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(54) LIGHT CONDUCTOR

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London, EC2V 8AH, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a light conductor and to photo-couplers comprising said light conductor.

The term "light" hereinafter refers to the electromagnetic spectrum, specially the part thereof extending mainly from the infrared up to and including the ultraviolet.

It is known that for the manufacture of photo-couplers three methods are used in optoelectronics for mounting the light emitter and the light receiver.

According to the first method, a light emitter element and a light receiver element are each accommodated in a housing, then enveloped with a resin which ensures a coupling by a plate having parallel sides.

The second method consists of assembling the light emitter and light receiver in a single envelope or a single housing and then connecting them by a transparent cement which facilitates the light passage and ensures the insulation of the relevant parts.

According to the two preceding mounting methods the emitter and the receiver should be provided on the same optical axis opposite to each other; the positioning is an extremely difficult and comparatively aleatory operation involving a low production efficiency. Furthermore the transfer efficiency, which depends mainly on the distance between the emission face and the reception face and on the parallelism of these, is subject to great variations between individual assemblies because said distance can be determined only by approximation.

According to a third mounting method it has also been proposed to provide the emitter and the receiver in the same plane and to connect them by an optical fibre; experience proves that the mounting is expensive and difficult to realize, that the resulting device is fragile and that the light transfer is low as a result of losses.

In order to mitigate these drawbacks and to obtain a restriction of the cost-price of the resulting device, Applicants have suggested a solution which is the subject of French Patent No. 2,106,710; in the device described in said Patent Specification the light emitter and the light receiver are co-planar and are provided on the same support opposite to a concave mirror of elliptical or possibly spherical shape.

However, this solution is useless for photo-couplers which must support a high voltage between emitter and receiver because the metal layer of which the mirror consists introduces a low impedance in a part of a circuit which should be insulating.

It is an object of the present invention which relates to a light conductor to mitigate these drawbacks. It is based on the idea that it is not necessary in such a device for the light transmission to be stigmatic and it takes into consideration the properties of total internal reflection, particularly at spherical surfaces and notably at hemispheres. Applicants have found that by the use of said properties a "trap" for the light can be obtained in certain cases which enables the transmission thereof.

The invention provides a light conductor for conducting light from an injection zone to a collection zone by total reflection, in which the light conductor

has the shape of at least part of a half-sphere with a spherical surface and a base surface, the half-sphere having a radius R and being formed from a material having an index of refraction n_1 , at least the spherical surface where the total reflection occurs bounding an exterior medium having an index of refraction n_2 which is lower than n_1 , the injection zone and the collection zone being situated diametrically opposite one another on the base surface, the distance d between each of said zones and the centre of the sphere fulfilling the following condition:

$$R \sin \theta \leq d \leq R$$

in which $\sin \theta = n_2/n_1$.

Such a light conductor has numerous advantages. As is disclosed hereinafter, the light transmission is excellent. The direction of propagation of the light can be varied, while maintaining the losses within reasonable limits. The light conductor may be given different shapes each having their own advantages and certain of which are described in detail in the description of the Figures.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings. The radius of the half-sphere is termed R and the limit angle for total internal reflection, hereinafter referred to as total reflection is denoted by θ .

In order to simplify the drawings, the present invention is described without showing the exterior medium which in fact is usually air, and has an index of refraction n_2 equal to 1.

Figures 1a—g form an assembly of theoretical figures in which the paths of light rays are indicated originating from points situated on the main diameter of a transparent hemisphere and from which it appears that said paths are situated in a cortical region.

Figures 1a and 1b show the path of two light rays incident at the same angle from the same source point, in two cases having slightly different figures. The two light rays shown in Figure 1a experience, before emergence, the same number of reflections while one of the light rays shown in Figure 1b, before emergence, experiences one reflection more than the other.

Figure 1c introduces the limit of the cortical region of the spherical conductor in accordance with the invention by showing the path of the light rays of maximum incidence originating from three source points which are situated at different distances from the centre.

Figure 1d shows the path of two maximum opening-angle rays, for total reflection for a beam of rays originating from a source point in the cortical region within which beam the rays traverse a path through the cortical region.

Figure 1e shows the path of light rays originating from a source point situated near the injection end of the main diameter.

Figures 1f and 1g show the path of twelve rays through the cortical region, which rays form part of the same beam. For reasons of clarity the beam is divided into two parts: one is described in Figure 1f, the other in Figure 1g.

Figures 2a and 2b are also theoretical figures for studying the path of the light rays originating from the same point of a light source and propagating in different diametrical planes.

Figure 2a is a plan view and Figure 2b a sectional view taken on the line B—B in Figure 2a.

Figures 3a—d are also theoretical figures showing the propagation of light rays in a diametrical plane of a conductor element in the shape of a hollow half-sphere the inner face of which comprises a hemispherical cavity concentric with the spherical surface of the light conductor, for several mutual values of the radius r of the cavity with respect to R and $R \sin \theta$. This radius r is smaller than $R \sin \theta$ for Figure 3a, equal to $R \sin \theta$ for Figure 3b and situated between $R \sin \theta$ and R for the figures 3c and 3d.

Figures 4a, 4b and 4c are sectional views in the plane perpendicular to the main diameter at the level of the source point in the case in which the conductor element has the shape of a symmetrical spherical segment having two bases, for three different apertures of the conductor element.

Figures 5a and 5b are a sectional view (taken on the line CC of figure 5b) and a plan view, respectively, of a light conductor in accordance with the invention the conductor element of which comprises complementary metalisation faces.

Figures 6a and 6b show the assembly of a photo-coupler in accordance with the invention, as a sectional view in Figure 6a and as a plan view in Figure 6b.

In Figure 1, a semicircle $1a$ having centre O and radius R subtended by a main diameter AA' denotes the circumference of a cross-section of a semi-circular body 2. The broken line circle $1a'$ is the symmetry thereof with respect to AA' .

The extremity A of the diameter AA' is termed injection extremity and the extremity A' is termed receiving extremity of the light rays.

Each light ray which is incident from the interior and which impinges upon the wall of a sphere having an index of refraction n_1 which is larger than 1, which wall is present in a medium having an index of refraction n_2 which is smaller than n_1 at an angle of incidence i which is so much larger than the limit angle θ for total reflection, is reflected; because the curvature of a sphere is constant, said light ray again meets the surface of the sphere under the same angle of incidence i ; so this is trapped definitely within the said sphere in which it traverses, in the diametrical plane in which it is situated, a series of chords of equal length, which chords subtend equal archs of the same great circle, unless a cut in a given point of the said sphere modifies the travel of the said ray and possibly permits it to emanate and to be collected.

Figure $1a$ shows such a light ray PI, I' , which originates from a point P and is collected in the hemisphere 2 in the plane of the drawing and which impinges upon the outer surface of said hemisphere at I , and I' , at an angle of incidence which is constantly equal to i until it emerges at P' .

In Figure $1a$ the straight lines I, P and I', P' , have been prolonged to beyond P and P' , respectively, and their point of intersection with the semi-circle $1a'$ has been denoted by I'' , and I''' .

For clarifying the remainder of the figure, the chord I''', I'' , has been drawn in the lower hemisphere. The length of each chord of which a light ray of angle of incidence i traverses at least a part, is $2R \cos i$; the distance thereof to the centre, the length of the apotheme OH , is $R \sin i$, and the angle in the centre, which corresponds to said chord (for example angle I''', OI'' ,) is equal to $\pi - 2i$.

The angle of incidence i (always smaller than π) of a light ray on the sphere is given as a function of the radius R of the said sphere, of the distance l between the light point P in question and the centre O of the sphere and of the distance x between the centre O and the projection of the first point of impact of the said light ray on the diameter AA' , by the equation:—

$$\cos i = \frac{R^2 - lx}{R\sqrt{R^2 - 2lx + l^2}} \quad (1)$$

There are two rays emanating from P which impact on the circle $1a$ for the first time at an angle i ; the horizontal projection of these impacts is:

$$x_1, x_2 = \frac{-R^2 \sin^2 i \mp R \cos i \sqrt{l^2 - R^2 \sin^2 i}}{l} \quad (2)$$

The first point of impact of the second ray which originates from P and which impinges on the sphere 2 in the plane of the drawing at the angle i is shown in Figure $1a$ at I_2 , the next point of impact at I'_2 and the emerging point from the hemisphere $1a$ at P'_2 . The elongation of the straight line $I'_2 P'_2$ on the side P'_2 intersects the semi-circle $1a'$ at I''_2 and the elongation on the side P of the straight line PI_2 intersects the semi-circle $1a'$ at I'''_2 .

