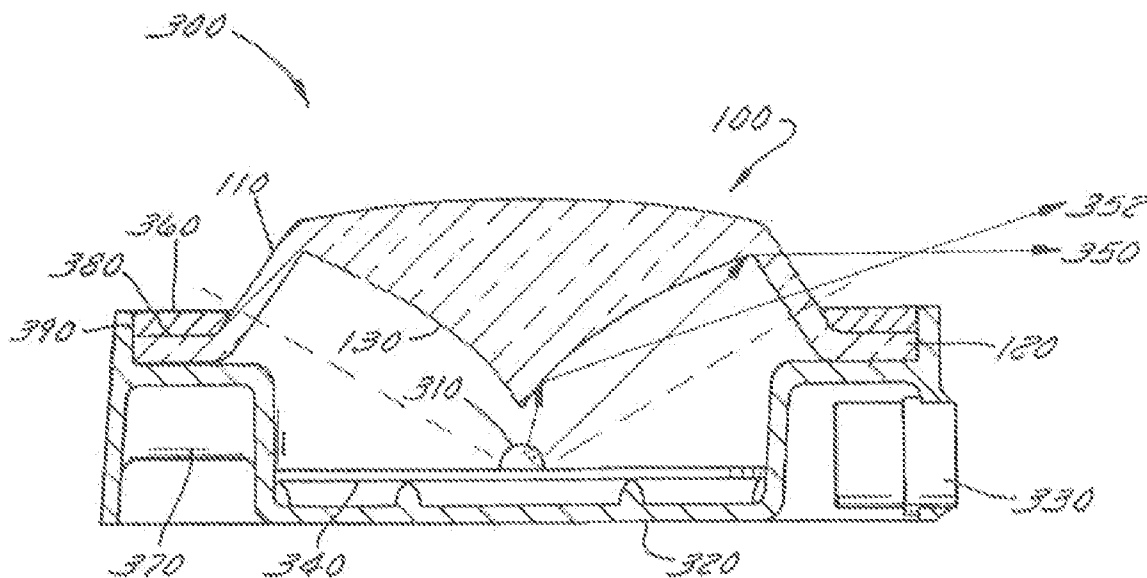




US 20130265778A1

(19) **United States**(12) **Patent Application Publication**
Rizkin et al.(10) **Pub. No.: US 2013/0265778 A1**(43) **Pub. Date: Oct. 10, 2013**(54) **HIGHLY EFFICIENT LUMINAIRE HAVING
OPTICAL TRANSFORMER PROVIDING
PRECALCULATED ANGULAR INTENSITY
DISTRIBUTION AND METHOD THEREFORE**Oct. 21, 2002, now Pat. No. 7,503,669, which is a
continuation-in-part of application No. 09/566,521,
filed on May 8, 2000, now Pat. No. 6,543,911.**Publication Classification**(71) Applicants: **Alexander Rizkin**, Redondo Beach, CA
(US); **Robert H. Tudhope**, Rancho Palos
Verdes, CA (US)(51) **Int. Cl.**
F21V 13/04 (2006.01)(72) Inventors: **Alexander Rizkin**, Redondo Beach, CA
(US); **Robert H. Tudhope**, Rancho Palos
Verdes, CA (US)(52) **U.S. Cl.**
CPC **F21V 13/04** (2013.01)
USPC **362/327**(21) Appl. No.: **13/862,795**(57) **ABSTRACT**(22) Filed: **Apr. 15, 2013****Related U.S. Application Data**(63) Continuation of application No. 13/470,006, filed on
May 11, 2012, now Pat. No. 8,419,214, which is a
continuation of application No. 12/780,824, filed on
May 14, 2010, now Pat. No. 8,220,959, which is a
continuation of application No. 11/930,423, filed on
Oct. 31, 2007, now Pat. No. 7,744,246, which is a
continuation of application No. 10/277,230, filed on

A highly efficient luminaire. The luminaire includes a light source that emits light. The emitted light is redirected by a light transformer having a curved circular reflective interior surface, the reflective interior surface reflecting the light in a predetermined pattern. A substantial amount of light being may be reflected close to an axis coincident with a radial line defining a radius of the circular reflective interior surface. Additionally, a substantial amount of light may be reflected in a pattern with low divergency or parallel with an axis of the light transformer. The light is transmitted to the exterior of the luminaire by an optical window.



