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Berman et al.

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(54) **LED LIGHTING SYSTEM**

(75) Inventors: **George Berman**, Plano, TX (US); **Jerry Haden Graves**, Valley View, TX (US); **John Bartholomew Gunter**, Flower Mound, TX (US)

(73) Assignee: **Luminator Holding, L.P.**, Plano, TX (US)

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H05B 37/00 (2006.01)
F21S 4/00 (2006.01)

(52) **U.S. Cl.** **315/189**; 362/800

(58) **Field of Classification Search** .... 340/912, 340/925, 916; 362/249, 800, 226; 313/512, 313/505; 315/184, 185 R, 185 S, 189, 191
See application file for complete search history.

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Primary Examiner—Don Wong
Assistant Examiner—Minh Dieu A
(74) *Attorney, Agent, or Firm*—Darby & Darby

(57) **ABSTRACT**

A lighting device that can generate light of variable color and intensity under processor control. Multiple lighting devices of a modular design can be incorporated into a lighting system to illuminate larger areas. A lighting module includes three groups of LEDs each of which generates light of a different color whose intensity can be controlled. A lighting system can be formed by coupling multiple lighting devices to a central controller comprising an operator interface panel and an interface to an external computer. The external computer can be provided with programming tools that allow the creation of lighting programs for controlling the operation of the lighting system. A user can select programs or modify the operation of the lighting system from the operator interface panel provided at the central controller or from the external computer. Procedures are provided for calibrating the color and power output of each lighting device.

12 Claims, 11 Drawing Sheets

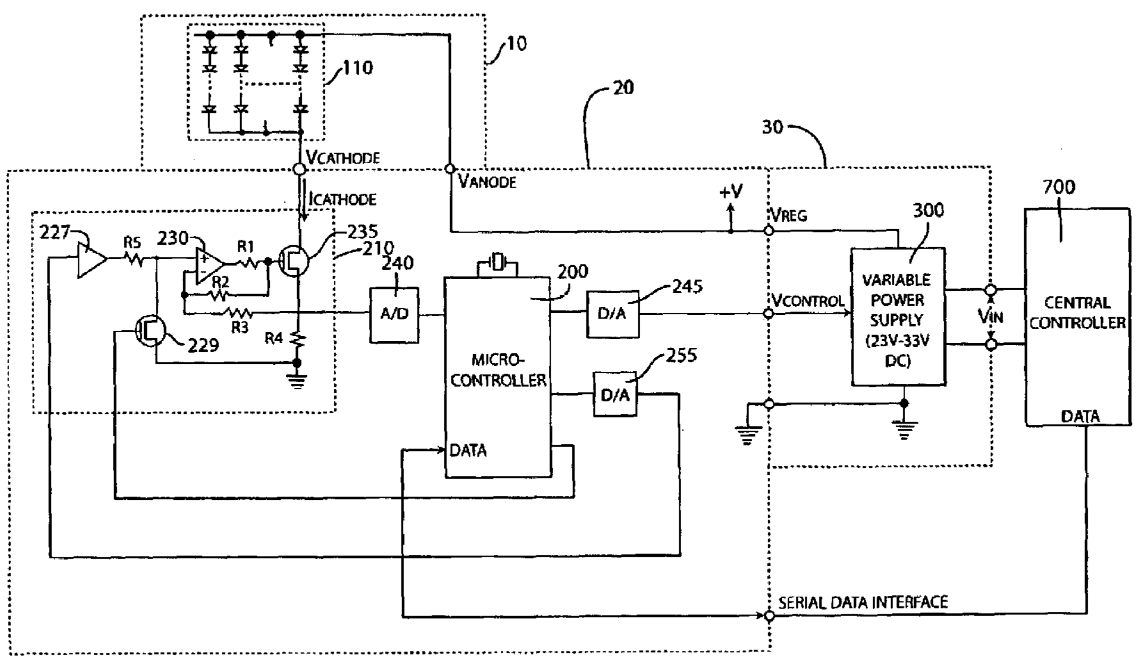


FIG. 1

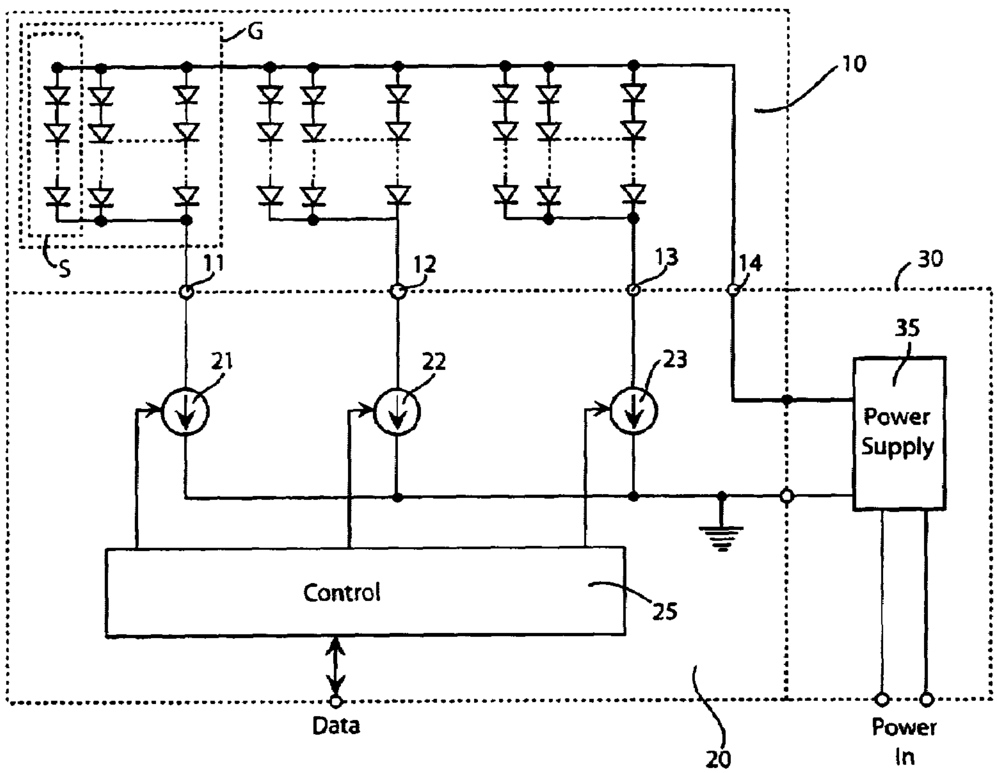
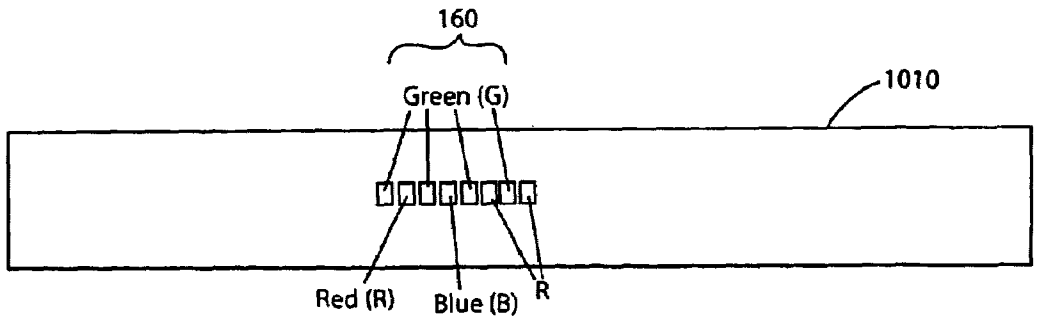

G
10
S
11
12
13
14
30
35
21
22
23
Power Supply
Control
25
Data
20
Power In

FIG. 2


160
Green (G)
1010
Red (R)
Blue (B)
R

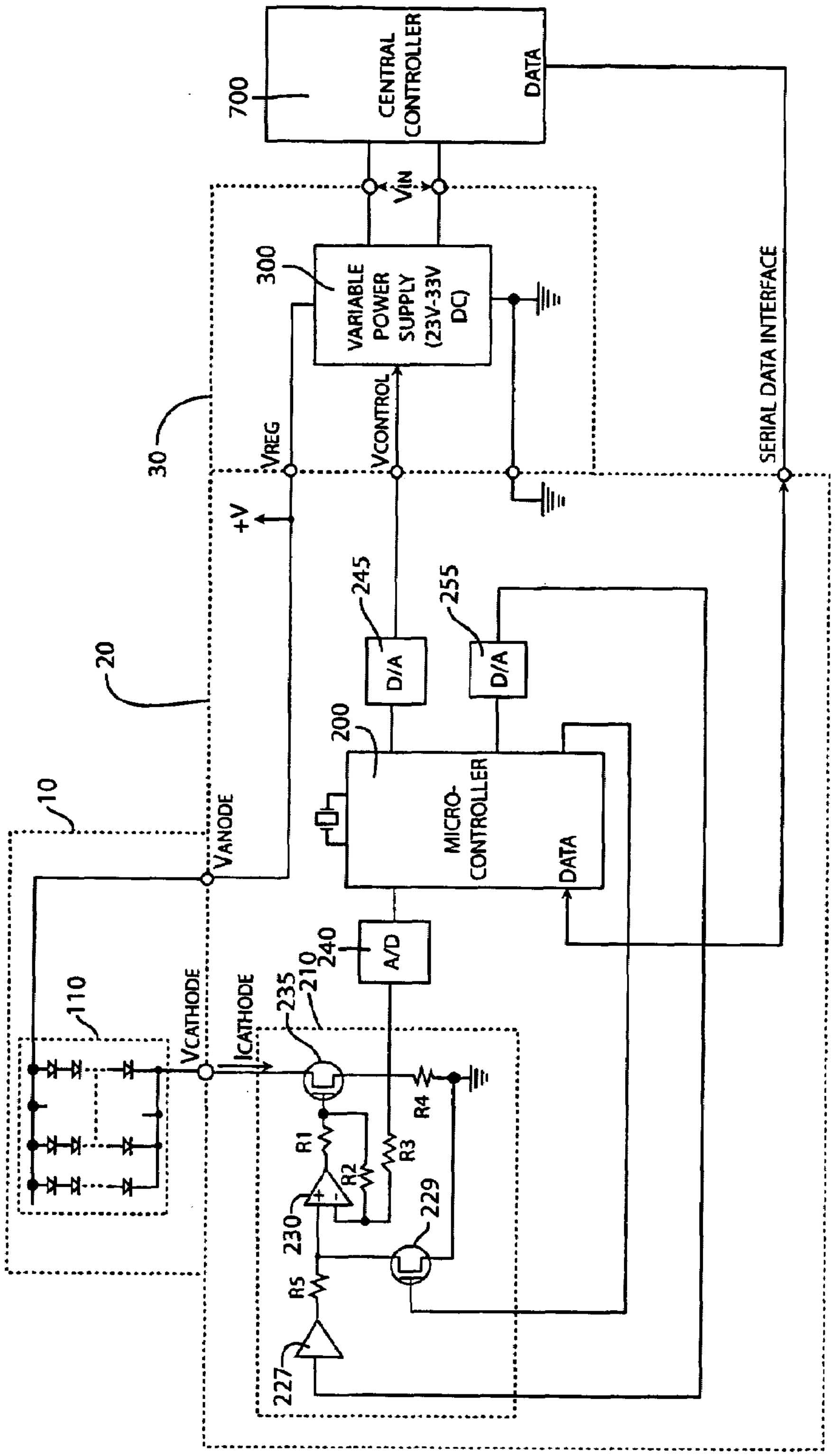

700
CENTRAL CONTROLLER
DATA
VIN
300
VARIABLE POWER SUPPLY (23V-33V DC)
30
VREG
VCONTROL
SERIAL DATA INTERFACE
+V
20
245
D/A
255
D/A
200
MICRO-CONTROLLER
DATA
10
VANODE
240
A/D
110
VCATHODE
ICATHODE
235
210
R1
R2
R3
R4
229
230
R5
227