The light rays PI, I', P' , and PI_2, I'_2, P'_2 originating from the same point meet each other again in points which are denoted by C_1, C_2 and C_3 .

Hereinafter, the angle ω , possibly followed by an index, refers to the first central angle of impact. The angle ω is the central angle which is formed by the line OA and the line OI_1, OI_2, I_1 and I_2 being the first point of impact. This angle is always smaller than $\pi - 2i$.

$$\omega < \pi - 2i \quad (3a)$$

At least the smaller of these two angles is smaller than $\pi/2$. Hereinafter, the smaller of the two angles is denoted by the index 1 and the larger angle, as well as the corresponding light rays, are denoted by the index 2.

Consequently, the central angles $\angle AOI_1$ and $\angle AOI_2$ are noted by ω_1 and ω_2 .

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$$\omega_1 < \omega_2 \quad (3b)$$

$$\omega_1 < \frac{\pi}{2} \quad (3c)$$

On the other hand

$$\cos \omega_1 = \frac{x_1}{R} \quad (3d)$$

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and

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$$\cos \omega_2 = \frac{x_2}{R} \quad (3e)$$

From Figure 1a it appears that there is symmetry between on the one hand I_1''' and I_2 on the other hand between I_1'' and I_2 , with respect to the diameter A'A and that $\angle OI_1''' = \angle OI_1'' = \omega_1$.

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In fact

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$$\angle I_2 O I_1''' = \pi - 2i$$

$$\omega_1 + \omega_2 = \pi - 2i \quad (3f)$$

$$\omega_1 < \pi - 2i \quad (3g)$$

$$\omega_2 < \pi - 2i \quad (3h)$$

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In fact the inequality (3h) implies the inequality (3g).

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On the other hand it appears from the figure that the point O is a centre of the order

$$\frac{2\pi}{\pi - 2i}$$

As a result of this the angles $\angle I_1''' O I_1$, $\angle I_2 O I_1$, $\angle I_2 O I_1'''$ are mutually equal and are equal to $2\omega_1$.

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Considered furthermore in this application are:

the angles $\angle I_1 P A$ and $\angle I_2 P A$ which are noted by Ω_1 and Ω_2 . Because

$$\angle I_1 P A = \angle I_1''' P A \text{ and } \angle I_2 P A = \angle I_2' P A$$

$$\Omega_1 + \Omega_2 = \pi \quad (4a)$$

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and because one has

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$$\Omega_1 = \omega_1 + i \quad (4b)$$

$$\Omega_2 = \omega_2 + i \quad (4c)$$

one has

$$\Omega_2 > \Omega_1 \quad (4d)$$

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the angles $\angle I_1 P I_0$ and $\angle I_2 P I_0$ which make PI_1 and PI_2 with the normal PI_0 on OA; these two angles are equal and are denoted hereinafter by α . It is obvious that

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$$\alpha = \frac{\pi}{2} - \Omega_1 = \Omega_2 - \frac{\pi}{2} \quad (5a)$$

$$2\alpha = \Omega_2 - \Omega_1 = \omega_2 - \omega_1 \quad (5b)$$

$$\alpha = \frac{\pi}{2} - (i + \omega_1) = i + \omega_2 - \frac{\pi}{2} \quad (5c)$$

or $2\omega_1 = \pi - 2i - 2\alpha \quad (5d)$

and $2\omega_2 = \pi + 2\alpha - 2i \quad (5e)$

and $0 < 2\alpha < \pi - 2i \quad (5f)$

It is shown in Figure 1a that the central angles $\widehat{I_1 O I_2}$ and $\widehat{I' O I' _2}$ are equal to 2α and that the central angles $\widehat{A O C_1}$, $\widehat{A O C_2}$, $\widehat{A O C_3}$ are equal to

$$\omega_1 + \alpha, 2(\omega_1 + \alpha), 3(\omega_1 + \alpha),$$

respectively, and so on.

The central angles which intercept the archs situated between the collecting extremity of the main diameter and the last point of impact before emergence and which are termed last central impact angle are denoted by ω' possibly followed by an index, said index being that of the corresponding first central impact angle of the

ray in question. Consequently, the angles $\widehat{I' O A'}$ and $\widehat{I' _2 O A'}$ are denoted by ω'_1 and ω'_2 . It is obvious that

$$\omega' < \pi - 2i \quad (6a)$$

$$\omega'_1 < \pi - 2i \quad (6b)$$

$$\omega'_2 < \pi - 2i \quad (6c)$$

Because the various points of impact of the same light ray in a path through the cortical region are separated by archs which are equal to $\pi - 2i$, the number N of impacts on the said path depend on the length of the main arch, on the value of the angle of incidence i and on that of the first central impact angle ω .

If the main arch is a semi-circle, the number N of impacts before emergence are obtained by adding i to the integer q which is the quotient of $\pi - \omega$ by $\pi - 2i$.

$$N = q + 1 \quad (9a)$$

and the value ω' of the last central impact angle is:

$$\omega' = \pi - N - q(\pi - 2i) \quad (9b)$$

The larger i , the larger is the number of impacts of the same light ray on an arch of a given length.

It may also be written that:

$$q = \frac{\pi - \omega - \omega'}{\pi - 2i} \quad (9c)$$

with $\omega < \pi - 2i \quad (3a)$

and $\omega' < \pi - 2i \quad (6a)$

For light rays originating from source points situated at different distances from the centre and for which $\Omega = 90^\circ$, such as the rays $L I_{om} I'_{om} P'_L$ or $P_b I_{bl} I'_{bl} P'_b$ in Figure 1c, the angle which has the value

$$\omega = \frac{\pi}{2} - i_s$$

wherein i_s is the angle of incidence. For such rays a calculation of ω' from the conditions (9a) and (9c) gives:

$$N=1q=0\omega'=i_s+\frac{\pi}{2}$$

$$N=2q=1\omega'=3i_s-\frac{\pi}{2}$$

$$N=3q=2\omega'=5i_s-3\frac{\pi}{2}$$

$$N=4q=3\omega'=7i_s-5\frac{\pi}{2} \text{ etc.}$$

(9d)

The limits within which in each case the angle of incidence and the position of the source points on OA can vary can be calculated from the two conditions:

$$\omega' < \pi - 2i \text{ (6a) and } \omega' > 0$$

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N=1

$$i_s < 30^\circ$$

$$OP < \frac{R}{2}$$

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N=2

$$30^\circ < i_s < 54^\circ$$

$$\frac{R}{2} < OP < \frac{4R}{5}$$

N=3

$$54^\circ < i_s < \frac{5\pi}{14}$$

$$\frac{4R}{5} < OP < 0,89R$$

N=4

$$\frac{5\pi}{14} < i_s < 70^\circ$$

$$0,89R < OP < 0,94R$$

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For the two rays originating from the same source point P and having the same angle of incidence i

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$$q_1 = \frac{\pi - \omega_1 - \omega'_1}{\pi - 2i} \quad (10a)$$

$$q_2 = \frac{\pi - \omega_2 - \omega'_2}{\pi - 2i} \quad (10b)$$

$$\omega'_1 = \pi - \omega_1 - q_1(\pi - 2i) \quad (10c)$$

$$\omega'_2 = \pi - \omega_2 - q_2(\pi - 2i) \quad (10d)$$

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with the above-stated conditions

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$$\omega_1 < \frac{\pi}{2} \quad (3e)$$

$$\omega_2 < \pi - 2i \quad (3h)$$

$$0 < 2a < \pi - 2i \quad (5f)$$

$$\omega'_1 < \pi - 2i \quad (6b)$$

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$$\omega'_2 < \pi - 2i \quad (6c)$$

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At a given angle of incidence, q_1 and q_2 can assume only two relative values: either

$$q_1 = q_2 = q \quad (11a)$$

this case is that of Figure 1a.

or

$$q'_1 = q'_2 + 1 = q' \quad (12a)$$

with $\omega_1 < \omega_2$. This case is that of Figure 1b.

