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Brass

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[54] **TANGENT PLANE LIGHT REFLECTOR LUMINAIRE**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 881,834, Dec. 3, 1969, abandoned.

[52] **U.S. Cl.** .... **240/41.36,** 240/25, 240/103 R

[51] **Int. Cl.** **F21v 7/09**

[58] **Field of Search** .... 240/41.36, 41.35 R, 240/41.35 E, 41.35 F, 41.35 C, 41.4, 51.11, 25, 41.3, 103, 1.1; 350/288, 296; 219/347, 348, 349

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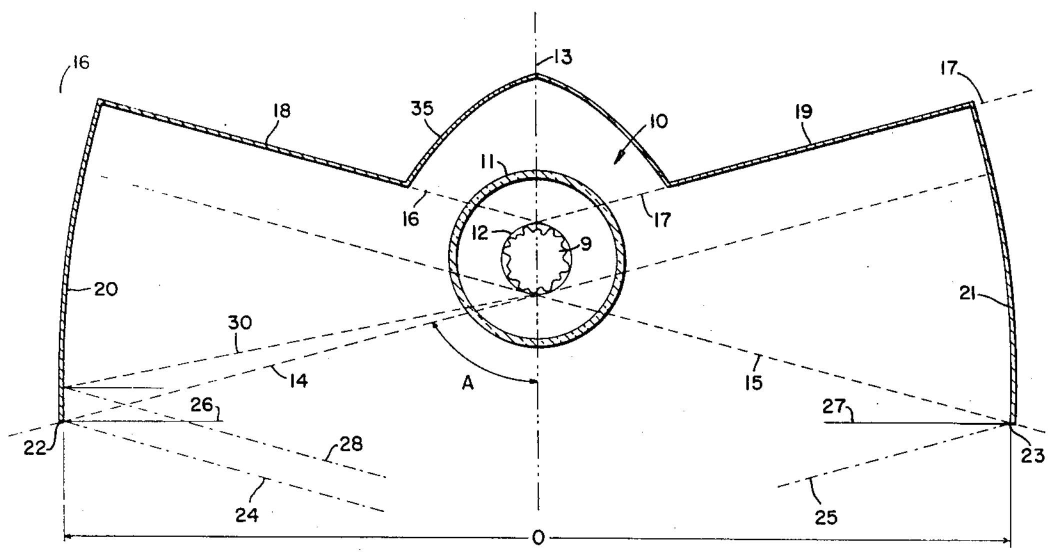
[57] **ABSTRACT**

A tangent plane light reflector principle for use in the design of luminaires is disclosed. Luminaires embodying the tangent light plane principle are described. The design and fabrication of luminaires embodying the tangent light plane principle for specific applications are discussed.

