(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 449 566 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
25.08.2004 Bulletin 2004/35

(51) Int Cl.7: **A62C 3/02**

(21) Application number: **04386007.1**

(22) Date of filing: **18.02.2004**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR
Designated Extension States:
AL HR LT LV MK

(30) Priority: **21.02.2003 GR 2003100093**

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(54) Detector of heat sources

(57) A detector of heat sources, capable of locating a forest fire from afar, even if the fire is still in its early stages, and acting as a deterrent against attempted arson, one of the most common causes of forest fires.

The proposed detector may also be used for defensive military purposes, as well as for the protection of isolated buildings and installations.

It may be installed at a high point or (still better) suspended from an airborne balloon (figure 1).

It consists of two polyhedral surfaces 4.1 and 4.3 (figure 4), one placed inside the other. Each face of the outside surface is a converging lens 3.1 (figure 3), while each face of the inside surface carries (at its center) a small photosensitive surface 4.2, which has some property that varies with the intensity of the incident radiation (e.g. photoresistance 2a and 2b). This allows the creation of an image of the ambient area by synthesizing the individual traces formed on the photosensitive surfaces, in a way similar to that of a television image.

Finally, the detector will be equipped with television cameras sensitive to infrared radiation, capable of taking pictures at nighttime and from afar. All data collected will be controlled and processed by a computer installed at the observation post.

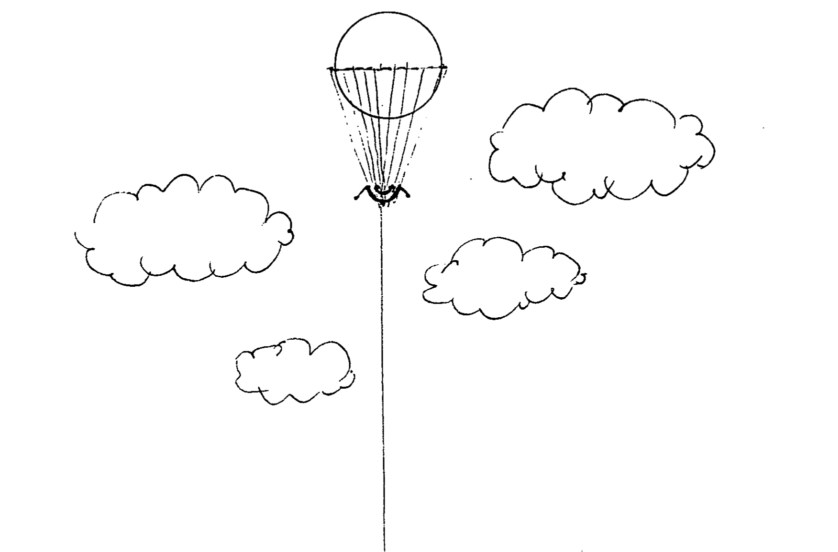

fig.1

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Printed by Jouve, 75001 PARIS (FR)

Description

[0001] This invention involves a detection system capable of (i) locating a forest fire from afar, even if the fire is still in its early stages, and (ii) providing effective protection of an area against arson, one of the most common causes of forest fires.

[0002] This kind of arson is carried out for mainly economic reasons (creation of building plots, farming land or grazing land).

[0003] The arsonists are active mostly during the summer, taking advantage of seasonal dry conditions and strong winds.

[0004] Among the regions hardest hit by forest arson are the countries of the Mediterranean, the US state of California, Australia, etc. The dramatic reduction of forest areas throughout the world in recent years necessitates the development of ways to deter and/or to deal quickly and effectively with such fires.

[0005] Naturally, time is the most critical element in the development of a forest fire, which can be fought with relatively few and simple means when caught early.

[0006] Moreover, preventing a fire is certainly preferable to fighting it, even with the best possible means. Therefore, this is where our efforts should be focused.

[0007] The usual way of detecting a fire is by establishing observation posts at high points in high-risk areas. However, monitoring by humans it is not always reliable, due to the physical limitations of human beings.

[0008] New ways of monitoring have been tried in recent years; for example, rotating television cameras (with a rotation period of 8 min), equipped with telephoto lenses and reportedly capable of detecting fires up to 20 km away, have been used lately in forest areas of France and Poland. The 'Lidar' system (a light and site detector, a kind of laser) also belongs to this class.

