



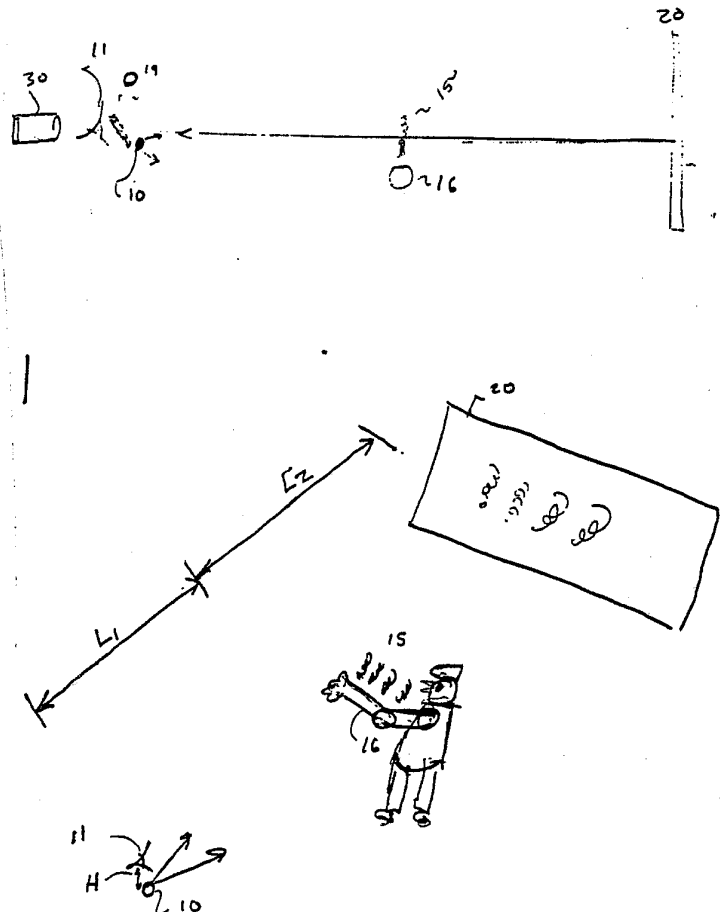
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: INDEX-SIGHT

(57) Abstract

Method and apparatus for rendering visible changes in a refractive media such as gas and fluid flows which cause changes in the index of refraction due to pressure or thermal gradients, detection of leaks and distortion in window glass. In one embodiment the medium (15) whose deviation in index of refraction is to be determined is located between a point light source (10) and retroreflective screen (20). A camera (30) is focused to make the effect visible.



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INDEX-SIGHTFIELD OF THE INVENTION

This is a continuation-in-part of copending PCT applications Appln. No. US85/00125 (corresponding to U.S. Patent No. 4,629,319) and Appln. No. US86/00519, the
5 disclosures of which are incorporated by reference herein. Those applications relate to a unique method for observing deviations in geometric forms of surfaces. This technique is hereby extended to the examination of variations in index of refraction caused by similar distortions and disturbances
10 in fluids such as air, gases and glass. This new version is called "Index-Sight", and is a continuation-in-part of the previous efforts called "DiffractoSight".

DESCRIPTION OF THE PRIOR ART

15 Researchers in fluid mechanics often use flow visualization techniques to qualitatively determine how fluids mix together, flow over obstructions, or pass through orifices restricting such flow, etc. Similarly, researchers in heat transfer use flow visualization to study heat

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transfer through barriers and via heat sinks attempt to identify sources of heat loss and the like.

Typical systems used in the prior for the visualization of index of refraction have included shadowgraphs, Schlieren effect systems and others.

A shadowgraph such as shown in Figure 1A is a device used to generate a collimated beam of light from a source S using a lens L1 over a test section sufficiently large to accommodate a model O of the physical system being examined. This field of light is then collected using lens L2 so that it can be projected or imaged as an image I onto a screen. Figure 1A shows such an arrangement typical of the shadowgraph and Figure 1B shows such an arrangement typical of the Schlieren device used to study shock wave phenomena.

In the Schlieren arrangement, the image I from lens L of the light source S is removed using a knife edge 8 near the focus of the field mirror M2 such that only the optical perturbations (for example, due to the pressure and temperature change in compressible fluids in object O) can be observed. In both cases, mirrors M1 and M2 are normally used to compensate for the prohibitive cost of large

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lenses. These mirrors are usually canted, which contributes to optical parallax. Models must be used since the cost of large lenses or mirrors makes real object sized test fields expensive.

5 Variations in fluid density due to changes in pressure, temperature or type of fluid mixing with the host, result in variations of refractive index. This in turn causes the light to image at variable locations and a visual two-dimensional record of the effects results. Typical
10 references are included for flow visualization.

The Scientific American article referenced below (April/86) shows a means for on-axis illumination with a retroreflecting screen used for the purpose of removing noise in an optical path. This arrangement introduces a
15 point light source with a beam splitter to achieve illumination and imaging on the same axis. The object or system generating the optical disturbance(s) must be placed close to the retroreflecting screen in order that the optically encoded signal is decoded by passing back along
20 essentially the same light path. This filters out the offending optical noise.

The 3M Technical Service Bulletin Industrial Optics #34-7016-4250-5 describes installation instructions and on the last page shows guidelines for equipment and screen

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placement for photographing an object with a superimposed background. The background is projected from a large format projector onto the retroreflective screen through the beam splitter shown. The object would be located close to the retroreflecting screen so that both object and background can be in focus and the composite scene imaged on axis by the camera looking through the beam splitter. Because the projector is not a small light source, the effects of index changes in the light path cannot be resolved easily. As well, index effects will be further minimized having the object close to the screen.