12 Claims, 7 Drawing Figures



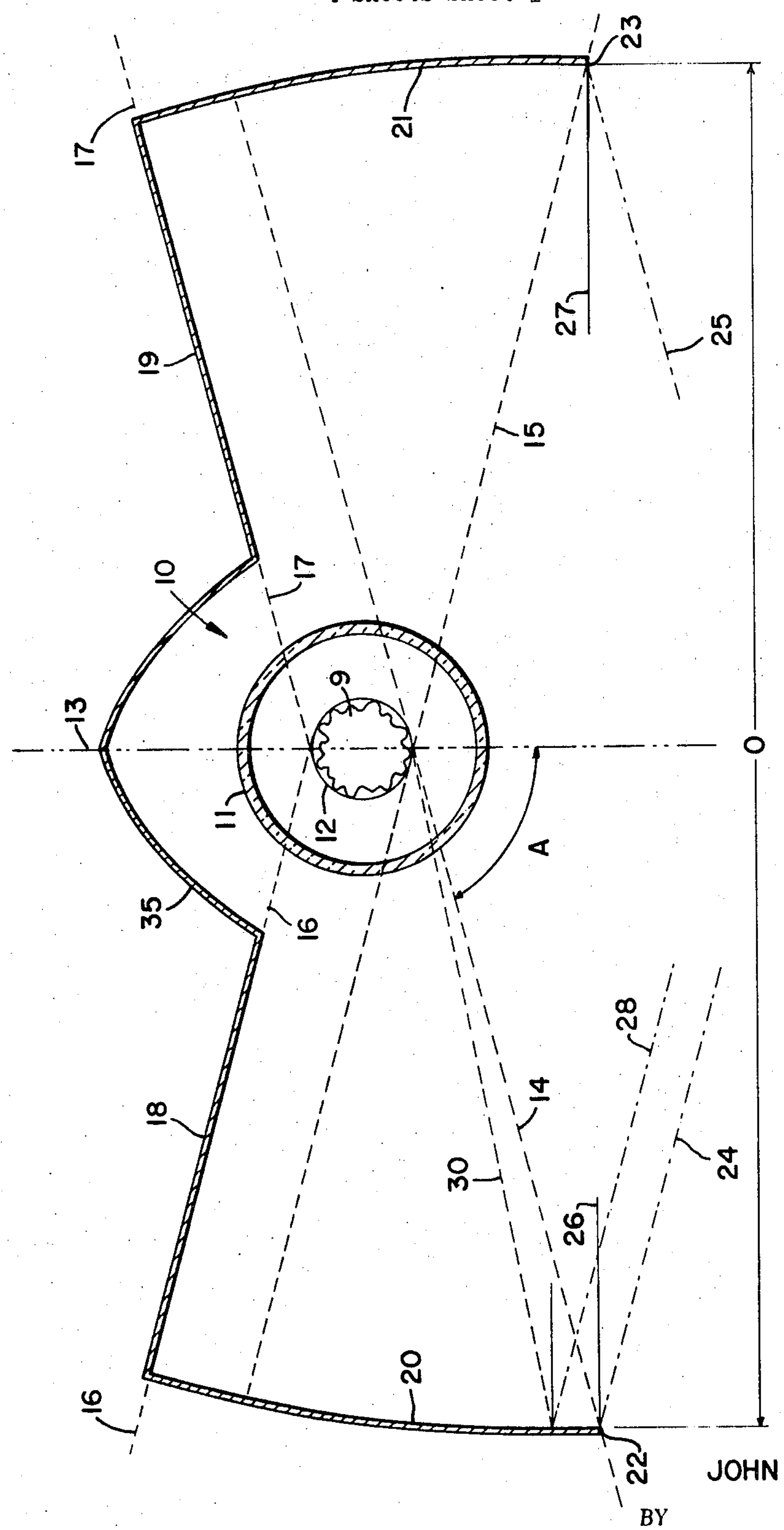


FIG_1

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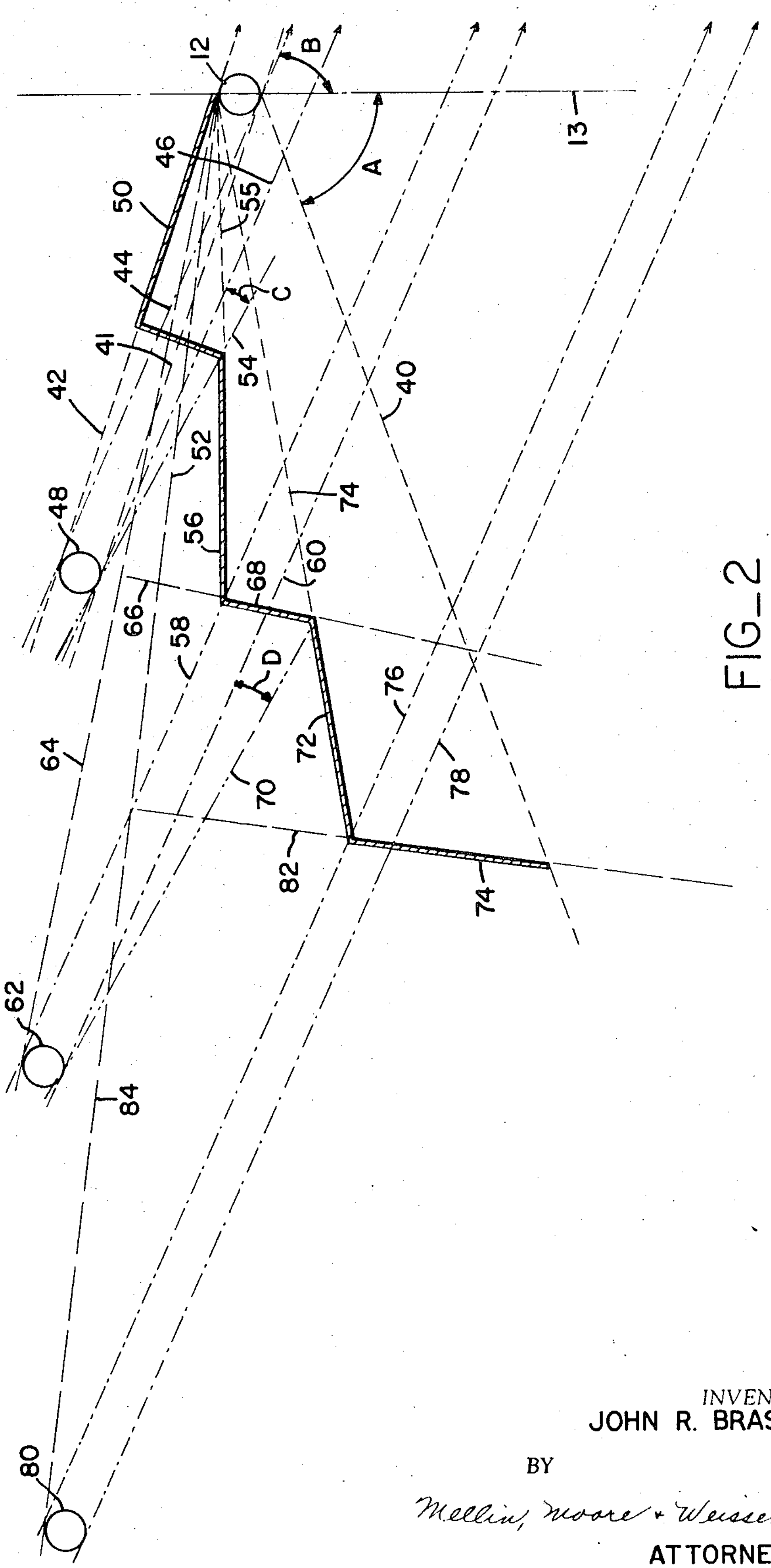

FIG_2

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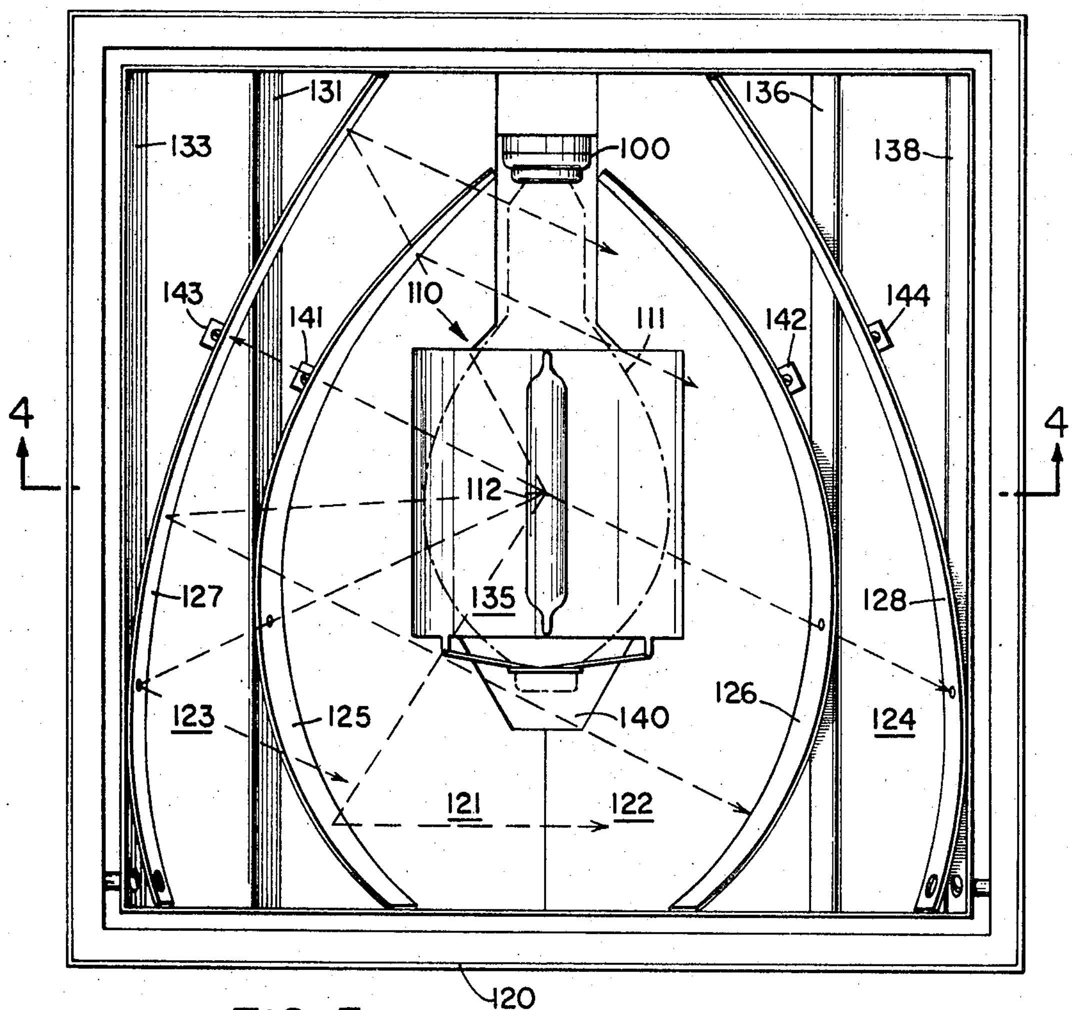

