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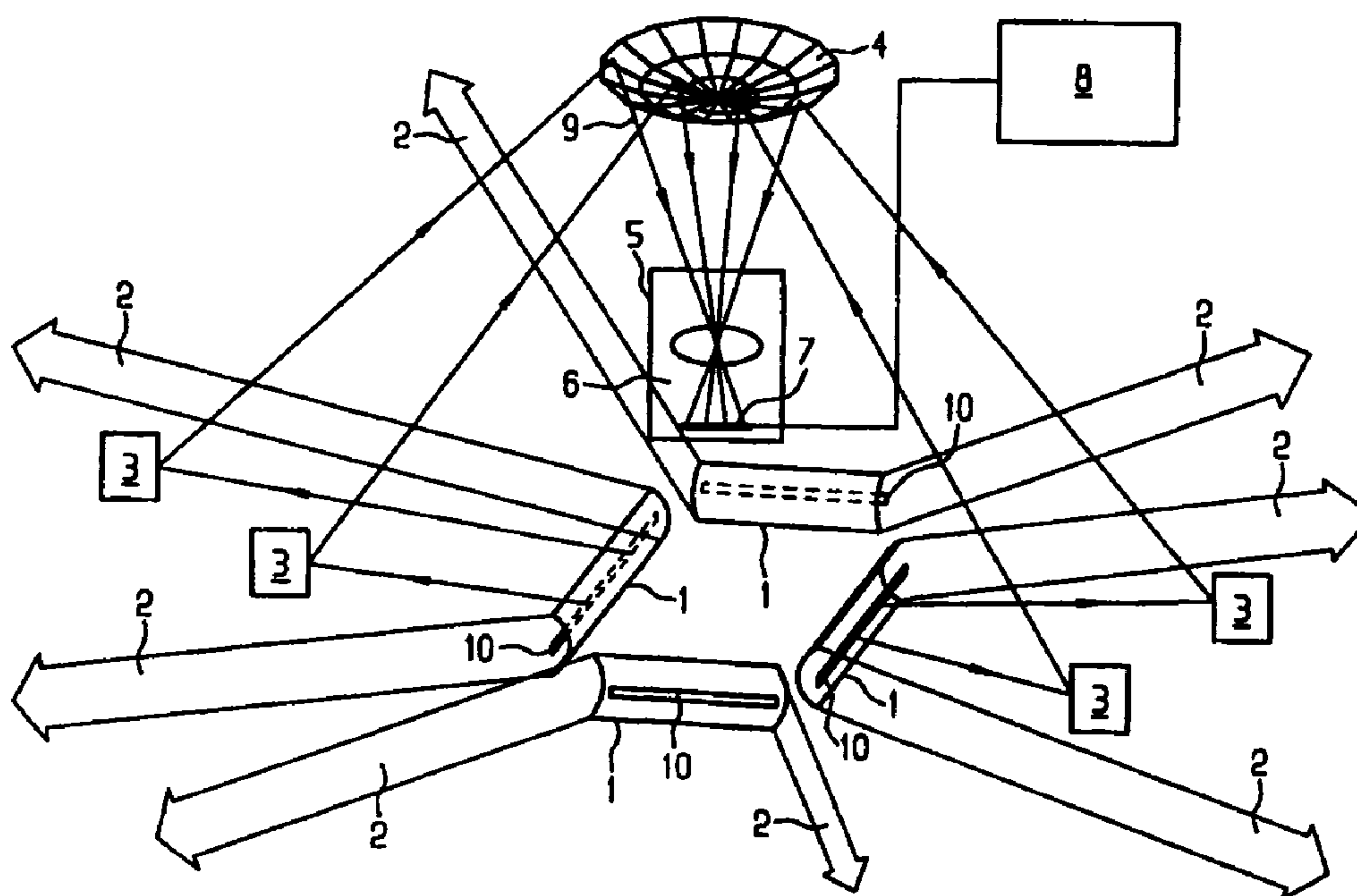
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(54) **SYSTEME OPTIQUE DESTINE A LA DETECTION DE LA
POSITION D'UN OBJET**

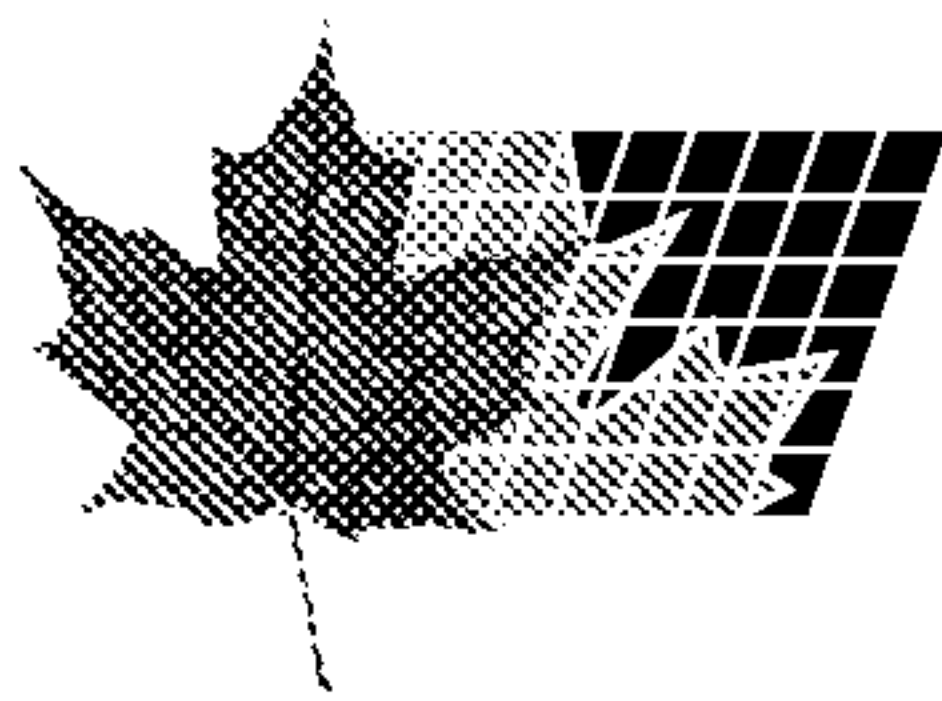
(54) **OPTICAL SENSOR SYSTEM FOR DETECTING THE POSITION
OF AN OBJECT**



(57) L'invention concerne une source lumineuse spéciale produisant une bande lumineuse horizontale. Cette bande lumineuse est réfléchiée par des objets situés dans l'environnement du système de détection et dirigée sur

(57) The invention relates to a special light source which produces a horizontal strip of light. Said strip of light is reflected by objects in the vicinity of the sensor system and conducted to a photoelectric converter by a special





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un convertisseur photoélectrique via un dispositif imageur spécial. Ce dispositif imageur permet de représenter encore plus éloignés des objets déjà plus éloignés afin d'obtenir par un objectif courant de résolution linéaire une meilleure résolution de la position des objets sur toute la surface image, ces objets étant encore plus loin du système de détection. On utilise avantageusement comme éléments émetteurs de lumière des diodes électroluminescentes placés sur l'axe optique d'un miroir cylindrique. Les signaux électriques cédés par le convertisseur photoélectrique sont exploités en termes de position par une unité d'évaluation qui détermine par triangulation la distance des objets qui ont réfléchi la lumière.

imaging device. Said imaging device is configured in such a way that objects situated further away are represented as being somewhat further apart so that an ordinary objective with linear resolution can obtain better position resolution of objects situated further away from the sensor system over the entire imaging area. Advantageously, light-emitting diodes are provided on the optical axis of a cylindrical mirror as the light-emitting elements. The electrical signals emitted by the photoelectric converter are evaluated by an evaluation unit in relation to their position. Using triangulation, said evaluation unit then determines how far away the objects which reflected the light are situated.