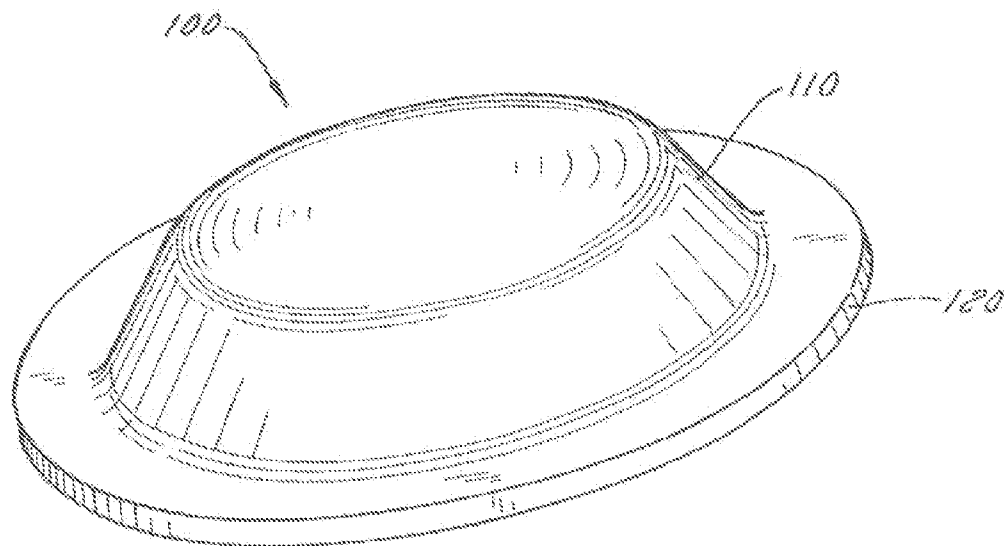


FIG. 1

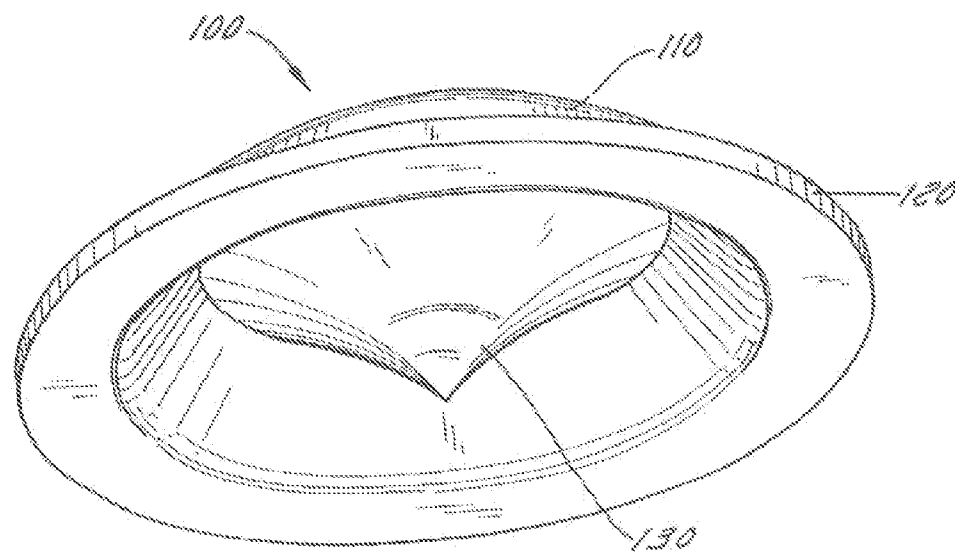


FIG. 2

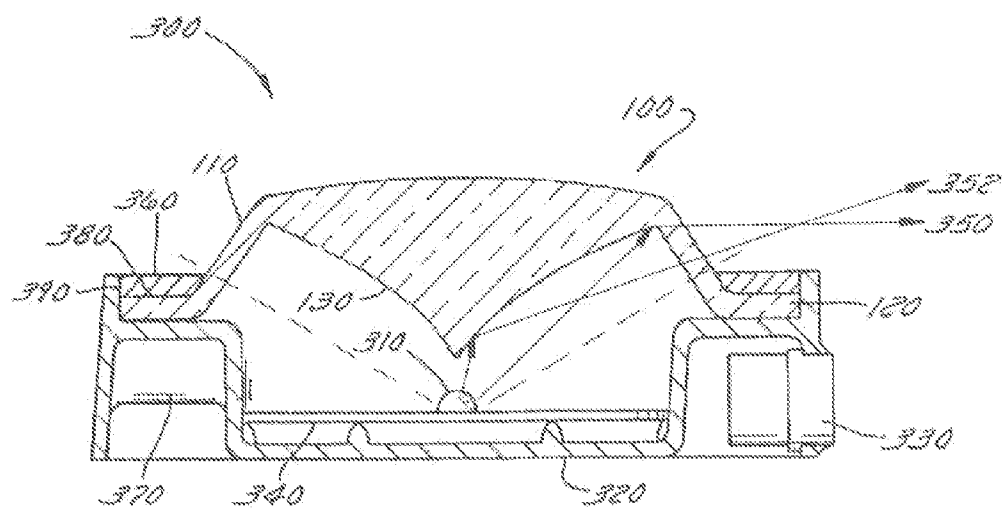


FIG. 3

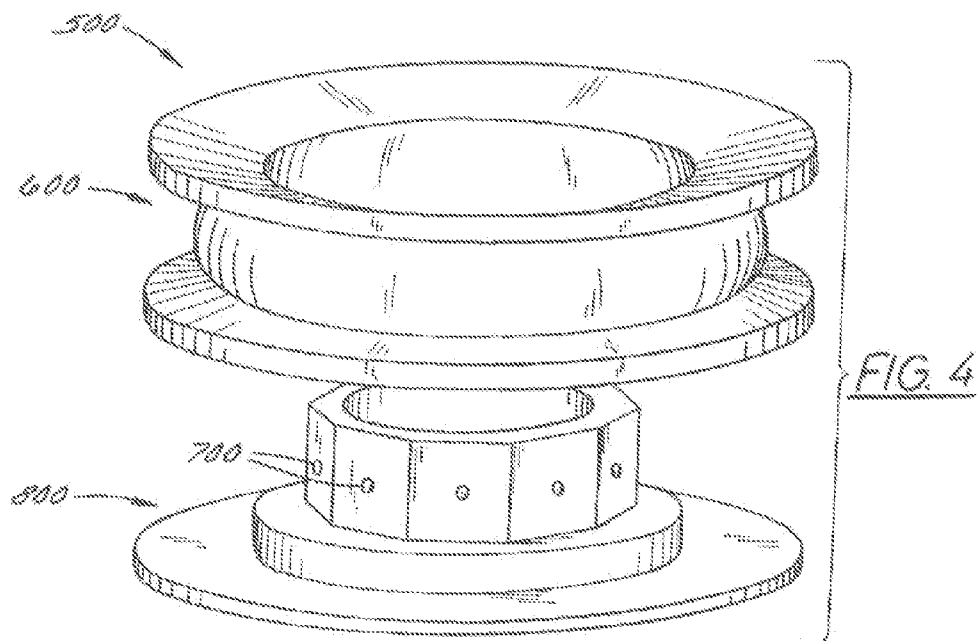


FIG. 4

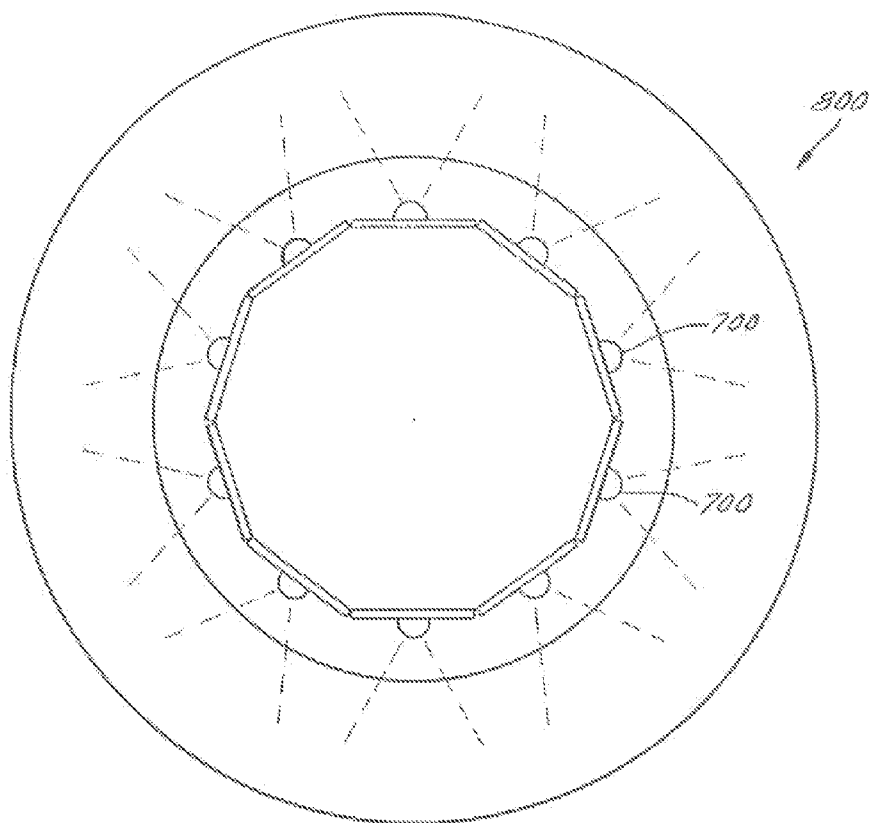


FIG. 5

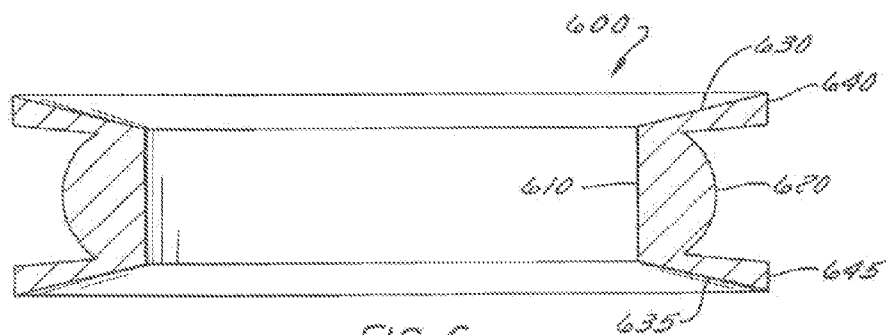


FIG. 6

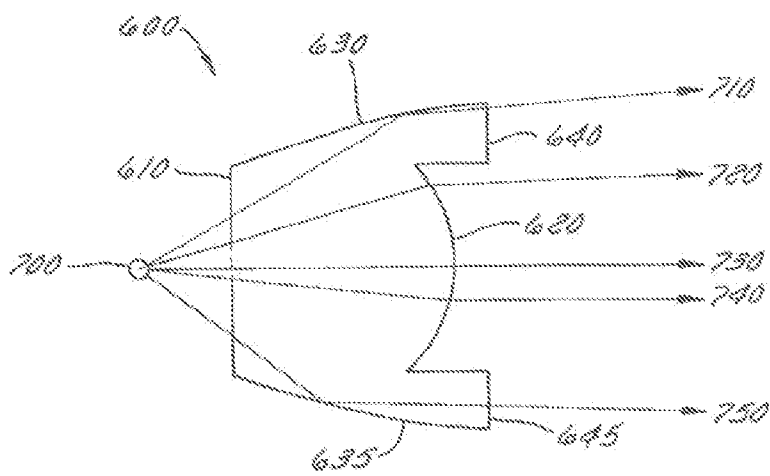