FIG_3

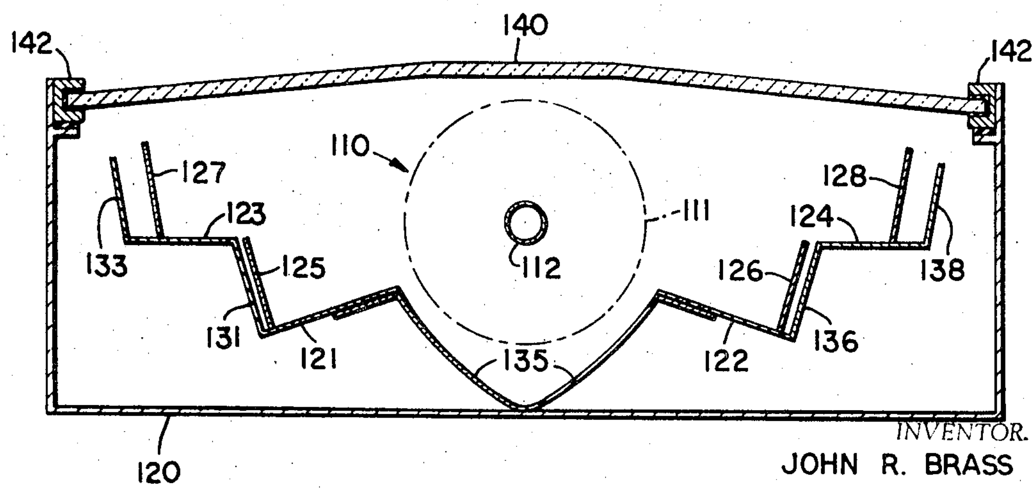

FIG_4

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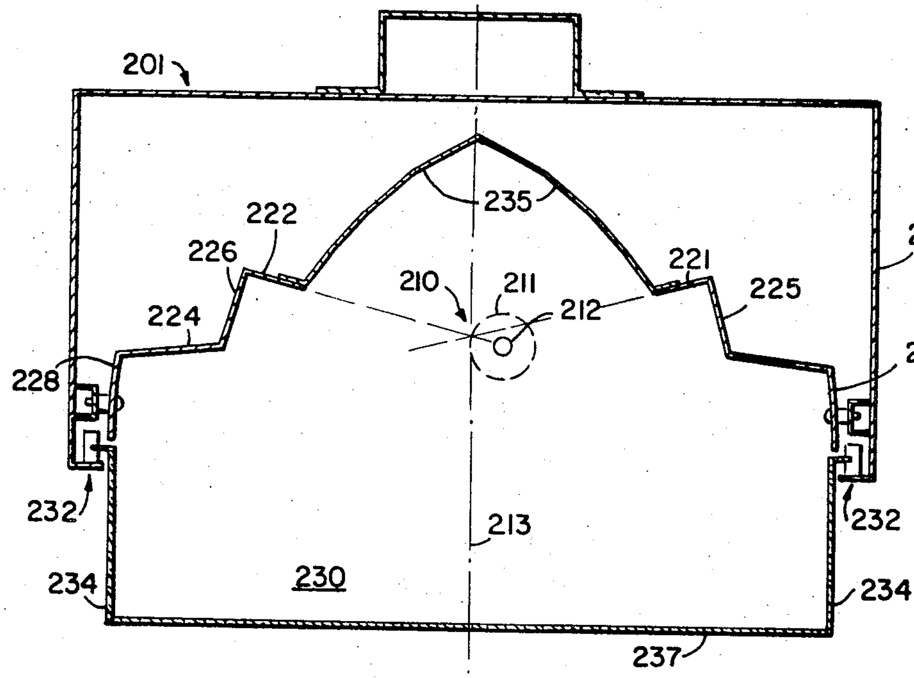

FIG_5

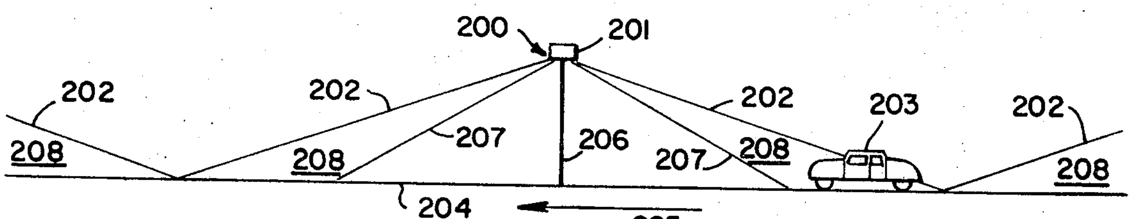

FIG_6

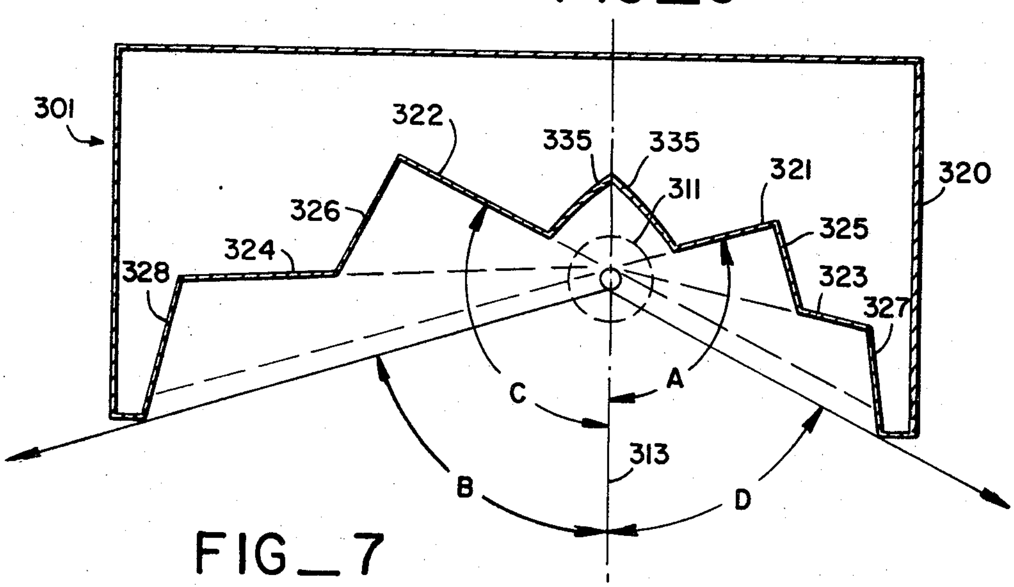

FIG_7

TANGENT PLANE LIGHT REFLECTOR LUMINAIRE

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of applicant's co-pending application Ser. No. 881,834, filed Dec. 3, 1969, now abandoned, having the same title.

BACKGROUND OF THE INVENTION

This invention relates to a lighting unit hereinafter called a "luminaire", designed to spread the light emitted by a given source over an area of substantial dimensions and particularly to a luminaire capable of providing a precise distribution of light over a precise area.

Electrical sources of non-coherent light such as are commercially usable for area illumination may be broadly divided into three major categories; incandescent, fluorescent and arc discharge. All of such sources tend to emit light in all directions unless impeded by structural elements of the source.

In an incandescent source a solid such as a refractory metal wire is heated to a high temperature (i.e., incandescence) by the passage of electrical current therethrough and the ultimate source of light is therefore the finite dimensions of the heated solid which may be compactly formed to approximate a point source of light or elongated and distributed in one or more of its dimensions to approximate a line, area or volume source of light. In any event there is a physical limit to the total amount of light that may be obtained from a given volume of the incandescent refractory metal solid and in addition it must be surrounded by an envelope to protect it from deleterious effects of the atmosphere at elevated temperatures which envelope must be of substantial volume to withstand such elevated temperatures.

A gaseous discharge light source of the compact arc type is capable of providing a larger amount of total light from a smaller overall volume than an incandescent light source. In a compact arc gaseous discharge light source a pair of closely spaced electrodes are disposed in a gaseous medium and a potential difference sufficient to ionize such gaseous medium is established between such electrodes. The ionization of the gaseous medium results in the emission of light from the volume of the ionized gas and the total amount of light is a function of the gas pressure and the amount of electrical current carried by the arc. Carbon arc lamps of the type commerically used in movie projectors are one example of this type of light source. An example of a gaseous discharge lamp of intermediate arc size is the commercially available mercury arc lamp comprising a transparent envelope filled with mercury vapor and having electrodes disposed therein between which the arc is established. In all arc lamps the light source is a finite volume of ionized gas, usually elongated and of irregular cross-sectional dimensions, the length of the arc and the cross-sectional dimensions for maximum practical light output being dictated by the type of gas utilized and the operating pressure thereof.

A fluorescent light source also utilizes an ionized gas. However, the great spacing of the electrodes, pressure of the gas and amount of electrical current passed through the ionized gas are not usually appropriate to sustain the high intensity arc type of discharge, and the light is produced instead mainly by the action of the particles of the ionized gas on a fluorescent coating on the inner surface of a transparent envelope which contains the ionized gas. The total amount of light produced by a given unit of area of such coating is small compared to the amount of light emitted per unit surface area from an arc or an incandescent source. For this reason fluorescent sources tend to take the form of elongated tubes in order to have enough total area to provide a sufficient total amount of light to be commerically useful.