Abstract

The invention proposes a specific light source, which generates a horizontal light strip. This light strip is reflected by objects in the environment of the sensor system and conducted via a specific imaging device to a photo-electrical converter. This
5 imaging device is configured such that it represents objects situated further away as being somewhat further apart, so that an ordinary objective with a linear resolution can obtain better position resolution of objects situated further away from the sensor system over the entire imaging area. Advantageously, light-emitting diodes are
10 provided on the optical axis of a cylindrical mirror as the light-emitting elements. The electrical signals emitted by the photo-electrical converter are evaluated by an evaluation unit in relation to their position; which evaluation unit determines how far the objects, which reflected the light, are situated.

OPTICAL SENSOR SYSTEM FOR DETECTING THE POSITION OF AN OBJECT

The invention relates to an optical sensor system for exploring objects and for
5 detecting their position. Preferably, this sensor system can be arranged at autonomous mobile systems, so that it is possible for them to orientate themselves in an unknown environment.

Autonomous mobile systems, which are in the making and planning, will be found in
10 the future more frequently in household environments as well. They will carry out transport and cleaning tasks in that they autonomously carry out the tasks imposed on them with the aid of an orientation system, which makes it possible for them to create an image of their environment. Apart from the different path planning and evaluation algorithms, the sensor system for detecting obstacles in the environment of the
15 autonomous mobile unit is extremely important. In order to make autonomous mobile systems attractive to consumers, it is particularly important that they can be produced in large quantity cost-efficiently and technically simple. Therefore, the sensor systems of the autonomous mobile systems must be robust and able to be produced
inexpensively.

20 The prior art discloses optical sensor systems that carry out the detection of objects by means of triangulation. For example, a specific measuring method carries out an active triangulation with strip lighting. The main elements of such a measuring system are a light source, which illuminates a strip in space, an optical imaging
25 system, a two-dimensional image receiver and an electronic unit for processing and evaluating the signals received by the image receiver. For purposes of performing a triangulation, such a system requires a light source, which exclusively illuminates a space strip. An important feature of this light source is the surface density of its emitted luminous power. A great power density for being able to also recognize dark
30 objects are [sic] a requirement to be met by such a light source. Another feature of

such light sources is the thickness of the illuminated strip, which thickness influences the size of the detectable space area and the resolution during the position measuring of detected objects.

5 The following possibilities for fashioning light sources for the output of luminous strips are currently known: a cylindrical lens in front of a collimator objective, which collimates the light of a laser source or of a filament, halogen or arc lamp; the parallelization of light from a filament or halogen lamp with the aid of an collimator objective and its spreading by means of a cone mirror. The utilized imaging system
10 must meet two main requirements. On one hand, it must image the space area to be measured onto the surface of the two-dimensional image detector; on the other hand, it must assure the desired position resolution regarding the objects to be measured. In this context, the position resolving capacity is the smallest distance between objects, which can still be resolved after the imaging onto the opto-electrical converter. It is
15 determined by the utilized converter and also by the imaging system. The task to image a large space area, optimally in the form of a whole half-space in a wide-angle manner and to thereby generate a sufficient distance resolving capacity with the same objective, represent [sic] contradictory requirements [sic]. A possible means for enlarging the measurable space area by means of such an imaging system is the
20 application of a wide-angle objective, which generates an image that is free of distortions. However, such objectives with a plurality of lenses have the disadvantage that they cannot image the entire half space around the objective. Other objectives, in turn, which image an entire half-space, no longer work without distortions and are expensive to buy. Distorting objectives also influence the position resolution during
25 the triangulation. The distance in the imaging area between the images of the back-scattered light of two neighboring objects, which are close to the imaging system, is represented larger compared to the two neighboring objects that are situated further away from the imaging system. This has the effect that the position resolution becomes poorer with an increasing distance from the objective or, respectively,
30 imaging system. The imaging system cannot image far-away objects sufficiently far-

away from one another by applying normal or aspherical refracting surfaces, as they are conventional for normal objectives. In order to image such objects, it would be necessary to use an optical imaging element that is optimized for this specific purpose; however, said imaging element is not known from the literature.

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The European publication EP 0 358 628 A2 with the title "Visual navigation and obstacle avoidance structured light system" discloses a triangulation system for applying to mobile vehicles, which triangulation system uses strip illumination and a normal objective in an imaging system. The disadvantages of this solution are that the vehicle can only detect objects in front, namely objects situated in driving direction and that only a restricted area or close objects can be utilized with a sufficient resolution for the distance measuring of objects due to the utilization of a normal objective. The articles of R. A. Jarvis, J. C. Byrne: "An automated guided vehicle with map building and path finding capabilities"; in R. C. Bolles and B. Roth, publisher, 4th International Symposium on Robotics Research, p. 497-504, MIT press, Cambridge, Massachusetts, 1998, - and Y. Yagi, Y. Nishizawa, M. Yachida: "Map based navigation of the mobile robot using omnidirectional image sensor COPIS, Proc. Of the 1992 IEEE International Conference on Robotics and Automation, Nice, France, May 1992 discloses to carry out the imaging of the environment by means of a cone mirror and an objective. The utilized cone mirror does not change the resolving capacity of the system with respect to far-away objects. Furthermore, it is determined by the camera objective. The article of J. Hong, X. Tan, B. Pinette, R. Weiss, E. M. Riseman; "Image-based Homing, Proc. Of the 1991 IEEE International Conference on Robotics and Automation, Sacramento, California, April 1991 discloses to carry out the imaging of the environment by means of a spherical ball. However, a strip lighting, which could be used for the triangulation, is not utilized. Such what are referred to as passive systems have the disadvantage that the objects are not illuminated by a light beam with known height level, so that position information items are very difficult to obtain, since a triangulation cannot be performed. Realtime image processing systems, which require

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a great outlay with respect to computer capacity, must be used for the evaluation. Furthermore, the article of P. Greguss: "PAL-Optik basierende Instrumente fuer Raumforschung und Robot-Technik, in Laser und Optoelektronik 28 (5) / 1996, page 43-49 discloses the utilization of a PAL-objective for the applications of navigation tasks with respect to autonomous mobile robots. The PAL-objective of Greguss is a wide-angle imaging element, which contains two mirrorin [sic] and one refracting aspherical surface and which is able to image an entire half-space. The application of the PAL-optics as imaging element of an active triangulating obstacle recognition system for robots is described there.

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Therefore, the invention is based on the object of proposing an optical sensor system, which can be attached to mobile vehicles, such as autonomous mobile robots; which is fashioned technically simple; which enables a detection of obstacles in all directions around the vehicle, whereby its imaging system has the position of objects in the close range of the system with respect to distances smaller than 50 cm and also in the remote range of the system with respect to distances of more than 2 m an sufficient position resolving capacity of approximately 5-10 cm an angle resolution of $< 1^\circ$. [sic]

20 This object is achieved according to the features of patent claim 1. Developments of the invention derive from the dependent claims.