Related art for this invention occurs in other fields. As disclosed in recent literature, atmosphere distortion of images can be corrected by placing retroreflective material such as that used herein directly and immediately behind the disturbing medium. See Walker, J. "Wonders with the retroreflector, a mirror that removes distortion from a light beam", Scientific American, Vol. 254, No. 4, April 1986 at 118.

20 SUMMARY OF THE INVENTION

With the present invention, startling results have been obtained. With simple equipment, it is possible to visualize effects including (but not restricted to) changes

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in refractive index surrounding one's head or arm in normal room environments. The technique particularly utilizes a retroreflector material such as Scotchlite 7615 manufactured by 3M making possible the application to large fields of view. Such material is typically comprised of large numbers of small retroreflective elements such as reflective glass beads.

In comparison with prior art wind tunnel shadow graph techniques, there are some similar effects produced. However, the disclosed invention is much more energy efficient and further is capable of irradiating much larger areas since there is no requirement for large lenses, mirrors or the like. In addition, it requires very little alignment and is capable of much easier set up and use.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A and 1B illustrate the prior art in the form of shadowgraphs (Fig. 1A) and Schlieren effect (Fig. 1B) used for examination of fluid flow.

Figures 2A and 2B illustrate a two dimensional and three dimensional system according to the invention for rendering visible thermal waves from a human arm utilizing a substantially point source and TV camera. Such waves are

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also visible using the human eye directly, and can be recorded by means such as photographic film, etc.

Figures 3A and 3B illustrate alternative off-axis and on-axis optical arrangements of the invention.

5 Figure 4 illustrates an application of the invention to monitoring turbulence of airflow near airfields.

Figure 5 illustrates an application of the invention to the inspection of glass panes.

10 Figure 6 illustrates an application of the invention to the determination of leaks in car bodies.

Figure 7 illustrates the detection of water waves.

DESCRIPTION OF THE INVENTION

15 Figures 2A and 2B illustrate a substantially point light source 10 located near the eye 11 of the observer, or a camera 30, used to obtain the data.

The medium 15 in this case is air near a human arm 16 whose deviation in index of refraction is to be determined. The medium 15 is arranged to be between the camera 30 and the retroreflective screen 20, which are preferably distant
20 from each other so that maximum optical leverage occurs. The camera system 30 (or eye 11) is focused to make the effect visible. It is generally preferable to have the image of the screen 20 substantially in focus.

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It is essential that the medium 15 be remote from the screen 20 so that the deviations become manifest. While effects can be noticed as close as one (1) foot (1/3 m), best results occur at distances over 1 meter. For example, in the experiment depicted in Figs. 2A and 2B, the distance L1 from the screen 20 to the human arm 16 was 10 meters (30 ft.), while the distance L2 from the camera 30 to the person's arm 16 was 6 meters (20 ft.). It is also generally preferable that the light source 10 be substantially a "point" source, for best resolution of minute index change related fluctuations.

When this image is taken with the camera 30, the heat waves rising from the person's arm 16 are made visible. That is, the air medium 15 has been heated by the person's arm 16 and becomes distorted from its normal quasi-homogenous state. Ideally, a camera such as 30 can be utilized with a telephoto lens whose field of view substantially encompasses the screen 20 and/or medium 15 whose distortion is to be examined. This allows for clear discernment of index gradient effects including the heat waves which occur when a thermally variant object radiates into its surroundings.

In one embodiment of the invention, images are produced with the light source 10 directly along the axis of the

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camera 30. This can be accomplished by either a beam splitter 22 and light source 19 or by placing a small point light source, such as a fiber optic, in the middle of the lens.

5 Alternatively, a substantially off-axis arrangement 40 can also be used as shown in Fig. 3A. Where the distance H is large, the shadow 42 of the object 44 falls on the screen 46 as shown, but the camera 48 does not see the direct image of the object 44. Interestingly, in this case if the object
10 is, for example, a butane fuel lighter, the fuel coming out of the lighter can be seen as an index change but the flame
 can be seen only in the direct image.

 Unlike the previously disclosed DiffractoSight reflective effect described in the above-identified patent
15 where there is a definite preference in practice for off-axis illumination, the herein described effect, generally speaking, appears to work best on-axis. The near off-axis (H small) condition is, however, easier to arrange experimentally since the light source 50 can be off to the
20 side. Indeed one can even have an image which only results essentially from the shadow 42 of the object 44 and not the backlit object itself.

 For example, in practicing the invention, it has been found that a possible alternative arrangement is to locate

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the light source 50 off the axis of the camera unit 48 such that the shadow 42 (so to speak) of the object 44 falls onto the screen 46 but with the object 44 itself not being directly in the field of view of the camera 48 (Fig. 3A).

5 In such a case, one sees the shadowed effects caused by the variations in index which are typically light and dark zones due to the deformation of the light waves passing through the index variant medium. This arrangement includes warmer air rising from the surface of the ground.

10 For longer wavelength variation, however, it may well be that of-axis illumination is best, as in the example on slowly changing sheet metal surfaces discussed subsequently. An example herein is glass defects such as waves caused by the float glass process or other curvature defects due to distortion of the glass itself.

15 Also in this category are long wavelengths on the surface of water which can be illuminated both in reflection as to the previous disclosures or in refraction as in this disclosure creating virtually the same kind of a refractive low spot or high spot as has been seen on sheet metal for example (see Fig. 7).