FIG. 7

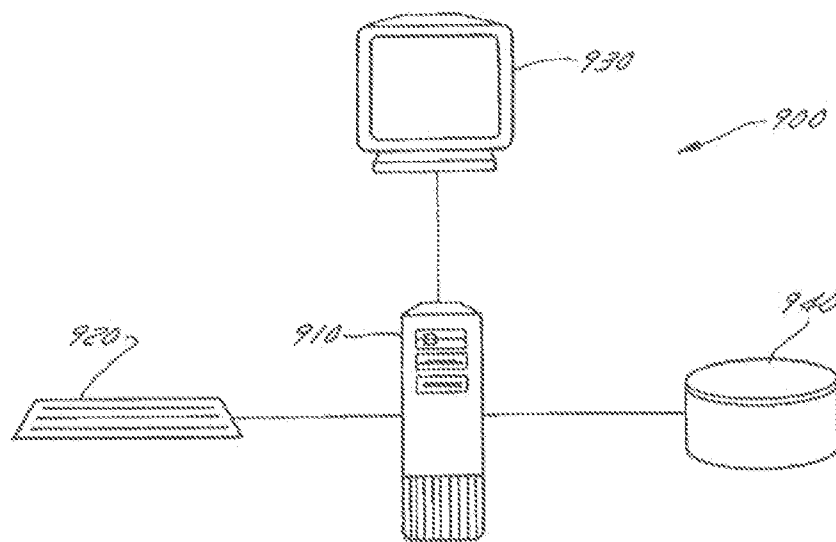


FIG. 8

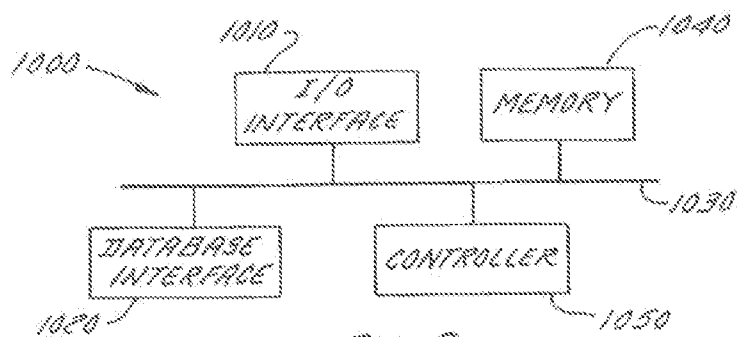


FIG. 9

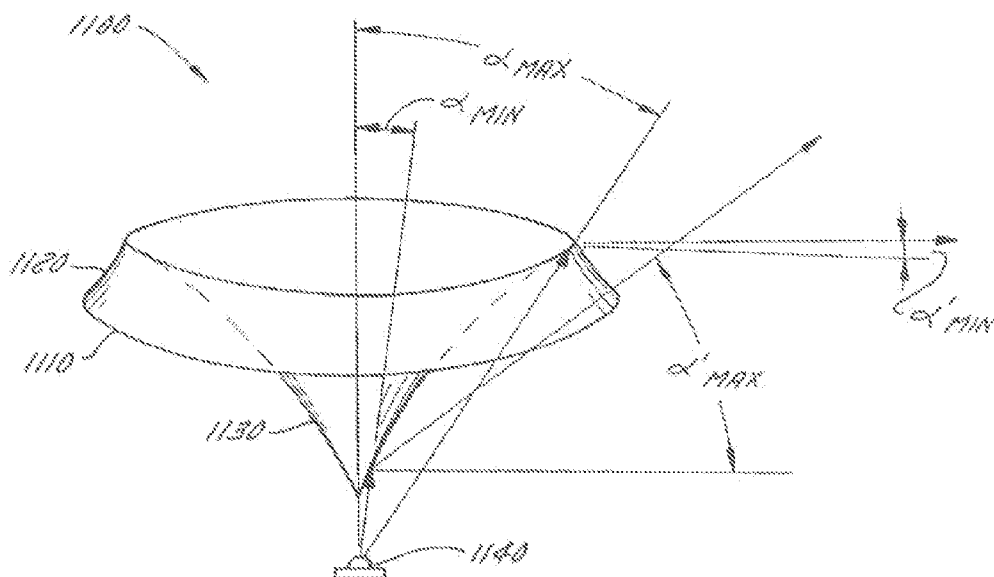


FIG. 10

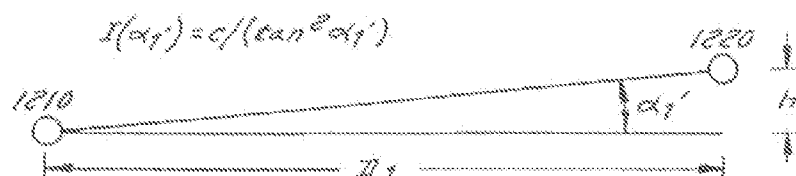


FIG. 11(a)

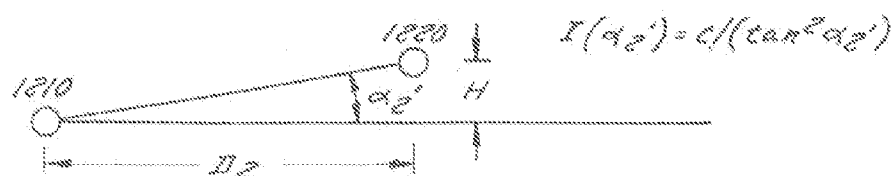


FIG. 11(b)

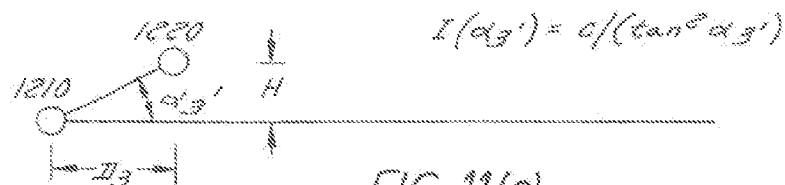


FIG. 11(c)