A luminaire embodying this invention may be used to advantage with any conventional source of light and particularly those broadly described above. Prior art reflectors used with such sources of light have adequately handled light which is emitted from the source in directions toward the area to be lighted and even light emitted in directions generally lateral of the optical axis of such reflectors (i.e., at angles ranging downwardly from about 100° measured from nadir). However, prior art reflectors have not adequately handled light emitted by the source in directions which recede from the surface to be illuminated (i.e., at angles ranging upwardly from about 100° measured from nadir). Instead, light emitted at high angles measured from nadir has been permitted to escape (thus reducing the efficiency of the luminaire) or has been reflected back near the center of the area to be illuminated (thus reducing the apparent uniformity of illumination of such area).

It is an object of this invention to provide a luminaire which is more efficient than cutoff type luminaires of the prior art.

It is a further object of this invention to provide a luminaire capable of spreading light from a source over a given area with improved uniformity of illumination.

It is yet another object of this invention to provide a luminaire capable of spreading more of the light emitted by a given source in a desired pattern with precise light cutoff.

Light emitted by a source thereof without a reflector tends to be emitted in all directions. Thus, a planar area illuminated thereby is inherently circular with the source at the center, whereas in most applications it is desired to distribute the light from such source over a rectangular area that is not necessarily symmetrically located with respect to the source.

Thus, it is still another object of this invention to provide a luminaire having a light distribution pattern which, due to the geometry of the optical system, is inherently rectangular and which pattern may be asymmetrically located with respect to the luminaire.

Luminaires of the prior art tend to have large dimensions along the optical axis thereof and have included die-formed reflectors consisting of continuously curved surfaces. Although, the principles of this invention may be used in the design of die-formed reflectors, the complex reflector surfaces of a multiple stage tangent light plane reflector according to the teaching of the invention would be very complicated and difficult to die-form with precision. However, the precise contours of luminaires according to the invention disclosed and claimed herein may be simply and inexpensively fabricated and assembled and such contours may be easily changed to obtain a desired light distribution pattern by methods which would not be applicable to reflectors of the prior art.

Thus, it is yet a further object of this invention to provide a luminaire which is compact along the optical axis and a method of fabricating such luminaire from reflector surfaces that are rectilinear in cross-section.

DESCRIPTION OF THE DRAWING

These and other objects and features of this invention will be more fully understood from the following description of preferred embodiments thereof when read in conjunction with the drawing wherein:

FIG. 1 is a cross-sectional view taken through the optical axis of a single stage embodiment of this invention shown in conjunction with a cross-sectional representation of a light source and including dotted lines indicating design principles for light control in the plane thereof according to this invention.

FIG. 2 is a cross-sectional view taken through the optical axis of a multiple stage embodiment of this invention in which the light source is represented schematically and including dotted lines indicating design principles for light control in the plane thereof in accordance with this invention.

FIG. 3 is a plan view looking into a particular luminaire according to a preferred embodiment of this invention showing structural details thereof and including dotted lines which illustrate the design principles for lateral multiple stage light control as projected onto the plane of the reflector opening.

FIG. 4 is a cross-sectional view taken along line 4—4 of FIG. 3.

FIG. 5 is a cross-sectional view of an embodiment of this invention as actually used in a specific situation.

FIG. 6 is a schematic representation showing certain operational characteristics of the embodiments of this invention shown in FIG. 5.

FIG. 7 is a cross-sectional view of a further embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1 a light source is indicated at 10. Such light source may be of any type, however for purpose of discussion in connection with the embodiment of this invention as shown in FIG. 1 a light source representative of either the incandescent or arc discharge type is shown. It will be understood that the actual source of light 9 will comprise a volume of refractory metal of ionized gas contained within an envelope 11 to protect it from the deleterious effects of the atmosphere in operation. Such volume may be somewhat irregular in cross-section and may shift its location within the envelope during operation. Thus, for the purpose of this invention it is necessary to assume a circular cross-section 12, of sufficient diameter and properly centered to circumscribe the irregular cross-section and shifting location of the volume of the actual source of light 9 as indicated.

In designing a luminaire in accordance with this invention the first step is to establish an optical axis 13 through the center of the circular cross-section 12. Such axis 13 will, of course, be perpendicular or nearly perpendicular to the area to be illuminated and the portion of such axis extending between the light source and the area to be lighted may be conveniently designated "nadir".

The next step is to select the appropriate cut-off angle A with respect to nadir for the light emanating from the luminaire and the appropriate luminaire opening for the particular application involved. Although the selection of such cut-off angle A and luminaire opening do not form a part of this invention, it will be seen that a luminaire constructed in accordance with the teaching of this invention provides an unusually sharp cut-off in the light emanating therefrom at angles greater than the selected angle A with respect to nadir. Thus, the desired cut-off angle A and luminaire opening are selected according to criteria known in the art taking into account the light output of the source, the area to be illuminated and the illumination intensity desired thereon, the angle of incidence which may be tolerated, mounting considerations, etc. A cut-off angle A of about 75° with respect to nadir is believed to be desirable for area illumination and will be used in connection with the further description of FIG. 1. An arbitrarily selected luminaire opening is indicated by dimension line O.

In accordance with this invention and as shown in FIG. 1 two lines 14 and 15 are constructed which are tangent to the circular cross-section 12, intersect each other on the optical axis and each of which forms an angle with respect to nadir equal to the desired cut-off angle (e.g., 75°). "Tangent light plane" lines 16 and 17 are then constructed which are tangent to the circular cross-section at the side thereof opposite from nadir and parallel to the cut-off lines. Such lines 16 and 17 will, of course, intersect on the optical axis at a point on the opposite side of the light source 7 from the intersection of the cut-off lines 14 and 15.

Two of the reflecting surfaces 18 and 19 of the luminaire according to this invention are then disposed along tangent light plane lines 16 and 17 on opposite sides of the optical axis 13 and in diverging relation to the cut-off lines 14 and 15, respectively. In other words, the reflecting surfaces 18 and 19 form angles with respect to nadir that are supplementary angles to the desired cut-off angle. It will be understood that any conventional mounting means may be used to maintain the surfaces 18 and 19 in proper relation to the light source 10.

In accordance with this invention the reflector surfaces 18 and 19 should extend as close as is practical to the actual source of light 9. The envelope 11 surrounding the actual source of light 9, of course, imposes an ultimate limit on the extent of the surfaces in this dimension. In addition the operating temperature of the light source and the consequent need for air circulation, if not mechanical clearance, will require some practical spacing between the inner ends of surfaces 18 and 19 and the envelope 11.

The extent of the surfaces 18 and 19 along the tangent plane lines 16 and 17 away from the source of light according to this embodiment of the invention is a function of the selected dimension for the luminaire opening. Thus, according to the embodiment of the invention shown in FIG. 1 specular perimeter reflector surfaces 20 and 21 are generated so that substantially no light is permitted to leave the luminaire at an angle greater than the selected cut-off angle as described below. Beginning at the points 22 and 23 where the cut-off lines 14 or 15 intersect the luminaire opening dimension lines, lines 24 and 25 are drawn extending toward the optical axis parallel to reflectors 18 and 19, respectively. The bisectors 26 and 27 of the angles formed between lines 24, 25, and cut-off lines 14, 15, respectively, are constructed. A line perpendicular to bisector 26 is drawn through point 22 and a line perpendicular to bisector **27** is drawn through point **23.** These lines define the locus that the specular surface of the perimeter reflectors **20** and **21**, respectively, should have at the points **22** and **23**, respectively.