Although a thorough geometric study is not indispensable for the use of the invention, a few equations are given below which may be useful.

In the case in which $q_1 = q_2 = q$ (11a) — this case is that of Figure 1a, for which $q=1$ — one has the following equations:

$$q = \frac{\pi - \omega_1 - \omega'_1}{\pi - 2i} = \frac{\pi - \omega_2 - \omega'_2}{\pi - 2i} \quad (11b)$$

$$\omega'_1 = \pi - \omega_1 - q(\pi - 2i) \quad (11c)$$

$$\omega'_2 = \pi - \omega_2 - q(\pi - 2i) \quad (11d)$$

$$\omega_1 + \omega'_1 = \omega_2 + \omega'_2 = \pi - q(\pi - 2i) \quad (11e)$$

$$\omega'_1 - \omega'_2 = \omega_2 - \omega_1 = 2\alpha \quad (11f)$$

$$\omega'_1 + \omega_2 = 2\pi - (2q+1)(\pi - 2i) \quad (11g)$$

$$2\omega'_1 = 2\pi + 2\alpha - (2q+1)(\pi - 2i) \quad (11h)$$

$$2\omega'_2 = 2\pi - 2\alpha - (2q+1)(\pi - 2i) \quad (11i)$$

It will be obvious that the following equations have to be realized: $\omega'_2 < 2\omega_1$, otherwise ω'_1 would be larger than $\pi - 2i$ (11f) or the number of impacts of the ray 1 would be $q+2$.

$\omega'_1 > 2\alpha$ otherwise the number of impacts of the ray 2 would be q (11k).

Figure 1b shows in particular two rays $P_a I_{1a} I'_{1a} I''_{1a} P'_{1a}$ and $P_a I_{2a} I'_{2a} P'_{2a}$ originating from a source point P_a with the same angle of incidence, which paths traverse through the cortical region and emerge, the former after three impacts and the second after two impacts on the hemispherical surface ($q'_1 = q'_2 + 1 = 2$). It will be obvious that the angles i , α , ω_1 and ω_2 which characterize the light rays I_{1a} and I_{2a} have the same definitions as before; only the values are different.

In the case in which $q'_1 = q'_2 + 1$ (12a) the following equations may be established:

$$q' = \frac{\pi - \omega_1 - \omega'_1}{\pi - 2i} = \frac{2(\pi - i) - \omega_2 - \omega'_2}{\pi - 2i} \quad (12b)$$

$$\omega'_1 = \pi - \omega_1 - q'(\pi - 2i) \quad (12c)$$

$$\omega'_2 = \pi - \omega_2 - (q'-1)(\pi - 2i) \quad (12d)$$

$$\omega_1 + \omega'_1 = \pi - q'(\pi - 2i) \quad (12e)$$

$$\omega_2 + \omega'_2 = \pi - (q'-1)(\pi - 2i) \quad (12f)$$

$$\omega'_2 - \omega'_1 = \pi - 2i - 2\alpha \quad (12g)$$

$$\omega'_1 + \omega'_2 = 2\pi - 2q'(\pi - 2i) \quad (12h)$$

$$2\omega'_1 = \pi + 2\alpha + 2i - q'(\pi - 2i) \quad (12i)$$

$$2\omega'_2 = 2\pi - 2\alpha + (1 - 2q')(\pi - 2i) \quad (12j)$$

with the following conditions

$$\omega'_1 < 2\alpha \quad (12k)$$

$$\omega'_2 > 2\omega_1 \quad (12l)$$

In the case in which π is a whole multiple of the sum $\omega_1 + \alpha$ of the angles ω_1 and α , this is a whole multiple of $1/2 (\pi - 2i)$ and in which hence

$$2\pi = (N_1 + N_2)(\pi - 2i) \quad (13)$$

(N_1 and N_2 being the number of impacts of the rays I_1 and I_2 , respectively, originating from P having the same angle of incidence i), a crossing C of said light rays is situated at OA' and the two rays of equal angle of incidence emerge and can be collected in the same point. In that case which is not shown in the figures, $\omega'_1 = \omega_2$ and $\omega_1 = \omega'_2$.

In all other cases, the rays having the same angle of incidence and originating from the same source point emerge in two different points, for example P'_1 and P'_2 in Figure 1a and P'_{1a} and P'_{2a} in Figure 1b.

These points can be determined by their distance to the centre

$$OP'_1 = \frac{-R \sin i}{\sin (i + \omega'_1)}$$

and

$$OP'_2 = \frac{-R \sin i}{\sin (i + \omega'_2)}$$

In any case, for a given angle of incidence i the point of emergence can never be situated between the point O and the point P'_0 of which the distance $R \sin i$ to the point θ is equal to OH , the distance between the centre O and the chords which are traversed by the light rays in question.

Because each light point P is the source of a beam of light rays having different angles of incidence, it will be obvious that also when the condition (13) is satisfied for a given angle of incidence, this need not apply to most of the others. The light originating from a point P is scattered along a light rod. There is light transfer, but there is no image of the point P .

If a light source in the form of a rod is placed along OA , a light distribution is available along OA' in the form of a rod which is not an image of the rod-like source.

Each source P is the origin of a beam of light rays of which the angle of incidence on the sphere in the plane of the drawing varies (if the source emits in all directions) between zero, the value of the angle of incidence of the light ray PA , and a maximum value which is obtained for the normal light ray on the diameter OA . Such a light ray is shown between the source thereof and the first impact thereof (the continuation of the path is not shown for reasons of clarity), for example in Figure 1b at $P_0 I_0$. The angle of incidence i_0 thereof is the maximum angle of incidence of the light rays originating from P_0 . For this light ray $\alpha = 0$ and the first central impact angle is:

$$\omega_0 = \frac{\pi}{2} - i_0$$

and

$$OP_0 = R \sin i_0$$

The angle of incidence of the other light rays originating from a given source point, for example P_0 , decreases progressively on either of said ray $P_0 I_0$ according as α increases.

On the other hand, the value of said maximum angle of incidence varies with the position of the source point on the half diameter OA . Said value decreases

when the source point P approaches O (for P in O the incidence would be zero) and increases when the source point P approaches A (for P in A the incidence would be equal to $\pi/2$).

Figure 1c shows the light ray with maximum incidence for three positions P_c , L and P_b of the source point. It will be obvious from the figures that the angles of incidence i_{oc} and i_{ob} increase from P_c to P_b .

In the same Figure 1c and the following figures are shown in broken lines the semi-circle of centre O and of radius $R \sin \theta$, θ being the limit angle of the transparent hemisphere with respect to the medium in which it is present. The light used in the conductor element of the conductor according to the invention can propagate within the cortical region 4 formed by the circles 1a and 3a. The semi-circle 3a intersects the main diameter AA' in the limit points L and L'.

In this Figure 1c the semi-circles 1a' and 3a' are also shown in broken lines and are symmetrical with respect to the semi-circles 1a and 3a on the other side of the diameter AA'.

Each light ray, for example, $P_c I_c$ originating from a point of the region 5 of the hemisphere 1 which is situated within said hemispherical limit surface 3 impinges on the face 1 at an angle of incidence which is smaller than the limit angle θ . So said light ray emerges from the conductor element as is shown in Figure 1c at I'_c and can be reflected only in the presence of a complementary metallization.

Each light ray originating from a point, for example L, which is situated on the limit surface 3 and which propagates tangentially to said limit surface, impinges on the face 1 at an angle of incidence which is equal to the limit angle θ in a point, for example I_{om} . It forms the limit ray which is reflected again at I'_{om} before being collected at P'_L .