[0009] Airplanes and helicopters (as well as satellites) have been used to monitor large and remote forest regions of Russia, USA, Canada and Australia. They can cover much larger areas and are much more flexible than ground-based monitoring posts. Their main disadvantages are that they cannot provide continuous coverage, nor can they fly when the wind is very strong (a very common cause of fire spreading).

[0010] They are equipped with instruments sensitive to infrared radiation, imaging cameras and radar. To locate a smoldering fire, the 'Thermovision' system is used. The system consists of an aluminum mirror which reflects thermal radiation; placed at the belly of an airplane /helicopter, it can monitor an area whose size is twice the operating height of the airplane / helicopter. Radar can also locate areas which are being struck by lightning, and are therefore at a high risk for fire.

[0011] The most up-to-date way of fire detection is by using Earth-orbiting satellites. These satellites orbit at various altitudes, depending on their intended purpose.

[0012] To be effective, a forest-fire monitoring satellite must orbit at a relatively low altitude. In this case, however, the satellite cannot remain stationary over a fixed point of the Earth's surface, but it keeps moving relative to it.

[0013] The orbital period of a satellite depends on its altitude above the Earth's surface. For example, at an altitude of 500 km, the orbital velocity is 7.63 km/sec and the orbital period 1 hour and 34 minutes. This is certainly a disadvantage, if one of the intended purposes of the satellite is the continuous monitoring of a specific forest area.

[0014] At these altitudes, a force of friction (due to the presence of some residual atmosphere) acts on the satellite. This causes the satellite to lose altitude and go into a lower orbit, on which it moves faster (the satellite paradox: the force of friction helps increase orbital velocity). Ultimately, the satellite is destroyed, either by burning in the atmosphere or by falling back to the surface.

[0015] Thus, the satellite fleet must be constantly renewed, and this entails considerable expense.

[0016] Satellites are equipped with sensitive scientific instruments, among them photosensitive surfaces (i.e. surfaces sensitive to light), especially to infrared radiation, which is scattered by the atmosphere much less than radiation of shorter wavelengths, i.e. visible or ultraviolet.

[0017] The photosensitive surfaces detect the flux of radiation, whose intensity varies inversely proportional to the square of the distance of the emitting source ($\sim 1/r^2$).

[0018] From a satellite orbiting at an altitude of 600 km, an area of 500,000 km^2 (i.e. a medium-size country) appears under a solid angle of about 80°. Inside that area, there are literally millions of small, moving sources of heat (e.g. engines and exhaust gases of cars); many of them are so close to one another that they can leave only a single (albeit faint) trace on a photosensitive surface.

[0019] Thousands of other, larger sources of light and heat (such as villages and towns, exhaust gases from large factories, etc) are also detected. Thus, a forest fire can be detected from such an altitude only if it is large enough to leave on the photosensitive surface a trace which can be distinguished from all the others; this means that, by the time of detection, the fire has already spread considerably. Moreover, if the fire is the result of arson, the culprit has already had enough time to leave the area.

[0020] It has also been found that satellite monitoring is economically disadvantageous for regions with small forests (e.g. for countries like Italy, Greece, etc). It would probably be useful for large and remote forests (e.g. in Canada, Siberia, etc) where, however, the risk of arson is very small.

[0021] The proposed invention is based on a different philosophy, which gives rise to its main advantage. The invention is not just capable of locating a fire very early: it can also act preventively by deterring prospective arsonists. As described in the following, it can spot suspicious movements and photograph any culprit(s).

[0022] The monitoring of a forest area must be conducted from a high point, e.g. a mountaintop. The area around this point should be as steep as possible and clear of any nearby clumps of trees blocking optical contact with more distant points.

[0023] Still better monitoring results may be achieved if the entire system is suspended from an airborne balloon hovering over or near the forest area and permanently linked to a ground-based observation post.

[0024] Thus, the balloon is the first characteristic element of the proposed invention. Small photosensitive surfaces, in combination with small converging lenses placed in front of them, are the second characteristic element of the invention. Taken together, these two characteristics will not only allow the identification of a heat source from afar; with the help of a computer installed at the observation post, they will also make possible the mapping of an extended area. Finally, a third characteristic element is the use of television camera(s) equipped with a telephoto lens, capable of taking pictures at nighttime and similar to those used on satellites.

[0025] Regarding the balloon, we recommend the use of a closed-typed balloon, similar to those already used in Meteorology and Physics of the Atmosphere.