At this point it will be less confusing to consider the further development of perimeter reflectors **20** and **21** separately although the process is the same for both. Considering the perimeter reflector **20**, a further line **30** tangent to circular cross-section **12** but at a slightly larger angle with respect to nadir than line **14** is drawn and extended until it intersects the line drawn through point **22** perpendicular to bisector **26.** Through the point of intersection a further line **28** is drawn parallel to reflectors **18** and **19**, respectively. The angle formed between such further line **28** and the further tangent line **30** is bisected and a perpendicular to the bisector constructed through the point of intersection which perpendicular defines the locus of the specular surface at such point of intersection. This process is repeated at small angular increases until the further tangent line coincides with line **15.** A smooth curve may then be drawn through the locus points generated as described, which curve will define the specular surface of the perimeter reflector **20** between lines **14** and **15.** The specular surface of the perimeter reflector **20** between the line **15** and the tangent plane reflector **18** may simply lie on a line perpendicular to the specular surface of reflector **18** since light will either be reflected therefrom into or to the side of the source **9** or at an angle less than the cut-off angle. The curve for the specular surface of the perimeter reflector **21** is generated in the same way, it being understood that the process may be continued to include the portion of the perimeter reflectors **20, 21** immediately adjacent the tangent plane reflectors **18, 19,** if desired.

The construction shown in FIG. **1** and described above is the optimum, however, practical devices may be made in which the tangent light plane lines **16** and **17** vary a few degrees from absolute parallelism with the cut-off angle. More importantly, it is possible to design practical devices in which the tangent light plane lines **16** and **17** intersect each other at the center of the actual source of light **12** or at any point along the optical axis **13** opposite nadir that is at a distance from the center of the actual light source not greater than about one-fifth of the length of tangent light plane reflectors **18** and **19.**

The function of the tangent plane reflectors **18** and **19** is to direct all light which impinges thereon at a grazing angle (i.e., small angles with respect to the surfaces thereof) toward the perimeter reflectors **20** and **21.** The perimeter reflectors **20** and **21** have specular surfaces and are oriented to reflect the light which impinges thereon at angles with respect to nadir approaching the cut-off angle. It will be understood that the reflectors **18** and **19** need not have specular reflector surfaces according to this invention since it is a known physical phenomena that even a painted or other non-specular surface will exhibit high reflectivity approaching specularity to light impinging thereon at grazing angles. Thus, one of the distinctive features of a luminaire made in accordance with the teaching of this invention is that the reflector surfaces will exhibit low brightness when viewed along the optical axis looking into the luminaire whether they have specular surfaces or not.

It will be seen that the luminaire constructed as shown and described will provide an extremely sharp cut-off in the lateral dimension of the area illuminated thereby since no light is permitted to emanate from the luminaire at an angle greater than the cut-off angle. However, the construction of the luminaire is such that most of the light is directed therefrom at angles which approach the cut-off angle. Thus, the luminaire tends to provide maximum candlepower at or adjacent to the lateral extremes of the area illuminated where it is needed to overcome the loss in apparent illumination due to distance from the source and due to the grazing incidence angle (cosine law) and thus provide apparent uniformity of illumination. Uniformity of illumination is also enhanced due to the fact that the luminaire does not tend to concentrate light along the optical axis. Referring to FIG. **1**, it will be seen that all light emanating from the source at angles less than about 105° from nadir will be spread by the luminaire over the area to be illuminated. In addition, all light emanating from about 70° of the circumference of the circular cross section **12** on each side of nadir will be appropriately spread by the luminaire regardless of its angle of emanation.

The remaining light emanating from the source **9** may be recovered by means of an up-light recovery box **35.** If the specular surface of such box **35** is generated substantially in the manner described with respect to the perimeter reflectors **20** and **21** much of such light can be spread over the area to be illuminated with little contribution to the candlepower at the optical axis and substantial contribution to the candlepower at the lateral boundaries of the area to be illuminated. It will be understood that such uplight recovery box **35** will not permit the emanation of light at angles greater than the cut-off angle thus preserving the sharp cut-off characteristic of the luminaire. It will also be understood that no up-light recovery box at all will be needed where it is possible to extend the specular surface of the tangent plane reflectors **18** and **19** to intersection at the optical axis **13.** Such construction would be possible where the light source **13** is of the fluorescent type, broadly described above, since the actual source of light in fluorescent devices nearly coincides with the exterior of the envelope thereof. that the luminaire would have

A particular advantage of the tangent light plane structure in accordance with this invention is that it makes possible the location of the reflector surfaces of an up-light recovery box **35,** when one is used or required, much closer to the optical axis and much closer to the actual light source than was possible according to the teaching of the prior art. Thus, light that enters the uplight recovery box **35** will emanate therefrom at angles much closer to the cut-off angle than was possible according to the teaching of the prior art.

The description thus far has been limited to the consideration of the operation of a luminaire in accordance with this invention in the plane of the paper on which FIG. **1** is drawn.

It will be understood that if the light source **9** is spherical in shape (i.e., approaching a point source) a luminaire in accordance with this invention would be made symmetrical thereabout in which case the tangent plane reflectors **18** and **19** would join to form an inverted truncated conical surface and the reflectors **20** and **21** would join to form a generally cylindrical surface. The area illuminated would, of course, be circular.

However, as pointed out above, the total amount of light which can be generated by any practical and commercially available type of light source in a mode approaching a point source is sharply limited. Thus, high intensity discharge light sources tend to be elongated for increased total light output. According to the teaching of this invention the axis of elongation would be oriented perpendicularly to the plane of the paper on which FIG. 1 is drawn and the tangent plane reflectors would become flat planes extending along the axis of elongation. Similarly, the perimeter reflectors **20** and **21** would be straight or curved on these planes in the direction of such axis and the area illuminated would inherently tend to be rectangular.

End reflector shapes (not shown in FIG. 1) may be designed in the manner described with respect to perimeter reflectors **20** and **21** to provide a sharp cut-off along the axis of elongation if desired, however, it will be understood that a relatively small amount of the total light of an elongated source will emanate in directions along the axis of elongation. Appropriate curvature of the perimeter reflectors and appropriate end reflectors enable the recovery and appropriate spreading of much of such light over the inherently rectangular illuminated area.

Thus, it will be seen that the luminaire shown in FIG. 1 consists essentially of reflector surfaces of substantially rectilinear cross-section. Reflectors **18, 19, 20** and **21** may be metallic strips, for example. The light box **35** and end reflectors (not shown) may be formed separately for subsequent assembly. The absence of extreme curvatures in any of the reflecting surfaces will enable the use of inexpensive forming techniques thus further contributing to reduced fabrication costs. As shown, a luminaire according to this invention will have a minimum extent along the optical axis thus providing a compact "slim-line" contour which is highly desirable from an esthetic standpoint.

Referring to FIG. 2 a portion of another embodiment of this invention is shown in which a plurality of tangent light plane reflector stages formed entirely of reflector surfaces of rectilinear cross-section are used. For simplicity only the left hand portion of the luminaire is shown, it being understood that the luminaire will include an identical complementary right hand portion. In FIG. 2 the actual source of light is depicted schematically as a circular cross-section **12.** However, it will be understood that the aluminaire would have to be slightly modified adjacent the light source **12** as discussed in connection with FIG. 1 to accommodate the envelope associated therewith unless a fluorescent type of light source is used.

As discussed in connection with FIG. 1 an appropriate cut-off angle A is selected according to criteria known in the art, however a luminaire opening smaller than a certain minimum cannot be preselected according to this embodiment of the invention since such minimum will be determined by the design technique utilized. Instead a desired maximum candlepower angle B is selected for the particular application involved according to criteria known in the art. In general, in applications involving area illumination it will be desirable for the maximum candlepower angle to approach the cut-off angle A for uniformity in apparent illumination. Thus, in FIG. 2 a cut-off angle A of 70° and a maximum candlepower angle B of 65°, both with respect to nadir, have been selected for depiction and discussion. Although the criteria by which the maximum candlepower angle is selected does not form part of this invention, it will be seen that a luminaire constructed in accordance with this invention inherently tends to produce an angle of maximum candlepower approaching the cut-off angle.