FIG. 3

FIG. 4

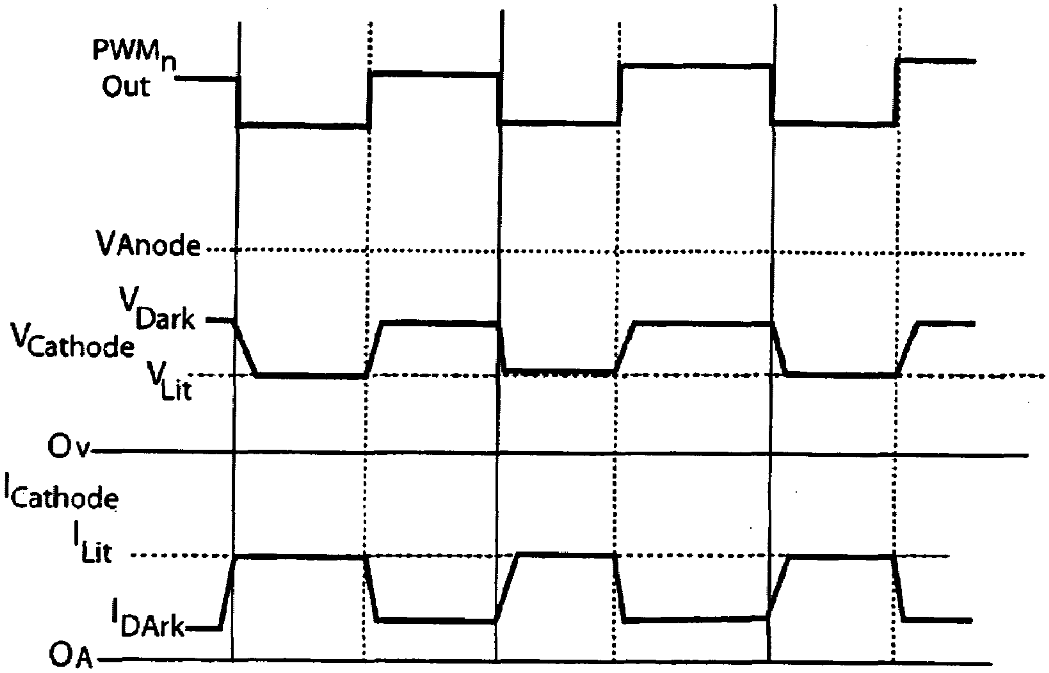

PWMn
Out
VAnode
VDark
VCathode
VLit
Ov
ICathode
ILit
IDArk
OA

FIG. 5

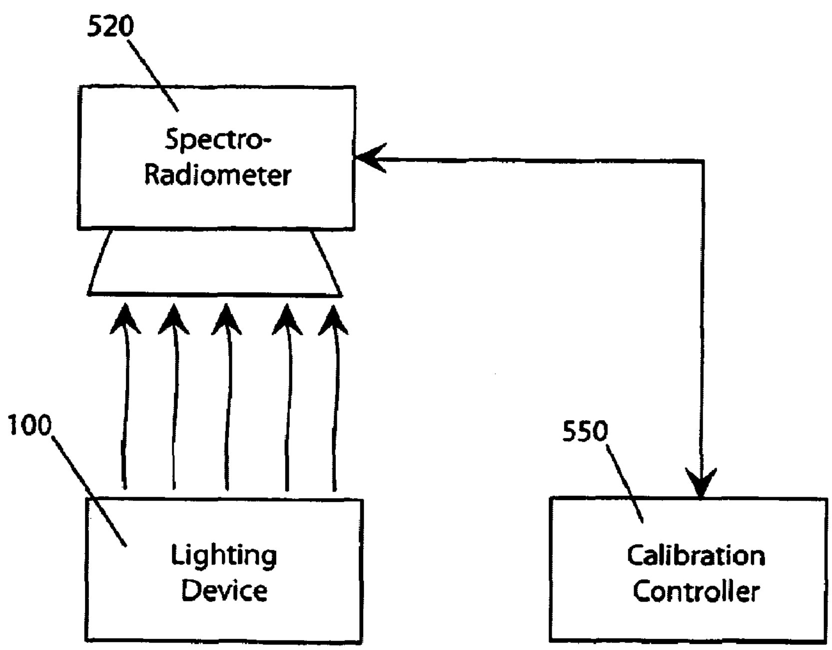

520
Spectro-
Radiometer
100
Lighting
Device
550
Calibration
Controller

FIG. 6

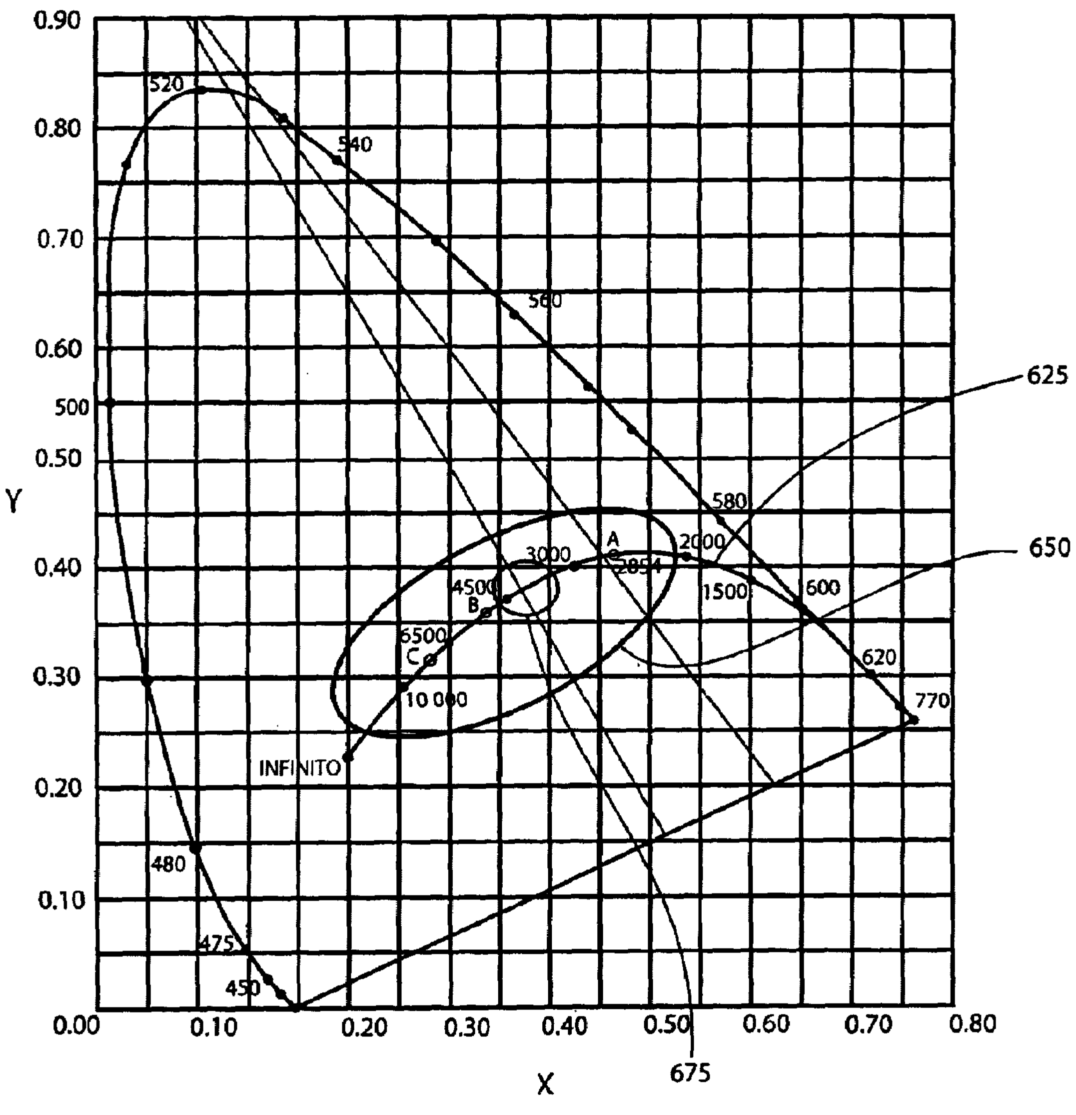

0.90
0.80
0.70
0.60
500
0.50
0.40
0.30
0.20
0.10
0.00
Y
X
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
520
540
560
580
600
620
770
480
475
450
3000
A
2000
2854
1500
4500
B
6500
C
10 000
INFINITO
625
650
675

FIG. 7

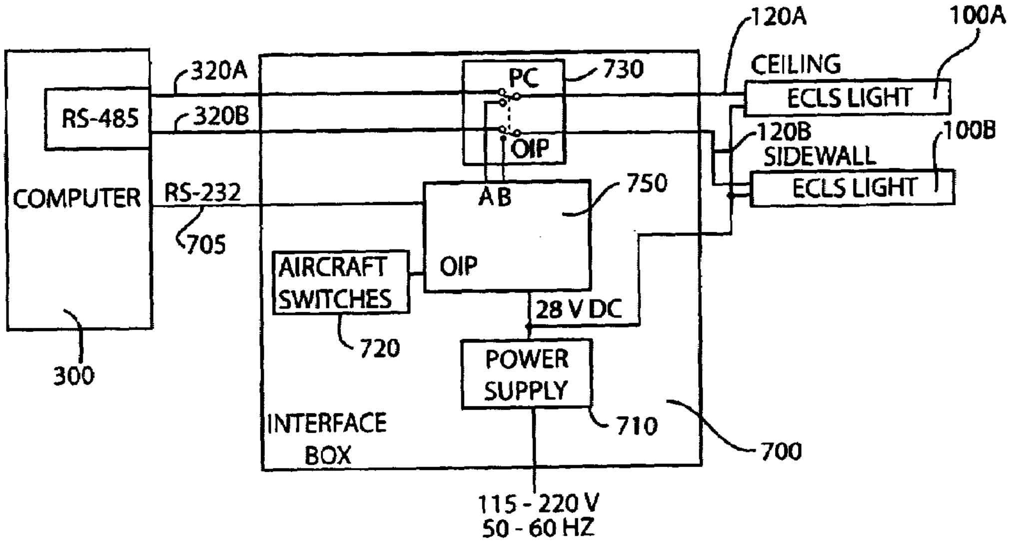

120A
100A
320A
PC
730
CEILING
ECLS LIGHT
RS-485
320B
120B
100B
OIP
SIDEWALL
COMPUTER
RS-232
AB
750
ECLS LIGHT
705
AIRCRAFT SWITCHES
OIP
28 V DC
720
POWER SUPPLY
300
INTERFACE BOX
710
700
115 - 220 V
50 - 60 HZ

