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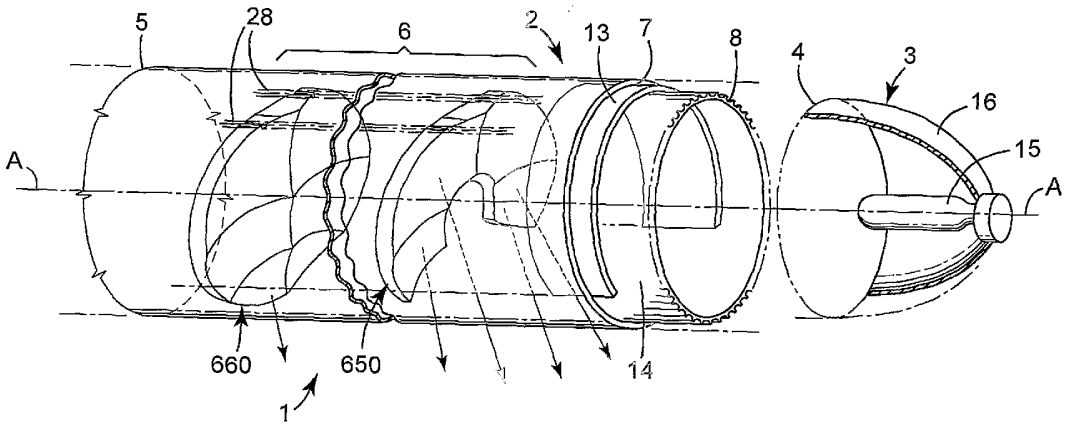
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(54) Title: LIGHT GUIDE SYSTEM



(57) Abstract: The invention relates to a light guide system (1) comprising a hollow light guide (2) and a light source (3) positioned to direct light into the light guide (2) from one end (4), the light guide (2) having light-guiding walls that cause the light to travel in the space within the light guide (2) towards the other end (5) thereof; and, in the space within the light guide (2), at least one light-extracting element (650, 660) having at least one curved surface that functions as a non-transmissive specular or narrow- or wide-scattering reflector, the curved reflecting surface(s) being shaped so that light from the source that is reflected therefrom will inpinge on a light-guiding wall of the light guide (2) at such an angle as to emerge from the light guide (2).

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LIGHT GUIDE SYSTEM

Field

The present invention relates to a light guide system and more particularly to a hollow light guide system having a particular extracting mechanism.

Background

Light guide systems are known and include essentially tubular hollow constructions the internal surfaces of which are essentially totally internally reflecting (see e.g. US 4,260,220). The light rays entering such a hollow light guide system at a first end thereof propagate within the tubular construction through a series of successive reflections, arriving at the opposite end.

Hollow light guide systems obtained using totally internally reflecting films (or TIR films, acronym of English words Total Internal Reflection) are particularly effective.

Such TIR films are for example known from EP 0 225 123 to which reference is made for a detailed description of their characteristics; an example of such TIR films are those available from 3M Company, St. Paul, Minnesota, U.S.A., under the trade name 3M™ Optical Lighting Film. They are in the form of flexible sheets or webs, having a surface with a sequence of parallel micro-structures, essentially of triangular cross-section, hereinafter referred to as micro-prisms; such films may be formed into tubes, with the micro-prisms axially oriented with respect to the tube and facing outwards, to create an effective light guide system as described, for example, in US 4,805,984.

Suitable elements, called light extractors, may be inserted within a hollow light guide system, or applied to its walls, to cause a controlled diffusion of a portion of the light that propagates within the light guide, thus causing some of the light rays to be deflected and become incident on the walls of the light guide system with such angles as to exit from the light guide. The light that is emitted through the walls of the light guide system can thus be more uniformly distributed, i.e. the light guide obtains a comparatively uniform overall appearance when illuminated.

For example, WO 02/23084 discloses a light extractor for a light guide lamp which useful surface – i.e., the surface that, in the use of the light extractor, faces the emission

surface of the light guide lamp- comprises a predetermined distribution of diffusing points and a complementary distribution of reflecting points. The light guide lamp is more particular of rectangular cross section and the extractor is essentially flat, adhered to a wall of the light guide.

EP 1 180 640 discloses a light extractor for a light guide lamp, having a diffusing surface and intended to be coaxially inserted into a light guide of the light guide lamp, wherein the diffusing surface is at least partly sloped with respect to the longitudinal direction, diverging from a light inlet end. The slope of the extractor with respect to the longitudinal direction may follow a logarithmic, parabolic, ellipsoidal or circular curve.

US 6,285,814 discloses a light guide luminaire that may include an extractor element in the form of a sheet of diffusely reflecting material secured to the inner surface of the optical lighting film forming the light guide, or in the form of a separate component extending radially inwardly from the inner surface of the housing for scattering light. Such document also teaches that, when the latter type of extractor element is used, either the radial dimension (i.e. height) or width of the extractor elements may vary as a function of the distance along the luminaire in order to yield a light output which is reasonably uniform along the length of the luminaire, notwithstanding the fact that the amount of light inside the light guide changes as a function of the distance along the luminaire.

US 4,615,579 discloses a luminaire for a prism light guide system, and teaches to put a convex mirror or, more generally, a mirror both not perpendicular to the axis of the guide and planar at the end of the luminaire to cause the light that reaches the end of the luminaire to be reflected and at the same time its divergence angle to be increased, so that the brightness of the released light along the length of the luminaire remains constant.

US 4,850,665 relates to a method and apparatus for the controlled emission of light from a light guide, the aim of which is that of causing the light to escape from the guide at selected regions (as opposed to continually along the length of a given surface of the guide) and at a selected angular orientation with respect to the guide, so as to achieve the optimum coefficient of utilization with minimum glare for interior lighting applications. US 4,850,665 relates specifically to a light guide system having planar inner and outer surfaces that are in "octature" and is particularly concerned with the preferred case in which light is made to escape from the guide at an angle of 90° with respect to the internal

planar surface of the guide section through which the escaping light is refracted. US 4,850,665 describes the use of planar light reflecting elements which are precisely located within the light guide so as to (i) enable a certain fraction of the light to pass unattenuated for processing at further region(s) along the light guide, and (ii) reflect the rest of the light toward a selected light guide wall section such that, when refracted through the wall, the light escapes from the guide at a selected angular orientation with respect to the guide. As described, the light is emitted from the light guide as a substantially collimated beam that will produce comparatively localized illumination on a surface to be illuminated.

Summary

A light guide system having an improved light extraction mechanism, allowing for both a more precise control of the illumination provided by the light guide system, and greater efficiency of light extraction.

The present invention is based on the realization that this can be achieved by the provision, in a light guide system, of light extractor elements that reduce the number of inefficient reflections that light undergoes within the light guide before it is extracted, and that are constructed to produce a desired illumination pattern at a surface to be illuminated instead of producing uniform illumination of the surface of the light guide itself.

The present invention provides a light guide system comprising a hollow light guide and a light source positioned to direct light into the light guide from one end, the light guide having light-guiding walls that cause the light to travel in the space within the light guide towards the other end thereof; and, in the space within the light guide, at least one light-extracting element having at least one curved surface that functions as a non-transmissive specular or narrow- or wide-scattering reflector, the curved reflecting surface(s) being shaped so that light from the source that is reflected therefrom will inpinge on a light-guiding wall of the light guide at such an angle as to emerge from the light guide.

In a light guide system in accordance with the present invention, the shape of the curved light-reflecting surfaces is selected to ensure that the light incident thereon will be extracted and not remain within the light guide for possible extraction elsewhere.

Preferably, there will be a plurality of light-extracting elements located in the space within the light guide and spaced apart from each other along the length of the guide, each light-extracting element having at least one curved light-reflecting surface that functions as a non-transmissive specular or narrow- or wide-scattering reflector, the curved reflecting surface(s) being shaped so that light from the source that is reflected therefrom will impinge on a light-guiding wall of the light guide at such an angle as to emerge from the light guide.

Further selection of the number, shape and location of the curved light-reflecting surfaces of each light-extracting element enables the light guide system to produce a desired illumination pattern at a surface to be illuminated. In particular, each light-extracting element can be tailored to direct light to regions of the surface to be illuminated that lie outside the "footprint" of the extracting element on that surface (i.e. the projection of the extracting element onto the surface along a line lying in a plane normal to the axis of the light guide) thereby enabling, for example, a series of spaced light-extracting elements to provide continuous uniform illumination of a surface along the length of a light guide system even in the regions between the extracting elements.

At least a portion of each curved reflecting surface may be shaped and/or positioned to receive light directly from the light source.

Additionally, at least one curved reflecting surface may be shaped and/or positioned to receive light following reflection from a wall of the light guide.

In an embodiment, the light-extracting element comprises at least two curved reflecting surfaces that are mirror images of each other, the junction between the two surfaces lying in a plane containing the longitudinal axis of the light guide.

Preferably, the light extracting-elements are non-increasingly spaced apart from each other along the length of the guide, in a direction away from the light source.

Additionally or alternatively, the light extracting-elements have a non-decreasing size in the cross-section of the light guide, in a direction away form the light source.

Advantageously, the/each curved reflecting surface is asymmetrical with respect to the longitudinal axis of the light guide.

The/each curved reflecting surface may be generally concave in the direction facing the light source.

The/each curved reflecting surface may be a portion of a three-dimensional surface obtained by rotation of a second order curve or of a logarithmus, about its axis.

In a preferred embodiment, the/each curved reflecting surface is a portion of a three-dimensional surface obtained by rotation of a parabola, about its axis.

The axis of the/each curved reflecting surface is preferably parallel to the axis of the light guide system, spaced therefrom towards a surface to be illuminated by the light guide.

In an embodiment, the/each light-extraction element comprises a plurality of pairs of curved reflecting surfaces, the junction between the pairs lying in a plane parallel to the longitudinal axis of the light guide and to a surface to be illuminated by the light guide.

In such a case, the axes of pairs of light-reflecting surfaces are preferably displaced outwards from a plane passing through the axis of the light guide and orthogonal to a surface to be illuminated by the light guide at decreasing distances towards the surface to be illuminated, the axes of the light-reflecting surfaces of a same pair being displaced by the same distance on both sides of such plane.

Also, the axes of pairs of light-reflecting surfaces are preferably displaced from a plane passing through the axis of the light guide and parallel to a surface to be illuminated by the light guide at increasing distances towards the surface to be illuminated, the axes of the light-reflecting surfaces of a same pair being displaced by the same distance from said plane.

Moreover, the focal lengths of the pairs of light-reflecting surfaces preferably decrease toward a surface to be illuminated by the light guide.

Each light-reflecting surface is preferably taken as a non centered portion of the half of its three-dimensional surface obtained from rotation of a parabola opposite a surface to be illuminated.

In an embodiment, the/each light-extracting element is located adjacent the wall of the light guide on one side of the latter, to direct light out of the light guide on the other side.

Typically, the/each light-guiding wall of the light guide comprises a prismatic film arranged so that the prisms extend lengthwise of the guide.

Typically, moreover, the light guide system is cylindrical.

Preferably, light from the source that is reflected from the/each light extracting element emerges from the light guide as a single discrete beam having a cross-section that is elongated in the direction transverse to the length of the guide.

The single discrete beam may in particular be a conical beam having an elliptical cross-section, the major axis of which extends in a direction transverse to the length of the light guide.

Where the light guide system includes a surface positioned to be illuminated by light from the light guide, the cross-section of the beam of light caused to emerge from the light guide by the/each extracting element, at the surface to be illuminated, extends preferably over a greater distance than the respective extracting element in the direction of the length of the light guide.

Advantageously, the cross-section of the beam of light extends over a greater distance than the respective extracting element in the direction across the length of the light guide.

