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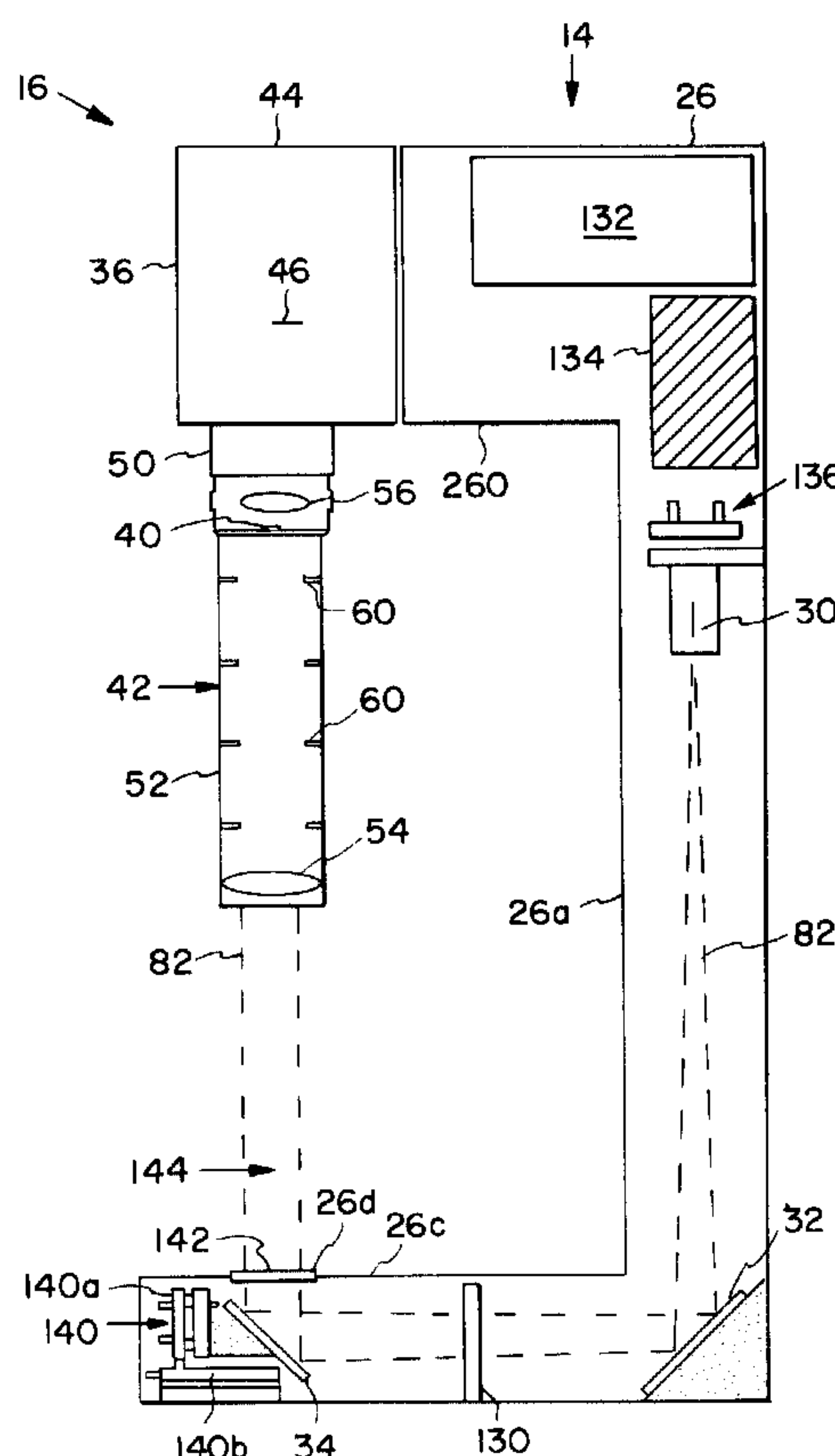
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(54) Titre : METHODE ET SYSTEME POUR L'INSPECTION AUTOMATIQUE DE LENTILLES OPHTHALMIQUES

(54) Title: METHOD AND SYSTEM FOR AUTOMATICALLY INSPECTING OPHTHALMIC LENSES



(57) Abrégé/Abstract:

A method and system for automatically inspecting an ophthalmic lens. The method includes the steps of directing a light beam through the lens and onto an array of pixels, and assigning to each pixel a data value representing the intensity of the light beam on the pixel. The data values are then processed according to a predetermined program to determine if the lens contains any one of a group of predetermined conditions.



ABSTRACT

A method and system for automatically inspecting an ophthalmic lens. The method includes the steps of directing a light beam through the lens and onto an array of pixels, and assigning to each pixel a data value representing the intensity of the light beam on the pixel. The data values are then processed according to a predetermined program to determine if the lens contains any one of a group of predetermined conditions.

1 A METHOD AND SYSTEM FOR
 AUTOMATICALLY INSPECTING OPHTHALMIC LENSES
 BACKGROUND OF THE INVENTION

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 This invention generally relates to methods and
 systems for inspecting ophthalmic lenses such as contact
15 lenses, and more particularly, to lens inspection methods and
 systems of the type in which an illuminating beam is directed
 through the lens to produce an image thereof.

 Contact lenses are, typically, made with a high
 degree of precision and accuracy. Nevertheless, on rare
20 occasions, a particular lens may contain an irregularity; and
 for this reason, contact lenses are inspected before sale to
 the consumer to be certain that the lenses are acceptable for
 consumer use.

 In one type of prior art lens inspection system, a
25 multitude of lenses are placed in a lens carrier that is
 moved to carry each of the lenses, one at a time, through a
 lens inspection position, where an illuminating beam is
 transmitted through each of the lenses. That illuminating
 beam is then focused on a screen to produce thereon an image
30 of the lens, and an operator looks at that image to determine
 if the lens contains any irregularities. If any irregularity

VTN-64

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1 or flaw is found that makes the lens unsuitable for consumer
use, then the lens is either removed from the inspection
system or otherwise identified so that it is not subsequently
sold to a consumer.

5 This prior art inspection system is very effective
and reliable. Nevertheless, it is believed that the system
can be improved. For instance, the system is comparatively
slow and expensive. This is because a human operator must
focus on the lens image produced on the screen and check that
10 whole image for any irregularities. It is thus believed that
the cost of the lens inspection can be reduced and the speed
of the inspection can be increased by employing image
processing equipment to analyze the produced image of the
lens to determine if the lens contains any irregularities.

15 Moreover, with the above-described prior art
system, the decision by the operator to accept or not to
accept a lens involves some subjective considerations, which
may vary from operator to operator, and even with one
operator, may vary from time to time. Typically, the
20 operators err on the side of not accepting lenses, which
results in good lenses occasionally being identified as
unsuitable for consumer use. The inspection system could
thus be improved by providing it with a more constant
procedure that can be applied uniformly to determine whether
25 the lenses are acceptable.

SUMMARY OF THE INVENTION

An object of this invention is to improve methods
and systems for inspecting ophthalmic lenses.

Another object of the present invention is to
30 produce an image of a lens, and to analyze that image using

1 image processing equipment to determine if the lens contains any irregularities.

5 A further object of this invention is to process an image of an ophthalmic lens, using image processing equipment and according to a well-defined, standard and uniform procedure, to determine whether the lens is acceptable for consumer use.

10 These and other objectives are attained with a method for automatically inspecting an ophthalmic lens, and comprising the steps of directing a light beam through the lens and onto an array of pixels, and assigning to each pixel a data value representing the intensity of the light beam on the pixel. The method further comprises the step of processing those data values according to a predetermined program to determine if the lens contains any one of a plurality of predetermined conditions.

15 For example, the method may be used to inspect the lens for gaps along or for extra pieces on the outside edge of the lens. To do this, an image of that outside edge may be formed on the pixel array, and that edge may then be searched for any gaps or extra pieces. If any such gaps or extra pieces are found, the pixels in the gaps and extra pieces may be assigned a high data value, and additional pixels adjacent the gaps and extra pieces may also be assigned high data values to emphasize the gaps and extra pieces. Then, the pixels on the lens edge itself may be assigned low data values, leaving only the pixels in or adjacent the gaps and extra pieces with high data values. The area of each group of contiguous pixels with high data values may then be calculated and compared to a predetermined standard to determine if the pixel group represents an

VTN-64

1 irregularity that renders the lens unsuitable for consumer
use.

5 Further benefits and advantages of the invention
will become apparent from a consideration of the following
detailed description given with reference to the accompanying
drawings, which specify and show preferred embodiments of the
invention.

BRIEF DESCRIPTION OF THE DRAWINGS

10 Figure 1 schematically illustrates a system for
automatically inspecting ophthalmic lenses.

Figure 2 is a plan view of one type of ophthalmic
lens that may be inspected by the system of Figure 1.

Figure 3 is a side view of the lens shown in Figure
2.

15 Figure 3A is an enlarged view of a peripheral
portion of the lens shown in Figures 2 and 3.

Figure 4 is a more detailed view of the transport
subsystem used in the lens inspection system of Figure 1.

20 Figure 5 is a plan view of a lens carrier used in
the system of Figure 1.

Figure 6 is a side view of the lens carrier shown
in Figure 1.

25 Figure 7 is a schematic diagram generally
illustrating the principles of an illumination technique
referred to as dark field illumination.

Figure 8 is a more detailed diagram of the
illumination and imaging subsystems of the lens inspection
system shown in Figure 1.

30 Figure 9 shows a portion of a pixel array of the
imaging subsystem.

1 Figure 10 shows an image that is formed on the pixel array when an ophthalmic lens of the type shown in Figures 2 and 3, is being inspected in the lens inspection system of Figure 1.

5 Figures 11A, 11B, and 11C show three alternate optical configurations that may be used in the illumination and imaging subsystem.

 Figure 12A illustrates the operation of a control subsystem of the lens inspection system.

10 Figure 12B is a time diagram illustrating the sequence of various events in the operation of the transport, illumination, and imaging subsystems.

 Figure 13 schematically illustrates the data processing subsystem of the lens inspection system.

15 Figure 14 generally illustrates the major components of a preferred data processing procedure employed with the lens inspection system.

 Figure 15 shows an image of an ophthalmic lens formed on the pixel array of the lens inspection system.

20 Figures 16A and 16B are flow charts illustrating a lens inspection procedure referred to as a decentration test.

 Figure 17A is similar to Figure 15 and shows the image of an ophthalmic lens formed on the pixel array.

25 Figure 17B is an enlarged view of a portion of the annulus shown in Figure 17A.

 Figure 17C is a graph showing the intensities at which certain pixels, on a line segment across Figure 17B, are illuminated.

30 Figures 17D-17I graphically illustrate the results of various processes performed on the illumination intensity values of those certain pixels to derive processed values for

1 the pixels that help identify the edges of the annulus shown
in Figure 17A.

Figure 17J shows the pixels of the pixel array
illuminated at their processed illumination values.

5 Figure 18 is a flow chart showing a preferred
procedure for processing the initial illumination intensity
values determined for the pixels of the pixel array.

Figures 19A-19C show the effect of a masking
procedure on data values for the pixels of the pixel array.

10 Figure 20 is a flow chart illustrating a preferred
masking procedure.

Figures 21A and 21B illustrate a further data
processing procedure referred to as the rubber band
algorithm.

15 Figure 22 shows a subroutine used to identify a
first pixel on the edge of the line image.

Figure 23 is a flow chart showing in greater detail
a first main section of the rubber band algorithm.

20 Figure 24 is a flow chart showing a subroutine that
is invoked when a gap is found in the outside edge of the
image of the lens.

Figures 25A-25E show a portion of the outside edge
of the image of the lens and identify various pixels of
interest on that edge.

25 Figure 26 is a flow chart of a subroutine that is
invoked when an extra piece is found on the outside edge of
the lens image.

Figure 27 shows a routine that is invoked after the
procedure outlined in Figure 23 is complete.

30 Figure 28 is a flow chart showing in greater detail
a second main section of the rubber band algorithm.

1 Figure 29 shows the outer edge of a portion of the lens image, and shows several vectors that are used in the second section of the rubber band algorithm.

5 Figure 30 is a flow chart outlining in greater detail a third main section of the rubber band algorithm.

 Figures 31 and 32 pictorially illustrate the effect of two steps of the procedure shown in Figure 30.

 Figure 33 shows a portion of the outer edge of the annulus, with certain lines added on to that edge.

10 Figures 34A-34E generally illustrate the results of various operations referred to as MAX, PMAX, MIN, and PMIN.

 Figure 35 shows a preferred procedure that is applied to pixel data values to emphasize or highlight possible defects in the lens edge.

15 Figure 36 illustrates the results of the procedure shown in Figure 35.

 Figure 37 is a flow chart showing a second masking procedure employed in the processing of the pixel data.

20 Figures 38A-38C pictorially illustrate this second masking procedure and the results thereof.

 Figure 39 is a flow chart of a further procedure applied to the pixel data to emphasize further any defects in the lens being inspected.

25 Figures 40A-40D pictorially illustrate the operation and results of the procedure outlined in Figure 39.

 Figures 41A and 41B show a flow chart of a procedure used to identify any flaws or defects in the lens being inspected.

30 Figure 42 shows various types of possible defects in the lens.

1 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

5 Figure 1 is a block diagram illustrating lens inspection system 10; and generally system 10 comprises transport subsystem 12, illumination system 14, imaging
10 subsystem 16, and image processing subsystem 20. With the preferred embodiment of system 10, transport subsystem 12 includes lens carrier 22 and support assembly 24 (shown in Figure 4); and illumination subsystem 14 includes housing 26, light source 30, and mirrors 32 and 34. Also, with this
15 preferred system 10, imaging subsystem 16 includes camera 36, stop 40, and lens assembly 42. More specifically, with reference to Figure 8, the camera includes housing 44, pixel array 46, and shutter 50; and the lens assembly includes housing 52, a pair of lenses 54 and 56, and a plurality of baffles 60. As shown in Figure 1, image processing subsystem
20 20 includes preprocessor 62, main processor 64, and input means such as keyboard 66; and preferably subsystem 20 further includes memory unit 70, video monitor 72, keyboard terminal 74, and printer 76.

20 Generally, transport subsystem 12 is provided to move a multitude of ophthalmic lenses along a predetermined path to move each of those lenses, one at a time, into a lens inspection position, and Figure 1 shows one such lens 80 in this lens inspection position. Illumination subsystem 14 is
25 provided to generate a series of light pulses and to direct a respective one light pulse onto light path 82 and through each ophthalmic lens moving through the lens inspection position. Subsystem 16 generates a set of signals representing selected portions of the light pulses
30 transmitted through the ophthalmic lens and then transmits these signals to processing subsystem 20. The image

VTN-64

1 processing subsystem receives those signals from subsystem 16
and processes those signals according to a predetermined
program to identify at least one condition of each of the
lenses that is inspected; and in the preferred embodiment of
5 subsystem 20 described below in detail, that subsystem
determines whether each inspected lens is acceptable for
consumer use.

System 10 may be used to inspect a large variety of
types and sizes of ophthalmic lenses. The system is
10 particularly well-suited for inspecting contact lenses, and
Figures 2 and 3 illustrate, for example, contact lens 84 that
may be inspected by system 10. Lens 84 has a generally hemi-
spherical shape, including front and back surfaces 86 and 90;
and the lens forms a central optical zone 84a and an outer
15 zone 84b. The lens has a substantially uniform thickness;
however, as particularly shown in Figure 3A, the thickness of
the lens gradually decreases over the annulus 84C immediately
adjacent the outside edge of the lens.

Figure 4 illustrates transport subsystem 12 in
greater detail; and as discussed above, this subsystem
20 preferably includes lens carrier 22 and support assembly 24.
More specifically, this support assembly includes translation
table 92 and first and second stepper motors 94 and 96, and
the translation table, in turn, includes base member 100 and
frames 102 and 104.
25

Generally, lens carrier 22 is provided to hold a
multitude of the ophthalmic lenses, and Figures 5 and 6 show
the lens carrier in greater detail. As shown therein, the
lens carrier includes a rectangular base member 106 and an
array of lens inspection cups 110 connected to the base
30 member. Preferably, each cup consists of a frusto-conical

VTN-64

1 sidewall 110a and a hemi-spherically shaped bottom portion
110b integrally connected to and extending downward from the
sidewall of the cup. In addition, the bottom portion of each
cup preferably has a constant radius of curvature,
5 approximately 10% larger than the radius of curvature of the
ophthalmic lens 84 placed in the cup, and the diameter of the
bottom portion 110b is greater than the diameter of the
ophthalmic lens. Also, the sidewall of each cup extends at a
slope of about 20° with respect to the axis of the cup, and
10 the thickness of each sidewall is preferably less than about
0.010 inches.

With the particular lens carrier 22 shown in
Figures 5 and 6, the diameter of the top of each cup 110 is
about 22 mm; and the depth of each cup is preferably greater
15 than the diameter of the lens to be inspected, which, for
contact lenses, is typically 20 mm. As shown in Figures 5
and 6, the lens carrier includes a 3 x 4 array of inspection
cups. As will be understood by those of ordinary skill in
the art, the inspection cups may be arranged in other
20 configurations; and for instance, the cups may be arranged in
a 3 x 3 array, a 3 x 8 array, a 4 x 8 array, a 3 x 10 array,
or a 4 x 10 array.