FIG. 8A

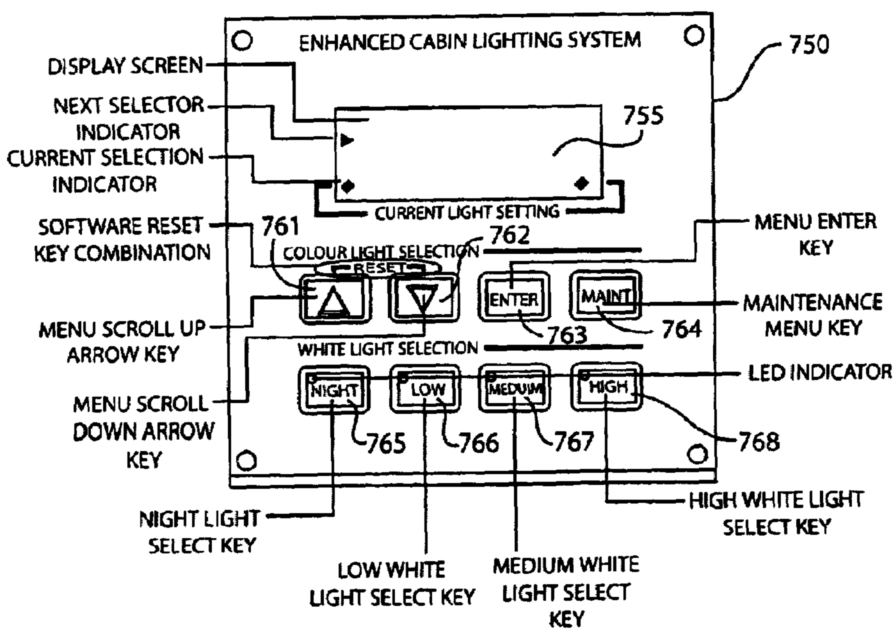

ENHANCED CABIN LIGHTING SYSTEM
750
DISPLAY SCREEN
NEXT SELECTOR INDICATOR
755
CURRENT SELECTION INDICATOR
CURRENT LIGHT SETTING
SOFTWARE RESET KEY COMBINATION
761
762
COLOUR LIGHT SELECTION
RESET
MENU ENTER KEY
ENTER
MAINT
MAINTENANCE MENU KEY
MENU SCROLL UP ARROW KEY
763
764
WHITE LIGHT SELECTION
LED INDICATOR
MENU SCROLL DOWN ARROW KEY
NIGHT
LOW
MEDIUM
HIGH
765
766
767
768
NIGHT LIGHT SELECT KEY
HIGH WHITE LIGHT SELECT KEY
LOW WHITE LIGHT SELECT KEY
MEDIUM WHITE LIGHT SELECT KEY

FIG. 8B

FEATURE	DESCRIPTION
DISPLAY SCREEN	Displays scrolled menu selections. Used for selecting and displaying desired lighting. Also used for selecting maintenance options after "MAINT" key is selected.
RESET	Pressing and holding for 5 seconds initiates a software reboot. Reset does not effect current completed light setting. Reset during light transition causes lights to revert to last completed light setting.
UP ARROW	Allows operator to scroll upward through menu selection until desired lighting or maintenance option is aligned with selection indicator
DOWN ARROW	Allows operator to scroll downward through menu selection until desired lighting or maintenance option is aligned with selection indicator
ENTER	Pressed to initiate selected lighting or maintenance option.
MAINTENANCE	**(Accessible only with plane on ground.)** Causes maintenance menu to display. Maintenance menu options are : Part Numbers, Test, and Return.
LED INDICATORS	Illuminates when associated light setting is activated. Can be activated by pressing key on this panel or comparable cabin lighting key on cabin services panel
NIGHT	Sets ECLS lighting to a uniform low level blue light in ceiling. Sidewall lights are off.
LOW	Sets ECLS lighting to dimmed white light. Ceiling lights are OFF. Sidewall lights are at 50% full white light. Can be activated by pressing this key or cabin services panel
MEDIUM	Sets ECLS lighting to a diminished white light level. Ceiling lights are at 50% brightness. Sidewall lights are on full white. Can be activated by pressing this key or cabin services panel.
HIGH	Sets ECLS lighting to full on white light. Both ceiling and sidewall lights are on full white. Can be activated by pressing key or cabin services panel.