20 As disclosed in the referenced copending applications, it is also possible to computer-process the image to find the changes in index, distortions in glass, or other

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variables. High speed photographs can also be taken using
strobes, electronic images, cinema cameras, or the like.
Processing can be used to compare the image of the object
index patterns to master stored images as well as to
5 determine the gradient across the image in real time or
after the fact. Recording devices such as film, videotape,
disc, etc., can be used to record images produced for later
analysis.

There are numerous additional applications proposed for
10 this invention. Pressure gradients accompanying wind shear
is an interesting idea. For example, consider Figure 4
wherein a substantial zone area along (or near) an airport
runway 301 is covered with retroreflective material 302.
This retroreflective material 302 is then viewed by the
15 pilot 304 on approach using a point light source 306 (such
as a landing light) and produces information regarding the
wind shear characteristics which may be present in the
flight path. This can also be caused by turbulence from
preceding aircraft as well.

20 Another application is in the detection of fluid leaks,
including the butane lighter example hereabove. This would
be useful in transportation applications where a fluid of a
different refractive index could be introduced into the body
of a vehicle in order to see leaks that emanated therefrom

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(e.g. from a bad door seal). In this case, the leaking would be immediately apparent and this obviates using costly helium "sniffers" on robots or the like.

Another application is in determining over large
5 expands the presence of potential fires or overheating
components in areas, electrical devices, etc. Another is
studying air flow in air conditioner or heating ducts, pipes
or other heat transfer situations. The sole requirement is
to create a refractive index change which can be detected
10 with the invention.

The on-axis version of the invention appears to produce
light and dark shadows on the screen, such shadows
corresponding to positive or negative gradients of index.
When one moves the light off-axis, there is an apparent
15 change in the type of phenomenon being examined in respect
of the positive gradients, such change being different but
related. As in the preceding applications, it seems likely
that the positive and negative going slopes of the
refraction surface are being resolved differently.
20 Depending on the offset direction of the light source from
the camera, the viewing angle slope is either positive or
negative going.

An analogous case, for example, is depicted in Figure 5
wherein waves 60 in the surface of and within a piece of

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glass 61 are visualized using a light source 64, a screen 66, and a TV camera 68. Such waves 60 are typically within 2 in. (5 cm) in wavelength and are visible in reflection as well. (See window glass "ripple" in the DiffractoSight photograph in the above-mentioned patent).

Figure 6 illustrates such an embodiment of the invention, used for leak tests on vehicles 70. A very important task in the production of vehicles 70 is to ascertain the structural integrity of numerous door, window and body seals. Leaks occurring in transmission cases, engines, cylinder blocks/oil pans and the like are similarly important. However, the major leak tests of interest relate to the passenger area.

For this it has been known in the prior art to fill the vehicle with a gas such as Freon and "sniff" this with a gas detector carried by a robot. Other proposals such as acoustics and the like have also been investigated.

It is proposed herein to fill the vehicle 70 with gaseous helium, Freon or the like gas 74 such that a difference in refractive index between the introduced gas 74 and the ambient air is thereby created. Human vision or TV cameras 72 can examine the vehicle 70 as it passes by or rests in a fixed position adjacent a screen 78 to check for a leak 82. Ideally, such gas 74 may be pressurized or

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heated by a suitable fan/heater 76; hot pressurized air would be potentially useful. A remote monitor 80 could be used to display an image of the section of vehicle 70 of interest.

5 It is felt at this writing (and this applies also to the copending applications) that the return cone angle of the individual retroreflective elements, be they beads or corner cubes, etc., in the large array of such elements used on Scotchlite, Reflexite or similar screens, contributes to the
10 sensitivity of the system. This is particularly thought to be true in the off-axis viewing mode; in other words the present roughly 2 degree return cone angle of the glass beads used in Scotchlite 7610 or 7615 produces good
15 results. However, even sharper results could be produced if a screen with, say, a 1 degree cone were available. It may be alternatively desirable to "de-tune" the system when one does not want to see certain effects, and this could be
20 effected by using a screen with, say, a 5 degree return cone.

20 For use on index changes having high frequency, the point source is extremely valuable. Where broad effects such as waves in glass are to be viewed, a larger source size is possible.

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Typical satisfactory point sources include half inch apertures over flash guns with a screen-to-light-source distance of 10 meters (30 ft.), halogen movie light bulbs but without the rear reflector as at the same distance, etc. Even smaller sources are available, but one reaches a limit of being unable to sufficiently illuminate the screen in order to see the effect with the eye. If a TV camera is used, it is of course possible to increase the sensitivity of the camera and therefore decrease the size of the source. The same is true with high speed photographic film.

Generally speaking it has been found preferable to focus the camera on the retroreflective material screen, or somewhere between the screen and source of index change.

It is also possible, as disclosed in the copending applications, to have an alternative grid (or other portion) based arrangement 90. This includes placing grid lines on the screen or making the screen out of retroreflective strips, grids or other periodic members. It can also be accomplished by projecting a grid 91 or other pattern as shown in Fig. 3B onto a screen 94 using a Renchi Ruling 96, and light source 98, and lens 100. As shown, distortions in medium 100 cause modulation 104 of the grid 92 on screen 94. These modulations are imaged by a TV camera 106 using a beam splitter 108. As disclosed in the copending

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applications, this allows grids to be easily changed rotated, dithered, etc. As noted previously, data may also be processed by determining grid line deviations (as a result of index change), by comparing the returning grid
5 images to standard images (e.g. by optical filtering) or the like. The returning image can be filtered to show changes only when deviation occurs.