Cups 110, and preferably base member 106, are made
of a substantially transparent material, such as polyvinyl
25 chloride plastic. Moreover, preferably cups 110 and base
member 106 are integrally molded together and are relatively
thin, which reduces the cost and thus, as a practical matter,
allows the carrier to be disposed after a single use.
Disposing of the carrier after a single use substantially
30 reduces or eliminates the formation of scratches in the cups,
which are often made when lens inspection cups are reused.

VTN-64

1 Since, as discussed below, a scratch on a cup may be
interpreted as a flaw or defect in the lens inside the cup,
the use of readily disposable lens carriers improves the
accuracy of the lens inspection process.

5 In use, each cup 110 is partially filled with a
fluid solution 112 such as, for example, a saline solution,
and a respective one ophthalmic lens is placed at the bottom
of each cup, fully submerged in the solution therein. When a
lens is placed in a cup, the cup tends to center the lens
10 automatically therein at the bottom of the cup, due to the
above-described shape and parameters of the cup.

With reference again to Figure 4, support assembly
24 is provided to support the lens carrier and to move the
lens carrier so as to move each of the lenses therein, one at
15 a time, into the lens inspection position. Preferably,
support assembly 24 moves lens carrier 22 continuously along
a predetermined path to move lenses 84 smoothly into and
through that lens inspection position. For instance, the
support assembly may be designed to move the lens carrier so
20 that cups 110 of that carrier are moved through the lens
inspection position, one row of cups at a time; and after
each row of cups is passed through the lens inspection
position, support assembly 24 moves carrier 22 to align
another row of cups with the lens inspection position.

25 With the preferred support assembly 24 shown in
Figure 4, frame 102 of translation table 92 is supported by
base 100 for lateral movement thereon, to the right and to
the left as viewed in Figure 4; frame 104 is supported by
frame 102 for movement thereon, upward and downward as viewed
30 in Figure 4; and lens carrier 22 is supported on frame 104
for movement therewith. Stepper motor 94 is mounted on base

VTN-64

1 100 and connected to frame 102 to move that frame across the
base member, and stepper motor 96 is mounted on frame 102 and
connected to frame 104 to move this latter frame.

5 Any suitable frames 102 and 104 and stepper motors
94 and 96 may be used in support assembly 24. Moreover, as
will be understood by those of ordinary skill in the art,
other suitable support assemblies are known and may be used
to move lens carrier 24 in the desired manner.

10 With reference again to Figure 1, subsystems 14 and
16, together, produce and then utilize an effect referred to
as dark field illumination to inspect the ophthalmic lenses
moving through the lens inspection position. In this
procedure, an image is formed on pixel array 46 of features
15 of the ophthalmic lens that scatter or reflect light
transmitted through the lens. Dark field illumination may be
used --and indeed is a highly effective procedure-- to detect
flaws or irregularities in ophthalmic lenses because
essentially all defects, as well as some normal features, of
the ophthalmic lenses scatter light; and even very subtle,
20 shallow defects, such as those referred to as puddles, can be
readily detected by using a dark field illumination
procedure.

The principle of dark field illumination may be
understood with reference to Figure 7, which shows an
25 ophthalmic lens 114, a collimated light beam 116, a pair of
lenses 120 and 122, an opaque stop 124, and a pixel array
126. Light beam 116 is transmitted through ophthalmic lens
114 and then is incident on imaging lens 120. If the
illumination beam 116 were perfectly collimated when incident
30 on lens 114, then that beam would be brought to a focus at
the back focal point of lens 120. Even if the illuminating

VTN-64

1 beam 116 is completely unaffected by ophthalmic lens 114,
though, that beam is not perfectly collimated when incident
on lens 120, and the beam 116 forms a small circle, referred
to as a circle of least confusion, at approximately the back
5 focal point of lens 120. Stop 124 is located on the other
side of imaging lens 120, at this back focal point thereof,
and the size of the stop is selected to be slightly larger
than that circle image formed by the illuminating beam 116 at
the back focal point of lens 120.

10 Thus, in the absence of any scattering or
refraction of illumination beam 116 by lens 114, no light is
transmitted past stop 124, and pixel array 126 is completely
dark. However, any feature of lens 114 that deflects light
enough to miss the stop 124, will cause some light to be
15 incident on the pixel array. The ophthalmic lens 114 is
located at a position that is optically conjugate to the
position of the pixel array 126; and thus, if any light is
transmitted past stop 124, that light forms an image on the
pixel array of the entity of ophthalmic lens 114 that
20 scattered the light.

Figure 8 shows the preferred apparatus for
producing and then utilizing this dark field illumination
effect in system 10; and in particular, this figure shows the
preferred illumination subsystem and imaging subsystem in
greater detail. As shown in this figure, subsystem 14
25 includes housing or casing 26, light source 30, mirrors 32
and 34, diaphragm 130, power supply 132, control circuit 134,
first and second adjustable support means 136 and 140, and
exit window 142. Also, subsystem 16 includes camera 36, stop
40, and lens assembly 42. More specifically, camera 36
30 includes housing 44, pixel array 46, and shutter 50; and lens

VTN-64

1 assembly 42 includes housing 52, lenses 54 and 56, and
baffles 60.

5 Housing 26 of subsystem 14 provides a protective
enclosure for other elements of this subsystem; and light
source 30, mirrors 32 and 34, and diaphragm 130 are all
secured in that housing. More specifically, housing 26
includes a main vertical leg 26a and top and bottom
horizontal legs 26b and 26c, and light source 30 is
positioned inside the main leg of the housing. Mirror 32 is
10 secured in the intersection of legs 26a and 26c, mirror 34 is
positioned adjacent the distal end of leg 26c, and diaphragm
130 is positioned inside leg 26c, between mirrors 32 and 34.
Housing 26 also forms an opening 26d directly above mirror
34, and window 142 is secured in that opening. In use, light
15 source 30 generates a multitude of light flashes or pulses
and directs each of those pulses onto light path 82. Mirror
32 is located on this path and directs the light pulses
through diaphragm 130 and onto mirror 34, which in turn
directs the light pulses upwards, through window 142, through
20 the lens inspection position, referenced at 144 in Figure 8,
and toward or onto imaging subsystem 16.

Preferably, light source 30 is mounted on
adjustable support means 136 that allows the specific
direction of the light emitted from that light source to be
25 adjusted, and mirror 34 is mounted on another adjustable
support means 140 that allows both the specific direction and
the specific position of the light reflected from that mirror
to be adjusted. More particularly, with the preferred
embodiment of subsystem 14 shown in Figure 8, support means
30 136 includes a tilt stage that is secured to housing 26 and
is pivotal about two mutually orthogonal horizontal axes.

VTN-64

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1 Also, with this embodiment of subsystem 14, mirror support
means 140 includes tilt stage 140a and translation stage
140b; and mirror 34 is mounted on the former stage, which in
turn is mounted on the latter stage. Stage 140b is movable
5 laterally, to the left and to the right as viewed in Figure
8, allowing the lateral position of mirror 34 to be adjusted;
and stage 140a is pivotal about two mutually perpendicular
horizontal axes, also allowing the specific angle of mirror
34 to be adjusted.

10 Imaging subsystem 16 receives light pulses
transmitted through the ophthalmic lenses located in the lens
inspection position 144, and generates a series of signals
representing selected portions of the light transmitted
through those ophthalmic lenses. More particularly, pixel
15 array 46 is disposed inside camera housing 44, directly
behind shutter 50; and the pixel array is preferably
comprised of a multitude of light sensors each of which is
capable of generating a respective one electric current
having a magnitude proportional to or representing the
20 intensity of light incident on that sensor.

Figure 9 is an enlarged view of a small portion of
pixel array 46, and in particular, shows a multitude of
individual light sensors of the pixel array. With reference
to this Figure, preferably these light sensors, or pixels,
25 are arranged in a uniform grid of a given number of rows and
columns, and for example, that grid may consist of one
million pixels arranged in one thousand columns and one
thousand rows. Preferably, in that grid, the pixels form a
multitude of uniformly spaced rows and a multitude of
30 uniformly spaced columns; and, except for those pixels along
the very edge of the array, each pixel has eight immediate

VTN-64

1 neighbors. For example, pixel 146a has eight neighbors:
pixel 146b located directly above, pixel 146c located
directly below, pixels 146d and 146e located directly to the
left and to the right respectively, and pixels 146f, 146g,
5 146h, and 146i located, respectively, above and to the right,
above and to the left, below and to the right, and below and
to the left.

With reference again to Figure 8, stop 40 and
lenses 54 and 56 are located forward of shutter 50 and are
coaxially aligned with each other and with pixel array 46 and
10 the camera shutter. Stop 40 is positioned between lenses 54
and 56 and substantially at the back focal plane of lens 54,
and lens 56 is positioned so that the pixel array is at the
back focal plane of this lens 56. Preferably, lenses 54 and
15 56 and stop 40 are mounted inside housing 52, which in turn
is mounted on the front end of camera 36. In addition,
baffles 60, which may comprise a series of ring-shaped
members, are preferably mounted in and spaced along the
length of housing 52 to help collimate the light travelling
20 therethrough.

With this specific position of lenses 54 and 56 and
stop 40, most or all of the light beam transmitted through a
particular ophthalmic lens being inspected is focused by lens
54 onto stop 40, and is thus not incident on pixel array 46.
25 However, some of the light passing through irregular features
of the ophthalmic lenses, as well as some of the light
passing through regular features of some ophthalmic lenses,
may be deflected sufficiently so that this light is not
focused onto stop 40 by lens 54, but instead is transmitted
past that stop and is incident on the pixel array 46. In
30 addition, the lens inspection position is located at a

-17-

1 position that is optically conjugate to the position of pixel
array 46, and thus any light that is transmitted past stop 40
forms an image on the pixel array of the entity of the
ophthalmic lens that scattered that light.

5 This dark field illumination technique is a very
effective way to illuminate irregularities in ophthalmic
lenses; and Figure 10 shows the image formed on pixel array
46 by a beam of light transmitted through an ophthalmic lens,
and in particular, through a contact lens 84 shown in Figures
10 2 and 3. Most of the light transmitted through the lens is
blocked from the pixel array by stop 40. However, due to the
non-uniform thickness of annulus 84c of the lens, the light
transmitted through this portion of the lens is deflected
past stop 40 and is incident on pixel array 46, forming a
15 picture of the annulus on that array. Other irregularities
in lens 84 also produce illuminated areas on the pixel array.
For instance, even subtle, shallow defects, such as puddles
can be seen on the pixel array. In particular, if a puddle
is present in the interior of the lens, then the puddle will
20 readily appear on the pixel array as a bright outline on a
dark field; and if a puddle is present in the peripheral zone
of a lens, then the puddle will readily appear on the pixel
array as dark lines on a bright field. Also, since the
peripheral zone of the contact lens has a wedge-shaped cross-
25 section, that peripheral zone deflects enough light past stop
40 to cause the entire zone to appear on pixel array 46 as a
bright white annulus 150 on a dark field.

As will be understood by those of ordinary skill in
the art, any suitable light source, lenses, and camera may be
30 used in subsystems 14 and 16. For instance, the light source
30 may be a short-arc xenon flash lamp made by Hamamatsu.TM

VTN-64

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-18-

1 This particular flash lamp has a unique combination of arc
stability and longevity, and the output of this flash lamp is
rated plus or minus 2%, with a lifetime of 10^9 flashes.

5 Further, with an embodiment of subsystem 16 that
has been actually reduced to practice, first imaging lens 54
is a 100 mm focal length achromatic lens that is diffraction-
limited for objects within 2.5° of the optical axis of the
lens, and the lens 54 is mounted in a black-anodized aluminum
tube, with internal baffles 60 to eliminate degradation of
10 contrast due to the reflection of light from the inside walls
of the tube. The second lens 56 is a standard 50 mm focal
length F-1.8 NikonTM lens. The end of the barrel for the first
lens 54 is cemented onto an ultraviolet haze filter, which is
threaded into the housing of the 50 mm lens.

15 Opaque stop 40 is a small plastic circle with a
diameter of 0.100 inches, and includes an adhesive backing to
secure the stop in place. Suitable stops are commercially
available and are used as solder pad masks in manual layout
of art work for printed circuit boards, and these stops are
20 available in a large variety of sizes. The preferred size of
stop 40 may vary depending on other parameters of system 10,
and the selected size of the stop is preferably chosen to
provide the best compromise between contrast, ease of
alignment, and sensitivity to vibration.

25 The camera used in the subsystem 16 that has been
actually constructed, is a high-resolution camera sold by
VidekTM, and that accepts a standard Nikon mount lens. The F-
1.8 50 mm NikonTM lens 56 is first mounted on camera 36, and
then the housing of lens 54 is threaded onto the lens 56.
30 The effective field of view of this VidekTM camera is $13.8 \times$
 13.8 mm, which is, for example, about 10-15% larger than the

VTN-64

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1 maximum contact lens size. It is desirable that the
ophthalmic lens being inspected occupy as much of the field
of view of camera 36 as possible in order to optimize the
accuracy of the inspection. Hence, by automatically
5 centering the lens to be inspected, the inspection cups 110
of lens carrier 22 make maximum use of the resolution
available in the camera.

The preferred configurations of subsystems 14 and
16 have a number of advantages. First, because light path 82
10 is folded, the flash lamp 30 may be placed a larger distance
from the ophthalmic lens that is at the lens inspection
position 144, and this produces a highly collimated beam of
light at that ophthalmic lens. Second, the size of the image
of the arc on the stop 40 is substantially equal to the
15 physical size of the arc, multiplied by the ratio of (i) the
distance from lamp 30 to lens 54 to (ii) the distance from
lens 54 to stop 40. The preferred configuration shown in
Figure 8 also minimizes the arc image size, allowing the use
of a smaller stop and consequently producing greater
20 sensitivity. Third, iris diaphragm 130 limits the cross-
sectional area of light beam 82 and thus the area that is
illuminated by that beam. Preferably, diaphragm 130 is used
to adjust the cross-sectional area or size of beam 82 so that
the beam illuminates a circular area about only 10 to 15%
25 larger than the diameter of the ophthalmic lens being
inspected. Limiting the size of the illumination beam 82
improves the contrast between the image produced on the pixel
array and the rest of that array; and in particular, limiting
the size of beam 82 eliminates or substantially reduces the
30 amount of light that scatters from artifacts of the lens
inspection cup. This scattered light might appear as

VTN-64

1 background light on pixel array 46, reducing the contrast
between the image of interest on the pixel array and the rest
of that array.

5 In addition, with the preferred configuration of
subsystems 14 and 16, the magnification factor of the
system --that is, the ratio of the size of the image of the
ophthalmic lens on the pixel array 46 to the actual size of
that ophthalmic lens-- is approximately equal to the ratio of
10 the focal length of the second lens 56 to the focal length of
the first lens 54. The actual magnification factor also
depends upon the distance between the lenses 54 and 56 and
the distance of the ophthalmic lens being inspected from the
first imaging lens 54. In addition, tilt stage 140a and
translation stage 140b allow the center of the output beam
15 reflected off of mirror 34 to be adjusted to coincide with
the axis of the imaging optical subsystem 16.

As described above, imaging subsystem 16 includes
two lenses 54 and 56, separated by approximately the focal
length of the first lens 54. The use of two lenses is not
20 necessary; however, this is preferred because the use of two
lenses provides for a greater control over various parameters
of subsystems 14 and 16, and for example, it decouples the
separation between the back focal plane and the image plane
from the magnification of the subsystems.

25 Figures 11A, 11B, and 11C illustrate alternate
optical configurations, generally referenced at 152, 154, and
156 respectively, that may be employed in system 10 for
directing light beam 82 through the lens inspection position
and the ophthalmic lens held in that position, and onto stop
30 40 and pixel array 46.

1 Configuration 152 includes only one lens 160, which
simultaneously images light beam 82 onto stop 40 and images
the lens being inspected onto pixel array 46. More
specifically, the optical configuration shown in Figure 11A
5 includes mirror 162, imaging lens 160 and stop 40; and the
Figure also shows a lens holder, schematically represented at
164, an ophthalmic lens 166 to be inspected and pixel array
46. With this configuration, light beam 82 or pulses from
light source 30 is directed to mirror 162, which in turn
10 directs the light through lens 166 and onto imaging lens 160.
Most of the light directed to lens 160 is focused thereby
onto stop 40; however certain features of lens 166 will
deflect light sufficiently so that this deflected light is
transmitted past stop 40 and is focused on pixel array 46,
15 producing thereon an image of the features of lens 166 that
caused the light to be transmitted past stop 40. The
configuration of Figure 11A may be the preferred
configuration if the CCD screen of camera 36 is larger than
the CCD screen of the above-mentioned high-resolution Vidik
20 camera.

With configuration 154 of Figure 11B, the functions
of imaging the light source onto stop 40 and imaging the
ophthalmic lens being inspected onto pixel array 46 are
separated. To elaborate, this configuration includes mirror
25 170, lenses 172 and 174 and stop 40; and Figure 11B also
shows lens holder 164, ophthalmic lens 166 and pixel array
46. In this configuration, light beam 82 from light source
30 is directed onto mirror 170, and this mirror directs the
light beam to lens 172. Lens 172 directs the light through
ophthalmic lens 166, and most of the light transmitted
30 through lens 166 is focused on stop 40. Some features of

VTN-64

- 1 lens 166 deflect light away from stop 40, however; and this
deflected light is incident on lens 174, which focuses that
light onto pixel array 46, producing thereon an image of the
feature of lens 174 that deflected the light past stop 40.
- 5 An advantage of the lens arrangement of Figure 11B is that
the actions of the two lenses 172 and 174 are completely
independent.