FIG. 9

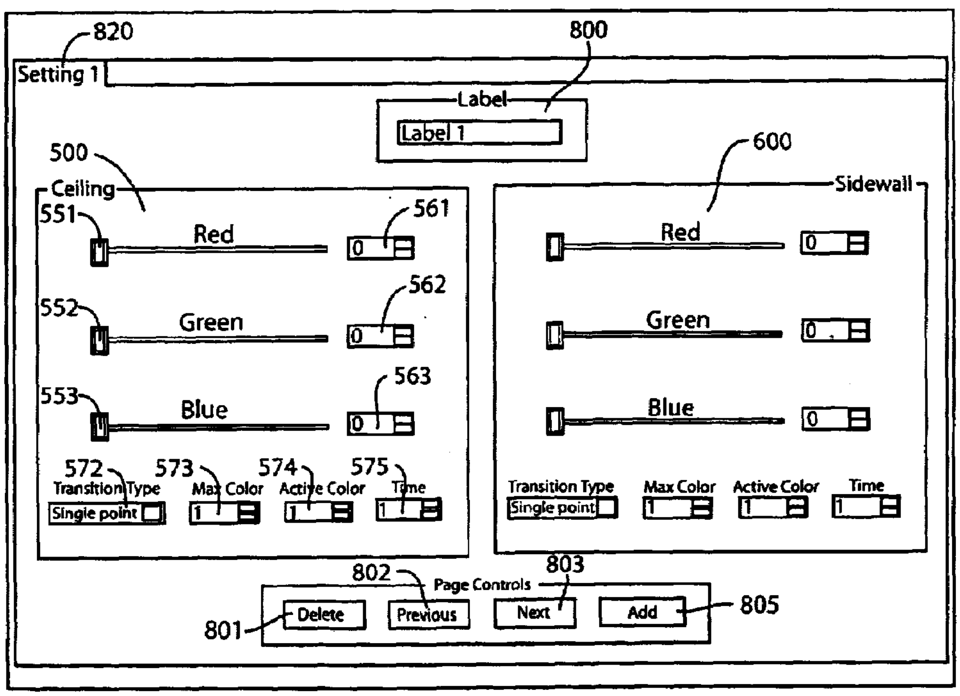


FIG. 10 A

FIG. 10 B

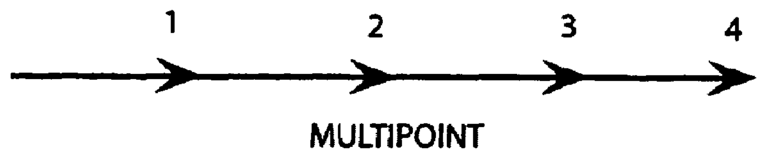


FIG. 10 C

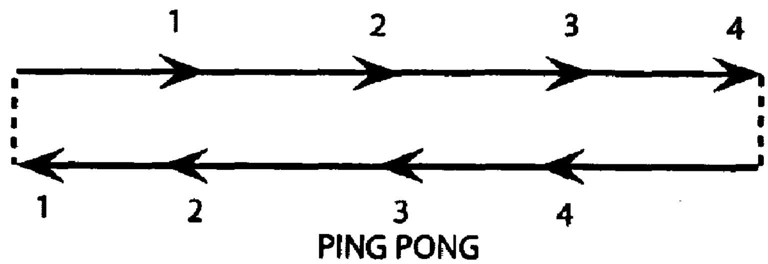


FIG. 10 D

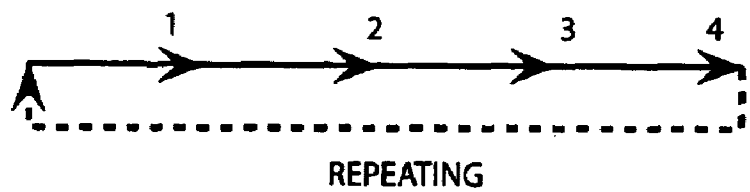


FIG. 10 E

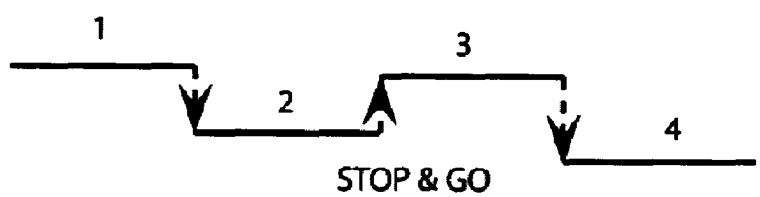


FIG. 11

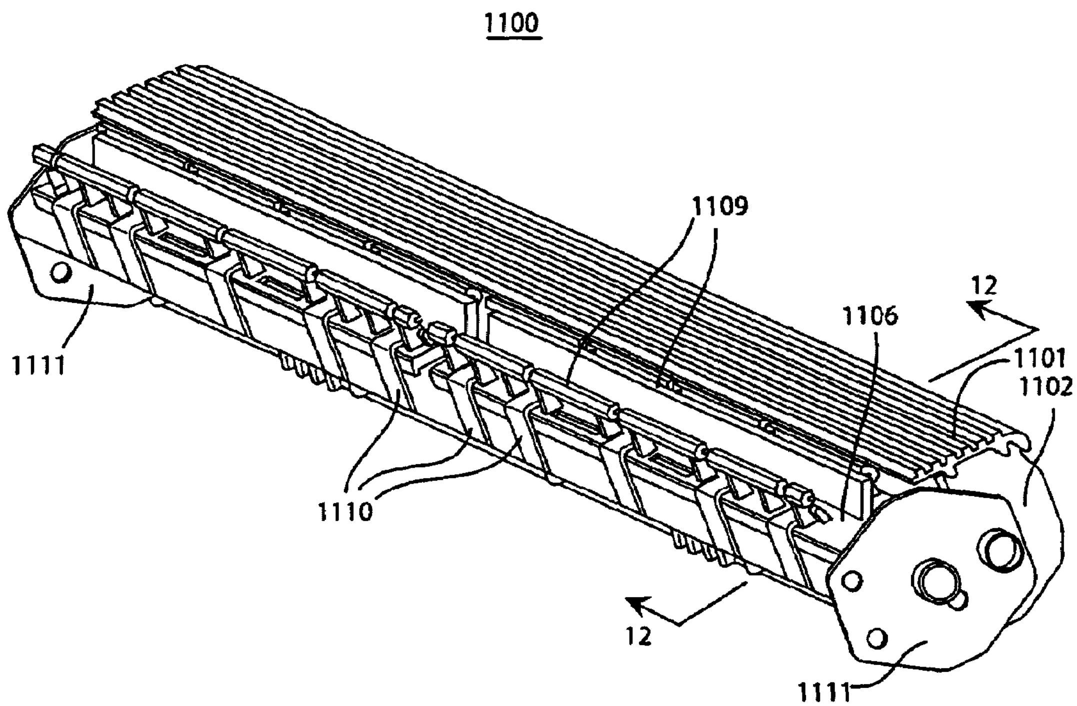

1100
1109
12
1106
1101
1102
1111
1110
12
1111

FIG. 12

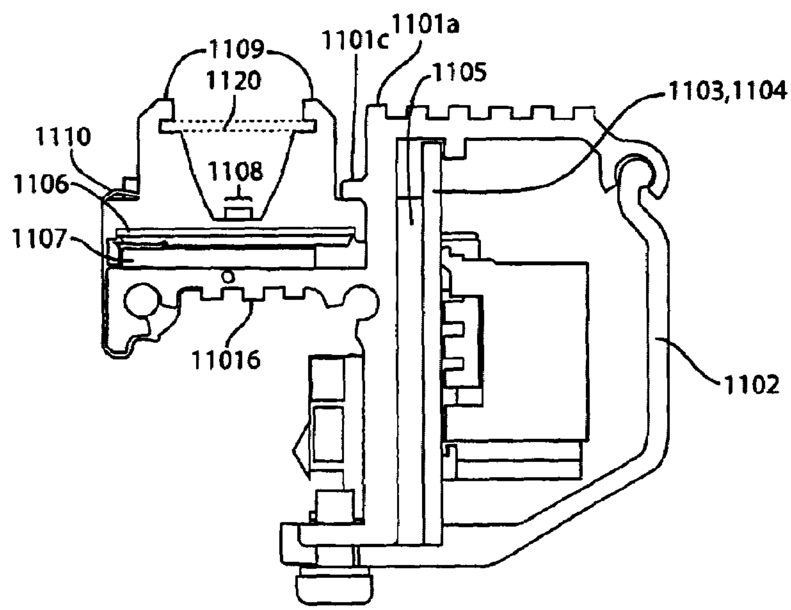

1109
1101c
1101a
1105
1103,1104
1120
1110
1108
1106
1107
11016
1102

FIG. 13

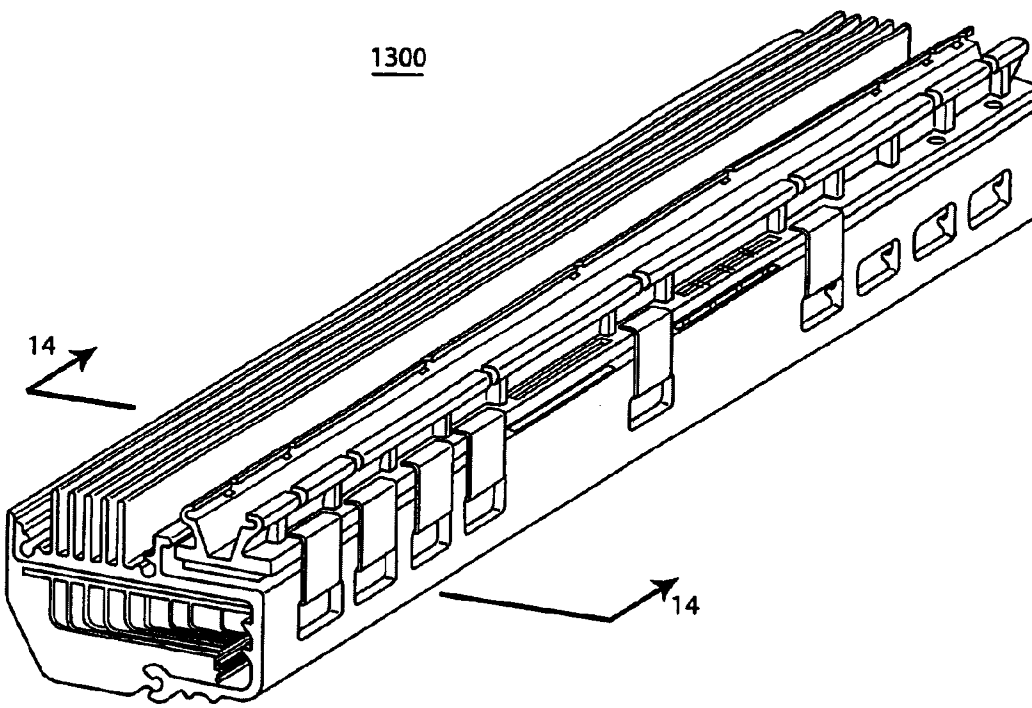

1300
14
14

FIG. 14

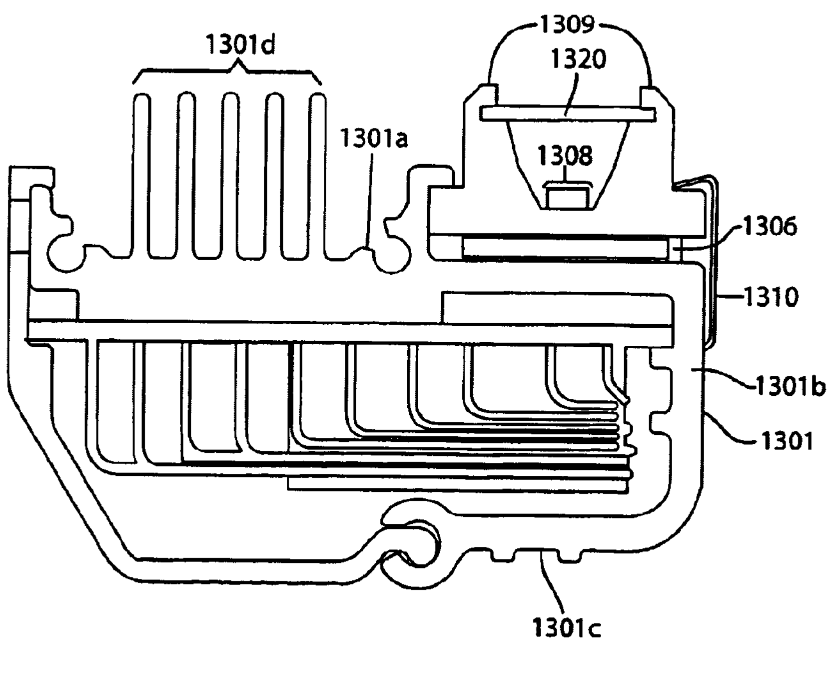

1301d
1309
1320
1301a
1308
1306
1310
1301b
1301
1301c

FIG. 15

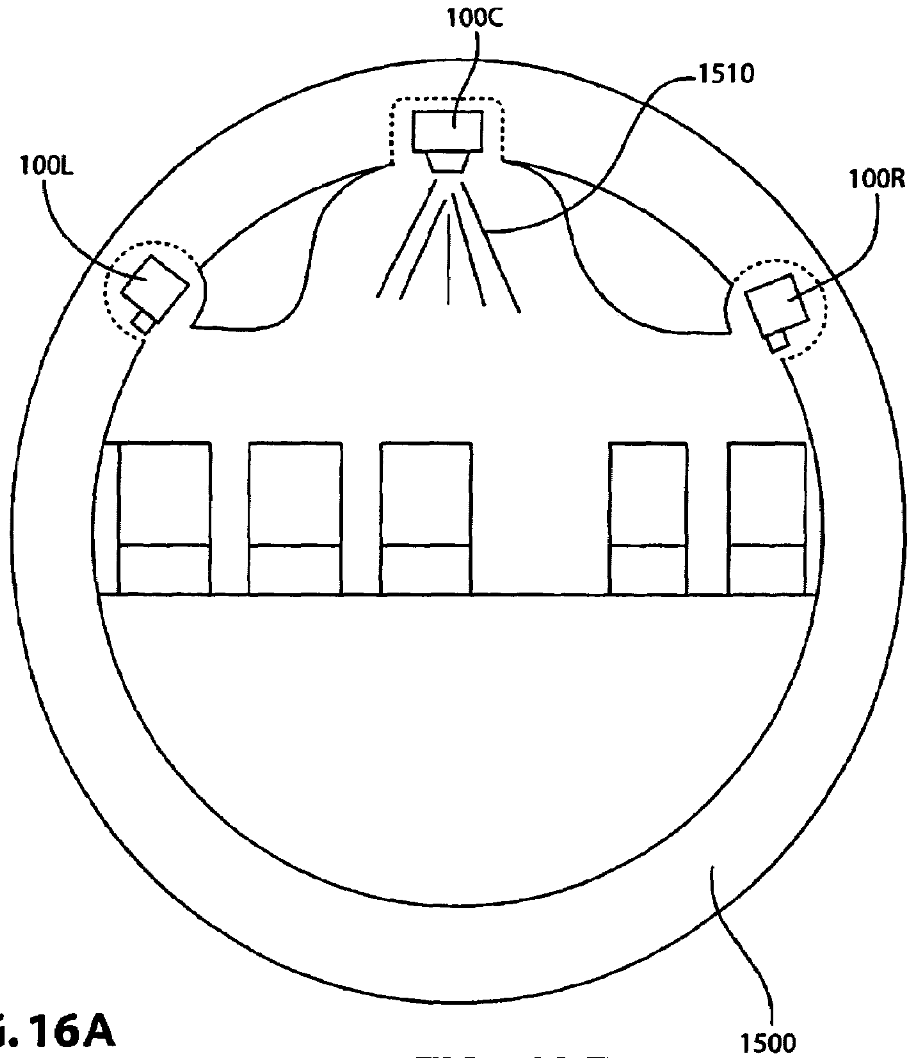


FIG. 16A

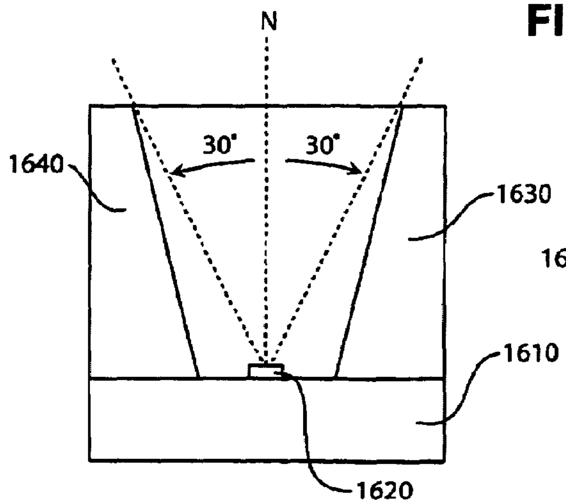


FIG. 16 B

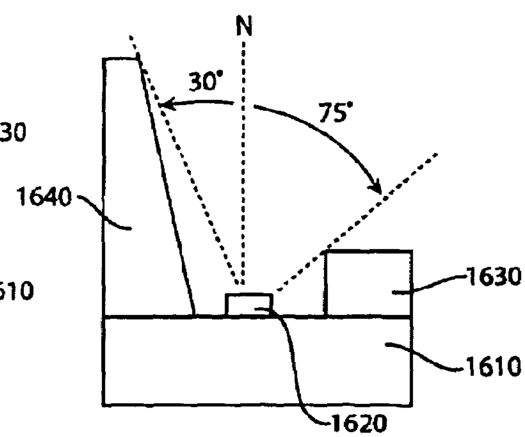


FIG. 16 C

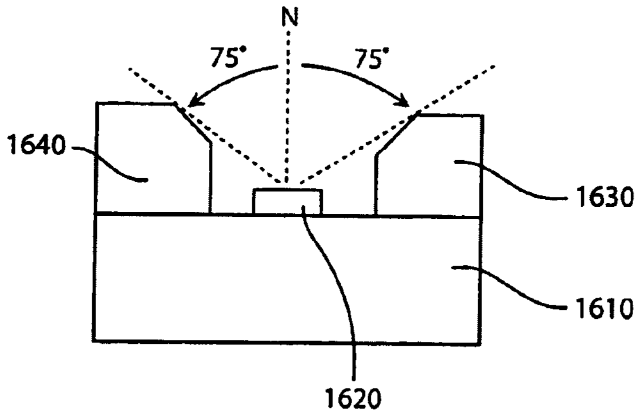


FIG. 17 A

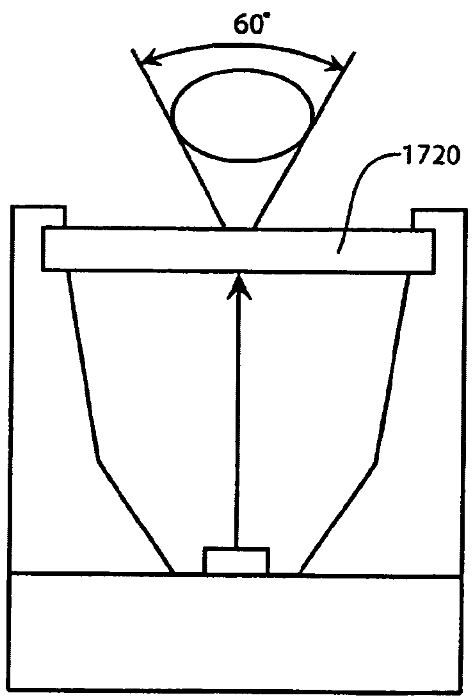
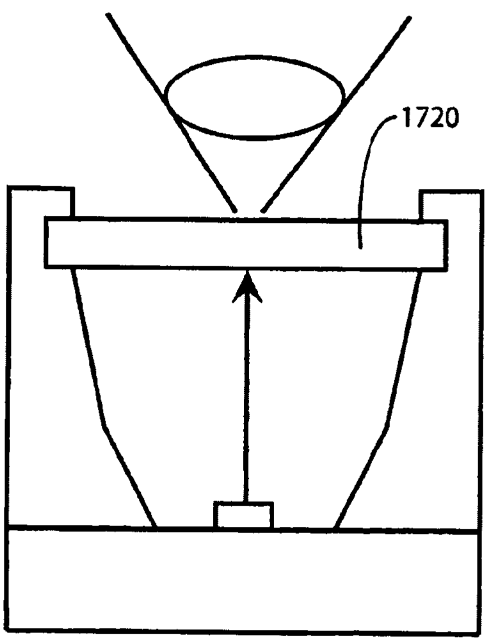


FIG. 17 B



LED LIGHTING SYSTEM

FIELD OF THE INVENTION

The present invention relates to lighting systems employing multiple light emitting diodes (LEDs) to generate light whose color and intensity can be varied under computer control.

BACKGROUND INFORMATION

It is well known that light of different colors, particularly the primary colors red, blue and green, can be combined in various proportions to generate light having a wide variety of colors, including white light. It is also well known to use light emitting diodes (LEDs) for such a purpose. The intensity of light emitted by an LED can be varied by pulse width modulating (PWM) the power applied to the LED. The application of power to an LED or group of LEDs can be controlled by a PWM control signal generated by a microcontroller or the like. The microcontroller can be programmed to control multiple groups of LEDs, each generating light of a different primary color. By controlling the intensity of light generated by each color group of LEDs, the microcontroller can thus control the LEDs to generate a combined light of a specified color and intensity. The microcontroller can carry out such an operation in accordance with a variety of data inputs from sources such as a central controller, a user interface, a measurement device or the like.

SUMMARY OF THE INVENTION

The present invention is directed to an improved lighting device that can generate light of variable color and intensity under processor control. Multiple lighting devices can be incorporated into a lighting system to illuminate larger areas.

In an exemplary embodiment, a lighting device in accordance with the present invention comprises a lighting module which is coupled to one or more additional modules that provide power and control the operation of the lighting module. The lighting module includes three groups of LEDs each of which is comprised of LEDs of the same color. The colors of the three groups are green, red and blue and the LEDs are arranged in a line in a repeating pattern of green, red, green, blue, green, red, green and red.

In a further aspect of the present invention, a lighting system is formed by coupling multiple lighting devices to a central controller comprising an operator interface panel and an interface to an external computer. The external computer can be provided with programming tools in accordance with the present invention that allow the creation of lighting programs for controlling the operation of the lighting system. The lighting programs developed on the external computer can be downloaded to the central controller which then carries out the downloaded programs in conjunction with the lighting devices coupled thereto. A user can select programs or modify the operation of the lighting system from the operator interface panel provided at the central controller. A user can also control the operation of the lighting system directly from the external computer while it is coupled to the central controller.

The present invention also provides methods for calibrating the color and power output of each lighting device.

These and other aspects of the present invention will be described below in greater detail.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is schematic representation of an exemplary embodiment of a lighting device in accordance with the present invention.,

FIG. **2** shows the linear arrangement of LEDs on a lighting module of an exemplary embodiment of a lighting device in accordance with the present invention.

FIG. **3** shows a more detailed schematic representation of an exemplary embodiment of a lighting device in accordance with the present invention.

FIG. **4** shows the control signal, common cathode voltage and common cathode current for a group of LEDs of an exemplary embodiment of a lighting device in accordance with the present invention.

FIG. **5** shows an arrangement for an exemplary color calibration method in accordance with the present invention.

FIG. **6** shows a chromaticity diagram for illustrating the exemplary color calibration method of the present invention.

FIG. **7** shows a block diagram of an exemplary embodiment of a lighting system in accordance with the present invention.

FIGS. **8**A and **8**B show an exemplary embodiment of an operator interface panel of a lighting system in accordance with the present invention.

FIG. **9** shows an exemplary display of a user interface for programming a lighting system in accordance with the present invention.

FIGS. **10**A through **10**E illustrate various lighting transition modes of an exemplary embodiment of a lighting system in accordance with the present invention.

FIG. **11** shows a first exemplary embodiment of a lighting device in accordance with the present invention.

FIG. **12** shows a cross-sectional view of the device of FIG. **11**.

FIG. **13** shows a second exemplary embodiment of a lighting device in accordance with the present invention.

FIG. **14** shows a cross-sectional view of the device of FIG. **12**.

FIG. **15** shows a cross-sectional view of an aircraft passenger cabin illustrating the placement of lighting devices of the present invention within the aircraft passenger cabin.

FIGS. **16**A through **16**C show cross-sectional views of three exemplary reflector arrangements of a lighting module of a lighting device of the present invention.

FIGS. **17**A and **17**B show how a ray of light is affected by two exemplary lens arrangements.

DETAILED DESCRIPTION