In the design of the luminaire shown in FIG. 2 the optical axis **13** and the cut-off lines **40** and **41** at the selected cut-off angle A with respect to nadir intersecting on the optical axis **13** of the light source are drawn as described in connection with FIG. 1. Similarly, the tangent light plane line **42** parallel to the right hand cut-off line **41** and tangent to the cross-section **12** on the side thereof opposite nadir is drawn as described in connection with FIG. 1.

According to the embodiment of the invention shown in FIG. 2 the next step is to draw a first maximum candlepower line **44** tangent to cross-section **12** at the nadir side thereof and at the selected maximum candlepower angle B with respect to nadir. A second maximum candlepower line **46** is then constructed parallel to the first and spaced therefrom along the optical axis a distance equal to the diameter of the cross-section **12.** The maximum candlepower lines **44** and **46** are extended until they intersect the tangent light plane line **42** and the right-hand cut-off line **41**, respectively, and at this point a light source image **48** may be constructed tangent to the intersections of the two pairs of lines **44, 42,** and **46, 41.**

The specular or glossy surface of the first tangent light plane reflector **50** is then disposed along the tangent light plane line **42** as described in connection with FIG. 1. For reasons to be discussd below the surface of the tangent light plane reflector **50** should extend from as close as is practical to the optical axis to a point midway between the optical axis **13** and the intersection of the first maximum candlepower line **44** with the tangent light plane line **42.** The specular surface of the first perimeter reflector **52** is then disposed along a line perpendicular to the tangent light plane line **42** at the end of the tangent light plane reflector **50.** The specular surface of the first perimeter reflector **52** may be extended to a point beyond the second maximum candlepower line **46** so that an angle C, not greater than about 5° with respect to the maximum candlepower line, is formed by a line **54** drawn through such point and tangent to the light source image **48.**

The criterion for the optimum lengths of the reflectors **50** and **52** is that the complete image **48** should be visible tangent to the cross-section **12** of the light source from points along the line **44** to the right of the optical axis and that the angle C be small enough (i.e., about 5° or less) to insure that minimum light will be reflected from the perimeter reflectors at angles smaller than the angle B. Thus, if the surface of reflector **50** does not extend to a point at least about midway between the optical axis and the intersection of lines **42** and **44**, the repositioned image **48** when observed in the specular surface of reflector **52** from a point along line **44** to the right of the optical axis will be partially obscured by the cross-section **12** of the light source.

For practical purposes the surface of reflector **50** may be extended beyond the minimum distance shown. In this case the perimeter reflector will function in a way which reduces the difference between angles A and B. The disadvantage is that the reflector dimension is increased on the optical axis.

Upon selection of the appropriate lengths for the surfaces of reflectors **50** and **52** a second tangent light plane line **55** is drawn through the free end of the specular surface of reflector **52** and tangent to cross-section **12** of the light source opposite nadir. The surface of the second tangent plane reflector **56** is disposed along line **55** and must extend at least to a point having a distance from the optical axis about equal to the distance of the center of image **48** from the optical axis since if the surface of reflector **56** is shorter it will tend to cause light to be reflected from the specular surface of the second perimeter reflector at an angle greater than the cut-off angle.

A line **58** is then constructed through the end of the specular surface of reflector **56** and parallel to maximum candlepower lines **44**. A further line **60** is constructed parallel to line **58** but spaced therefrom toward nadir a distance equal to the diameter of cross-section **12** of the light source and image **62** is drawn tangent to lines **58** and **60** with its center at a distance from the end of the specular surface of reflector **56** equal to the distance from the end of such specular surface to the center of cross-section **12**. An imaginary tangent light plane line **64** is then drawn tangent to image **62** and cross-section **12** opposite nadir and a line **66** perpendicular thereto is drawn through the end of the specular surface of reflector **56**. The specular surface of the second perimeter reflector **68** is disposed along perpendicular line **66** and such specular surface is extended to a point at which a line **70** drawn through the end thereof and tangent to the image **64** on the nadir side forms an angle D with line **60** which is no greater than angle C in order to insure good light control.

The specular surface of a third tangent light plane reflector **72** is disposed along a line **74** drawn through the end of the specular surface on reflector **70** and tangent to cross-section **12** on the side thereof opposite nadir. The length of the third **72** and subsequent tangent plane light reflectors, if any, will not be critical nor will the length of the specular surface on the third **74** or subsequent perimeter reflectors since the images will now be formed far from such surfaces and therefore the cut-off angle cannot be exceeded. However, for optimum results the angle of the specular surface of the perimeter reflectors with respect to the specular surfaces of the associated tangent light plane reflectors should nevertheless be determined as described above. That is, a line **76** parallel to the maximum candlepower lines should be constructed through the end of the specular surface of the tangent plane reflector **72**, a further line **78** parallel thereto should be constructed at a distance therefrom equal to the diameter of cross-section **12**, and an image **80** should be drawn between and tangent to line **76** and **78** with its center at a distance from the end of the specular surface of tangent plane reflector **72** equal to the distance from such reflector end to the center of cross-section **12**. The specular surface of perimeter reflector **74** should then be disposed along a line **82** perpendicular to a line **84** drawn tangent to image **80** and circular cross-section **12**.

Thus, additional tangent light plane reflectors and additional perimeter reflectors after the second may be designed as desired to provide an appropriate luminaire opening larger than a certain minimum. Such desired luminaire opening is attained by extending the third or a subsequent perimeter reflector to the cut-off line **40**.

Referring to FIG. 3 a plan view of an actual luminaire constructed in accordance with this invention is shown in detail looking into the reflector. According to this embodiment of the invention the light source is a mercury arc lamp **110** comprising an inner translucent or transparent envelope **112** containing mercury vapor under pressure which is ionized to provide the light output and an outer transparent envelope **111** which is evacuated to protect the inner envelope from the deleterious effects of the atmosphere at elevated operating temperatures. It will be understood that other commercially available high intensity arc lamps such as sodium vapor lamps, for example, could be used and that the lamp **110** is selected to provide the desired amount of total light output for the particular application. The structure of the lamp **110** itself is dictated by practical design considerations which do not form a part of this invention but which must be taken into account in designing a luminaire in accordance with this invention. Thus, the diameter of the inner envelope **112** is taken as the cross-section **12** of the actual source of light as described in connection with FIGS. **1** and **2**. For a given total light output such envelope **112** will have a certain diameter and length and the outer envelope or bulb **111** will have a certain corresponding length and maximum diameter dictated by practical considerations. An appropriate socket **100** must be provided for the lamp **110** and the reflector surfaces of the luminaire must be designed around these given structural features of the light source.

The actual design of the luminaire will vary according to the particular application for which it is intended. Thus, the specific luminaire shown in FIG. **3** is designed for roadway illumination in which the luminaire would be mounted at the side of the road with the longitudinal axis of the light source **112** generally horizontal and at right angles to the roadway direction lines and with the socket **100** at the end thereof away from the roadway. As explained above, a luminaire designed in accordance with this invention tends to illuminate a rectangular area with very sharp cut-off lines parallel to the longitudinal axis of the light source **112** and with the maximum candlepower adjacent to such cut-off lines.

Referring to FIG. **4** which is a cross-sectional view taken along line **4—4** of FIG. **3** it will be seen that the reflector of the luminaire according to this embodiment of the invention is a combination of the reflectors shown in FIGS. **1** and **2**. Thus, the luminaire comprises an outer housing **120** within which is mounted the light source **110** and the specular surfaces of the reflector. The reflector includes tangent light plane surfaces **121**, **122**, **123** and **124**, and perimeter reflectors **125**, **126**, **127** and **128** which are designed as described in connection with FIG. **2**. In addition, due to the large size of the envelope **111** with respect to the light source **112** of the mercury arc lamp **110**, the reflector includes an up-light recovery box **135** as described in connection with FIG. **1**. A transparent protective lens **130** is mounted across the luminaire opening by means of the flange structure **132** on the housing **120**.