Optical configuration 156 shown in Figure 11C is
very similar to the optical configuration shown in Figure 8;
10 however configuration 156 does not include mirror 32 or
diaphragm 130. More particularly, configuration 156 includes
mirror 176, lenses 180 and 182 and stop 40; and Figure 11C
also shows lens holder 164, ophthalmic lens 166 and pixel
array 46. With the arrangement of Figure 11C, light beam 82
15 from light source 30 is directed onto mirror 176, which
directs the light through lens 166 and onto first lens
180. Most of the light directed to lens 180 is focused onto
stop 40; however some features of lens 166 deflects light
sufficiently so that this light is transmitted past stop 40
20 and onto second lens 182, and this lens 182 focuses this
light onto pixel array 46. In this configuration, lens 180
images the light source onto stop independent of lens 182.
Both lenses 180 and 182, however, are involved in imaging any
defects in lens 166 onto pixel array 46.

25 In addition to the foregoing, system 10 also
preferably includes a control subsystem to synchronize the
operation of illumination subsystem 14 and imaging subsystem
16 with the operation of transport subsystem 12; and, in
particular, to actuate the light source 30 to generate a
30 light pulse, and to open camera shutter 50, when a lens is in
the lens inspection position 144. The preferred control

VTN-64

1 subsystem is illustrated schematically in Figure 12A. With
this preferred control subsystem, transport subsystem 12
generates an electric signal each time one of the lens
inspection cups is in the lens inspection position. This
5 signal may be generated, for example, by stepper motor 94, or
by another drive means for translation table 92, or by a
limit switch that is engaged each time one of the lens
inspection cups reaches the lens inspection position.
Preferably, this signal is transmitted to camera shutter 50
10 to open that shutter, and also transmitted to a delay circuit
184 that delays the electric signal for a short period, to
allow the camera shutter to open completely, and after this
short delay, this electric signal is then transmitted to a
lamp driver 134 that then actuates light source 30.

15 For example, with an embodiment of system 10 that
has been constructed, and with reference to Figure 12B, when
an ophthalmic lens is in the lens inspection position, the
transport subsystem generates and transmits a 24 volt pulse
both to camera 36 and to delay circuit 184. The camera
20 shutter opens in response to the leading edge of this pulse,
and takes about 9 milliseconds to open completely. The delay
circuit delays passage of the signal to lamp driver 134 for
about 15 milliseconds; and after this delay, this trigger
pulse is transmitted to the lamp driver. The leading edge of
25 this trigger pulse actuates an SCR, which ignites the flash
lamp 30. At this point of ignition, the lamp becomes
electrically conductive, and a previously charged capacitor
is discharged across the lamp. The capacitance and voltage
to which that capacitor were charged determine the total
30 light energy emitted by the lamp and the duration of the
light pulse. Meanwhile, an interface circuit holds the

VTN-64

1 camera shutter open for about 30 milliseconds and then closes
the shutter.

5 The use of a camera shutter in the above-described
manner avoids or substantially reduces the integration of
ambient light in pixel array 46 between lens inspections.
Also, preferably, the high voltage power supply, lamp driver
electronics and storage capacitor are mounted in the housing
structure 26 that contains the illumination optics.

10 The light from lamp 30 is sufficient to allow the
capture of an image on pixel array 46 in such a short period
of time that it is not necessary to stop the ophthalmic lens
being inspected. Thus, the transport subsystem 12 is
preferably designed to move an array of ophthalmic lenses
continuously under the imaging subsystem 16. This
15 continuous, smooth movement of the ophthalmic lens array is
advantageous because it reduces or eliminates the development
of ripples or other disturbances of the top of the solution
112 in cups 110, which might interfere with the imaging
process.

20 As will be understood by those of ordinary skill in
the art, the desired synchronization or coordination between
transport subsystem 12, illumination subsystem 14, and
imaging subsystem 16 may be achieved in other ways. For
instance, light source 30 may be activated and shutter 50 may
25 be opened at predetermined time intervals that are chosen to
coincide with the positioning of a lens in the lens
inspection position 144.

30 The illumination, imaging, and transport subsystems
may be enclosed within a housing (not shown) to minimize the
effects of airborne debris on the illumination and imaging
processes. That housing may be provided with transparent

VTN-64

1 front doors or with front doors having transparent windows to
provide access to and to allow observation of the interior of
the housing, and the transparent portions of those front
doors may be tinted to minimize the effects of ambient room
5 light on the illumination and imaging processes.

Figure 13 is a block diagram illustrating image
processing subsystem 20. In this subsystem, the electric
signals from the pixel array are conducted, in a combination
of a series and parallel formats, to pre-processor 62. These
10 electric signals being transmitted to pre-processor 62 may be
identified in any suitable way with the specific pixels that
generated the signals. For instance, the signals from the
pixels of camera 36 may be transmitted to pre-processor 62 in
a given, timed sequence, and a clock signal may also be
15 transmitted to the preprocessor from the camera to identify
the start, or selected intervals, of that sequence.
Alternately, each signal transmitted to processor 62 may be
provided with a header or another data tag identifying the
particular pixel that generated the signal.

20 Unit 62 converts each electric current signal from
each pixel of array 46 into a respective one digital data
value, I_0 , and stores that data value at a memory location
having an address associated with the address of the pixel
that generated the electric signal. These data values are
25 available to processor 64 and may be transmitted thereto via
bus lines 186. Preferably, as discussed in detail below, a
plurality of additional sets of data values $I_1 \dots I_n$ are
generated, with each data set having a respective one data
value associated with each pixel of array 46, and pre-
30 processor 62 may include a multitude of memory sections, or

VTN-64

1 boards, each one of which is used to store a respective one
set of these data values.

5 Processor 64 is connected to preprocessor 62 via
bus lines 186 to obtain data values from and to transmit data
values to that preprocessor. As explained in greater detail
below, processor 64 is programmed to process and analyze the
data values stored in the preprocessor to identify at least
one condition or parameter of each lens inspected by system
10, and for example, to indicate whether each lens is
acceptable for consumer use.

Memory disk 70 is connected to processor 64 to
receive and to hold data values on a permanent or semi-
permanent basis. For instance, memory disk 70 may be
provided with various look-up tables used by processor 64,
15 and the memory disk may be used to store data relating to or
obtained in the lens inspection process. For example, memory
disk 70 may be used to keep track of the total number of
lenses inspected during a given day or time period, and to
keep track of the total number, type, and size of any defects
20 found in any given sample or group of lenses.

Keyboard 66 is connected to processor 64 to allow
operator input thereto, and keyboard terminal 74 is used to
display visually data or messages being input into the
processor. Monitor 72 is connected to preprocessor 62 and is
25 provided to produce video images from the data values stored
in the preprocessor. For example, the I_0 data values may be
transmitted to monitor 72 to produce thereon an image of the
real image produced on pixel array 46. Others of the sets of
data values $I_1 \dots I_n$ may be transmitted to monitor 72 to
30 produce refined or processed images of that real image.
Printer 76 is connected to processor 64, via serial-parallel

VTN-64

1 converter 190, to provide a visual, permanent record of
selected data values transmitted to the printer from
processor 64. As will be understood by those of ordinary
skill in the art, subsystem 20 may be provided with other or
5 additional input and output devices to allow an operator or
analyst to interact with processor 64, preprocessor 62, and
memory unit 70.

The individual components of subsystem 20 are
conventional and well-known by those of ordinary skill in the
10 art. Preferably, processor 64 is a high-speed digital
computer, and monitor 72 is a high resolution color monitor.
Also, for example, preprocessor 62 may be an assembly of
Datacube signal processing boards, and processor 64 may be a
Sun 3/140 work station.

15 As discussed above, each time an ophthalmic lens
passes directly beneath camera 36, light is transmitted
through the ophthalmic lens and focused on pixel array 46,
and each pixel of array 46 generates a respective one
electric output current having a magnitude representing the
20 intensity of the light incident on that pixel. This output
current for each pixel is converted to a digital data value
that is stored in an address in preprocessor memory
associated with the pixel. These digital data values,
referred to as the I_o values, are processed, as described
25 below, to determine whether the lens passing beneath the
camera 36 includes one or more of a selected group of
features; and in particular, to determine whether that lens
contains any feature that may be considered as a flaw or
defect that renders the lens unsuitable for consumer use.

30 Figure 14 shows the major components of a preferred
image processing procedure to identify any defects in the

VTN-64

1 type of lens 84 shown in Figures 2 and 3. After the lens
image is acquired on the pixel array, that image is tested,
in a procedure referred to as decentration, to determine if
the inside and outside circumferential edges of annulus 84c
5 of the lens are properly centered relative to each other, and
this decentration test involves fitting first and second
circles to the inner and outer edges of the annulus produced
on the pixel array. After this, the actual edges of the
annulus are found or extracted. Then, a first masking
10 procedure is used to reduce or eliminate data associated with
light refracted or deflected by the periphery of the lens
inspection cup, and any edge defects are highlighted by a
procedure referred to as the rubber band algorithm. Next,
any defects are further emphasized by procedures referred to
15 as fill-in and clean-up and by a second mask procedure that
eliminates data associated with certain pixels near the
center of the annulus image.

After any possible defects are emphasized or
highlighted, a search is made to determine if in fact any
20 defects exist. In particular, the pixels of array 46 are
searched --or, more precisely, data values associated with
those pixels are searched-- to identify line segments, or
runlengths, of pixels that may be part of a defect, and those
runlengths are then clustered to identify defect candidates.
25 Then, the sizes and locations of these defect candidates are
analyzed to determine if they are actual defects that make
the lens unsuitable for consumer use.

As mentioned above, the decentration test is used
to determine whether the inside and outside circumferential
30 edges of annulus 84c of the lens passing beneath the camera
are concentric. Generally, with reference to Figure 15, this

1 is done by making a multitude of scans 202 across the pixel
array 46 --or, more precisely, by studying data values at
addresses in the preprocessor memory that correspond to the
addresses of pixels in selected line segment on array 46-- to
5 determine whether the outside and inside edges 150a and 150b
of annulus 150 are concentric.

Figures 16a and 16b illustrate the decentration
test or routine R_1 . The first step 204 in this routine is
referred to as a thresholding subroutine; and the purpose of
10 this routine is to associate each pixel with a new intensity
value I_1 equal to either the maximum or minimum illumination
values, $T_{\max}$ or $T_{\min}$, depending on whether the original
illumination value I_0 of the pixel is, respectively, above or
below a given threshold value T_t . Thus, for example, each
15 pixel having an original illumination value I_0 greater than
127 may be provided with a new illumination value I_1 of 255,
and each pixel having an original illumination value of 127
or less may be provided with a new illumination value I_1 of
zero.

20 The next step 206 in the decentration test is to
set the number, locations, and sizes of the scans 202 used in
this test, and this is done by providing the processor 64
with the address of the starting pixel and the length and
direction of each scan. These parameters are chosen so that,
25 unless the lens is badly decentered, each of a multitude of
the scans cross both edges of annulus 150. Preferably,
processor 64 or memory disc 70 is provided with a semi-
permanent record of these starting addresses, directions and
scan lengths. This record is used during the inspection of
30 each lens of a given nominal type or size, and this semi-

VTN-64

1 permanent record may be changed when lenses of a different
nominal type or size are inspected.

5 Next, at step 210, the selected scans are made
across the pixel array or display 46. Unless a lens is badly
decentered, most of these scans will cross an illuminated
portion of that display. When a scan crosses an illuminated
portion of the display, the addresses of the first and last
pixels of the line segment crossing that illuminated portion
and the length of that line segment, referred to as the run
length, are recorded in a file f_1 . Subroutines for detecting
10 the first and last pixels in a run length, for obtaining the
addresses of those pixels, and for determining the length of
each run length, are well-known by those of ordinary skill in
the art, and any such suitable routines may be employed in
15 the decentration test.

Then, at step 212, the length of each of these run
lengths is compared to a predetermined value, and the data
--that is, the addresses of the first and last pixel in the
run length and the length of the run length-- associated with
20 each run length less than that predetermined value, are
discarded. This discarding is done to eliminate, or at least
to reduce the amount of, data caused by noise on the pixel
array 46 --that is, undesirable light that is incident on the
pixel array. To elaborate, noise, which may be due to
25 background light or to light that is deflected off the
desired light path by dust or other particles, may produce
illuminated areas on the pixel array. In the vast majority
of instances, each of these illuminated areas consists of
only one or a small group of adjacent pixels. If one of the
above-mentioned scans made during step 210 crosses such an
30 illuminated area, then the processor records the addresses of

VTN-64

1 the first and last pixel of and the length of the run length
across that illuminated area. This illuminated area and the
associated data, however, are not related to annulus 162 or
to the edges thereof, and thus step 212 is provided to
5 eliminate this data.

The next step 214 in the decentration test is to
identify each of the remaining pixel addresses as being on
the outer edge or the inner edge of the annulus, and any
suitable subroutine may be employed to do this. For
10 instance, the addresses of the first and last pixel of each
run length may be compared to each other; and the pixel
closer to the center of the entire pixel array 46 may be
considered as being on the inner edge of annulus 162, while
the pixel further away from the center of the pixel array may
15 be considered as being on the outer edge of the annulus.
Alternatively, the scans may be separated into two groups
such that for each scan in the first group, if an illuminated
run length is found during the scan, the first and last
pixels in the run length are on the outer and inner edges,
20 respectively, of the annulus; and for each scan in the second
group, if an illuminated run length is found during the scan,
the first and last pixels in the run length are on the inner
and outer edges, respectively, of the annulus.

After each pixel is determined to be on the inside
25 or the outside edge of annulus 162, then at step 216 the
number of pixels that have been found on each edge is
counted. If either of these numbers is less than three, then
at step 220, the lens is rejected on the basis that the lens
is badly decentered. If, though, at least three pixels have
30 been found on each edge, then at step 222, a subroutine is
invoked, first, to fit a first circle onto the pixels that

VTN-64

1 were found on the outside edge of the annulus, second, to fit
a second circle onto the pixels that were found on the inside
edge of the annulus, and third to determine the centers and
radii of these two circles. Numerous subroutines are well-
5 known for fitting a circle onto three or more points and to
calculate the center and radius of that circle, and any such
subroutine may be used in the decentration test at step 222.

After the centers of these two fitted circles are
calculated, the distance d between these two centers is
10 determined at step 224. This distance is then compared, at
step 226, to a first value d_1 ; and if the distance is greater
than d_1 , then the lens is rejected at step 230 as being badly
decentered. If the distance d is less than d_1 , then, at step
232, that distance d is compared to d_2 , which is the maximum
15 acceptable distance between the centers of the inner and
outer edges of annulus 150. If the distance d between
centers of the fitted circles is greater than d_2 , then the
lens is rejected, at step 234, as being decentered; however,
if the distance d is equal to or less than d_2 , then the lens
20 passes the decentration test, as indicated by step 236.

If a lens passes the decentration test, processor
64 then initiates a process or routine R_2 , referred to as
edge detector, to produce a set of illumination values that,
in turn, may be used to identify the pixels on the edges of
25 annulus 150. Typically, these edges are not perfect circles
and thus are different from the fitted circles found during
the decentration test. This new set of illumination values
is obtained through a series of morphological operations or
changes in the original intensity values assigned to or
30 associated with each pixel of array 46. These morphological
changes are pictorially illustrated in Figures 17a through

1 17i, and shown in the form of a flow chart in Figure 18.
More specifically, Figure 17a shows an image of annulus 150
on pixel array 46; and Figure 17b shows an enlarged view of a
portion of that annulus, and also shows a short line segment
5 240, or scan, across that annulus portion and the adjacent
areas of the pixel array. Figure 17c illustrates the
intensity values I_1 of the pixels in that scan 240; and as
represented therein, the pixels in the dark areas of Figure
17b have a lower or zero I_1 value, and the pixels in the
10 light areas of Figure 17b have a higher I_1 value, such as
 $T_{\max}$.

With reference to Figure 18 and Figures 17c and
17d, in the first step 242 of the edge detector process, a
new value I_2 is calculated for each pixel; and, in
15 particular, the I_2 value for each pixel is set equal to the
average of the I_1 values of that pixel and its eight
immediately adjacent pixel neighbors. The difference between
the I_1 and the I_2 values for the pixels in array 46 is that
the latter values change more gradually between the pixels
20 having the lowest I_2 value (which generally are those pixels
in the dark areas of the pixel array), and the pixels having
the highest I_2 value (which generally are those pixels in the
light areas of array 46). This difference may be best
understood by comparing Figures 17c and 17d.

25 Then, at step 244, a further value I_3 is determined
for each pixel; and specifically, the I_3 value for each pixel
is set equal to the minimum I_2 value of that pixel and its
eight immediately adjacent pixel neighbors. With reference
to Figures 17d and 17e, the I_3 values may vary across the
30 scan 240 in a manner very similar to the way in which the I_2
values vary across that pixel scan. The principle difference

1 between the manner in which the I_2 and I_3 values of the pixels vary across the pixel array is that the band of pixels having the highest I_3 value is slightly narrower than the band of pixels having the highest I_2 values.