[0026] The balloon may be filled with any gas lighter than air (e.g. hydrogen, helium, coal gas, etc). As the balloon rises, the outside atmospheric pressure drops, so the gas inside the balloon expands; thus, the balloon must be made of an elastic, extensible material to prevent it from bursting as it rises.

[0027] If the balloon is made of a non-extensible material, a small pipe must be installed at the lowest point of the balloon to permit the pressure inside the balloon to be always equal to the outside atmospheric pressure.

[0028] The light gas is likely to leak out slowly through the balloon's envelope, thus leading to a reduction of the buoyancy force and the eventual fall of the balloon. Therefore, the balloon needs to be replenished with light gas at regular intervals. This may be done either (i) from a cylinder of light gas under pressure carried aloft by the balloon, which ensures a high degree of operational autonomy; or (ii) through a lightweight pipe connecting the balloon to its base on the ground. If a gaseous filling material is difficult to use, we propose the use of a volatile liquid instead.

[0029] This liquid is to be conveyed under pressure through an even lighter pipe into the balloon, where it will be sprayed and vaporized.

[0030] Of all commercially available kinds of photosensitive surfaces (photocells, photoresistances, photodiodes, etc), we recommend the use of photoresistances because of their excellent properties (e.g. small size and high sensitivity, even to very low radiation levels). We certainly do not exclude the use of the other kinds of photosensitive surfaces.

[0031] The photoresistances are semiconductors whose electrical resistance varies considerably when they are illuminated; this variation is proportional to the intensity of the incident radiation.

[0032] There are photoresistances which are highly sensitive to the infrared region of the spectrum.

[0033] A short list of such semiconductors follows:

Semiconductor	Upper Limit
RbS	3.6 μm
RbTe	5.5 μm
InSb	8.0 μm

[0034] The lowest amount of radiation flux which can be detected by a photoresistance is of the order of 3×10^{-10} Lumen. Thus, even a faint and/or remote source of light and/or heat can be detected.

[0035] The radiation flux Φ from a point source is given by the equation $d\Phi = I \times d\Omega$; I is the intensity of the radiation emitted by the source (measured in candela [cd]), Φ is the flux (measured in Lumen), $d\Omega$ is the solid angle subtended by a small surface dS at a distance r and defined by the equation $d\Omega = dS / r^2$ ($d\Omega$ is measured in radians).

[0036] Such photoresistances are capable of detecting intercontinental missiles at daytime from many hundreds of kilometers away, because their exhaust gases are strong emitters of infrared radiation.

[0037] At this point, it should be noted that most of the radiation emitted by a heat source of relatively low temperature (which, however, is higher than the ambient temperature) lies in the infrared region of the spectrum; as the temperature of the heat source rises, the peak of the emitted radiation shifts toward shorter wavelengths.

[0038] The flux to be detected may be enhanced through the use of suitable converging lenses, to be placed in front of the photoresistance.

[0039] A combination of lenses and photoresistances may be used to pinpoint the position of the source.

[0040] This is possible because of the properties of lenses. If a thermal point source lies on the main axis of the lens, its image will form on this axis; if the source moves off the axis, its image will do likewise, and by a corresponding amount.

[0041] Similarly, a beam of incident rays parallel to the main axis of the lens will focus at the main focus (which lies on the main axis); a beam which makes some angle with the main axis will focus at a secondary focus (which lies some distance off the main axis). Thus, if the angle between the beam and the main axis exceeds a certain value, the photosensitive surface behind the lens will not be illuminated. Moreover, as the angle between the parallel beam and the main axis of the lens (i.e. the line perpendicular to the lens) increases, the flux of radiation which goes through the lens will decrease. Only the component of the flux perpendicular to the lens is now important; according to a well-known law of physics, it is proportional to the cosine of the incidence angle.

[0042] The variations of the values of the photoresistances will be fed into an integrated computer program to give the precise position of the source.

[0043] For this application, the most suitable type of converging lens is the meniscus, the thinnest (and therefore lightest) type of lens. Only the central beam of rays falling on each of the system's lenses will form a trace on the photosensitive surface behind that lens; therefore, each of those lenses will be monitoring an area whose size will depend on the distance of that particular area from the system (the more distant the area, the larger its size).

[0044] With the help of a computer, the system will form its final image in a way similar to that employed for a television screen, where the final image is made up of a large number of dots.

[0045] It is also reasonable to assume that, the higher the number of lenses /photosensitive surfaces (i.e. the smaller those surfaces are), the more perfect the image of the area will be.