Advantageously, the described sensor system is composed of light sources, which illuminate the environment of the autonomous mobile unit in the form of strips around the unit, since [sic] so that obstacles or, respectively, objects can be simultaneously detected all around the unit. Advantageously, a plurality of light sources that are above one another can be provided, which are switched on in different time intervals, so that different height dimensions of the space can be detected or, respectively, measured. Advantageously, the light that is back-scattered by illuminated objects is implemented [sic] by using a specific wide-angle imaging element, which only has

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one single arched, spherical or aspherical, mirroring surface for the light guidance, in connection with an objective and a filter, as well as with a photo-electrical converter, whereby the imaging system projects the environment onto the converter. This arrangement makes it possible to solve this task with an optimally low technical
5 outlay. Advantageously, the best space covering and the best position resolving capacity is achieved in a development of the invention in that the shape of the aspherical mirroring surface of the wide-angle imaging system is described with the aid of spline functions. The spline function describes the shape of the imaging element as follows: areas that are further away are represented in a stretched manner,
10 depending on the utilized objective, due to the spline function. On the basis of the spline function, the distance areas and the sub-areas of the aspherical imaging element that are valid for the respective distance areas are described such that the adjacent polynomial functions exhibit the same value and the same derivations in the respective transfer points, so that the utilized function is continuous and without
15 fractions. What is advantageously achieved by utilizing such an imaging system is that simple objectives with a normal viewing angle can be used for the wide-angle linear imaging characteristics that is necessary with respect to a further development of the invention. Due to the utilization of spline functions, it can be achieved that light, which is back-scattered from areas that are further away, is pre-distorted before
20 it passes through the objective, so that areas that are further away can be represented with a higher resolution as it would be normally possible by means of the objective. In this way, an imaging system is made available that offers a simple economical solution for the manufacture of wide-angle, linear optical systems.

25 Exemplary embodiments of the invention are explained in greater detail on the basis of images. Shown are:

- Figure 1 an exemplary embodiment of a sensor system.
- 30 Figure 2 a possible arrangement of a utilized light source in side view.

- Figure 3 a possible arrangement for generating a light strip around the sensor system.
- Figure 4 a further embodiment for generating a light strip around the sensor system.
- 5
- Figure 5 a further embodiment for generating a light strip around the imaging device.
- 10 Figure 6 a possible construction of the sensor system on a vehicle or, respectively, robot in side view.
- Figure 7 a plan view onto the sensor system and a vehicle.
- 15 Figure 8 a sensor system for the utilization with an one-dimensional photo-electrical converter.
- Figure 9 an embodiment with two-dimensional optical position detector.
- 20
- As shown in Figure 1, a possible embodiment of a described sensor system, which illuminates a space strip all around, is composed of 4 light sources 1. It is particularly important with respect to the arrangement of these light sources for illuminating a light strip that these light strips are situated in a plane that is essentially plane-parallel
- 25 to the base on which the autonomous mobile unit, which has the sensor attached, moves. If this plane-parallel arrangement is not possible, the triangulation is made more difficult, since it is important, when the reflect [sic] light beams are evaluated, that they have met the reflecting objects under different angle positions, so that different triangulation angles result for the triangulation for determining the distance
- 30 of the objects. The light sources 1 thereby generate light strips 2, which illuminate the

space. The utilized imaging element 4 projects the light that is back-scattered from the objects 3 through the objective 6 onto the photo-electrical converter 7, which, in this arrangement, is fashioned as a two-dimensional CCD image detector of a camera 5. The photo-electrical converter 7 is in connection with an evaluation electronic unit 8, which is at, for example, is in a computer [sic], which evaluation electronic unit 8 determines the position of objects 3, due to the image projected onto the photo-electrical converter 7, upon employment of the principle of the active optical triangulation, whereby particularly the imaging properties of the objective 6 and of the imaging element 4 are utilized in connection with the level of the plane in which the light strip is illuminated. Advantageously, the sensor system is utilized on mobile vehicles 12, such as a mobile robot. The current information items thereby can be determined by means of the evaluation electronic unit 8 via the control of the vehicle 12 or, respectively, of the robot, and the further driving path of the unit can be planned as a result of these information items. These information items indicate the positions of objects 3, for example, under which the vehicle 12 moves through, or between which the vehicle 12 must move.

In the embodiment shown in Figure 1, the optical axis of the imaging element 4 is advantageously perpendicularly directed toward the light strip 2, which are [sic] outputted by the light sources 1. In this embodiment, the imaging element 4 is fashioned as an optical element having a spherical or aspherical mirroring surface 9, whereby the outside of the mirroring surface 9 is used for the imaging of the reflected light beams in the imaging system. The light strips outputted by the light sources and the light beams reflected by the objects 3 are thrown via the imaging element 4 through the objective 3 onto the light detector 7, as it is schematically shown by means of the beam paths, which are provided with numbers. The distance of the light beams impinging onto the photo-detector 7 is characterizing for the distance of the objects 3 from the sensor system depending on the imaging properties of the objective and the imaging element 4. In the embodiment of the sensor system shown in Figure

1, any arbitrary two-dimensional image detector 7 can be used. For example, a photodiode matrix can be applied as a photo-electrical converter 7 instead of a two-dimensional CCD sensor.

5 In side view, Figure 2 shows a possible basic embodiment of the applied light source 1. The light source 1 shown in Figure 2 is composed of a cylindrical mirror 11, which expediently exhibits an aspherical cross-section and is composed of light emitters 10, which can be light-emitting diodes, for example. These light emitters are situated in the focus line of the cylindrical mirror 11. The light emitters 10, following one
10 another, are arranged in series [sic] in the focus line of the aspherical cylindrical mirror 11, so that the light-emitting surfaces of the light emitters 10 point in the direction of the aspherical cylindrical mirror 11. The light emitted by the light emitters 10 thereby initially reaches the aspherical cylindrical mirror 11 and subsequently emerges as a light strip 2 projected by the mirror. As a result of the
15 utilization of an aspherical mirror shape that is adapted to the light emitters 10, the light source 1 illuminates a parallelized light strip. It must be mentioned in this context that light-emitting diodes (LED) represent a cost-efficient, simple and small light source and that an inexpensive light source can be made available by the selected arrangement of the light-emitting diodes on the axis of the cylindrical mirror.

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As shown in Figure 3, one possible basis arrangement for generating a light strip 2 is composed of a part of a cylindrical mirror. The cylindrical mirror 11 hereby stands in a what is referred to as off-axis arrangement to the light emitters 10, so that only a part of the cylindrical mirror 11 (previously described in Figure 2) is utilized. The light
25 emitters are advantageously fashioned as LEDs and, following one another, are arranged on the focus line of the aspherical cylindrical mirror such that their light-emitting surfaces are directed in the direction of the aspherical cylindrical mirror 11. The parallelized light beam valid for the sensor system can also be generated by means of such a light source. This is indicated by the beam curve provided with arrows.

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As shown in Figure 4, another possible solution for generating a light strip 2 that illuminates all around the imaging device is that a parallelized light beam is placed in rotation. The rotating light beam 2 is generated such that not only the light emitter 10 but also the collimator optics 14 is placed in rotation all around an axis t. For
5 example, another embodiment is that not only the light emitter 10 but also the collimator optics 14 are fixed and that the light beam 2 is moved all around with the aid of a rotating mirror.

Figure 5 shows another possible embodiment for generating a light strip 2 that is
10 outputted all around . In this embodiment, the light strip 2 is generated by a cone mirror 15. The light outputted by the light emitter 10 is initially parallelized by means of a collimator optics 14 and is subsequently fanned into the desired light strip 2 by a cone mirror 15. For example, a filament lamp, halogen lamp, arch lamp or laser can be utilized as a light emitter 10 in this embodiment.