Where the light guide system includes a surface positioned to be illuminated by light from the light guide, the light extracting-elements may be so arranged that the illumination of the surface is comparatively uniform in the direction of the length of the light guide.

Brief Description of the Drawings

Features and advantages of the invention shall now be illustrated with reference to embodiments represented by way of non-limitative examples in the attached drawings, wherein:

Fig. 1 shows a perspective diagrammatic view of a unidirectional light guide system according to the present invention;

Fig. 2 shows a diagrammatic cross-section along a bi-directional light guide system according to the present invention;

Figs. 3 and 4 show two practical applications of the light guide system according to the present invention;

Fig. 5 shows the polar distribution of the light at two different locations along the light guide system according to the present invention;

Fig. 6 shows an extractor of an extraction mechanism for the light guide system according to the present invention, in a perspective front view;

Fig. 7 shows a side section of the extractor of Figure 6, taken to the left of the vertical mid-plane;

Fig. 8 shows a bottom view of the extractor of Figure 6;

Fig. 9 shows a front view of the extractor of Figure 6;

Fig. 10 shows how two curved surfaces of the extractor of Figure 6 are obtained;

Fig. 11 shows a front perspective view of the extractor of Figure 6, showing how light is reflected by it;

Fig. 12 shows a top schematic view of the extractor of Figure 6 and of the zone illuminated by it;

Fig. 13 shows a rear perspective view of the extractor of Figure 6;

Figs. 14a-f show how further extractors of the light extraction mechanism according to the present invention are obtained from the extractor of Figure 6; and

Fig. 15 shows a perspective diagrammatic view of a further embodiment of an extraction mechanism according to the present invention.

Detailed Description

Figure 1 shows a cylindrical light guide system 1 according to the present invention horizontally arranged in order to illuminate a surface (illumination plane) parallel to and below the light guide, such as a road surface or the floor of a building, desks, tables, working surfaces etc.

It will be however manifest from the following description that a light guide system according to the invention could also be used vertically arranged, in order to illuminate a plane such as a wall of a building or a pair of adjacent walls of a building. Therefore, any reference to such a horizontal arrangement, such as in expressions like "horizontal mid-plane", "vertical mid-plane", should not be construed as limiting. It will also be apparent from the following description that the present invention is not restricted to cylindrical light guide systems but extends also to systems employing light guides that have, for example, rectangular cross-sections and light guides that follow a curved path.

The invention is also not restricted to systems in which the distance between a light guide and the surface to be illuminated remains constant along the length of the light guide.

Light guide system 1 of Figure 1 comprises, generally and in a manner known per se, a hollow light guide 2 and a light source assembly 3 suitable to direct light into the hollow light guide 2 from a first (or light entry) end 4 thereof. Light guide 2 comprises a tubular, sufficiently rigid structure having walls that constrain or guide part of the light to travel in the space within the light guide 2 from the light entry end 4 towards the second end 5, and that allow some of the light to exit from the light guide 2. A light extracting mechanism, generally indicated with 6 and to be described in greater detail later, is also provided within the light guide 2 to increase in a controlled way the amount of light that is allowed to exit along the light guide 2. Unidirectional light guide system 1 will thus transport the light from the first end 4 to the second end 5, while illuminating a surface parallel to and outside the light guide 2.

The main advantage of a light guide system such as system 1 is that the actual light source, as well as its electric connections, are located at assembly 3, while the illumination provided may extend for several meters, even more than 40 meters. Servicing and cooling of the light source assembly 3 are therefore eased, which is a great advantage especially in road illumination. Also, the length of the light guide emits cool light, which may be useful e.g. for pieces of art and jewelry, as well as working places that require a lot of light and that, with typical illumination, become very hot, such as theaters, TV and cinema stages, manufacturing lines, etc.

In the case of a bi-directional light guide system 1a as schematically shown in Figure 2, two light source assemblies 3, 3a will be provided, one at each end 4, 4a of the hollow light guide 2, and each suitable to direct light into the light guide 2 from the respective end 4, 4a. The bi-directional light guide system 1a corresponds effectively to two unidirectional light guide systems 1 arranged in a mirror fashion each of which will guide light from the respective light source assembly 3, 3a to approximately half the length of the light guide 2, indicated with 5 in Figure 2. Such a bi-directional light guide is suitable for illuminating over a very long span.

More particularly, light guide 2 may typically be made of a rigid tubular material 7, for example a polycarbonate cylinder, internally coated with a Total Internal Reflection or

TIR film 8, that is a polymeric sheet of an optically clear material such as acrylic plastic having a smooth face and a micro-structured face on the opposite side. The micro-structured face comprises an array of parallel prisms having a size in the order of the micrometers, or micro-prisms, arranged side by side. The micro-prisms are typically right angled prisms, the perpendicular sides of which may make an angle of approximately 45° with the tangent to the smooth face of the film.

The TIR film 8 is arranged with its smooth face inwardly of the light guide 2 and with its micro-prisms facing outwards of the light guide 2 and oriented in the longitudinal direction, i.e. parallel to the longitudinal axis A of the light guide 2. As is well known, light from the assembly 3 that strikes the interior surface of the light guide 2 may, depending on its angle of incidence, be reflected back into the light guide or pass through the film 8 and the tubular material 7 and thus escape from the light guide.

Among the known TIR films, a film that is particularly suitable for the light guide 2 is that marketed by 3M Company, St.Paul, Minnesota, U.S.A. under the trade designation 3M™ Optical Lighting Film 901.

A cover 13 is provided extending about the TIR film 8 at those wall portions of the light guide 2 other than where light is desired to be released from the light guide 2, thereby defining light release window 14 (see portion 14 in Figure 1). It will be understood from the description below that the cover 13 is not an essential component of the light guide system but is provided only to reduce or eliminate leakage of light from the light guide 2. As described below, the light extracting mechanism 6 within the light guide will ensure that most of the light from the light source assembly 3 will leave the light guide through the region of the light release window 14, even in the absence of the cover 13.

While in Figure 1 cover 13 is only shown extending for a very short length of the light guide 2, in order to make the inside of the light guide visible, it will be manifest that cover 13 will in practice extend along the whole length of light guide 2. In some cases, the cover 13 may, at intervals along the light guide 2, extend completely around the light guide thereby defining a series of discrete, spaced, light release windows along the length of the guide.

Cover 13 will be typically made of a light reflecting and/or diffusing material, preferably as a reflective diffuse material, i.e. a material that is highly reflective but which

is not a flat specular reflector, such that an incident ray will be spread into a broadened reflected beam, thereby acquiring a higher probability of later striking the light release window 14 under such angles as to be refracted thereby and exit therefrom.

Also, while in Figure 1 cover 13 is shown as a separate layer sandwiched between the rigid tubular material or support 7 and the TIR film 8, other embodiments of cover 13 are customary in the art and may well work in the present invention, such as a separate layer arranged outside of support 7, or a paint or varnish coated internally or externally of support 7. The rigid support 7 may also be itself made of a reflective and/or diffusing material to the extent of the cover 13.

The angular extent of the light release window 14 will be selected according to the intended practical lighting application of the light guide system 1, and will typically range from 90° to 180°.

Moreover, the orientation of the light release window 14 with respect to the surface to be illuminated will be selected according to the intended practical lighting application.

For example, in the case of a light guide system 1 intended to be placed centrally above a surface to be illuminated, such as a single lane of a road surface, a manufacturing line or more generally any room within a building, the light release window 14 will typically extend symmetrically about the vertical mid-plane of the light guide system 1 (see e.g. Figure 3).

On the contrary, when the light guide system 1 is to be asymmetrically arranged above the surface to be illuminated, the light release window 14 will correspondingly be positioned asymmetrically with respect to the vertical mid-plane of the light guide system 1. An asymmetrically-positioned light guide system 1 could, for example, be used to illuminate a two-lanes road surface, as depicted in Figure 4, offering the advantage that replacement or service of the light guide system 1 will require traffic to be stopped only on the lane directly under the light guide.

Light source assembly 3 comprises a light source 15 and a reflecting parabola 16 (more particularly, a reflecting surface obtained from revolution of a parabola, or paraboloid) having its axis coincident with the axis A of the light guide. The light source 15 is located at the focus of the reflecting parabola 16 so that, were the light source 15 perfectly punctiform, the light rays directed onto the parabola 16 would be reflected by it

and enter the light guide 2 parallel to its longitudinal axis A; moreover the reflecting parabola 16 is sized so that, were the light source 15 perfectly punctiform, the light rays directly projected into the light guide 2, i.e. without reflection by reflecting parabola 16, would be incident on the inner surface of the light guide 2, that is onto the TIR film 8, at an angle such that they would always be reflected by the TIR film and not pass out of the light guide.

In the real case of a light source 15 having a finite dimension, the light flux emitted from light source assembly 3 will have a polar distribution as qualitatively shown by curve 17 in Figure 6. Curve 17 more particularly shows the illuminance as a function of the angle with respect to the longitudinal axis A of the light guide 2.

In the case of a real finite light source 15, the situation will thus depart slightly from that discussed above, and there will be also light rays that enter the light guide 2 with such angles as to be refracted by the TIR film, and either be reflected and/or diffused by cover 13, or exit the light guide 2 from light release window 14, thus contributing to illumination.

However, most of the light will still enter the light guide 2 with a comparatively small angle with respect to the longitudinal axis A of the light guide. That will ensure that most of the light will not escape the light guide 2 close to the light entry end 4 but will (in the absence of extraction mechanism 6) continue to rather, be guided along the light guide 2 by total internal reflection towards the second end 5 thereof (or towards the longitudinal centre of the light guide 2 in the case of a bi-directional light guide system 1a). As a consequence, at a distance from the light entry end 4 along the light guide 2, the light flux will have a decreased absolute value, but will still have qualitatively the same shape of polar distribution, as shown by curve 18 in Figure 6, as it has at the light entry end 4 (curve 17).

Extraction mechanism 6 is provided for allowing for a controlled deflection of the light so as to increase in a controlled way the amount of light that will impinge on the TIR film 8 at light release window 14 with such angles as to be refracted and thus exit from the light guide 2, contributing to illumination. The design of the extraction mechanism 6 according to present invention will now be described in greater detail.

The light extraction mechanism 6 comprises a plurality of light-extracting elements, or briefly extractors, arranged along the light guide 2. Each extractor comprises curved reflecting surfaces, with concavity towards the light entry end 4 of the light guide 2.

The or each curved reflecting surface may be a specularly-reflecting surface, such as made of or coated with chromium or aluminium, or a narrow- or wide-scattering reflecting surface, such as a white surface made of moulded resin, as opposed to diffusely-reflecting surfaces as are most typical in the art of light extraction mechanisms.

The terms "narrow-scattering reflective material", "wide-scattering reflective material", and "diffusely-reflecting material" mean (see e.g. "Daylighting in Architecture – A European Reference Book" (ISBN number 1-873936-21-4), pages 4.3 – 4.5) a material that reflects an incident collimated light beam into a broadened beam having a dispersion angle of between about 0° and 15°, between about 15° and 45°, and between about 45° and 60°, respectively. The term "dispersion angle" means the angle between the direction of maximum intensity (I_{max}) of reflected light and the direction of intensity with a value $I_{max}/2$, assuming an intensity of reflected light distribution curve that is symmetrical about the direction of I_{max}. If the intensity distribution curve of the reflected light is not symmetrical about the direction of I_{max}, the term dispersion angle means the mean angle between the direction of I_{max} and a direction of intensity $I_{max}/2$. The broadened reflected beam may, or may not, exhibit a pronounced peak in the direction of maximum intensity.