5 The next step 246 in the edge detector process is to determine a still further value I_4 for each pixel according to the equation $I_4 = I_2 - I_3$. With particular reference to Figure 17f, most of the pixels in the scan 240 have I_4 values of zero; however, the pixels on and radially immediately inside the two edges of annulus 162 have positive I_4 values. Next, at step 250, an I_5 value is determined for each pixel; and more specifically, the I_5 value of each pixel is set equal to the maximum I_2 value of the pixel and its eight immediately adjacent pixel neighbors. For most of the
10 pixels on the pixel array 46, the I_5 value of the pixel is the same as the I_2 value of the pixel. However, for the pixels within a given distance of the edges of annulus 150, the I_5 values of the pixel are greater than the I_2 values of the pixel, and the band of pixels having the highest I_5 value is slightly wider than the band of pixels having the highest
15 I_2 value.
20

The next step 252 in the edge detector process is to determine a still further value I_6 for each pixel according to the equation $I_6 = I_5 - I_2$. With particular reference to Figure 17h, most of the pixels on the pixel
25 array will have I_6 values of zero; however, the pixels on and radially immediately outside the two edges of annulus 150 have positive I_6 values. Next, at step 254, an I_7 value is assigned to each pixel; and more specifically, the I_7 value of each pixel is set equal to the smaller of the I_4 and I_6
30 values for the pixel. With reference to Figure 17i, most of

VTN-64

1 the pixels on the pixel array have an I_1 value of zero;
however, the pixels directly on and immediately adjacent the
two edges of annulus 150 have positive I_1 values. In this
way, the I_1 values of the pixels identify the pixels that are
5 on the edges of annulus.

A thresholding subroutine may then be invoked at
step 256 to sharpen the distinction between the pixels on the
edges of annulus 150 and the other pixels in display 46. In
particular, each pixel may be assigned a still further value
10 I_8 equal to either the maximum illumination intensity value
 $T_{\max}$ or the minimum illumination intensity value $T_{\min}$ depending
on whether the I_1 value of the pixel is, respectively, above
or below a given threshold value such as T_t . Thus, for
instance, each pixel having an I_1 value greater than 32 may
15 be provided with an I_8 value equal to 255, and each pixel
having an I_1 value of 32 or less may be provided with an I_8
value of zero.

Figure 17j shows each pixel of array 46 illuminated
at an intensity equal to its I_8 value.

20 During the calculation and processing of the I_1 - I_8
values, preferably each set of pixel values is stored in a
respective one memory register in preprocessor 62 --that is,
for example, the I_0 values are all stored in a first
register, the I_1 values are all stored in a second register,
25 and the I_2 values are all stored in a third register. It is
not necessary to store all of the I_1 - I_8 values during the
entire processing period for each lens, however; and, for
instance, during each processing period, the I_1 values may be
discarded after the I_4 values are calculated, and the I_5
30 values may be discarded after the I_6 values are determined.

1 In addition, it is not necessary to calculate I_2-I_8
values for all the pixels in the array 46. For any
ophthalmic lens of a given type, the annulus of the lens will
appear in a relatively well-defined region or area of the
5 pixel array 46, and it is only necessary to determine the I_2-I_8
 I_8 values for the pixels in that region or area. However, as
a practical matter, it may often be easier simply to
calculate the I_2-I_8 values for all the pixels in array 46,
rather than to add a further processing step to identify
10 those pixels in the given area of interest.

 After the edge detector routine is completed, the
lens inspection system invokes a masking routine to produce a
set of pixel illumination values that is free of the effect
produced by the edge of the lens inspection cup used to hold
15 the lens. To elaborate, as an ophthalmic lens is illuminated
by a flash of light from flash lamp 30, light is also
transmitted through the cup holding the lens. The edge of
the cup may diffract some of this light sufficiently enough
to transmit the light past stop 40 and onto the pixel array
20 46, producing thereon an image or a partial image of the edge
of the cup, as shown at 260 in Figure 19a. This edge image
is not related to the lens itself, and thus any data
associated with that cup edge image are unnecessary and
undesirable to the processing of the data associated with the
25 lens image itself; and a masking routine is invoked to
eliminate the cup edge image from pixel array 46, or more
precisely, to produce a set of pixel illumination values that
is free of the pixel data associated with the above-mentioned
cup edge image 260.

30 Figure 20 is a flow chart illustrating a preferred
masking routine R_3 . The first step 262 in this routine is to

VTN-64

1 determine whether, at steps 216 or 226 of the decentration
test, at least three pixels had been found on the outside
edge of annulus 162 or if the ophthalmic lens was found to be
badly decentered. If the lens had been found to be badly
5 decentered at either of these two steps of the decentration
test, then masking routine R_3 itself terminates at step 262.

If routine R_3 does not terminate at step 262, the
routine proceeds to step 264, which is to obtain the
coordinates of the center of the circle that had been fitted
10 to the outside edge 150a of annulus 150 during the
decentration test. These coordinates had been determined and
then stored in memory, either in the memory of processor 64
or in memory disc 70, during the decentration test, and thus,
these coordinates can be obtained by simply retrieving them
15 from the memory. Once these center coordinates are obtained,
a mask subroutine is invoked at step 266. With reference now
to Figure 19b, this subroutine, in effect, superimposes over
pixel array 46, a circular mask 270 centered on the above-
mentioned center coordinates, and having a diameter slightly
20 larger than the diameter of the circle fitted to the outer
edge of annulus 150. The masking subroutine then assigns an
 I_9 value to each pixel based on whether the pixel is inside
or outside this mask. In particular, for each pixel outside
that mask, the masking subroutine assigns the pixel an I_9
25 value of zero; and for each pixel inside the mask, the
masking subroutine assigns the pixel an I_9 value equal to the
 I_8 value for the pixel.

More precisely, at step 266, the coordinates $(x_0,$
 $y_0)$ of the above-mentioned center point and a radius value r_1 ,
30 which is selected to be slightly larger than the radius of
the circle fitted to the outside edge of annulus 150, are

VTN-64

1 transmitted to the mask subroutine. Then this subroutine
forms a file f_2 of the addresses of all of the pixels in
array 46 that are within the distance r_1 of that center point
(x_0, y_0). Then, at step 272, the address of each pixel in
5 array 46 is checked to determine if it is in that file. If
the pixel address is in that file, then at step 274 the I_0
value of the pixel is set equal to the I_0 value of the pixel;
however, if the pixel address is not in that file, then at
step 276 the I_0 value of the pixel is set to zero.

10 Numerous specific mask subroutines are well-known
in the art and may be employed at step 266 of routine R_3 .

Figure 19c shows the pixels of array 46 illuminated
at an intensity equal to their respective I_0 values.

After the masking procedure shown in Figure 20 is
15 completed, processor 64 initiates a further procedure,
referred to as the rubber band algorithm. This algorithm,
generally, involves analyzing and processing data values for
or relating to the pixels in and immediately adjacent to the
annulus edge 150a, and Figures 21a and 21b show a flow chart
20 that generally illustrates the rubber band algorithm. With
reference to these Figures, the first step 280 in this
algorithm is to obtain the center coordinates and the radius
of the circle fitted to the outer edge 150a of the lens in
the decentration test. As discussed above, these values had
25 been determined and then stored in memory during the
decentration test, and these values can be obtained by
retrieving them from that memory.

The next step 282 in the rubber band algorithm is
to locate a pixel on the outer edge 150a of annulus 150 by
30 searching inward from the left edge of pixel array 46, until
an illuminated pixel is found. It is possible that the first

1 illuminated pixel found during a given search might not be on
the edge of the image of the lens, but might be somewhere
else and illuminated because of background noise. Hence,
preferably, a multitude of scans or searches are conducted at
5 step 282 to find a multitude of illuminated pixels, and the
locations of these pixels are then analyzed or compared to
each other to help ensure that a pixel is found on the edge
of the lens image.

Once a first pixel is found on the edge of the lens
10 image, the rubber band algorithm proceeds to step 284; and at
this step this algorithm, in effect, starts at this first
pixel and traces all the way around the edge of the lens
image, eventually returning to that first pixel. During this
first trace, the algorithm records in file f_3 the addresses
15 of most or all of the pixels on the outside edge of the lens
image; and the algorithm also identifies larger gaps in the
lens edge, the lengths of those gaps, and larger extra pieces
on the lens edge. At step 286, the algorithm records in file
 f_4 the addresses of the pixels that are the end points of
20 selected lines, discussed in greater detail below, that in
effect are drawn across any larger gaps in the lens edge and
across and on either side of any larger extra pieces on that
edge.

After this first pass or trace around the lens
25 image is completed, the rubber band algorithm then
determines, at step 290, if any gap that might have been
found is large enough to cause the lens to be rejected. If
such a gap is found, the lens is rejected, and at step 292,
the printer 76 prints the message that the lens has a bad
30 edge.

1 If the lens passes this gap test at step 290, the
rubber band algorithm proceeds to make a second pass or trace
around the edge of the lens image. In this second pass, as
indicated at 294 in Figure 21b, the algorithm identifies
5 shallow features, such as smaller gaps and smaller extra
pieces, extending either radially inward or outward along the
outside edge of the lens, and the algorithm tests each such
detected feature to determine if the lens should be rejected
because of it. Generally, this is done by computing, for
10 each of at least selected pixels on the outside edge of the
lens, the dot product of two vectors, referred to as the
radial vector and the edge vector, through that pixel. The
radial vector through a pixel is that vector that also
extends through the center point of the circle fitted to the
15 outside edge 150a of annulus 150. The edge vector through a
pixel is the vector that extends through that pixel and a
second pixel on the outside edge of annulus 150, a given
number of pixels rearward, or counterclockwise, from the
former pixel along the outside edge 150a of annulus 150.

20 For any pixel on a regular, circular portion of the
lens edge that does not contain any defect --either a gap or
an extra piece-- the dot product of the two above-identified
vectors will be substantially zero, because the radial and
edge vectors through that pixel are substantially
25 perpendicular. However, for most or all pixels on the edge
of a gap or an extra piece on the lens edge, the dot product
of the edge and radial vectors through that pixel will not be
zero, because these two vectors are not perpendicular. If
any calculated dot product is greater than a given value,
30 then the lens is considered as not suitable for consumer use
and may be rejected.

VTN-64

35

1 If the lens passes the tests applied during the
second pass around the lens edge, then the rubber band
algorithm makes a third pass around the edge of the lens
image, as represented by step 296 in Figure 21B. This third
5 pass does not include any test to determine if the lens
should be rejected, but instead involves processing or
preparing data for subsequent tests. In particular, this
third pass is made to produce a set of data values that is
free of data associated with any defects in the lens that are
10 just inside the outer edge 150a of annulus 150. This set of
data values is subsequently subtracted from a set of data
values containing data associated with those defects, to
produce thereby a set of data values having only the data
associated with those flaws.

15 Generally, in this third pass around the lens edge,
the rubber band algorithm determines the average radial
thickness of the outside edge 150a of the annulus 150; and
then the algorithm sets to zero the I_0 values of all the
pixels that are just inside that outside edge of the annulus.
20 For example, if the outside edge of the annulus has an
average thickness of six pixels, then the rubber band
algorithm may set to zero the I_0 values of all of the pixels
that are between 7 and 27 pixels radially inward of the
outside edge of the annulus.

25 Figures 22-32 illustrate the rubber band algorithm
in more detail. More specifically, Figure 22 illustrates one
suitable subroutine S_1 for locating a first pixel, $P(x, y)$,
on the outer edge 150a of the annulus 150. At step 300, $(x_0,$
 $y_0)$ is set equal to the coordinates of the center of the
30 circle that was fitted to the outer edge of the annulus
during the decentration test; and at step 302, r_0 is set

VTN-64

1 equal to the radius of that outer fitted circle. Then, as
represented by step 304, a multitude of horizontal scans are
made across the pixel array 46, starting at, or about at, the
center of the left edge of the array. More precisely,
5 processor 64 studies data values I_i at addresses in the
preprocessor memory that correspond to the addresses of
pixels in selected horizontal line segments on the pixel
array. During each of these scans, the processor 64 checks
the I_i value of each pixel in a given horizontal row of
10 pixels, and identifies the first pixel in that row that has
an I_i value above a given value; and preferably, a multitude
of such scans are made, resulting in a multitude of
identified pixels.

Typically, all of these identified pixels will be
15 on the outer edge 150a of the annulus 150. It is possible,
though, that a pixel somewhere on the array and to the left
of that edge might have a high I_i value due to background
noise or stray light incident on the pixel during the lens
inspection procedure, and such a pixel might be identified as
20 an illuminated pixel in the above-mentioned scans. To
prevent such a pixel from being identified as an edge pixel,
subroutine, S_1 , at step 306, identifies and discards the
addresses of any such pixels. More specifically, the
subroutine, first, determines the distance between each of
25 the pixels identified in the scans and the center (x_0, y_0) of
the outer circle fitted to the outside edge of the lens image
during the decentration test; and second, compares each
determined distance to r_0 , which had been set equal to the
radius of that fitted outer circle. If the distance between
30 a particular pixel and the center of that fitted circle
exceeds r_0 by more than a given distance, d_3 , then that pixel

VTN-64

1 is considered as not being on or immediately adjacent the
edge of annulus 150, and the address of that pixel is
discarded. After the addresses of all the pixels found
during the scan are checked to determine if they are on or
5 immediately adjacent the lens edge --and the ones that are
not are discarded-- then, as shown at step 310, any remaining
pixel address may be selected as pixel $P(x, y)$, and then the
first pass around the edge of the lens image is begun.

Figure 23 illustrates in greater detail how this
10 first pass is made, and in particular, shows Routine R_1 for
making this pass. Starting at pixel $P(x, y)$, at step 312,
the algorithm searches forward, or clockwise, along the outer
edge of the annulus 150 for either a large gap in that edge,
or a large extra piece on that edge, as represented by steps
15 314 and 320. Any suitable subroutine or procedure may be
used to search along the edge. For instance, from each given
pixel on that edge, starting with pixel $P(x, y)$, the processor
may check the three or the five closest pixels in the row
above or below the given pixel or in the column to the right
20 or to the left of the given pixel, depending on the quadrant
or sector of display 46 in which the given pixel is located,
to identify the next pixel on the lens edge. From this next
pixel, the processor may use this same procedure to identify
the still next pixel on the lens edge.

25 Also, for each pixel that is found on the lens
edge, the processor may determine the distance, r , between
that pixel and the center point (x_0, y_0) of the circle fitted
to the outside edge of the lens. The processor may conclude
that a large gap has been found when, for each of a given
30 number of consecutive pixels on the lens edge, r is smaller
than r_0 by more than a given amount d_g (that is, $r_0 - r > d_g$).

VTN-64

1 Conversely, the processor may conclude that a large extra piece has been found when, for each of a given number of consecutive pixels on the lens edge, r is greater than r_0 by more than a given amount d_{ep} (that is, $r - r_0 > d_{ep}$).

5 If a gap or an extra piece is found, subroutines S_2 or S_3 , both of which are discussed in greater detail below, are invoked respectively at steps 316 and 322. If neither a gap nor an extra piece is found, then routine R_4 moves on to step 324.

10 At step 324, routine R_4 tests to determine if the first pass around the edge of annulus 150 is complete, and any suitable specific procedure or subroutine may be used to do this. For instance, as mentioned above, as the trace is made around the image of the lens edge, a file f_3 is made of
15 the addresses of the pixels that have been found on that edge. At step 324, that file may be checked to determine if the address of the current edge pixel being considered is already on the file. If the pixel address is already on the file, then the first pass around the image of the lens edge
20 is considered to be complete, while the pass is considered as not complete if this current pixel address is not already on file f_3 . If the first pass is complete, then the rubber band algorithm moves onto routine R_5 ; but if the first pass around the lens is not complete, the algorithm moves on to step 326
25 and the address of this current edge pixel being considered is added to file f_3 . Then at step 330, the next pixel on the lens edge is found and $P(x, y)$ is set equal to the address of this next pixel, and the routine R_4 then returns to step 312.

30 Figure 24 is a flow chart outlining subroutine S_2 , which is invoked each time a gap is found on the outside edge of annulus 150. The first step 332 in this subroutine is to

VTN-64

1 identify and record in a file f_4 the address of the pixels at
 the beginning and the end of the gap and the distance between
 these two end pixels. These two pixels are shown at P_1 and P_2 ,
 respectively in Figure 25A. Once a gap is found --that is,
 5 for each of a given number of consecutive pixels on the lens
 edge, r is smaller than r_0 by more than d_g -- the last pixel on
 the lens edge before that given number of consecutive pixels
 may be considered as the pixel at the beginning of the gap.

Also, once a gap has been found, the end of the gap
 10 may be found by searching across the gap, along the pixels on
 the circle fitted to the outside edge of the lens in the
 decentration test, and searching radially inwardly and
 outwardly for a given number of pixels from that portion of
 the fitted circle, until the lens edge is found --that is,
 15 until illuminated pixels, or more precisely, pixels having
 high I_0 values are found. After the lens edge is found, the
 gap may be considered as having come to an end once a series
 of consecutive pixels is found that are all within a certain
 distance of that fitted circle; and in particular, when for
 20 each pixel in that series, $r_0 - r$ is less than d_g . The last
 pixel on the lens edge before that series of consecutive
 pixels may be considered as the pixel at the end of the gap.