[0046] All local heat sources (especially those fixed in space and emitting a constant amount of infrared radiation), which might otherwise give false alarms, may now be used to improve the mapping of the area under surveillance.

[0047] Given the fact that each body emits its own characteristic type of infrared radiation, it should be possible to know the exact position of each settlement, road, forest area, shrubby area, etc, on the final image.

[0048] Because it is suspended from a balloon, the system will in constant motion and/or rotation. But since the distances of the (fixed) sources are constant, their traces will also remain at (roughly) constant distances from one another. The angles formed by those traces will also be constant.

[0049] A reference source emitting in the infrared may be placed at the observation post.

[0050] As shown below, the position of any source (fixed or moving) can be determined with great accuracy if the precise position of the reference source is known.

[0051] It is, of course, possible, to place additional reference sources at other points of the area under surveillance.

[0052] Thus, the proposed system can locate a fire much more efficiently than a satellite: the area under surveillance is smaller, the monitoring altitude is lower, and the same heat source will now leave a much stronger trace on the photosensitive surface (as the flux to be detected is inversely proportional to r^2). An additional advantage is that the number of heat sources capable of giving false alarms will now be much smaller.

[0053] And last but not least, the system can identify prospective arsonists before they can carry out their task.

[0054] Such people will most likely have to use a vehicle in order to leave the area quickly; the vehicle, however, can be located from the infrared radiation emitted by its own exhaust gases.

[0055] Thus, any solitary vehicle moving on a forest road, or any vehicle which leaves a central highway to enter a secluded forest area shall be considered suspect; it will then be monitored and photographed.

[0056] Any vehicle which stops within a forested or shrubby area will also be considered suspect.

[0057] Using a database of photographs of vehicles belonging to residents of the area under surveillance, the computer at the observation post will be able to compare and identify the suspect vehicle.

[0058] Even a single individual may be located from afar (especially at nighttime) because of the infrared radiation emitted by the human body. (The human body is a heat source, from which power of the order of 100 Watt leaks out through conduction, convection and radiation).

[0059] It is also possible to prevent an accidental fire from breaking out: if, for some reason (e.g. pieces of broken glass acting like lenses; metal cans containing aerosols, etc), the temperature at a certain point of the forest rises, the resulting infrared radiation can be detected before the self-ignition temperature of the ambient material (e.g. dry grass) is reached.

[0060] Finally, it is possible to detect ground fires (i.e. hidden) as well as small, smoldering fires, which are hard for a human to detect.

[0061] At daytime, the photosensitive surfaces receive scattered, uniformly distributed sunlight. To prevent the direct incidence of sunlight on the photosensitive surfaces, we propose the use of a lightweight cover, whose outside surface will probably have to be reflective.

[0062] The system may be supplemented with television camera(s) equipped with a telephoto lens, similar to those used on satellites.

[0063] Since all bodies emit infrared radiation, it will be possible to take pictures at nighttime. It will also be possible to photograph large areas from afar (e.g. 100 km), even if they are covered by clouds or fog (because these are transparent to infrared radiation).

[0064] Infrared radiation is not visible to the human eye. For direct observation, it must be converted into visible light. This may be achieved by means of electronic infrared converters, whose operation is based on the photoelectric effect. They can also be used to magnify the image to any desired degree.

[0065] Such converters are already being used for nighttime warfare (night vision binoculars). The direct observation is done on a television screen.

[0066] The proposed system can be used for military purposes too, without major modifications. It is capable of monitoring and controlling large areas even when they are covered by clouds or fog.

[0067] It can thus locate military vehicles moving through a forest area; by measuring the total amount of infrared radiation emitted by the exhaust gases of enemy vehicles, it can also calculate the total enemy force.

[0068] Likewise, the system can detect enemy airplanes and helicopters before they become visible, especially when they fly low to avoid radar detection.

[0069] In its simplest form (i.e. without a balloon), the system can be used to protect isolated buildings and installations. In those cases, the system must be installed at the top of the building, from where it can monitor the surrounding area by detecting and photographing the infrared radiation emitted by uninvited guests and/or their vehicles.

[0070] The electronic system at the observation post should collect other data too (local meteorological data, in particular). Using these data, one can calculate the fire risk at any given time. Such data include air temperature, relative humidity, wind speed, moisture content of forest material, dryness of grass, status of new vegetation, the effect of long dry spells on thick, dead branches & trunks, etc.

[0071] Very often, forest fires break out because of thunderstorm lightnings.