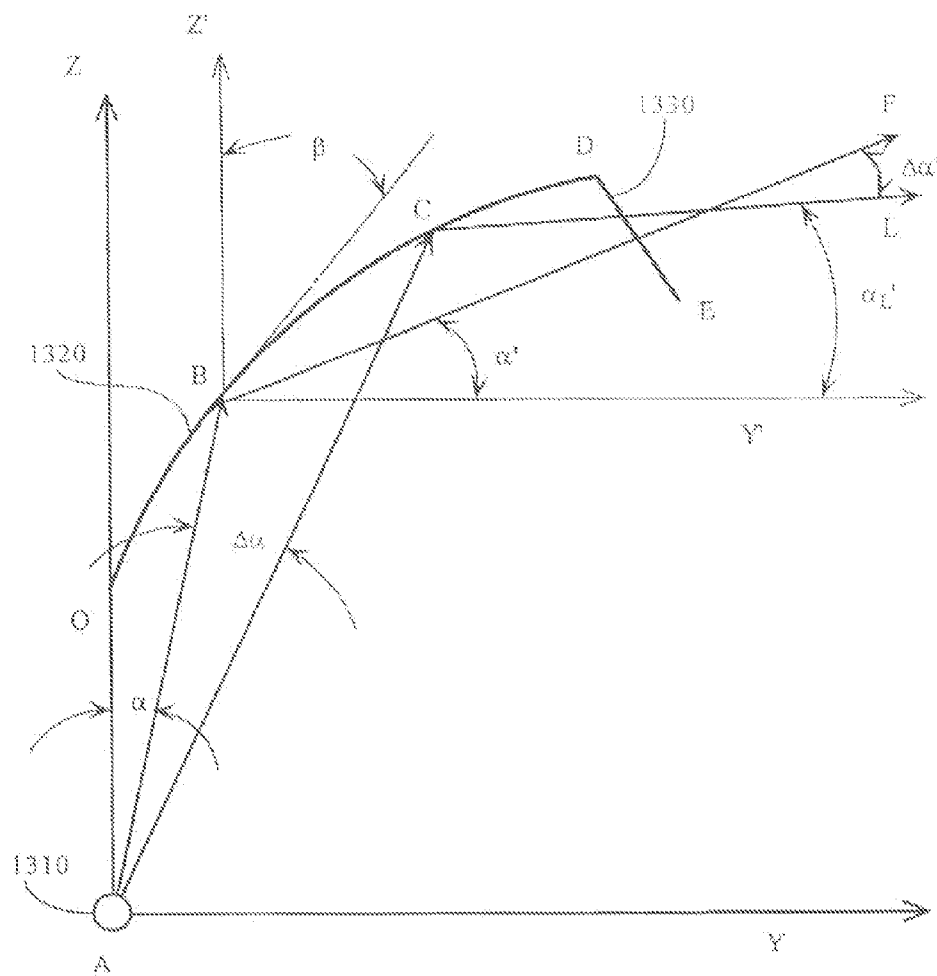


Fig. 12

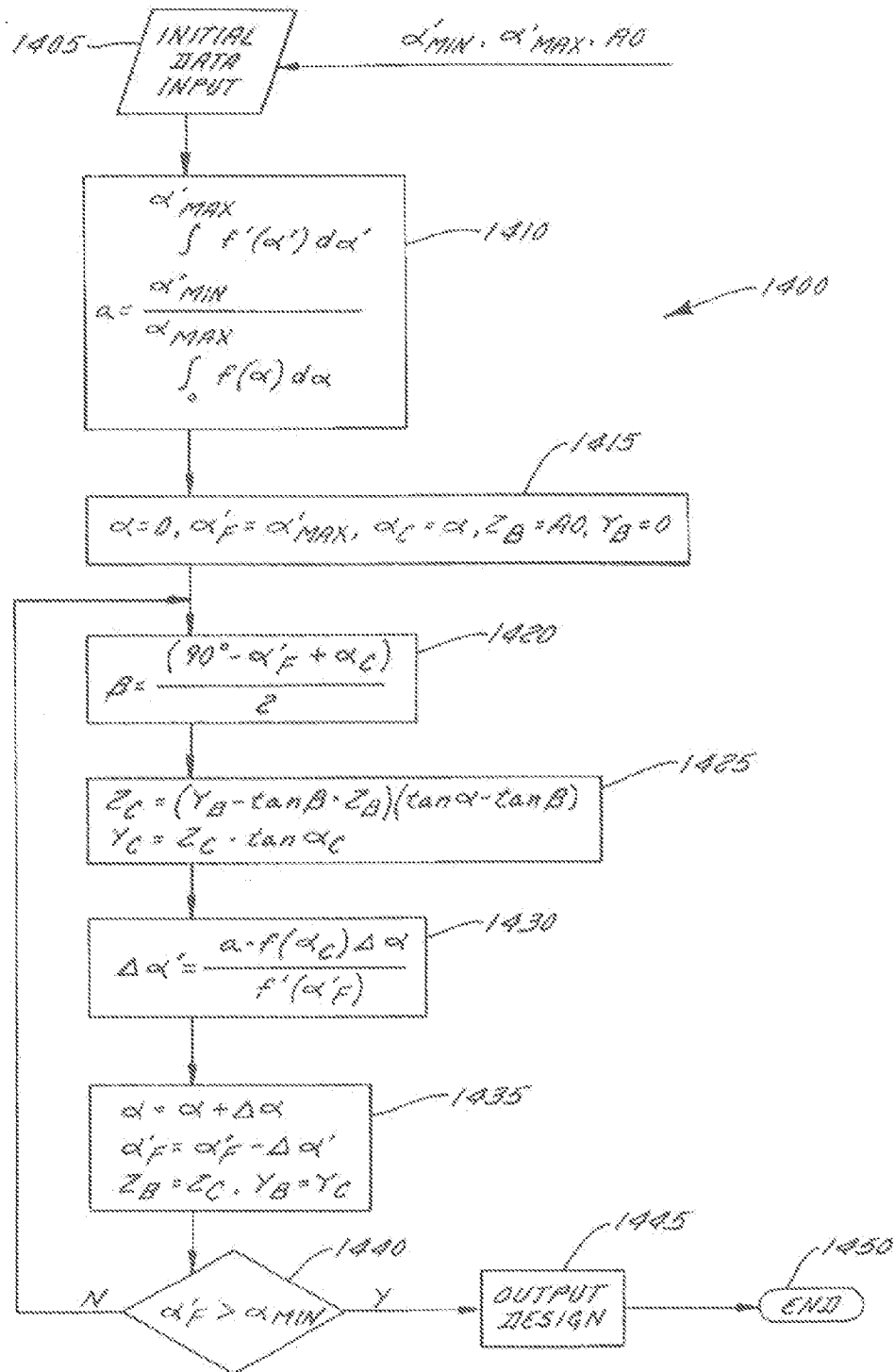


FIG. 13

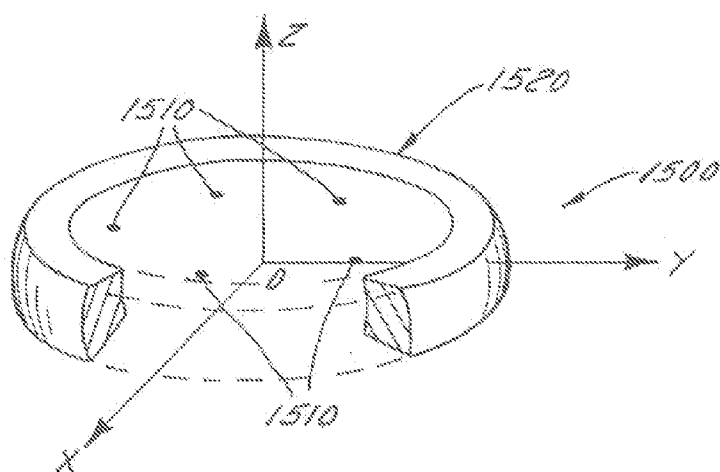


FIG. 14(a)

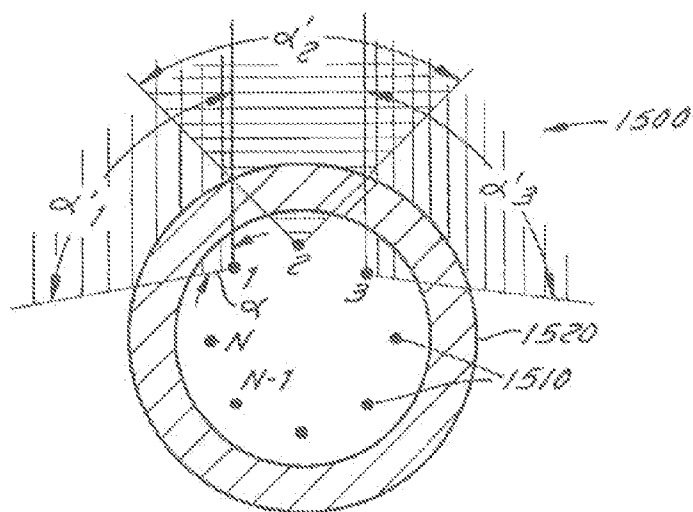


FIG. 14(c)

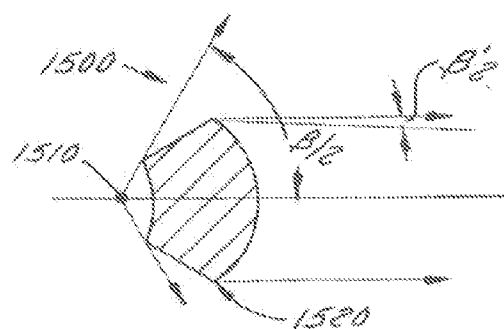
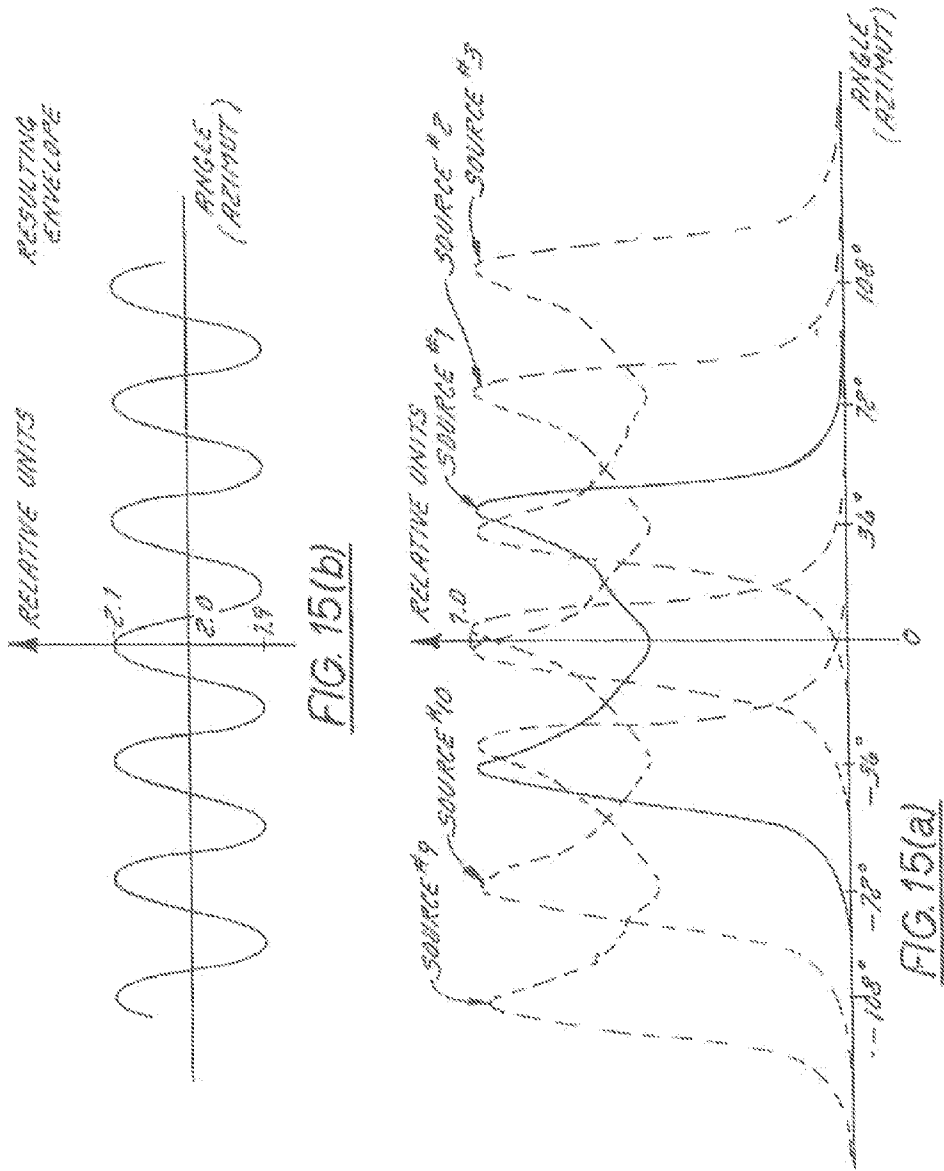