The actual construction of the luminaire will be better understood by reference to FIG. **3**. It will be seen that in this embodiment the housing **120** is simply a generally rectangular box although it may have any desired decorative shape. The tangent light plane surfaces 121 and 123 are formed by making simple longitudinal bends in a metallic sheet, for example, to provide such surfaces of proper length and at the proper angles interconnected by web 131 and having a mounting flange 133 at its outer edge. Similarly, tangent light plane surfaces 122 and 124 are formed by making longitudinal bends in a metallic sheet to provide such surfaces of proper length and at the proper angles interconnected by web 136 and having a mounting flange 138 at its outer edge. Edge portions of surfaces 121 and 122 are removed to provide cutout 140 to accommodate the envelope 111 of the mercury vapor lamp 110. The up-light recovery box 135 may comprise a simple rectangular sheet of specular surfaced metal, for example, bent to provide the flanged cross-sectional shape shown in FIG. 4 and mounted in cut-out 140 by its flanges on surfaces 121 and 122 as shown. For greatest efficiency the width of the up-light recovery box 135 is made somewhat greater than the length of the light source. End walls for box 135 could, of course, be provided if desired and a formed box would also be practical.

The perimeter reflectors 125, 126, 127 and 128 may comprise strips of metal, for example, mounted at the proper angle on surfaces 121, 122, 123 and 124, respectively, by means of brackets 141, 142, 143 and 144. By fabricating perimeter reflectors 125, 126, 127 and 128 in strip form independently of the associated tangent plane surfaces, it is possible to curve them along the longitudinal axis of the light source as indicated in order to provide maximum candlepower at a particular lateral angle from such axis as required by the application. Furthermore, the effect of this reflector geometry is to produce a constant longitudinal cut-off angle at all lateral angles. This is highly desirable performance for area lighting. In other words and considering FIG. 2 and FIG. 3 together, if the perimeter reflectors are curved in the longitudinal direction as shown in FIG. 3 but are maintained in the cross-sectional orientation to the tangent light plane reflector associated therewith as described in connection with FIG. 2, the cut-off angle and angle of maximum brightness shown in FIG. 2, will remain constant for all cross-sectional planes along the longitudinal axis of the light source. This performance could not be duplicated by prior art design techniques without resorting to extremely complex surfaces such as might be produced by curving or warping strip reflectors in two dimensions.

In addition, it will be seen that each reflection stage including the up-light recovery box may be shaped to produce high candlepower at different lateral angles thus providing very uniform illumination. It will be understood that the above configurations would be extremely difficult to fabricate in one piece by conventional means used in luminaire fabrication, and conversely, that if a luminaire were designed according to the teaching of the prior art in such a way as to approach this performance, the reflector surface would be too complex to be economically fabricated.

In the case of the luminaire shown in FIGS. 3 and 4 the opening of the housing lens frame approximates the actual cut-off angle which is provided by the second stage of the tangent light plane surfaces and perimeter reflectors rather than by an additional stage as described in connection with FIG. 2. Thus, it will be understood that the design concept of this invention is quite flexible enabling a wide variety of embodiments thereof. It will also be seen that luminaires embodying this invention may be simply and inexpensively fabricated from sheet material without complex surfaces or difficult mounting techniques.

It will be understood that the various ranges of departure from optimum design mentioned herein will enable those skilled in the art to make many embodiments of this invention different from those specifically described above but which fall within the scope of the following claims.

For example, referring to FIG. 5, an embodiment of this invention as adapted for actual use in illuminating the roadway of a specific major highway bridge is shown. The design of the luminaire 201 shown in FIG. 5 is substantially identical to that shown in FIGS. 3 and 4 with minor structural and dimensional changes. In addition the light source used in the embodiment shown in FIG. 5 is a high pressure sodium arc lamp 210 which differs from the mercury arc lamp 110 shown in FIGS. 3 and 4, so far as this invention is concerned, only in that it has a smaller outer envelope 211 then a mercury arc lamp for the same or greater total light output.

The most important difference in the embodiment of this invention shown in FIG. 5 from that shown in FIGS. 3 and 4 is that the center of the actual source of light 212 is displaced laterally from the optical axis 213 of the luminaire in accordance with the teaching of this invention as set forth above. Such displacement provides a slight but very useful difference between the illumination characteristics of the embodiment of FIG. 5 and the embodiment of FIGS. 3 and 4 as will be more-fully described hereinafter.

The tangent light plane reflector surfaces 221, 222, 223, and 224 of FIG. 5 correspond to tangent light plane reflector surfaces 121, 122, 123, and 124, respectively, of FIGS. 3 and 4. Similarly, perimeter reflectors 225, 226, 227, and 228 of FIG. 5 correspond to perimeter reflectors 125, 126, 127, and 128, respectively, of FIGS. 3 and 4. The up-light recovery box 235 of FIG. 5 appears somewhat larger in proportion to the rest of the luminaire 200 than the up-light recovery box of FIGS. 3 and 4 partly due to the smaller size of the envelope 211 of light source 210.

The substantially planar transparent lens 130 of FIGS. 3 and 4 is replaced in FIG. 5 by a transparent, open-topped, hollow, box-like member 230 mounted on the housing 220 by flange means 232 and having sides 234 projecting from the housing 220 closed by a flat bottom 237. The purpose of the projecting lens member 230 is to enable the luminaire 201 to provide a "beacon" or "roadway marker" function in addition to illuminating the roadway. It will be understood that a luminaire according to this invention is difficult to see from a distance at night due to the sharp cut-off angle of light emanating therefrom. Thus, the projecting transparent lens member 230 will tend to scatter a slight amount of light from the source 210 due to surface effects but without appreciable effect on the total distribution of the light from the source 210 on the roadway by the luminaire 201. The light scattered by the transparent lens member 230 by dust particles on its surface, for example, will cause it to appear to glow softly, thus making it visible for some distance along the bridge or roadway and enabling a plurality of such luminaires mounted along the side of the bridge or roadway to serve to delineate or mark the course of the roadway for the convenience of travelers. It may be necessary for the lens member **230** to be slightly tinted to enhance such effect and to provide a pleasing color when viewed from a distance along the roadway or to the side of the roadway. However, the change in light distribution on the roadway introduced by the lens member **230**, even if tinted, is so slight as to be negligible so far as this invention is concerned.

Referring to FIG. **6**, the effect of the lateral displacement of the center of the actual source of light **212** from the optical axis (as shown in FIG. **5**) upon the light distribution on the roadway is also so slight as to be negligible so far as this invention is concerned although such effect is of considerable importance in the specific bridge illuminating application in which the luminaire **201** of FIG. **5** is used. In such specific application represented schematically in FIG. **6**, the number and spacing of locations **200** along each side of the bridge at which luminaires **201** could be mounted was fixed long ago when the bridge was constructed. Furthermore, the maximum angle with respect to nadir at which light approaching the intensity of the source **210** may be allowed to escape from the luminaire **201** (referred to herein as the "cut-off angle" and indicated in FIG. **6** by the lines **202**) is sharply limited by practical considerations.

As shown in FIG. **6** a car **203** traveling along the roadway **204** in the direction of the arrow **205** will pass in turn through the areas illuminated by each of the luminaires **201** in the row on one side of the bridge. It has been found that, when a high intensity light source is used, a cut-off angle of about 75° is the maximum that can be tolerated in a luminaire for roadway lighting without allowing high intensity light from the luminaire to pass directly through the windshield of the average car **203** and into the eyes of the driver. It is, of course, possible to cause the areas illuminated by adjacent luminaires **201** to meet or even overlap each other although they have a cut-off angle of less than 75° by simply increasing the height of the mounting means **206** by which the luminaires **201** are supported above the roadway **204**. However, such an increase in height will also increase the attenuation of light due to atmospheric conditions between the luminaire and the roadway and in the particular bridge application mentioned above the presence of fog on the roadway is a regular occurrence. Thus, it is desirable to keep the height of the luminaire above the roadway near the minimum necessary for continuous illumination by a row of luminaires having cut-off angles of about 75° as indicated in FIG. **6**.