[0072] These lightnings are highly dangerous, as they are capable of destroying the system itself To prevent this, two well-known methods are currently employed. One involves the dropping of fine aluminum fibers from an airplane: by releasing a large number of ions, the fibers help increase the electric conductivity of the air and thus decrease the ambient electric field. The other method involves the seeding of clouds with fine particles of silver iodide (AgJ).

[0073] These two methods may be adapted to the present case either by letting fine aluminum fibers hang from the balloon, or by attaching fine particles of AgJ on the outside surface of the balloon.

[0074] One way of implementing the invention is described below. The description refers to the accompanying figures, which explain simply and clearly the system as a whole as well as its particular components, especially the combination of converging lenses / photosensitive surfaces.

[0075] This is only one of possible implementations.

[0076] Figure 1 shows a panoramic view of a forest area, together with a balloon from which the detection / monitoring system is suspended. The balloon is permanently connected to the ground. Also shown are the control post for the whole area as well as the cover which protects the system from the direct incidence of sunlight.

[0077] At the bottom of the suspended system (not shown in the figure) there will be television camera(s), equipped with a telephoto lens and capable of moving on a horizontal as well as on a vertical plane.

[0078] Of all commercially available kinds of photosensitive surfaces, we recommend the use of photoresistances (without, however, excluding any other kind of photosensitive surface). Two typical forms of such photoresistances are shown in figure 2. In particular, figure 2a shows a photoresistance of selenium (2.1 selenium, 2.2 metal electrode, 2.3 glass), while figure 2b shows a small photoresistance of cadmium sulfide (CdS).

[0079] A unit may be formed (figure 3) by combining a converging meniscus 3.1 with a photoresistance 3.2 to maximize the intensity of incident radiation; this unit can then be used to monitor its respective area with high efficiency. Two parallel beams falling perpendicularly on their respective lenses have been drawn; the converging beams are intercepted by their respective photosensitive surfaces before they can focus at their respective focal centers. As the incidence angle θ increases, the radiation falling on the lens and its respective photosensitive surface decreases (in proportion to $\cos\theta$).

[0080] Moreover, if the incidence angle θ exceeds a certain value, the incident beam will focus at a secondary focus (on the focal plane) and will not illuminate the respective photosensitive surface.

[0081] Two polyhedra (beehive-like solids) are partly shown in figure 4. The first one is formed by polygonal surfaces 4.1, which carry (at their respective centers) the small photosensitive surfaces 4.2; the second one is formed by the lens surfaces 4.3. The first polyhedron is to be suitably placed inside the second one, as shown in figure 4.

[0082] Recesses and projections 4.4 around the lenses and photoresistances may be employed to facilitate (because of symmetry) the assembly of the respective polyhedral surface from its individual parts.

[0083] Using Euclidean geometry and the laws of optics, it may be shown (figure 5) how the position of any source (fixed or moving) with respect to the reference source A (observation post) may be found.

[0084] In this figure, the combination lenses / photoresistances has been drawn as a dashed circular arc. Two rays, BE and BE', have been drawn from a point source B (whose unknown position is to be determined). The first ray BE falls perpendicularly on a certain photoresistance, which may be identified from the fact that its measured value is the smallest among all photoresistance values measured by the system. The second ray BE' falls obliquely on an adjacent photoresistance, whose measured value exceeds the previous one by a factor equal to the inverse cosine of the angle x. This gives the value of angle x. Angle y, which is subtended by the (known) short arc Δs ($y=\Delta s/R$, where angle y is measured in radians), may also be calculated. Angle x is an external angle of the triangle BE'C, therefore $x=y+z$; thus, angle z may also be calculated.

[0085] As both distances BE and BE' are much larger than the radius R of the circle, they may be considered equal (BE=BE'). They may therefore be thought of as radii of another circle centered at point B, and the short arc Δs may be thought of as subtending the small angle z at the center B of that circle.

[0086] Without an appreciable error, the short arc Δs may be taken equal to its chord (i.e. the straight-line segment joining its ends). Thus, $z=\Delta s/BE$, and this leads to the calculation of the distance BE. Angle BCA is also known, because it is subtended by the known arc ED.

[0087] In exactly the same way, one may calculate the distance and direction angles formed by the traces on the photosensitive surface of the reference point A. Therefore, the position of point B in space is fully defined at any moment, because both its distance from the lens / photosensitive surface as well as its direction with respect to the reference point A are known.