By using specularly-reflecting surfaces, the impinging ray will be reflected with lower absorption losses, that is with a very high reflection coefficient – as high as 92%. Even more important in the present context, the impinging ray will be reflected with a pre-established angle (angle of reflection equal to angle of incidence). In the case of the individual extractors of the light extraction mechanism 6, the direction of the reflected rays from the extractors is controlled by properly designing the local curvature of the reflecting surfaces so as to reflect the light onto the light release window 14 of the light guide 2 at such an angle as to be refracted by the TIR film 8 and exit the light guide.

White, scattering reflecting surfaces have the advantage of being less expensive to manufacture, but they tend to have higher light absorption rates. They also make it more

difficult to control the direction of the reflected light rays than specularly-reflecting surfaces, still easier than diffusely-reflecting materials.

By way of an example, the extractor mechanism 6 depicted in Figure 1 comprises two individual extractors 650, 660.

A more typical arrangement is depicted in Figure 2, where seven extractors 610, 610a, 620, 620a, 640, 650, 660 (the references of the extractors being based on Figure 14 to be later described) are arranged along the light guide 2 in the light propagation direction, i.e. from the light entry end 4 to the longitudinal center of the bi-directional light guide system 1a. As pointed out above, each half of bi-directional light guide system 1a may be taken as representative of a unidirectional light guide system.

The arrangement shown is suitable to provide a substantially uniform illumination of an external surface along the whole length of the light guide system. To this end, as may be appreciated from Figure 2, the various extractors 610, 610a, 620, 620a, 640, 650, 660 are arranged along the light propagation direction at decreasing distances between adjacent extractors (although, in some cases, it might be possible for the extractors to be equispaced). Also, along the light propagation direction, adjacent extractors 610, 610a, 620, 620a, 640, 650, 660 have an equal or increasing (i.e., non-decreasing) surface extent in the radial direction or, in other words, adjacent extractors 610, 610a, 620, 620a, 640, 650, 660 extend increasingly towards and then beyond the axis of the light guide. Further, will be described below with reference to Figure 17, along the light propagation direction, adjacent extractors 610, 610a, 620, 620a, 640, 650, 660 have also an increasing surface extent in the angular direction (i.e. around the longitudinal axis of the light guide).

The criteria to be considered in selecting the number of extractors, the radial and/or angular extent of each extractor, and their location along the light guide 2, are multiple, and depend on the length and cross-section of the light guide system 1, as well as on the type of illumination that is desired, e.g. substantially uniform illumination of an external surface along the whole light guide system 1, or separate illuminated zones on the external surface along the light guide system 1. Generally, as will be apparent from the description below, successive extractors (proceeding from the light entry end 4 of the light guide) should occlude increasing fractions of the cross-section of the guide in order to provide

uniform illumination of a surface, either within a continuous zone or within discrete zones, along the length of the guide.

As an example, Figure 3 illustrates (as already described) a light guide system 1 according to the present invention used in an open space working place or in a school room. Such a light guide system 1 should provide some illumination along the whole length of the light guide 2, but should also provide distinct regions 25, 26 of high illumination at each desk below it. As shown in that Figure, one extractor 610, 620 will be located above each desk, further from the light entry end 4 than the center of the desk because, as described below, each extractor 610, 620 in this case is designed to project a cone of light skewed towards the light entry end 4 of the light guide.

A similar type of illumination might be desirable in manufacturing lines, where high illumination is necessary at each work station, in trains or planes, where high illumination is necessary at each seat, etc.

As a further example, Figure 4 illustrates (as already described) a light guide system 1 according to the present invention used in a road tunnel. Such a light guide system 1 should provide as uniform illumination as possible of the road along the whole length of the light guide 2. Several extractors will therefore be arranged along it so that the cones of light projected by two adjacent extractors will be adjacent or slightly overlapped in the longitudinal direction. A similar type of illumination might be desirable in long corridors or passages, etc.

In both examples above, each extractor should produce an illumination of the same intensity, although this will not be necessarily always the case.

In the case where as uniform illumination as possible along the whole length of the light guide 2 is desired, the following criteria will have to be considered.

A first criterion is that, departing from the light entry end 4, the available luminous flux will decrease, because losses of luminous efficiency are proportional to the ratio L/D of the light guide length to the diameter of its circular cross-section, in that the number of internal reflections to guide the light towards the second end 5 will increase proportionally to such ratio L/D, and in that some of the light is output along the light guide 1 itself.

Thus, extractors farther from the light entry end 4 should have a greater surface to extract the same amount of light as extractors closer to the light entry end 4.

A second criterion is that the available luminous flux at a certain location along the light guide system 1 has to be shared between light that will be output at that location, and light that will propagate along the light guide system 1 for contributing to illumination downstream. In other words, the more light is "extracted" by a first extractor in the propagation direction, the less light will be available for extraction by a second and further extractor(s) in the propagation direction.

A third criterion is that the spacing between adjacent extractors should be sufficiently large that the extractor closer to the light entry end 4 will not completely mask the adjacent extractor, to ensure that some light directly emitted by the light source assembly 3 and/or reflected by the light guide 2 will reach also the extractors furthest from the light entry end 4.

A fourth criterion, as stated above, is that the spacing between adjacent extractors and the shape of the extractors should be such that the cones of light projected by two adjacent extractors will be adjacent or slightly overlapped in the longitudinal direction of the light guide system 1.

Further criteria to design the actual shape and extent of each extractor will be understood by the following description.

According to a preferred embodiment of the present invention, all extractors forming extraction mechanisms 6 may be regarded as obtained by removal of portions from the extractor 660 closest to the second end 5 of the unidirectional light guide or, respectively, the extractor at the middle of a bi-directional light guide. Indeed, at that location, no light needs to be spared for further propagation, so that the criteria above reduce to maximizing the light that is extracted, i.e. that is deflected so as to exit from the light release window 14 of the light guide 2.

With reference first to Figures 6 (front perspective view), 7 (a section taken to the left of the vertical mid-plane), and 8 (bottom view), the extractor 660 intended to be placed furthest from the light entry end 4 is a rigid element globally shaped as a disk extending in a plane slightly skew with respect to the transverse plane of the light guide 2.

Extractor 660 comprises means for attachment to the light guide system 1, such as a pair of T-shaped grooves 27 near its top to slidably hang from a pair of rails 28 diagrammatically shown in Figure 1. Rails 28 may conveniently be part of a construction

(not shown) provided to longitudinally join the edges of the TIR film 8 and possibly of cover 13, and/or to fix the TIR film 8 and possibly cover 13 to the tubular support 7.

The front face of extractor 660, i.e. that facing toward light entry end 4, is comprised of three pairs of curved surfaces 31-36, the intersections of adjacent pairs of curved surfaces 31-32, 33-34, 35-36 extending along two essentially horizontal planes, and the intersections of curved surfaces of a same pair 31 and 32, 33 and 34, 35 and 36 extending along the vertical mid-plane 29 of the light guide system 1 (and of extractor 660), so that extractor 660 is mirror-symmetrical with respect to the vertical mid-plane 29.

Each curved surface 31-36 is most preferably formed as a portion of a paraboloid, that is as a portion of a surface generated by the rotation of a parabola around its axis. For the sake of brevity, such portions of paraboloids will hereinafter be referred to simply as parabolas 31-36.

The axes of the three pairs of parabolas 31-36 are all parallel to and (in the case in which the light release window 14 is at the bottom of the light guide 2) below the axis A of the light guide system 1. More particularly, the axes A1-A6 of the parabolas 31-36, and thus their vertexes V1-V6 and their focuses F1-F6, are spaced from the axis A of the guide system 1 at increasing distances (going from the top pair of parabolas 31, 32 to the bottom pair of parabolas 35, 36), as may be best appreciated from Figure 7 and also from Figure 9, (wherein the projections onto the plane of the Figure of the focuses F1-F6 and vertexes V1-V6 are also indicated.

None of axes A1-A6 lies in the vertical mid-plane 29 of the light guide system 1. Indeed, the axes A1-A6 of the three pairs of parabolas 31-36 (going from the bottom pair of parabolas 35,36 to the top pair of parabolas 31,32) are increasingly displaced outwards from the vertical mid-plane 29, the axes of the parabolas of a same pair 31 and 32, 33 and 34, 35 and 36 being displaced by the same distance on both sides of the vertical mid-plane 29, as may be best seen in Figure 8, which is a bottom view of extractor 660 wherein the focuses F1-F6 vertexes V1-V6 and axes A1-A6 are also indicated.

In other words, the axes A1, A2 of the parabolas 31, 32 of the top pair are parallel to each other and to the axis A of the light guide system 1, spaced below axis A by the shortest distance, and spaced apart by the largest distance; the axes A3, A4 of the parabolas 33, 34 of the middle pair are parallel to each other and to the axis A of the light

guide system 1, spaced below axis A by an intermediate distance, and spaced apart by an intermediate distance; and the axes A5, A6 of the parabolas 35, 36 of the bottom pair are parallel to each other and to the axis A of the light guide system 1, spaced below axis A by the largest distance, and spaced apart by the shortest distance.

More particularly, the axis A1-A6 of each paraboloid to which each parabola 31-36 belongs falls below and offset (to the left or to the right) with respect to parabola 31-36, or, stated in other words, each parabola 31-36 is taken as a non centered portion of the upper half of its paraboloid, as may be best appreciated from Figure 10, wherein for the sake of clarity only the upper pair of parabolas 31, 32 are shown along with the paraboloids 37, 38 of which they are part.

Finally, the focal distance (i.e., the distance between vertex and focus) of the parabolas 31, 32 of the upper pair is the biggest, the focal distance of the parabolas 33, 34 of the middle pair is intermediate, and the focal distance of the parabolas 35, 36 of the bottom pair is the shortest, as can be best seen from Figures 7, 8.

As is well known, light rays striking a parabolic surface parallel to its axis are reflected along a direction passing through the focus of the parabolic surface. As explained above, the most of the light traveling along the light guide 2 is, by virtue of the construction of the light source assembly 3 and the nature of the TIR film 8, parallel or almost parallel to the axis of the light guide 2. As a result, most of the light striking extractor 660 will be reflected by it so as to converge at or near to the six focuses F1-F6 of the six parabolas 31-36. Downstream of each focus, the light focused at or near the focuses F1-F6 of parabolas 31-36 will again diverge. The light path is shown schematically in Figures 7 and 11.

The parabolas 31-36 are sized and arranged so that the reflected light will strike the TIR film 8 under angles so as to be refracted thereby and leave the light guide, thus contributing to illumination. More particularly, they are sized and arranged so that the illuminated areas from the six parabolas 31-36 are adjacent or partly overlap, so that as a whole the illuminated zone 24 at a surface lying horizontally below the light guide 2 will have the shape of an ellipse having its major axis perpendicular to the direction of axis A of the guide, and having its minor axis extending from slightly behind the footprint of extractor 660 to a comparatively great distance in front of such footprint, towards the light

entry end 4 of the light guide system 1, as diagrammatically shown in top view of Figure 12.

In the arrangement of focuses F1-F6 shown in Figures 7-11, it may occur that some minor parts of the parabolas 31-36, close to the longitudinal axis A, will still reflect incoming light rays in such directions as to be internally reflected at the TIR film 8. The extent and even the existence of such minor portions may be controlled by changing the position of the focuses F1-F6 of parabolas 31-36, provided that the condition that the illuminated areas from the six parabolas 31-36 are adjacent or partly overlap is still met. However, the effect of these minor portions on the overall performance of the light guide system is not particularly significant, for the following reasons:

First, as stated above, most of the rays that are incident on the extractor 660 extend parallel to axis A of the light guide, but there are also rays incident non parallel to axis A. Second, as also stated above, extractor 660 is intended to be arranged near the second end 5 of the light guide system 1, (or the mid-point of a bi-directional light guide system 1a), in a position where all incident light would, in the absence of any extraction mechanism, be lost (unless a mirror were to be placed at that location as shown in the prior art), so that even if the efficiency of extraction of portions 41, 42, 45, 46, 49, 50 is lower than the efficiency of extraction of the remainder of parabolas 31-36, some extraction will notwithstanding occur. Third, as described in greater detail below, the other extractors of extraction mechanism 6 according to the present invention are obtained by removing some portions from extractor 660, the removed portions being selected so as to minimize the extent of said low extraction-efficiency minor portions close to the axis A of the light guide, or to avoid them altogether. To this purpose, the back face of extractor 660 preferably comprises a web of preferential cutting lines, generally indicated with 51 and further illustrated shortly below with reference to Figure 16. This has the advantage that only one mould may be used for moulding all extractors of an extraction mechanism 6 for a given diameter of the light guide system 1.

