65) **Prior Publication Data**

US 2006/0208667 A1 Sep. 21, 2006

Related U.S. Application Data

(63) Continuation of application No. 10/435,687, filed on May 9, 2003, now Pat. No. 7,038,399, and a continuation-in-part of application No. 09/805,368, filed on Mar. 13, 2001, now Pat. No. 7,186,003, and a continuation-in-part of application No. 09/805,590, filed on Mar. 13, 2001, now Pat. No. 7,064,498.

(60) Provisional application No. 60/391,627, filed on Jun. 26, 2002, provisional application No. 60/379,079, filed on May 9, 2002.

(51) **Int. Cl.**
H05B 37/02 (2006.01)

(52) **U.S. Cl.** **315/291**; 315/DIG. 4

(58) **Field of Classification Search** .... 315/200 R, 315/246, 247, 291, 307, DIG. 4
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,318,185 A 5/1967 Kott

(Continued)

FOREIGN PATENT DOCUMENTS

AU 6 267 9 12/1996

(Continued)

OTHER PUBLICATIONS

"LM117/LM317A/LM317 3-Terminal Adjustable Regulator," National Semiconductor Corporation, May 1997, pp. 1-20.

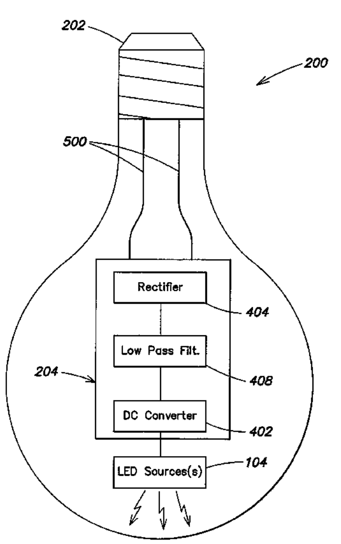
(Continued)

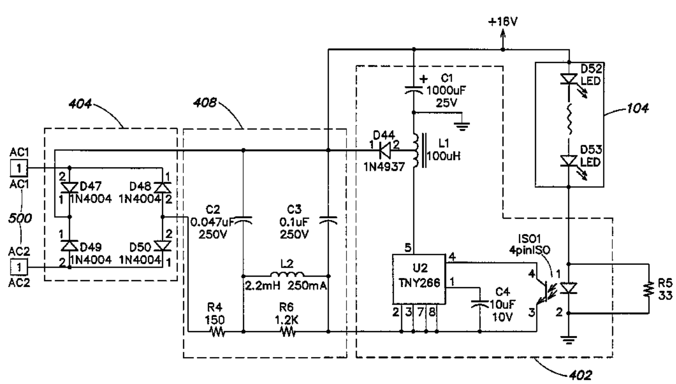
Primary Examiner—Thuy Vinh Tran
(74) *Attorney, Agent, or Firm*—Wolf, Greenfield & Sacks, P.C.

(57) **ABSTRACT**

Methods and apparatus for providing power to devices via an A.C. power source, and for facilitating the use of LED-based light sources on A.C. power circuits that provide signals other than standard line voltages. In one example, LED-based light sources may be coupled to A.C. power circuits that are controlled by conventional dimmers (i.e., "A.C. dimmer circuits"). Hence, LED-based light sources may be conveniently substituted for other light sources (e.g., incandescent lights) in lighting environments employing conventional A.C. dimming devices and/or other control signals present on the A.C. power circuit. In yet other aspects, one or more parameters relating to the light generated by LED-based light sources (e.g., intensity, color, color temperature, temporal characteristics, etc.) may be conveniently controlled via operation of a conventional A.C. dimmer and/or other signals present on the A.C. power circuit.

34 Claims, 10 Drawing Sheets





U.S. PATENT DOCUMENTS

3,561,719 A 2/1971 Grindle
3,586,936 A 6/1971 McLeroy
3,601,621 A 8/1971 Ritchie
3,643,088 A 2/1972 Osteen et al.
3,746,918 A 7/1973 Drucker et al.
3,818,216 A 6/1974 Larraburu
3,832,503 A 8/1974 Crane
3,858,086 A 12/1974 Anderson et al.
3,909,670 A 9/1975 Wakamatsu et al.
3,924,120 A 12/1975 Cox, III
3,958,885 A 5/1976 Stockinger et al.
3,974,637 A 8/1976 Bergey et al.
4,001,571 A 1/1977 Martin
4,054,814 A 10/1977 Fegley et al.
4,070,568 A 1/1978 Gala
4,082,395 A 4/1978 Donato et al.
4,096,349 A 6/1978 Donato
4,241,295 A 12/1980 Williams, Jr.
4,271,408 A 6/1981 Teshima et al.
4,272,689 A 6/1981 Crosby et al.
4,273,999 A 6/1981 Pierpoint
4,298,869 A 11/1981 Okuno
4,329,625 A 5/1982 Nishizawa et al.
4,339,788 A 7/1982 White et al.
4,342,947 A 8/1982 Bloyd
4,367,464 A 1/1983 Kurahashi et al.
4,388,567 A 6/1983 Yamazaki et al.
4,388,589 A 6/1983 Molldrem, Jr.
4,392,187 A 7/1983 Bornhorst
4,420,711 A 12/1983 Takahashi et al.
4,455,562 A 6/1984 Dolan et al.
4,500,796 A 2/1985 Quin
4,597,033 A 6/1986 Meggs et al.
4,622,881 A 11/1986 Rand
4,625,152 A 11/1986 Nakai
4,635,052 A 1/1987 Aoike et al.
4,647,217 A 3/1987 Havel
4,656,398 A 4/1987 Michael et al.
4,668,895 A 5/1987 Schneiter
4,675,575 A 6/1987 Smith et al.
4,682,079 A 7/1987 Sanders et al.
4,686,425 A 8/1987 Havel
4,687,340 A 8/1987 Havel
4,688,154 A 8/1987 Nilssen
4,688,869 A 8/1987 Kelly
4,695,769 A 9/1987 Schweickardt
4,701,669 A 10/1987 Head et al.
4,705,406 A 11/1987 Havel
4,707,141 A 11/1987 Havel
4,727,289 A 2/1988 Uchida
4,740,882 A 4/1988 Miller
4,753,148 A 6/1988 Johnson
4,771,274 A 9/1988 Havel
4,780,621 A 10/1988 Bartleucci et al.
4,794,383 A 12/1988 Havel
4,818,072 A 4/1989 Mohebban
4,824,269 A 4/1989 Havel
4,837,565 A 6/1989 White
4,843,627 A 6/1989 Stebbins
4,845,481 A 7/1989 Havel
4,845,745 A 7/1989 Havel
4,857,801 A 8/1989 Farrell
4,863,223 A 9/1989 Weissenbach et al.
4,870,325 A 9/1989 Kazar
4,874,320 A 10/1989 Freed et al.
4,887,074 A 12/1989 Simon et al.
4,922,154 A 5/1990 Cacoub
4,934,852 A 6/1990 Havel
4,962,687 A 10/1990 Belliveau et al.
4,965,561 A 10/1990 Havel
4,973,835 A 11/1990 Kurosu et al.
4,979,081 A 12/1990 Leach et al.
4,980,806 A 12/1990 Taylor et al.
4,992,704 A 2/1991 Stinson
5,003,227 A 3/1991 Nilssen
5,008,595 A 4/1991 Kazar
5,008,788 A 4/1991 Palinkas
5,010,459 A 4/1991 Taylor et al.
5,027,262 A 6/1991 Freed
5,034,807 A 7/1991 Von Kohorn
5,036,248 A 7/1991 McEwan et al.
5,038,255 A 8/1991 Nishihashi et al.
5,072,216 A 12/1991 Grange
5,078,039 A 1/1992 Tulk et al.
5,083,063 A 1/1992 Brooks
5,089,748 A 2/1992 Ihms
5,122,733 A 6/1992 Havel
5,126,634 A 6/1992 Johnson
5,128,595 A 7/1992 Hara
5,130,909 A 7/1992 Gross
5,134,387 A 7/1992 Smith et al.
5,142,199 A 8/1992 Elwell
5,154,641 A 10/1992 McLaughlin
5,161,879 A 11/1992 McDermott
5,164,715 A 11/1992 Kashiwabara et al.
5,184,114 A 2/1993 Brown
5,194,854 A 3/1993 Havel
5,209,560 A 5/1993 Taylor et al.
5,225,765 A 7/1993 Callahan et al.
5,226,723 A 7/1993 Chen
5,254,910 A 10/1993 Yang
5,256,948 A 10/1993 Boldin et al.
5,278,542 A 1/1994 Smith et al.
5,282,121 A 1/1994 Bornhorst et al.
5,283,517 A 2/1994 Havel
5,287,352 A 2/1994 Jackson et al.
5,294,865 A 3/1994 Haraden
5,298,871 A 3/1994 Shimohara
5,301,090 A 4/1994 Hed
5,307,295 A 4/1994 Taylor et al.
5,329,431 A 7/1994 Taylor et al.
5,350,977 A 9/1994 Hamamoto et al.
5,357,170 A 10/1994 Luchaco et al.
5,371,618 A 12/1994 Tai et al.
5,374,876 A 12/1994 Horibata et al.
5,375,043 A 12/1994 Tokunaga
5,381,074 A 1/1995 Rudzewicz et al.
5,388,357 A 2/1995 Malita
5,402,702 A 4/1995 Hata
5,404,282 A 4/1995 Klinke et al.
5,406,176 A 4/1995 Sugden
5,410,328 A 4/1995 Yoksza et al.
5,412,284 A 5/1995 Moore et al.
5,412,552 A 5/1995 Fernandes
5,420,482 A 5/1995 Phares
5,421,059 A 6/1995 Leffers, Jr.
5,430,356 A 7/1995 Ference et al.
5,432,408 A 7/1995 Matsuda et al.
5,436,535 A 7/1995 Yang
5,436,853 A 7/1995 Shimohara
5,450,301 A 9/1995 Waltz et al.
5,461,188 A 10/1995 Drago et al.
5,463,280 A 10/1995 Johnson
5,465,144 A 11/1995 Parker et al.
5,475,300 A 12/1995 Havel
5,489,827 A 2/1996 Xia
5,491,402 A 2/1996 Small
5,493,183 A 2/1996 Kimball
5,504,395 A 4/1996 Johnson et al.
5,519,496 A 5/1996 Borgert et al.
5,530,322 A 6/1996 Ference et al.
5,545,950 A 8/1996 Cho
5,550,440 A 8/1996 Allison et al. 315/294
5,559,681 A 9/1996 Duarte

5,561,346	A	10/1996	Byrne
5,575,459	A	11/1996	Anderson
5,575,554	A	11/1996	Guritz
5,592,051	A	1/1997	Korkala
5,614,788	A	3/1997	Mullins et al.
5,621,282	A	4/1997	Haskell
5,621,603	A	4/1997	Adamec et al.
5,633,629	A	5/1997	Hockstein
5,634,711	A	6/1997	Kennedy et al.
5,640,061	A	6/1997	Bornhorst et al.
5,642,129	A	6/1997	Zavracy et al.
5,656,935	A	8/1997	Havel
5,673,059	A	9/1997	Zavracy et al.
5,688,042	A	11/1997	Madadi et al.
5,701,058	A	12/1997	Roth
5,712,650	A	1/1998	Barlow
5,721,471	A	2/1998	Begemann et al.
5,734,590	A	3/1998	Tebbe
5,751,118	A	5/1998	Mortimer
5,752,766	A	5/1998	Bailey et al.
5,769,527	A	6/1998	Taylor et al.
5,784,006	A	7/1998	Hockstein
5,790,329	A	8/1998	Klaus et al.
5,803,579	A	9/1998	Turnbull et al.
5,808,689	A	9/1998	Small
5,812,105	A	9/1998	Van de Ven
5,821,695	A	10/1998	Vilanilam et al.
5,828,178	A	10/1998	York et al.
5,836,676	A	11/1998	Ando et al.
5,848,837	A	12/1998	Gustafson
5,850,126	A	12/1998	Kanbar
5,851,063	A	12/1998	Doughty et al.
5,852,658	A	12/1998	Knight et al.
5,854,542	A	12/1998	Forbes
5,859,508	A	1/1999	Ge et al.
5,896,010	A	4/1999	Mikolajczak et al.
5,907,742	A	5/1999	Johnson et al.
5,912,653	A	6/1999	Fitch
5,924,784	A	7/1999	Chliwnyj et al.
5,927,845	A	7/1999	Gustafson et al.
5,946,209	A	8/1999	Eckel et al.
5,952,680	A	9/1999	Strite
5,959,547	A	9/1999	Tubel et al.
5,963,185	A	10/1999	Havel
5,974,553	A	10/1999	Gandar
5,980,064	A	11/1999	Metroyanis
6,008,783	A	12/1999	Kitagawa et al.
6,016,038	A	1/2000	Mueller et al.
6,018,237	A	1/2000	Havel
6,020,825	A	2/2000	Chansky et al.
6,025,550	A	2/2000	Kato
6,031,343	A	2/2000	Recknagel et al.
6,068,383	A	5/2000	Robertson et al.
6,069,597	A	5/2000	Hansen
6,072,280	A	6/2000	Allen
6,092,915	A	7/2000	Rensch
6,095,661	A	8/2000	Lebens et al.
6,097,352	A	8/2000	Zavracy et al.
6,127,783	A	10/2000	Pashley et al.
6,132,072	A	10/2000	Turnbull et al.
6,135,604	A	10/2000	Lin
6,149,283	A	11/2000	Conway et al.
6,150,774	A	11/2000	Mueller et al.
6,166,496	A	12/2000	Lys et al.
6,175,201	B1	1/2001	Sid
6,175,220	B1	1/2001	Billig et al.
6,181,126	B1	1/2001	Havel
6,183,086	B1	2/2001	Neubert
6,183,104	B1	2/2001	Ferrara
6,184,628	B1	2/2001	Ruthenber
6,196,471	B1	3/2001	Ruthenber
6,211,626	B1	4/2001	Lys et al.
6,215,409	B1	4/2001	Blach
6,250,774	B1	6/2001	Begemann et al.
6,252,358	B1	6/2001	Xydis et al.
6,273,338	B1	8/2001	White
6,292,901	B1	9/2001	Lys et al.
6,310,590	B1	10/2001	Havel
6,323,832	B1	11/2001	Nishizawa et al.
6,340,868	B1	1/2002	Lys et al.
6,369,525	B1	4/2002	Chang et al.
6,379,022	B1	4/2002	Amerson et al.
6,445,139	B1	9/2002	Marshall et al.
6,448,550	B1	9/2002	Nishimura
6,459,919	B1	10/2002	Lys et al.
6,469,457	B2	10/2002	Callahan 315/294
6,495,964	B1	12/2002	Muthu et al.
6,528,954	B1	3/2003	Lys et al.
6,548,967	B1	4/2003	Dowling et al.
6,577,080	B2	6/2003	Lys et al.
6,586,890	B2	7/2003	Min et al.
6,596,977	B2	7/2003	Muthu et al.
6,608,453	B2	8/2003	Morgan et al.
6,624,597	B2	9/2003	Dowling et al.
6,636,003	B2	10/2003	Rahm et al.
6,683,419	B2	1/2004	Kriparos
6,717,376	B2	4/2004	Lys et al.
6,720,745	B2	4/2004	Mueller et al.
6,744,223	B2	6/2004	Laflamme et al.
6,774,584	B2	8/2004	Lys et al.
6,777,891	B2	8/2004	Lys et al.
6,781,329	B2	8/2004	Morgan et al.
6,788,011	B2	9/2004	Mueller et al.
6,801,003	B2	10/2004	Schanberger et al.
6,806,659	B1	10/2004	Mueller et al.
6,869,204	B2	3/2005	Piepgras et al.
6,883,929	B2	4/2005	Dowling
6,888,322	B2	5/2005	Dowling et al.
6,897,624	B2	5/2005	Ducharme et al.
6,936,978	B2	8/2005	Morgan et al.
6,965,205	B2	11/2005	Piepgras et al.
6,967,448	B2	11/2005	Morgan et al.
6,969,954	B2	11/2005	Lys
6,975,079	B2	12/2005	Lys et al.
7,031,920	B2	4/2006	Dowling et al.
7,038,398	B1	5/2006	Lys et al.
7,038,399	B2	5/2006	Lys et al.
7,042,172	B2	5/2006	Dowling et al.
2001/0045803	A1	11/2001	Cencur
2002/0038157	A1	3/2002	Dowling et al.
2002/0048169	A1	4/2002	Dowling et al.
2002/0070688	A1	6/2002	Dowling et al.
2002/0074559	A1	6/2002	Dowling et al.
2002/0078221	A1	6/2002	Blackwell et al.
2002/0130627	A1	9/2002	Dowling et al.
2002/0145394	A1	10/2002	Morgan et al.
2002/0145869	A1	10/2002	Dowling
2002/0152045	A1	10/2002	Dowling et al.
2002/0158583	A1	10/2002	Lys et al.
2002/0176259	A1	11/2002	Ducharme
2003/0011538	A1	1/2003	Lys et al.
2003/0028260	A1	2/2003	Blackwell
2003/0057884	A1	3/2003	Dowling et al.
2003/0057887	A1	3/2003	Dowling et al.
2003/0076281	A1	4/2003	Morgan et al.
2003/0100837	A1	5/2003	Lys et al.
2003/0133292	A1	7/2003	Mueller et al.
2003/0222587	A1	12/2003	Dowling et al.
2004/0036006	A1	2/2004	Dowling
2004/0052076	A1	3/2004	Mueller et al.
2004/0090191	A1	5/2004	Mueller et al.
2004/0090787	A1	5/2004	Dowling et al.
2004/0105261	A1	6/2004	Ducharme et al.
2004/0116039	A1	6/2004	Mueller et al.
2004/0130909	A1	7/2004	Mueller et al.
2004/0178751	A1	9/2004	Mueller et al.