Claims

1. A detector of heat sources, capable of locating a forest fire from afar, even if the fire is still in its early stages, and acting as a deterrent against attempted arson. The detector may also be used for defensive military purposes, as well as for the protection of isolated buildings and installations. The detector is **characterized by** three elements: (a) an airborne balloon, which may be used to provide the best possible monitoring of the area under surveillance (figure 1); (b) two polyhedral surfaces 4.1 and 4.3 (figure 4), one placed inside the other. Each face of the outside surface is a converging lens 3.1 (figure 3), while each face of the inside surface carries (at its center) a small photosensitive surface 4.2, which has some property that varies with the intensity of the incident radiation (e.g. photoresistance 2a and 2b); (c) television cameras, capable of transmitting enlarged images of the area under surveillance to a receiver installed at the observation post. A computer, also at the observation post, will control and process all data collected.

2. A detector of heat sources, which, according to claim 1, is **characterized by** the possible use of an airborne balloon, capable of providing the best possible monitoring of the area under surveillance (figure 1).

3. A detector of heat sources, which, according to claim 1, is **characterized by** two polyhedral surfaces 4.1 and 4.3 (figure 4), one placed inside the other and receiving radiation from the surrounding area. Each face of the outside surface is a converging lens 3.1 (figure 3), while each face of the inside surface carries (at its center) a small photosensitive surface 4.2, which has some property (e.g. electrical resistance) that varies with the intensity of the incident radiation (e.g. photoresistance 2a and 2b). The simultaneous operation of these two components allows the creation of an image of the ambient area by synthesizing the individual traces formed on the photosensitive surfaces, in a way similar to that of a television image.

4. A detector of heat sources, which, according to claim 1, is **characterized by** the use of television cameras equipped with a telephoto lens, sensitive to infrared radiation, capable of taking pictures at nighttime (or when the area is covered by fog) and transmitting them to a television receiver installed at the observation post. This television equipment is similar to that used on satellites.

5. A detector of heat sources, which, according to claim 1, is **characterized by** the use of a computer, installed at the observation post, which shall control and process all data collected (e.g. how the value of each photoresistance varies).