The elongation $P'_L I'_{om}$ of the ray $I'_{om} P'_L$ is also shown in broken lines in the figure. The chords $I_{om} I'_{om}$ and $I'_{om} I''_{om}$ are tangents to the circle 3a, 3a'. If the first central impact angle $\angle AOI_{om}$ of value $\pi/2 - \theta$ is termed ω_{om} and the last central

impact angle $\angle A'OI'_{om}$ is denoted by ω'_{om} a simple calculation supplies the distance OP'_L between the centre O and the point of emergence P'_L of the limit ray.

In the case of the figure, for which the limit angle θ lies between 30° and 54° , the number of impacts of the light ray $LI_{om} I'_{om} P'_L$ is $2(q=1)$, and $\omega'_{om} = 3 \cdot \theta - \pi/2$.

A simple trigonometric calculation gives:

$$OP'_L = \frac{R \sin \theta}{\cos 4 \theta}$$

It is to be noted that if the light ray LI_{om} is a limit ray, the point of emergence P'_L thereof is in the general case not a limit point; light rays originating from points of the source situated between L and A emerge on either side of P'_L .

Since the light ray LI_{om} is perpendicular to OA, the angle of incidence thereof is a maximum and any other light ray originating from L and propagating in the plane of Figure 1c impacts on the surface 1 at an angle of incidence which is smaller than the limit angle and emerges from the conductor element in the absence of a complementary metallisation. No ray of this type is shown in Figure 1c.

On the contrary, the angle of incidence i_{ob} for the ray $P_b I_b I'_{ob} P'_b$, originating from the source point P_b situated between A and the limit point L on the outer segment of the diameter OA, is larger than θ and for any point of the cortical region 4 two limit light rays, hereinafter termed opening limit light rays, can be determined in each region on either side of the normal to the diameter through said source point which emanate on two first impact limit points, thereafter termed opening limit points, for which the angle of incidence is equal to θ .

The light rays which originate from said source point and which are situated within the beam between the said two opening limit rays and of which the first point of impact consequently is situated between the said two opening limit points, impinge upon the surface of the sphere at an angle of incidence exceeding θ ; they are reflected and traverse a path through the cortical region. The light rays outside the beam situated between said two opening limit light rays and of which the first point of impact is not situated between the two above-defined opening limit impact points, impinge upon the spherical surface at an angle of incidence which is smaller than θ ; they are not reflected and leave the sphere.

For clarity, Figure 1d shows at I_{m1} and I_{m2} the two points of the first impact of

the opening limit light rays originating from P and propagating in the plane of the drawing. The light rays PI_{m1} and PI_{m2} , or their elongation, not shown in the drawing, as well as these same light rays after reflection $I_{m1}I'_{m1}$, $I'_{m1}P'_{m1}$ and $I_{m2}P'_{m2}$ are tangents to the circle 3a.

For the source point P the whole arch of I_{m1} to I_{m2} is reflecting: it is the reflection of this arch which the present invention uses.

In the absence of a complementary metallisation the light rays originating from P and of which the first impact is between A and I_{m1} on the one hand and beyond I_{m2} on the other hand, experience no total reflection and they emerge from the spherical surface. In fact said light rays would intersect the central region 5 which does not transmit any light.

The angle within which rays are recovered by total reflection is termed the opening angle, or opening, of the conductor element in a considered plane and for a considered point. This opening angle, as regards point P in the plane of the Figure

1d, is $\angle I_{m1}PI_{m2}$.

Like the value of the maximum angle of incidence, the opening of the conductor elements depends on the place of the source point P. This opening value is zero when P is in L and is maximum when P is in the proximity of A.

Figure 1e relates to light rays originating from the source point A, the injection extremity of the main diameter.

In this figure is shown the opening limit light ray $AI'_{a1}P'_{a1}$ which may be collected in the point P'_{a1} which lies near L'; a light ray of which the path in the cortical region extends along the circumference $AI'_{a1}I'_{a2}I'_{a3}I'_{a4}I'_{a5}I'_{a6}P'_{a1}$ and which can be collected in the point P'_{a1} which lies near A' and a central light ray $AI'_{a1}I'_{a2}P'_{a2}$ of which, because the angle of incidence is equal to $3\pi/10$, the latter part of the path $I'_{a2}P'_{a2}$ is perpendicular to OA' . For these three rays, Ω is larger than $\pi/2$, the part of the beam for which $\Omega < \pi/2$ not being considered for this extreme point.

By means of the equations 11 and 12 given above it is possible to exactly determine the light distribution at the collecting extremity of the diameter AA' but this is not necessary for the comprehension and the use of the invention. The light is distributed between A' and P'_{a1} , the strong light intensities being in the proximity of A' and the small ones near L'. In fact, according as the angle Ω decreases, the emergence of the reflected light ray first moves from L' to A'; for the light ray (which is not shown in the figure for clarity) for which the impact takes place in the summit of the hemisphere 2 and for which $\Omega = 3\pi/4$ the emergence takes in place in A'. According as the angle Ω decreases further, the emergence point moves in the opposite direction to in P'_{a1} ; it then returns to A', then again towards L' to in P'_{a2} , the emergency point of the ray not shown in the figure of which the number impacts is three and of which the last part of the path is perpendicular to OA' , then again towards A', and so on.

It is to be noted that the emergence point P'_{a1} of the opening limit ray, that is the point of the light rod which is collected nearest to L' results from the value of the limit angle. If $\theta = 45^\circ$, the emergence point of the limit ray would be in A' and the light ray would extend from A' to P'_{a1} , the diameter LL' of the circle 3a of course would be larger ($R/\sqrt{2}$). For other values of θ the emergence point of the opening limit ray would not be at an extremity of the collected light ray.

In Figure 1f, the path in the cortical region of the light rays $PI_{m1}I'_{m1}P'_{m1}$, $PI_{31}I'_{31}P'_{31}$, $PI_{32}I'_{32}P'_{32}$, $PI_{33}I'_{33}P'_{33}$, $PI_{34}I'_{34}P'_{34}$ of the first half beam which originates from P is shown in such manner that the angles ω which OA makes with the light rays which they form, are smaller than $\pi/2$ and in Figure 1g the path in the cortical region of the light rays $PI_{34}I'_{34}P'_{34}$, $PI_{35}I'_{35}P'_{35}$, $PI_{36}I'_{36}P'_{36}$, $PI_{37}I'_{37}P'_{37}$, $PI_{38}I'_{38}P'_{38}$, $PI_{m2}I'_{m2}P'_{m2}$ of the second half beam which originates from P is shown in such manner that the angles of the light rays which they form with A are larger than $\pi/2$.

For the first half beam shown in Figure 1f it is seen that, when the various rays thereof are considered in the sequence in which ω decreases, that the point of the first impact moves away from I_{m1} in the direction of the path of the light rays and that the length of the chords which are traversed by the light rays, as well as the arches which they subtend decrease. As a result of this there is a concentration of the whole beam or a part thereof during the travel of the first traversed chords. More correctly, if two rays, for example PI_{31} , having a first central impact angle ω_{31} and an angle of incidence i_{31} , and PI_{32} , having a first central impact angle ω_{32} and an angle of incidence i_{32} , for which $\omega_{31} < \omega_{32}$ and $i_{31} < i_{32}$, and which moreover satisfy the condition

$$\pi - 2i_{31} + \omega_{31} > \pi - 2i_{32} + \omega_{32} \quad (15a)$$

that is by introducing the angles α_{31} and α_{32} defined above according to the equation 5c, they satisfy the condition

$$3(i_{32} - i_{31}) > \alpha_{31} - \alpha_{32} \quad (15b)$$

the sequence of impact of the two rays is inverted in the first main face between the first and the second impact, the point of impact I'_{32} being nearer to I_{m1} than the point of impact I'_{31} .

In the case in which the equation 15b is not satisfied, for example for the rays I_{32} and I_{33} , the light rays cross each other and their points of impact I'_{32} and I'_{33} approach each other.

As a result of this there is a concentration of the light beam and the arch which supports the second point of impact of the various rays is generally smaller than the arch $I_{m1}I_0$ which supports the first point of impact of these rays.