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Figure 6 shows the possible structure of a sensor system at an autonomous mobile unit 12, which can be a service robot, for example. Figure 6 shows the representation in side view. Advantageously, a plurality of light strips arranged above one another can be generated, which are outputted by a plurality of light sources 1 situated above one
20 another. Advantageously, the light strips 2 are generated above one another in different time intervals and are illuminated in a pulsed manner. A better height differentiation of the obstacles is achieved, since a plurality of light sources are arranged above one another. In order to be able to detect and measure possibly all obstacles all around the mobile vehicle 12, 2 imaging elements 4 with the in [sic]
25 appertaining cameras 5 are advantageously provided at two opposite corners of the mobile vehicle 12. The evaluation electronic unit assures that the corresponding height level of the currently switched-on light source is utilized for evaluating the triangulation results given the triangulation of obstacles.

Figure 7 shows a plan view onto an [sic] mobile vehicle 12 provided with the sensor system, for example a robot with the reception range of the detector system 13. As also shown in Figure 7, the individual imaging elements 4 are attached to respectively 2 opposite corners of the mobile system 12. I [sic] two imaging systems 4 are
5 arranged as shown in Figure 7, the detection range 13 of the optical sensor system can be extended to the entire environment of the mobile system 12 or, respectively, to the entire space surrounding the mobile system.

Figure 8 shows a possible embodiment of the photo-electrical converter 7 in the form
10 of an one-dimensional photo-electrical converter 7. The imaging element 4 projects the light through the objective 6 onto the one-dimensional light detector, which is moved or, respectively, advantageously rotated in the imaging area. This photo-electrical converter 7 can be fashioned as an one-dimensional position-sensitive detector, as CCD or PSD, for example. Since the one-dimensional light detector is
15 moved or, respectively, advantageously rotated in the imaging area, it detects the light intensity distribution in the entire imaging area, whereupon the imaging element 4 and the objective 6 images the spatial area situated around the mobile vehicle 12. The measuring results, which are received in this way, can be advantageously temporarily stored, or the evaluation ensues synchronously to the number of revolutions of the
20 photo-electrical sensor.

Figure 9 shows a further possible embodiment of a photo-electrical converter 7, which is represented here as a two-dimensional position-sensitive detector. In this embodiment, the photo-electrical converter 7 is fashioned as a two-dimensional
25 position-sensitive detector, which is situated behind the objective 6 in its imaging area. In this embodiment, an impermeable pane 16, which is provided with a gap 17, is situated between the objective 6 and the photo-electrical converter 7. The area above the position-sensitive detector, which is currently swept by the gap 17, is always released when this pane rotates. For example, the gap 17, on the opaque pane
30 16, only allows the light through of a well-defined spatial area, for example with an

opening angle of 1° . In this way, a direction resolving capacity having an arbitrarily small angle can be achieved. The gap width to be selected depends on how much light is retroreflected or, respectively, on the sensitivity with which the detector works and with which luminous power the light strip is illuminated by means of the light source. When a rotating parallelized light beam is applied as light strip 2, as this is shown in the exemplary embodiment of Figure 4, the application of the pane 16 is not necessary, since the direction resolution is already assured by the rotating light source. All in all, the described sensor system has the advantage that its reception range is larger compared to other known triangulating sensor systems. As a result of the wide-angle imaging, the positions of objects, which are far away from the sensor system, can be measured. The specific shape of the imaging element 4 thereby assures the uniform resolution of the distance measuring in the entire detection range in that it, as it were, corrects the deficient resolving capacity of the objective 6 with respect to the distance of the sensor system, since it scatters light beams reflected from there and thus pulls apart objects that are further away.

Patent claims

1. Optical sensor system for detecting the position of an object, with a light source for illuminating the environment, a photo-electrical converter, which converts the intensity distribution of the light back-scattered by objects into electrical signals and forwards them to a sensor signal evaluation system, characterized in that the sensor system has a light source (1) by means of which one or more light strips are generated in horizontal direction in a plurality of spatial directions, and which has an optical imaging element (4) for reflecting the light back-scattered by objects (3) and for projecting it onto the photo-electrical converter (7), whereby the optical imaging element (4) merely has one single spherical or aspherical mirroring surface (9).
2. Optical sensor system according to claim 1, which has an objective (6) in the beam path between the imaging element (4) and the photo-electrical converter (7).
3. Optical sensor system according to one of the claims 1 or 2, wherein the optical axis of the imaging element (4) is perpendicular to the illuminated light strip (2) and which has four light sources (1).
4. Optical sensor system according to one of the previous claims, which has a wide-angle imaging element (4).
5. Optical sensor system according to one of the previous claims, wherein the imaging element (4) has at least one aspherical mirroring surface (9) that can be described by two spline functions.
6. Optical sensor system according to one of the previous claims,

which has at least 2 light sources (1) situated above one another in order to generate two light strips (2) that are situated above one another.

7. Optical sensor system according to one of the previous claims,
5 which, as photo-electrical converter (7), has an one-dimensional position-sensitive light detector, which is moved.

8. Optical sensor system according to one of the claims 1 - 6,
which, as photo-electrical converter (7), has a two-dimensional position-sensitive
10 detector, whereby a spatial light modulator is attached in the beam path between the imaging element (4) and the photo-electrical converter (7).

9. Optical sensor system according to claim 8,
wherein a rotating pane (16), which is provided with a gap, or a liquid crystal
15 modulator is provided as a spatial light modulator.

10. Optical sensor system according to one of the claims 1 - 6,
wherein the photo-electrical converter (7) is fashioned as a two-dimensional image
detector matrix.

20

11. Optical sensor system according to one of the claims 1 - 5,
Wherein [sic] the light source (1) is fashioned as a rotating light source.

12. Optical sensor system according to one of the claims 1 - 10,
25 wherein the light source (1) is composed of light-emitting elements (10) and of a cylindrical mirroring surface (11) with an aspherical cross-section, whereby the light-emitting elements (10) are placed as light-emitting diodes in the focus line of the cylindrical mirror surface (11) such that the light-emitting surfaces of the elements (10) are faced toward the cylindrical mirror (11).

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13. Optical sensor system according to one of the claims 1 - 10, wherein the light source (1) for generating the light strip (2) is composed of a known light-emitting element, such as a filament lamp, halogen lamp, a light arch lamp or a laser, of a collimator optics (14) and of a cone mirror (15).