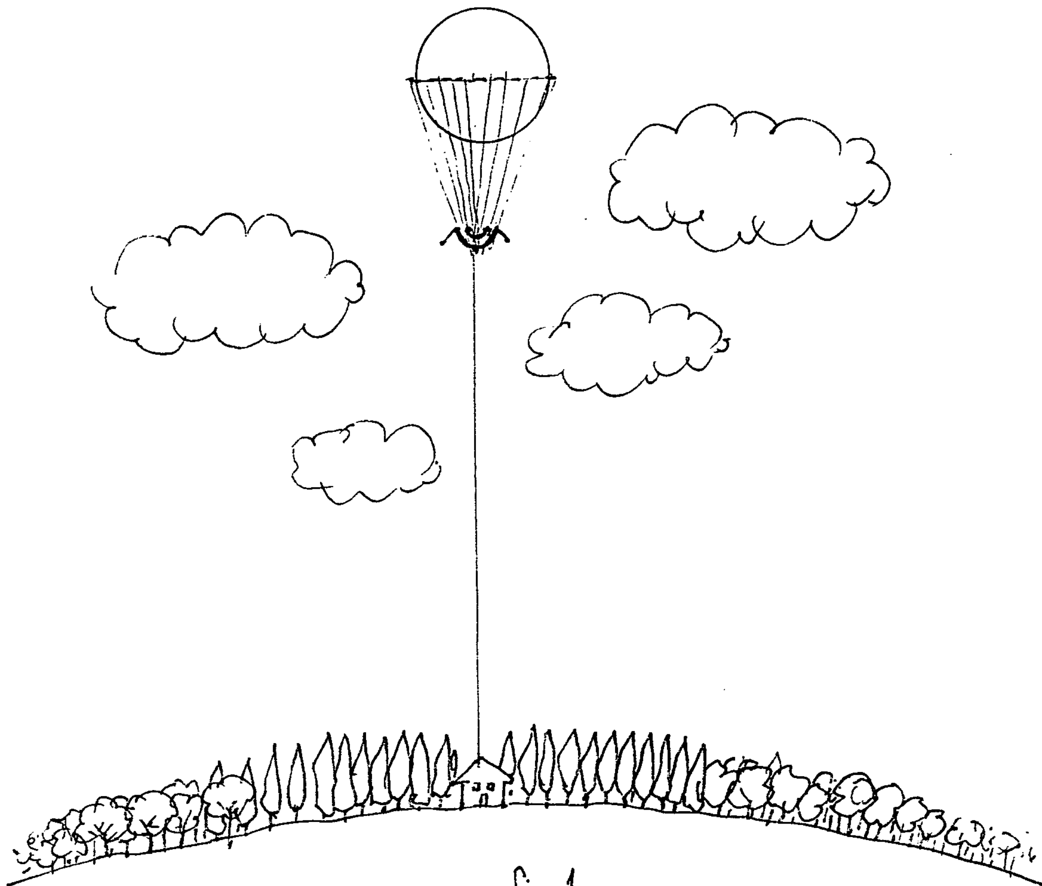

fig.1

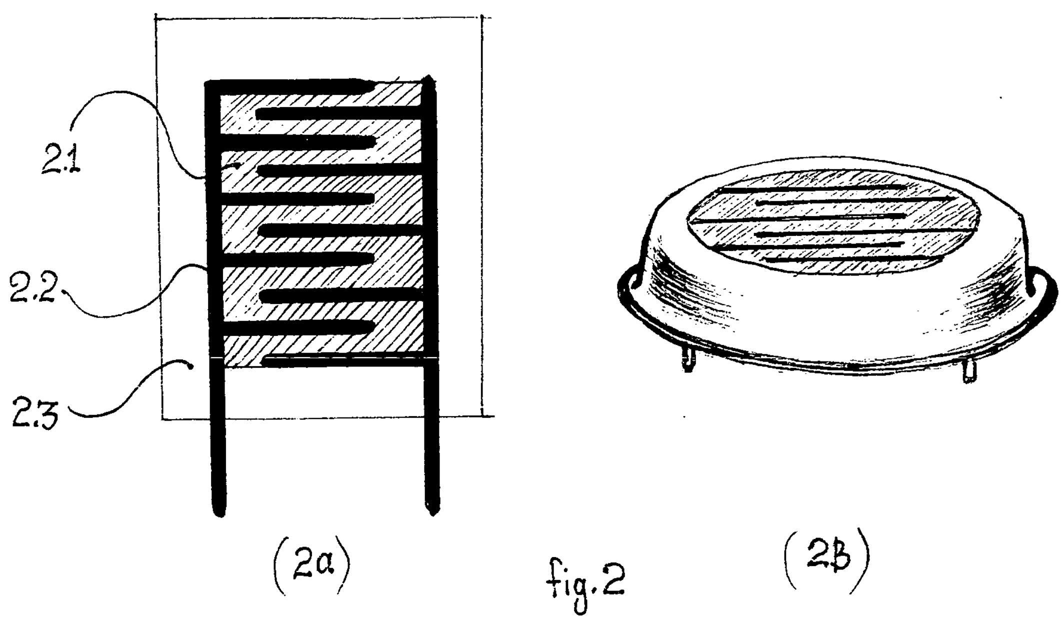

fig.2

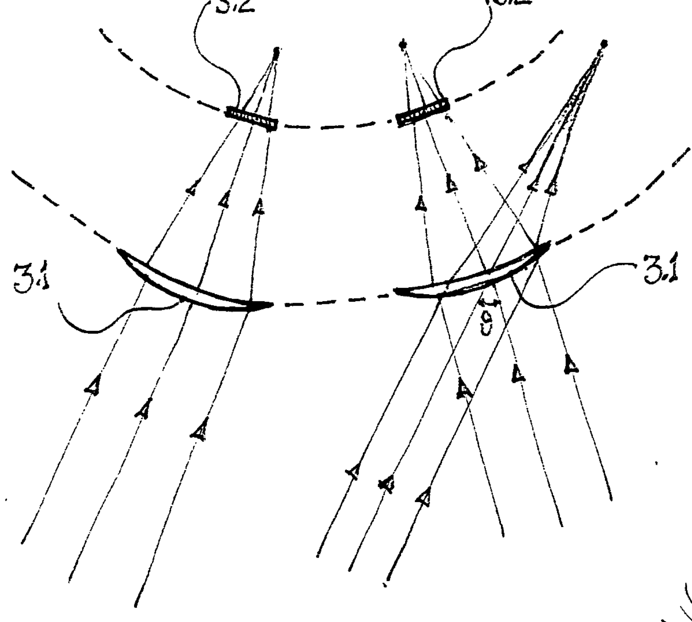