At step 340 of subroutine S_2 , the I_0 values of the
 pixels on the line between pixels P_1 and P_2 --the line segment
 25 L_1 in Figure 25b-- are set equal to the maximum illumination
 intensity value, and then the subroutine returns to routine
 R_4 .

Figure 26 shows a flow chart illustrating
 subroutine S_3 , which is invoked at step 322 of routine R_4 when
 30 an extra piece 350 is found on the edge of annulus 150. The
 first few steps in routine S_3 are done, in effect, to draw

1 various bridge lines relating to the extra piece. In
particular, at step 352, the subroutine identifies pixels P_3
and P_4 , shown in Figure 25b, on the edge of the annulus 150
at the start and at the end of the extra piece 350; and then,
5 at step 354, the I_0 value of each pixel on a line segment L_2 ,
shown in Figure 25c, between pixels P_3 and P_4 , is set to T_{max} .
Next, at step 356, the subroutine identifies the address of a
pixel P_5 that is on the edge of the annulus 150 a given
number of pixels rearward, or counterclockwise, of the start
10 of the extra piece 350; and at step 360, the pixel P_6 on the
edge of the extra piece that is a given distance d_4 from
pixel P_5 is found. Next, at step 362, and also with
reference to Figure 25d, the I_0 value of each pixel on a line
 L_3 between pixels P_5 and P_6 is set to T_{max} .

15 Next, at step 364, the subroutine identifies the
address of another pixel P_7 that is on the edge of the
annulus 150 a given number of pixels forward, or clockwise,
of the end of the extra piece; and then, at step 366, the
subroutine identifies the pixel P_8 on the edge of the extra
20 piece that is a given distance d_5 from pixel P_7 . At step 370,
the I_0 value of each pixel on the line L_4 , shown in Figure
25e, between pixels P_7 and P_8 is also set to T_{max} . After the
appropriate bridge lines are drawn, the subroutine returns to
routine R_4 .

25 After the first pass around the image of the lens
edge is completed, subroutine R_5 is invoked. This routine,
which is illustrated in Figure 27, is used to determine if
any of the gaps, which may have been found during the first
pass around the image of the lens edge, is wide enough to
30 make the lens unsuitable for consumer wear. The first step
376 in routine R_5 is to determine if any gaps were in fact

VTN-64

1 found during the first pass around the lens edge. If no gaps
were found, routine R_5 itself is terminated and the rubber
band algorithm proceeds to routine R_6 . However, if any gaps
5 were found during the first pass around the lens edge,
routine R_5 proceeds to step 380. At this step, each gap
width is compared, one at a time, to a given value d_6 ; and if
any gap width is greater than that value d_5 , then the lens is
considered to be unsuitable for consumer use, and the lens is
rejected at step 382. If all of the gap widths are less than
10 d_5 , however, then routine R_5 terminates, and the rubber band
algorithm proceeds to routine R_6 , which performs the second
pass or trace around the image of the lens edge.

Routine R_6 is illustrated in Figure 28. As
previously mentioned, this routine primarily searches for
15 shallow gaps in the lens edge and small extra pieces on the
lens edge that were not identified as gaps or extra pieces in
routine R_4 , which was the first pass around the lens edge.
In particular, at step 384, the address of pixel $P(x, y)$ is
set equal to the address of the first pixel in file f_3 .
20 Then, at steps 386, 390, and 392, two vectors V_1 and V_2 ,
referred to as edge and radial vectors respectively, are
identified and the dot product of these two vectors is
calculated. More specifically, the first vector V_1 is the
vector through pixel $P(x, y)$ and a second pixel on the lens
25 edge, a given number of pixels rearward or counterclockwise
of pixel $P(x, y)$ along that lens edge, and the second vector
 V_2 is the radial vector of the annulus 150 that extends
through pixel $P(x, y)$. The slopes of these two vectors and
their dot product can be easily determined from the addresses
30 of the pixels through which the vectors extend.

VTN-64

1 With reference to Figure 29, if pixel $P(x, y)$ is
along a regular, circular portion of the lens edge, then the
edge vector V_1 through the pixel is substantially tangent to
the lens edge, as shown at 394 in Figure 29. Also, this
5 vector V_1 is substantially perpendicular to the radial vector
 V_2 through that pixel, and the dot product of these two
vectors V_1 and V_2 is substantially zero. However, if pixel
 $P(x, y)$ is on an irregular portion of the lens edge, such as
on the edge of a gap or of an extra piece on the lens, as
10 shown at 396 and 400 in Figure 29, then the edge vector V_1
and the radial vector V_2 through pixel $P(x, y)$ are not
normally perpendicular, and the dot product of these two
vectors will normally not be zero.

The dot product of these two vectors V_1 and V_2 is
15 compared, at step 402, to a given value d_7 . If that dot
product is equal to or greater than that given value --which
indicates that an appreciable gap or extra piece is present
in the area of pixel $P(x, y)$ -- then the lens is considered
unacceptable for consumer use and is rejected at step 404,
20 and the entire routine R_6 terminates. If at step 402, the
calculated dot product is less than d_7 --which indicates that
in the area of pixel $P(x, y)$, any departure of the lens edge
from a perfect circle is within an acceptable limit-- then
routine R_6 moves on to step 406. At this step, the routine
25 tests to determine if this second pass or trace around the
image of the lens edge is complete. This is done, more
specifically, by testing to determine if pixel $P(x, y)$ is the
last pixel on file f_3 . If it is, then the second pass is
complete, and the rubber band algorithm proceeds to routine
30 R_7 . If, though, at step 406, it is determined that this
second pass around the lens edge image is not complete, then

VTN-64

1 at step 408, the address of pixel $P(x, y)$ is set equal to the
address of the next pixel on file f_3 , and then the routine
returns to step 386. Steps 386 through 408 are repeated
5 until either the lens is rejected or, for each pixel on file
 f_3 , the associated dot product of the two vectors V_1 and V_2
through that pixel has been calculated and found to be less
than d_7 , at which time the rubber band algorithm proceeds to
routine R_7 , which performs the third pass or trace around the
lens edge.

10 Preferably, the above-mentioned dot product is not
calculated for all the pixels on the lens edge, and in
particular, that product is not calculated for the pixels
that are on the edges of gaps or extra pieces that were found
during the first trace around the lens edge. It is not
15 necessary to calculate this dot product for these gap and
extra piece pixels since it is already known that the pixels
are on either a gap or an extra piece, and an appreciable
amount of processing time may be saved by not determining the
 V_1 and V_2 vectors through those pixels and the dot product of
those two vectors.

20 After routine R_6 is completed, the rubber band
algorithm proceeds to routine R_7 , which performs the third
pass or trace around the lens edge. As previously discussed,
the purpose of this third pass is, in effect, to produce a
new set of data values I_{10} that are free of any data
25 associated with any flaws in the lens that are just inside
the outside edge of the lens. Figure 30 shows routine R_7 in
greater detail; and this routine, generally, is comprised of
three parts. In the first part, the I_{10} value for each pixel
is set equal to the I_9 value for the pixel; in the second
30 part, an average edge thickness value, N , is calculated for

VTN-64

1 the outside edge 164 of annulus 162; and in the third part,
the I_{10} values of the pixels in a given range further inside
of that average edge thickness are set to zero.

5 More specifically, at step 410 of routine R_7 , the
 I_{10} value for each pixel is set equal to the I_0 value for the
pixel. Next, with reference to Figures 30 and 31, at step
412, a given number of pixels, shown at 414a-e in Figure 31,
on the extreme outside edge 150a of annulus 150 are selected.
Then, at step 416, routine R_7 counts the number of
10 illuminated pixels on each of the radii, shown at 420a-e in
Figure 31, of the lens image that passes through the pixels
414a-e. For instance, the routine may count the pixel on the
extreme outside edge of the annulus as the first pixel, and
then search radially inward from that pixel, and increase
that count value by one for each illuminated pixel on that
15 radius. At step 422, the average number of illuminated
pixels per radius is calculated; and this may be done, for
example, simply by dividing the total number of counted
illuminated pixels by the number of radial scans made.
Typically, this average value is not a whole number, and thus
20 preferably that average value is then increased to the next
largest whole number.

In the next part of routine R_7 , a third pass is
made around the outside edge 150a of annulus 150. To start
this pass, any pixel on that edge is selected as the starting
25 pixel $P(x, y)$, as indicated at step 424 in Figure 30. Then,
as represented by steps 426 and 430, the I_{10} values for
selected pixels radially inward of the average edge
thickness, are set to zero. More specifically, at each pixel
on the outside edge of annulus 162, the routine counts N
30 number of pixels radially inward along the radius of the

1 lens. Then, for each of a given number of pixels further
radially inward along that radius, the I_{10} value of the pixel
is set to zero. With reference to Figure 32, these steps of
the routine, in effect, set to zero the I_{10} values of the
pixels in the cross hatched area 432.

5 At step 434 of Routine R_7 , a check is made to
determine if this third pass around the image of the lens
edge is complete, and any suitable subroutine may be invoked
to do this. For instance, if the pixel selected as the
starting pixel for this pass is the top pixel in file f_3 ,
10 then the pass may be considered as complete after the routine
has performed steps 426 and 430 for the bottom pixel on that
file. Alternatively, a separate list of the addresses of the
pixels used in steps 426 and 430, of routine R_7 , may be made;
and each time a pixel address is added to that list, the list
15 can be checked to see if the new address being added is
already on the list. If an address value that is added to
list is already on that list, then the third pass around the
image of the lens edge is considered to be complete.

20 If, at step 434, this third pass around the lens
image is not complete, then at step 436, the address of pixel
 $P(x, y)$ is set equal to the address of the pixel that is,
clockwise, next to the current pixel $P(x, y)$ along the
outside edge 150a of annulus 150. For example, this address
may be taken from file f_3 ; and at step 436, the address of
25 pixel $P(x, y)$ may simply be set equal to the address on that
file that is next to the current pixel address. Then, the
routine R_7 returns to step 426, and steps 426, 430, and 434
are repeated for the new pixel address $P(x, y)$.

1 After this third pass around the image of the lens
edge is completed, processor 64 exits routine R₇ and the
rubber band algorithm terminates.

5 After the rubber band algorithm is finished, a
number of further operations are performed, the general
objective of which is to emphasize any irregularities in the
lens under consideration or inspection, thereby to make it
easier to identify those irregularities subsequently.

10 The first of these procedures, referred to as a
fill-in procedure, is to establish a further set of data
values I_{11} for the pixels in array 46, and which may be used
to identify pixels in any irregularities in, on, or adjacent
the outside edge of annulus 150. More specifically, with
reference to Figure 33, these data values are used to
15 identify pixels in (i) any gaps in the lens edge, such as
shown at 436, (ii) any irregularities inside the lens edge,
such as shown at 440, (iii) any extra pieces on the lens
edge, such as shown at 442 and (iv) the pixels between any
extra pieces and the adjacent line segments L_3 and L_4 formed
at steps 362 and 370 in subroutine S_3 .

20 This fill-in procedure comprises a number of more
specific operations referred to as MAX, PMAX, MIN, and PMIN,
which involve processing a set of base data values associated
with the pixels. In a MAX operation, a new data value is
25 established for a given pixel that is equal to the maximum
base data value of that pixel's eight immediately adjacent
neighbors; and in a PMAX operation, a new data value is
established for a given pixel that is equal to the maximum
base data value of the four pixels that are immediately to
the left, to the right, above, and below the given pixel. In
30 a MIN operation, a new data value is established for a given

VTN-64

1 pixel that is equal to the minimum base data value of that
pixel's eight immediate neighbors; and in a PMIN operation, a
new data value is established for a given pixel that is equal
to the minimum base data value of the four pixels that are
5 immediately to the left, to the right, above, and below the
given pixel.

Figures 34a through 34e illustrate the MAX, PMAX,
MIN, and PMIN operations. More specifically, Figure 34a
shows a 7 x 7 array of numbers; and each number represents a
data value for an associated pixel, with the position of the
10 number in the array corresponding to the address of the
associated pixel. Hence, for instance, the data value for
the pixel at address (1,1) is 7; the data value for the pixel
at address (4,1) is 0; and the data values for the pixels at
addresses (4,2), (4,7), and (5,2) are 7, 0, and 0,
15 respectively.

Figure 34b shows the values produced after a MAX
operation has been performed on the whole array of numbers
shown in Figure 34a. Thus, for example, in Figure 34b, the
data value at address (2,6) is 7 because, in Figure 34a, one
20 of the eight pixels adjacent that pixel address has a value
of 7. Similarly, the value at address (6,2) in Figure 34b is
7 because, in the data set of Figure 34a, one of the eight
pixels adjacent that pixel address has a value of 7. Figure
34c shows the values produced as a result of a PMAX operation
25 on the whole data set of Figure 34a; and for instance, the
values at addresses (6,3) and (6,4) in Figure 34c are 7
because, in Figure 34a, each of these two pixel addresses is
immediately to the right of a pixel having a value of 7.

Figures 34d and 34e show the values produced after
30 MIN and PMIN operations, respectively, have been performed on

1 the array of values shown in Figure 34a. For example, in
Figure 34d, the value at address (4,3) is zero because, in
Figure 34a, one of the eight pixels neighboring address (4,3)
has a zero value; and in Figure 34e, the value at address
5 (4,2) is zero because, in Figure 34a, the pixel immediately
to the right of that pixel address has a value of zero.

Figure 35 illustrates a preferred fill-in procedure
 R_8 . With reference thereto, the procedure involves 14
separate operations performed on data values for the pixel
array 46; and each of these operations is performed, one at a
10 time, over the entire pixel array. These operations are, in
order: MAX, PMAX, PMAX, MAX, MAX, PMAX, PMAX, MIN, PMIN,
PMIN, MIN, MIN, PMIN, and PMIN. These operations start with
the I_9 values for the pixels, and the resulting data values,
after all 14 operations are completed, are referred to as the
15 I_{11} values.

The results of these operations are, in effect, to
fill in the gaps 436, the extra pieces 442, and the
irregularities 440 in, on, or adjacent the outside edge of
annulus 150. More specifically, Figures 33 and 36 show the
20 same portion of the annulus 150, with the former figure
showing the pixels illuminated at their I_9 values, and the
latter figure showing the pixels illuminated at their I_{11}
values. The differences between these two figures show the
effect of the fill-in procedure of Figure 35. In particular,
25 this difference is that for the pixels in the gaps 436, in
the extra pieces 442, in irregularities 440, and in the areas
between the extra pieces and the line segments L_3 and L_4 , the
 I_{11} values for these pixels are $T_{\max}$ while the I_9 values for
these pixels are zero.
30

1 As will be understood by those of ordinary skill in
the art, other specific procedures are known and may be used
to produce the desired I_{11} values for the above-described
pixels.

5 After the fill-in operation R_8 is completed,
processor 64 invokes a second masking procedure R_9 to produce
a set of pixel illumination values I_{12} that is free of the
effect of any light incident on pixel array 46 within a given
radius of the center point of the circle fitted to the inside
10 edge 150b of annulus 150 during the decentration test. As
discussed in greater detail below, this set of pixel
illumination values I_{12} is subsequently used to help identify
defects in the interior of the lens --that is, in the area
radially inside the inside edge of annulus 150.

15 The masking procedure R_9 employed at this stage of
the lens inspection process is very similar to the masking
routine R_3 shown in Figures 19a-19c and 20. The principle
difference between these two masking procedures is that the
radius of the mask used in procedure R_9 is slightly smaller
than the radius of the circle fitted to the inside edge of
20 annulus 150, while the radius of the mask used in procedure
 R_3 is slightly larger than the radius of the circle fitted to
the outside edge of annulus 150.

25 Figure 37 is a flow chart illustrating a preferred
masking routine R_9 . The first step 446 in this routine is to
determine whether at steps 216 or 226 of the decentration
test, at least three pixels had been found on the inside edge
of annulus 150, or if the ophthalmic lens was found to be
badly decentered. If the lens had been found to be badly
decentered at either of these two steps of the decentration
30 test, then masking routine R_9 itself terminates at step 450.

1 If routine R_9 does not terminate at step 450, the
routine proceeds to step 452, which is to obtain the
coordinate of the center of the circle that had been fitted
to the inside edge 150b of annulus 150 during the
5 decentration test. These coordinates had been determined and
then stored in processor memory during the decentration test,
and these coordinates can be obtained by simply retrieving
them from the processor memory. Once these center
coordinates are obtained, a mask subroutine is invoked at
10 step 454. With reference now to Figures 38a-38c, this
subroutine in effect, superimposes over pixel array 46, a
circular mask 456 centered on the above-mentioned center
coordinates and having a diameter slightly smaller than the
diameter of the circle fitted to the inside edge 150b of
annulus 150, and then the masking subroutine assigns an I_{12}
15 value to each pixel. In particular, for each pixel outside
that mask, the masking subroutine assigns the pixel an I_{12}
value equal to the I_8 value for the pixel; and for each pixel
inside the mask, the masking subroutine assigns the pixel an
 I_{12} value of zero.

20 More precisely, at step 452, the coordinate (x_1, y_1)
of the above-mentioned center point and a radius value r_2 ,
which is selected to be slightly smaller than the radius of
the circle fitted to the inside edge of annulus 150, are
transmitted to the mask subroutine. Then, at step 454, this
25 subroutine forms a file f_5 of the addresses of all of the
pixels in array 46 that are within the distance r_2 of that
center point (x_1, y_1) . Then, at step 460, the address of each
pixel in array 46 is checked to determine if it is in that
file. If the pixel address is in that file, then at step
30 462, the I_{12} value of the pixel is set to zero; however, if

1 the pixel address is not on the list, then at step 464, the
I₁₂ value of the pixel is set equal to the I₈ value of the
pixel.