It is seen in Figure 1f, for example, at the places indicated by Y_1 and Y_2 that the light rays of this first half of the beam form a light spot which does not cover the total segment of the cortical region. If for two light rays, for example PI_{33} and PI_{31} , the equation

$$5(i_{33} - i_{31}) > \alpha_{33} - \alpha_{31} > 3(i_{33} - i_{31}) \quad (15c)$$

is satisfied, the inversion of the point of impact of the light rays in question, which have crossed each other between the first and the second impact and of which the second points of intersection have come nearer to the first points of intersection, occurs between the second and the third impact provided there is a third impact.

As long as the sequence of all the points of intersection is not inverted, the half beam in question remains narrow, from point of impact to point of impact.

As soon as the sequence of the points of impact is inverted, the deviation between the points of impact increases more and more and the beam is progressively scattered.

For the second half beam which originates from the point P which is shown in Figure 1g, the length of the chords which are traversed by the light beam, as well as the archs which they subtend, increase when ω becomes larger and the first point of impact moves away from A; scattering of the light ray occurs.

The length of the arch $I'_0I'_{m2}$ along which the two points of impact are scattered is larger than the length of the arch I_0I_{m2} of the first impact.

As a result of this, a light spot of a large area is collected when the light beam is intersected by a plane.

In general, the addition of the two half beams forms light spots of a large area which make it possible, when optimum efficiency is not desired, to determine without great accuracy the place of a possible collection device, the more so because the sources are never punctiform. In extreme cases, however, it is useful to calculate or verify with the drawing whether the useful beam which originates from a given source point covers the area of collection.

It will be obvious from the above that the collecting area has much more changes of becoming smaller when the emission point is near the sphere of radius $R \sin \theta$ limiting the cortical region of the interior, especially when it is on the portion of the cortical segment having a length of approximately

$$\frac{R(1 - \sin \theta)}{10}$$

and near the limit point and when θ is large. In fact when the various light rays originating from a given point are considered, the variations of the angle of incidence i with the first angle of impact ω are smaller than the variations of α .

Figures 1a—g may be considered as the diametral section normal to the base surface of a conductor having the shape of a half-sphere. This half-sphere is shown in a plan view in Figure 2a and in a sectional view in Figure 2b, the said sectional view being taken at the place of the line BB of Figure 2a in a plane perpendicular at P to the plane of Figure 2.

In Figure 2a, 1b denotes the circumference of the hemispherical surface 1 and, in broken lines, AA' denotes the main diameter with respect to the source point P.

Figure 2b shows in solid lines at 1c the circumference of the hemispherical surface 1, at 6b a solid line denotes the circular circumference of the line of intersection of the plane of section with the hemisphere 1, Z and Z' denotes the extremities of the diameter perpendicular to AA' in the plane opposite to the summit Q of the hemispherical surface 1, and the sectional area is shaded.

The advantage of giving the spherical surface the shape of a hemisphere or at least that of a zone drawn through an arc exceeding $\pi - 2\theta$ is demonstrated hereinafter starting from the path of the rays originating from P and perpendicular to the diameter AA' in the various diametrical planes of the hemisphere through the said diameter AA'.

In Figure 2a the light ray $PI_2I'_2P'_2$ of Figure 1a is projected on a part of the main diameter AA', in Figure 2b the same light ray is projected in broken lines on the segment which in the drawing joins O and I_2 . Figures 2a and 2b show a second light ray originating from the point P and propagating in a diametrical plane which encloses an angle Δ with the plane of Figure 1a and which in said plane impinges on the hemispherical surface at the same angle of incidence i .

The projection of the great circle which corresponds to said diametrical plane is denoted at 7a in Figure 2a and at 7b in Figure 2b, and the various points of incidence on the sphere of the said light ray are references I_2, I'_2 and the ray reaches point P'_2 .

All light rays originating from a given point at a given angle form a substantially conical beam and impinge on the hemisphere at the same angle and reach the same area of the image light spot.

Figures 3a—d are cross-sectional views in the main plane of a conductor element according to the invention of which the first main face is a hemisphere and of which the second main face is a cavity in the form of a hemisphere which is concentric with respect to the preceding, said cavity leaving at its circumference a flat edge which in this case is coronal.

The radius of the first and the second main face are referred to by R and r in this specification, possibly followed by a suitable index. Because the medium outside the first main face and the medium inside the second main face is identical, the limit angle is the same for the reflections on both faces. In the figures it has been chosen to be equal to 38° .

Each light ray which is reflected on the second main face in general and especially as compared with a possible later reflection, behaves as if it originates from the said main face.

For light rays, which originate from a source point which is situated in the corona on the main diameter the arch of the circumference of the second main face which is reflecting is restricted on the one hand by the ray which is a tangent to said arch and on the other hand by the limit point for which the angle of incidence is equal to θ . These limits are denoted in Figures 3a—d.

In Figure 3a the conductor element 30 is bounded by the first hemispherical main faces 31a thereof having the centre O_3 and summit Q_3 and by the second main face 38 which comprises a hemispherical cavity 32 which is concentric with the first and furthermore comprises a corona 38a. The main diameter $A_3A'_3$ intersects the second main face at B_3 and at B'_3 . The circumference, in the plane of the drawing, of the hemisphere of radius $R \sin \theta$ is denoted at 33a; it intersects the main diameter at L_3 and at L'_3 .

Because in Figure 3a the radius r_3 of the cavity is smaller than $R \sin \theta$, all light rays which have experienced a reflection to the said second main face emerge from the first main face during their later impact on same, if the first main face does not comprise any metallisation.

Figure 3a also shows the opening limit points I_{m6}, I_{m6} and the limit points I_{m7}, I_{m7} as well as the tangents P_3T_4 at the hemispherical cavity 32a and P_3T_3 at the circle 33a which correspond to a source point P_3 . The tangent P_3T_3 reaches precisely I_{m5} .

The tangent P_3T_4 intersects the spherical surface 31a at T'_4 . The rays which originate from P_3 and which impinge upon the first main face between the opening limit points I_{m6} and I_{m5} are reflected on same and collected between A'_3 and L'_3 as if the cavity 32 does not exist.

The rays which originate from P_3 and which impinge upon the first main face between A_3 and I_{m6} on the one hand and between I_{m5} and T'_4 on the other hand emerge from the conductor element equally as if the cavity 32 did not exist.

The rays impinging upon the second main face between B_3 and I_{m7} emerge directly from same; the rays which impinge upon the said second main face between I_{m7} and T_4 are reflected on said second face towards the first face, where

they emerge because, as a matter of fact, to them everything occurs as if they originate from the second main face. In the absence of the cavity, the rays would have impinged upon the first main face between T'_4 and A'_3 , from which main face they would have emerged.

In the absence of a metallisation the light balance thus is identical to that of the hemisphere without cavity. Nevertheless, such conductor elements have a great number of advantages, for example, a low weight, an easy moulding operation, saving of material, which advantages are important.

Calculation permits of knowing the ordinates x_{T_4} and y_{T_4} of T_4 as a function of r and of the length l_4 of O_3P_3 :

$$x_{T_4} = \frac{x^2}{l_4} \quad (16a)$$

$$y_{T_4} = \frac{r}{l_4} \sqrt{l_4^2 - r^2} \quad (16b)$$

the abscissa x_7 of I_{m7} :

$$x_7 = \frac{r^2 \sin^2 \theta}{l_4} + \frac{r \cos \theta}{l_4} \sqrt{l_4^2 - r^2 \sin^2 \theta} \quad (16c)$$

and the reflecting arch by:

$$x_{T_4} - x_7 = \frac{r^2}{l_4} - \left(\frac{r^2 \sin^2 \theta}{l_4} + \frac{r \cos \theta}{l_4} \sqrt{l_4^2 - r^2 \sin^2 \theta} \right) \quad (17)$$

When P_3 approaches B_3 , the points T_4 and I_{m7} also approach B_3 and the length of the arch T_4I_{m7} becomes smaller to become equal to zero when P_3 is in B_3 . When P_3 moves away from B_3 , the arch $I_{m7}T_4$ increases to become equal to $\pi - \theta$ if P_3 were to move to infinity. On the contrary, the angle from the point P_3 the said arch $I_{m7}T_4$ is a maximum and equal to $\pi/2 - \theta$ when P_3 is in B_3 . This angle decreases when P_3 moves away from B_3 and would become equal to zero if P_3 were an infinity.