FIG. 14(b)



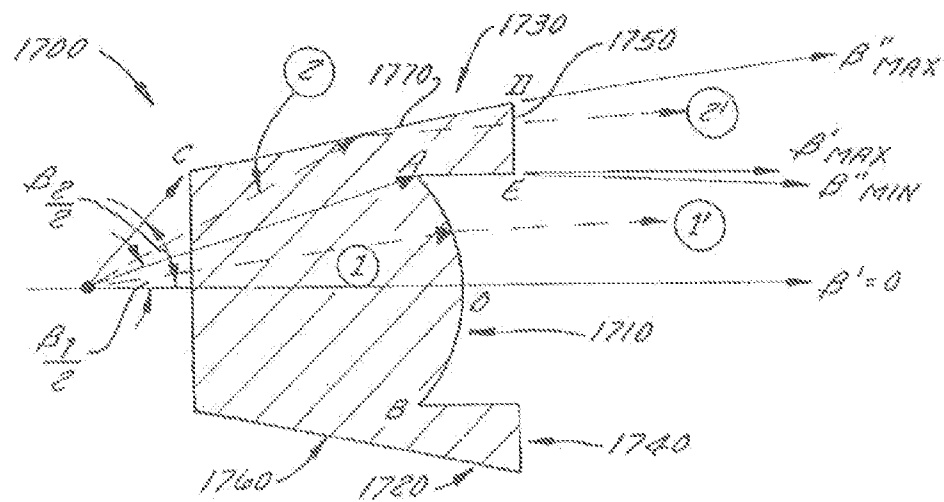


FIG. 16

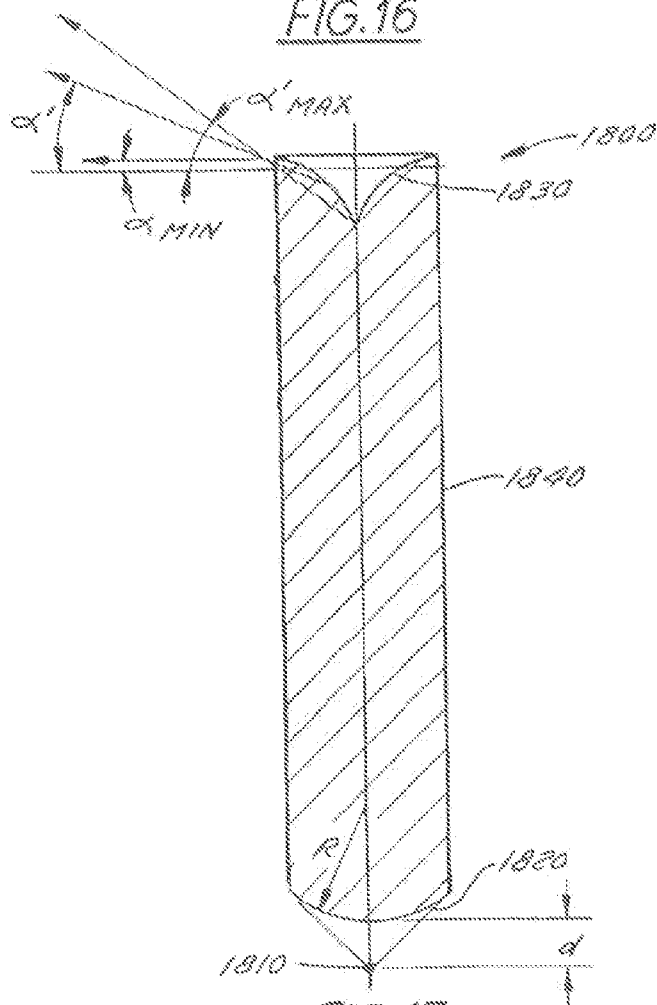


FIG. 12

HIGHLY EFFICIENT LUMINAIRE HAVING OPTICAL TRANSFORMER PROVIDING PRECALCULATED ANGULAR INTENSITY DISTRIBUTION AND METHOD THEREFORE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of 13/470,006 filed May 11, 2012, which is a continuation of and claims priority to U.S. application Ser. No. 12/780,824 filed May 14, 2010 now U.S. Pat. No. 8,220,959, which is a continuation of U.S. application Ser. No. 11/930,423, filed Oct. 31, 2007, now U.S. Pat. No. 7,744,246, which is a continuation of U.S. application Ser. No. 10/277,230, filed Oct. 21, 2002, now U.S. Pat. No. 7,503,669, which is a continuation-in-part of U.S. application Ser. No. 09/566,521, filed May 8, 2000, now U.S. Pat. No. 6,543,911, and all of which are herein incorporated by reference.

FIELD OF THE INVENTION

[0002] The present invention is directed generally to lighting systems. More particularly, the present invention is directed to light transforming devices that provide a precisely determined light distribution pattern, such as those used for navigation, obstructions and other signal lights.

DESCRIPTION OF RELATED ART

[0003] Presently, lighting systems are used to mark obstructions and curves on roadways and paths on airport taxiways and runways. For example, airports incorporate a system of lighting to provide guidance to approaching and taxiing aircraft. Thousands of halogen lamps can be used in airports. Unfortunately, these lamps require excessive amounts of power.

[0004] In roadway lighting systems, lamps are placed around the obstructions and along roadway curves to signal the presence of the obstructions and curves to drivers. These lighting systems do not sufficiently redirect light in an optimal pattern for drivers. For example, the lamps do not provide adequate light to drivers located far away from the lamps. Accordingly, the lamps also do not compensate for an inverse square relationship of illuminance to distance as a driver approaches the lamp. In particular, the lamps do not adjust for the fact that a driver can see the lamp better when the driver is closer to the lamp. Additionally, most of such signal devices direct only a portion of light emitted by a light source in a useful pattern. Accordingly, they have low efficiency. Some in the prior art have sought to allow "hands-free" access to a user's voice mail messaging system. By way of example, without intending to limit the present invention, U.S. Pat. No. 6,868,142, issued on Mar. 15, 2005 to Gupta et al., discloses a voice-operated interface for communicating with a voice mail messaging system. A speech recognition unit is utilized to retrieve certain voice commands (e.g., "next", "skip", "repeat") and then translate the commands into a proper tone sequence which is transmitted to the voice mail messaging system. The voice mail messaging system then retrieves and transmits the voice mail to the user.