FIG. **1** shows a block diagram of an exemplary embodiment of a lighting device **100** in accordance with the present invention. In the exemplary embodiment shown, the lighting device **100** comprises a lighting module **10**, a control module **20** and a power module **30**. The lighting, control and power modules can be combined into one or more modules and may be implemented on one or more circuit boards. The lighting device **100** need not be modular at all.

The lighting module **10** comprises a plurality of light emitting diodes (LEDs) each of which emits green, red or blue light. Naturally, other combinations of colors are possible within the scope of the present invention. For example, green, orange and blue LEDs may be used. In yet a further embodiment, any three colors whose wavelengths are separated by at least some minimum wavelength difference (for example 30 nm) can be used. Furthermore, as can be understood by a person of ordinary skill in the art, aspects of the present invention are applicable to systems with LEDs of any number of different colors including single-color LED applications.

Physically, the LEDs are arranged substantially along a line in a repeating pattern of green, red, green, blue, green, red, green and red. This arrangement is illustrated in FIG. **2**. Electrically, the LEDs are grouped by color, wherein the cathodes of the LEDs of a particular color are coupled to a common terminal **11**, **12** or **13**. The anodes of all of the LEDs are coupled to a common power terminal **14**. As can be understood, each of the terminals **11**–**14** can be implemented using multiple terminals as may be required for current carrying capacity but are described as single terminals for the sake of simplicity.

As shown in FIG. **1**, each group (G) of LEDs is comprised of one or more parallel strings (S) of LEDs. Each LED string comprises one or more LEDs connected in series. All of the LEDs within a string preferably emit the same color light. The common cathode of each group of LEDs is coupled to a respective current source **21**, **22**, and **23** on the control module **20**. The common anode of all LEDs on the LED module **10** is coupled to a power supply **35** on the power module **30**. The current through each group of LEDs is determined by the respective current source **21**–**23**, each of which is under the control of a control circuit **25** on the control module **20**. When on, each of the current sources **21**–**23** sinks a current that is regulated to be substantially constant. Naturally, as can be readily understood, the polarity of the LEDs and of the power supply and the direction of current flow can be reversed in an alternative embodiment. The control and power circuitry will be described in greater detail below.

The number of LEDs in each string is selected so as to substantially equalize the voltage drop across the multiple LED strings of the LED module. By equalizing the voltage drops across the multiple LED strings, the amount of power wasted in the control module is reduced, thereby improving the efficiency of the device.

Because LEDs of different colors have different forward voltage drops, the preferred number of LEDs in each string depends on the color of the LEDs in that string. Thus, for example, where green and blue LEDs each have a forward voltage drop of approximately 3.2 volts, a string of eight green or blue LEDs will have a voltage drop of approximately 25.6 volts. A string of 12 red LEDs, each of which has a forward voltage drop of 2.1 volts, will have a voltage drop of 25.2 volts.

In an exemplary embodiment, the LED module **10** includes 192 LEDs arranged linearly along a board which is 12.4" long. The 192 LEDs include 96 green LEDs, 72 red LEDs and 24 blue LEDs physically arranged in the repeating pattern of green, red, green, blue, green, red, green and red. The 96 green LEDs are electrically arranged in 12 strings of eight LEDs each; the 72 red LEDs in six strings of 12 LEDs each; and the 24 blue LEDs in three strings of eight LEDs each.

In another exemplary embodiment, an LED module **10** with a board that is 11 inches long has 160 LEDs: 80 green LEDs, 60 red LEDs and 20 blue LEDs physically arranged in the aforementioned repeating pattern of green, red, green, blue, green, red, green and red. As in the previously described embodiment, each string of red LEDs includes 12 LEDs, whereas each string of green or blue LEDs includes eight LEDs. In the case of the blue LEDs, four "ballast" LEDs are added to the 20 LEDs so as to form three full strings of eight LEDs each. The ballast LEDs are obscured so that the light they emit is not combined with that of the other LEDs and thus does not disturb the color emission balance of the lighting module. By thus utilizing ballast LEDs, any combination of LEDs can be arranged in voltage-equalized strings of LEDs while also providing the desired color emission balance.

The ballast LEDs can be obscured by a variety of means, such as by placing them on the side of the circuit board opposite to that on which the other LEDs are placed and/or by applying a dark paint over their emitting surfaces. In order to avoid dark spots in the emission of the LED module, the ballast LEDs preferably are not placed along the line of LEDs whose emissions are visible.

Because different LEDs can have different forward voltages, even if of the same color, some strings of LEDs may not be as bright as other strings of LEDs. To avoid the appearance of dark or bright spots along the row of LEDs, it is desirable to distribute the LEDs of the same string as widely as possible over the LED module. For example, LEDs of the same string must be at least N LEDs apart, where N is at least one.

Physically distributing the LEDs of the same string across the LED board also has the benefit of minimizing the perceived effect of an LED burning out. When an LED burns out, the current in the string in which the LED is coupled is interrupted and all of the LEDs in that string turn off. The LEDs of the same color that are in other strings, however, become brighter as the same amount of current is now shared by fewer LEDs of the same color. By widely distributing the LEDs of each string over the board, the brighter LEDs will compensate for the inactive LEDs and the perception of any bright or dark spots will be minimized.

FIG. **3** shows a block/schematic diagram of an exemplary embodiment of a lighting device **100** in accordance with the present invention. FIG. **3** shows in greater detail the control circuitry for one color group **110** of LEDs. The control circuitry for the remaining color groups is similar and has been omitted for clarity.