In Figure 3b the conductor element is bounded by the first hemispherical main face 36a of centre O_4 and summit Q_4 and by the second main face 39 which comprises a hemispherical cavity 37a and a corona 39a. The main diameter $A_4A'_4$ intersects the cavity 37a at L_4 and at L'_4 . The radius r_4 of the cavity is exactly equal to $R \sin \theta$.

Rays of the beam which originate from the source R_4 which impinge upon the first main face between the two opening limits points I_{m8} and I_{m10} are reflected. Besides the ray P_4I_{m10} which is tangent at T_5 , no light ray of said beam impinges on the second main face.

Rays which originate from P_4 and which in the first impact impinge upon the first main face between A_4 and the opening limit point I_{m8} or the second main face between L_4 and the limit point I_{m9} immediately emerge from the conductor element.

The beam originating from P_4 which during the first impact impinges on the second main face between the limit point I_{m9} and T_5 is reflected towards the first main face at such an angle of incidence that in the absence of a metallisation the beam emerges from the conductor element. The angle of incidence i' of the first main face of each light ray which has already experienced a reflection on the second main face at an angle of incidence i actually is always equal to $i - \gamma$ where γ is the centre angle between the two points of impact. Such a light ray is shown at

$P_4I_9I'_9$, in which the angle $\widehat{I_9OI'_9}$ is the angle γ , $i_9 = i'_9 + \gamma$ (18a). For the limit point T_5 in which the angle of incidence is 90° the "reflected" light ray impinges on the first main face in a point for which the angle of incidence is exactly equal to θ . In the absence of the complementary metallisation, this whole beam of which the first point of impact is between I_{m9} and T_5 thus leaves the conductor element upon the second impact.

Figures 3c and 3d relate to the case in which the radius r of the second main face is situated between R and $R \sin \theta$. For clarity, the figure is shown twice.

In Figures 3c and 3d the conductor element 40 is bounded by its first

hemispherical main face 41a having centre O_s and summit Q_s and by its second main face 44 which has a hemispherical cavity 42a which is concentric with the first and a corona 44a.

The main diameter $A_s A'_s$ intersects the second main face at B_s and at B'_s . The semi-circle of which the radius is $R \sin \theta$ is shown at 43a. It intersects the main diameter $A_s A'_s$ at L_s and at L'_s . The radius r_s of the cavity is such that

$$R > r_s > R \sin \theta$$

This figure also shows for a source point P_s the tangent $P_s T_s$ at the second main face of which the elongation at T_s intersects the first main face and also the tangent $P_s T$ at the semi-circle 43a. This tangent $P_s T$ intersects the first main face in the total reflection limit point I_{m13} and the second main face in the points S and S'. The point S is also a total reflection limit point.

For each light ray, for example for $P_s I_{10} I_{11} I'_{10}$ originating from P_s (Figure 3c) and which, for example, is reflected totally (for example as a result of the presence of a metallisation which forms a mirror) successively at least once on the two main faces as a result of the property of the spheres, the angles of incidence i_{10} on the second main face and i_{11} on the first main face generally remain constant during the whole path until the collection. Moreover

$$\frac{\sin i_{10}}{\sin i_{11}} = \frac{R}{r_s} \quad (20)$$

and

$$i_{10} - i_{11} = \alpha' \quad (18b)$$

wherein α' is the value of the central angle O between two successive points of impact, one on the first the other on the second main face, for example the angle



Thus if the medium outside the conductor element on the side of the first main face and the medium outside the conductor element on the side of the second main face have the same indices of refraction for a light ray the angle of incidence of which on the first main face is such that said ray is reflected totally, for example if the first impact takes place between the two total reflection limit points I_{m11} and I_{m13} , the angle of incidence of said ray on the second main face is sufficiently large to cause total reflection to occur. This is verified a fortiori if the index of refraction of the medium outside the conductor element on the side of the first main face is larger than the index of refraction of the medium outside the conductor element on the side of the second main face.

It may be concluded that each light ray which originates from P_s and the first point of impact of which lies on the second main face between the opening limit point S and T_s as a result of which it has an angle of incidence with respect to the first main face which is larger than θ is reflected on the two faces of the conductor element and is finally collected. The corresponding beam is that one of which the first impact, in the absence of the cavity, would take place on the first main face between T'_s and I_{m13} .

On the contrary, a light beam of which the first impact takes place on the second main face, directly leaves the conductor element if said impact takes place between B_s and the limit point I_{m12} and a light ray of which the first point of impact is situated on the second main face between I_{m12} and the opening limit point S is reflected on same and, in the absence of a metallisation on the first main face, emerges from the conductor element during the next impact on the first main face, its angle of incidence being smaller than the limit angle.

Figure 3d shows the path of the limit ray $P_s S I_{13} S' I_{m13} I_{12} I'_{12} P'_s$ of which the angles of incidence i_{12} , i_{13} and the central angle between two points of impact γ_0 are connected by the following relationships:

$$i_{13} = \theta \quad (19a)$$

$$i_{12} = \frac{\pi}{2} - \gamma_0 \quad (19b)$$

$$\text{and} \quad \sin i_{12} = \frac{R}{r_s} \sin \theta = \frac{R}{r_s} \frac{n_2}{n_1} \quad (19c)$$

(n_2 being the index of refraction of the exterior medium and n_1 that of the conductor element). This ray also passes through the point S' and through the opening limit point I_{m13} .

This relation does not depend on the position of the point P_s . Thus, with the exception of the losses by absorption or during reflections — which losses are slightly higher by increase of the length of the path (the absorption losses over 10 cm are in the order of 10%) and of the number of incidences — the light balance is the same whether the conductor element is provided with a cavity or not.

The only exception would relate to the case of the figure for which I_{m12} would lie beyond S , the limit angle corresponding to the second main face being much larger than the limit angle corresponding to the first main face. This case is very unlikely.

All the above reasonings, as well as those which follow, have been conducted as a function of the points and of light rods. It will be obvious that the reasoning would be the same as regards light areas of small dimensions and of indetermined shape, as well as regards sources of which the various light points are not exactly co-planar.

Figures 4a, 4b and 4c show very diagrammatically the sectional view of a conductor element that is formed as a disc cut out of a half-sphere. The sectional view has been taken through the plane which is perpendicular to the main diameter through the source point which is denoted by P_s in Figure 4a, by P , in Figure 4b, and by P_s in Figure 4c. In these figures, the circumference of the conductor is shown in solid lines and the circular circumference formed by the intersection of the sectional plane with the conductor element is denoted by $16a$ in Figure 4a, $16b$ in Figure 4b, $16c$ in Figure 4c and the "cut-off" region is shaded. The summits of said three archs are denoted by N_s , N'_s , N''_s , respectively.

In such a conductor element the light rays can be reflected with suitable angle of incidence either on the first main face or on the flat side faces of the conductor element, as for instance indicated by D_1, D_2 and G_1, G_2 in Figure 4a.

A light ray impinging on the first main face during its first impact at such an angle of incidence that total reflection occurs, traverses the chords which subtend a great circle until either the collection thereof or until incidence on a side face of the conductor element, if the great circle is interrupted. This also applies to a light ray which has already experienced one or more reflections on the side faces of the conductor element.

In fact when a light ray impinges on one of the side faces of the conductor element, it emerges or, with suitable angle of incidence, it is reflected towards the interior of the conductor element. It may then either meet the opposite side face on which it is reflected or the first main face on which it is reflected with suitable angle of incidence (or from which it emerges in the opposite case). If it is reflected it traverses the chords which subtend a great circle until its collection or, if said great circle is interrupted by one of the side faces, until its meeting with said side face.