5 Numerous specific mask subroutines are well-known
in the art for accomplishing the above objective and any
suitable subroutine may be employed at step 454 of routine
R₉.

Figure 38c shows the pixels of array 46 illuminated
at intensities equal to their respective I₁₂ values.

10 After this second masking procedure is completed, a
further routine R₁₀, consisting of a series of operations, is
performed to provide a set of pixel illumination values that
clearly identify the pixels that are in any irregularity or
defect in the lens being inspected. More specifically, the
15 purpose of these further operations is to provide a set of
pixel illumination values that is free of any effect produced
on array 46 by background noise or light as well as any
effect produced on array 46 by the normal or regular edges
150a and 150b of annulus 150. These further operations are
shown in the flow chart of Figure 39.

20 At step 466, a further I value, I₁₃, is obtained for
each pixel; and in particular, the I₁₃ value for each pixel is
obtained by subtracting the I₁₂ value for the pixel from the
I₁₀ value for the pixel. Figures 40a, 40b, and 40c show the
25 pixels in a portion of annulus 162 illuminated at intensities
equal to their I₁₀, I₁₂, and I₁₃ values, respectively; and as
can be seen, the practical effect of step 466 is to subtract
the image of Figure 40b from the image of Figure 40a to
produce the image of Figure 40c.

30 Then, at step 470, an operation, referred to as a
clean-up operation, is performed to, in effect, help

eliminate spurious illuminated pixels. More particularly, starting with the I_{13} values for the pixels, MAX, MIN, PMIN, and PMAX operations are performed, in that order, on the entire pixel array 46, producing a further set of pixel values referred to as I_{14} values. Figure 40d shows the pixels of annulus 46 illuminated at intensities equal to their respective I_{14} values; and as can be seen by comparing Figures 40c and 40d, the effect of the clean-up operation is simply to eliminate various isolated pixels that, for one reason or another, are illuminated in Figure 40c.

After system 10 has processed the data according to the routines R_1 - R_{10} described above, a flaw or defect analysis is made, and Figures 41a and 41b show a flow chart illustrating a preferred defect detection or analysis routine R_{11} . This analysis may be best understood with reference to Figure 42, which shows the pixels of a portion of annulus 150 illuminated at intensities equal to their respective I_{14} values.

With reference to Figures 41a, 41b, and 42, in the first part of this defect analysis, at steps 472 and 474 of Figure 41a, a list is made of the addresses of the pixels at the start and at the end of each horizontal series of consecutive illuminated pixels, referred to as a run length. More specifically, processor 64, in effect, scans across each horizontal row of pixels in array 46; and during each scan, each time a series of illuminated pixels is encountered, the addresses of the first and last pixels in that series are recorded in file f_6 . In the case of a single isolated illuminated pixel --that is, the pixels on the left and right of this illuminated pixels are themselves not illuminated-- the address of this illuminated pixels is recorded as both

1 the address of the first and the address of the last pixel in
the run length formed by the illuminated pixel.

5 More precisely, the processor does not in fact scan
across an image of the pixel array, but instead compiles the
above-mentioned address list by checking the I_{14} values stored
in the processor memory for the pixels in array 46.

10 After file f_6 is completed, routine R_{11} invokes a
clustering subroutine at step 476 to create a separate file
 $f_{6a} \dots f_{6n}$ for each area or group of contiguous illuminated
pixels --or, more precisely, for each area or group of
contiguous pixels having high I_{14} values. Any suitable
clustering subroutine may be employed to do this clustering.
After these separate files $f_{6a} \dots f_{6n}$ are created, then at step
480 the files for illuminated areas that are near to each
15 other, such as those shown at 482 and 484 of Figure 42, are
merged. This may be done, for instance, by checking to
determine if any pixel in one illuminated area is within a
given number of pixels, such as two or three pixels, of any
pixel in another illuminated area. These close illuminated
20 areas are considered as forming, in fact, one illuminated
area.

After step 480 is completed, subroutines are
invoked at step 486 to compute the area and centroid of, and
a bounding box for, each area of illuminated pixels.
Numerous subroutines are well-known in the art for performing
25 these computations. Any such suitable subroutines may be
employed in routine R_{11} , and it is not necessary to describe
these subroutines in detail herein.

30 Next, routine R_{11} determines the general location of
each illuminated area. More specifically, at step 490, the
address of the centers and the radii of the two circles

1 fitted to the outer and inner edges 150a and 150b of annulus
150 are obtained. These data were determined or found during
the decentration test and were then stored in the processor
memory, and these data can be obtained by simply retrieving
5 the data from that processor memory. Then, at step 492,
processor 64 determines whether the centroid of each area of
illuminated pixels is located (i) inside the central zone of
the lens (the area radially inside the circle fitted to the
inner edge of the annulus), or (ii) the peripheral zone of
10 the lens (the area of the lens between the two circles fitted
to the inner and outer edges of the annulus).

Numerous subroutines are well known for determining
whether a centroid of an area is within a first circle or
between two generally concentric circles, and it is not
necessary to describe these subroutines in detail herein.

15 Steps 490 and 492 are not necessary to the
operation of system 10 in its broadest sense. Preferably,
though, these steps are done and the associated data are
collected for analysis purposes, and in particular, to help
identify where possible irregularities or defects are
20 occurring in the lenses. These data may be helpful in
adjusting or refining the procedure or materials used to make
the lenses.

After steps 490 and 492 are completed, the
processor then determines whether the size of each
25 illuminated area of pixels is sufficiently large to qualify
as a flaw or defect for which the lens may be rejected. More
specifically, at step 494, the size of each area of
illuminated pixels is compared to a preselected size. If
that illuminated area is smaller than that preselected size,
30 then the illuminated area is not sufficient to reject the

VTN-64

1 lens. However, if that area of illuminated pixels is larger
than the preselected size, then that illuminated area
qualifies as a flaw or defect that makes the lens unsuitable
for consumer use. This preselected size may be stored, for
example, in memory unit 70.

5 Also, preferably at step 496 a count is maintained
of the number of defects found in each lens. This count may
also be useful for analyzing the process and materials used
to make the lenses.

10 At step 500, a display is produced on monitor 72
showing the areas of illuminated pixels, with those areas
that are larger than the above-mentioned threshold size being
shown within a bounding box. Then, at step 502, processor 64
checks to determine if any defects were in fact found in the
15 lens. If a defect had been found, then at step 504 a reject
lens signal is generated and transmitted to monitor 72 and
printer 76, and the lens may be removed from system 10. If,
however, no defect had been found in the lens, then routine
R₁₁ simply terminates. Subsequently, system 10 operates to
20 move another lens past illuminated subsystem 14 and another
pulse of light is transmitted through that other lens. This
transmitted light is focused on pixel array 46 and the above-
described processing procedure is repeated to determine if
this other lens is acceptable for consumer use.

25 While it is apparent that the invention herein
disclosed is well calculated to fulfill the objects
previously stated, it will be appreciated that numerous
modifications and embodiments may be devised by those skilled
in the art, and it is intended that the appended claims cover
30 all such modifications and embodiments as fall within the
true spirit and scope of the present invention.

VTN-64

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for automatically inspecting an ophthalmic lens which comprises an annular
5 edge portion having generally circumferential inner and outer edges, comprising:
 - directing a light beam through the lens and onto an array of pixels to form images thereon
of the inner and outer edges of the annular edge portion;
 - assigning to each pixel a data value representing the intensity of the light beam on the
pixel; and
 - 10 processing said data values according to a predetermined program to determine if the lens
contains one or more lens defect conditions;
 - wherein the processing further comprises the steps of:
 - i) identifying a center point on the pixel array and a radius of a first circle having a
circumference commensurate with the image of the outer edge of the annular edge
15 portion,
 - ii) identifying a center point on the pixel array and a radius of a second circle having a
circumference commensurate with the image of the inner edge of the annular edge
portion,
 - iii) determining a distance between the center points of the first and second circles,
 - 20 iv) comparing said distance to a predetermined distance value, and
 - v) identifying the lens as being decentered if said distance is greater than said
predetermined distance value.

2. A method according to Claim 1, wherein the ophthalmic lens includes first and second discs, each of the discs having a circumferential outside edge, and wherein: the directing step includes the step of forming on the pixel array images of the outside edges of the first and second discs.

5

3. A method according to Claim 2, wherein:
the step of identifying the center point and the radius of the first circle includes the steps of

10

i) identifying at least three first pixels on the image of the outside edge of the first disc,

and

ii) identifying a center point and a radius of a circle having a circumference passing through said three first pixels; and

the step of identifying the center point and the radius of the second circle includes the steps of

15

i) identifying at least three second pixels on the image of the outside edge of the second disc, and

ii) identifying a center point and a radius of a circle having a circumference passing through said three second pixels.

20

4. A method according to Claim 3, wherein:
the steps of identifying the three first pixels and the three second pixels include the steps of

identifying a multitude of series of pixels, each of said pixels forming a line segment; and

checking each said series of pixels for transitions between pixels illuminated above and below a selected intensity level.

5. A method according to Claim 4, wherein the step of identifying a multitude of series of
5 pixels includes the steps of
- for each said series, identifying a starting point for the series,
identifying a direction for the series, and identifying a length for the series.
6. A method according to Claim 1, wherein the line has an outside edge, and wherein:
10 the directing step includes the step of forming on the pixel array an image of the outside
edge of the lens; and
the processing step includes the steps of
- i) identifying at least selected ones of the pixels located on the image of the outside edge
of the lens, and
- 15 ii) identifying gaps and extra pieces on the image of the outside edge of the lens,
iii) for each identified gap, determining a width of the gap, comparing said width to a
predetermined value and identifying the lens as flawed if said width is greater than said
predeterminal value,
- iv) for each identified extra piece on the image of the outside edge of the lens,
20 determining an area of the extra piece, comparing said area to a predetermined value and
identifying the lens as flawed if said area is greater than said predetermined value.
7. A method according to Claim 6, wherein the step of identifying gaps and extra pieces on
the image of the outside edge of the lens includes the steps of :

identifying a center point on the pixel array and a radius of a first circle having a circumference generally commensurate with the image of the outside edge of the lens;
for each of said selected ones of the pixels, determine a distance between said pixel and said circumference

5 identifying the lens as having a gap if, for each of a selected number of consecutive pixels on the outside edge of the lens image, the pixel is radially inside said circumference and the distance between the pixel and said circumference is greater than a selected distance;
and

10 identifying the lens as having an extra piece if, for each of a selected number of consecutive pixels on the outside edge of the lens image, the pixel is radially outside said circumference and the distance between the pixel and said circumference is greater than a selected distance.

8. A method according to Claim 7, wherein the step of determining the width of the gap includes the step of, once the gap has been identified, searching for an end of the gap by
15 searching across the gap, along said circumference of the first circle, and searching radially inward and outward from said circumference, for one of the pixels on the outside edge of the lens image.

9. A method according to Claim 1, wherein the lens has an outside edge, and wherein:
20 the directing step includes the step of forming on the pixel array an image of the outside edge of the lens; and
the processing step includes the steps of
i) identifying at least selected ones of the pixels located on the image of the outside edge of the lens,

- ii) identifying gaps on the image of the outside edge of the lens,
- iii) emphasizing each identified gap by assigning high data values to selected pixels in or adjacent the gap.

5 10. A method according to Claim 9, wherein the emphasizing step includes the steps of:
for each identified gap,
identifying a first pixel as a beginning of the gap,
identifying a second pixel as an end of the gap, and
assigning high data values to the pixels on a line segment between said first and second
10 pixels.

11. A method according to Claim 10, wherein the emphasizing step further includes the step
of also assigning high data values to the pixels in the gap in the image of the outside edge of the
lens.

15

12. A method according to Claim 1, wherein the lens has a circumferential outside edge, and
wherein:

the directing step includes the step of forming on the pixel array an image of the outside
edge of the lens; and

20

the processing step includes the steps of

- i) identifying a center point on the pixel array of a circle having a circumference commensurate with the image of the outside edge of the lens,
- ii) identifying at least selected ones of the pixels located on the image of the outside edge of the lens,

iii) for each of the selected ones of the pixels, identifying another pixel on the outside edge of the lens image, a selected distance from said selected one of the pixels, identifying a first vector extending through said selected one of the pixels and said another pixel,

5 identifying a second vector extending through said selected one of the pixels and said center point,

computing a dot product of said first and second vectors, comparing the dot product to a predetermined value, and identifying the lens as flawed if the dot product is greater than said predetermined value.

10

13. A method according to Claim 1, wherein the lens has an outside edge, and wherein:
the directing step includes the step of forming on the pixel array an image of the outside edge of the lens; and
the processing step includes the steps of

15

i) identifying at least selected ones of the pixels located on the image of the outside edge of the lens,
ii) identifying extra pieces on the outside edge of the lens image, and
iii) emphasizing each identified extra piece by assigning high data values to selected pixels adjacent the extra piece.

20

14. A method according to Claim 13, wherein the emphasizing step includes the steps of:
for each identified extra piece,
identifying a first pixel as a beginning of the extra piece,
identifying a second pixel as an end of the extra piece, and

assigning high data values to the pixels on a line segment between said first and second pixels.

15. A method according to Claim 14, wherein the emphasizing step further includes the step
5 of assigning high data values to the pixels on the extra piece.

16. A method according to Claim 13, wherein the emphasizing step includes the steps of:
for each identified extra piece,
identifying a first pixel on a front side of the extra piece,
10 identifying a second pixel on the edge of the lens image forward of the extra piece and a
selected distance from said first pixel,
identifying a third pixel on a back side of the extra piece,
identifying a fourth pixel on the edge of the lens image, rearward of the extra piece and a
selected distance from the third pixel,
15 assigning high data values to the pixels on a first line segment between said first and
second pixels, and
assigning high data values to the pixels on a second line segment between said third and
fourth pixels.

20 17. A method according to Claim 16, wherein:
the extra piece the outside edge of the lens image and the first line segment bound a first
area containing a first group of pixels;
the extra piece, the outside edge of the lens image and the second line segment bound a
second area containing a second group of pixels; and

the emphasizing step further includes the step of assigning high data values to the first and second groups of pixels.

18. A method according to Claim 1, wherein the processing step includes the steps of:

identifying selected areas of the pixel array having pixels having high data values; and
emphasizing said selected areas by assigning high data values to pixels adjacent said selected areas.

19. A method according to Claim 18, wherein the lens has an outside edge, and wherein:

the directing step includes the step of forming on the pixel array an image of the lens showing the outside edge thereof; and

the processing step further includes the steps of

i) identifying the pixels on the outside edge of the lens image, and

ii) assigning low data values to the pixels on the outside edge of the lens image.

20. A method according to Claim 19, wherein the processing step further includes the step of searching for groups of contiguous pixels having high data values.

21. A system for automatically inspecting an ophthalmic lens which comprises an annular edge portion having generally circumferential inner and outer edges, comprising:

an array of pixels;

a light source to direct a light beam through the lens and onto the array of pixels, the light source comprises means to form on the pixel array images of the inner and outer edges of the annular edge portion;

means to assign to each pixel a data value representing the intensity of the light beam on the pixel; and

an image processing system to process said data values according to a predetermined program to determine if the lens contains one or more lens defect conditions;

5 wherein the image processing system further comprises:

i) means to identify a center point on the pixel array of a first circle having a circumference commensurate with the image of the outside edge of the annular edge portion,

10 ii) means to identify a center point on the pixel array of a second circle having a circumference commensurate with the image of the inner edge of the annular edge portion,

iii) means to determine a distance between the center points of the first and second circles, and

15 iv) means to identify the discs of the lens as being decentered if said distance is greater than a predetermined value.

22. A system according to Claim 21, wherein the ophthalmic lens includes first and second discs, each of the discs having a generally circumferential outside edge, and wherein: the light source includes means to form on the pixel array images of the outside edges of the first and
20 second discs.

23. A system according to Claim 21, wherein the lens has an outside edge, and wherein: the light source includes means to form on the pixel array an image of the outside edge of the lens; and

the image processing system includes

i) means to identify gaps and extra pieces on the image of the outside edge of the lens,

ii) means to determine a width of each identified gap, and to identify the lens as flawed if said width is greater than a predetermined value, and

5 iii) means to determine a size of each identified extra piece, and to identify the extra piece as flawed if said size is greater than a preselected value.

24. A system according to Claim 23, wherein the image processing system includes means to emphasize each gap and each extra piece by assigning high data values to pixel adjacent the gaps
10 and the extra pieces.

25. A system according to Claim 21, wherein the lens has a generally circumferential outside edge, and wherein:

15 the light source includes means to form in the pixel array an image of the outside edge of the lens; and

the image processing system includes

i) means to identify a center point on the pixel array of a circle having a circumference generally commensurate with the image of the outside edge of the lens,

20 ii) means to identify at least selected ones of the pixels located on the image of the outside edge of the lens,

iii) means to identify, for each one of the selected pixels, another pixel on the outside edge of the lens image, a selected distance from said selected one of the pixels; and to identify a first vector extending through said selected one of the pixels and said another

pixel, and to identify a second vector extending through said selected one of the pixels and said center point, and

iv) means to identify the lens as flawed if a dot product of said first and second vectors is greater than a predetermined value.