The control circuitry, which resides on the control module **20**, includes a microcontroller **200** which operates in accordance with a program stored in a memory device (not shown or incorporated in microcontroller **200**). The microcontroller **200** may be a single-chip device which includes a CPU and one or more of a random access memory (RAM), read-only memory (ROM) for program storage, non-volatile memory such as EEPROM for storing parameters or settings, one or more digital-to-analog converters, one or more analog-to-digital converters, one or more pulse-width modulators, a serial communications interface, and various other auxiliary functions, such as timers, counters, interrupt handlers and the like. These function can be implemented in one integrated circuit (IC) or with several ICs and discrete components. In an exemplary embodiment, the microcontroller **200** is implemented with a TMS320LF2406A 16-bit Digital Signal Processor (DSP) IC from Texas Instruments of Dallas, Tex.

The microcontroller **200** includes a bidirectional serial data interface for communicating with a central controller **700** (discussed in greater detail below). Over this interface, the microcontroller **200** can receive commands from the central controller **700** specifying the state of operation of each LED group of the device **100**. In an exemplary embodiment, the central controller **700** specifies the duty cycle of the power applied to each LED group (thereby specifying the brightness of the light emitted by each LED group and thus the color of the combined light as well.) In response, the microcontroller **200** controls the LED groups accordingly. In an exemplary embodiment, the data interface can be compliant with the RS-485 protocol. In other embodiments, the data interface can alternately be a parallel interface. The data interface may also be wireless (e.g., infrared, radio frequency, etc.)

In the exemplary embodiment shown, the microcontroller **200** includes three on-chip pulse width modulation (PWM) generators, each of which generates a pulse-width modulated signal which is used to control a respective color group of LEDs. The on-chip PWM generators operate in accordance with internal registers under software control. Once the appropriate registers have been set, the PWM generators carry out the generation of the respective control signals without involving the CPU, thus freeing the CPU to perform other functions. Naturally, as can be understood by a person of ordinary skill, other implementations are also possible within the scope of the present invention, including, among others, a CPU-intensive bit-banging implementation, or an interrupt-driven implementation using one of the internal timers. The PWM generators can also be implemented with dedicated hardware and controlled by the microcontroller **200**.

A control circuit **210** controls the activation of LED color group **110** under the control of the microcontroller **200**. The control circuit **210** acts as a constant current source which can be switched on or off by the respective PWM control signal (PWMn) generated by the microcontroller **200**. FIG. **4** shows the voltage at the common cathode of the LED color group **110**, Vcathode, and the current through the common cathode of the LED color group **110**, Icathode, with respect to the PWM control signal generated by the microcontroller **200**. As described above, the anodes of all LEDs are coupled together at a common anode. The voltage at the anode, Vanode, is coupled via the control module **20** to the regulated power supply output voltage Vreg.

As shown in FIG. **4**, when the PWM control signal is in the ON state (in the illustrated case a logic "1" or high), the LEDs of the color group are turned on as the cathode voltage drops to Vlit and the cathode current rises to Ilit. When the PWM signal is in the OFF state, the LEDs of the color group are turned off, as the cathode voltage rises to Vdark and the cathode current drops to Idark.

In an exemplary embodiment of the present invention, the control circuit **210** operates so that when the LEDs of the group **110** are dark, or not emitting any perceptible light, the LEDs are nonetheless conducting some current so that the combined current for the group **110**, Idark, is greater than zero, as shown in FIG. **4** This causes the common cathode voltage Vdark to be less than the anode voltage since there is a voltage drop across each LED in the group. In a conventional arrangement in which the LEDs do not conduct at all when off, Vdark would be higher, substantially equal to the anode voltage. By thus reducing the amplitude of the cathode voltage swing between the active (or lit) and inactive (or dark) states of the LEDs, the stress to which the LEDs are subjected is reduced, thereby increasing their longevity. Furthermore, the slew rate of the voltage transition between the active and inactive states is reduced, thereby reducing the high frequency components in the voltage signal and thus the electrical noise emitted by the lighting device of the present invention.

The magnitude of the cathode current in the lit state, Ilit, is controlled by the microcontroller **200** via a digital-to-analog (D/A) converter **225**. The output of the D/A converter **225** is coupled to a buffer **227** whose output controls a voltage-controlled current source comprising an operational amplifier (op-amp) **230**, a MOSFET **235** and resistors R**1**–R**4**.

The amount of current conducted by the MOSFET **235** is controlled by the voltage applied to the non-inverting input of the op-amp **230** so that the larger the input voltage, the greater the current. Icathode, the current conducted by the MOSFET **235**, is substantially equal to the voltage at the non-inverting input of the op-amp **230** divided by the value of R**4**.

A MOSFET **229** is arranged at the output of the buffer **227** so that when the PWM control signal is low (logic 0), the MOSFET **229** is off and the voltage generated by the buffer **227** is provided unattenuated to the non-inverting input of the op-amp **230**. This causes the current through the MOSFET **235** to be Ilit.

When the PWM control signal is high (logic 1), the MOSFET **229** turns on, shunting the output of the buffer **227** through R**5** to ground and attenuating the voltage at the non-inverting input of the op-amp **230**. This causes the current through the MOSFET **235** to be Idark. The value of Ilit is substantially equal to the unattenuated voltage at the output of the buffer **227**, which is set by the microcontroller via the D/A converter **225**, divided by the value of R**4**. The microcontroller **200** can set the value of Ilit in accordance with the number of LED strings in the respective LED group **110**. This allows the use of LED modules **10** of different sizes (i.e., different numbers of LED strings) with the same control module **20**. The microcontroller **200** can also set the value of Ilit to calibrate the power provided to the LEDs.

The value of Idark is substantially equal to the voltage at the output of the buffer **227** attenuated by the combination of R**5** and the conducting resistance of MOSFET **229**, divided by the value of R**4**. As discussed above, Idark is selected so as to reduce the noise generated by the switching of the LEDs and to reduce the switching stresses on the LEDs. As with Ilit, the microcontroller **200** can control the value of Idark by controlling the voltage at the output of the buffer **227** via the D/A **225**.

In an exemplary embodiment, the current through each LED string when lit is substantially 40 mA. In the case of a 12.4" long LED module with 96 green LEDs organized in 12 strings of eight LEDs each, the microcontroller **200** controls the voltage-controlled current source **210** to sink a cathode current of 12×40 mA, or 480 mA, when the green LEDs are on. Thus the desired value of Ilit is 480 mA. With R**4** having a resistance of 1.25 ohm, the voltage at the output of the buffer **227** should be 1.25×0.480=0.600 volts. Therefore, the microcontroller **200** is programmed so that when a 12.4" LED module **10** with 96 green LEDs is coupled to the control module **20**, the microcontroller **200** controls the D/A converter **245** to generate a voltage of 0.600 volts at the output of the buffer **227**, which in turn causes the MOSFET **235** to conduct a current of 480 mA. The 480 mA current is shared by 12 strings of LEDs, each string conducting 40 mA, as desired.

In an exemplary embodiment in which the MOSFET **229** has a conducting resistance of 4 ohms and the resistor R**5** has a value of 20 kohms, the output of the buffer **227** is attenuated to 1 mV at the input to the op-amp **230**. If the op-amp **230** has an input bias offset voltage of approximately 0.360 mV, Idark is approximately:

$$(1\ \text{mv}+0.360\ \text{mV})/1.25\ \text{ohm}=1.088\ \text{mA}.$$

Distributed over 12 strings, each string conducts 1.088 mA/12=90 μA.

The current through the common cathode of the LED color group **110** is monitored by the microcontroller **200** via an analog-to-digital (A/D) converter **240**. The input of the A/D converter **240** senses the voltage across R**4**, which is substantially proportional to the cathode current. The microcontroller **200** monitors the cathode current of each LED color group using a similar arrangement for each group. The microcontroller **200** uses the current information in performing a power calibration procedure described below.

In an exemplary embodiment of a lighting device in accordance with the present invention, one control module **20** can be coupled to and control multiple lighting modules **10**. In this case, the control circuitry **210** is replicated for each LED group. For example, in an exemplary embodiment with three LED modules **10**, the control module **20** will have nine groups of LEDs. The TMS320LF2406A DSP is well suited in this case for use as the microcontroller **200** as it includes nine, on-chip PWM generators as well as multiple A/D converters that can sample the nine current sensing points in such a device.

In a further aspect of an exemplary embodiment of the present invention, the power module **30** comprises a variable power supply **300**. The power supply **300** takes in a voltage Vin from the central controller **700** and generates a regulated DC voltage Vreg which can be varied in accordance with a control voltage Vcontrol. Vcontrol is generated on the control module by a D/A converter **245** coupled to the microcontroller **200**. The microcontroller can thus control the regulated output of the power module **30** over a given range. The regulated output of the power module **30** is routed via the control module **20** to the LED module **10** as the common anode voltage, Vanode. (Naturally, Vreg can alternately be directly coupled from the power module **30** to the common anode of the LED module **10**.)

In an exemplary embodiment, Vin is nominally 28 volts DC and Vreg can be 23 to 33 volts DC. The variable power supply **300** can be implemented in a conventional way.

As described above, the microcontroller **200** can measure the cathode current for each LED color group as well as control the common anode voltage Vanode. The microcontroller **200** can be programmed to use these capabilities to carry out a power calibration procedure in accordance with the present invention. In an exemplary procedure, the microcontroller **200** initially sets Vanode (Vreg) close to the bottom end of its range of adjustability, e.g., 24 volts. The microcontroller **200** then turns on each LED group and measures the common cathode current for each LED group. If the cathode current for each LED group is not at least some minimum predetermined current for that group, the microcontroller **200** then adjusts the Vcontrol to increase Vanode by at least some predetermined increment, e.g., 0.25 volts. The minimum predetermined current for each LED color group is equal to a minimum predetermined current for each string of LEDs multiplied by the number of LED strings of that color group. In an exemplary embodiment, the average current through each LED string is 40 mA, with a variation of ±10%; i.e., a minimum current of 36 mA and a maximum of 44 mA. If there are 12 strings in the green LED group, for example, the minimum current for the green LED group is 36×12 or 432 mA. Similarly, for six strings of red LEDs and three strings of blue LEDs, the minimum currents would be 216 mA and 108 mA, respectively. If in this exemplary arrangement the microcontroller **200** does not sense at least 432 mA, 216 mA and 108 mA in the green, red and blue LED groups, respectively, the microcontroller will then increase Vanode and re-measure the cathode currents of each group, as before. The microcontroller **200** repeats this iterative process until the aforementioned minima are met or exceeded for all three LED color groups.

An exemplary method of calibrating the color emitted by a lighting device of the present invention will now be described with reference to FIGS. **5** and **6**. FIG. **5** shows an exemplary calibration setup in which a lighting device **100** to be calibrated emits light which is detected by a spectro-radiometer **520**. The spectro-radiometer **520** determines the color rendering index (CRI) and the correlated color temperature (CCT) of the light detected. The spectro-radiometer **520** is coupled to a calibration controller **550** which is in turn coupled to the lighting device **100** via the above-described data interface. The calibration controller **550** may comprise a personal computer with the appropriate software and interfaces for interacting with the spectro-radiometer **520** and the lighting device **100**.

In an exemplary method of the present invention, the calibration controller **550** initially controls the lighting device **100** to generate white light by specifying the appropriate duty cycles with which the red, blue and green LEDs of the lighting device **100** are to be energized in order for their combined output to appear as white light. In an alternate embodiment, the calibration controller **550** initially controls the lighting device **100** to generate all three colors with maximum intensity: i.e., the duty cycle specified for each of the red, green and blue LED groups is at its maximum value.