Figures 4a, 4b and 4c show, also in solid lines, the path in the plane of intersection of the studied light rays. The circumference of the first main face in the plane of the Figure is denoted by $11ac$, $11ad$, $11ae$, respectively, and the circumference of the second main face is denoted by $12ac$, $12ad$, $12ae$ in Figures 4a, 4b and 4c.

The two side faces in Figure 4a are denoted by D and G , in Figure 4b by E and F and in Figure 4c by J and K , said different letters being completed by suitable indices. For example, index 1 denotes the meeting point of each side face with the second main face of the conductor element and with the plane of section, index 2 denotes the meeting point of each side face with the end of the circumference of the first main face situated in the plane of the figure. Index 3, also in Figures 4a and 4b, denotes the meeting point of each side face of the main face of the conductor element and of the plane of section and J_3 and K_3 in Figure 4c denote the meeting points of the plane of section and of the main faces of the conductor element.

The angles of value $\pi-2$ with the source points P_s , P , and P_s as origin and situated in the plane of section are also denoted at $\widehat{M_1 P_s M'_1}$, at $\widehat{M_2 P M'_2}$ and at

$M_3P_3M'_3$. The sides of these angles intersect, on the one hand at U_1 and U'_1 and at U_2 and U'_2 , respectively, the elongation of the archs D_2G_2 and E_2F_2 in the Figures 4a and 4b, and on the other hand, at U_3 and U'_3 , the arch J_2K_2 in Figure 4c.

It will be obvious that it is useless to describe all kinds of cases in this specification. It is restricted hereinafter to the description of what happens with a few light rays propagating in the plane of section until they meet the first main face for the first time.

It has also been decided to consider in the following remarks the points D'_2 and G'_2 on the arch of a circle D_3G_3 , E'_2 and F'_2 on the arch of circle E_3F_3 , J'_2 and K'_2 on the semi-circle K_3J_3 , as well as the points Q_6 , Q'_6 and Q''_6 , the summits of the archs D_2G_2 , E_2F_2 , J_2K_2 .

Furthermore only rays in one of the halves of the conductor element are considered because of the symmetry with respect to the main face of the conductor element in which the source point in question is situated.

A light ray which meets a side face at a small angle of incidence emerges from the conductor element in the absence of a complementary metallisation. A ray which is reflected on a side face propagates up to the next impact as if the same originated from a symmetrical point of the source point relative to the side face.

In Figure 4a each ray originating from P_6 and propagating in the plane of section and the first impact of which is on the side face D, leaves the conductor element if the impact takes place between D_1 and M_1 , as is the case for the ray $P_6I_1I'_1$; likewise each ray emerges from the conductor element which originates from P_7 and which in Figure 4b propagates in the plane of section and the first impact of which is at E between E_1 and E_3 , as is the case with the ray $P_7I_2I'_2$.

In Figure 4a a light ray is reflected to the interior of the conductor element if the impact takes place between M_1 and D_3 , as is the case for the ray $P_6I_4I'_4$. If it does not emerge at I'_4 the light ray begins a path through the cortical region in the plane which is symmetrical with respect to D and it has a chance to be collected usefully whether it has met a side face or not.

A light ray of which the first impact takes place between D_3 and D'_2 (Figure 4a) or between E_3 and E'_2 (Figure 4b) or between J_3 and J'_2 (Figure 4c) begins a path in the cortical region which is interrupted by an impact on the side faces D, E or J: if the first impact of said ray takes place between E_3 and M_2 (Figure 4b) or between J_3 and J'_2 (Figure 4c) the light ray during said impact emerges from the conductor element, this is the case with the rays $P_7I_{aa}I_{ab}I_{ac}$ (Figure 4b) and $P_8I_{aa}I_{ab}I_{ac}$ (Figure 4c); if on the contrary the first impact takes place between D_3 and D'_2 (Figure 4a), between M_2 and E'_2 (Figure 4b), then the light ray is reflected on the side face D or E, it begins a path in the cortical region in the plane which is symmetrical with respect to the said side face, it is collected and can possibly be collected usefully. This is the case with the ray $P_7I_{bb}I_{bc}$ (Figure 4b).

Each light ray the first impact of which takes place in the cortical region between D'_2 and N_6 (Figure 4a) between E'_2 and N'_6 (Figure 4b) and between J'_2 and N''_6 (Figure 4c) traverses a normal path in the cortical region without the side faces intervening. So it is collected normally. $P_6D'_2D_2$, $P_6G'_2G_2$, $P_7E'_2E_2$, $P_8J'_2J_2$, $P_8K'_2K_2$ in Figure 4 denote the light rays originating from P_6 , P_7 , P_8 and the limit of the beam of rays which traverse a normal path in the cortical region.

In practice the opening of the conductor element in figures 4a and 4b is $\pi - 2\theta$ for which the height of the spherical segment is smaller than $R \sin \theta$; this is equal to

the angle $J_2P_8K_2$ in the case of Figure 4c in which the height of the spherical segment is larger than $R \sin \theta$.

So if the arch of the spherical zone which forms the first main face of a conductor element having the shape of a spherical segment having two side faces is smaller than $\pi - 2\theta$, the aperture of the said conductor element is in fact substantially equal to $\pi - 2\theta$. If said arch is larger than $\pi - 2\theta$, the opening of the said conductor element is equal to the arch itself.

So very thin conductor elements can be made having an opening which is substantially equal to $\pi - 2\theta$, which may have advantages in the case of lack of space. It may also be preferred to use conductor elements having an opening larger than $\pi - 2\theta$ having a better efficiency. So it is obvious that the conductors including conductor elements having the shape of a spherical segment having two side faces and provided with a cavity in the second main face, which, for example, gives said second main face a homothetical shape of the shape of the first main face, are according to the invention. These show in particular the advantage of a low weight.

Conductor elements of the conductors in accordance with the invention of which the first main face is a spherical zone (and this irrespective of the shape of their second main face) are well distinguished from a number of known conductor elements. In particular, the conductor elements of the light conductors in accordance with the invention are to be distinguished from optical fibres of which the cross-section is square, rectangular or even circular. If such fibres are bent in the form of a circle, the shape obtained is completely different from the conductor in accordance with the invention. The transfer efficiency in these fibres is much smaller than in the embodiments of the invention. It is also of importance to distinguish them from the conductor elements of which the first main face is not circular because the cross-section of such conductor elements through the plane of propagation of the light ray cannot be circular. In general it is a cone. The angle of incidence is not maintained and the light rays are collected in a much less efficient manner. The light transfer only can be lower.

Figures 5a and 5b are a sectional view (taken on the line CC of Figure 5b) and a plan view, respectively, of a light conductor 20 according to the invention which has a hemispherical conductor element 21, two optical fibres, one 22 for the injection and the other 23 for collection, and three extra metallisation faces which are denoted by 25, 26a and 26b.

The conductor element 21 is bounded by a first main face 81a, and by a second main face 82, which is parallel to the tangential plane at the summit of the hemisphere relative to the plane to which the two fibres 22 and 23 are perpendicular.

The centre of the hemispheres is denoted by O_0 , the main diameter by $A_0A'_0$, the two limit points by L_0 , L'_0 , the limit angle being taken into account, and the semi-circle 84a of radius $O_0L_0=O_0L'_0=R \sin \theta$ is shown in broken lines which in the plane of the drawing is the circumference of the hemispherical face 84 which bounds the area of the cortical region.

The intersection of said surface 84 with the second main face 82 defines on the same a region 82a of the cortical region at the circumference on which the two optical fibres emerge.

The emitter is placed at 27 in the entrance of the fibre 22. Its dimensions and those of the injection fibre are such that the injection takes place between the two points P_0 and P_7 which themselves are situated within the cortical segment A_0L_0 . Actually, in the case of Figure 5a, the points P_0 and P_7 limit the above-mentioned injection zone.

In Figure 5a are shown the opening limit light rays P_0I_{m01} and P_0I_{m02} (tangent to the limit circle) for the point P_0 , and P_7I_{m71} and P_7I_{m72} (tangent to the limit circle) for the point P_7 . Also shown in Figure 5b is the projection for said two source points of the circles on which said opening limit points are situated and which are denoted by I'_{m01} , I''_{m01} , I'_{m71} , I''_{m71} , I'_{m02} , I''_{m02} , I'_{m72} and I''_{m72} .