SUMMARY OF THE INVENTION

[0005] The present invention provides a method and apparatus for a high efficiency redirected light emitted by a light source in a predetermined pattern by using an optical trans-

former with a precisely calculated reflective surface. In one embodiment, the present invention provides emitted light redirected by a light transformer having a curved circular reflective interior surface, the reflective interior surface reflecting the light in a predetermined pattern. For example, the reflective interior surface reflects the light with a substantial amount of light being reflected close to an axis coincident with a radial line defining a radius of the circular reflective interior surface. The light is transmitted to the exterior of the light transformer by an optical window.

[0006] In another embodiment, the present invention provides a light redirecting device for transmitting light with low divergence or substantially parallel with an axis of light direction. The device can include a first total internal reflection surface, a first member including a portion of the first total internal reflection surface, a first planar optical window located at an end of the first member, the first planar optical window being substantially perpendicular to the axis of light direction, and an aspheric lens adjacent to the first member. The device can further include a second total internal reflection surface symmetrical across the axis of light direction with the first total internal reflection surface, and a second member including a portion of the second total internal reflection surface, the second member symmetrical across the axis of light direction with the first member. The device can additionally include a second planar optical window located at an end of the second member, the second planar optical window being substantially perpendicular to the axis of light direction, the second planar optical window further being symmetrical across the axis of light direction with the first planar optical window.

[0007] In another embodiment, the present invention provides a light redirecting device that can include a first end that receives light from a light source, a second end that outputs the received light, the second end located on an opposite end of the device from the first end, a first member located on a third end of the light redirecting device the first member having an outer wall comprising a total internal reflection surface, a second member located on a fourth end of the light redirecting device, the fourth end located on an opposite end of the redirecting device from the third end, the second member having an outer wall comprising a total internal reflection surface, and an axis located between the third end and the fourth end, the axis being perpendicular to the first end. The first face and the second face can redirect the received light in a direction of the second end.

[0008] In another embodiment, the present invention provides a method for designing a reflective surface for a light transformer that can include the steps of receiving maximum and minimum output angles, receiving a location of a portion of the light transformer with respect to a light source that provides light, and iteratively, point-by-point, calculating an optical transformer reflective surface by providing for each increment of an input angle, an associated increment of the output angle which is consistent with predetermined output intensity distribution to reflect light provided by the light source according to the received maximum and minimum output angles based on the received location of a portion of the light transformer.

[0009] In another embodiment, the present invention provides an apparatus for transforming and emitting light that can include a light source that emits light, a light transformer having a curved circular reflective interior surface, the reflective interior surface reflecting the light emitted by the light

source in a predetermined pattern with a substantial amount of light being reflected close to an axis coincident with a radial line defining a radius of the circular reflective interior surface and an optical window the transmits the light to the exterior of the light transformer. The reflective interior surface can reflect the light at an angle α to achieve an intensity proportional to $1/(\tan^2 \alpha)$. The reflective interior surface can further reflect light rays of the light at different angles to compensate for an inverse proportional relationship between perceived intensity and distance from a light source.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The preferred embodiments of the present invention will be described with reference to the following figures, wherein like numerals designate like elements, and wherein:

[0011] FIG. 1 is an exemplary perspective view of a light transformer according to one embodiment;

[0012] FIG. 2 is another exemplary perspective view of a light transformer according to one embodiment;

[0013] FIG. 3 is a cross-sectional diagram of a semi-flush omnidirectional luminaire according to another embodiment;

[0014] FIG. 4 is an exemplary perspective view of a light transformer according to another embodiment;

[0015] FIG. 5 is an exemplary top view of a lighting system for a light transformer according to another embodiment;

[0016] FIG. 6 is a cross-sectional diagram of a light transformer according to another embodiment;

[0017] FIG. 7 is another cross-sectional diagram of a light transformer according to another embodiment;

[0018] FIG. 8 is an exemplary block diagram of a light transformer design system;

[0019] FIG. 9 is an exemplary block diagram of a light transformer design module;

[0020] FIG. 10 is an exemplary illustration of an omnidirectional light transformer system;

[0021] FIGS. 11(a)-11(c) are exemplary illustrations of inverse square law compensation using source luminous intensity;

[0022] FIG. 12 is an exemplary illustration of how a reflective surface is designed;

[0023] FIG. 13 is an illustration of an exemplary flowchart for the design of a light transformer;

[0024] FIGS. 14(a)-14(c) are exemplary illustrations of a system that provides an omnidirectional light pattern in a horizontal plane with precision predetermined luminous intensity distribution in a vertical plane;

[0025] FIGS. 15(a) and 15(b) are exemplary illustrations of a resulting envelope and a overlapping intensity distribution pattern of a lighting system;

[0026] FIG. 16 is an exemplary illustration of a vertical cross section of a toroidal precision optical transformer; and

[0027] FIG. 17 is an exemplary illustration of an optical transformer for an elevated omnidirectional light transformer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0028] FIG. 1 is an exemplary perspective view of an integrated omnidirectional light transformer 100 according to one embodiment. The integrated light transformer 100 can include an optical window 110 and a support 120. The optical window 110 may comprise an omnidirectional window or it may comprise any other means for transmitting light, such as lenses, diffusers or open areas. In operation, when it is desir-

able to distribute light out of the light transformer 100 in a 360 degree pattern, the light transformer 100 can be circular as illustrated. Other shapes and various masks can be used to effectuate different light distribution patterns. For example, part of the optical window 110 may be masked in order to distribute light out of only a portion of the light transformer 100.

[0029] FIG. 2 is another exemplary perspective view of the light transformer 100 according to one embodiment. FIG. 2 illustrates that the light transformer 100 can further include an arbitrary aspherical reflective surface 130. The reflective surface 130 may be a curved conical reflective interior surface. In operation, light can be projected from the bottom of the light transformer onto the reflective surface 130. The reflective surface 130 can then reflect the light through the optical window 110 out of the light transformer 100.

[0030] FIG. 3 is a cross-sectional diagram of a semi-flush omnidirectional luminaire semi-flush omnidirectional luminaire 300 according to another embodiment. The semi-flush omnidirectional luminaire 300 can include a light transformer 100, a light source 310, a shell 320, a connector 330, a printed circuit board (PCB) 340 and light rays 350-352. The semi-flush omnidirectional luminaire 300 can also include a gasket plate 360, a rib 370, a seal 380 and a bond 390. The light source 310 may be a light emitting diode or any other device that emits light. The connector 330 may provide an electrical connection to outside circuitry that provides power and control for the semi-flush omnidirectional luminaire 300. The PCB 340 can provide electrical connection for the light source 310, the connector 330 and useful circuitry for operating the semi-flush omnidirectional luminaire 300. The PCB 340 can also provide control circuitry and a power source so that the semi-flush omnidirectional luminaire 300 can operate autonomously from outside circuitry and power.

[0031] In operation, the light source 310 emits light rays 350-352 towards the reflective surface 130. The light rays 350-352 are reflected in accordance with the curvature of the reflective surface 130. A ray with a minimal angle with respect to the vertical axis is reflected in a direction of the maximum elevation (ray 352), and a ray with a maximum angle is reflected in a direction of minimum elevation (ray 350). Therefore, the waist of the outgoing beam will be formed in order to minimize the vertical size of the transmissive wall. Preferably, a higher percentage of the light rays 350-352 are reflected along the path of ray 350.

[0032] For example, 70% of the light emitted from the light source 310 can be reflected substantially along the path of light ray 350, 10% substantially along the path of light ray 352 and the remaining 20% substantially between paths 350 and 352. Therefore, the luminaire 300 will have a luminous intensity higher at lower angles, and about all light emitted by the light source will be directed in a predetermined pattern. In particular, the luminaire 300 can redirect the light so that illuminance at a long range distance (i.e. at the lower observation angles) will be equal to illuminance at a short range distance (i.e. at the higher observation angles). Therefore, as a driver in a car approaches the luminaire 300, the driver can perceive light of equal intensity at long distances and at short distances from the luminaire 300.

[0033] FIG. 4 is an exemplary perspective view of a luminaire 500 according to another embodiment. The luminaire 500 can include a light transformer 600 and a lighting system 800 comprising multiple light sources 700. In operation, the

light transformer **600** can be placed over the lighting system **800** to receive and distribute light from the light sources **700**.