2004/0212320	A1	10/2004	Dowling et al.
2004/0212993	A1	10/2004	Morgan et al.
2005/0024877	A1*	2/2005	Frederick 362/277
2005/0099824	A1	5/2005	Dowling et al.
2005/0116667	A1	6/2005	Mueller et al.
2005/0151489	A1	7/2005	Lys et al.
2005/0213352	A1	9/2005	Lys et al.
2005/0213353	A1	9/2005	Lys
2005/0218838	A1	10/2005	Lys
2005/0218870	A1	10/2005	Lys
2005/0219872	A1	10/2005	Lys
2005/0231133	A1	10/2005	Lys
2005/0236029	A1	10/2005	Dowling
2005/0236998	A1	10/2005	Mueller
2005/0253533	A1	11/2005	Lys et al.
2005/0275626	A1	12/2005	Mueller
2005/0276053	A1	12/2005	Nortrup
2006/0002110	A1	1/2006	Dowling
2006/0012987	A9	1/2006	Ducharme
2006/0016960	A1	1/2006	Morgan
2006/0022214	A1	2/2006	Morgan
2006/0050509	A9	3/2006	Dowling
2006/0076908	A1	4/2006	Morgan
2006/0098077	A1	5/2006	Dowling
2006/0104058	A1	5/2006	Chemel et al.
2006/0109649	A1	5/2006	Ducharme et al.

FOREIGN PATENT DOCUMENTS

CA	2 134 848		5/1995
CA	2 178 432		12/1996
DE	02315709		10/1974
DE	0205307		12/1983
DE	03438154	A1	4/1986
DE	3837313		5/1989
DE	3805998		9/1989
DE	3925767	A1	4/1990
DE	8902905		5/1990
DE	3917101		11/1990
DE	3916875		12/1990
DE	4041338		7/1992
DE	4130576	C1	3/1993
DE	9414688	U1	2/1995
DE	9414689		2/1995
DE	4419006	A1	12/1995
DE	29607270	U1	8/1996
DE	19525987		10/1996
DE	29620583	U1	3/1997
DE	19651140	A1	6/1997
DE	19602891	A1	7/1997
EP	0482680	A1	4/1992
EP	0495305	A2	7/1992
EP	0567280	B1	10/1993
EP	0534710	B1	1/1996
EP	0734082	A2	9/1996
EP	0752632	A2	1/1997
EP	0752632	A3	8/1997
EP	0823812	A2	2/1998
EP	0935234	A1	8/1999
EP	0942631	A2	9/1999
EP	1020352	A2	7/2000
EP	1113215	A2	7/2001
EP	1162400	A2	12/2001
FR	2 640 791		6/1990
FR	88 17359		12/1998
GB	2045098	A	10/1980
GB	2131589	A	11/1982
GB	2176042	A	12/1986
GB	2210720	A	6/1989
GB	2135536	A	8/1994
JP	02-007393		1/1990
JP	2247688		10/1990
JP	03045166		2/1991
JP	06043830		2/1994
JP	7-39120		7/1995
JP	07-282614		10/1995
JP	8-106264		4/1996
JP	09-139289		5/1997
JP	3076701		1/2001
KR	1019910009812		11/1991
WO	WO 89/05086		6/1989
WO	WO 94/18809		8/1994
WO	WO 95/13498		5/1995
WO	WO 96/41098		12/1996
WO	WO 99/06759		2/1999
WO	WO 02/061328	A1	8/2002

OTHER PUBLICATIONS

"DS96177 RS-485 / RS-422 Differential Bus Repeater," National Semiconductor Corporation, Feb. 1996, pp. 1-8.
"DS2003 / DA9667 / DS2004 High Current / Voltage Darlington Drivers," National Semiconductor Corporation, Dec. 1995, pp. 1-8.
"LM140A / LM140 / LM340A / LM78000 Series 3—Terminal Positive Regulators," National Semiconductor Corporation, Jan. 1995, pp. 1-14.
High End Systems, Inc., Trackspot User Manual, Aug. 1997, Excerpts (Cover, Title page, pp. ii through iii and 2-13 through 2-14).
Artistic License, AL4000 DMX512 Processors, Revision 3.4, Jun. 2000, Excerpts (Cover, pp. 7, 92 through 102.
Artistic License, Miscellaneous Drawings 3 sheets Jan. 12, 1995.
Artistic License, Miscellaneous Documents 2 sheets Feb. 1995 and Apr. 1996.
Newnes's Dictionary of Electronics, Fourth Edition, S.W. Amos, et al., Preface to First Edition, pp. 278-279.
"http://www.luniinus.cx/projects/chaser," (Nov. 13, 2000), pp. 1-16.
Hewlett Packard Components, "Solid State Display and Optoelectronics Designer's Catalog," pp. 30-43, Jul. 1973.
INTEC Research, TRACKSPOT, http://www.intec-research.com/trackspot.htm, pp. 1-4, Apr. 24, 2003.
SHARP, Optoelectronics Data Book, pp. 1096-1097, 1994/1995.
About DMX-512 Lighting Protocol—Pangolin Laser Systems, pp. 1-4, Apr. 7, 2003.
Avitec Licht Design '89-90, pp. 1-4.
Furry, Kevin and Somerville, Chuck, Affidavit, LED effects, Feb. 22, 2002, pp. 24-29.
Putman, Peter H., "The Allure of LED," www.sromagazine.biz, Jun./Jul. 2002, pp. 47-52.
Bremer, Darlene, "LED Advancements Increase Potential," www.ecmag.com, Apr. 2002, p. 115.
Longo, Linda, "LEDS Lead the Way," Home Lighting & Accessories, Jun. 2002, pp. 226-234.

* cited by examiner

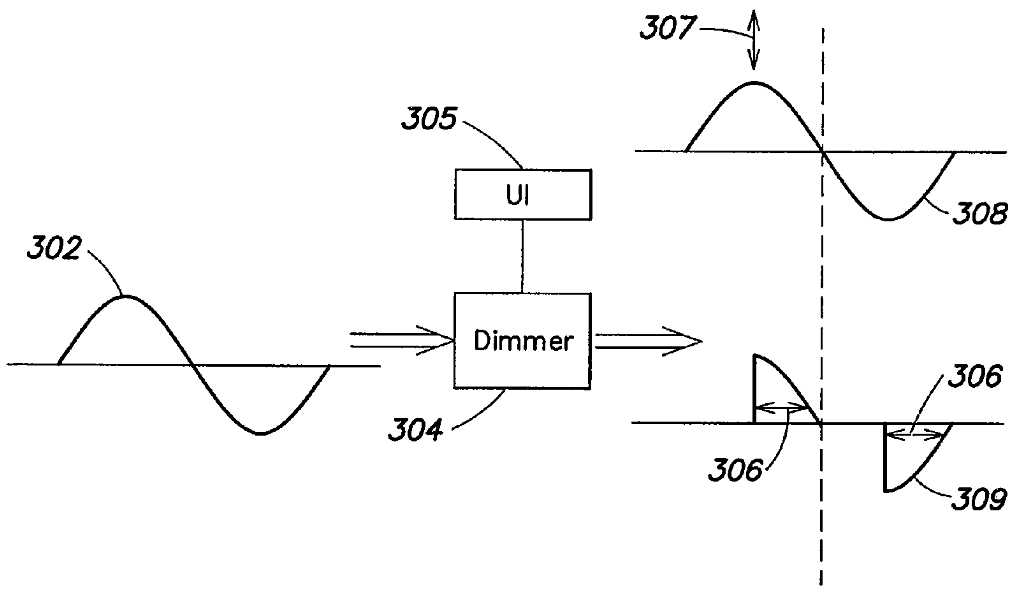


FIG. 1
(PRIOR ART)

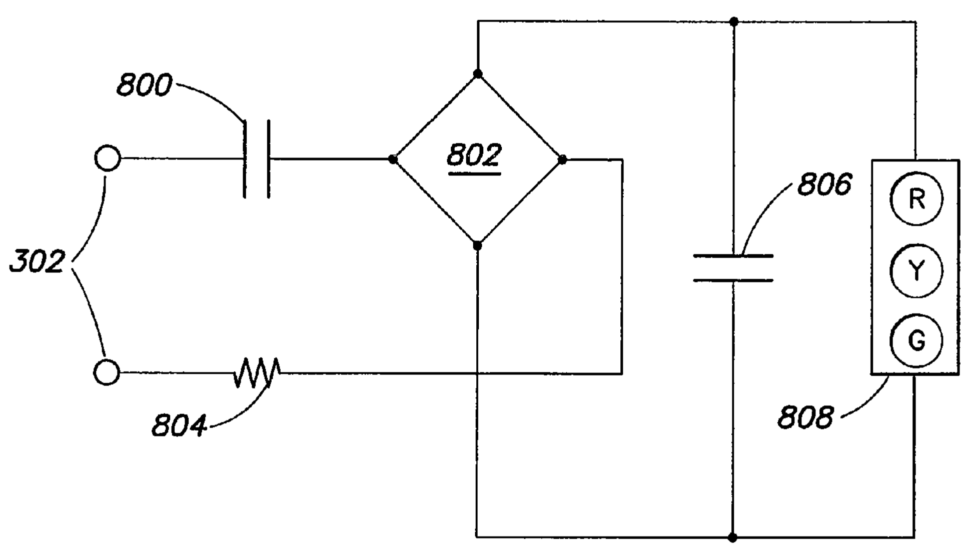
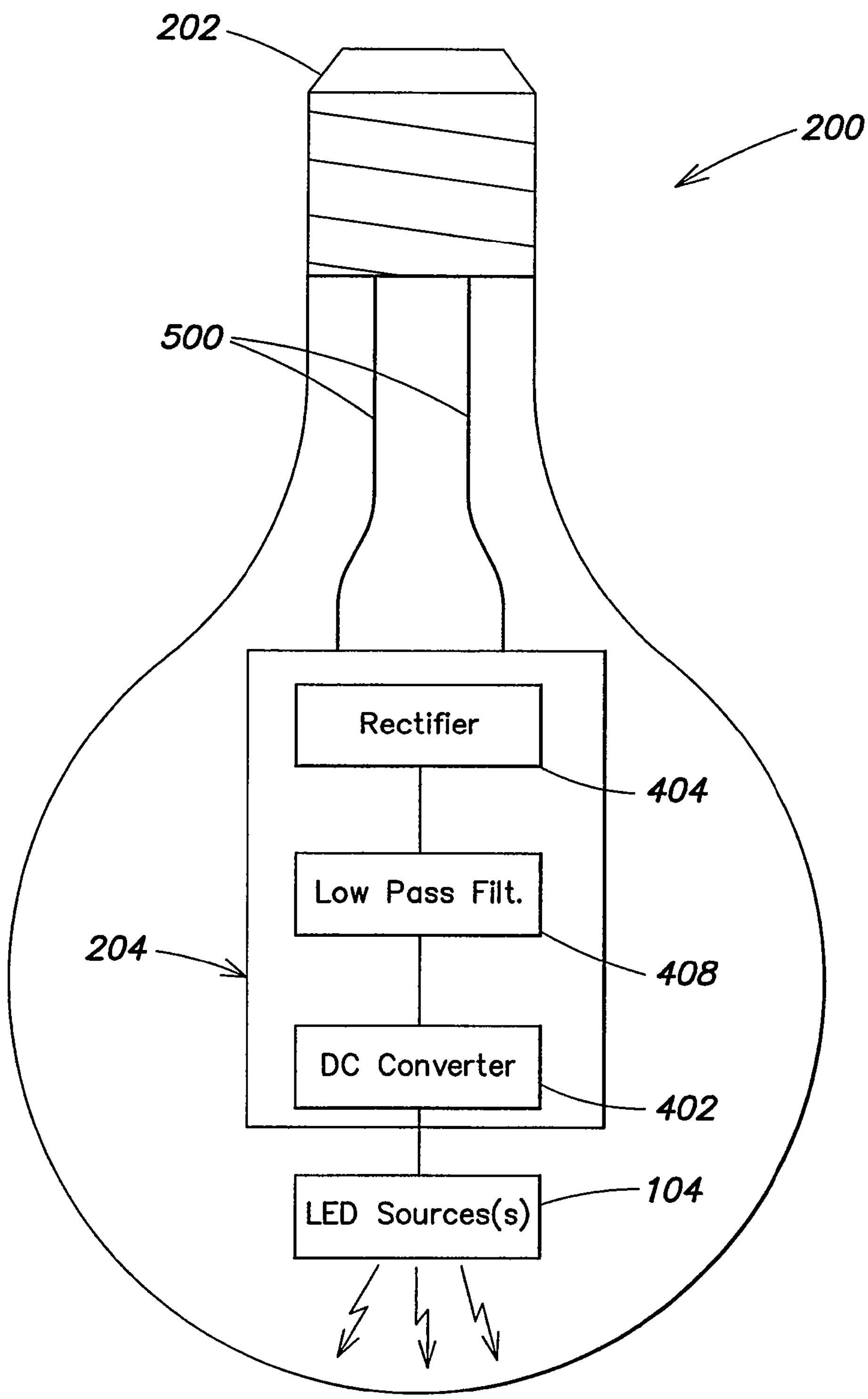


FIG. 2
(PRIOR ART)



202
200
500
Rectifier
404
Low Pass Filt.
204
408
DC Converter
402
104
LED Sources(s)

FIG. 3

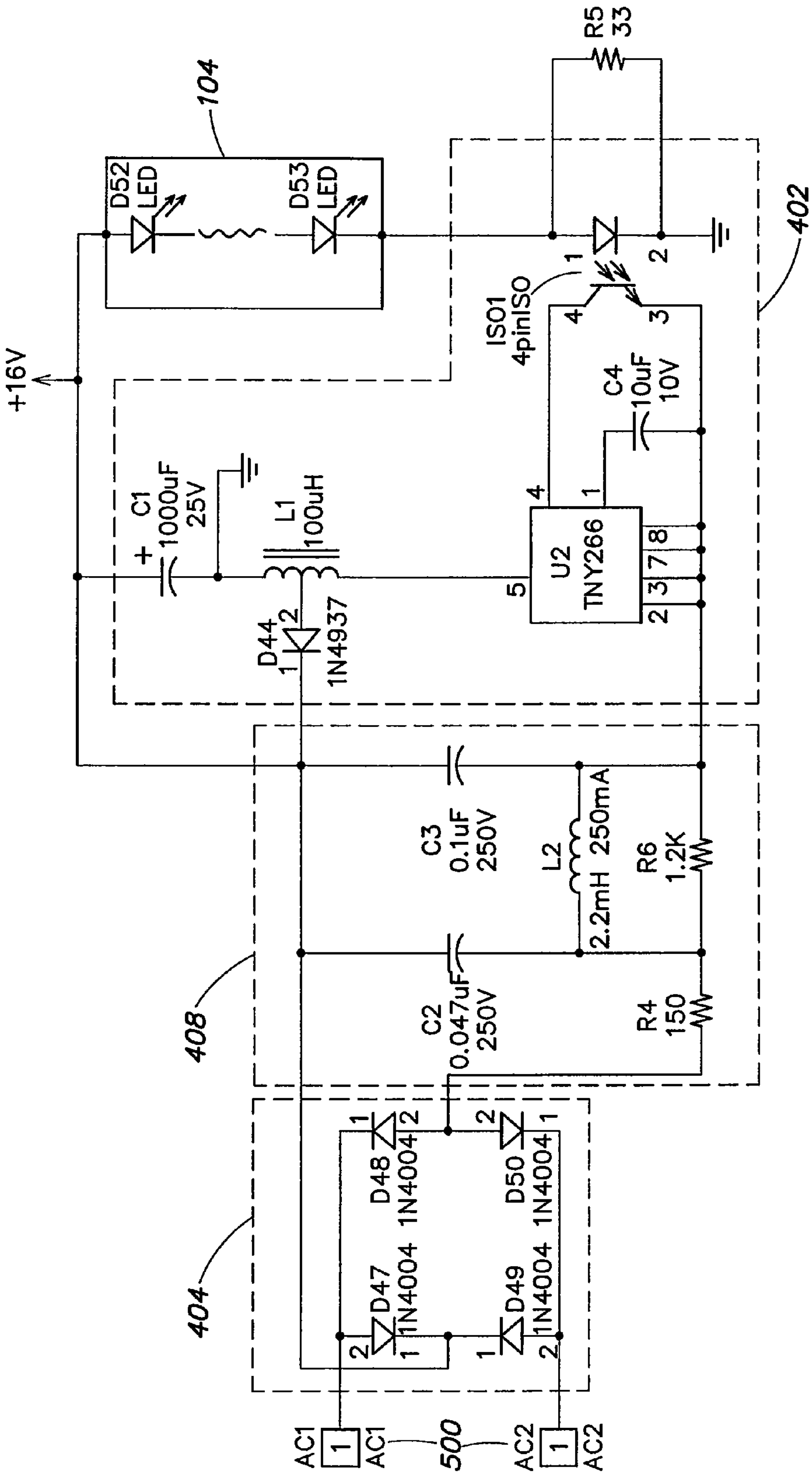

R5
33
104
D52
LED
D53
LED
402
ISO1
4pinISO
+16V
C4
10uF
10V
C1
1000uF
25V
L1
100uH
U2
TNY266
D44
1N4937
C3
0.1uF
250V
L2
2.2mH 250mA
R6
1.2K
408
C2
0.047uF
250V
R4
150
D48
1N4004
D50
1N4004
D47
1N4004
D49
1N4004
404
AC1
AC1
500
AC2
AC2