In this particular aspect of the invention, examination is being made of the deviation in the surface curvature of a
10 refractive medium, the amount of refractive medium, or the index of refraction of the medium itself. Aside from the experimental differences involved, the effect appears to be similar to that disclosed previously. On-axis illumination produces the most power, while off-axis illumination can
15 provide desirable aspects of light/dark shading indicative of refractive surface or index contour variation.

In the above examples, the effect is seen by looking through the distorted index medium of the screen. In other words, both a "primary" (first pass that hits the screen)
20 and a "secondary" (on the return pass through the medium) effect occurs.

The chief contributor seems to be the primary effect, i.e. the information concerning the disturbance needs to be present on the screen. In this case the possibility exists

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of creating a screen which directs the light to an imaging camera positioned such that the light never passes back through the medium in reaching the camera.

5 The glass inspection system of Figure 5 has been shown to be capable of detecting forming irregularities in windshields and waves both caused by the tin in the float glass process.

10 Figure 7 illustrates both reflective and transmissive (refractive) embodiments of the invention wherein waves 120 on water in a tank are viewed. In the reflective embodiment, light from a light source 122 is reflected off of waves 120 to a screen 124 and back to an observer 126. In the transmissive (refractive) embodiment, light from a light source 128 is passed through the water and a glass
15 bottom 130 to a screen 132 and then back to an observer 134. Using the invention, wave data can be studied for its own sake, or the system used to view waves carrying ultrasonic image data produced by coherent beating of waves passing through an object with a reference wave (ultrasonic
20 holography), for example.

Any suitable wavelength of light from ultraviolet to infrared can be used, commensurate with the function of the retroreflective screen. The latter is typically composed of glass beads, but can be a myriad of minute corner cube

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reflectors for example. For visible light, typical retroreflector size is 20-200 microns in width (diameter), spaced closely adjacent to each other for maximum efficiency.

- 5 As noted previously, the best light source for producing these effects is a substantially point light source. For example at a screen distance of 20 meters (60 ft.), a 1/2" (1.2 cm) wide source works much better than a source 4" (10 cm) wide when viewing thermal gradients.

WHAT IS CLAIMED IS:

1. A method for visualizing distortions in media comprising:

illuminating a retroreflective material composed of a large number of small reflective elements with light from a light source, said light travelling to said material via said media, and

viewing said retroreflective material through said media from a position angularly proximate said light source to determine said distortions from the dark and/or bright indications produced.

2. A method according to Claim 1 wherein said media are of differing indices of refraction than the surrounding media through which said light also travels.

3. A method according to Claim 2 wherein the presence of said distortions indicates the presence of said media, as in leak testing.

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4. A method according to Claim 2 wherein the indices of said refraction of said media are varied by thermal, pressure or density effects whose presence, magnitude or distribution are to be determined.

5. A method according to Claim 1 wherein said media are of substantially constant and uniform index of refraction, but geometrically distorted locally so as to produce said distortions.

6. A method according to Claim 1 wherein said distortion is observed by a TV camera.

7. Apparatus for rendering visible distortions in a media comprising:

light source means for illuminating said media; and
retroreflective material means for returning light

5 pass.