5

14. Autonomous mobile unit having a sensor system according to one of the claims 1 through 13.

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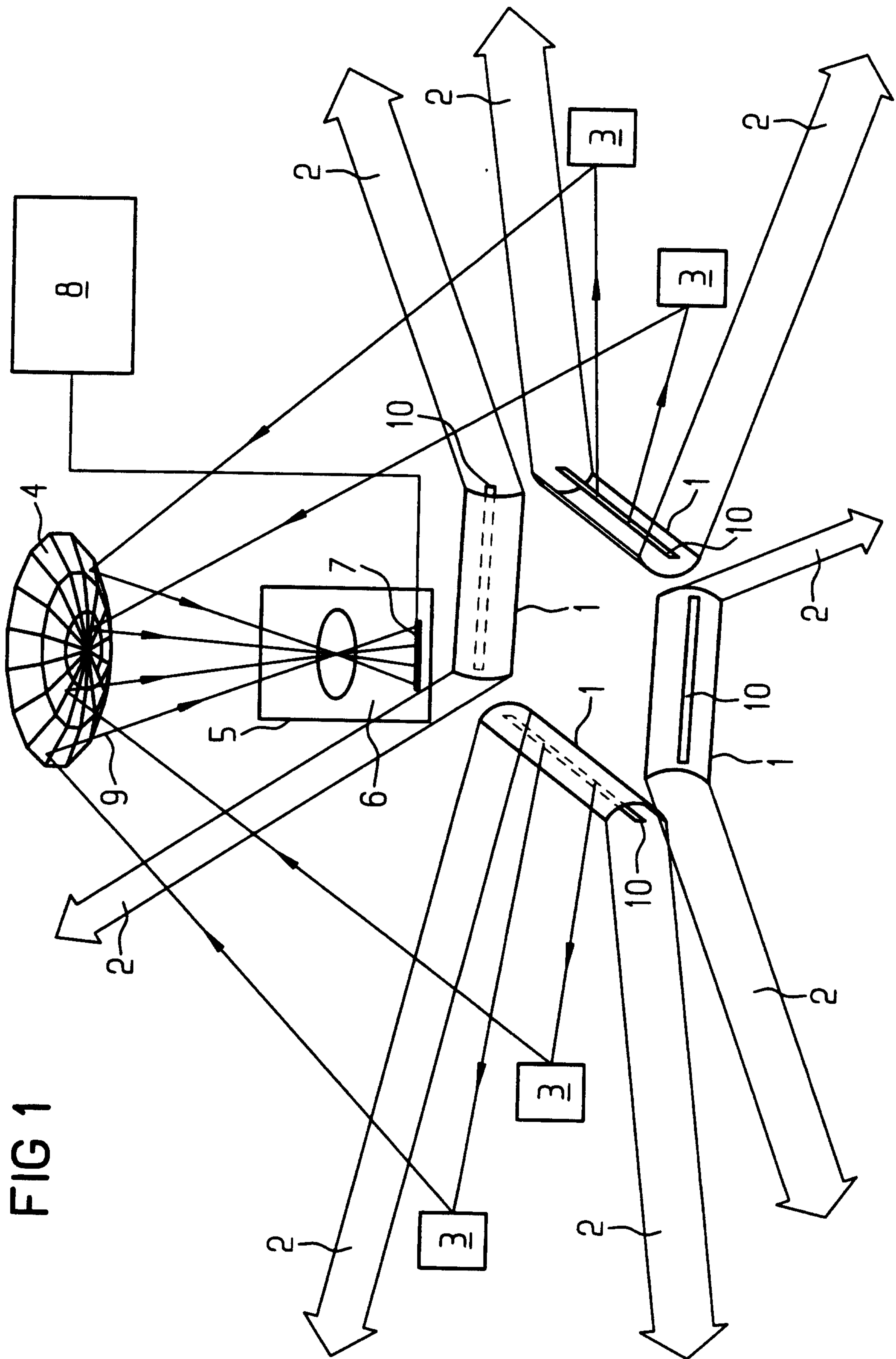


FIG 1

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FIG 2

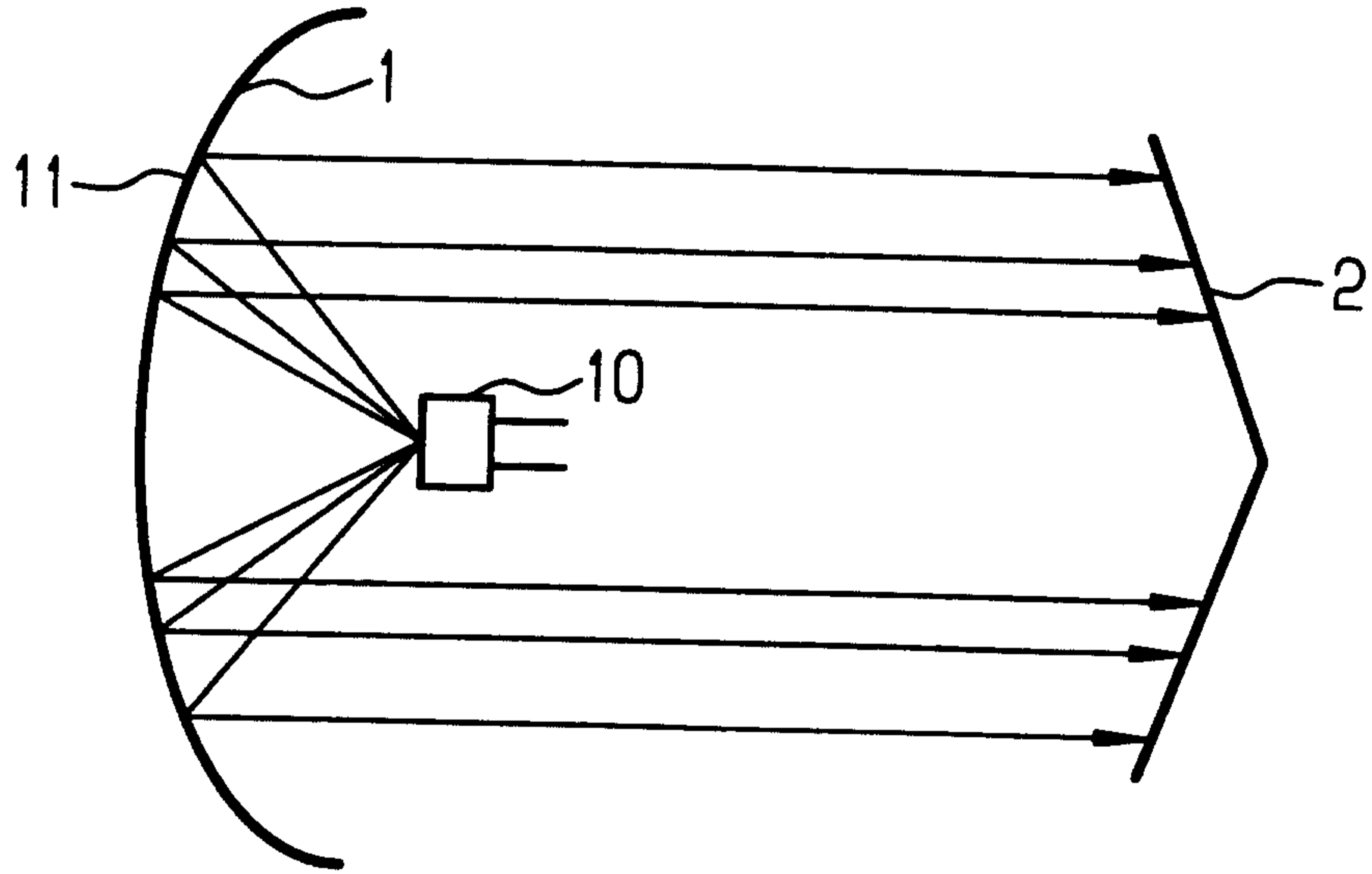
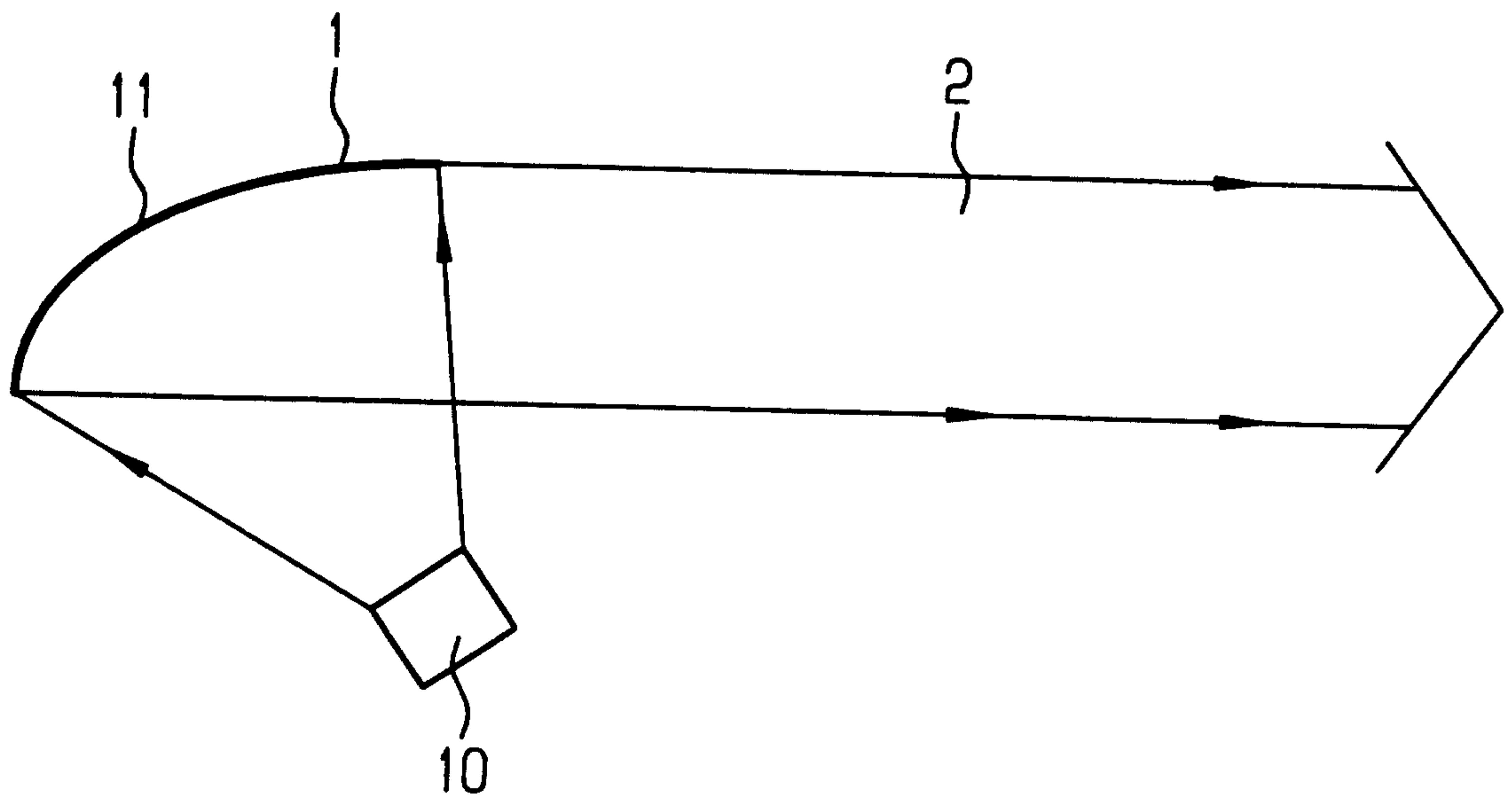