FIG. 4

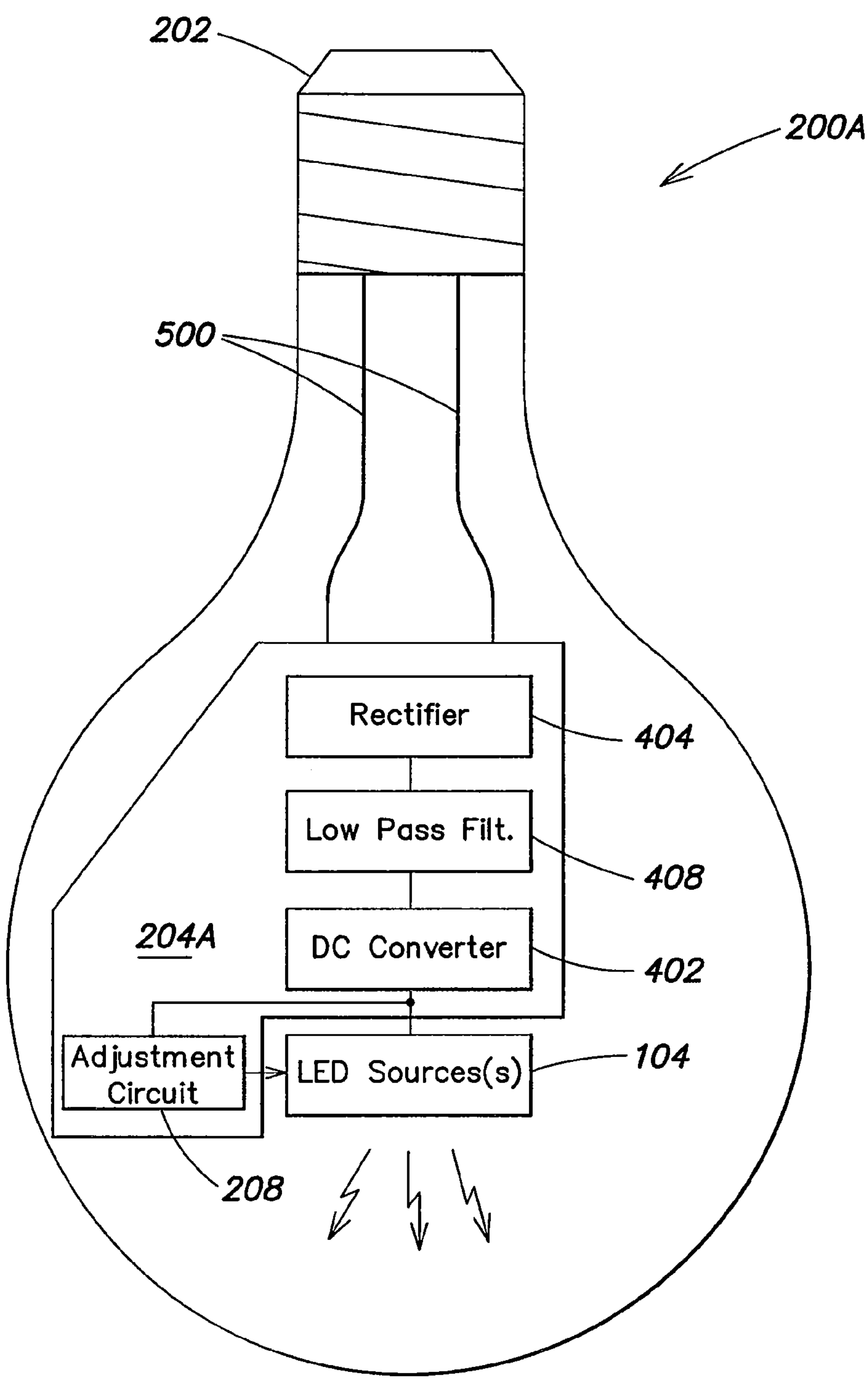

202
200A
500
Rectifier
404
Low Pass Filt.
408
204A
DC Converter
402
Adjustment Circuit
LED Sources(s)
104
208

FIG. 5

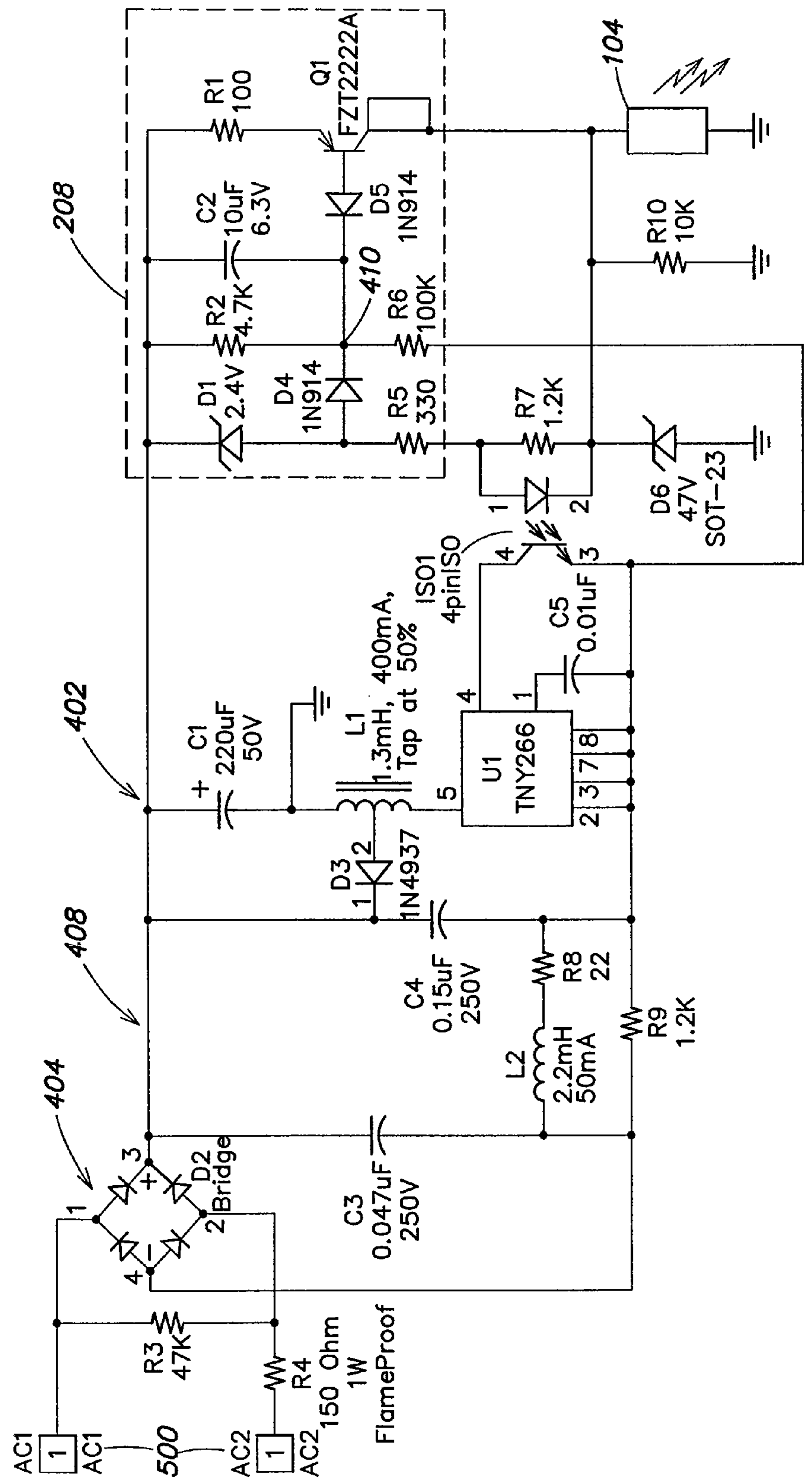

208
R1
100
Q1
FZT2222A
104
C2
10uF
6.3V
D5
1N914
R10
10K
410
R2
4.7K
R6
100K
D1
2.4V
D4
1N914
R5
330
R7
1.2K
D6
47V
SOT-23
ISO1
4pinISO
C5
0.01uF
402
C1
220uF
50V
L1
1.3mH, 400mA,
Tap at 50%
U1
TNY266
D3
1N4937
408
C4
0.15uF
250V
R8
22
R9
1.2K
L2
2.2mH
50mA
404
D2
Bridge
C3
0.047uF
250V
R3
47K
R4
150 Ohm
1W
FlameProof
AC1
AC2
500

FIG. 6

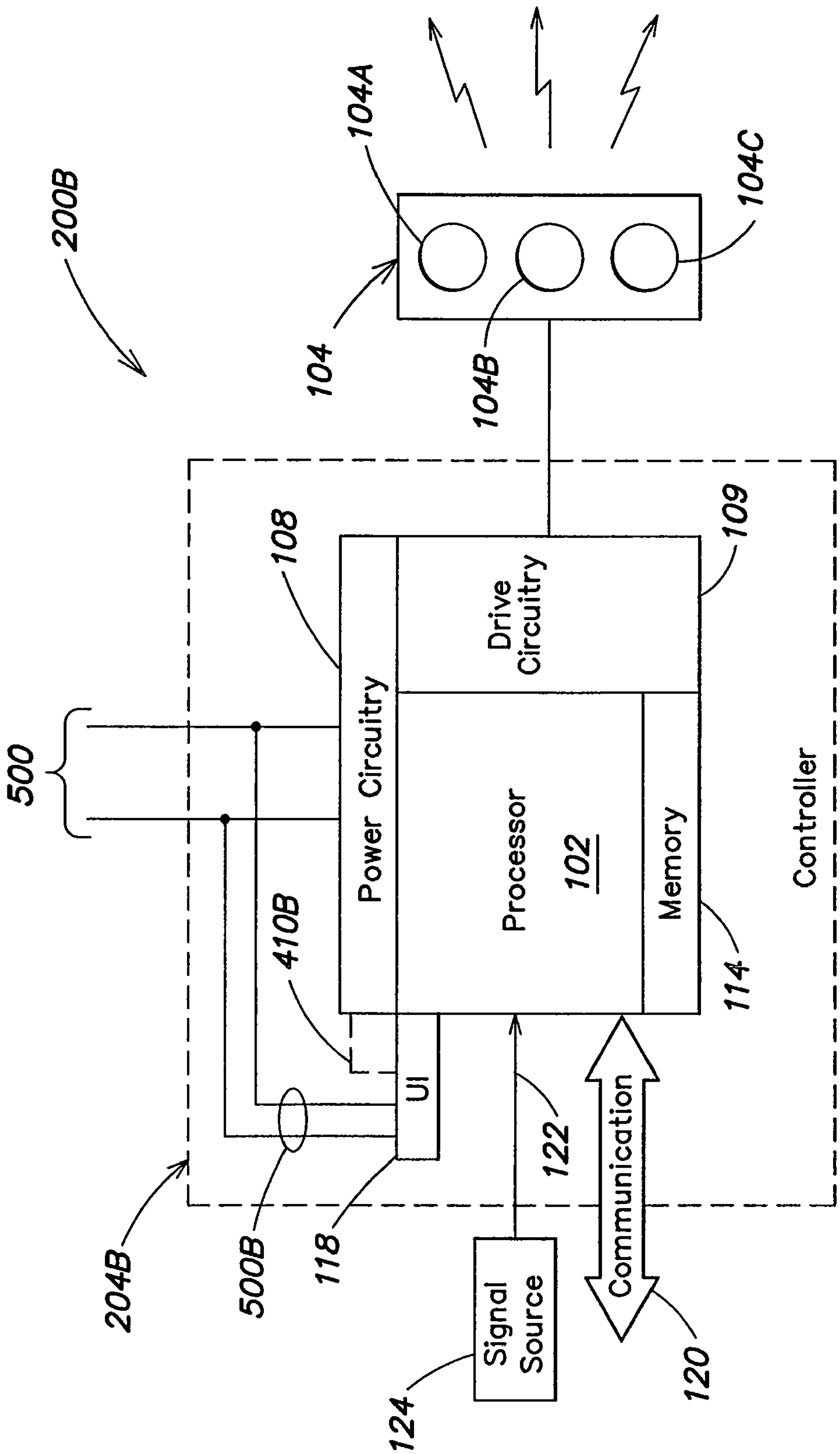

200B
104A
104
104B
104C
108
109
Drive Circuitry
Power Circuitry
Processor
102
Memory
Controller
500
410B
114
UI
122
Communication
204B
500B
118
Signal Source
120
124

FIG. 7

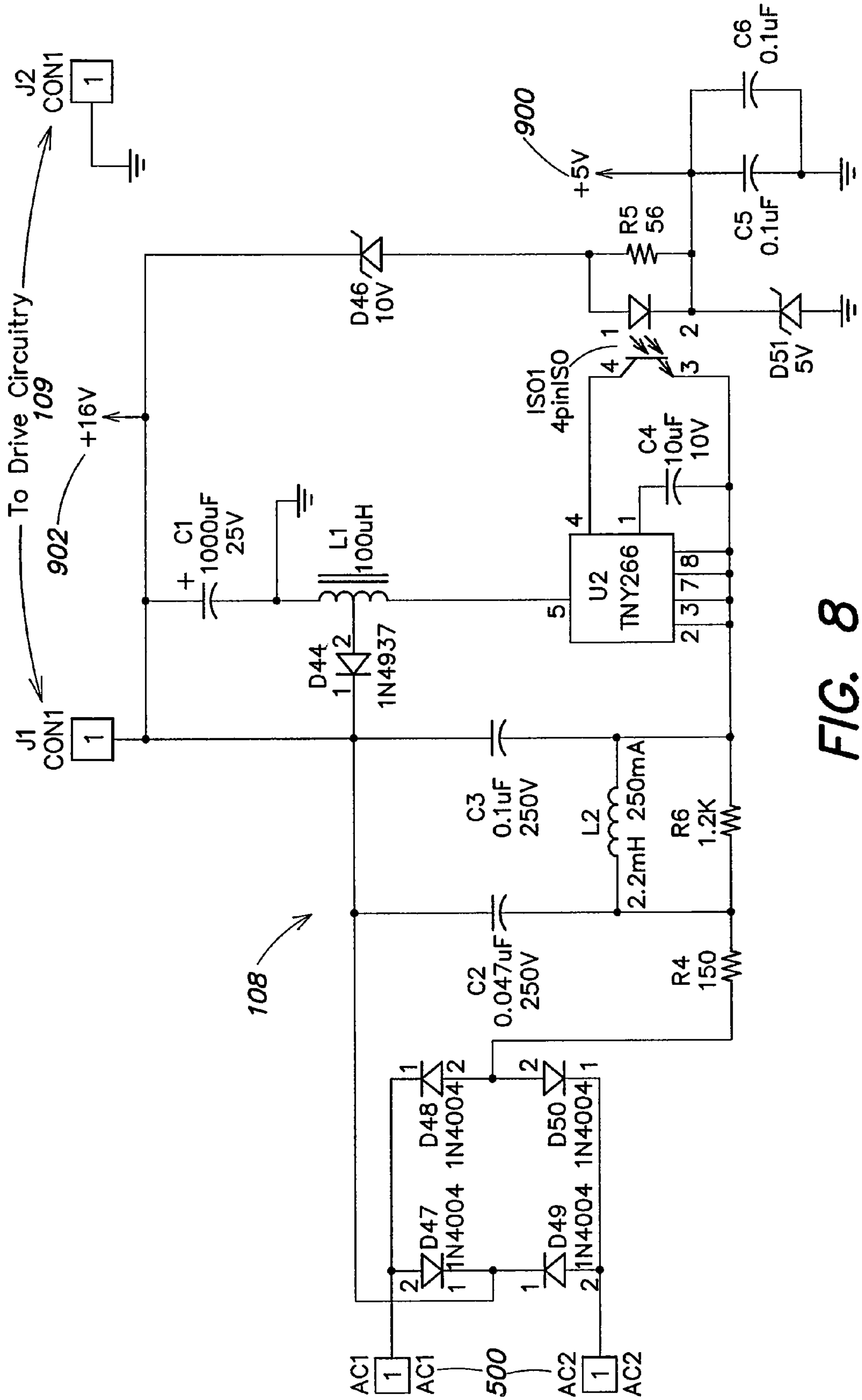

J2
CON1
To Drive Circuitry
109
902
+16V
J1
CON1
C1
1000uF
25V
L1
100uH
D44
1N4937
D46
10V
ISO1
4pinISO
U2
TNY266
C4
10uF
10V
R5
56
900
+5V
C5
0.1uF
C6
0.1uF
D51
5V
C3
0.1uF
250V
L2
2.2mH 250mA
R6
1.2K
C2
0.047uF
250V
R4
150
108
D47
1N4004
D48
1N4004
D49
1N4004
D50
1N4004
AC1
AC2
500