[0034] FIG. **5** is an exemplary top view of a lighting system **800** for a light transformer according to another embodiment. The lighting system can include light sources **700**. The light sources **700** can be LEDs or any other device useful for emitting light. The light sources **700** may surround the lighting system **800** or the light sources may partially surround the lighting system **800** to only emit light out of part of the lighting system **800**.

[0035] FIG. **6** is an exemplary cross-sectional diagram of a light transformer **600** according to another embodiment. The light transformer **600** may include a window such as a window **610**, an aspherical lens **620**, total internal reflection surfaces (TIR) **630** and **635** and clear windows or optical windows **640** and **645**. The TIR surfaces **630** and **635** may be curved circular reflective interior surfaces or arbitrary aspherical reflective surfaces.

[0036] FIG. **7** is another exemplary cross-sectional diagram of a light transformer according to another embodiment. FIG. **7** illustrates a light source **700** distributing light rays **710-750** to a portion of the light transformer **600**. The light source may be a LED or any other device useful for emitting light. In operation, the light source **700** radiates light rays **710-750** towards the light transformer **600**. The light rays **710-750** enter the light transformer **600** at the window **610**. As illustrated, light ray **730** propagates straight from the light source along an axis coincident with a radial line defining a radius of the circular reflective interior surface. Those light rays **720**, **730** and **740** which travel directly to the surface **620** are refracted in a direction with low divergence or substantially parallel to light ray **730**. Those light rays **750** and **760** which travel to surfaces **630** and **635** are reflected through clear windows **640** and **645** in a direction with low divergence or substantially parallel to light ray **730**.

[0037] FIG. **8** is an exemplary block diagram of a light transformer design system **900**. The light transformer design system **900** can include a design processing unit **910**, an input device **920**, an output device **930** and a database **940**. The design processing unit **910** may be a processor, a personal computer, a mainframe computer, a palm computer or any other device useful for processing data. The input device **920** may be a keyboard, a voice recognition system, a modem, a scanner or any other device useful for inputting data. The output device **930** may be a video monitor, a printer, a modem or any other device useful for outputting data. The output device **930** may also be a machining system for manufacturing a light transformer. The database **940** may be located in memory on the design processing unit **910**, on a compact disk, on a floppy disk, on a hard drive or on any other device useful for storing data.

[0038] In operation, the input device **920** is used to input data to the design processing unit **910**. The data may be input by a user of the system **900**. The design processing unit **910** can process the data and store the data on the database **940**. The design processing unit **910** can also retrieve data from the database **940** for processing. The design processing unit **910** can further send data to the output device **930**. The output device **930** may print out or display the data to a user. The output device **930** may additionally machine a light transformer based on the data.

[0039] FIG. **9** is an exemplary block diagram of a light transformer design module **1000**. The light transformer design module **1000** may include a controller **1050**, a memory

1040, an input/output (I/O) interface **1010**, a database interface **1020** and a bus **1030**. The controller **1050** controls the operation of the light transformer design system **900** and communicates with the input device **920** and the output device **930** through the network interface **1010** and the database **940** via the database interface **1020**. In operation, when a designer uses input device **920**, for example, the design processing unit **910** may be accessed and the communication signals may be routed by the controller **1050** to the design processing unit **910**.

[0040] In an exemplary embodiment, the controller **1050** operates in accordance with the invention by receiving maximum and minimum output angles and receiving a location of a portion of the light transformer with respect to a light source. The controller **1050** can iteratively calculate points on the light transformer to reflect light provided by the light source according to the received maximum and minimum output angles based on the received location of a portion of the light transformer.

[0041] The design module **1000** can be used to create an arbitrary aspherical reflective surface, for example, reflective surfaces **130**, **630** or **635** that will provide equal omnidirectional patterns in a horizontal space with precisely predetermined luminous intensity distribution in the vertical plane utilizing a single light source or multiple light sources with given photometric characteristics.

[0042] FIG. **10** is an exemplary illustration of an omnidirectional light transformer system **1100**. The omnidirectional light transformer system **1100** can include an omnidirectional light transformer **1110** such as the light transformer **1100** that has an omnidirectional window **1120** and an aspherical reflective surface **1130**. The omnidirectional light transformer system **1100** can also include a light source **1140** such as an LED.

[0043] The aspherical reflective surface **1130** can be designed so that all light rays emitted from the light source **1140** are reflected through the omnidirectional window **1120** at an angular domain between α'_{min} and α'_{max} . A ray with a minimal angle, with respect to the vertical axis (α'_{min}) should be reflected in the direction of the maximum elevation (α'_{max}) and a ray with a maximum angle (α'_{max}) should be reflected in the direction of the minimum elevation (α'_{min}). Therefore, the waist of the outgoing beam will be formed in order to minimize the vertical size of the omnidirectional window.

[0044] FIGS. **11(a)-11(c)** are exemplary illustrations of inverse square law compensation using source luminous intensity with angle distribution $f(\alpha')=1/\tan^2(\alpha')$. FIGS. **11(a)-11(c)** illustrate an observer **1220** observing light emitted from a light transformer or light source **1210**. For analysis, let the spatial light distribution of the light source **1210** be described by some known function $f(\alpha)$. Assume that the light transformer output luminous intensity distribution, in the vertical plane, is described by an arbitrary function $f(\alpha')$, that satisfies the predetermined custom requirements. For example, if the requirement calls for equal visibility from different distances (i.e., to compensate for the inverse square law), this function should be inverse to $\tan^2(\alpha')$. The inverse square law results in

$$E = I(\alpha) \frac{I(\alpha)}{D^2}$$

where E is illuminance, I is the source luminous intensity and D is the distance. Because,

$$D = \frac{H}{\tan \alpha} \text{ and } I(\alpha) = EH^2 \frac{1}{\tan^2 \alpha} \text{ or } f'(\alpha') = \frac{c}{\tan^2 \alpha'},$$

where c is constant.

[0045] The design of the reflective surface **1130** is an iterative process. FIG. **12** is an exemplary illustration of how a reflective surface **1320** is designed step-by-step for the number of emitted rays AB, AC, etc. with increment $\Delta\alpha$. FIG. **12** includes a light source **1310** and an output window **1330**. If the reflective surface **1320** has been designed from the apex point O to point B, the next following point C of the reflective surface **1320** can be found from:

$$\alpha \cdot f(\alpha) \cdot \Delta\alpha = f'(\alpha') \cdot \Delta\alpha' \quad (1)$$

where a is the constant for the full cycle of the design. The condition in Equation (1) means that output energy in sector $\Delta\alpha'$ is equal to emitted energy in the sector $\Delta\alpha$ with the factor a. Factor a is shown in Equation (2):

$$a \cdot \int_0^{\alpha_{max}} f(\alpha) \cdot \Delta\alpha = \int_{\alpha_{min}}^{\alpha_{max}} f'(\alpha') \cdot \Delta\alpha' \quad (2)$$

[0046] With the output power function $f'(\alpha')$ the boundary conditions α_{min} and α_{max} will determine factor a unambiguously. So as illustrated in FIG. **12**, where $\alpha'_F = \alpha'_L$ and

$$\alpha'_F = \alpha'_L + \Delta\alpha' \quad (3)$$

[0047] is the local angle of the reflection cone, β can be found from the reflection's law as:

$$\beta = \frac{(90^\circ - \alpha'_F + \alpha'_L)}{2} \quad (4)$$

The coordinate of point C, which is next to the known point B can be found as the point of intersection of ray AC with the local conical surface from the system of linear equations:

$$Y - Y_B = \tan \beta \cdot (Z_C - Z_B)$$

$$Y = Z \cdot \tan \alpha \quad (5)$$

where the second equation is the equation of ray from point A with angle α with respect to the z-axis. So,

$$Z_C = \frac{Y_B - \tan \beta \cdot Z_B}{\tan \alpha - \tan \beta} \quad (6)$$

and,

$$Y_C = Z_C \cdot \tan \alpha \quad (7)$$

[0048] This can be repeated from point C to the new point of the reflective surface **1320** until the outgoing angle α' will not reach α'_{max} .