fig.3

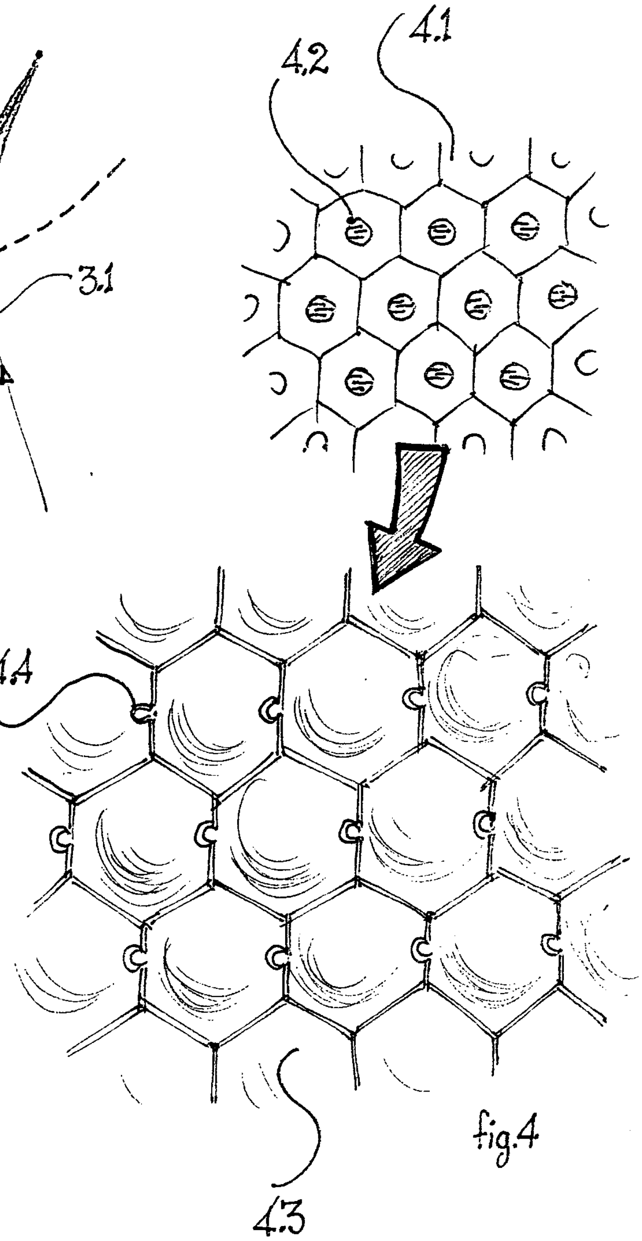

fig.4

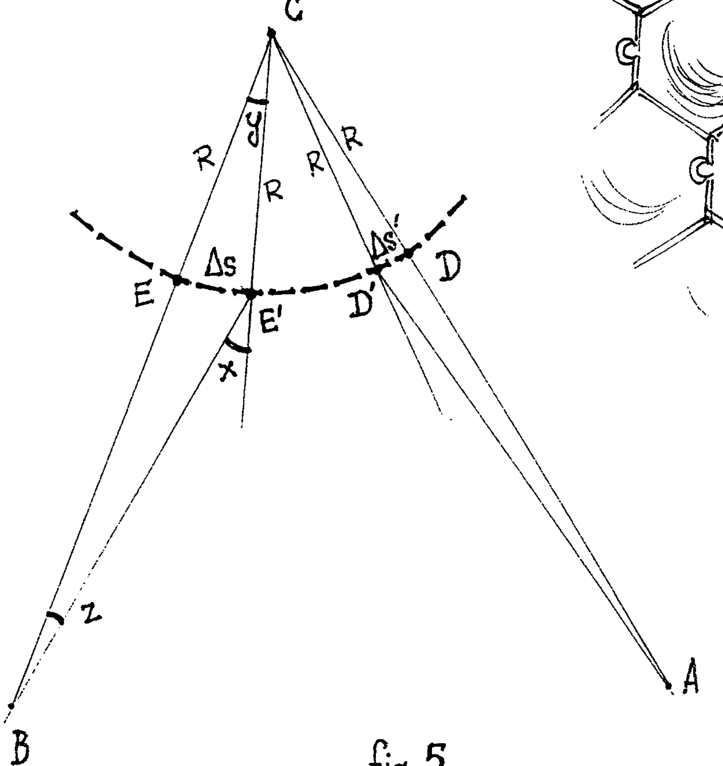

fig.5