FIG 3



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FIG 4

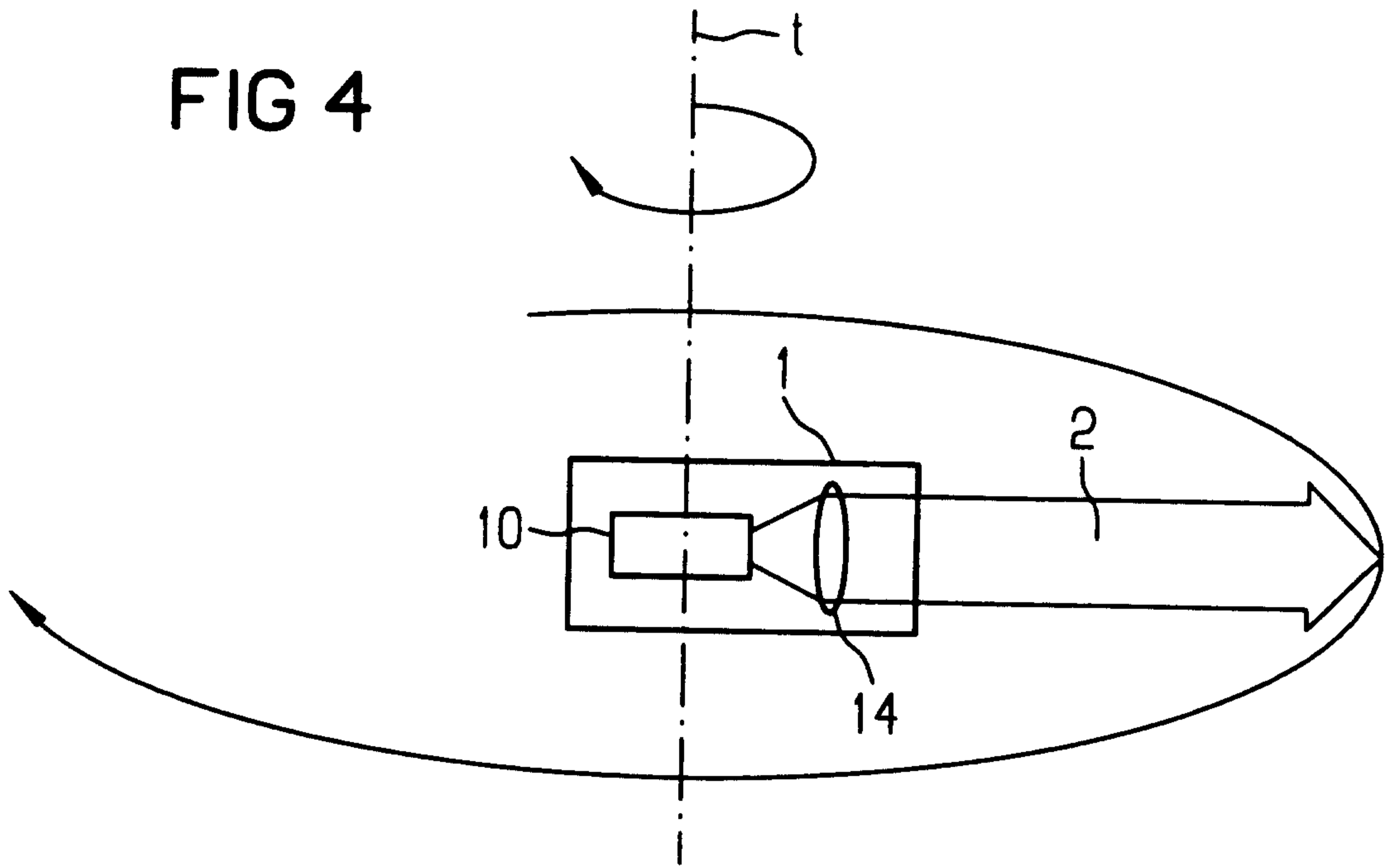


FIG 5