[0049] FIG. **13** is an illustration of an exemplary flowchart for the design of a light transformer by the controller **1050**. In step **1405**, initial data is received by the controller **1050**. The initial data can include the minimum angle, the maximum

angle, and the location or distance of an initial design point (AO) of the light transformer with respect to a light source. In step **1410**, the controller **1050** calculates an asymmetrical reflective surface constant based on the input minimum and maximum angles. In step **1415**, the controller **1050** sets the initial points and angles for the design process. In step **1420**, the controller **1050** calculates local angles of the reflective surface of the light transformer. In step **1425**, the controller **1050** calculates the coordinates of the next point along the reflective surface of the light transformer. In step **1430**, the controller **1050** calculates the difference in the reflective angle of the reflective surface of the light transformer. In step **1435**, the controller **1050** sets new points for the reflective surface of the light transformer. In step **1440**, the controller **1050** determines whether the resulting calculated reflective angle is greater than the received minimum angle. If the calculated reflective angle is not greater than the received minimum angle, the controller **1050** returns to step **1420**. If the calculated reflective angle is greater than the received minimum angle, the controller **1050** advances to step **1445**. In step **1445**, the controller **1050** outputs the final design of the reflective surface of the light transformer. In step **1450**, the flowchart ends.

[0050] This method illustrates how the controller **1050** can design a light transformer to have a predetermined light distribution pattern. Accordingly, the controller **1050** iteratively calculates points on a light transformer to reflect light provided by a light source according to received maximum and minimum output angles based on a received location of a portion of the light transformer.

[0051] In some cases, when a single-source luminous intensity distribution does not provide adequate illumination to match desired specifications, an alternative design with multiple light sources, such as depicted in FIG. **5** above, can be implemented. FIGS. **14(a)**-**14(c)** are exemplary illustrations of a system **1500** that provides an omnidirectional light pattern in a horizontal plane with a precisely predetermined luminous intensity distribution in the vertical plane. A number of identical light sources **1510** form a circular array in the horizontal plane (XOY) and are encircled by a toroidal precision optical transformer **1520**. This transformer **1520** is designed to provide minimal impact of intensity distribution in the horizontal plane and predetermined precise intensity distribution in the vertical plane. For example, FIG. **14(b)** illustrates a cross-sectional side view of how the transformer provides intensity distribution from angle β of input light to angle β' of output light where $\beta/2$ and $\beta'/2$ represent half of β and β' respectively.

[0052] FIG. **14(c)** illustrates how a horizontal pattern is created by way of overlapping individual outgoing patterns $\alpha'_1, \alpha'_2, \alpha'_3$, etc. When given a desired angular intensity distribution for a particular light source **1510**, it is possible to choose the number of light sources **1510** and their relative location to provide a horizontal envelope with predetermined non-uniformity. FIGS. **15(a)** and **15(b)** are exemplary illustrations of the resulting envelope and the overlapping intensity distribution pattern, respectively, of the system **1500**. FIGS. **15(a)** and **15(b)** illustrate an example using 10 LEDs located with equal angular separation of 36° that provide an envelope with non-uniformity of $\pm 0.5\%$.

[0053] FIG. **16** is an exemplary illustration of a vertical cross section of a toroidal precision optical transformer **1700**. A vertical pattern is created by a combination of an aspheric lens **1710** which is the central part of the optical transformer

(AOB) and members **1720** and **1730**. For example, member **1730** includes the transformer periphery (CDE). The members **1720** and **1730** can include planar optical windows **1740** and **1750** and total internal reflection surfaces **1760** and **1770**. The aspheric lens **1710** transforms all rays emitted in angle $\beta_1/2$ into the pattern limited by the outgoing ray with angle β'_{max} (ray 1', for example). The periphery performance is based on total internal reflection and, as a result, all rays emitted between angles and $\beta_1/2$ and $\beta_2/2$ will be reflected from the total internal reflection surface **1770** and through the planar optical window **1750**, directed in the domain between angles β'_{min} and β'_{max} (for example, ray 2'). Both aspherical lens profile and total internal reflection surface shapes may be calculated as functions of predetermined intensity distribution in the vertical plane using methodology and procedures described with respect to FIGS. 9-14. This concept and design provides light transformation with a very high ratio (β/β_1 up to 50) which is not practical with conventional aspheric optics because of unreasonable dimensions.

[0054] FIG. 17 is an exemplary illustration of an optical transformer for an elevated omnidirectional luminaire. The luminaire can include a light source **1810**, an input surface **1820**, a reflective surface **1830** and light channel **1840**. The light source **1810** can be located a distance d from the input surface **1820**. Additionally, the input surface can be semi-spherical about a radius R . Furthermore, the reflective surface **1830** can be designed according to the method disclosed with reference to FIGS. 9-14.

[0055] In operation, the light source **1810** can transmit light through the input surface **1820**. The input surface **1820** can direct the light through the light channel **1840** by way of total internal reflection to the reflective surface **1830**. The reflective surface **1830** can reflect the light according to a specified distribution pattern. For example, the reflective surface **1830** can reflect the light at an angle α' where α' falls between α'_{min} and α'_{max} . Additionally, the reflective surface can reflect the light in a manner similar to the semi-flush omnidirectional luminaire **300** of FIG. 3.

[0056] The method of this invention is preferably implemented on a programmed processor. However, the method may also be implemented on a general purpose or special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit elements, an ASIC or other integrated circuit, a hardware electronic or logic circuit such as a discrete element circuit, a programmable logic device such as a PLD, PLA, FPGA or PAL, or the like. In general, any device on which resides a finite state machine capable of implementing the flowcharts shown in the Figures may be used to implement the processor functions of this invention.

[0057] While this invention has been described with specific embodiments thereof, it is evident that many alternatives, modifications, and variations will be apparent to those skilled in the art. Accordingly, the preferred embodiments of the invention as set forth herein are intended to be illustrative, not limiting. Various changes may be made without departing from the spirit and scope of the invention.

What is claimed is:

1. A light transformer comprising:

a first outer wall comprising a total internal reflection surface, the first outer wall being configured to receive light, to redirect some of the received light and to redistribute some other portion of the received light;

a first optical window positioned at an end of the first outer wall;

a second outer wall comprising a total internal reflection surface, the second outer wall being configured to receive light, to redirect some of the received light and to redistribute some other portion of the received light;

a second optical window positioned at an end of the second outer wall; and

an aspheric lens located between the first and the second outer walls, the aspheric lens being configured to receive light and to redirect the received light.

2. The light transformer of claim 1, wherein the light transformer redistributes the received light in a precalculated pattern, where some light rays of the received light cross paths with other light rays of the received light.

3. The light transformer of claim 2, wherein the precalculated pattern is determined by a computer.

4. The light transformer of claim 1, wherein the light transformer redistributes the received light in a precalculated pattern, where some light rays of the received light merge with other light rays of the received light.

5. The light transformer of claim 4, wherein the precalculated pattern is determined by a computer.

6. The light transformer of claim 1, wherein the light transformer redistributes the received light in a pattern that was arranged by a computer, where some light rays of the received light cross paths with other light rays of the received light.

7. The light transformer of claim 1, wherein the light transformer redistributes the received light in a pattern that was arranged by a computer, where some light rays of the received light merge with other light rays of the received light.

8. The light transformer of claim 1, wherein the light transformer redirects and redistributes the received light with an efficiency of equal or greater than 60%.

9. The light transformer of claim 1, wherein the first outer wall and the second outer wall are non-parabolic.

10. A light transformer comprising:

an aspheric lens; and

at least two outer walls, where at least one of the walls is on a different side of the aspheric lens, each of the at least two outer walls has a total internal reflection surface that is configured to receive light and to redirect and redistribute the received light with an efficiency greater than or equal to 60 percent.

11. The light transformer of claim 10, wherein the light transformer redistributes the received light in a precalculated pattern, where some light rays of the received light cross paths with other light rays of the received light.

12. The light transformer of claim 11, wherein the precalculated pattern is determined by a computer.

13. The light transformer of claim 10, wherein the light transformer redistributes the received light in a precalculated pattern, where some light rays of the received light merge with other light rays of the received light.

14. The light transformer of claim 13, wherein the precalculated pattern is determined by a computer.

15. The light transformer of claim 10, wherein the light transformer redistributes the received light in a pattern that was arranged by a computer, where some light rays of the received light cross paths with other light rays of the received light.

16. The light transformer of claim 10, wherein the light transformer redistributes the received light in a pattern that

was arranged by a computer, where some light rays of the received light merge with other light rays of the received light.

17. The light transformer of claim **10**, wherein the light transformer redirects and redistributes the received light with an efficiency of equal or greater than 60%.

18. The light transformer of claim **10**, wherein the first outer wall and the second outer wall are non-parabolic.

* * * * *