FIG. 8

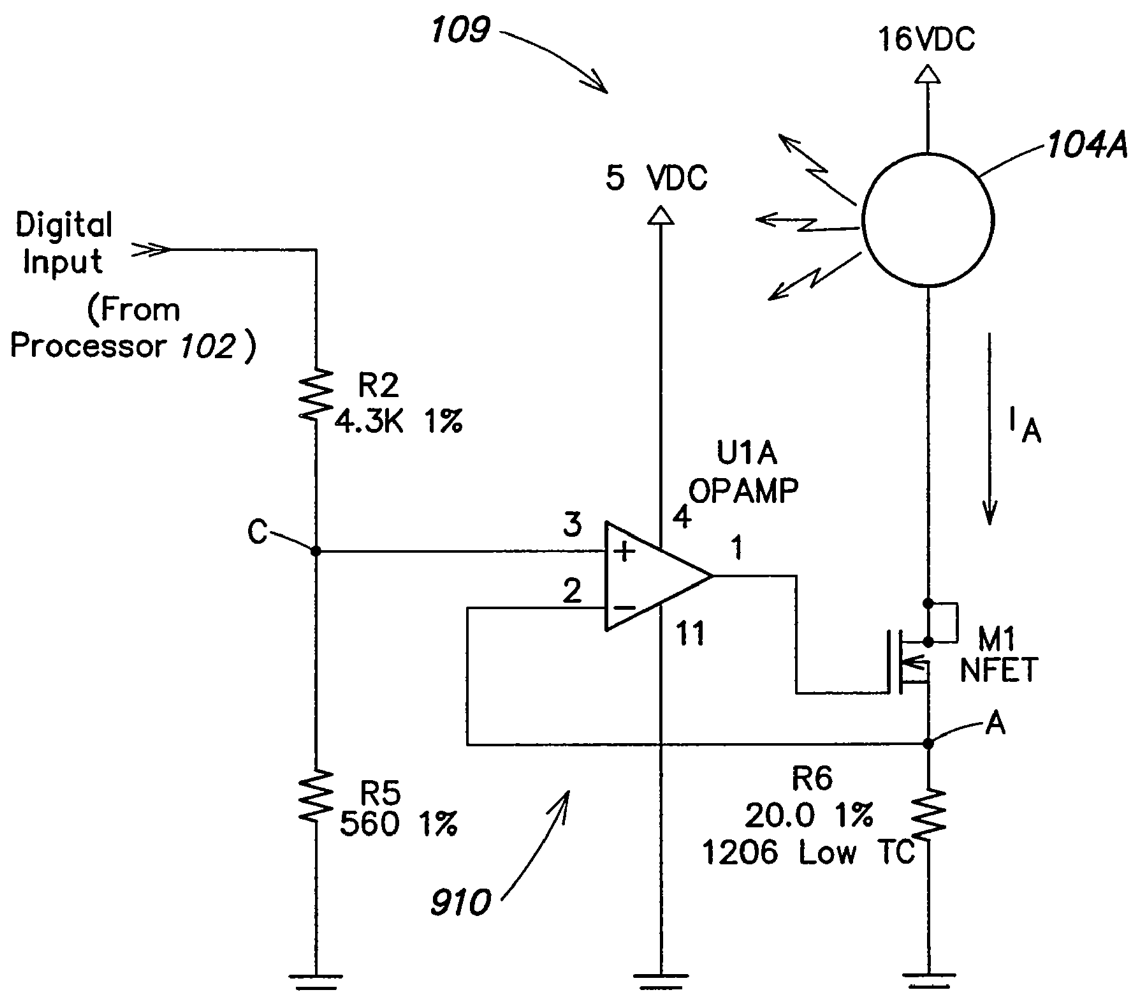

109
16VDC
104A
5 VDC
Digital
Input
(From
Processor 102)
R2
4.3K 1%
I_A
U1A
OPAMP
C
3
4
1
2
11
M1
NFET
A
R6
20.0 1%
1206 Low TC
R5
560 1%
910

FIG. 9

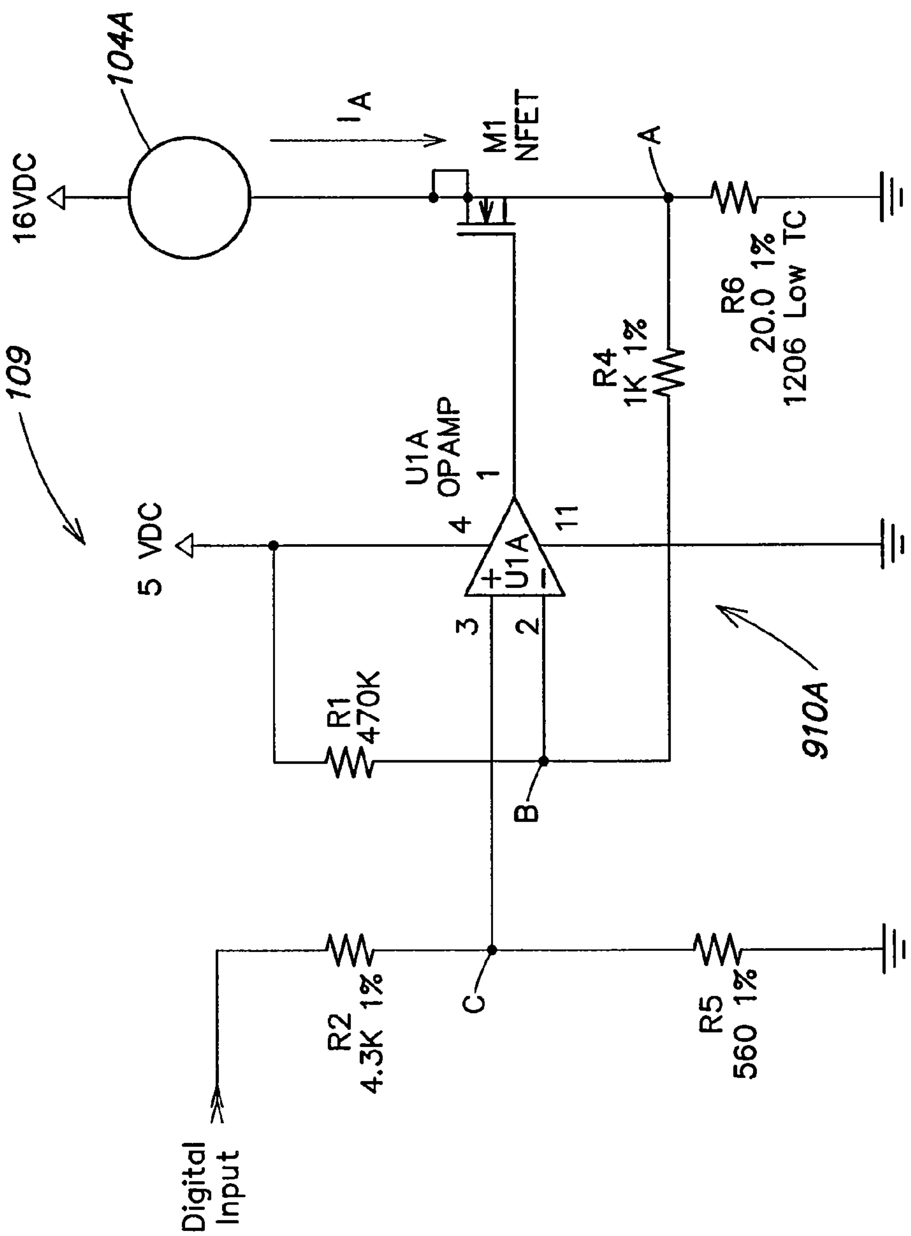

104A
16VDC
I_A
M1
NFET
A
R6
20.0 1%
1206 Low TC
109
R4
1K 1%
U1A
OPAMP
1
4
11
5 VDC
U1A
+
−
3
2
R1
470K
910A
B
C
R2
4.3K 1%
R5
560 1%
Digital
Input

FIG. 10

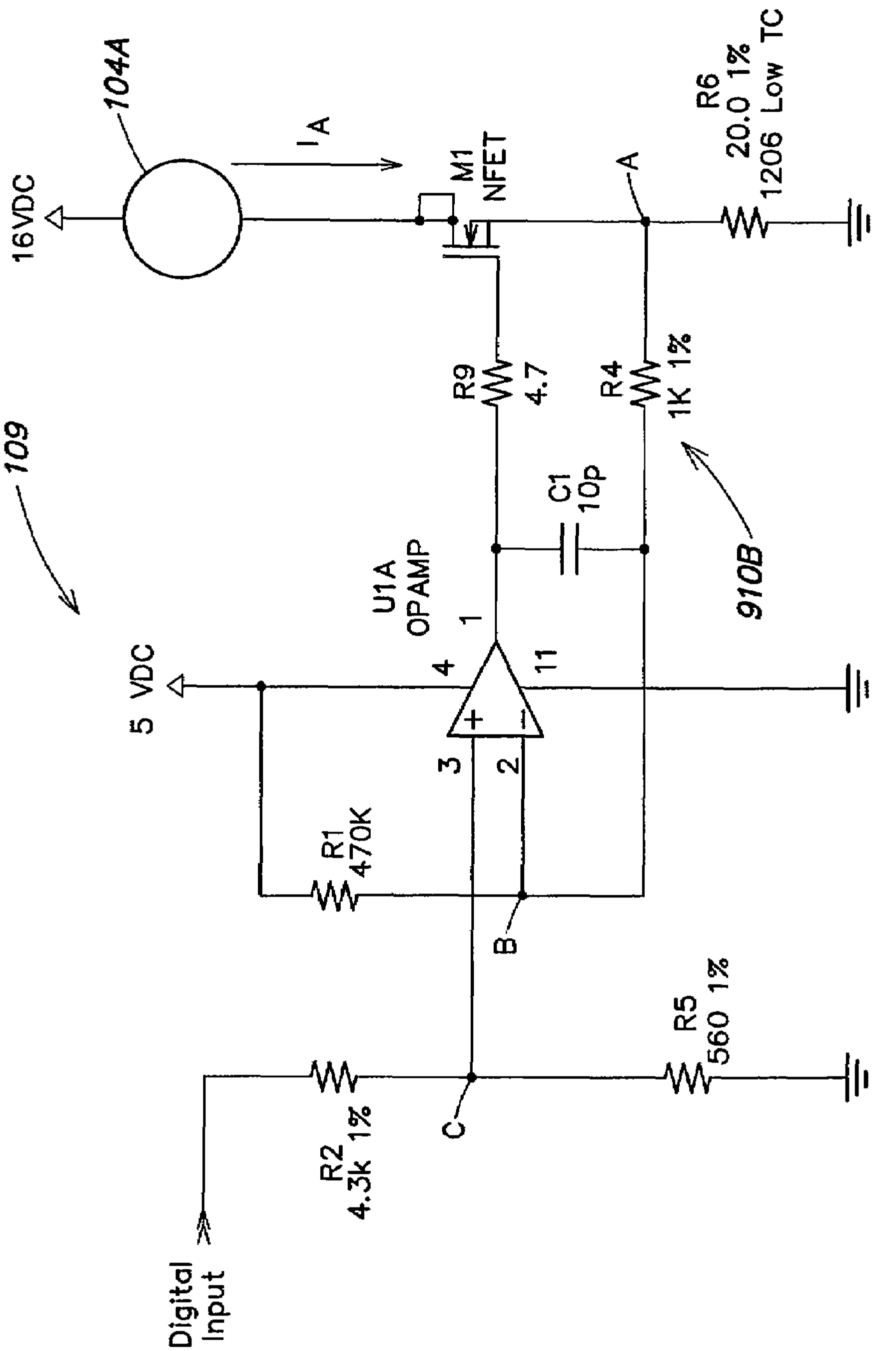

104A
16VDC
I_A
M1
NFET
A
R6
20.0 1%
1206 Low TC
109
R9
4.7
R4
1K 1%
C1
10p
910B
U1A
OPAMP
5 VDC
1
4
11
3
2
R1
470K
B
R5
560 1%
R2
4.3k 1%
C
Digital
Input

FIG. 11

METHODS AND APPARATUS FOR PROVIDING POWER TO LIGHTING DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit, under 35 U.S.C. §120, as a continuation of U.S. non-provisional application Ser. No. 10/435,687, filed May 9, 2003, entitled Methods and Apparatus for Providing Power to Lighting Devices," which is now U.S Pat. No. 7,038,399, which is hereby incorporated herein by reference.

Ser. No. 10/435,687 in turn claims the benefit, under 35 U.S.C. § 119(e), of U.S. Provisional Application Ser. No. 60/379,079, filed May 9, 2002, entitled "Systems and Methods for Controlling LED Based Lighting," and U.S. Provisional Application Ser. No. 60/391,627, filed Jun. 26, 2002, entitled "Switched Current Sink," which applications are hereby incorporated herein by reference.

Ser. No. 10/435,687 also claims the benefit under 35 U.S.C. §120 as a continuation-in-part (CIP) of the following U.S. non-provisional applications:

Ser. No. 09/805,368, filed Mar. 13, 2001, entitled LIGHT-EMITTING DIODE BASED PRODUCTS, which is now U.S. Pat. No. 7,186,003; and

Ser. No. 09/805,590, filed Mar. 13, 2001, entitled LIGHT-EMITTING DIODE BASED PRODUCTS, which is now U.S. Pat. No. 7,064,498.

FIELD OF THE INVENTION

The present invention is directed generally to methods and apparatus for providing power to devices on A.C. power circuits. More particularly, the invention relates to methods and apparatus for providing power to light emitting diode (LED) based devices, primarily for illumination purposes.

BACKGROUND

In various lighting applications (e.g., home, commercial, industrial, etc.), there are instances in which it is desirable to adjust the amount of light generated by one or more conventional light sources (e.g., incandescent light bulbs, fluorescent light fixtures, etc.). In many cases, this is accomplished via a user-operated device, commonly referred to as a "dimmer," that adjusts the power delivered to the light source(s). Many types of conventional dimmers are known that allow a user to adjust the light output of one or more light sources via some type of user interface (e.g., by turning a knob, moving a slider, etc., often mounted on a wall in proximity to an area in which it is desirable to adjust the light level). The user interface of some dimmers also may be equipped with a switching/adjustment mechanism that allows one or more light sources to be switched off and on instantaneously, and also have their light output gradually varied when switched on.

Many lighting systems for general interior or exterior illumination often are powered by an A.C. source, commonly referred to as a "line voltage" (e.g., 120 Volts RMS at 60 Hz, 220 Volts RMS at 50 Hz). A conventional A.C. dimmer typically receives the A.C. line voltage as an input, and provides an A.C. signal output having one or more variable parameters that have the effect of adjusting the average voltage of the output signal (and hence the capability of the A.C. output signal to deliver power) in response to user operation of the dimmer. This dimmer output signal

generally is applied, for example, to one or more light sources that are mounted in conventional sockets or fixtures coupled to the dimmer output (such sockets or fixtures sometimes are referred to as being on a "dimmer circuit").

Conventional A.C. dimmers may be configured to control power delivered to one or more light sources in one of a few different ways. For example, in one implementation, the adjustment of the user interface causes the dimmer to increase or decrease a voltage amplitude of the A.C. dimmer output signal. More commonly, however, in other implementations, the adjustment of the user interface causes the dimmer to adjust the duty cycle of the A.C. dimmer output signal (e.g., by "chopping-out" portions of A.C. voltage cycles). This technique sometimes is referred to as "angle modulation" (based on the adjustable phase angle of the output signal). Perhaps the most commonly used dimmers of this type employ a triac that is selectively operated to adjust the duty cycle (i.e., modulate the phase angle) of the dimmer output signal by chopping-off rising portions of A.C. voltage half-cycles (i.e., after zero-crossings and before peaks). Other types of dimmers that adjust duty cycles may employ gate turn-off (GTO) thyristors that are selectively operated to chop-off falling portions of A.C. voltage half-cycles (i.e., after peaks and before zero-crossings).

FIG. **1** generally illustrates some conventional A.C. dimmer implementations. In particular, FIG. **1** shows an example of an A.C. voltage waveform **302** (e.g., representing a standard line voltage) that may provide power to one or more conventional light sources. FIG. **1** also shows a generalized A.C. dimmer **304** responsive to a user interface **305**. In the first implementation discussed above, the dimmer **304** is configured to output the waveform **308**, in which the amplitude **307** of the dimmer output signal may be adjusted via the user interface **305**. In the second implementation discussed above, the dimmer **304** is configured to output the waveform **309**, in which the duty cycle **306** of the waveform **309** may be adjusted via the user interface **305**.