The spectro-radiometer **520** then determines the CRI and CCT of the light emitted by the lighting device **100** and communicates those results to the calibration controller **550**. The calibration controller **550**, in turn, determines whether the measured CRI and CCT are acceptable. In an exemplary embodiment, a CRI of 60 to 100 is considered acceptable and a CCT of approximately 4000 Kelvin is sought. If not acceptable, the calibration controller **550** adjusts the duty cycles of the red, green and blue LEDs of the lighting devices. The light output of the device **100** is measured again and the process is repeated until the CCT and CRI values measured fall within the above-mentioned ranges.

The spectro-radiometer **520** may also determine the components of the color of the light generated by the device **100** which components can be used in an alternate color calibration procedure. FIG. **6** shows a chromaticity diagram which helps illustrate the color calibration process of the present invention. The chromaticity diagram of FIG. **6** is an x, y chromaticity diagram which projects the cone of visible light onto the x, y tristimulus plane. A region **650** of the chromaticity diagram represents white light. The region **650** surrounds the black body curve **625**. The white light output desired falls within a predetermined target area **675** within the region **650** on or near the curve **625**.

In an exemplary calibration procedure of the present invention, the calibration controller **550** initially controls the lighting device **100** to generate all three colors with maximum intensity. The spectro-radiometer **520** then determines the x and y tristimulus components (i.e., the location on the chromaticity diagram of FIG. **6**) of the light emitted by the lighting device **100** and communicates those results to the calibration controller **550**. The calibration controller **550**, in turn, determines whether the measured x and y components represent a point within the predetermined target area **675**. If not, the calibration controller **550** adjusts the duty cycles of the red, green and blue LEDs of the lighting devices accordingly. The light output of the device **100** is measured again and the process is repeated until the measured tristimulus components represent a point within the predetermined target area **675**. At that point, the x, y and z tristimulus values (where x+y+z=1) are used to determine the relative intensities of the LED color groups in order to achieve the calibrated white light.

A lighting system comprising multiple lighting devices in accordance with the present invention will now be described.

FIG. **7** shows a block diagram of an exemplary lighting system comprising lighting devices **100**A and **100**B and a central controller **700** coupled thereto. The central controller **700** can also be coupled to a computer **300**. Each of the lighting devices **100**A and **100**B can be implemented as described above. A system with two lighting devices is shown for simplicity. Larger systems with more lighting devices can readily be implemented within the scope of the present invention.

The exemplary embodiment of the central controller **700** shown in FIG. **7** comprises an operator interface panel (OIP) **750**, a power supply **710**, a plurality of switches **720** and a data selector **730**. The OIP **750** includes a microcontroller (not shown) which provides the intelligence of the central controller **700** and provides a user interface at the central controller. The lighting system can be controlled from the OIP **750** or from the external computer **300**. The computer **300** can be temporarily coupled to the central controller **700** in order to program the OIP **750**. Once programmed, the OIP **750** can then take over operation of the lighting system in accordance with the downloaded program.

The central controller **700** is coupled to the lighting devices **100**A and **100**B via respective data interfaces **120**A, **120**B. In an exemplary embodiment, the interfaces **120**A, **120**B are bidirectional serial data interfaces which conform to the RS-485 protocol. The lighting devices **100**A and **100**B are also coupled to the power supply **710** which provides DC power to the lighting devices. The power supply **710** may be coupled to a 115–120 V, 50–60 Hz AC power source (not shown) or other suitable power source.

The central controller **700** also includes interfaces **320**A, **320**B and **705** for coupling to the computer **300**. The interfaces **320**A and **320**B are similar to the interfaces **120**A and **120**B and are used by the computer **300** to communicate with the lighting devices **100**A and **100**B, respectively. The data selector **730** is coupled to the lighting devices **100**A, **100**B via the interfaces **120**A and **120**B, to the computer **300** via the interfaces **320**A and **320**B, and to ports A and B of the OIP **750**. The ports A and B of the OIP **750** are compatible with the interfaces **120**A and **120**B. Under the control of the OIP **750**, the data selector **730** couples the lighting devices **100**A, **100**B to either the computer **300** or to the OIP **750**. The interfaces associated with the respective lighting devices **100**A and **100**B may be switched by the selector **730** in tandem or individually. Thus, depending on the state of the selector **730**, the lighting devices **100**A, **100**B may communicate either with the computer **300** or with the OP **750** over the interfaces **120**A, **120**B, respectively.

An additional data interface **705** couples the computer **300** to the OIP **750**. In an exemplary embodiment, the interface **705** is a bidirectional serial data interface which conforms to the RS-232 protocol. The interface **705** is used to program the OIP **750** from the computer **300** and to exchange data as needed.

As can be readily understood by a person of ordinary skill in the art, the interfaces **120**A, **120**B, **320**A, **320**B and **705** can be implemented in a variety of known ways, the specifics of which are matters of design choice. Moreover, in alternate embodiments, these data interfaces may be parallel interfaces or wireless (e.g., IR, RF).

The switches **720** are used to input various information and place the system into various modes under user control. For example, in an aircraft application, the switches **720** may include a decompression simulation activation switch which causes the system to enter an emergency lighting mode. Another switch may be included to simulate high-temperature conditions in which case the lighting is dimmed to reduce the possibility of over-heating.

FIG. **8**A shows the front panel of an exemplary embodiment of an OIP **750**. The OIP **750** includes a display **755** and a plurality of buttons **761**–**768**. A pair of buttons **761**, **762** are used to scroll up and down a menu structure that is displayed on the display **755** and an ENTER button **763** is used to enter menu selections. A set of buttons **765**–**768** are used to control the generation of white light. FIG. **8**B shows exemplary functions for the various buttons of the OIP **750**.

The lighting system comprising the lighting devices **100**A and **100**B can be controlled from the OIP **750** of the central controller **700**. A computer **300** can be coupled to the central controller **700** via the interface **705** to program the operation of the lighting system. The computer **300** can be loaded with software in accordance with the present invention which allows a user to create programs for the operation of the lighting system or to control the lighting system directly. The programs can be developed on the computer **300** off-line and then downloaded to the central controller **700** when coupled via the interface **750**. The programs created on the computer **300** can control various operating characteristics of the lighting system such as the colors, intensities and durations of light to be emitted by the system. The computer **300** can also be used to create scenes or sequences of scenes, including transitions between scenes, fading, etc. The various lighting devices **100** coupled to the lighting system can operate independently of each other thereby allowing different lighting programs to be executed for different lighting areas.

FIG. **9** illustrates an exemplary user interface as displayed by the computer **300** programmed in accordance with the present invention. In the embodiment shown, independent control of ceiling and sidewall lighting is provided. A first area **500** of the display is used to display and control parameters related to the ceiling lighting and a second, similar area **600** is provided for the sidewall lighting.

Each area **500**, **600** includes three slider widgets **551**, **552** and **553** with corresponding data windows **561**, **562**, **563**. The sliders **551**, **552**, and **553** are used to control the relative intensities of the red, green and blue light, respectively, emitted from the one or more lighting devices **100** that provide the ceiling light (or sidewall light, in the case of area **600**). The data windows **561**, **562** and **563** display numerical values corresponding to the settings selected by the sliders and provide an alternate means of entering and/or modifying said values. The widgets used in the present invention such as the sliders and data windows are well known functions and need no further description. Other suitable widgets or constructs may also be used. In an alternative embodiment, a two-dimensional color palette can be provided. The user can select the desired color by placing a cursor over the desired color point in the palette and selecting that point.

Below the color selection widgets within each area **500** (**600**) are four windows **572**–**575** that allow the user to specify additional parameters that affect the operation of the respective lighting devices. A "transition type" window **572** allows the user to select, from a pull down menu, one of five transition modes which determine how the color of the light emitted will vary over a certain transition period. The number of different colors which the emitted light will take on over the transition period is specified by the user via a "max colors" window **573**. In an exemplary embodiment, 1 to 10 colors can be specified via window **573**. Each of these colors is automatically assigned a number between 1 and the number specified in the window **573**, with the numbers being assigned in the order of appearance. Each color can be selected by entering its assigned number in the "active color" window **574**. The color selected via the window **574** can be adjusted via the widgets **551**–**553** or **561**–**563**. Finally, a "time" window **575** is provided whereby the user can specify the duration of the transition period.

To better illustrate the operation of this aspect of the present invention, an exemplary scene programming sequence will now be described. The user first enters a name for the scene to be created using a label window **800**. Using the sliders **551**–**553** (or windows **561**–**563**) the user specifies a first color to be generated in a color transition procedure which may have one or more steps. The user then selects one of five available transition types which are illustrated schematically in FIGS. **10**A through **10**E. The first available transition type referred to as "single point" yields a smooth transition from the present color to the specified color (color **1**) in one continuous step, as represented in FIG. **10**A. In this mode, the "max colors" window **573** and "active color" window **574** are fixed at one and cannot be altered by the user.

The second available transition type referred to as the "multipoint" transition mode is illustrated in FIG. **10**B. This mode yields a smooth transition from selected color to selected color in a number of steps divided evenly over the time period specified in the time window **575**. The number of steps (colors) through which this mode transitions is selected via the max colors window **573**. FIG. **10**B illustrates the case of four colors.

The third available transition type, referred to as the "ping pong" transition mode is illustrated in FIG. **10**C. In this mode, a multipoint transition is followed by a multipoint transition through the same colors in reverse order.

The fourth available transition type, referred to as the "repeating" transition mode is illustrated in FIG. **10**D. In this mode, a multipoint transition is repeated in the same order.

The last available transition type, the "stop and go" transition mode, is illustrated in FIG. **10**E. This mode yields abrupt transitions from selected color to selected color. Each selected color is emitted for a period of time equal to the time period selected via the widget **575** divided by the number of colors selected via the widget **574**.

The settings programmed via the screen of FIG. **9** can be given a name or label which is entered in the label window **800**. During normal operation of the lighting system, the programmed settings can be invoked via the OIP **750** using the label provided in the label window **800**. When a settings label is selected at the OIP **750**, the settings associated with the label are put into effect.

As shown in FIG. **9**, a set of "page control" buttons **801**–**805** is provided for controlling the programming of additional scenes, each of which can be programmed as described. When the "Add" button **805** is pressed, a new scene is created. A scene can be deleted with the "delete" button **801** and the previous and next buttons **802** and **803**, respectively, can be used to sequence through multiple scenes. The settings window for each scene also can be accessed by a tab **820** arranged proximate to the top of the main window. In an exemplary embodiment, up to **15** scenes can be created and programmed individually as described. The sequence of scenes can be saved as a program on the computer **300**. The program can then be downloaded from the computer **300** to the central controller **700** via the interface **705** and then executed by the lighting system, with or without the computer **300** coupled thereto. The execution of the downloaded program can be controlled by a user via the OIP **750**.

The lighting system can be programmed to enter different modes under certain conditions. For example, during an emergency, the lighting system can turn off all LEDs with the exception of a subset of red LEDs located proximate to an emergency exit door. In another embodiment, the red LEDs can be sequenced so as to indicate the path to an emergency exit door. Other conditions that can cause the system to enter a special mode of operation may include, among others, the loss of main power and the switching over to backup power.

Several exemplary physical configurations of the lighting devices of the present invention will now be described.