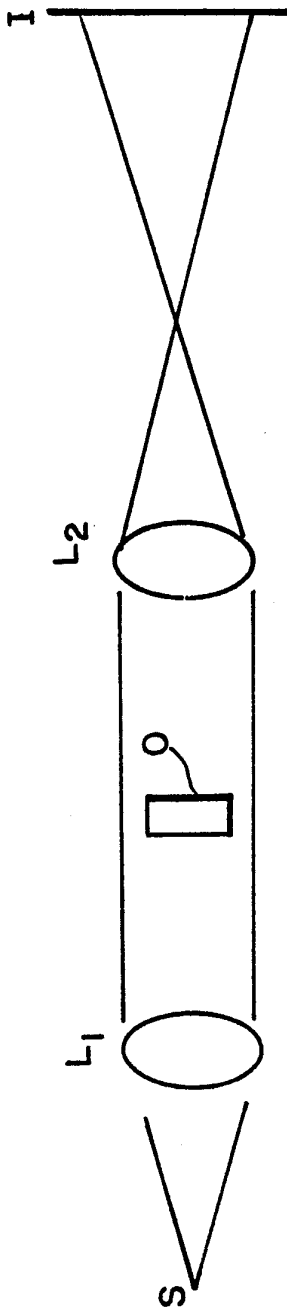


FIG. 1A
PRIOR ART

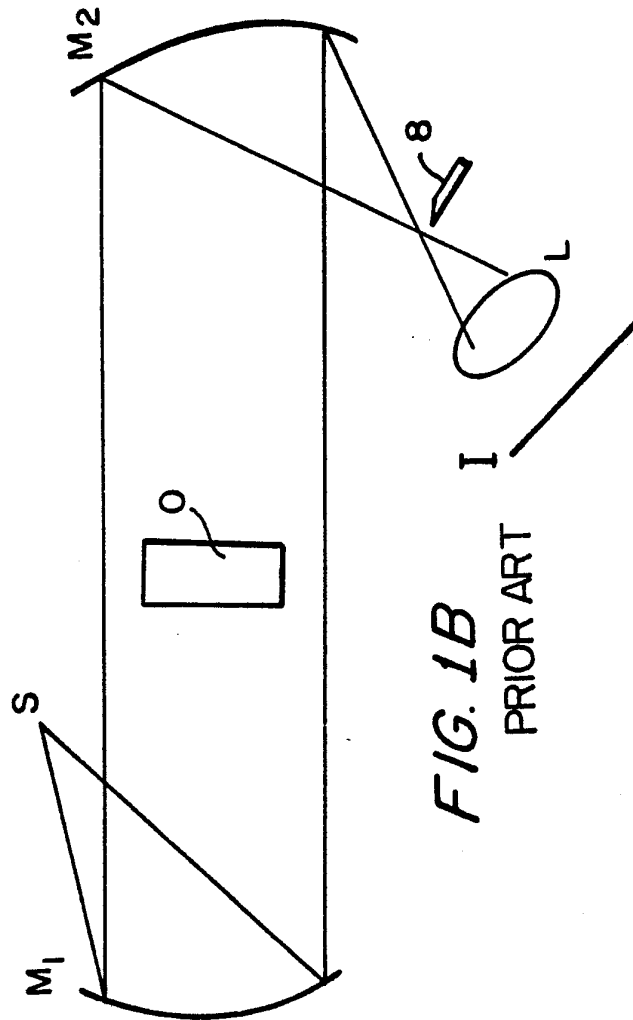


FIG. 1B
PRIOR ART

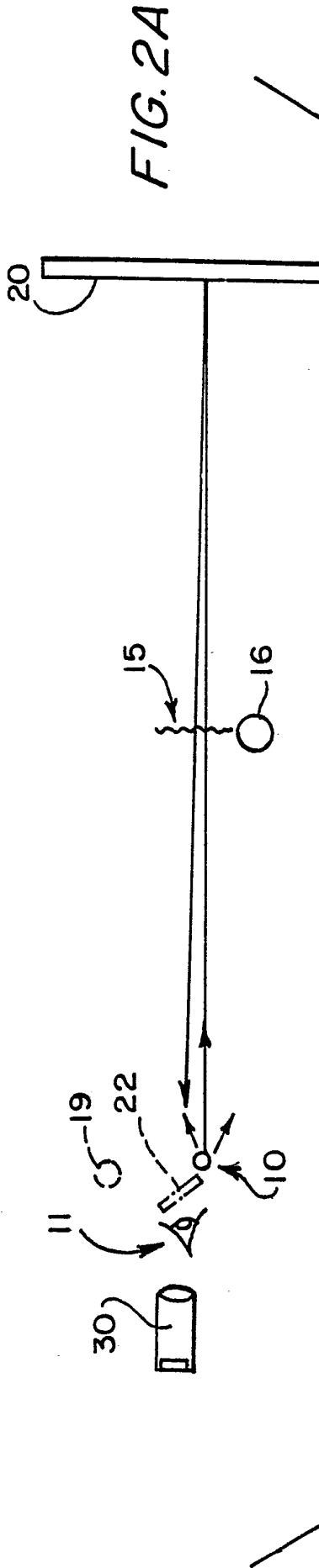


FIG. 2A

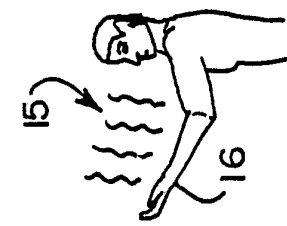
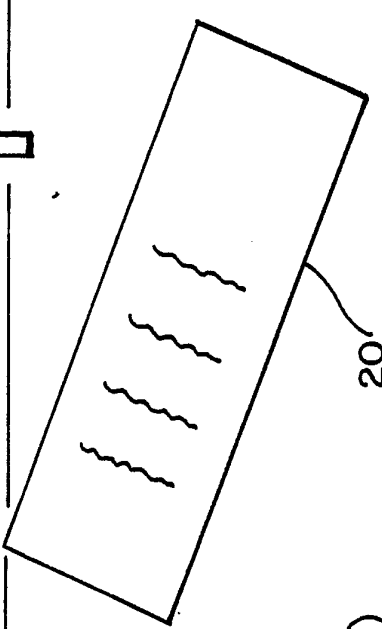


FIG. 2B

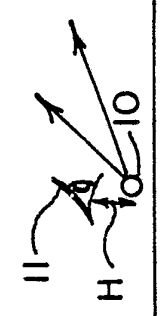
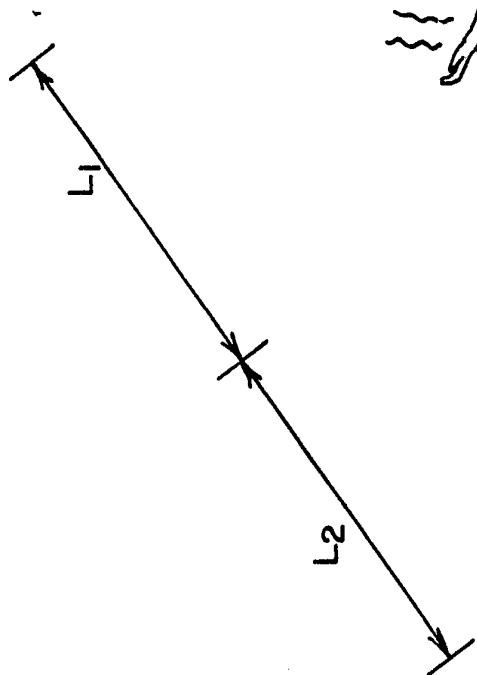