As discussed above, both of the foregoing techniques have the effect of adjusting the average voltage applied to the light source(s), which in turn adjusts the intensity of light generated by the source(s). Incandescent sources are particularly well-suited for this type of operation, as they produce light when there is current flowing through a filament in either direction; as the average voltage of an A.C. signal applied to the source(s) is adjusted (e.g., either by an adjustment of voltage amplitude or duty cycle), the current (and hence the power) delivered to the light source also is changed and the corresponding light output changes. With respect to the duty cycle technique, the filament of an incandescent source has thermal inertia and does not stop emitting light completely during short periods of voltage interruption. Accordingly, the generated light as perceived by the human eye does not appear to flicker when the voltage is "chopped," but rather appears to gradually change.

SUMMARY

The present invention is directed generally to methods and apparatus for providing power to devices on A.C. power circuits. More particularly, methods and apparatus according to various embodiments of the present invention facilitate the use of LED-based light sources on A.C. power circuits that provide either a standard line voltage or signals other than standard line voltages.

In one embodiment, methods and apparatus of the invention particularly facilitate the use of LED-based light sources on A.C. power circuits that are controlled by conventional dimmers (i.e., "A.C. dimmer circuits"). In one aspect, methods and apparatus of the present invention facilitate convenient substitution of LED-based light sources in lighting environments employing A.C. dimming devices and conventional light sources. In yet other aspects, methods and apparatus according to the present invention facilitate the control of one or more parameters relating to the light generated by LED-based light sources (e.g., intensity, color, color temperature, temporal characteristics, etc.) via operation of a conventional A.C. dimmer and/or other signals present on the A.C. power circuit.

More generally, one embodiment of the invention is directed to an illumination apparatus, comprising at least one LED and at least one controller coupled to the at least one LED. The controller is configured to receive a power-related signal from an A.C. power source that provides signals other than a standard A.C. line voltage. The controller further is configured to provide power to the at least one LED based on the power-related signal.

Another embodiment of the invention is directed to an illumination method, comprising an act of providing power to at least one LED based on a power-related signal from an A.C. power source that provides signals other than a standard A.C. line voltage.

Another embodiment of the invention is directed to an illumination apparatus, comprising at least one LED, and at least one controller coupled to the at least one LED and configured to receive a power-related signal from an alternating current (A.C.) dimmer circuit and provide power to the at least one LED based on the power-related signal.

Another embodiment of the invention is directed to an illumination method, comprising an act of providing power to at least one LED based on a power-related signal from an alternating current (A.C.) dimmer circuit.

Another embodiment of the invention is directed to an illumination apparatus, comprising at least one LED adapted to generate an essentially white light, and at least one controller coupled to the at least one LED and configured to receive a power-related signal from an alternating current (A.C.) dimmer circuit and provide power to the at least one LED based on the power-related signal. The A.C. dimmer circuit is controller by a user interface to vary the power-related signal. The controller is configured to variably control at least one parameter of the essentially white light in response to operation of the user interface so as to approximate light generation characteristics of an incandescent light source.

Another embodiment of the invention is directed to a lighting system, comprising at least one LED, a power connector, and a power converter associated with the power connector and adapted to convert A.C. dimmer circuit power received by the power connector to form a converted power. The system also includes an adjustment circuit associated with the power converter adapted to adjust power delivered to the at least one LED.

Another embodiment of the invention is directed to a method of providing illumination, comprising the steps of providing an AC dimmer circuit, connecting an LED lighting system to the AC dimmer circuit, generating light from the LED lighting system by energizing the AC dimmer circuit, and adjusting the light generated by the LED lighting system by adjusting the AC dimmer circuit.

Another embodiment of the invention is directed to method for controlling at least one device powered via an A.C. line voltage. The method comprises an act of generating a power signal based on the A.C. line voltage, wherein the power signal provides an essentially constant power to

the at least one device and includes at least one communication channel carrying control information for the at least one device, the at least one communication channel occupying a portion of a duty cycle over a period of cycles of the A.C. line voltage.

Another embodiment of the invention is directed to an apparatus for controlling at least one device powered via an A.C. line voltage. The apparatus comprises a supply voltage controller configured to generate a power signal based on the A.C. line voltage, wherein the power signal provides an essentially constant power to the at least one device and includes at least one communication channel carrying control information for the at least one device, the at least one communication channel occupying a portion of a duty cycle over a period of cycles of the A.C. line voltage. In one aspect of this embodiment, the supply voltage controller includes at least one user interface to provide variable control information in the at least one communication channel.

As used herein for purposes of the present disclosure, the term "LED" should be understood to include any electroluminescent diode or other type of carrier injection/junction-based system that is capable of generating radiation in response to an electric signal. Thus, the term LED includes, but is not limited to, various semiconductor-based structures that emit light in response to current, light emitting polymers, electroluminescent strips, and the like.

In particular, the term LED refers to light emitting diodes of all types (including semi-conductor and organic light emitting diodes) that may be configured to generate radiation in one or more of the infrared spectrum, ultraviolet spectrum, and various portions of the visible spectrum (generally including radiation wavelengths from approximately 400 nanometers to approximately 700 nanometers). Some examples of LEDs include, but are not limited to, various types of infrared LEDs, ultraviolet LEDs, red LEDs, blue LEDs, green LEDs, yellow LEDs, amber LEDs, orange LEDs, and white LEDs (discussed further below). It also should be appreciated that LEDs may be configured to generate radiation having various bandwidths for a given spectrum (e.g., narrow bandwidth, broad bandwidth).

For example, one implementation of an LED configured to generate essentially white light (e.g., a white LED) may include a number of dies which respectively emit different spectra of electroluminescence that, in combination, mix to form essentially white light. In another implementation, a white light LED may be associated with a phosphor material that converts electroluminescence having a first spectrum to a different second spectrum. In one example of this implementation, electroluminescence having a relatively short wavelength and narrow bandwidth spectrum "pumps" the phosphor material, which in turn radiates longer wavelength radiation having a somewhat broader spectrum.

It should also be understood that the term LED does not limit the physical and/or electrical package type of an LED. For example, as discussed above, an LED may refer to a single light emitting device having multiple dies that are configured to respectively emit different spectra of radiation (e.g., that may or may not be individually controllable). Also, an LED may be associated with a phosphor that is considered as an integral part of the LED (e.g., some types of white LEDs). In general, the term LED may refer to packaged LEDs, non-packaged LEDs, surface mount LEDs, chip-on-board LEDs, T-package mount LEDs, radial package LEDs, power package LEDs, LEDs including some type of encasement and/or optical element (e.g., a diffusing lens), etc.

The term "light source" should be understood to refer to any one or more of a variety of radiation sources, including, but not limited to, LED-based sources (employing one or more LEDs as defined above), incandescent sources (e.g., filament lamps, halogen lamps), fluorescent sources, phosphorescent sources, high-intensity discharge sources (e.g., sodium vapor, mercury vapor, and metal halide lamps), lasers, other types of electroluminescent sources, pyro-luminescent sources (e.g., flames), candle-luminescent sources (e.g., gas mantles, carbon arc radiation sources), photo-luminescent sources (e.g., gaseous discharge sources), cathode luminescent sources using electronic satiation, galvano-luminescent sources, crystallo-luminescent sources, kine-luminescent sources, thermo-luminescent sources, triboluminescent sources, sonoluminescent sources, radioluminescent sources, and luminescent polymers.

A given light source may be configured to generate electromagnetic radiation within the visible spectrum, outside the visible spectrum, or a combination of both. Hence, the terms "light" and "radiation" are used interchangeably herein. Additionally, a light source may include as an integral component one or more filters (e.g., color filters), lenses, or other optical components. Also, it should be understood that light sources may be configured for a variety of applications, including, but not limited to, indication and/or illumination. An "illumination source" is a light source that is particularly configured to generate radiation having a sufficient intensity to effectively illuminate an interior or exterior space.

The term "spectrum" should be understood to refer to any one or more frequencies (or wavelengths) of radiation produced by one or more light sources. Accordingly, the term "spectrum" refers to frequencies (or wavelengths) not only in the visible range, but also frequencies (or wavelengths) in the infrared, ultraviolet, and other areas of the overall electromagnetic spectrum. Also, a given spectrum may have a relatively narrow bandwidth (essentially few frequency or wavelength components) or a relatively wide bandwidth (several frequency or wavelength components having various relative strengths). It should also be appreciated that a given spectrum may be the result of a mixing of two or more other spectra (e.g., mixing radiation respectively emitted from multiple light sources).

For purposes of this disclosure, the term "color" is used interchangeably with the term "spectrum." However, the term "color" generally is used to refer primarily to a property of radiation that is perceivable by an observer (although this usage is not intended to limit the scope of this term). Accordingly, the terms "different colors" implicitly refer to multiple spectra having different wavelength components and/or bandwidths. It also should be appreciated that the term "color" may be used in connection with both white and non-white light.

The term "color temperature" generally is used herein in connection with white light, although this usage is not intended to limit the scope of this term. Color temperature essentially refers to a particular color content or shade (e.g., reddish, bluish) of white light. The color temperature of a given radiation sample conventionally is characterized according to the temperature in degrees Kelvin (K) of a black body radiator that radiates essentially the same spectrum as the radiation sample in question. The color temperature of white light generally falls within a range of from approximately 700 degrees K (generally considered the first visible to the human eye) to over 10,000 degrees K.

Lower color temperatures generally indicate white light having a more significant red component or a "warmer feel," while higher color temperatures generally indicate white light having a more significant blue component or a "cooler feel." By way of example, fire has a color temperature of approximately 1,800 degrees K, a conventional incandescent bulb has a color temperature of approximately 2848 degrees K, early morning daylight has a color temperature of approximately 3,000 degrees K, and overcast midday skies have a color temperature of approximately 10,000 degrees K. A color image viewed under white light having a color temperature of approximately 3,000 degree K has a relatively reddish tone, whereas the same color image viewed under white light having a color temperature of approximately 10,000 degrees K has a relatively bluish tone.

The terms "lighting unit" and "lighting fixture" are used interchangeably herein to refer to an apparatus including one or more light sources of same or different types. A given lighting unit may have any one of a variety of mounting arrangements for the light source(s), enclosure/housing arrangements and shapes, and/or electrical and mechanical connection configurations. Additionally, a given lighting unit optionally may be associated with (e.g., include, be coupled to and/or packaged together with) various other components (e.g., control circuitry) relating to the operation of the light source(s). An "LED-based lighting unit" refers to a lighting unit that includes one or more LED-based light sources as discussed above, alone or in combination with other non LED-based light sources.

The terms "processor" or "controller" are used herein interchangeably to describe various apparatus relating to the operation of one or more light sources. A processor or controller can be implemented in numerous ways, such as with dedicated hardware, using one or more microprocessors that are programmed using software (e.g., microcode) to perform the various functions discussed herein, or as a combination of dedicated hardware to perform some functions and programmed microprocessors and associated circuitry to perform other functions.

In various implementations, a processor or controller may be associated with one or more storage media (generically referred to herein as "memory," e.g., volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM, floppy disks, compact disks, optical disks, magnetic tape, etc.). In some implementations, the storage media may be encoded with one or more programs that, when executed on one or more processors and/or controllers, perform at least some of the functions discussed herein. Various storage media may be fixed within a processor or controller or may be transportable, such that the one or more programs stored thereon can be loaded into a processor or controller so as to implement various aspects of the present invention discussed herein. The terms "program" or "computer program" are used herein in a generic sense to refer to any type of computer code (e.g., software or microcode) that can be employed to program one or more processors or controllers.

The term "addressable" is used herein to refer to a device (e.g., a light source in general, a lighting unit or fixture, a controller or processor associated with one or more light sources or lighting units, other non-lighting related devices, etc.) that is configured to receive information (e.g., data) intended for multiple devices, including itself, and to selectively respond to particular information intended for it. The term "addressable" often is used in connection with a networked environment (or a "network," discussed further below), in which multiple devices are coupled together via some communications medium or media.

In one network implementation, one or more devices coupled to a network may serve as a controller for one or more other devices coupled to the network (e.g., in a master/slave relationship). In another implementation, a networked environment may include one or more dedicated controllers that are configured to control one or more of the devices coupled to the network. Generally, multiple devices coupled to the network each may have access to data that is present on the communications medium or media; however, a given device may be "addressable" in that it is configured to selectively exchange data with (i.e., receive data from and/or transmit data to) the network, based, for example, on one or more particular identifiers (e.g., "addresses") assigned to it.

The term "network" as used herein refers to any interconnection of two or more devices (including controllers or processors) that facilitates the transport of information (e.g. for device control, data storage, data exchange, etc.) between any two or more devices and/or among multiple devices coupled to the network. As should be readily appreciated, various implementations of networks suitable for interconnecting multiple devices may include any of a variety of network topologies and employ any of a variety of communication protocols. Additionally, in various networks according to the present invention, any one connection between two devices may represent a dedicated connection between the two systems, or alternatively a non-dedicated connection. In addition to carrying information intended for the two devices, such a non-dedicated connection may carry information not necessarily intended for either of the two devices (e.g., an open network connection). Furthermore, it should be readily appreciated that various networks of devices as discussed herein may employ one or more wireless, wire/cable, and/or fiber optic links to facilitate information transport throughout the network.

The term "user interface" as used herein refers to an interface between a human user or operator and one or more devices that enables communication between the user and the device(s). Examples of user interfaces that may be employed in various implementations of the present invention include, but are not limited to, switches, potentiometers, buttons, dials, sliders, a mouse, keyboard, keypad, various types of game controllers (e.g., joysticks), track balls, display screens, various types of graphical user interfaces (GUIs), touch screens, microphones and other types of sensors that may receive some form of human-generated stimulus and generate a signal in response thereto.

It should be appreciated the all combinations of the foregoing concepts and additional concepts discussed in greater detail below are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter appearing at the end of this disclosure are contemplated as being part of the inventive subject matter.

The following patents and patent applications are hereby incorporated herein by reference:

U.S. Pat. No. 6,016,038, issued Jan. 18, 2000, entitled "Multicolored LED Lighting Method and Apparatus;"

U.S. Pat. No. 6,211,626, issued Apr. 3, 2001 to Lys et al, entitled "Illumination Components,"

U.S. patent application Ser. No. 09/870,193, filed May 30, 2001, entitled "Methods and Apparatus for Controlling Devices in a Networked Lighting System;"

U.S. patent application Ser. No. 09/344,699, filed Jun. 25, 1999, entitled "Method for Software Driven Generation of Multiple Simultaneous High Speed Pulse Width Modulated Signals;"

U.S. patent application Ser. No. 09/805,368, filed Mar. 13, 2001, entitled "Light-Emitting Diode Based Products;"

U.S. patent application Ser. No. 09/663,969, filed Sep. 19, 2000, entitled "Universal Lighting Network Methods and Systems;"

U.S. patent application Ser. No. 09/716,819, filed Nov. 20, 2000, entitled "Systems and Methods for Generating and Modulating Illumination Conditions;"

U.S. patent application Ser. No. 09/675,419, filed Sep. 29, 2000, entitled "Systems and Methods for Calibrating Light Output by Light-Emitting Diodes;"

U.S. patent application Ser. No. 09/870,418, filed May 30, 2001, entitled "A Method and Apparatus for Authoring and Playing Back Lighting Sequences;"

U.S. patent application Ser. No. 10/045,629, filed Oct. 25, 2001, entitled "Methods and Apparatus for Controlling Illumination;"

U.S. patent application Ser. No. 10/143,549, filed May 10, 2002, entitled "Systems and Methods for Synchronizing Lighting Effects;"

U.S. patent application Ser. No. 10/158,579, filed May 30, 2002, entitled "Methods and Apparatus for Controlling Devices in a Networked Lighting System;"

U.S. patent application Ser. No. 10/325,635, filed Dec. 19, 2002, entitled "Controlled Lighting Methods and Apparatus;" and

U.S. patent application Ser. No. 10/360,594, filed Feb. 6, 2003, entitled "Controlled Lighting Methods and Apparatus."

BRIEF DESCRIPTION OF THE FIGURES

The following figures depict certain illustrative embodiments of the invention in which like reference numerals refer to like elements. These depicted embodiments are to be understood as illustrative of the invention and not as limiting in any way.

FIG. **1** illustrates exemplary operation of conventional A.C. dimming devices;

FIG. **2** illustrates a conventional implementation for providing power to an LED-based light source from an A.C. line voltage;

FIG. **3** illustrates a lighting unit including an LED-based light source according to one embodiment of the invention;

FIG. **4** is a circuit diagram illustrating various components of the lighting unit of FIG. **3**, according to one embodiment of the invention;

FIG. **5** illustrates a lighting unit including an LED-based light source according to another embodiment of the invention;

FIG. **6** is a circuit diagram illustrating various components of the lighting unit of FIG. **5**, according to one embodiment of the invention;

FIG. **7** is a block diagram of a processor-based lighting unit including an LED-based light source according to another embodiment of the invention;

FIG. **8** is a circuit diagram illustrating various components of the power circuitry for the lighting unit of FIG. **7**;

FIG. **9** is a circuit diagram illustrating a conventional current sink employed in driving circuitry for an LED-based light source, according to one embodiment of the invention;

FIG. **10** is a circuit diagram illustrating an improved current sink, according to one embodiment of the invention; and

FIG. **11** is a circuit diagram illustrating an improved current sink, according to another embodiment of the invention.

DETAILED DESCRIPTION

Overview

Light Emitting Diode (LED) based illumination sources are becoming more popular in applications where general, task, accent, or other lighting is desired. LED efficiencies, high intensities, low cost, and high level of controllability are driving demand for LED-based light sources as replacements for conventional non LED-based light sources.