The back face of extractor 660, i.e. that facing toward the second end 5 of the light guide system 1 or toward the center of a bi-directional light guide system 1a, may be specularly- or narrow- or wide-reflective, but it may also be made of any material in that it

does not play a major role, or does not play a role at all, in the control of the light within light guide system 1.

As shown in Figure 13, the back face of extractor 660 preferably further comprises a reinforcing edge 52. Reinforcing edge 52 preferably extends along the upper semi-circumference (as shown) or less, and extends radially for a short distance. The reason for making such a small reinforcing edge 52 is, again, to promote removal of selected portions from extractor 660 to make the other extractors according to the invention, i.e. those intended to be arranged closer to the light entry end 4 of the light guide 1.

The web 51 of preferential cutting lines at the back face of extractor 660 comprises: a number of essentially uniformly spaced concentric circles 53-57; a number of segments 58-67 extending radially from the outer circumference of extractor 660 to the inner concentric circle 53, and located at angles going from about 30° to about 120° from the top of extractor 660 on each side of vertical mid-plane 29; vertical mid-plane 29 itself; two segments 68, 69 tangent to the second innermost concentric circle 54 at the horizontal mid-plane and extending to the bottom edge of extractor 660; and two segments 70, 71 extending from the intersection of the second innermost concentric circle 54 with the upper radial segments 58, 63 to the intersection of the fourth concentric circle 56 with the vertical mid-plane 29.

The radiuses of the concentric circles 53-57 are selected so as to be essentially uniformly spaced.

It will be manifest that the number and arrangement of the preferential cutting lines may depart from that shown according to the number of extractors needed in a particular light guide system 1. The particular web 51 shown in Figure 13 is particularly suitable for a light extracting mechanism based on six differently shaped and sized extractors. Figures 14a-f show six such differently sized and shaped extractors 610-660, and how the first five may be obtained by removing selected portions from the sixth, full extractor 660.

As far as the fifth extractor 650 is concerned, the removed portion is defined by the innermost concentric circle 53, by the internal portion of the lowest radial segments 62, 67, and by the lower portion of vertical segments 68, 69. Note that lowest radial segments 62, 67 are spaced apart by approximately 90°. The last but one extractor 650 therefore comprises almost all of the surface of the two upper parabolas 31, 32, most of the surface

of the two middle parabolas 33, 34, and only a small portion of the two lower parabolas 35, 36.

The fourth extractor 640 has a removed portion defined by the second concentric circle 54, having a radius of approximately two sixths of the radius of the light guide 2, the upper portion of segments 68, 69 and the external portion of the two lowermost radial segments 62, 67. The fourth extractor 640 therefore comprises most of the surface of the two upper parabolas 31, 32, approximately half of the surface of the two middle parabolas 33, 34, and none of the two lower parabolas 35, 36. The third extractor 630 has a removed portion defined by the third concentric circle 55, having a radius of approximately three sixths of the radius of the light guide 2 and by the external portion of radial segments 61, 66, that are spaced apart by approximately 120°. The third extractor 630 therefore comprises most of the surface of the two upper parabolas 31, 32, approximately half of the surface of the two middle parabolas 33, 34, and none of the two lower parabolas 35, 36.

The second extractor 620 has a removed portion defined by the fourth concentric circle 56, having a radius of approximately four sixths of the radius of the light guide 2, and the external portions of radial horizontal segments 60, 65. The second extractor 620 is therefore almost entirely comprised of a portion of the surface of the two upper parabolas 31, 32.

The first extractor 610 has a removed portion defined by the fifth concentric circle 57, having a radius of approximately five sixths of the radius of the light guide 2, and the external portions of radial segments 59, 64. The second extractor 610 is therefore entirely comprised of a portion of the surface of the two upper parabolas 31, 32,.

It will be understood that like extractor 660, extractors 610-650 deflect the light so that it will strike the light release window 14 of the light guide 2 with angles so as to be refracted and transmitted outside by the TIR film 8. This is accomplished most effectively if the extractors 610-660 are made of specular-reflecting material, although a material that produces narrow- or wide-scattering reflection as described above could also be used.

As discussed regarding extractor 660, the illuminated area onto a surface located below the light guide 2 provided for by extractors 610-650 will be oval, and will extend beyond the projection (footprint) of the extractor 610-650 on said surface (see Figure 12).

Figure 15 shows an alternative embodiment of an extractor mechanism 6a according to the invention, suitable for a cylindrical light guide (only diagrammatically indicated by its section to the left of the Figure). Extractor mechanism 6a comprises five extractors that are shown as equispaced in Figure 13 by way of an example only. The extractor to the right, i.e. farthest from the light entry end, corresponds to extractor 660 shown in Figure 12. The two extractors 670, 670a preceding it are identical to each other and are of a shape obtained from extractor 660 removing a portion defined by the fourth inner circle 56, that is their shape is an annular ring. The two extractors 680, 680a closest to the light entry end 4 are identical to each other and are of a shape obtained from extractor 660 removing a portion defined by the fifth inner circle 57 and the two outer portions of vertical segments 68, 69.

In a still alternative embodiment of an extractor mechanism according to the invention (not shown), the extractors are all identical and are spaced increasingly-close together proceeding away from the light source assembly 3. The extractors may in particular be like extractor 610 shown in Figure 14a.

It should be understood that the embodiments illustrated and described are given only by way of a non-limiting example, and that many changes and alterations may be made without departing from the scope of the present invention.

Other alternative forms for the light extractors can be envisaged including, for example, strips that extend across the light guide, having suitably-shaped light-reflecting curved surfaces directed towards the light entry end of the light guide.

It is also not essential that the extractors should be mirror symmetric, or that the curved surfaces should be concave to the light entry end of the light guide. In some circumstances, other curvatures may be more appropriate, for example when an extractor is required to direct light from the light guide away from (rather than towards) the light source.

The number of pairs of parabolas may differ from three, ranging from only one pair to any desired number of pairs, depending on the diameter of the light guide system 1 and the number of extractors that are used.

Even more generally, the plurality of discretely-shaped curved facets on an extractor, as illustrated in Figures 6 to 9 and 14, is not essential and could be replaced by a

single continuously-curved surface. The particular form of the disc-like extractors of Figures 6 to 9 and 14 is, however, advantageous for a light guide having a circular cross-section because it enables a single design to be used for extractors at several different locations, and is easier and more economic to fabricate.

The efficiency of these extractors, although already high, could be further increased by replacing any less efficient portions, such as close to axis A, by another form of mirrored surface that would re-direct incident light into an orientation suitable for extraction from the light guide.

Also, the various curved surfaces of the extractors need not be part of a rotational paraboloid, and may be part of a rotational ellipsoid, part of a sphere, and also part of a three-dimensional curve obtained through rotation of whatever curve, such as a logarithm etc.

In the case of a bi-directional light guide as illustrated in Figure 2, extractors that have curved light-reflecting surfaces on both sides could be employed to extract light from both light sources. In that case, light from each source would continue to travel beyond the mid-point of the light guide.

If the light extractors are formed from a material that permits them to flex, this could be used to enable the illumination provided by a light guide to be finely adjusted.

The possibility of using extractors in accordance with the invention to illuminate a region that extends beyond the "footprint" of the extractor makes it possible, through the use of comparatively few extractors that provide slightly overlapping illuminated areas, to produce a uniformly-illuminated zone (for example, on a roadway) that extends along the length of the light guide. As an alternative, through the use of suitably-shaped extractors, two parallel illuminated zones (one on each side of the light guide) could be produced.

CLAIMS

1. A light guide system (1, 1a) comprising a hollow light guide (2) and a light source (3, 3a) positioned to direct light into the light guide (2) from one end (4), the light guide (2) having light-guiding walls that cause the light to travel in the space within the light guide (2) towards the other end (5) thereof; and, in the space within the light guide (2), at least one light-extracting element (610-680) having at least one curved surface (31-36) that functions as a non-transmissive specular or narrow- or wide-scattering reflector, the curved reflecting surface(s) (31-36) being shaped so that light from the source that is reflected therefrom will inpinge on a light-guiding wall of the light guide (2) at such an angle as to emerge from the light guide (2).

2. A light guide system (1, 1a) as claimed in claim 1, in which there is a plurality of light-extracting elements (610-680) located in the space within the light guide (2) and spaced apart from each other along the length of the guide (2), each light-extracting element (610-680) having at least one curved light-reflecting surface (31-36) that functions as a non-transmissive specular or narrow- or wide-scattering reflector, the curved reflecting surface(s) (31-36) being shaped so that light from the source (3, 3a) that is reflected therefrom will impinge on a light-guiding wall of the light guide (2) at such an angle as to emerge from the light guide (2).

3. A light guide system (1, 1a) as claimed in claim 1 or claim 2, in which at least a portion of the/each curved reflecting surface (31-36) is shaped and/or positioned to receive light directly from the light source (3, 3a).

4. A light guide system (1, 1a) as claimed in claim 3, in which at least one curved reflecting surface (31-36) is shaped and/or positioned to further receive light following reflection from a wall of the light guide (2).

5. A light guide system (1, 1a) as claimed in any one of the preceding claims, in which the/each light-extracting element (610-680) comprises at least two curved reflecting

surfaces (31-36) that are mirror images of each other, the junction between the two surfaces lying in a plane (29) containing the longitudinal axis (A) of the light guide (2).

6. A light guide system (1, 1a) as claimed in claim 2, in which the light extracting-elements (610-680) are non-increasingly spaced apart from each other along the length of the guide (2), in a direction away from the light source (3, 3a).

7. A light guide system (1, 1a) as claimed in claim 2, in which the light extracting-elements (610-680) have a non-decreasing size in the cross-section of the light guide (2), in a direction away form the light source (3, 3a).

8. A light guide system (1, 1a) as claimed in any one of the preceding claims, in which the/each curved reflecting surface (31-36) is asymmetrical with respect to the longitudinal axis (A) of the light guide (2).

9. A light guide system (1, 1a) as claimed in any one of the preceding claims, in which the/each curved reflecting surface (31-36) is generally concave in the direction facing the light source (3, 3a).

10. A light guide system (1, 1a) as claimed in any of the preceding claims, in which the/each curved reflecting surface (31-36) is a portion of a three-dimensional surface obtained by rotation of a second order curve or of a logarithmus, about its axis.

11. A light guide system (1, 1a) as claimed in any of the preceding claims, in which the/each curved reflecting surface (31-36) is a portion of a three-dimensional surface (37, 38) obtained by rotation of a parabola, about its axis (A1-A6).

12. A light guide system (1, 1a) as claimed in claim 11, in which the axis (A1-A6) of the/each curved reflecting surface (31-36) is parallel to the axis (A) of the light guide system (1, 1a), spaced therefrom towards a surface to be illuminated by the light guide (2).

13. A light guide system (1, 1a) as claimed in claim 11, in which the/each light-extraction element (610-680) comprises a plurality of pairs of curved reflecting surfaces (31-36), the junction between the pairs lying in a plane parallel to the longitudinal axis (A) of the light guide (2) and to a surface to be illuminated by the light guide (2).