FIG. 3A

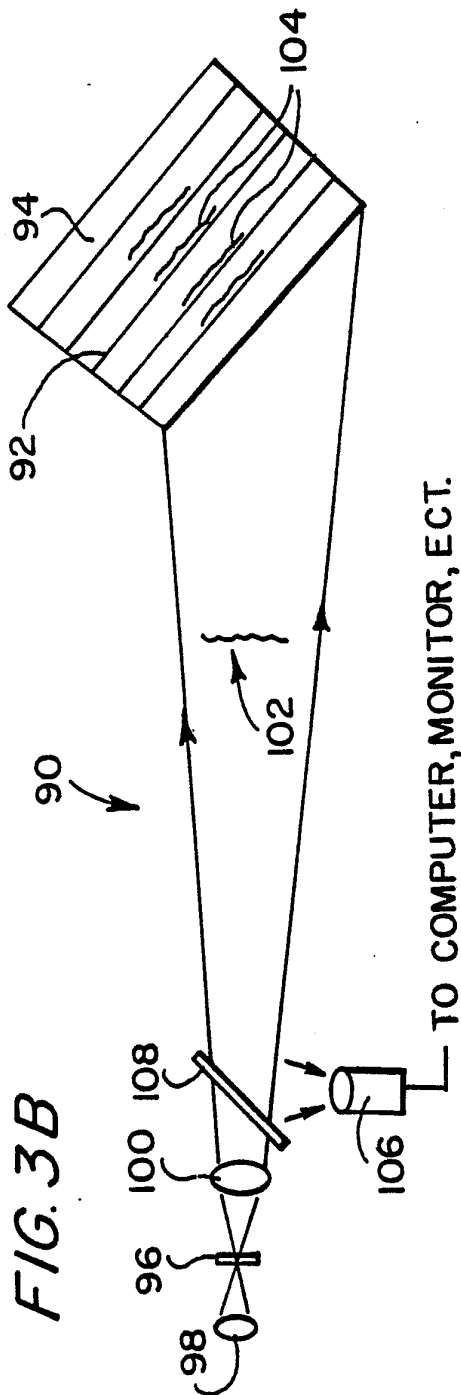
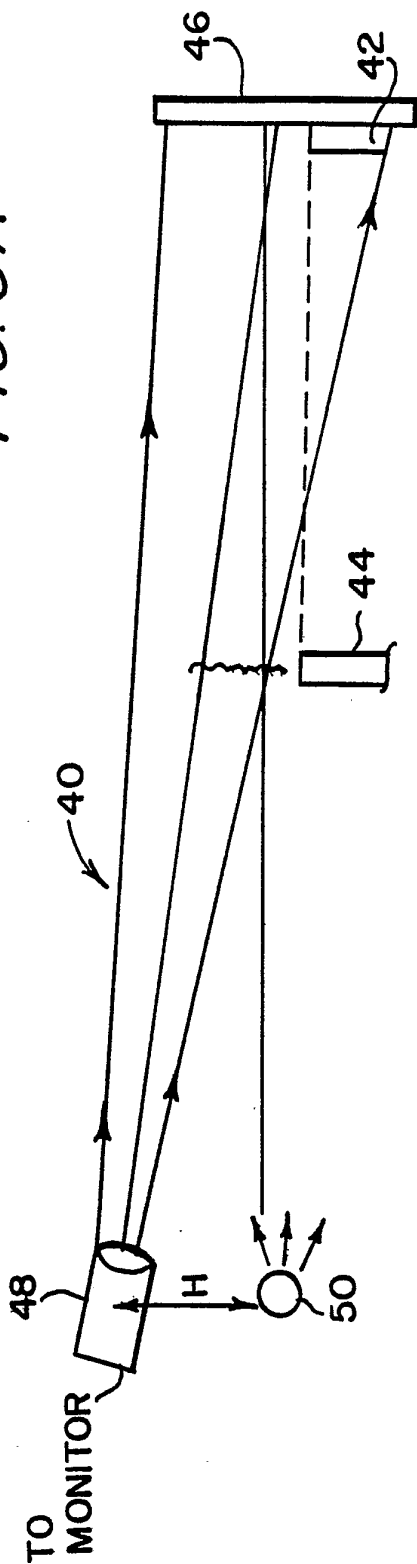