5

26. A system according to Claim 21, wherein the image processing system includes means to identify selected areas of the pixel array having pixels with high data values, and

means to emphasize said selected areas of assigning high data values to pixels adjacent said selected areas.

10

27. A system according to Claim 26, wherein the lens has an outside edge, and wherein: the light source includes means to form on the pixel array an image of the outside edge of the lens; and

15

the image processing system further includes

i) means to identify pixels on the outside edge of the lens image, and

ii) means to assign low data values to the pixels on the outside edge of the lens image.

28. A system according to Claim 27, wherein the image processing system further includes

means to search for groups of contiguous pixels having high data values.

20

FIG. 1

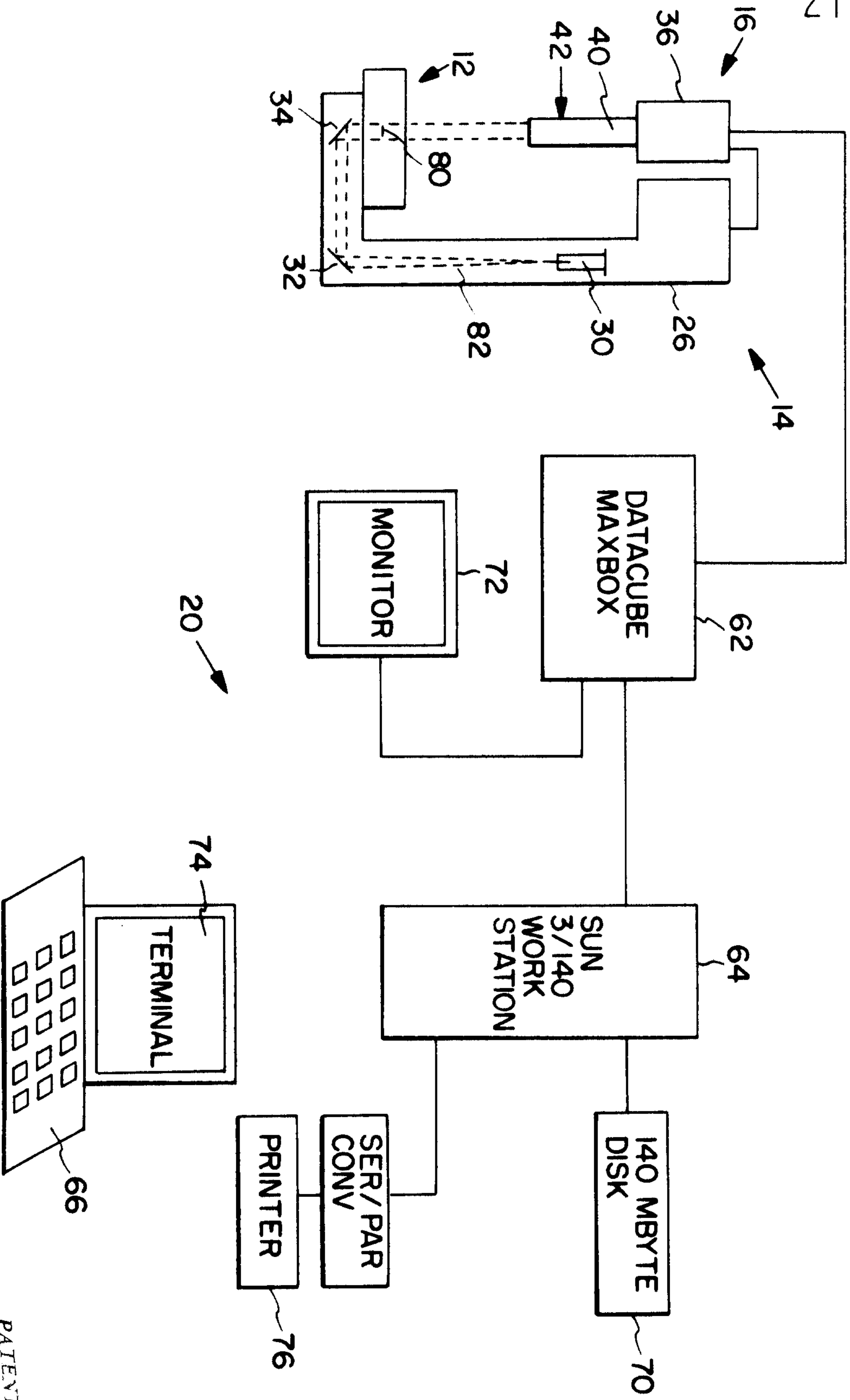


FIG. 2

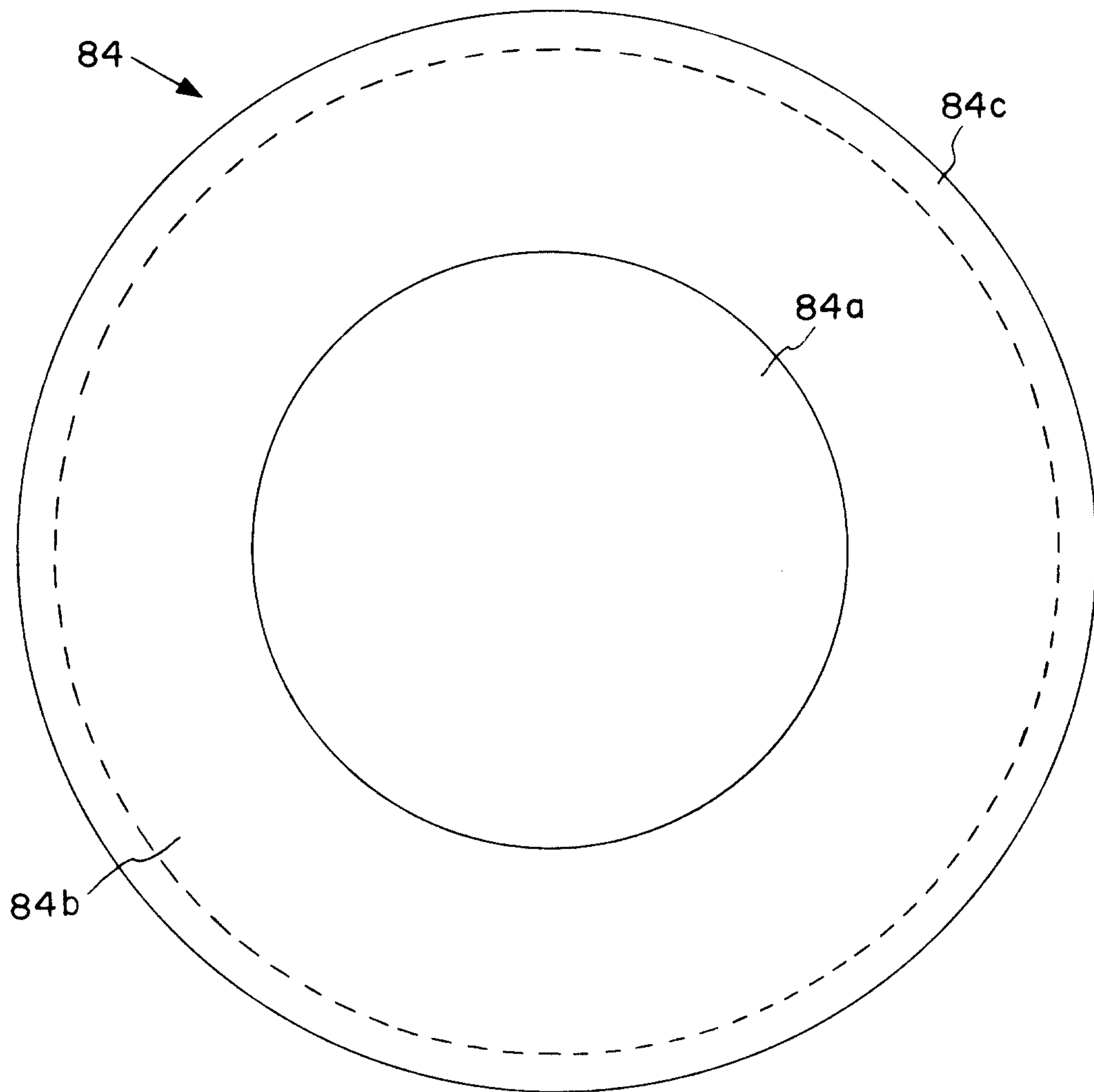


FIG. 3

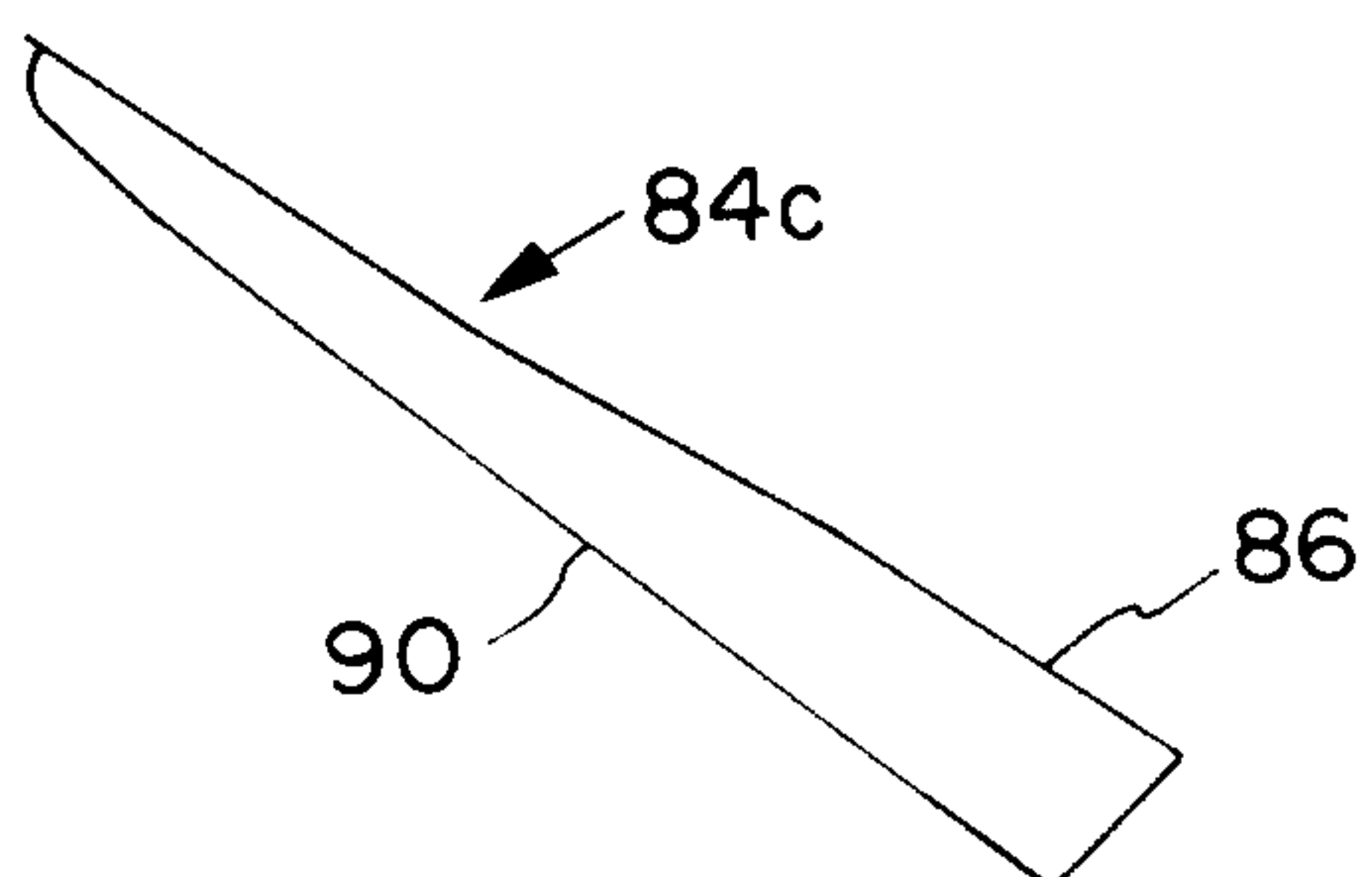
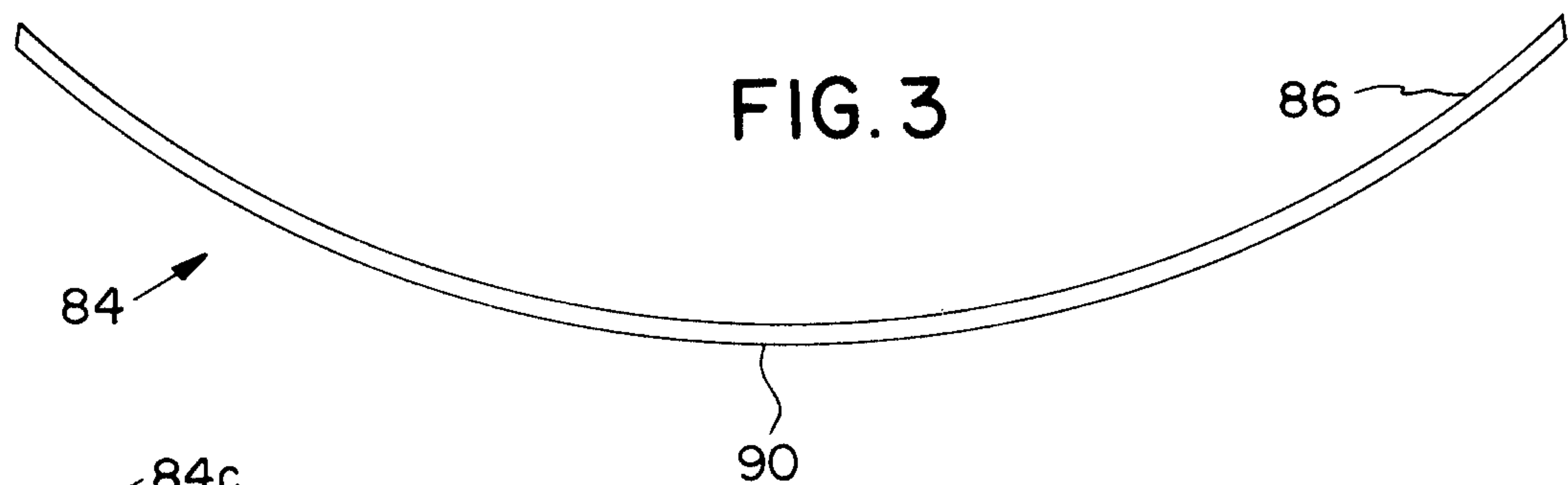