14. A light guide system (1, 1a) as claimed in claim 13, in which the axes (A1-A6) of pairs of light-reflecting surfaces (31-36) are displaced outwards from a plane (29) passing through the axis (A) of the light guide (2) and orthogonal to a surface to be illuminated by the light guide (2) at decreasing distances towards the surface to be illuminated, the axes (A1-A6) of the light-reflecting surfaces (31-36) of a same pair being displaced by the same distance on both sides of such plane (29).

15. A light guide system (1, 1a) as claimed in claim 13 or 14, in which the axes (A1-A6) of pairs of light-reflecting surfaces (31-36) are displaced from a plane passing through the axis (A) of the light guide (2) and parallel to a surface to be illuminated by the light guide (2) at increasing distances towards the surface to be illuminated, the axes (A1-A6) of the light-reflecting surfaces (31-36) of a same pair being displaced by the same distance from said plane.

16. A light guide system (1, 1a) as claimed in any of claims 13 to 15, in which the focal lengths of the pairs of light-reflecting surfaces (31-36) decrease toward a surface to be illuminated by the light guide (2).

17. A light guide system (1, 1a) as claimed in any of claims 13 to 16, wherein each light-reflecting surface (31-36) is taken as a non centered portion of the half of its three-dimensional surface (37-38) obtained from rotation of a parabola opposite a surface to be illuminated.

18. A light guide system (1, 1a) as claimed in any one of the preceding claims, in which the/each light-extracting element (610-680) is located adjacent the wall of the light guide (2) on one side of the latter, to direct light out of the light guide (2) on the other side.

19. A light guide system (1, 1a) as claimed in any one of the preceding claims, in which the/each light-guiding wall of the light guide (2) comprises a prismatic film (8) arranged so that the prisms extend lengthwise of the guide.

20. A light guide system (1, 1a) as claimed in any of the preceding claims, in which the light guide system (1, 1a) is cylindrical.

21. A light guide system (1, 1a) as claimed in any one of the preceding claims, in which light from the source (3, 3a) that is reflected from the/each light extracting element (610-680) emerges from the light guide (2) as a single discrete beam (24) having a cross-section that is elongated in the direction transverse to the length of the guide (2).

22. A light guide system (1, 1a) as claimed in claim 21, in which the single discrete beam (24) is a conical beam having an elliptical cross-section, the major axis of which extends in a direction transverse to the length of the light guide (2).

23. A light guide system (1, 1a) as claimed in any one of the preceding claims, including a surface positioned to be illuminated by light from the light guide (2), in which the cross-section of the beam (24) of light caused to emerge from the light guide (2) by the/each extracting element (610-680), at the surface to be illuminated, extends over a greater distance than the respective extracting element (610-680) in the direction of the length of the light guide (2).

24. A light guide system (1, 1a) as claimed in any one of the preceding claims, in which the cross-section of the beam (24) of light extends over a greater distance than the respective extracting element (610-680) in the direction across the length of the light guide (2).

25. A light guide system (1, 1a) as claimed in claim 2, including a surface positioned to be illuminated by light from the light guide (2), in which the light extracting-elements (610-680) are so arranged that the illumination of the surface is comparatively uniform in the direction of the length of the light guide (2).