The dimensions of the section of the collecting fibre are so much larger that collection can be carried out throughout the emergence area of the light rays which are transmitted by total reflection from A'_0 up to and including L_0 in the plane of Figure 5a.

In the case of Figure 5a the points A'_0 and L_0 limit, in the plane of the figure, the zone which above is termed collecting zone as well as the emergence area.

The length of the fibres 22 and 23 may be small or the fibres may even be omitted. In the latter case the said places for the transfer from the emitter to the conductor and/or from the conductor to the receiver then coincide with the injection and collection zone.

It may also be important to provide such a conductor in the light transfer places of the spaces in which the emitter and the receiver are accommodated, dipped, adhered or encapsulated. If the optical fibres are omitted the injection and collection zones may be situated within the conductor element beyond the second main face.

In the device shown in Figure 5 the conductor carries, directly and separately, the emitter and the receiver which it supports.

Figures 5a and 5b show two light rays originating from P_7 : $P_7I_{70}I'_{70}P'_7$ in the plane of Figure 5a and $P_7I_{700}I'_{700}P'_7$ in a plane which makes an angle with the plane of Figure 5a and the line of intersection of which with the hemisphere 20 is denoted by 29. The angle of incidence of these two light rays is such that there is no total reflection, but that they are reflected by the metallisation faces 26a and 25 which are deposited on the first main face 81a.

The forms given to the metallisation faces in the Figures 5, namely those of a

half cap for 26a and 26b and that of a zone which is symmetrical for the face 25 are particular important.

Good insulation between the emitter and the receiver can be obtained with such a conductor element.

It should be noted that in the figures the metallisation faces project beyond the total reflection surfaces; of course this is not inevitable but may be useful, especially for series manufacture in which the metallisation tolerances may be large.

The photocoupler shown in Figures 6a and 6b comprises a support 61 which mainly consists of a plate of insulating material, for example glass or ceramic, in which by local deposition two metal faces 62 and 63 of gold or another material have been formed which can be readily soldered to semiconductor crystals in which the light emitter 64 and the photoreceiver 65 are accommodated. These two faces 62 and 63 are connected to two of the connections which are passed through the insulating material of the support 61.

The emitter 64 is, for example, an electroluminescent semiconductor diode of gallium arsenide and the photoreceiver is, for example, a silicon photodiode.

For the emitter 64 the contacts are provided on the one hand on the lower face of the single crystals, via the metal face 62 on which it is soldered, and, on the other hand, via a wire 67 which is welded to the contact face 69 and which in addition is connected to one of the connections 66 which is insulated from the faces 62 and 63.

The contacts of the receiver are made via a wire 68 which is soldered to the contact face 70 and which in addition is connected to another connection 66 which is insulated from the faces 62 and 63 and via the lower face of the photodiode 65, which is soldered to the metal face 63.

The assembly is covered with a light conductor according to the invention which simply consists of a hemispherical conductor element 71 and is manufactured from a transparent material having a high index of refraction (for example, polycarbonate having an index of 1.58).

This conductor element 71 comprises a first hemispherical main face 72. The second main face 73 bounds a hemispherical cavity 74 which is concentric with the structure of the conductor element; it terminates at the periphery with a flat corona 73a of which the plane is parallel to the tangent at the summit of the hemispherical conductor element 71.

The hemispherical conductor element 71 supports on its face 72 three complementary metallisation faces 75a, 75b and 76.

The conductor element 71 bears on the emitter 64 and on the photoreceiver 65 at two zones 77 and 78 of the corona. These two zones serve as a supporting point and a connection point, the said connection being effected by means of a likewise transparent resin having the same index of refraction as the material of the conductor 71. They broadly coincide with the injection and collection zones which are not shown in the figure.

The device could be realized by moulding the conductor on the previously mounted assembly of supporting plate and the semiconductor crystals.

The photocoupler may be covered with a cap or an opaque resin which is not shown in the drawing.

Applicants have manufactured such photocouplers in which the conductor which is formed only by a conductor element is of polycarbonate ($n=1.58$) and has as a radius $R=1.2$ mm, $r=0.7$ mm ($R \sin \theta=0.75$ mm); the emitter and receiver crystals each have a length of 0.4 mm. The device operates perfectly, the light transfer is excellent and in the absence of a complementary metallisation said device has an electric insulation of 6000 volts between emitter and receiver. In addition it is very rigid.

One of the advantages of said photocoupler is that several of them can be accommodated in the same housing. Applicants have manufactured in particular photocouplers having four paths by arranging in the same housing four photocouplers according to the invention. Such light, if any, as may pass between one photocoupler and another is virtually eliminated by a black plastic envelope.

WHAT WE CLAIM IS:—

1. A light conductor for conducting light from an injection zone to a collection zone by total reflection, in which the light conductor has the shape of at least part of a half-sphere with a spherical surface and a base surface, the half-sphere having a radius R and being formed from a material having an index of refraction n , at least the spherical surface where the total reflection occurs bounding an exterior



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half cap for 26a and 26b and that of a zone which is symmetrical for the face 25 are particular important.

Good insulation between the emitter and the receiver can be obtained with such a conductor element.

It should be noted that in the figures the metallisation faces project beyond the total reflection surfaces; of course this is not inevitable but may be useful, especially for series manufacture in which the metallisation tolerances may be large.

The photocoupler shown in Figures 6a and 6b comprises a support 61 which mainly consists of a plate of insulating material, for example glass or ceramic, in which by local deposition two metal faces 62 and 63 of gold or another material have been formed which can be readily soldered to semiconductor crystals in which the light emitter 64 and the photoreceiver 65 are accommodated. These two faces 62 and 63 are connected to two of the connections which are passed through the insulating material of the support 61.

The emitter 64 is, for example, an electroluminescent semiconductor diode of gallium arsenide and the photoreceiver is, for example, a silicon photodiode.

For the emitter 64 the contacts are provided on the one hand on the lower face of the single crystals, *via* the metal face 62 on which it is soldered, and, on the other hand, *via* a wire 67 which is welded to the contact face 69 and which in addition is connected to one of the connections 66 which is insulated from the faces 62 and 63.

The contacts of the receiver are made *via* a wire 68 which is soldered to the contact face 70 and which in addition is connected to another connection 66 which is insulated from the faces 62 and 63 and *via* the lower face of the photodiode 65, which is soldered to the metal face 63.

The assembly is covered with a light conductor according to the invention which simply consists of a hemispherical conductor element 71 and is manufactured from a transparent material having a high index of refraction (for example, polycarbonate having an index of 1.58).

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The device could be realized by moulding the conductor on the previously mounted assembly of supporting plate and the semiconductor crystals.

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WHAT WE CLAIM IS:—

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medium having an index of refraction n_2 which is lower than n_1 , the injection zone and the collection zone being situated diametrically opposite one another on the base surface, the distance d between each of said zones and the centre of the sphere fulfilling the following condition:

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$$R \sin \theta \leq d \leq R$$

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in which $\sin \theta = n_2/n_1$.

2. A light conductor as claimed in Claim 1, characterized in that it has a hollow spherical cavity concentric with the spherical surface of the half-sphere, the radius r of the spherical cavity fulfilling the condition $r = R \sin \theta$.

3. A light conductor as claimed in Claim 1 or 2, characterized in that it has the shape of part of a disc cut out of the half-sphere, the parallel flat side surfaces of said disc being perpendicular to the base surface and lying one each on either side of the centre of the sphere at equal distances therefrom.

4. A light conductor as claimed in any of the Claims 1—3, characterized in that it consists mainly of glass.

5. A light conductor as claimed in any of the Claims 1—3, characterized in that it consists mainly of a synthetic resin.

6. A photocoupler having at least a light emitter, a light receiver and a light conductor as claimed in any one of Claims 1 to 5 for transmitting light between the emitter and the receiver.

7. A light conductor substantially as described with reference to Figure 5 of the accompanying drawings.

8. A photocoupler substantially as described with reference to Figure 6 of the accompanying drawings.

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