FIG. **11** is a perspective view of the exterior of a first exemplary embodiment of a lighting device **1100** in accordance with the present invention. FIG. **12** is a view of cross section A—A of the device of FIG. **12**. As shown, the device **1100** has a generally linear configuration with a generally rectangular cross-section. The device **1100** comprises an extruded metallic (e.g., aluminum) housing **1101** which in combination with a side cover **1102** forms a first compartment containing a circuit board **1103** for the control module and a circuit board **1104** for the power module. The boards **1103** and **1104** are arranged end-to-end in the same plane against a central wall **1101***a* of the housing extrusion **1101** with a layer of thermal padding **1105** arranged between the boards and the housing extrusion. The thermal padding **1105** may comprise any suitable material for conducting heat generated by the boards to the housing extrusion.

A third circuit board, an LED board **1106**, is supported on a platform-like structure **1101***b* which protrudes substantially perpendicularly from the central wall **1101***a* of the housing extrusion **1101**. A layer of thermal padding **1107** is arranged between the bottom of the LED board **1106** and the top of the platform-like structure **1101***b* for conducting heat from the LED board to the housing extrusion **1101**. The LED board **1106** preferably includes one or more layers of metallic material (not shown) as well as islands of metallic material (not shown) on its top and bottom surfaces for the purpose of conducting heat away from the LEDs to the platform-like structure **1101***b* of the housing extrusion through the thermal padding **1107**. The housing extrusion **1101** preferably includes groove-like features **1101***d* which increase its surface area and thus aid in the dissipation of heat from the housing.

A row of LEDs **1108** is arranged substantially down the center of the upper surface of the LED board **1106** along the length of the LED board. (See FIG. **2** for a plan view of the LED board.) As shown in FIG. **12**, a reflector **1109** is arranged on either side of the row of LEDs. The two reflectors **1109** form a trough between them having a generally parabolic cross-section with the row of LEDs **1108** being arranged at the bottom of the trough. Light emitted from the LEDs **1108** is reflected by the inner surfaces of the reflectors **1109**. The inner surfaces of the reflectors are smooth and may be specular. An optional cover plate **1120** may be arranged between the reflectors **1109** across the trough formed therebetween. The cover plate **1120** may be transparent or translucent and may be tinted.

The reflectors **1109** are attached to the LED board **1106**, such as by riveting or other appropriate attachment arrangement, thereby forming an LED board sub-assembly. The right edge of the LED board sub-assembly is retained by a lip **1101***c* protruding from the central wall **1101***a* of the housing extrusion whereas the left edge of the LED board sub-assembly is retained by a plurality of clips **1110** arranged along the length of the fixture.

As shown in FIG. **11**, end caps **1111** are attached to the ends of the housing extrusion **1101** for fixedly mounting the device **1100** such as to the interior of an aircraft cabin.

In an exemplary embodiment, the device **1100** is one to five feet in length. The cross-sectional dimensions of the exemplary device shown are approximately 1.75"×1.75".

FIGS. **13** and **14** show a further exemplary embodiment of a lighting device **1300** in accordance with the present invention. The various components of the device **1300** are similar to those of device **1100**, with the primary differences being the shape of the metallic housing extrusion **1301** and the arrangement of components. As shown in FIG. **14**, the housing extrusion **1301** of device **1300** comprises an upper horizontal wall **1301***a,* with a vertical wall **1301***b* extending downwards from the right edge of the upper wall and a bottom wall **1301***c* extending horizontally from the bottom edge of the vertical wall. Cooling fins **1301***d* may be formed in the outer surface of the upper wall **1301***a* and serve to dissipate heat from the device to the surrounding air.

An LED board assembly **1306**, **1308**, **1309**, similar to that of device **1100**, is removably attached by multiple clips **1310**, in a similar manner, to the outer surface of the upper wall adjacent to the right edge of the upper wall.

A control board **1303** and a power board **1304** are arranged end-to-end against the inner surface of the upper wall.

Exemplary cross-sectional dimensions of device **1300** are approximately 1.5" high and 2" wide.

FIG. **15** shows a cross-section of an aircraft **1500** illustrating exemplary placements for lighting devices **100** of the present invention for illuminating the passenger cabin **1510** of the aircraft. In the exemplary arrangement shown, a lighting device **100**C is placed in the ceiling of the passenger cabin and provides ceiling lighting. Lighting devices **100**L and **100**R are placed to illuminate the left and right sidewalls, respectively, of the passenger cabin. The three devices **100**C, **100**L and **100**R can be coupled to one or more central controllers **700** and programmed as described above.

Exemplary embodiments of reflector arrangements in accordance with the present invention will now be described in connection with FIGS. **16**–**16**C. FIGS. **16**A–**16**C show cross-sectional views of three different reflector arrangements for use in different applications. In FIG. **16**A, reflectors **1640** and **1630** are arranged on either side of a row of LEDs **1620** arranged along the length of a circuit board **1610**. As shown in FIG. **16**A, the cross-sections of the reflectors **1630** and **1640** are mirror images of each other. Light is emitted from the LEDs **1620** and reflected by the reflectors **1630**, **1640** in a pattern that is symmetric about the LEDs. A normal line N corresponds substantially to the center of the light that is emitted from the LEDs. In an exemplary embodiment, the cross-section of the pattern of light emitted by the LED/reflector assembly has an included angle of 60 degrees, with 30 degrees on each side of the normal line N. Such a pattern is well suited for illuminating the sidewall of an aircraft cabin, for example.

In the arrangement shown in FIG. **16**B, the reflector **1630** is substantially shorter than the reflector **1640**. As a result, light is emitted from the LEDs **1620** and reflected by the reflectors **1630**, **1640** in a pattern that is asymmetric about the LEDs. In an exemplary embodiment, the cross-section of the pattern of light emitted by the LED/reflector assembly has an included angle of 105 degrees, with 30 degrees on the left side of the normal line N and 75 degrees on the right side. Such a pattern is well suited for ceiling illumination in an aircraft cabin, for example.

In the arrangement shown in FIG. **16**C, the reflectors **1630** and **1640** have mirror-image cross-sections but are both substantially shorter than the reflectors of FIG. **16**A. As a result, light is emitted from the LEDs **1620** and reflected by the reflectors **1630**, **1640** in a pattern that is symmetric about the LEDs but which has a wider included angle than the embodiment of FIG. **16**A. In an exemplary embodiment, the cross-section of the pattern of light emitted by the LED/reflector assembly has an included angle of 150 degrees, with 75 degrees on each side of the normal line N. Such a pattern is well suited for ceiling illumination in an aircraft cabin, for example.

In systems such as that of the present invention in which light of different colors is emitted from different point sources (LEDs) it is desirable to thoroughly blend the different color light to prevent the appearance of multiple light sources of different colors. For confined spaces such as an aircraft cabin, it is desirable that light rays of different colors be perceived as mixed at relatively small distances from the light fixture: e.g., one inch, as opposed to several yards for large outdoor display applications. To promote the mixing of light of different colors emitted from different point sources, the reflective surfaces of the reflectors **1630**, **1640** preferably have a flat white finish, which tends to scatter the reflected light in multiple directions. A person looking at the lighting device will see the scattered light, which is mixed, and not the discrete LED point sources from which the light originated.

As discussed above in connection with FIGS. **12** and **14**, a cover **1120** (**1320**) may be optionally arranged between the reflectors **1109** (**1309**) arranged on either side of the LEDs. The cover may be a lens which helps promote light mixing. As shown in FIGS. **17**A and **17**B, a ray of light passing through the cover **1720** is diffused into a cone, with a circular cross-section (FIG. **17**A) or an elliptical cross-section (FIG. **17**B). In an exemplary embodiment, the cover **1720** can be implemented with a sheet of polycarbonate material having a thickness of 0.030 inches.

The present invention is not to be limited in scope by the specific embodiments described herein. Indeed, various modifications of the invention in addition to those described herein will become apparent to those skilled in the art from the foregoing description and the accompanying figures. Such modifications are intended to fall within the scope of the appended claims.

It is further to be understood that all values are to some degree approximate, and are provided for purposes of description.

The disclosures of any patents, patent applications, and publications that may be cited throughout this application are incorporated herein by reference in their entireties.

What is claimed is:

1. A light emitting diode (LED) lighting device comprising:

a first group of LEDs of a first color;

a second group of LEDs of a second color;

a third group of LEDs of a third color; and

a control circuit, the control circuit being coupled to each of the groups of LEDs and comprising a data interface, wherein the control circuit independently controls each group of LEDs in accordance with data received at the data interface and includes:

a processor, the processor being coupled to the data interface, and a controllable current source for each group of LEDs, the controllable current source being controlled by the processor,

wherein:

each group of LEDs comprises a plurality of LED strings coupled in parallel, each LED string comprising one or more LEDs coupled in series, and

at least one of the first, second and third groups of LEDs includes one or more ballast LEDs, and the light emitted from each of the one or more ballast LEDs is obscured from combining with light emitted by other LEDs in the first, second and third groups of LEDs.

2. The LED lighting device of claim **1**, wherein:

each LED string has a forward voltage that is a function of the number of LEDs in the LED string; and

the number of LEDs and ballast LEDs in each LED string is selected so that the forward voltages of all LED strings are substantially the same.

3. The LED lighting device of claim **1**, wherein the first, second and third colors are selected from the group of colors consisting of red, orange, green and blue.

4. The LED lighting device of claim **1**, wherein the first, second and third colors have respective wavelengths that are at least 30 nm apart.

5. A lighting system comprising the LED lighting device of claim **1** and a central controller coupled to the LED lighting device.

6. The lighting system of claim **5** comprising an additional LED lighting device.

7. The LED lighting device of claim **1**, wherein the first, second and third groups of LEDs are arranged substantially along a line so that LEDs of the same LED string are separated by one or more LEDs of a different LED string.

8. A light emitting diode (LED) lighting device comprising:

a first group of LEDs of a first color;

a second group of LEDs of a second color;

a third group of LEDs of a third color;

a control circuit, the control circuit being coupled to each of the groups of LEDs and comprising a data interface, wherein the control circuit independently controls each group of LEDs in accordance with data received at the data interface and includes:

a processor, the processor being coupled to the data interface,

a controllable current source for each group of LEDs, the controllable current source being controlled by the processor, and

a current monitor for each group of LEDs, the current monitor monitoring the current through its respective group of LEDs and providing a reading of the current to the processor, and

a power circuit, the power circuit being coupled to each of the groups of LEDs and to the control circuit, and including

a variable power supply, the variable power supply generating a voltage whose magnitude is controlled by the processor,

wherein:

each group of LEDs comprises a plurality of LED strings coupled in parallel, each LED string comprising one or more LEDs coupled in series, and

the processor controls the variable power supply to adjust a voltage V_{Reg} supplied at a common anode of each of the plurality of LED strings to set the voltage V_{Reg} at a lowest level required to produce a first predetermined current for the first group of LEDs, a second predetermined current for the second group of LEDs and a third predetermined current for the third group of LEDs, wherein the currents produced by each of the first, second and third groups of LEDs as respectively measured by the current monitor of each of the first, second and third groups.

9. The lighting system of claim **8**, wherein the central controller includes:

an operator interface panel;

a computer interface; and

a switch for selectively coupling the operator interface panel and the computer interface to the LED lighting device.

10. The LED lighting device of claim **8**, wherein the processor controls the variable power supply to incrementally increase the voltage V_{Reg} over a low range value until the measured currents for each of the first, second and third groups of LEDs respectively equal or exceed the first, second and third predetermined currents.

11. The LED lighting device of claim **8**, wherein each predetermined current value represents a nominal current value for its respective group.

12. The LED lighting device of claim **11**, wherein each nominal current value is a determined as a function of the number of LED strings in its respective group and the number of LEDs in each string of the respective group.

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