While conventional A.C. dimming devices as discussed above often are employed to control conventional light sources such as incandescent lights using an A.C. power source, Applicants have recognized and appreciated that generally such dimmers are not acceptable for use with solid-state light sources such as LED-based light sources. Stated differently, Applicants have identified that LED-based light sources, which operate based on substantially D.C. power sources, generally are incompatible with dimmer circuits that provide A.C. output signals. This situation impedes convenient substitution of LED-based light sources into pre-existing lighting systems in which conventional light sources are operated via A.C. dimmer circuits.

There are some solutions currently for providing power to LED-based lighting systems via an A.C. line voltage, but these solutions suffer from significant drawbacks if applied to A.C. dimmer circuits. FIG. **2** illustrates one such generalized scenario, in which a standard A.C. line voltage **302** (e.g., 120 Vrms, 220 Vrms, etc.) is used to power an LED-based lighting system, such as a traffic light **808** (the traffic light includes three modules of LED arrays, one red, one yellow and one green, with associated circuitry). In the arrangement of FIG. **2**, a full-wave rectifier **802**, together with capacitors **800** and **806** and resistor **804**, filter the applied A.C. line voltage so as to supply a substantially D.C. source of power for the traffic light **808**. In particular, the capacitor **800** may be specifically selected, depending on the impedance of other circuit components, such that energy is passed to the traffic light based primarily on the expected frequency of the A.C. line voltage (e.g., 60 Hz).

One problem with the arrangement shown in FIG. **2** if the applied A.C. signal is provided by a dimmer circuit rather than as a line voltage is that the applied signal may include frequency components that are significantly different from the frequency of the line voltage for which the circuit was designed. For example, consider a dimmer circuit that provides a duty cycle-controlled (i.e., angle modulated) A.C. signal **309** such as that shown in FIG. **1**; by virtue of the abrupt signal excursions due to the "chopping-off" of portions of voltage cycles, signals of this type include significantly higher frequency components than a typical line voltage. Were such an angle modulated A.C. signal to be applied to the arrangement of FIG. **2**, the capacitor **800** would allow excess energy associated with these higher frequency components to pass through to the traffic light, in most cases causing fatal damage to the light sources.

In view of the foregoing, one embodiment of the present invention is directed generally to methods and apparatus for facilitating the use of LED-based light sources on A.C. power circuits that provide either a standard line voltage or that are controlled by conventional dimmers (i.e., "A.C. dimmer circuits"). In one aspect, methods and apparatus of the present invention facilitate convenient substitution of LED-based light sources in lighting environments employing conventional dimming devices and conventional light sources. In yet other aspects, methods and apparatus according to the present invention facilitate the control of one or more parameters relating to the light generated by LED-based light sources (e.g., intensity, color, color temperature, temporal characteristics, etc.) via operation of a conventional dimmer and/or other control signals that may be present in connection with an A.C. line voltage.

Lighting units and systems employing various concepts according to the principles of the present invention may be used in a residential setting, commercial setting, industrial setting or any other setting where conventional A.C. dimmers are found or are desirable. Furthermore, the various concepts disclosed herein may be applied in lighting units according to the present invention to ensure compatibility of the lighting units with a variety of lighting control protocols that provide various control signals via an A.C. power circuit.

One example of such a control protocol is given by the X10 communications language, which allows X10-compatible products to communicate with each other via existing electrical wiring in a home (i.e., wiring that supplies a standard A.C. line voltage). In a typical X10 implementation, an appliance to be controlled (e.g., lights, thermostats, jacuzzi/hot tub, etc.) is plugged into an X10 receiver, which in turn plugs into a conventional wall socket coupled to the A.C. line voltage. The appliance to be controlled can be assigned with a particular address. An X10 transmitter/controller is plugged into another wall socket coupled to the line voltage, and communicates control commands (e.g., on, off, dim, bright, etc.), via the same wiring providing the line voltage, to one or more X10 receivers based at least in part on the assigned address(es) (further information regarding X10 implementations may be found at the website "www.smarthome.com"). According to one embodiment, methods and apparatus of the present invention facilitate compatibility of various LED-based light sources and lighting units with X10 and other communication protocols that communicate control information in connection with an A.C. line voltage.

In general, methods and apparatus according to the present invention allow a substantially complete retrofitting of a lighting environment with solid state LED-based light sources; in particular, pursuant to the present invention, the use of LED-based light sources as substitutes for incandescent light sources is not limited to only those A.C. power circuits that are supplied directly from a line voltage (e.g., via a switch); rather, methods and apparatus of the present invention allow LED-based light sources to be used in most any conventional (e.g., incandescent) socket, including those coupled to an A.C. dimmer circuit and/or receiving signals other than a standard line voltage.

In various embodiments, an LED-based lighting unit or fixture according to the invention may include a controller to appropriately condition an A.C. signal provided by a dimmer circuit so as to provide power to (i.e., "drive") one or more LEDs of the lighting unit. The controller may drive the LED(s) using any of a variety of techniques, including analog control techniques, pulse width modulation (PWM) techniques or other power regulation techniques. Although not an essential feature of the present invention, in some embodiments the circuitry of the LED-based lighting unit may include one or more microprocessors that are programmed to carry out various signal conditioning and/or light control functions. In various implementations of both processor and non-processor based embodiments, an LED-based lighting unit according to the invention may be configured for operation on an A.C. dimmer circuit with or without provisions for allowing one or more parameters of generated light to be adjusted via user operation of the dimmer.

More specifically, in one embodiment, an LED-based lighting unit may include a controller wherein at least a portion of the power delivered to the controller, as derived from an A.C. dimmer circuit, is regulated at a substantially constant value over a significant range of dimmer operation so as to provide an essentially stable power source for the controller and other circuitry associated with the lighting unit. In one aspect of this embodiment, the controller also may be configured to monitor the adjustable power provided by the dimmer circuit so as to permit adjustment of one or more parameters of the light generated by the lighting unit in response to operation of the dimmer.

In particular, there are several parameters of light generated by an LED-based light source (other than, or in addition to, intensity or brightness, for example) that may be controlled in response to dimmer operation according to the present invention. For example, in various embodiments, an LED-based lighting unit may be configured such that one or more properties of the generated light such as color (e.g., hue, saturation or brightness), or the correlated color temperature of white light, as well as temporal parameters (e.g., rate of color variation or strobing of one or more colors) are adjustable via dimmer operation.

As discussed above, in one embodiment, an LED-based lighting unit may include one or more processor-based controllers, including one or more memory storage devices, to facilitate the foregoing and other examples of adjustable light generation via dimmer operation. In particular, in one embodiment, such a lighting unit may be configured to selectively execute, via dimmer operation, one or more lighting programs stored in controller memory. Such lighting programs may represent various static or time-varying lighting effects involving multiple colors, color temperatures, and intensities of generated light, for example. In one aspect of this embodiment, the processor-based controller of the lighting unit may be configured to monitor the A.C. signal provided by the dimmer circuit so as to select different programs and/or program parameters based on one or more changes in the monitored dimmer signal having a particular characteristic (e.g., a particular instantaneous value relating to the dimmer signal, a particular time averaged value relating to the dimmer signal, an interruption of power provided by the dimmer for a predetermined duration, a particular rate of change of the dimmer signal, etc). Upon the selection of a new program or parameter, further operation of the dimmer may adjust the selected parameter or program.

In another exemplary embodiment, an LED-based lighting unit according to the present invention may be configured to be coupled to an A.C. dimmer circuit and essentially recreate the lighting characteristics of a conventional incandescent light as a dimmer is operated to increase or decrease the intensity of the generated light. In one aspect of this embodiment, this simulation may be accomplished by simultaneously varying the intensity and the color of the light generated by the LED-based source in response to dimmer operation, so as to approximate the variable lighting characteristics of an incandescent source whose intensity is varied. In another aspect of this embodiment, such a simulation is facilitated by a processor-based controller particularly programmed to monitor an A.C. signal provided by the dimmer circuit and respectively control differently colored LEDs of the lighting unit in response to dimmer operation so as to simultaneously vary both the overall color and intensity of the light generated by the lighting unit.

While many of the lighting effects discussed herein are associated with dimmer compatible control, several effects may be generated according to the present invention using other control systems as well. For example, the color temperature of an LED-based light source may be programmed to reduce as the intensity is reduced and these lighting changes may be controlled by a system other than a dimmer system (e.g. wireless communication, wired communication and the like) according to various embodiments of the invention.

Another embodiment of the present invention is directed to a method for selling, marketing, and advertising of LED-based light sources and lighting systems. The method may include advertising an LED lighting system compatible with conventional A.C. dimmers or dimming systems. The method may also include advertising an LED light that is compatible with both dimmable and non-dimmable lighting control systems.

Following below are more detailed descriptions of various concepts related to, and embodiments of, methods and apparatus for providing power to LED-based lighting according to the present invention. It should be appreciated that various aspects of the invention, as discussed above and outlined further below, may be implemented in any of numerous ways, as the invention is not limited to any particular manner of implementation. Examples of specific implementations are provided for illustrative purposes only.

Non-Processor Based Exemplary Embodiments

As discussed above, according to various embodiments, LED-based light sources capable of operation via A.C. dimmer circuits may be implemented with or without microprocessor-based circuitry. In this section, some examples are given of lighting units that include circuitry configured to appropriately condition A.C. signals provided by a dimmer circuit without the aid of a microprocessor or microcontroller. In the sections that follow, a number of processor-based examples are discussed.

FIG. **3** illustrates an LED-based lighting unit **200** according to one embodiment of the present invention. For purposes of illustration, the lighting unit **200** is depicted generally to resemble a conventional incandescent light bulb having a screw-type base connector **202** to engage mechanically and electrically with a conventional light socket. It should be appreciated, however, that the invention is not limited in this respect, as a number of other configurations including other housing shapes and/or connector types are possible according to other embodiments. Various examples of power connector configurations include, but are not limited to, screw-type connectors, wedge-type connectors, multi-pin type connectors, and the like, to facilitate engagement with conventional incandescent, halogen, fluorescent or high intensity discharge (HID) type sockets. Such sockets, in turn, may be connected directly to a source of A.C. power (e.g., line voltage), or via a switch and/or dimmer to the source of A.C. power.

The lighting unit **200** of FIG. **3** includes an LED-based light source **104** having one or more LEDs. The lighting unit also includes a controller **204** that is configured to receive an A.C. signal **500** via the connector **202** and provide operating power to the LED-based light source **104**. According to one aspect of this embodiment, the controller **204** includes various components to ensure proper operation of the lighting unit for A.C. signals **500** that are provided by a dimmer circuit and, more specifically, by a dimmer circuit that outputs duty cycle-controlled (i.e., angle modulated) A.C. signals as discussed above.

To this end, according to the embodiment of FIG. **3**, the controller **204** includes a rectifier **404**, a low pass (i.e., high frequency) filter **408** and a DC converter **402**. In one aspect of this embodiment, the output of the DC converter **402** provides an essentially stable DC voltage as a power supply for the LED-based light source **104**, regardless of user adjustments of the dimmer that provides the A.C. signal **500**. More specifically, in this embodiment, the various components of the controller **204** facilitate operation of the lighting unit **200** on a dimmer circuit without providing for adjustment of the generated light based on dimmer operation; rather, the primary function of the controller **204** in the embodiment of FIG. **3** is to ensure that no damage is done to the LED-based light source based on deriving power from an A.C. dimmer circuit.

In particular, according to one aspect of this embodiment, an essentially constant DC power is provided to the LED-based light source as long as the dimmer circuit outputs an A.C. signal **500** that provides sufficient power to operate the controller **204**. In one implementation, the dimmer circuit may output an A.C. signal **500** having a duty cycle of as low as 50% "on" (i.e., conducting) that provides sufficient power to cause light to be generated by the LED-based light source **104**. In yet another implementation, the dimmer circuit may provide an A.C. signal **500** having a duty cycle of as low as 25% or less "on" that provides sufficient power to the light source **104**. In this manner, user adjustment of the dimmer over a significantly wide range does not substantially affect the light output of the lighting unit **200**. Again, the foregoing examples are provided primarily for purposes of illustration, as the invention is not necessarily limited in these respects.

FIG. **4** is an exemplary circuit diagram that illustrates some of the details of the various components shown in FIG. **3**, according to one embodiment of the invention. Again, one of the primary functions of the circuitry depicted in FIG. **4** is to ensure safe operation of the LED-based light source **104** based on an A.C. signal **500** provided to the lighting unit **200** via a conventional A.C. dimmer circuit. As shown in FIG. **4**, the rectifier **404** may be realized by a diode bridge (D**47**, D**48**, D**49** and D**50**), while the low pass filter is realized from the various passive components (capacitors C**2** and C**3**, inductor L**2**, and resistors R**4** and R**6**) shown in the figure. In this embodiment, the DC converter **402** is realized in part using the integrated circuit model number TNY264/266 manufactured by Power Integrations, Inc., 5245 Hellyer Avenue, San Jose, Calif. 95138 (www.powerint.com), and is configured to provide a 16 VDC supply voltage to power the LED-based light source **104**.

It should be appreciated that filter parameters (e.g., of the low pass filter shown in FIG. **4**) are significantly important to ensure proper operation of the controller **204**. In particular, the cutoff frequencies of the filter must be substantially less than a switching frequency of the DC converter, but substantially greater than the typical several cycle cutoff frequency employed in ordinary switch-mode power supplies. According to one implementation, the total input capacitance of the controller circuit is such that little energy remains in the capacitors at the conclusion of each half cycle of the AC waveform. The inductance similarly should be chosen to provide adequate isolation of the high frequency components created by the DC converter to meet regulatory requirements (under certain conditions this value may be zero). In yet other implementations, it may be advantageous to place all or part of the filter components ahead of the bridge rectifier **404**.

The light source **104** of FIG. **4** may include one or more LEDs (as shown for example as the LEDs D**52** and D**53** in FIG. **4**) having any of a variety of colors, and multiple LEDs may be configured in a variety of serial or parallel arrangements. Additionally, based on the particular configuration of the LED source **104**, one or more resistors or other components may be used in serial and/or parallel arrangements with the LED source **104** to appropriately couple the source to the DC supply voltage.

According to another embodiment of the invention, an LED-based light source not only may be safely powered by an A.C. dimmer circuit, but additionally the intensity of light generated by the light source may be adjusted via user operation of a dimmer that controls the A.C. signal provided by the dimmer circuit. FIG. **5** shows another example of a lighting unit **200**A, similar to the lighting unit shown in FIG. **3**, that is suitable for operation via a dimmer circuit. Unlike the lighting unit shown in FIG. **3**, however, the lighting unit **200**A of FIG. **5** is configured to have an adjustable light output that may be controlled via a dimmer. To this end, the controller **204**A shown in FIG. **5** includes an additional adjustment circuit **208** that further conditions a signal output from the DC converter **402**. The adjustment circuit **208** in turn provides a variable drive signal to the LED-based light source **104**, based on variations in the A.C. signal **500** (e.g., variations in the average voltage of the signal) in response to user operation of the dimmer.

FIG. **6** is an exemplary circuit diagram that illustrates some of the details of the various components shown in FIG. **5**, according to one embodiment of the invention. Many of the circuit elements shown in FIG. **6** are similar or identical to those shown in FIG. **4**. The additional adjustment circuit **208** is implemented in FIG. **6** in part by the resistors R**2** and R**6** which form a voltage divider in the feedback loop of the integrated circuit U**1**. A control voltage **410** is derived at the junction of the resistors R**2** and R**6**, which control voltage varies in response to variations in the A.C. signal **500** due to dimmer operation. The control voltage **410** is applied via diode D**5** to a voltage-to-current converter implemented by resistor R**1** and transistor Q**1**, which provide a variable drive current to the LED-based light source **104** that tracks adjustments of the dimmer's user interface. In this manner, the intensity of the light generated by the light source **104** may be varied via the dimmer over a significant range of dimmer operation. Of course, it should be appreciated that if the dimmer is adjusted such that the A.C. signal **500** is no longer capable of providing adequate power to the associated circuitry, the light source **104** merely ceases to produce light.

It should be appreciated that in the circuit of FIG. **6**, the control voltage **410** is essentially a filtered, scaled, maximum limited version of average DC voltage fed to the DC converter. This circuit relies on the DC converter to substantially discharge the input capacitors each half cycle. In practice this is easily achieved because input current to the controller stays fairly constant or increases as the duty cycle of the signal **500** is reduced, so long as device output does not decrease faster than the control voltage.

Processor-Based Exemplary Embodiments

According to other embodiments of the invention, an LED-based lighting unit suitable for operation via an A.C. dimmer circuit may be implemented using a processor-based controller. Below, an embodiment of an LED-based lighting unit including a processor is presented, including a discussion of how such a lighting unit may be particularly configured for operation via an A.C. dimmer circuit. For example, in addition to a microprocessor, such a processor-based lighting unit also may include, and/or receive signal(s) from, one or more other components associated with the microprocessor to facilitate the control of the generated light based at least in part on user adjustment of a conventional A.C. dimmer. Once a processor-based control scheme is implemented in a lighting unit according to the present invention, a virtually limitless number of configurations are possible for controlling the generated light.