As discussed in detail hereinabove, a luminaire **201** according to the teaching of this invention provides a light distribution which approaches perfectly uniform apparent illumination by increasing the amount of light which emanates from the luminaire at angles approaching the cut-off angle. Thus, a luminaire **201** according to the teaching of this invention directs maximum candlepower in a zone or area adjacent the cut-off angle represented by lines **202**. Such zone is generally represented in FIG. **6** by the area **208** formed by the angle of about 10° between pairs of lines **202** and **207**.

The specific luminaire **201** of FIG. **5** designed for the particular bridge illumination application described in connection with FIGS. **5** and **6** has a cut-off angle of about 73° which, in actual use, enabled mounting at a minimum height for illumination of the roadway with the apparent uniformity of illumination approaching the uniformity of daylight. Such illumination was found to be unusually functional and pleasing to the drivers of most conventional U.S. made cars. However, drivers of certain sports cars and certain foreign cars having windshields which slope backward at a radical angle noticed an unpleasant and indefinable flashing in their eyes as they drove along under the luminaires **201** on the bridge. This effect was found to occur just as such drivers entered the zone illuminated by each luminaire **201** as represented by the position of the car **203** shown in FIG. **6**.

It is believed that the effect is caused by a combination of the increased candlepower present at the cut-off angle of a luminaire according to this invention and a "shutter" action performed by the roof of certain cars. In any event the effect is not noticeable in a car with no roof, such as a convertible with the top down, and was obviated by the slight displacement of the actual source of light laterally of the optical axis of the luminaire in the direction opposite to the direction of motion of the cars passing thereunder as shown in FIG. **5**. Measurements indicate that such lateral shift of the actual source of light has reduced the cut-off angle by about 1° on the side of the luminaire **201** in the direction of such displacement or from about 73° to about 72°, at the same time increasing the cut-off angle on the opposite side of the luminaire about 1° from 73° to 74°. No change in the apparent uniformity of light distribution can be discerned but the "flashing" effect is no longer noted.

It will be understood that if more than a few degrees of difference is required between the cut-off angles on opposite sides of a luminaire it would not be possible to obtain such difference by mere lateral displacement of the actual source of light without loss of the apparent uniformity of illumination provided according to the teaching of this invention. Specifically, if such lateral displacement exceeds a distance equal to about one-fifth of the distance of the first perimeter reflector **225** along the tangent light plane **221** from the optical axis, then apparent uniformity of illumination according to the teaching of this invention will no longer be obtained.

However, referring to FIG. **7**, it is possible to design a luminaire **301** according to the teaching of this invention having different cut-off angles with respect to a line drawn through the ideal location of the center of the actual source of light perpendicular to the plane of the opening of the luminaire on opposite sides thereof. In order to maintain the improved apparent illumination of the desired area in accordance with the teaching of this invention, it is necessary to maintain the angular relationship between the cut-off angle and tangent light plane on opposite sides of such line as set forth in connection with FIG. **2**. Thus, referring to FIG. **7**, it will be seen that the angle A formed by the tangent light plane line along which reflector **321** is mounted with respect to the line **313** drawn perpendicular to the plane of the opening in the housing **320** through the center of the light source **312** is the supplement of the cut-off angle B with respect to such line **313**. Similarly, it will be seen that the angle C formed by the tangent light plane along which the reflector **322** is mounted with respect to the line **313** is the supplement of the cut-off angle D with respect to such line **313**.

It will be seen that an optical axis for the luminaire 301 in the plane shown in FIG. 7 can be constructed by bi-secting the total angle formed by angles B and D. However, the teaching of this invention is more easily practiced by designing the portions of the luminaire on opposite sides of the line 313 separately, treating the line 313 as the optical axis of such portion and defining the cut-off angle on the opposite sides of the line 313 with respect to nadir of the line 313 as taught in connection with FIG. 2. The lengths of reflector surfaces 321 and 322 will of course differ from each other. The portions of the up-light recovery box 335 on opposite sides of line 313 will also differ from each other in shape and the lengths of perimeter reflectors 325, 326, 327, and 328 will differ from each other as will the lengths of reflectors surfaces 323 and 324. Otherwise, the structural details of luminaire 301 may be similar to the other embodiment of this invention described hereinabove.

What is claimed is:

1. A luminaire having a given optical axis and a given light cut-off angle measured with respect to said axis from nadir for spreading light emanating from a given light source having an actual source of light of finite maximum cross-sectional dimensions over a given area to be illuminated, said luminaire comprising a first reflector surface and a second reflector surface; said first reflector surface having a finite dimension along a first line intersecting said optical axis at a point on the opposite side of the center of said actual source of light of said given light source from said area to be illuminated and forming an angle with respect to said given optical axis from nadir which is the supplement of said given cut-off angle, said first line being substantially tangent to a minimum circular cross-section circumscribing the maximum cross-sectional dimensions of the actual source of light of said given light source, said point of intersection of said first line and said optical axis being spaced a finite distance from the center of said actual source; and said second reflector surface being spaced from said light source along said first line and extending from said first reflector surface toward said given area to be illuminated at an angle which is substantially a right angle with respect to said first line, the distance from the center of said light source to said point of intersection of said first line with said optical axis being less than one fifth of the distance from said optical axis along said first line by which said second reflector is spaced from said light source.

2. A luminaire as claimed in claim 1 wherein said center of said actual source of light has its locus on said optical axis of said luminaire.

3. A luminaire as claimed in claim 1 wherein the locus of said center of said actual source of light is displaced from said optical axis of said luminaire.

4. A luminaire as claimed in claim 1 wherein said given light source is elongated along a longitudinal axis which is substantially perpendicular to said given optical axis and wherein said first reflector surface is a planar surface having a substantial dimension parallel to said longitudinal axis.

5. A luminaire as claimed in claim 4 wherein said dimension of said first reflector surface parallel to said longitudinal axis is greater than the elongation of said light source.

6. A luminaire as claimed in claim 5 wherein said second reflector surface is a substantially planar surface having a major dimension extending in the same general direction as the direction of said longitudinal axis.

7. A luminaire as claimed in claim 6 wherein said major dimension of said second reflector surface is greater than the elongation of said light source and said second reflector surface is curved with respect to said longitudinal axis.

8. A luminaire as claimed in claim 6 comprising a pair of first reflector surfaces and a pair of second reflector surfaces, each one of said pairs having an orientation that is the mirror image of the orientation of the other of said pairs on opposite sides of said optical axis.

9. A luminaire as claimed in claim 8 wherein the ends of said pair of first reflector surfaces adjacent said light source are spaced therefrom.

10. A luminaire as claimed in claim 9 wherein a third reflector surface extends between the ends of said first reflector surfaces adjacent said light source, said third reflector surface being curved away from said light source.

11. A luminaire as claimed in claim 1 wherein said second reflector surface extends to a point located on a second line forming an angle with said optical axis equal to said given cut-off angle and tangent to said circular cross-section on the side thereof adjacent said area to be illuminated.

12. A luminaire as claimed in claim 11 wherein said second reflector has a length substantially equal to twice the diameter of said circular cross-section and including third and fourth reflector surfaces, said third reflector surface having a finite dimension beginning at the free end of said second reflector and extending away from said light source along a third line tangent to said circular cross section on the opposite side thereof from said area to be illuminated and passing through said free end of said second reflector, said fourth reflector surface being spaced along said third reflector surface from said light source and extending toward said area to be illuminated.

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