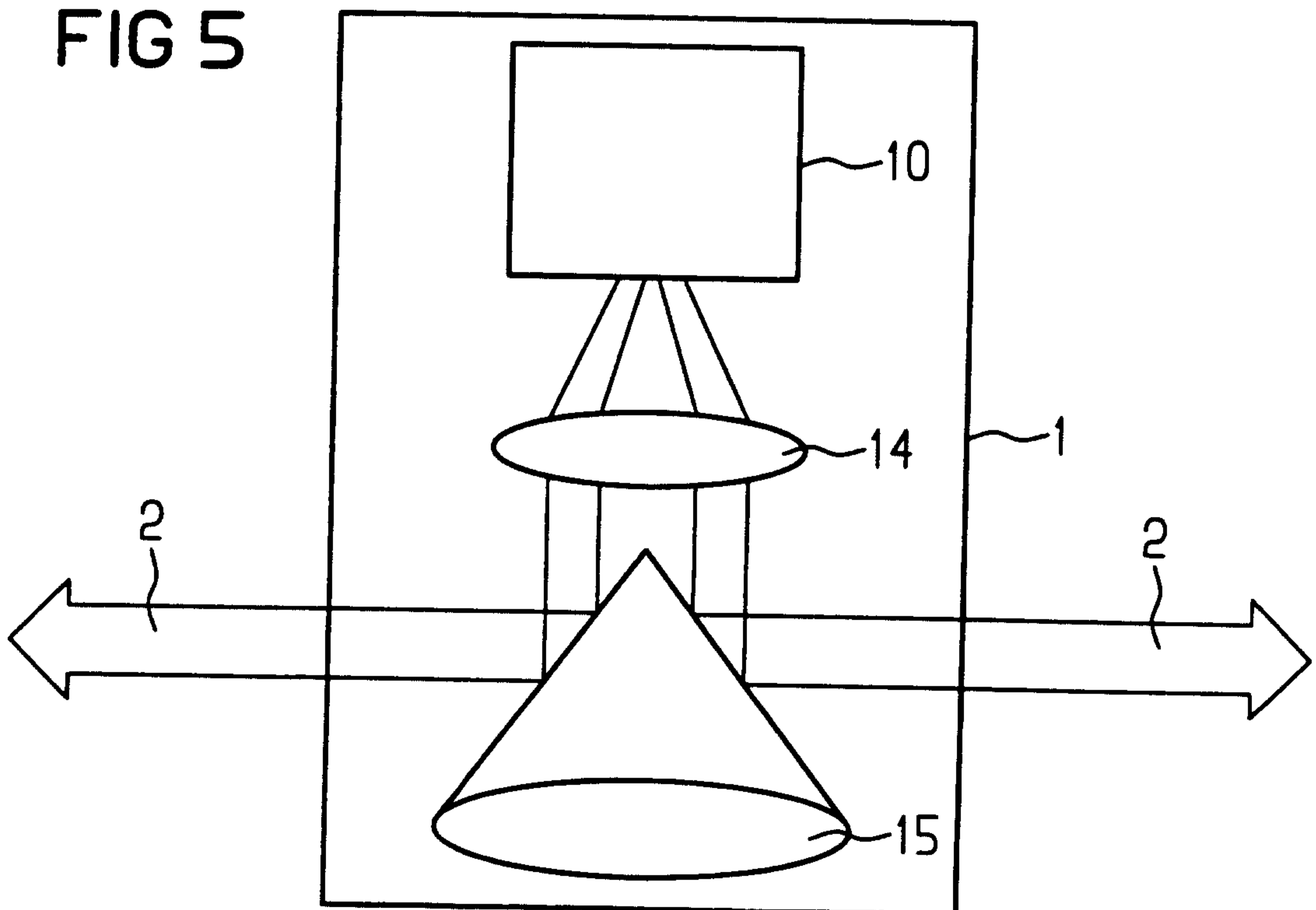


FIG 6

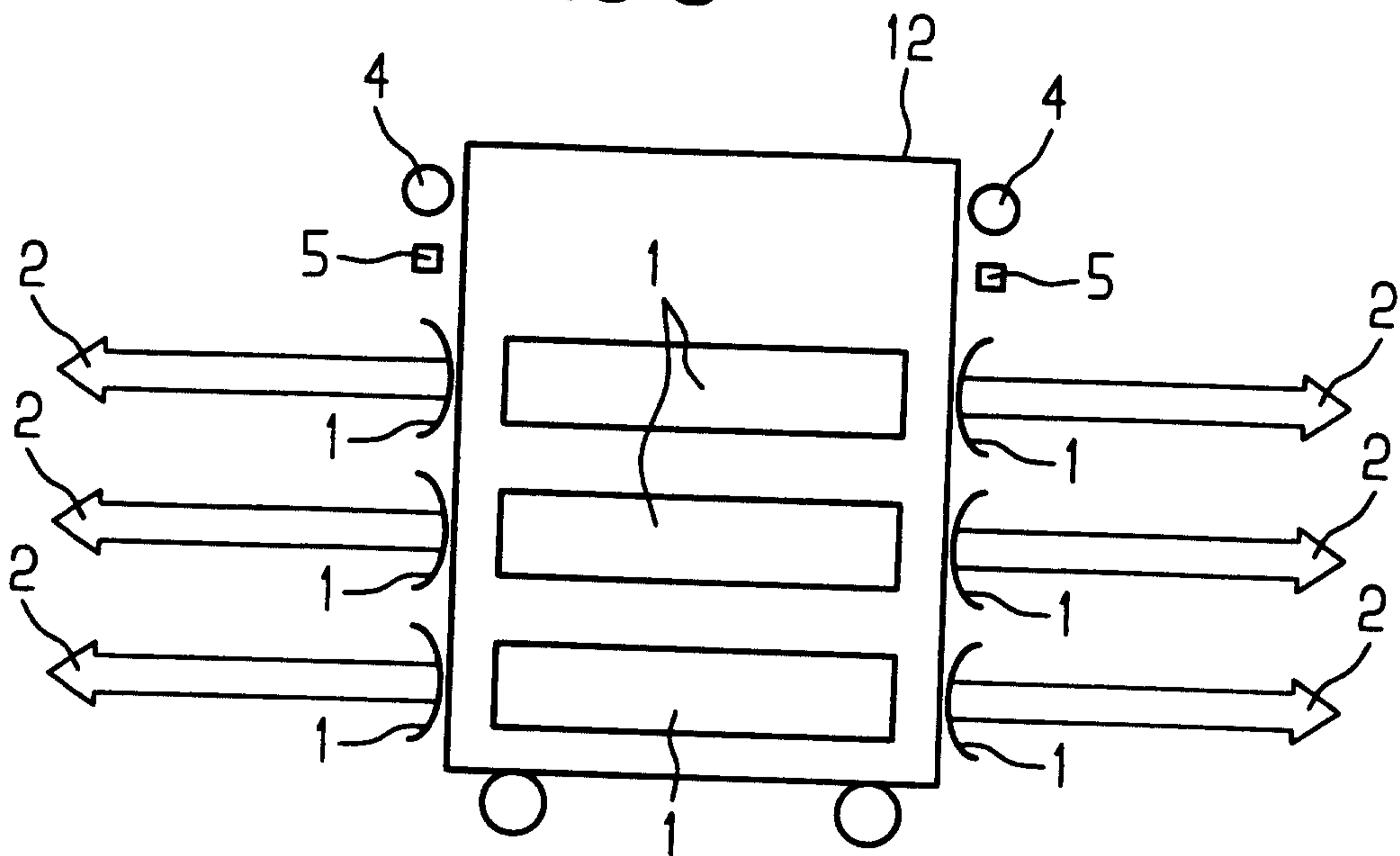
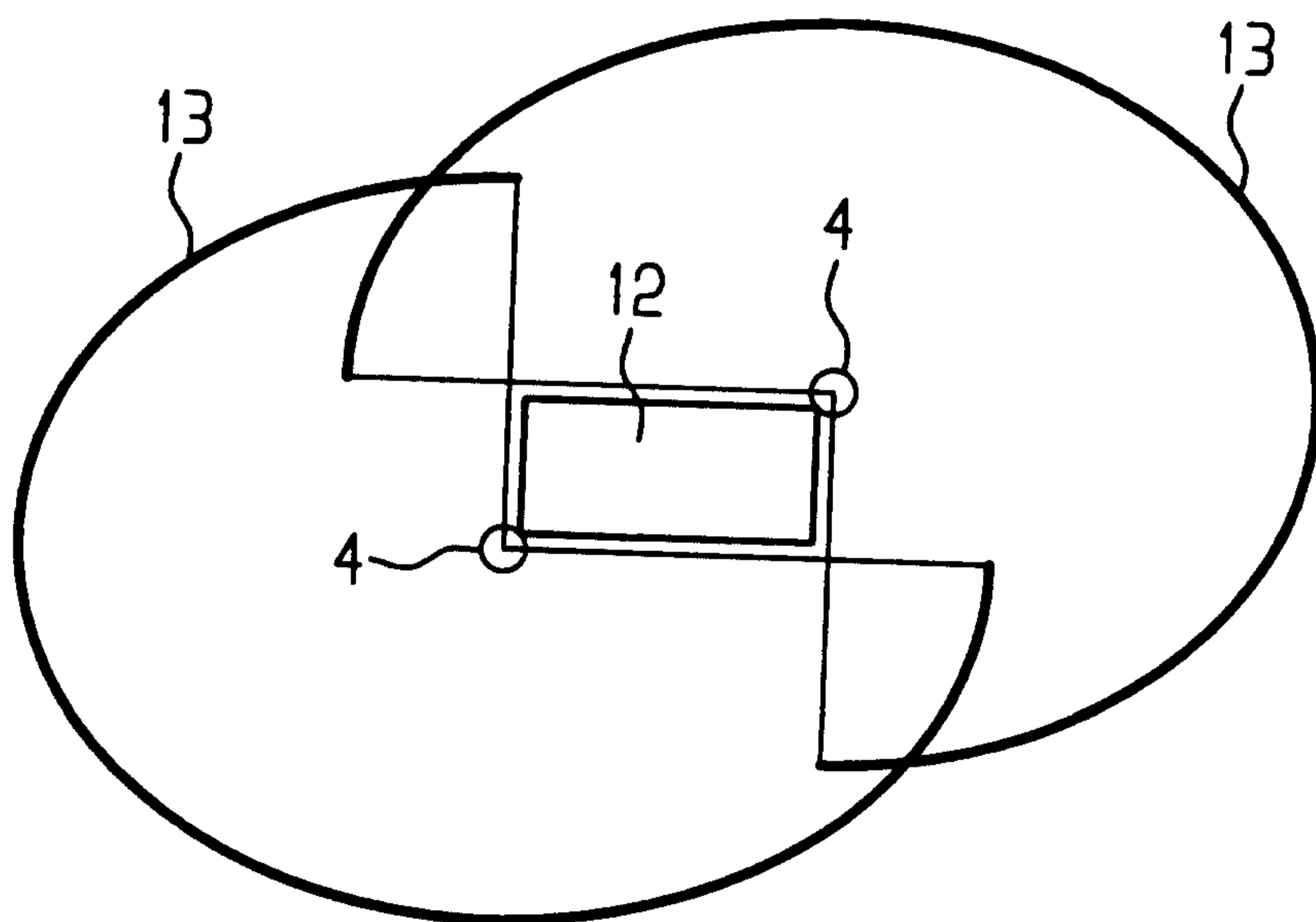