FIG. **7** shows a portion of an LED-based lighting unit **200**B that includes a processor-based controller **204**B according to one embodiment of the invention. Various examples of processor controlled LED-based lighting units similar to that described below in connection with FIG. **7** may be found, for example, in U.S. Pat. No. 6,016,038, issued Jan. 18, 2000 to Mueller et al., entitled "Multicolored LED Lighting Method and Apparatus," and U.S. Pat. No. 6,211,626, issued Apr. 3, 2001 to Lys et al, entitled "Illumination Components," which patents are both hereby incorporated herein by reference.

In one aspect, while not shown explicitly in FIG. **7**, the lighting unit **200**B may include a housing structure that is configured similarly to the other lighting units shown in FIGS. **3** and **5** (i.e., as a replacement for an incandescent bulb having a conventional screw-type connector). Again, however, it should be appreciated that the invention is not limited in this respect; more generally, the lighting unit **200**B may be implemented using any one of a variety of mounting arrangements for the light source(s), enclosure/housing arrangements and shapes to partially or fully enclose the light sources, and/or electrical and mechanical connection configurations.

As shown in FIG. **7**, the lighting unit **200**B includes one or more light sources **104**A, **104**B, and **104**C (shown collectively as **104**), wherein one or more of the light sources may be an LED-based light source that includes one or more light emitting diodes (LEDs). In one aspect of this embodiment, any two or more of the light sources **104**A, **104**B, and **104**C may be adapted to generate radiation of different colors (e.g. red, green, and blue, respectively). Although FIG. **7** shows three light sources **104**A, **104**B, and **104**C, it should be appreciated that the lighting unit is not limited in this respect, as different numbers and various types of light sources (all LED-based light sources, LED-based and non-LED-based light sources in combination, etc.) adapted to generate radiation of a variety of different colors, including essentially white light, may be employed in the lighting unit **200**B, as discussed further below.

As shown in FIG. **7**, the lighting unit **200**B also may include a processor **102** that is configured to control drive circuitry **109** to drive the light sources **104**A, **104**B, and **104**C so as to generate various intensities of light from the light sources. For example, in one implementation, the processor **102** may be configured to output via the drive circuitry **109** at least one control signal for each light source so as to independently control the intensity of light generated by each light source. Some examples of control signals that may be generated by the processor and drive circuitry to control the light sources include, but are not limited to, pulse modulated signals, pulse width modulated signals (PWM), pulse amplitude modulated signals (PAM), pulse code modulated signals (PCM) analog control signals (e.g., current control signals, voltage control signals), combinations and/or modulations of the foregoing signals, or other control signals.

In one implementation of the lighting unit **200**B, one or more of the light sources **104**A, **104**B, and **104**C shown in FIG. **7** may include a group of multiple LEDs or other types of light sources (e.g., various parallel and/or serial connections of LEDs or other types of light sources) that are controlled together by the processor **102**. Additionally, it should be appreciated that one or more of the light sources **104**A, **104**B, and **104**C may include one or more LEDs that are adapted to generate radiation having any of a variety of spectra (i.e., wavelengths or wavelength bands), including, but not limited to, various visible colors (including essentially white light), various color temperatures of white light, ultraviolet, or infrared. LEDs having a variety of spectral bandwidths (e.g., narrow band, broader band) may be employed in various implementations of the lighting unit **200**B.

In another aspect of the lighting unit **200**B shown in FIG. **7**, the lighting unit may be constructed and arranged to produce a wide range of variable color radiation. For example, the lighting unit **200**B may be particularly arranged such that the processor-controlled variable intensity light generated by two or more of the light sources combines to produce a mixed colored light (including essentially white light having a variety of color temperatures). In particular, the color (or color temperature) of the mixed colored light may be varied by varying one or more of the respective intensities of the light sources (e.g., in response to one or more control signals output by the processor and drive circuitry). Furthermore, the processor **102** may be particularly configured (e.g., programmed) to provide control signals to one or more of the light sources so as to generate a variety of static or time-varying (dynamic) multi-color (or multi-color temperature) lighting effects.

Thus, the lighting unit **200**B may include a wide variety of colors of LEDs in various combinations, including two or more of red, green, and blue LEDs to produce a color mix, as well as one or more other LEDs to create varying colors and color temperatures of white light. For example, red, green and blue can be mixed with amber, white, UV, orange, IR or other colors of LEDs. Such combinations of differently colored LEDs in the lighting unit **200**B can facilitate accurate reproduction of a host of desirable spectrums of lighting conditions, examples of which includes, but are not limited to, a variety of outside daylight equivalents at different times of the day, various interior lighting conditions, lighting conditions to simulate a complex multicolored background, and the like. Other desirable lighting conditions can be created by removing particular pieces of spectrum that may be specifically absorbed, attenuated or reflected in certain environments.

As shown in FIG. **7**, the lighting unit **200**B also may include a memory **114** to store various information. For example, the memory **114** may be employed to store one or more lighting programs for execution by the processor **102** (e.g., to generate one or more control signals for the light sources), as well as various types of data useful for generating variable color radiation (e.g., calibration information). The memory **114** also may store one or more particular identifiers (e.g., a serial number, an address, etc.) that may be used either locally or on a system level to identify the lighting unit **200**B. In various embodiments, such identifiers may be pre-programmed by a manufacturer, for example, and may be either alterable or non-alterable thereafter (e.g., via some type of user interface located on the lighting unit, via one or more data or control signals received by the lighting unit, etc.). Alternatively, such identifiers may be determined at the time of initial use of the lighting unit in the field, and again may be alterable or non-alterable thereafter.

In another aspect, as also shown in FIG. **7**, the lighting unit **200**B optionally may be configured to receive a user interface signal **118** that is provided to facilitate any of a number of user-selectable settings or functions (e.g., generally controlling the light output of the lighting unit **200**B, changing and/or selecting various pre-programmed lighting effects to be generated by the lighting unit, changing and/or selecting various parameters of selected lighting effects, setting particular identifiers such as addresses or serial numbers for the lighting unit, etc.). In one embodiment of the invention discussed further below, the user interface signal **118** may be derived from an A.C. signal provided by a dimmer circuit and/or other control signal(s) on an A.C. power circuit, so that the light generated by the light source **104** may be controlled in response to dimmer operation and/or the other control signal(s).

More generally, in one aspect of the embodiment shown in FIG. **7**, the processor **102** of the lighting unit **200**B is configured to monitor the user interface signal **118** and control one or more of the light sources **104**A, **104**B, and **104**C based at least in part on the user interface signal. For example, the processor **102** may be configured to respond to the user interface signal by originating one or more control signals (e.g., via the drive circuitry **109**) for controlling one or more of the light sources. Alternatively, the processor **102** may be configured to respond by selecting one or more pre-programmed control signals stored in memory, modifying control signals generated by executing a lighting program, selecting and executing a new lighting program from memory, or otherwise affecting the radiation generated by one or more of the light sources.

To this end, the processor **102** may be configured to use any one or more of several criteria to "evaluate" the user interface signal **118** and perform one or more functions in response to the user interface signal. For example, the processor **102** may be configured to take some action based on a particular instantaneous value of the user interface signal, a change of some characteristic of the user interface signal, a rate of change of some characteristic of the user interface signal, a time averaged value of some characteristic of the user interface signal, periodic patterns or interruptions of the user interface signal having particular durations, zero-crossings of an A.C. user interface signal, etc.

In one embodiment, the processor is configured to digitally sample the user interface signal **118** and process the samples according to some predetermined criteria to determine if one or more functions need to be performed. In yet another embodiment, the memory **114** associated with the processor **102** may include one or more tables or, more generally, a database, that provides a mapping of values relating to the user interface signal to values for various control signals used to control the LED-based light source **104** (e.g., a particular value or condition associated with the user interface signal may correspond to particular duty cycles of PWM signals respectively applied to differently colored LEDs of the light source). In this manner, a wide variety of lighting control functions may be performed based on the user interface signal.

FIG. **7** also illustrates that the lighting unit **200**B may be configured to receive one or more signals **122** from one or more other signal sources **124**. In one implementation, the processor **102** of the lighting unit may use the signal(s) **122**, either alone or in combination with other control signals (e.g., signals generated by executing a lighting program, user interface signals, etc.), so as to control one or more of the light sources **104**A, **104**B and **104**C in a manner similar to that discussed above in connection with the user interface. Some examples of a signal source **124** that may be employed in, or used in connection with, the lighting unit **200**B of FIG. **7** include any of a variety of sensors or transducers that generate one or more signals **122** in response to some stimulus. Examples of such sensors include, but are not limited to, various types of environmental condition sensors, such as thermally sensitive (e.g., temperature, infrared) sensors, humidity sensors, motion sensors, photosensors/light sensors (e.g., sensors that are sensitive to one or more particular spectra of electromagnetic radiation), various types of cameras, sound or vibration sensors or other pressure/force transducers (e.g., microphones, piezoelectric devices), and the like.

As also shown in FIG. **7**, the lighting unit **200**B may include one or more communication ports **120** to facilitate coupling of the lighting unit to any of a variety of other devices. For example, one or more communication ports **120** may facilitate coupling multiple lighting units together as a networked lighting system, in which at least some of the lighting units are addressable (e.g., have particular identifiers or addresses) and are responsive to particular data transported across the network.

In particular, in a networked lighting system environment, as data is communicated via the network, the processor **102** of each lighting unit coupled to the network may be configured to be responsive to particular data (e.g., lighting control commands) that pertain to it (e.g., in some cases, as dictated by the respective identifiers of the networked lighting units). Once a given processor identifies particular data intended for it, it may read the data and, for example, change the lighting conditions produced by its light sources according to the received data (e.g., by generating appropriate control signals to the light sources). In one aspect, the memory **114** of each lighting unit coupled to the network may be loaded, for example, with a table of lighting control signals that correspond with data the processor **102** receives. Once the processor **102** receives data from the network, the processor may consult the table to select the control signals that correspond to the received data, and control the light sources of the lighting unit accordingly.

In one aspect of this embodiment, the processor **102** of a given lighting unit, whether or not coupled to a network, may be configured to interpret lighting instructions/data that are received in a DMX protocol (as discussed, for example, in U.S. Pat. Nos. 6,016,038 and 6,211,626), which is a lighting command protocol conventionally employed in the lighting industry for some programmable lighting applications. However, it should be appreciated that lighting units suitable for purposes of the present invention are not limited in this respect, as lighting units according to various embodiments may be configured to be responsive to other types of communication protocols so as to control their respective light sources.

The lighting unit **200**B of FIG. **7** also includes power circuitry **108** that is configured to derive power for the lighting unit based on an A.C. signal **500** (e.g., a line voltage, a signal provided by a dimmer circuit, etc.). In one implementation of the lighting unit **200**B, the power circuitry **108** may be configured similarly to portions of the circuits shown in FIGS. **4** and **6**, for example. In particular, FIG. **8** illustrates one exemplary circuit arrangement for the power circuitry **108**, based on several of the elements shown in FIGS. **4** and **6**, that may be employed in one implementation of the lighting unit **200**B. In the circuit shown in FIG. **8**, a 5 Volt DC output **900** is provided for at least the processor **102**, whereas a 16 Volt DC output **902** is provided for the drive circuitry **109**, which ultimately provides power to the LED-based light source **104**. Like the circuits shown in FIGS. **4** and **6**, it should be appreciated that as the overall power provided by the A.C. signal **500** is reduced due to operation of a dimmer, for example, at some point the power circuitry **108** will be unable to provide sufficient power to the various components of the lighting unit **200**B and it will cease to generate light. Nonetheless, in one aspect, the power circuitry **108** is configured to provide sufficient power to the lighting unit over a significant range of dimmer operation.

According to another embodiment of the invention, the power circuitry **108** shown in FIG. **8** may be modified to also provide a control signal that reflects variations in the A.C. signal **500** (e.g., changes in the average voltage) in response to dimmer operation. For example, the circuit of FIG. **8** may be modified to include additional components similar to those shown in connection with the adjustment circuit **208** of FIG. **6** which provide the control voltage **410** (e.g., a resistor divider network in the opto-isolator feedback loop). A control signal similarly derived from the circuit of FIG. **8** may serve as the user interface signal **118** applied to the processor **102**, as indicated by the dashed line **410**B shown in FIG. **7**. In other embodiments, the circuit of FIG. **8** may be modified so as to derive a control/user interface signal from other portions of the circuitry, such as an output of the rectifier or low pass filter, for example.

In yet another embodiment, the user interface signal **118** provided to the processor **102** may be the A.C. signal **500** itself, as indicated in FIG. **7** by the connections **500**B. In this embodiment, the processor **102** may be particularly programmed to digitally sample the A.C. signal **500** and detect changes in one or more characteristics of the A.C. signal (e.g., amplitude variations, degree of angle modulation, etc.). In this manner, rather than respond to a control signal that is derived based on variations of an average voltage of the A.C. signal **500** due to dimmer operation, the processor may respond to dimmer operation by "more directly" monitoring some characteristic (e.g., the degree of angle modulation) of the A.C. dimmer output signal. A number of techniques readily apparent to those skilled in the art, some of which were discussed above in connection with the user interface signal **118**, may be similarly implemented by the processor to sample and process the A.C. signal **500**.

Once a user interface signal **118** that represents dimmer operation is derived using any of the techniques discussed above (or other techniques), the processor **102** may be programmed to implement any of a virtually limitless variety of light control functions based on user adjustment of the dimmer. For example, user adjustment of a dimmer may cause the processor to change one or more of the intensity, color, correlated color temperature, or temporal qualities of the light generated by the lighting unit **200**B.

To more specifically illustrate the foregoing, consider the lighting unit **200**B configured with two lighting programs stored in the memory **114**; the first lighting program is configured to allow adjustment of the overall color of the generated light in response to dimmer operation, and the second lighting program is configured to allow adjustment of the overall intensity of the generated light, at a given color, in response to dimmer operation. Moreover, the processor is programmed such that a particular type of dimmer operation toggles between the two programs, and such that on initial power-up, one of the two programs (e.g., the first program) is automatically executed as a default.

In this example, on power up, the first program (e.g., adjustable color) begins executing, and a user may change the overall color of the generated light by operating the dimmer user interface in a "normal" fashion over some range of adjustment (e.g., the color may be varied through a rainbow of colors from red to blue with gradual adjustment of the dimmer's user interface).

Once arriving at a desirable color, the user may then select the second program (e.g., adjustable intensity) for execution by operating the dimmer user interface in some particular predetermined manner (e.g., instantaneously interrupting the power for a predetermined period via an on/off switch incorporated with the dimmer, adjusting the dimmer's user interface at a quick rate, etc.). As discussed above in connection with user interface signal concepts, any number of criteria may be used to evaluate dimmer operation and determine if a new program selection is desired, or if adjustment of a currently executing program is desired. Various examples of program or mode selection via a user interface, as well as parameter adjustment within a selected program or mode, are discussed in U.S. Non-provisional Application Ser. No. 09/805,368 and U.S. Non-provisional Application Ser. No. 10/045,629, incorporated herein by reference.

In this example, once the second program begins to execute, the user may change the intensity of the generated light (at the previously adjusted color) by subsequent "normal" operation (e.g., gradual adjustment) of the dimmer's user interface. Using the foregoing exemplary procedure, the user may adjust both the intensity and the color of the light emitted from the lighting unit via a conventional A.C. dimmer.

It should be appreciated that the foregoing example is provided primarily for purposes of illustration, and that the invention is not limited in these respects. In general, according to various embodiments of the invention, multiple parameters relating to the generated light may be changed in sequence, or simultaneously in combination. Also, via selection and execution of a lighting program, temporal characteristics of the generated light also may be adjusted (e.g., rate of strobing of a given color, rate of change of a rainbow wash of colors, etc.).

For example, in one embodiment, an LED-based light source coupled to an A.C. dimmer circuit may be configured to essentially recreate the lighting characteristics of a conventional incandescent light as a dimmer is operated to increase or decrease the intensity of the generated light. In one aspect of this embodiment, this simulation may be accomplished by simultaneously varying the intensity and the color of the light generated by the LED-based source via dimmer operation.

More specifically, in conventional incandescent light sources, the color temperature of the light emitted generally reduces as the power dissipated by the light source is reduced (e.g., at lower intensity levels, the correlated color temperature of the light produced may be near 2000 K, while the correlated color temperature of the light at higher intensities may be near 3200 K). This is why an incandescent light tends to appear redder as the power to the light source is reduced. Accordingly, in one embodiment, an LED-based lighting unit may be configured such that a single dimmer adjustment may be used to simultaneously change both the intensity and color of the light source so as to produce a relatively high correlated color temperature at higher intensities (e.g. when the dimmer provides essentially "full" power) and produce lower correlated color temperatures at lower intensities, so as to mimic an incandescent source.

Another embodiment of the present invention is directed to a flame simulation control system, or other simulation control system. The system may include an LED-based light source or lighting unit arranged to produce flame effects or simulations. Such a flame simulation system may be used to replace more conventional flame simulation systems (e.g. incandescent or neon). The flame simulation lighting device may be configured (e.g., include a lighting program) for altering the appearance of the generated light to simulate wind blowing through the flame or random flickering effects to make the simulation more realistic. Such a simulation system may be associated with a user interface to control the effects, and also may be configured to be adapted for use and/or controlled via an A.C. dimmer circuit (e.g., a dimmer control system may be used to change the effects of the simulation system). In other implementations, the user interface may communicate to the simulation device through wired or wireless communication and a user may be able to alter the effects of the device through the user interface. The simulation device may include an effect that can be modified for rate of change, intensity, color, flicker rate, to simulate windy conditions, still conditions, moderate conditions or any other desirable modification.