FIG. 3B

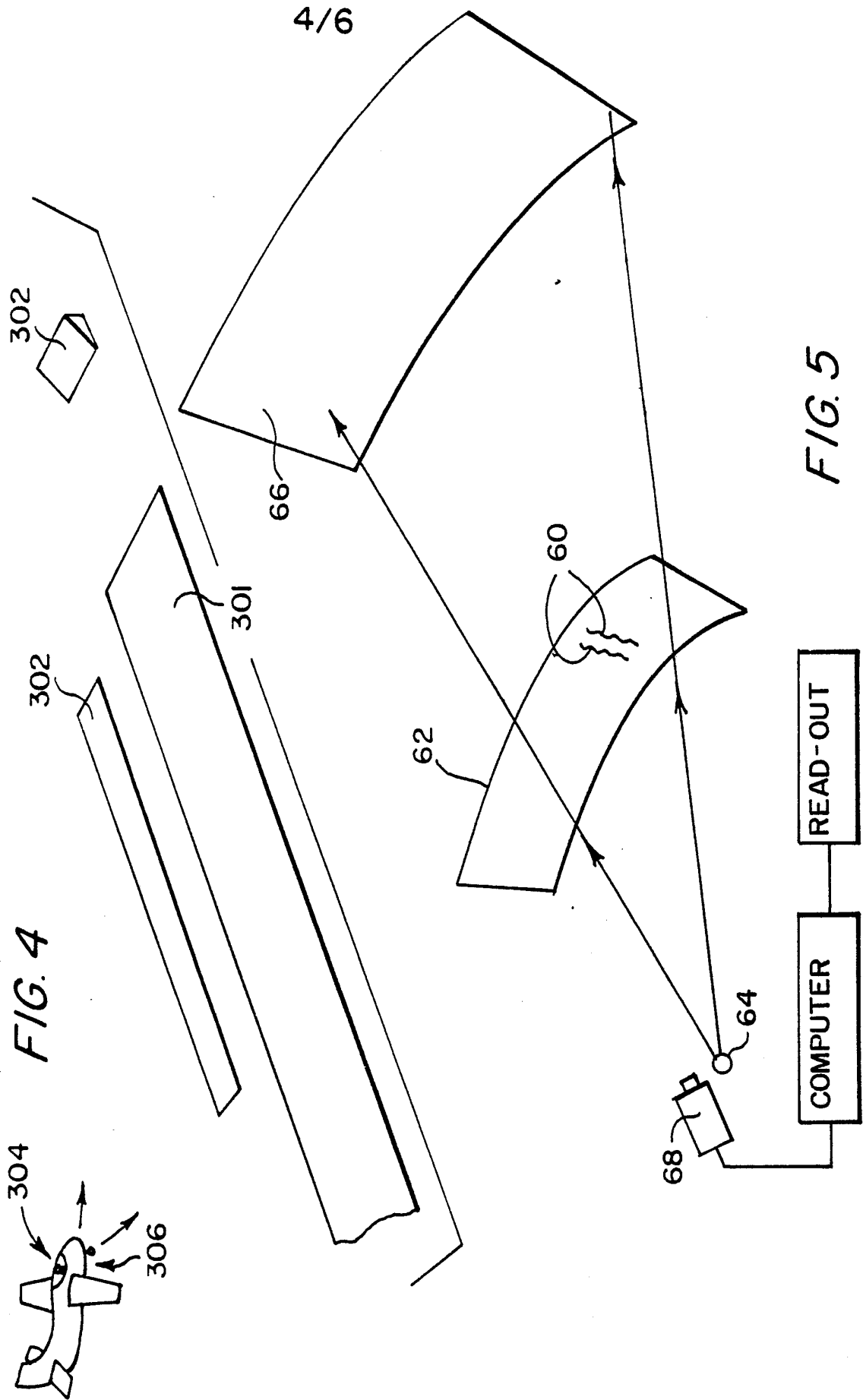


FIG. 4

FIG. 5

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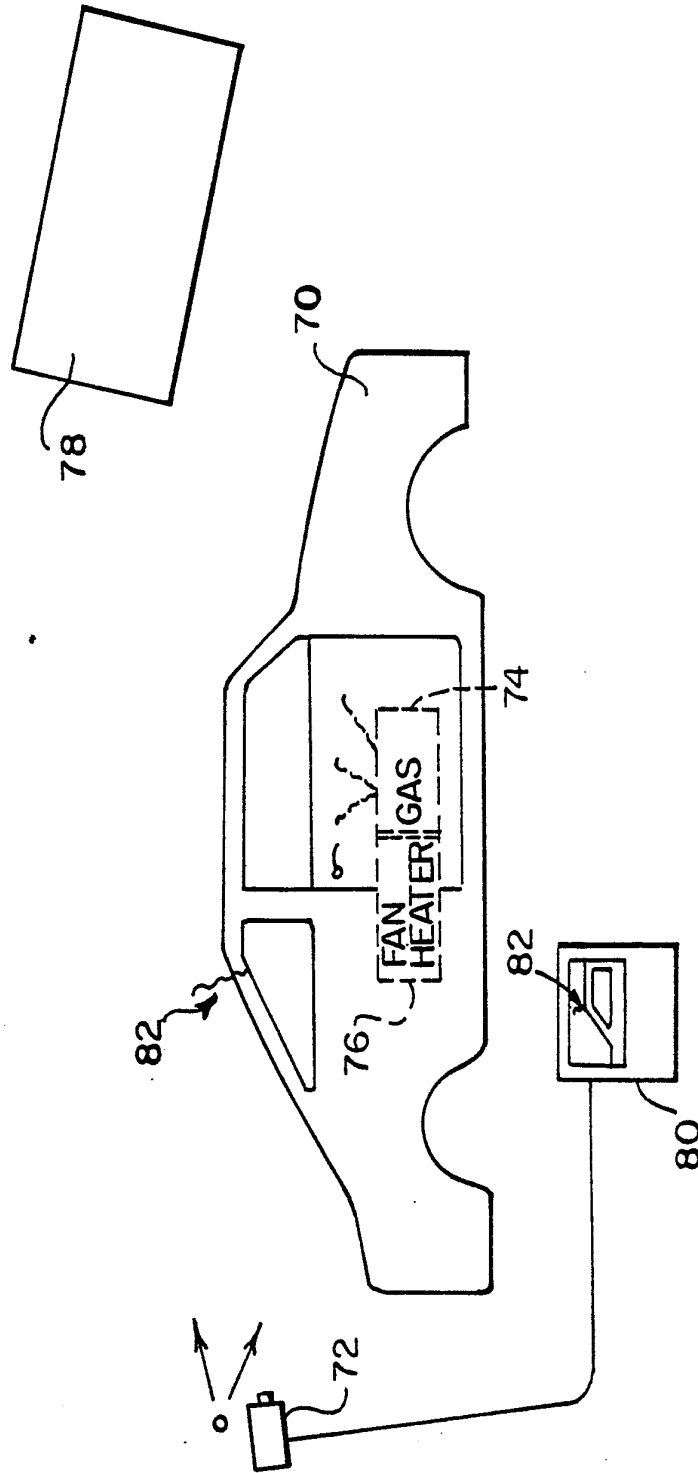