5

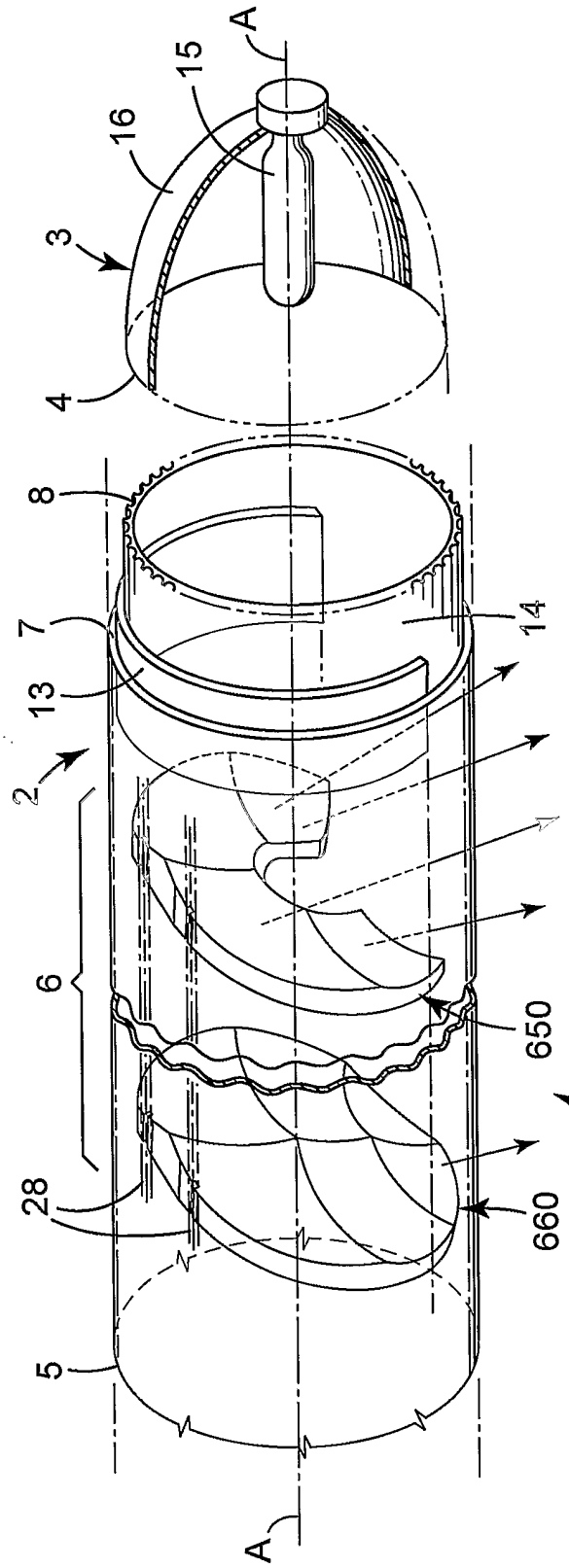


FIG. 1

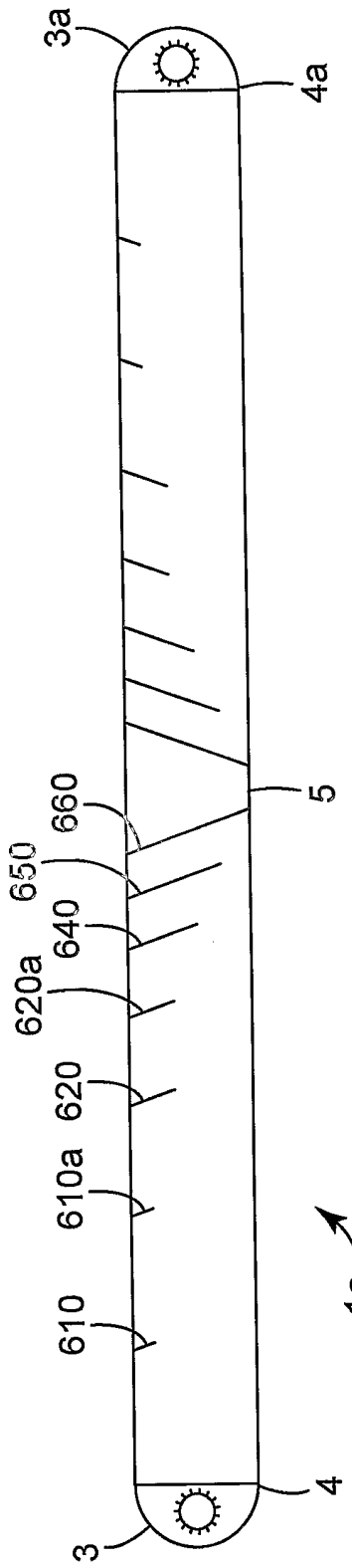


FIG. 2

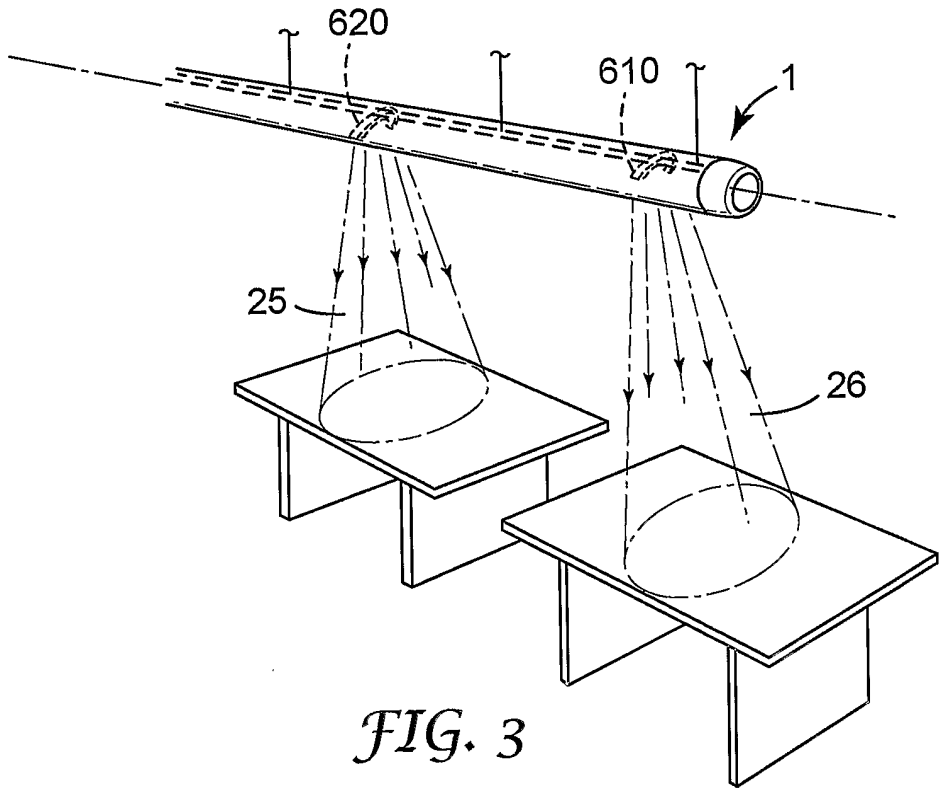


FIG. 3

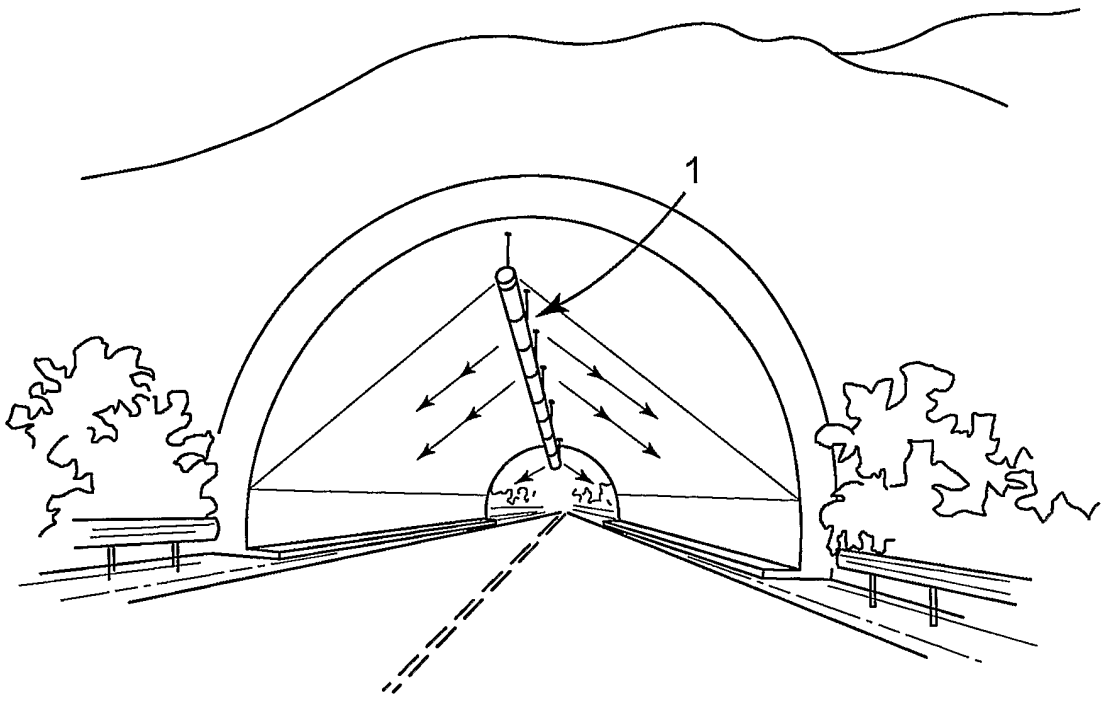


FIG. 4

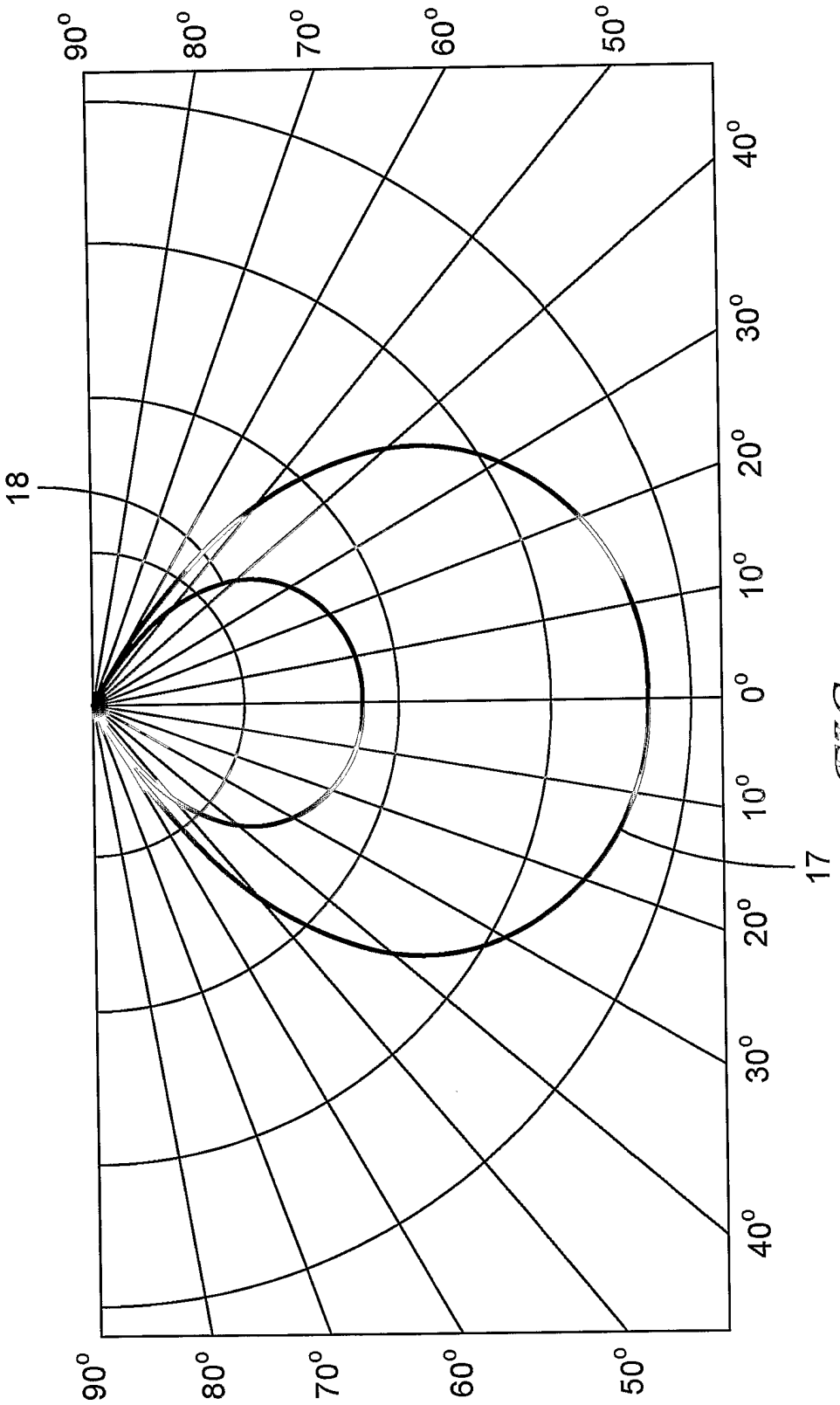


FIG. 5

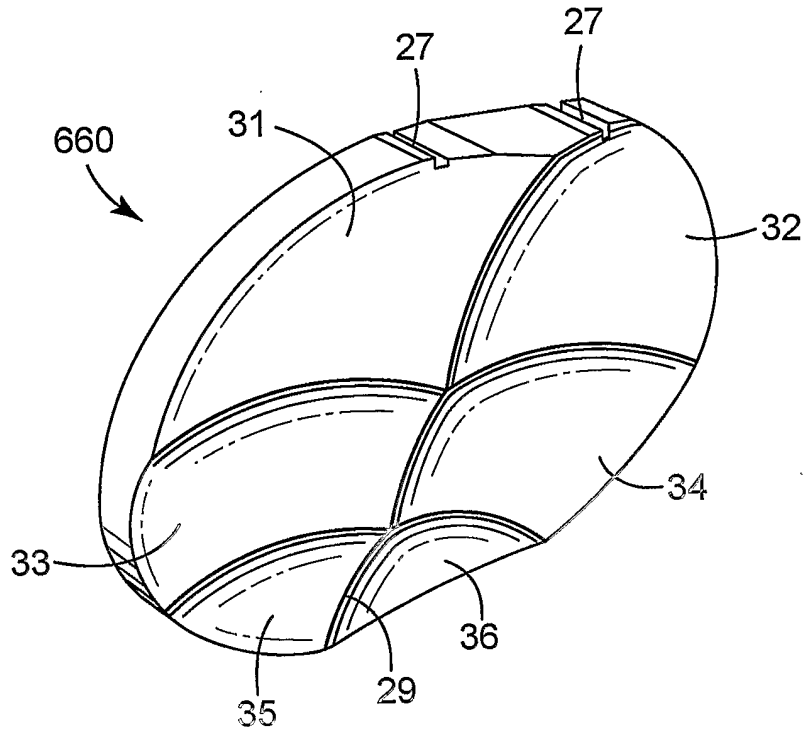


FIG. 6

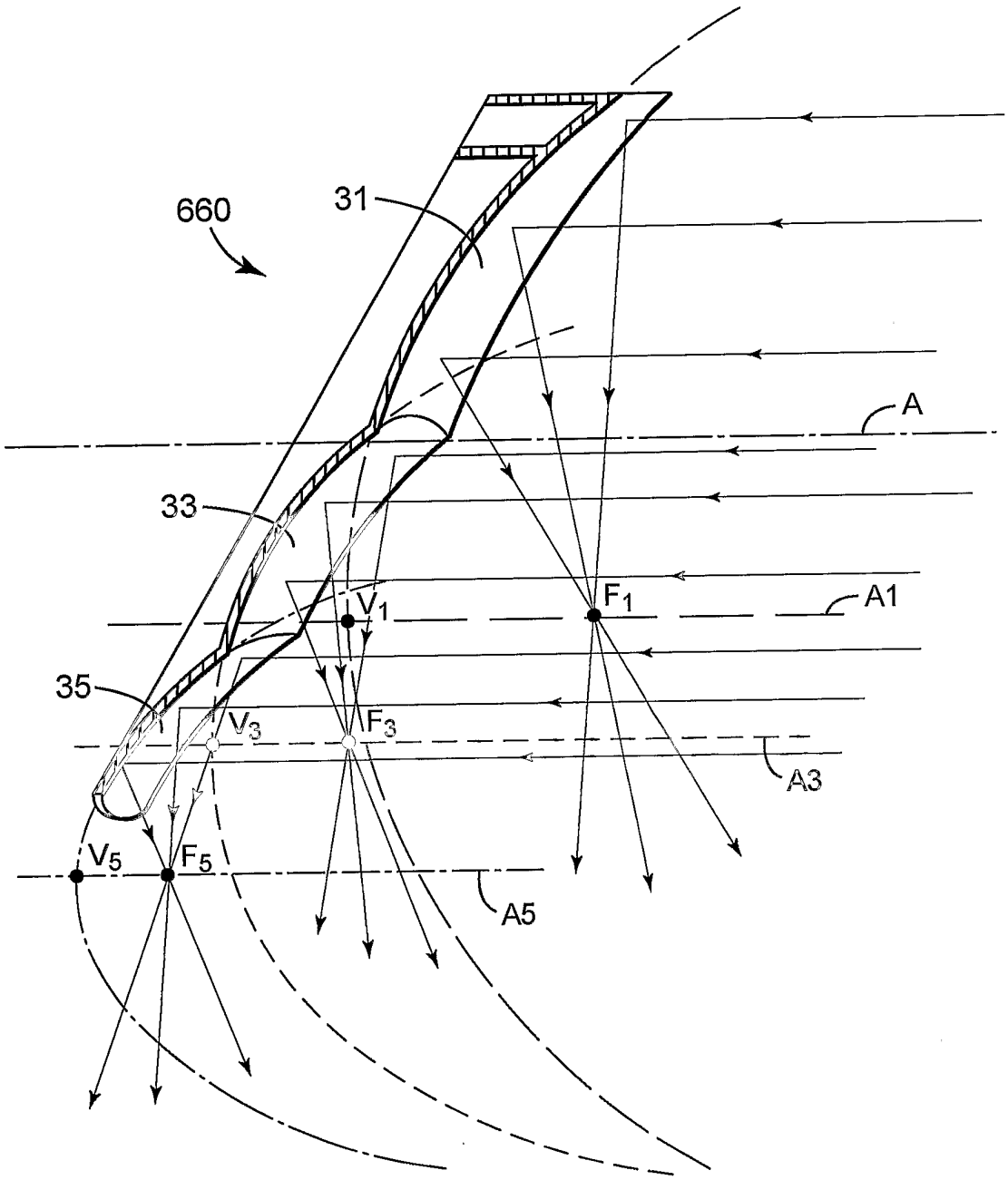


FIG. 7

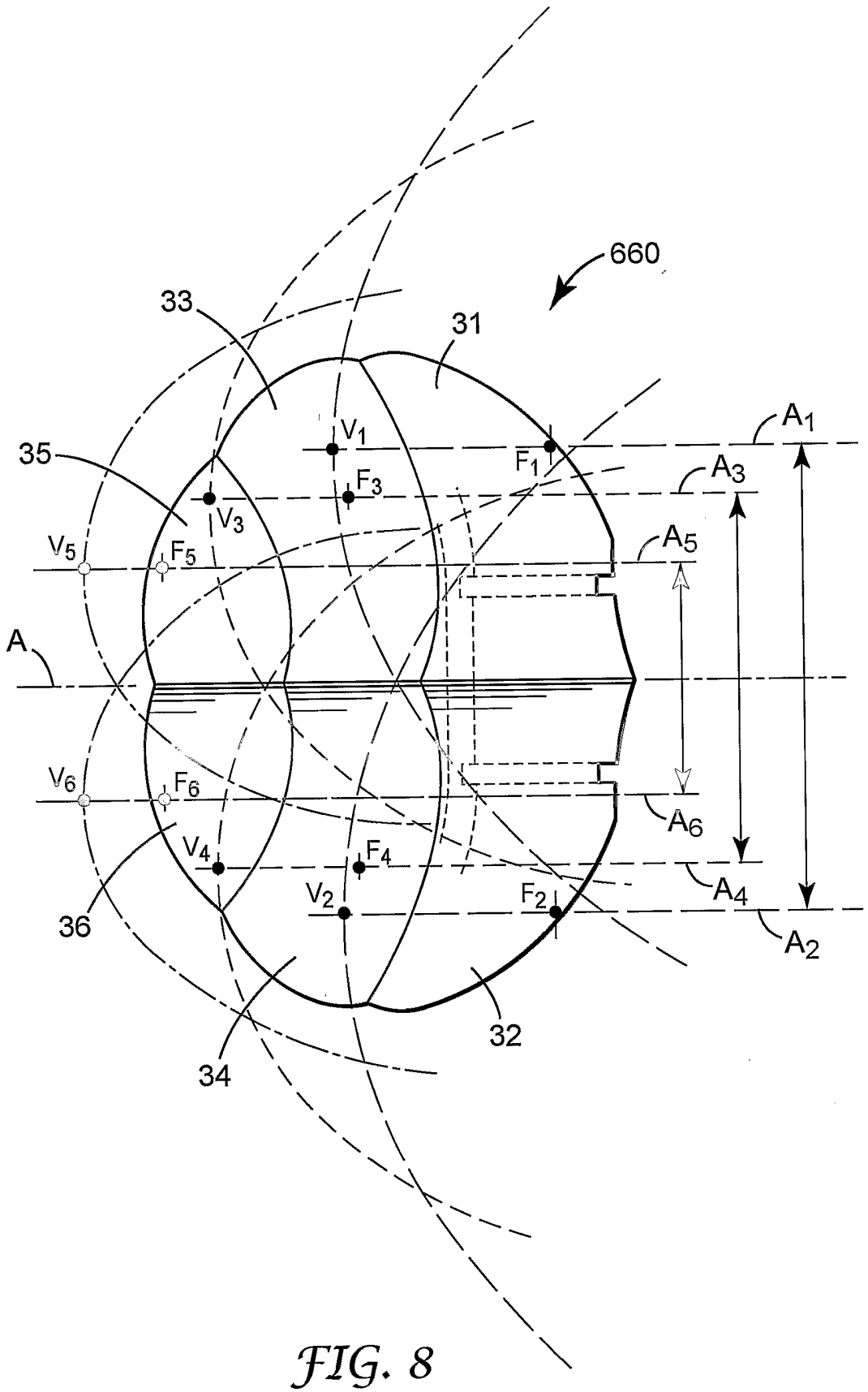

660
33
31
35
V1
F1
A1
F3
A3
V3
V5
F5
A5
A
V6
F6
A6
V4
F4
A4
V2
F2
A2
36
32
34

FIG. 8

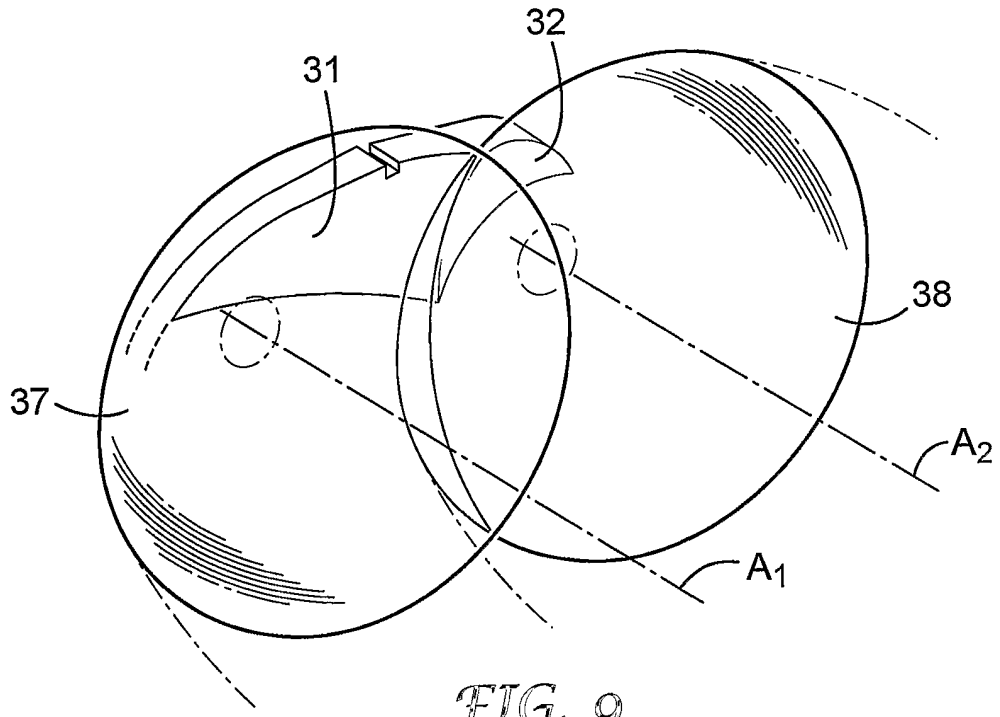

32
31
38
37
A_2
A_1

FIG. 9

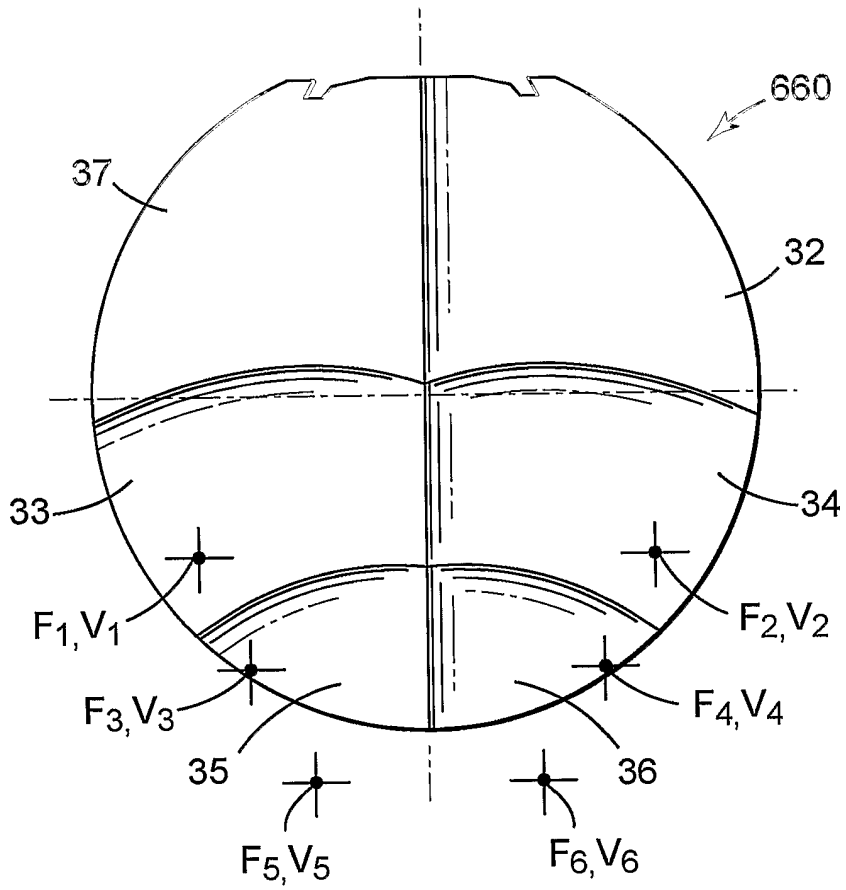

660
37
32
33
34
F_1,V_1
F_2,V_2
F_3,V_3
F_4,V_4
35
36
F_5,V_5
F_6,V_6