Many lighting control systems do not include dimmer circuits where dimming and other alterable lighting effects would be desirable. Accordingly, yet another embodiment of the present invention is directed to a lighting effect control system including a wireless control system. According to this embodiment, an LED-based light source or lighting unit may be adapted to receive wireless communications to effect lighting changes in the lighting system (e.g., see FIG. **7** in connection with communication link **120**). A wireless transmitter may be used by a user to change the lighting effects generated by the lighting system. In one implementation, the transmitter is associated with a power switch for the control system. For example, the power switch may be a wall mounted power switch and a user interface may be associated with the wall-mounted switch. The user interface may be used to generate wireless communication signals that are communicated to the lighting system to cause a change in the light emitted. In another embodiment, the signals are communicated to the lighting system over the power wires in a multiplexed fashion where the light decodes the data from the power.

Yet another embodiment of the invention is directed to methods and apparatus for communicating control information to one or more lighting devices, as well as other devices that typically are powered via a standard A.C. line voltage, by using a portion of the duty cycle of the line voltage to communicate the control information. For example, according to one embodiment, a supply voltage controller is configured to receive a standard A.C. line voltage as an input, and provide as an output a power signal including control information. The power signal provides an essentially constant A.C. power source; however, according to one aspect of this embodiment, the signal periodically is "interrupted" (e.g., a portion of the AC duty cycle over a period of cycles is removed) to provide one or more communication channels over which control information (e.g., digitally encoded information) may be transmitted to one or more devices coupled to the power signal. The device(s) coupled to the power signal may be particularly configured to be responsive in some way to such control information.

For example, it should be appreciated that the various LED-based lighting units disclosed herein, having the capability to provide power to LED-based light sources from a standard A.C. line voltage, an A.C. dimmer circuit (e.g., providing an angle modulated power source), or from a power source in which other control signals may be present in connection with an A.C. line voltage, may be particularly configured to be compatible with the power signal described above and responsive to the control information transmitted over the communication channel.

According to one aspect of this embodiment, a supply voltage controller to provide a power signal as discussed above may be implemented as a processor-based user interface, including any number of features (e.g., buttons, dials, sliders, etc.) to facilitate user operation of the controller. In particular, in one implementation, the supply voltage controller may be implemented to resemble a conventional dimmer (e.g., having a knob or a slider as a user interface), in which an associated processor is particularly programmed to monitor operation of the user interface and generate control information in response to such operation. The processor also is programmed to transmit the control information via one or more communication channels of the power signal, as discussed above.

In other aspects of this embodiment, unlike currently available home control networks/systems such as X10, the device(s) being controlled by the power signal essentially are defined by the electrical wiring that provides the power signal, rather than by programming or addresses assigned to the device(s). Additionally, other "non-controllable" devices (i.e., not configured to be responsive to the control information transported on the power signal) may be coupled to the power signal without any detrimental effect, and allow for a mix of controllable and non-controllable devices on the same power circuit (i.e., delivering the same power signal to all devices on the circuit). Moreover, devices in different wiring domains (i.e., on different power circuits) are guaranteed through topology not to interfere with, or be responsive to, the power signal on a particular power circuit. In yet another aspect, the power signal of this embodiment is essentially "transparent" to (i.e., does not interfere with) other protocols such as X10.

In one exemplary implementation based on a supply voltage controller providing a power signal as discussed above on a given power circuit, a number of lighting devices (e.g., conventional lighting devices, LED-based lighting units, etc) may be coupled to the power circuit and configured such that they are essentially non-responsive to any control information transmitted on the power circuit. For example, the "non-responsive" lighting devices may be conventional incandescent light sources or other devices that receive power via the portion of the power signal that does not include the communication channel. These lighting devices may serve in a given environment to provide general illumination in the environment.

In addition to the non-responsive lighting devices in this example, one or more other controllable lighting devices (e.g., particularly configured LED-based lighting units) also may be coupled to the same power circuit and configured to be responsive to the control information in the communication channel of the power signal (i.e., responsive to user operation of the supply voltage controller). In this manner, the controllable lighting device(s) may provide various types of accent/special effects lighting to complement the general illumination provided by the other "non-responsive" devices on the same power circuit.

Exemplary Drive Circuit Embodiments

With reference again to FIG. **7**, the drive circuitry **109** of the lighting unit **200**B may be implemented in numerous ways, one of which employs one or more current drivers respectively corresponding to the one or more light sources **104**A, **104**B and **104**C (collectively **104**). In particular, according to one embodiment, the drive circuitry **109** is configured such that each differently colored light source is associated with a voltage to current converter that receives a voltage control signal (e.g., a digital PWM signal) from the processor **102** and provides a corresponding current to energize the light source. Such a driver circuit is not limited to implementations of lighting units that are particularly configured for operation via an A.C. dimmer circuit; more generally, lighting units similar to the lighting unit **200**B and configured for use with various types of power sources (e.g, A.C. line voltages, A.C. dimmer circuits, D.C. power sources) may employ driver circuitry including one or more voltage to current converters.

FIG. **9** illustrates one example of a portion of the driver circuitry **109** employing a conventional voltage to current converter, also referred to as a "current sink" **910**. As shown in FIG. **9**, the current sink **910** receives a digital input control signal from the processor **102** and provides a current I_A to drive the light source **104**A. It should be appreciated that, according to one embodiment, multiple light sources are included in the lighting unit, and that the driver circuitry **109** includes circuitry similar to that shown in FIG. **9** for each light source (wherein the processor provides one control signal for each current sink).

The current sink **910** illustrated in FIG. **9** is widely used for control of current in various applications, and is discussed in many popular textbooks (e.g., see Intuitive IC OPAMPS, Thomas M. Frederiksen, 1984, pages 186-189). The operational amplifier based current sink of FIG. **9** functions to maintain the voltage at the node "A" (i.e., across the resistor R**6**) and the "reference" voltage at the node "C" (at the non-inverting input of the operational amplifier U**1**A) at the same value. In this manner, the light source current I_A is related to (i.e., tracks) the digital control signal provided by the processor **102**.

The reference voltage at the point "C" in FIG. **9** may be developed in a variety of ways, and the Frederiksen text referenced above suggests that a resistor divider (e.g., R**2** and R**5**) is a good method of creating this voltage. Generally, the reference voltage is chosen by a designer of the circuit as a compromise; on one hand, the voltage should be as low as possible, to reduce the burden voltage (i.e. the lowest voltage at which the current I_A is maintained) of the current sink. On the other hand, lowering the reference voltage increases the circuit error, due to various sources, including: 1) the offset voltage of the op-amp; 2) differences in the input bias currents of the op-amp; 3) poor tolerances of low value resistors; and 4) errors in sensing small voltages due to voltage drops across component interconnections. Lowering the reference voltage also decreases the speed of the circuit, because feedback to the op-amp is reduced. This situation can also lead to instabilities in the circuit.

The reference voltage at the point "C" in FIG. **9** need not be constant, and it may be switched between any desired voltages to generate different currents. In particular, a pulse width modulated (PWM) digital control voltage may be applied to the circuit from the processor **102**, to generate a switched current I_A. Through careful selection of resistor values for the voltage divider formed by resistors R**2** and R**5**, various circuit goals may be achieved, including the matching of op-amp bias currents.

One issue with the circuit shown in FIG. **9** is that when the digital control signal from the processor is not present or off (e.g., at zero volts), the operational amplifier U**1**A may not turn the transistor M**1** fully off. As a result, some current I_A may still flow through the light source **104**A, even though the light source is intended to be off. In view of the foregoing, one embodiment of the present invention is directed to drive circuitry for LED-based light sources that incorporates an improved current sink design to ensure more accurate control of the light sources.

FIG. **10** illustrates one example of such an improved current sink **910**A according to one embodiment of the invention. The current sink **910**A is configured such that there is a known "error voltage" at the node "B" (e.g., the inverting input of the operational amplifier U**1**A), through the use of resistors R**4** and R**1**. In particular, the values of resistors R**4** and R**1** are selected so as to slightly increase the voltage at the node "B" as compared to the arrangement shown in FIG. **9**. As a result, when the reference voltage at the node "C" is zero (i.e., when the digital control signal is such that the light source **104**A is intended to be off), the voltage at the node "B" is slightly above that at the node "C". This voltage difference forces the op-amp to drive its output low, which hence drives transistor M**1** well into its "off" region and avoids any inadvertent flow of the current I_A.

The small known error voltage introduced at the node "B" does not necessarily result in any increase in current error. In one embodiment, the values of resistors R**2** and R**5** may be adjusted to compensate for the effects of the error voltage. For example, resistors R**4** and R**1** may be selected to result in 20 mV at the node "B" when the node "C" is at zero volts (such that the OP AMP is in the "off" state). In the "on" state, the circuit may be configured such that there is approximately 5 mV of sense voltage at the node "A" (across the resistor R**6**). The error voltage is added to the desired sense resistor voltage, and the values of resistors R**2** and R**5** are appropriately selected to result in a 25 mV reference voltage at the node "C" in the presence of a digital control signal indicating an "on" state. In one embodiment, the circuit may be configured such that the output current I_A and sense voltage at node "A" may be much greater than the minimums, for various reasons, but most notably because lower cost op-amps may be used to achieve 1% accuracy if the sense voltage is increased to the 300-700 mV range.

FIG. **11** shows yet another embodiment of a current sink **910**B, in which several optional components are added to the circuit of FIG. **10**, which increase the speed and current capability of the circuit. In particular, as the size of transistor M**1** is increased towards larger currents, capacitor C**1** and resistor R**3** may be added to compensate for the larger capacitance of M**1**. This capacitance presents a large load to the op-amp, and for many op-amp designs, this can cause instability. Resistor R**3** lowers the apparent load presented by M**1**, and C**1** provides a high frequency feedback path for the op-amp, which bypasses M**1**. In one aspect of this embodiment, the circuit impedance at nodes "B" and "C" may be matched, to reduce the effects of op-amp bias current. In another embodiment this matching may be avoided by using modern FET input op-amps.

Having thus described several illustrative embodiments of the invention, various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be within the spirit and scope of the invention. While some examples presented herein involve specific combinations of functions or structural elements, it should be understood that those functions and elements may be combined in other ways according to the present invention to accomplish the same or different objectives. In particular, acts, elements and features discussed in connection with one embodiment are not intended to be excluded from a similar or other roles in other embodiments. Accordingly, the foregoing description is by way of example only, and is not intended as limiting.

The invention claimed is:

1. An illumination apparatus, comprising:

at least one LED; and

at least one controller coupled to the at least one LED and configured to receive a power-related signal from an alternating current (A.C.) power source that provides signals other than a standard A.C. line voltage, the at least one controller further configured to provide power to the at least one LED based on the power-related signal.

2. The apparatus of claim 1, wherein the A.C. power source is an (A.C.) dimmer circuit.

3. The apparatus of claim 2, wherein the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal, and wherein the at least one controller is configured to provide an essentially non-varying power to the at least one LED over a significant range of operation of the user interface.

4. The apparatus of claim 3, wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the at least one controller is configured to provide the essentially non-varying power to the at least one LED over a significant range of operation of the user interface notwithstanding variations in the duty cycle of the power-related signal.

5. The apparatus of claim 3, wherein the at least one controller comprises:

a rectifier to receive the power-related signal and provide a rectified power-related signal;

a low pass filter to filter the rectified power-related signal; and

a DC converter to provide the essentially non-varying power based on the filtered rectified power-related signal.

6. The apparatus of claim 3, further comprising:

a screw-type power connector configured to engage mechanically and electrically with a conventional incandescent light socket so as to couple the apparatus to the A.C. dimmer circuit.

7. The apparatus of claim 6, further comprising:

a housing, coupled to the screw-type power connector, to enclose the at least one LED and the at least one controller, the housing being structurally configured to resemble an incandescent light bulb.

8. The apparatus of claim 7, wherein the at least one LED includes a plurality of differently colored LEDs.

9. The apparatus of claim 2, wherein the A.C. dimmer circuit is controlled by a user interface to vary the power-related signal, and wherein the at least one controller is configured to variably control at least one parameter of light generated by the at least one LED in response to operation of the user interface.

10. The apparatus of claim 9, wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the at least one controller is configured to variably control the at least one parameter of the light based at least on the variable duty cycle of the power-related signal.

11. The apparatus of claim 9, wherein the at least one parameter of the light that is variably controlled by the at least one controller in response to operation of the user interface includes at least one of an intensity of the light, a color of the light, a color temperature of the light, and a temporal characteristic of the light.

12. The apparatus of claim 9, wherein the at least one controller is configured to variably control at least two different parameters of the light generated by the at least one LED in response to operation of the user interface.

13. The apparatus of claim 12, wherein the at least one controller is configured to variably control at least an intensity and a color of the light simultaneously in response to operation of the user interface.

14. The apparatus of claim 12, wherein the at least one LED is configured to generate an essentially white light, and wherein the at least one controller is configured to variably control at least an intensity and a color temperature of the white light simultaneously in response to operation of the user interface.

15. The apparatus of claim 14, wherein the at least one controller is configured to variably control at least the intensity and the color temperature of the essentially white light in response to operation of the user interface so as to approximate light generation characteristics of an incandescent light source.

16. The apparatus of claim 15, wherein the at least one controller is configured to variably control the color temperature of the essentially white light over a range from approximately 2000 degrees K at a minimum intensity to 3200 degrees K at a maximum intensity.

17. The apparatus of claim 15, further comprising:

a screw-type power connector configured to engage mechanically and electrically with a conventional incandescent light socket so as to couple the apparatus to the A.C. dimmer circuit.

18. The apparatus of claim 17, further comprising:

a housing, coupled to the screw-type power connector, to enclose the at least one LED and the at least one controller, the housing being structurally configured to resemble an incandescent light bulb.

19. The apparatus of claim 15, wherein the at least one LED includes a plurality of differently colored LEDs.

20. The apparatus of claim 9, wherein the at least one controller includes:

an adjustment circuit to variably control the at least one parameter of light based on the varying power-related signal; and

power circuitry to provide at least the power to the at least one LED based on the varying power-related signal.

21. The apparatus of claim 20, wherein the power circuitry includes:

a rectifier to receive the power-related signal and provide a rectified power-related signal;

a low pass filter to filter the rectified power-related signal; and

a DC converter to provide the power to at least the at least one LED based on the filtered rectified power-related signal.

22. The apparatus of claim 21, wherein the adjustment circuit is coupled to the DC converter and is configured to variably control the at least one LED based on the filtered rectified power-related signal.

23. The apparatus of claim 21, wherein the adjustment circuit includes at least one processor configured to monitor at least one of the power-related signal, the rectified power-related signal, and the filtered rectified power-related signal so as to variably control the at least one LED.

24. The apparatus of claim 23, wherein the power circuitry is configured to provide at least the power to the at least one LED and power to the at least one processor based on the varying power-related signal.

25. The apparatus of claim 23, wherein the at least one processor is configured to sample the varying power-related signal and determine at least one varying characteristic of the varying power-related signal.

26. The apparatus of claim 23, wherein the operation of the user interface varies a duty cycle of the power-related signal, and wherein the at least one processor is configured to variably control the at least one parameter of the light based at least on the varying duty cycle of the power-related signal.

27. The apparatus of claim **26**, wherein the at least one LED includes a plurality of differently colored LEDs.

28. The apparatus of claim **27**, wherein:

the plurality of differently colored LEDs includes:

at least one first LED adapted to output at least first radiation having a first spectrum; and

at least one second LED adapted to output second radiation having a second spectrum different than the first spectrum; and

the at least one processor is configured to independently control at least a first intensity of the first radiation and a second intensity of the second radiation in response to operation of the user interface.

29. The apparatus of claim **28**, wherein the at least one processor is programmed to implement a pulse width modulation (PWM) technique to control at least the first intensity of the first radiation and the second intensity of the second radiation.

30. The apparatus of claim **29**, wherein the at least one processor further is programmed to:

generate at least a first PWM signal to control the first intensity of the first radiation and a second PWM signal to control the second intensity of the second radiation; and

determine duty cycles of the respective first and second PWM signals based at least in part on variations in the power-related signal due to operation of the user interface.

31. The apparatus of claim **20**, wherein the adjustment circuit includes drive circuitry including at least one voltage-to-current converter to provide at least one drive current to the at least one LED so as to control the at least one parameter of the generated light.

32. The apparatus of claim **31**, wherein the at least one voltage-to-current converter includes an operational amplifier configured so as to have a predetermined error voltage applied across its non-inverting and inverting inputs during operation to essentially reduce to zero a current output of the at least one voltage-to-current converter when a voltage applied to the at least one voltage-to-current converter is essentially zero.

33. An illumination method, comprising an act of:

A) providing power to at least one LED based on a power-related signal from an alternating current (A.C.) power source that provides signals other than a standard A.C. line voltage.

34. The illumination method of claim **33**, wherein the act A) includes an act of:

providing power to the at least one LED based on a power-related signal from an alternating current (A.C.) dimmer circuit.

* * * * *