FIG. 6

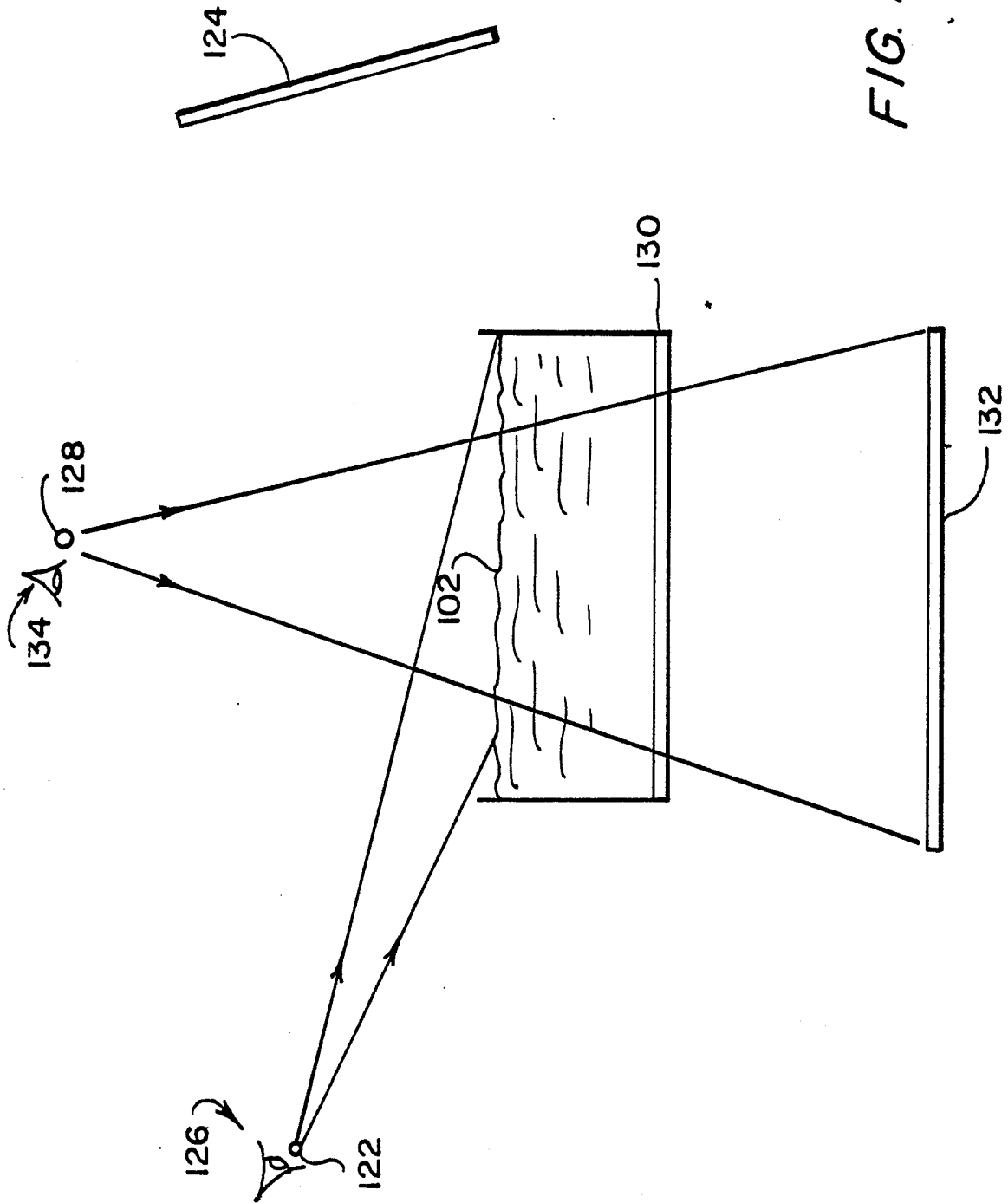
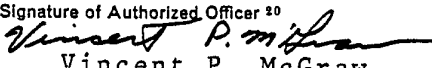


FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No **PCT/US 87/01279**

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ³		
According to International Patent Classification (IPC) or to both National Classification and IPC		
ICP4 GOIN 21/88 U.S. CLASS 356/239		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁴		
Classification System	Classification Symbols	
U.S.	356/239	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁶		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴		
Category [*]	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
X	US, A, 4,310,242 (GENCO ET AL) 12 JANUARY 1982 See the entire document.	1, 2, 4-7
P, Y	US, A, 4,612,797 (BARKHOUDARIAN) 23 SEPTEMBER 1986 See Fig. I and column 5, lines 18 to 20.	3
<p>* Special categories of cited documents: ¹⁵</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search ²	Date of Mailing of this International Search Report ²	
17 AUGUST 1987	31 AUG 1987	
International Searching Authority ¹ ISA/US	Signature of Authorized Officer ²⁰  Vincent P. McGraw	