FIG 7



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FIG 8

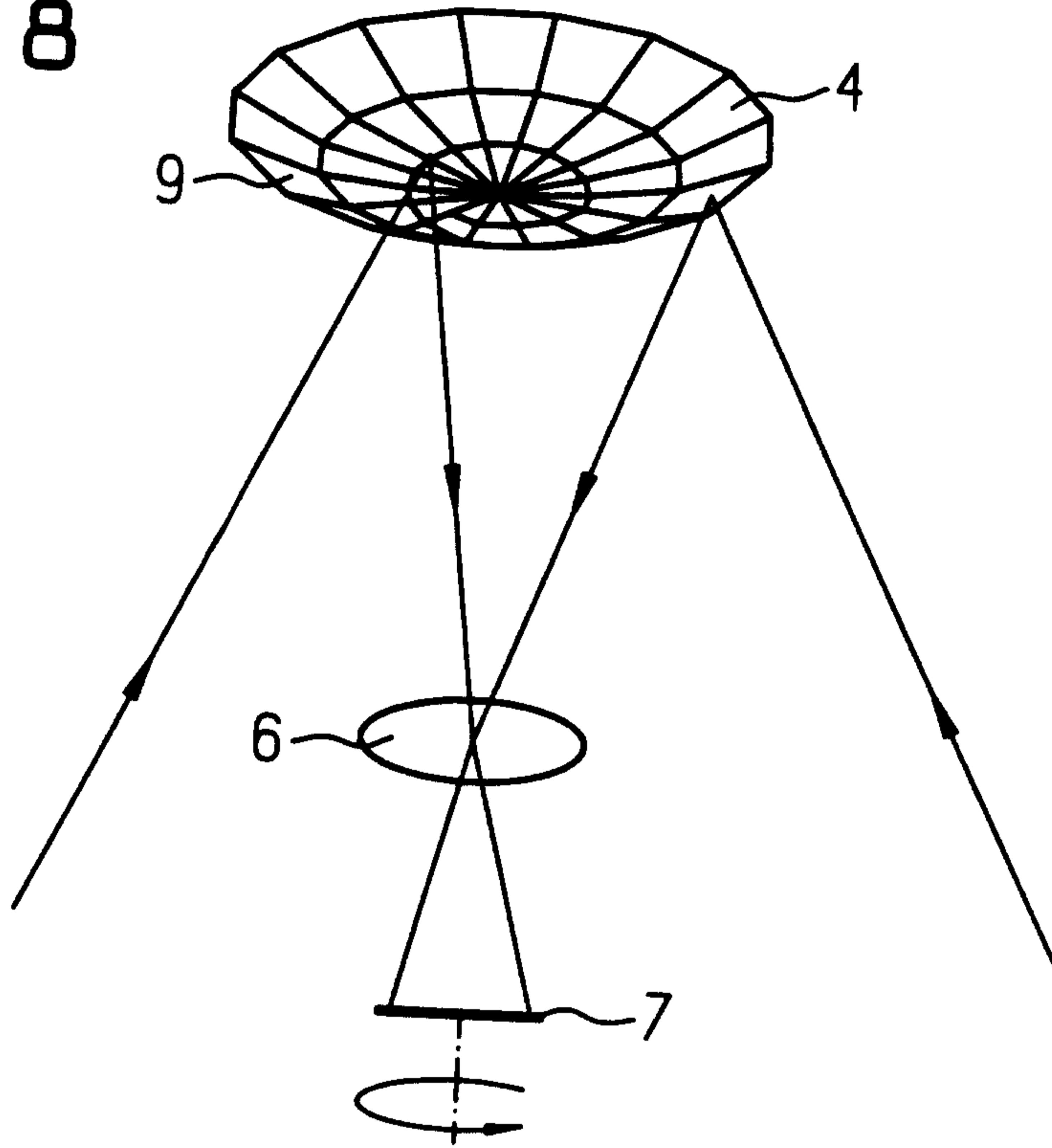


FIG 9