FIG. 10

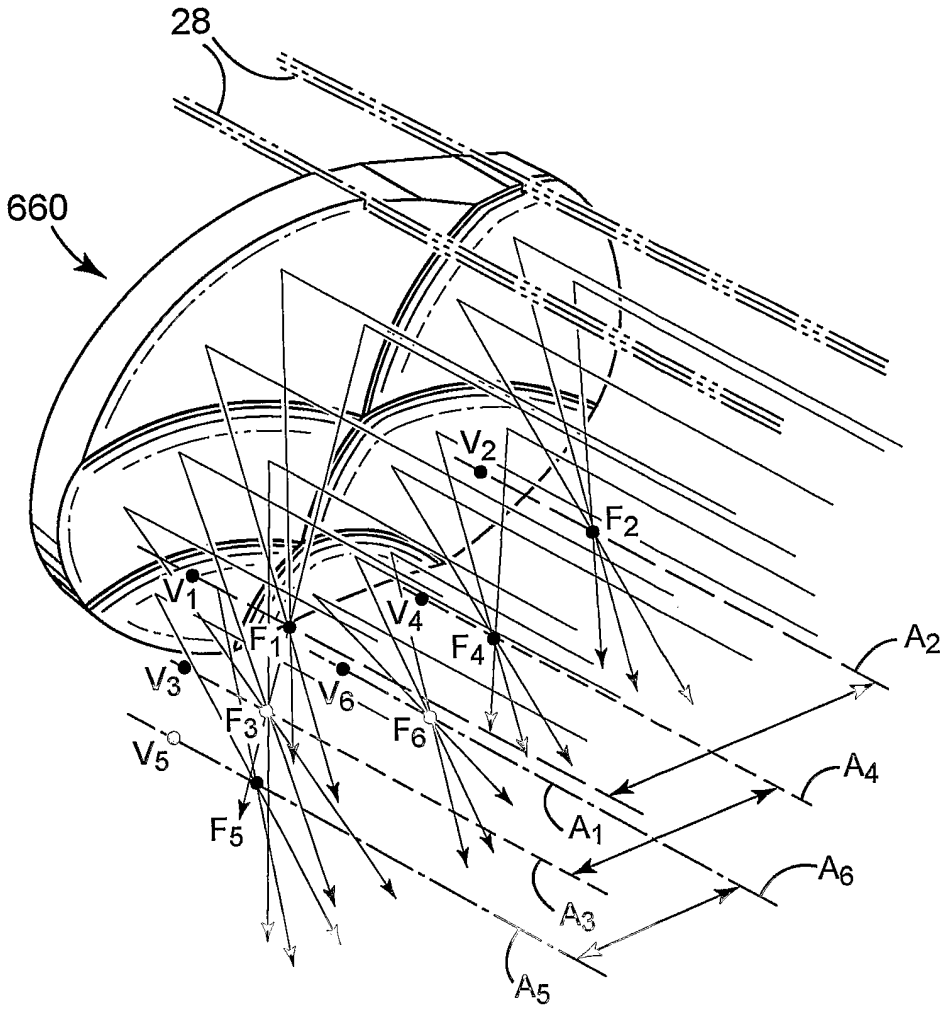


FIG. 11

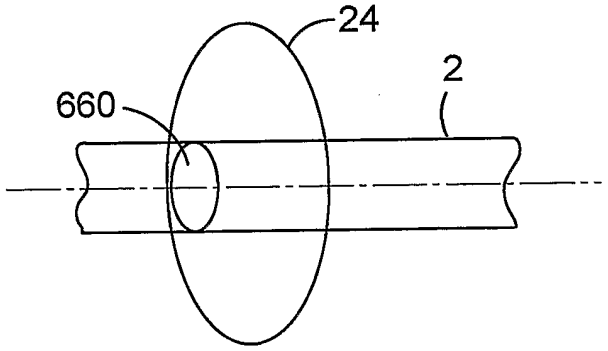


FIG. 12

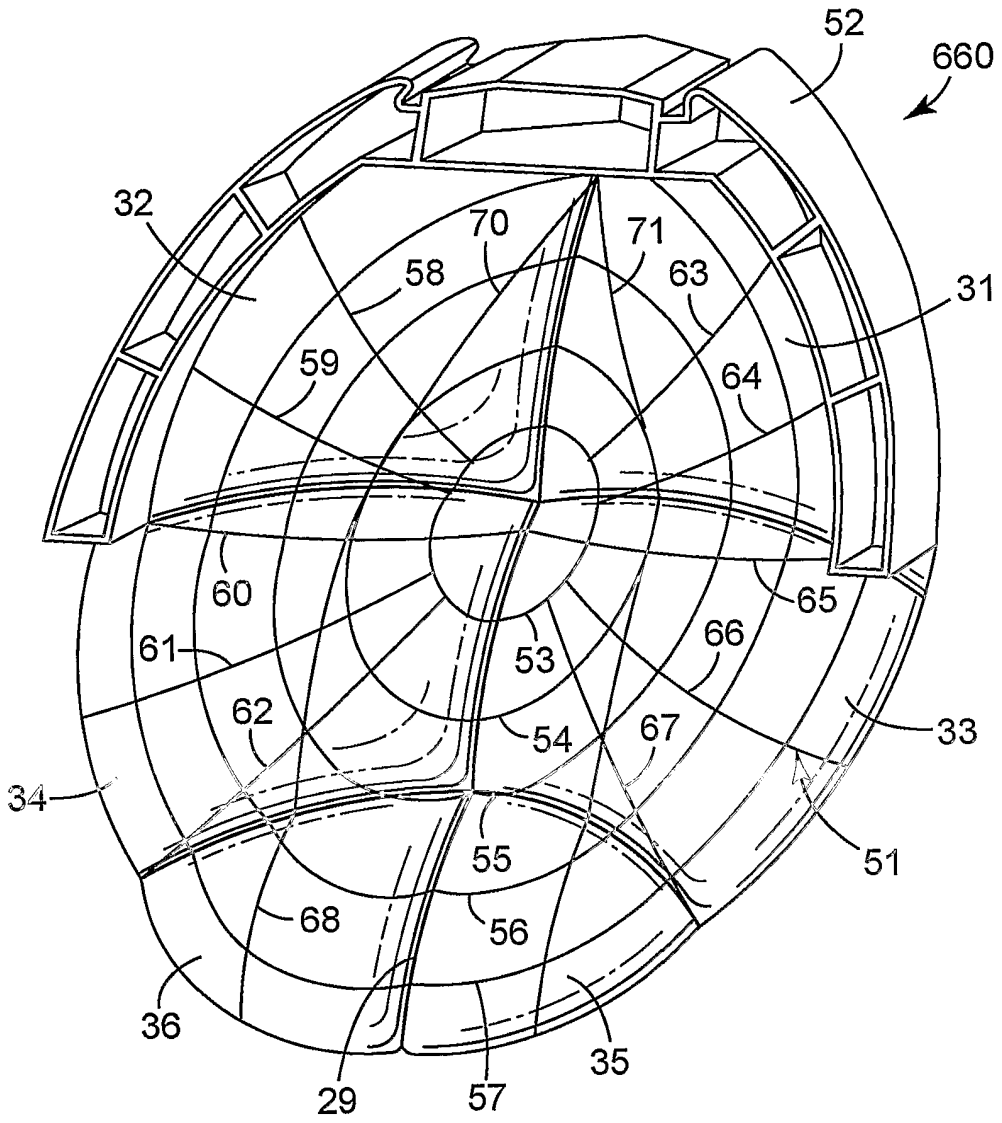

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FIG. 13

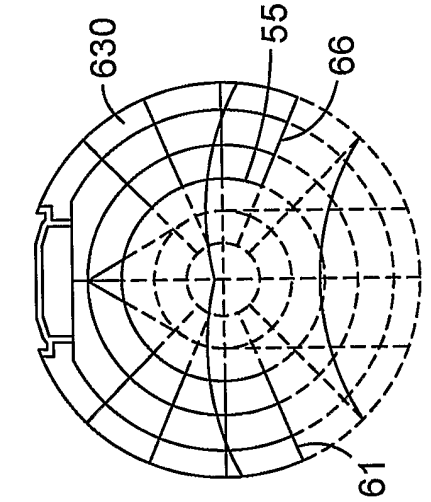


FIG. 14c

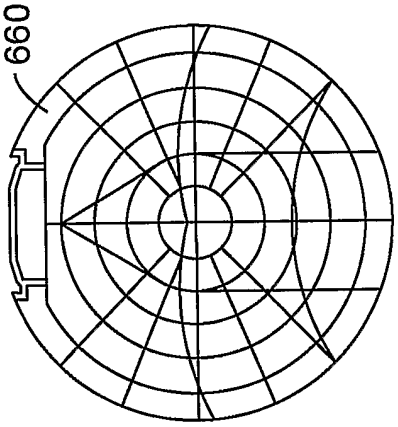


FIG. 14f

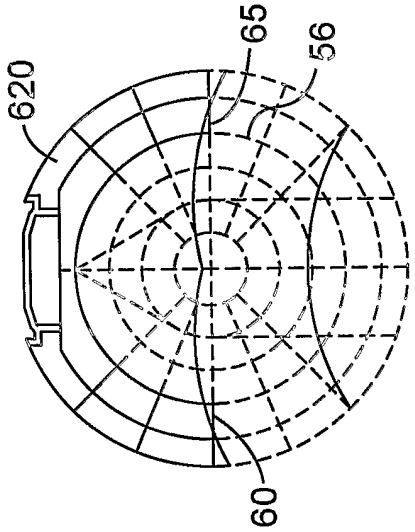


FIG. 14b

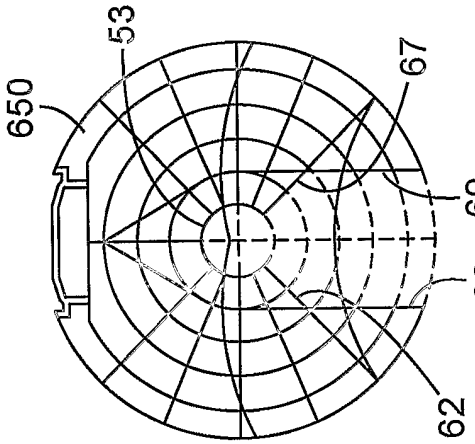


FIG. 14e

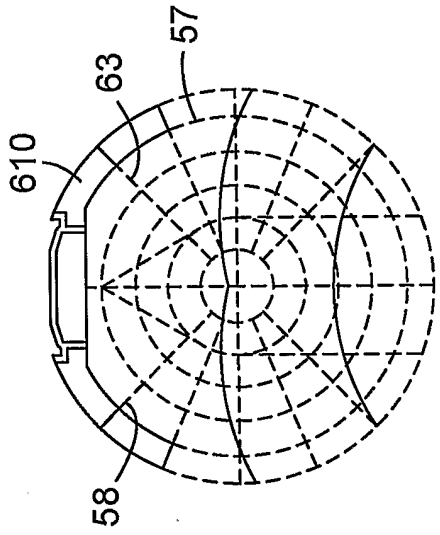


FIG. 14a

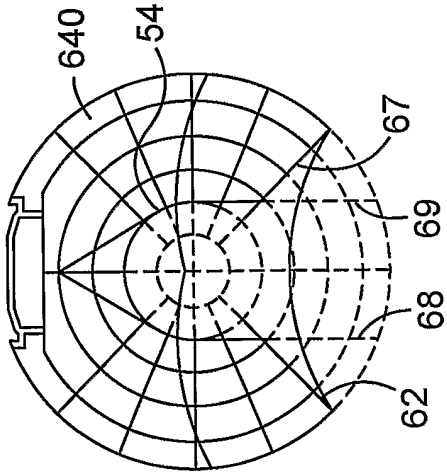


FIG. 14d

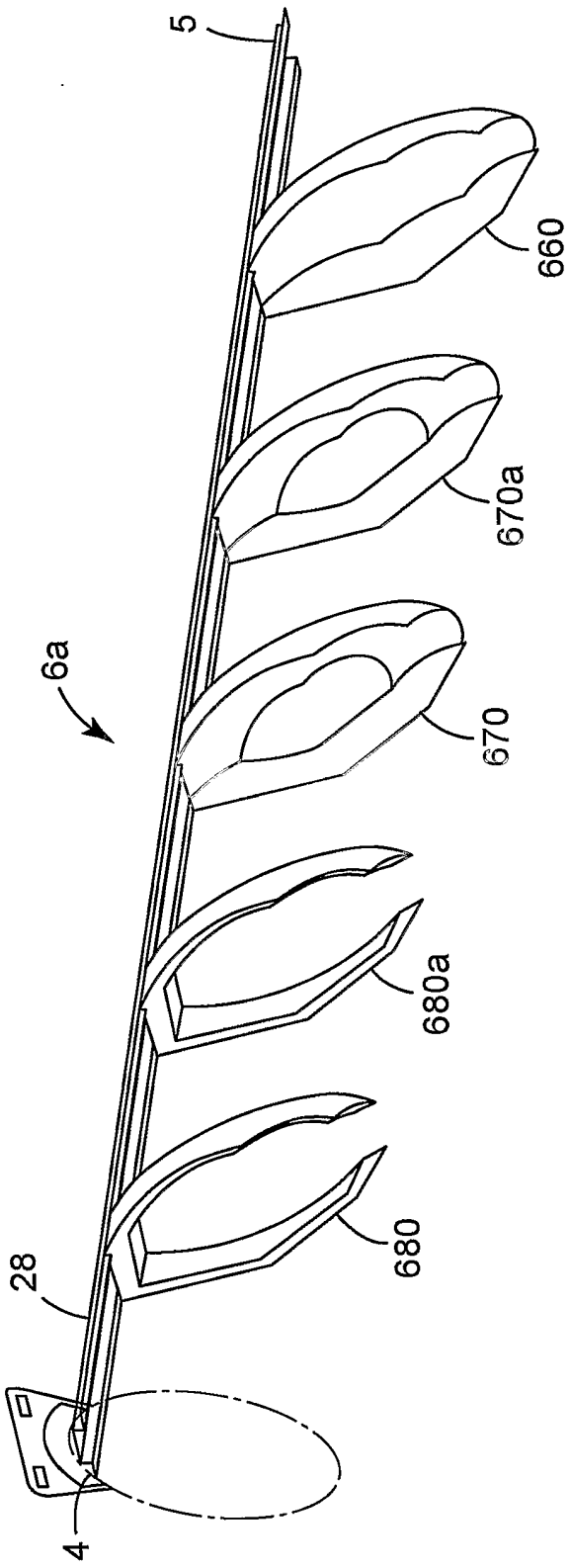


FIG. 15

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2004/003886

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 850 665 A (WHITEHEAD LORNE A) 25 July 1989 (1989-07-25) cited in the application abstract; figures 1-12	1
A	EP 1 180 640 A (MINNESOTA MINING MFG ITALIA) 20 February 2002 (2002-02-20) cited in the application abstract; figures 1-6	1
A	US 6 285 814 B1 (POJAR STEPHEN J) 4 September 2001 (2001-09-04) cited in the application abstract; figures 1-4	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 May 2004	15/06/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Verbandt, Y

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INTERNATIONAL SEARCH REPORT

International Application No
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