FIG. 3A

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FIG. 4

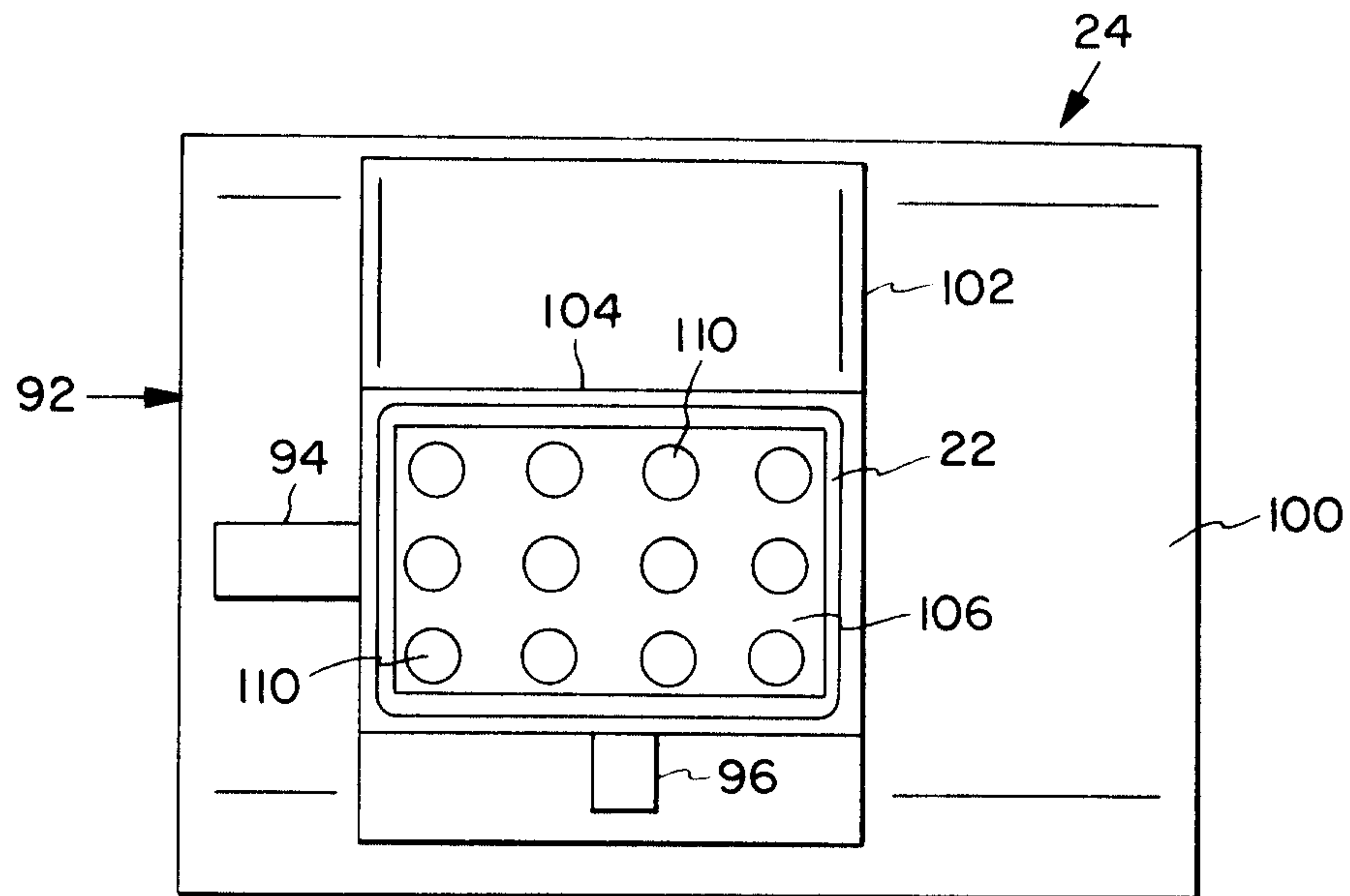


FIG. 5

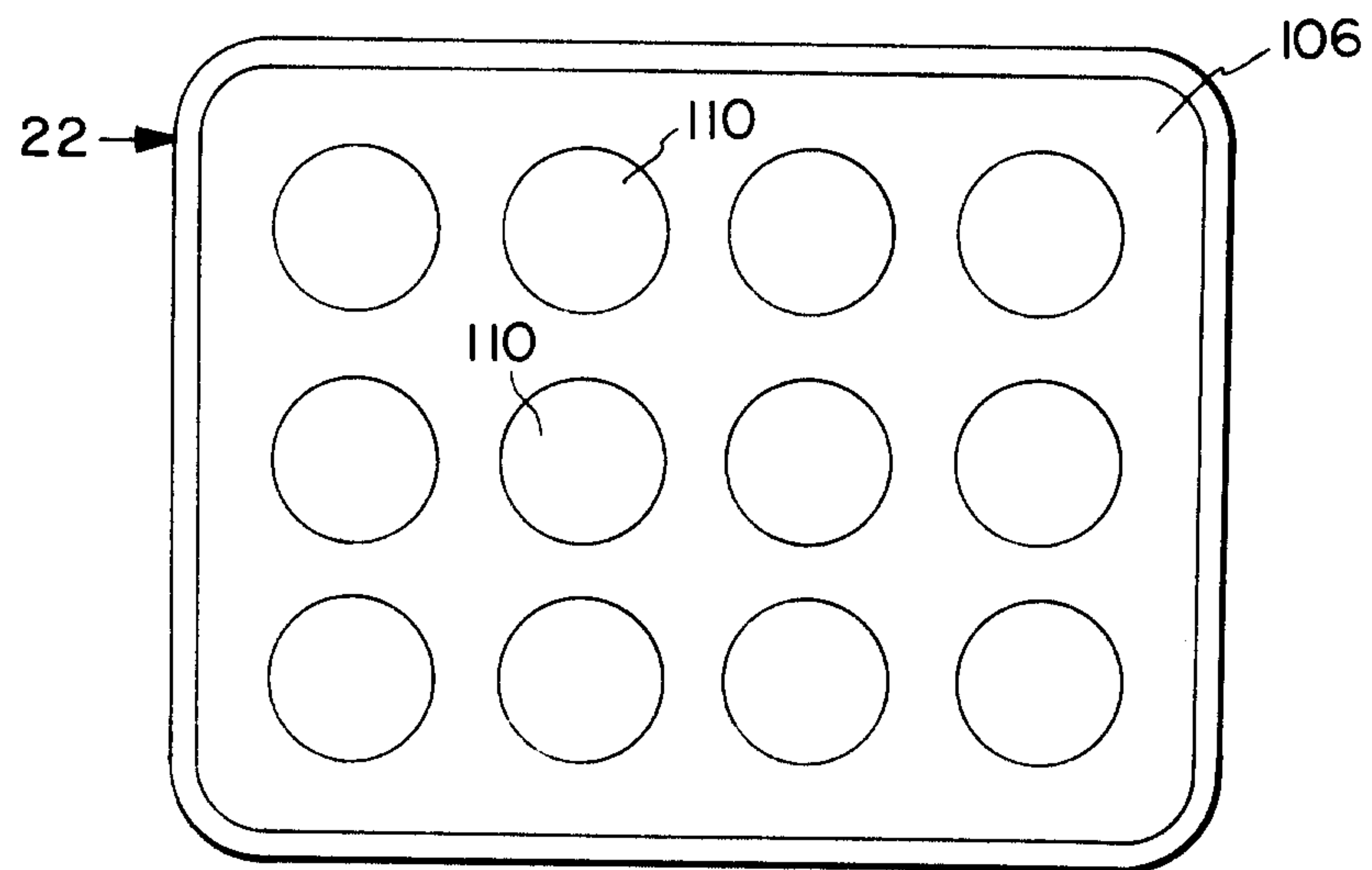
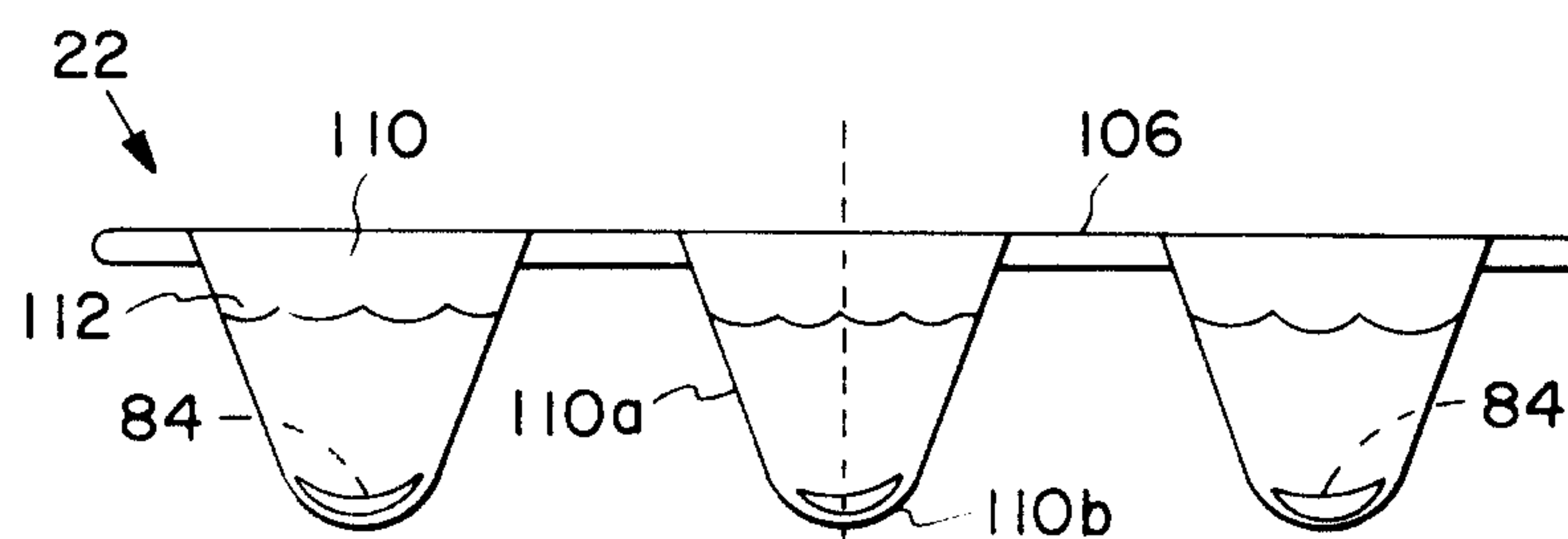


FIG. 6



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FIG. 8

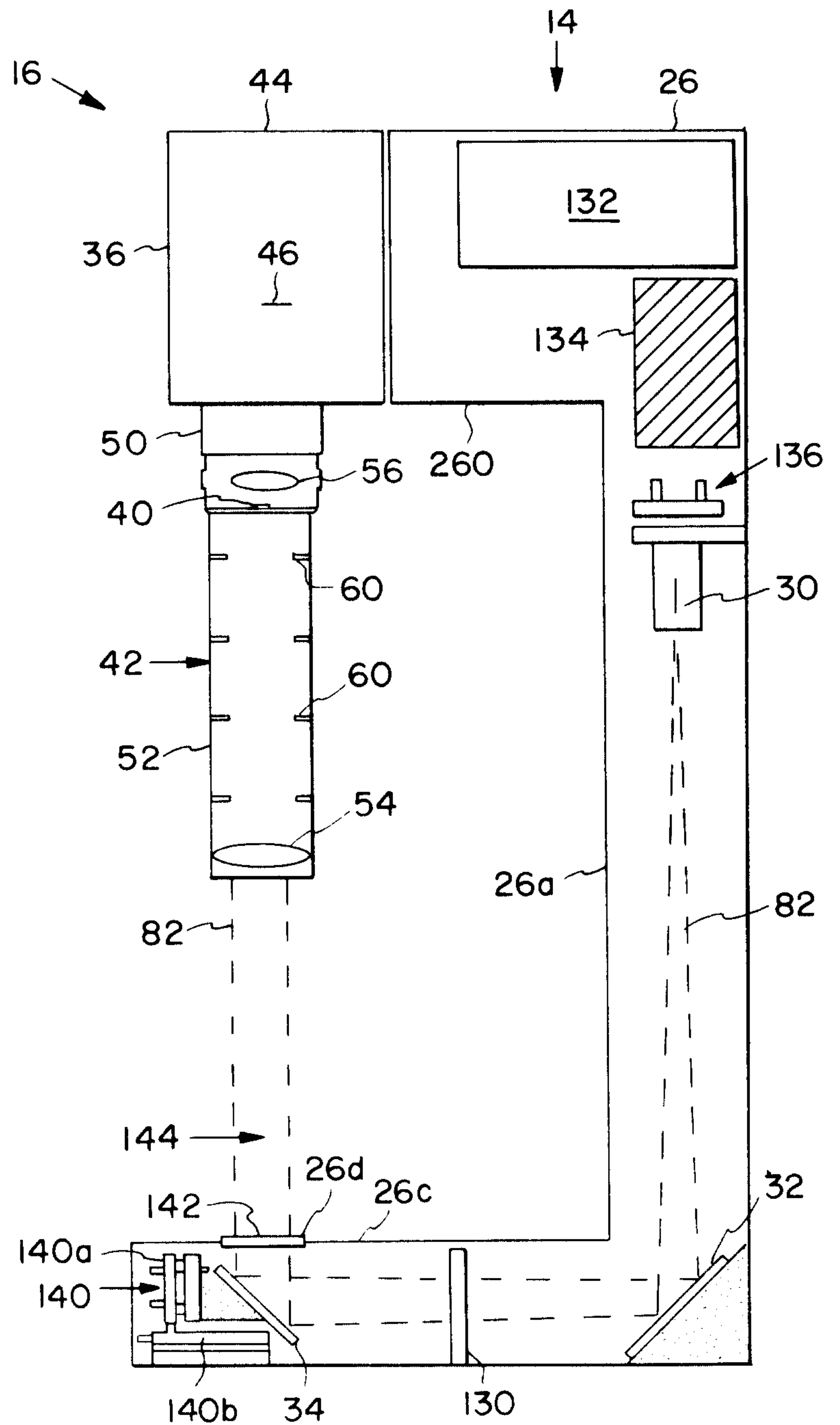
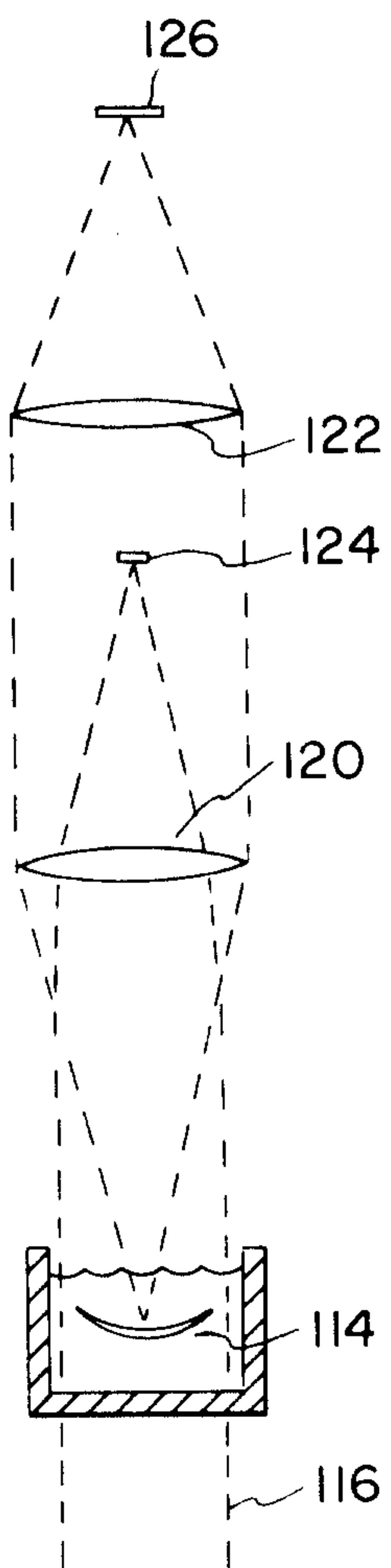


FIG. 7



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FIG. 9

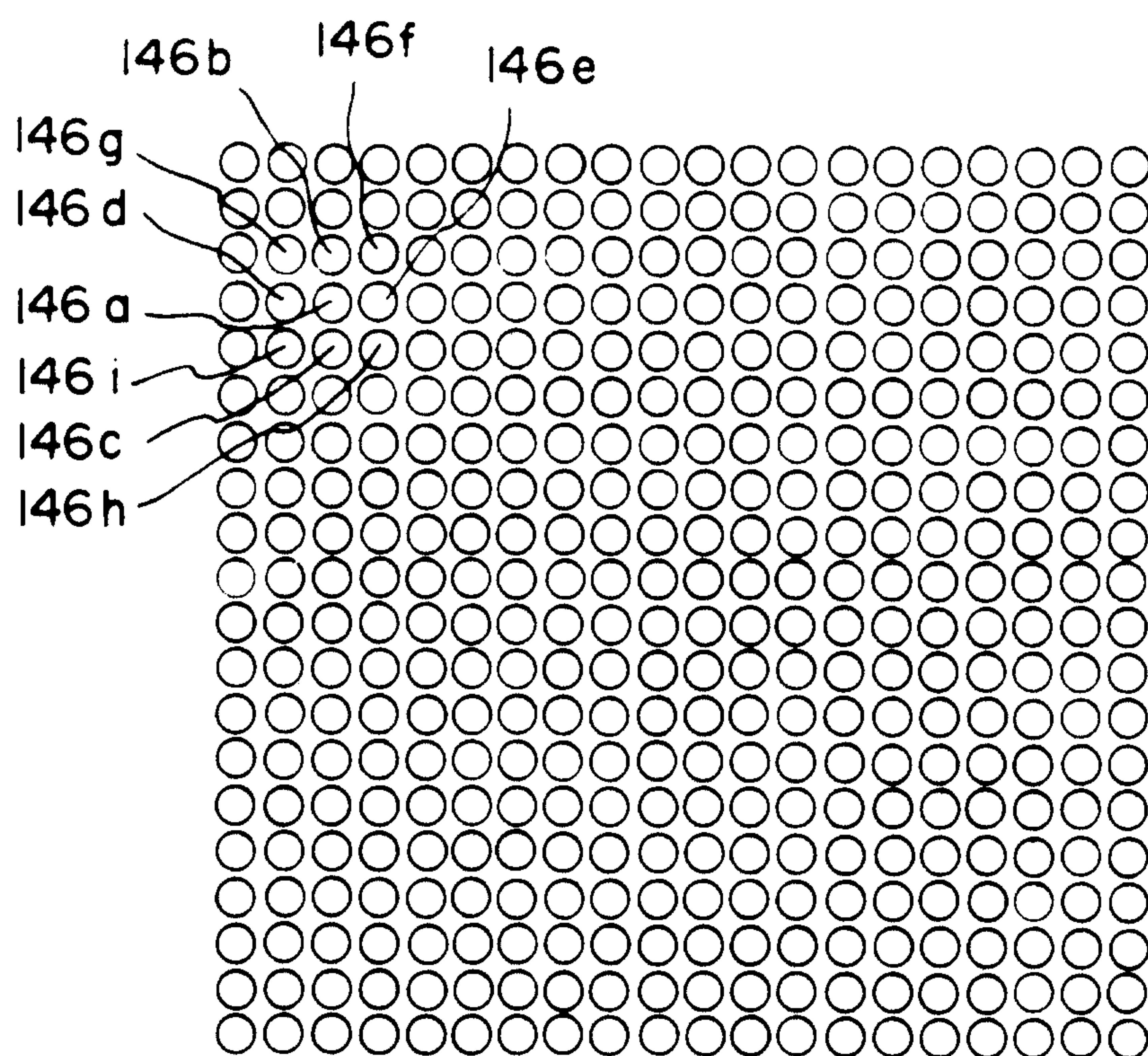


FIG. 10

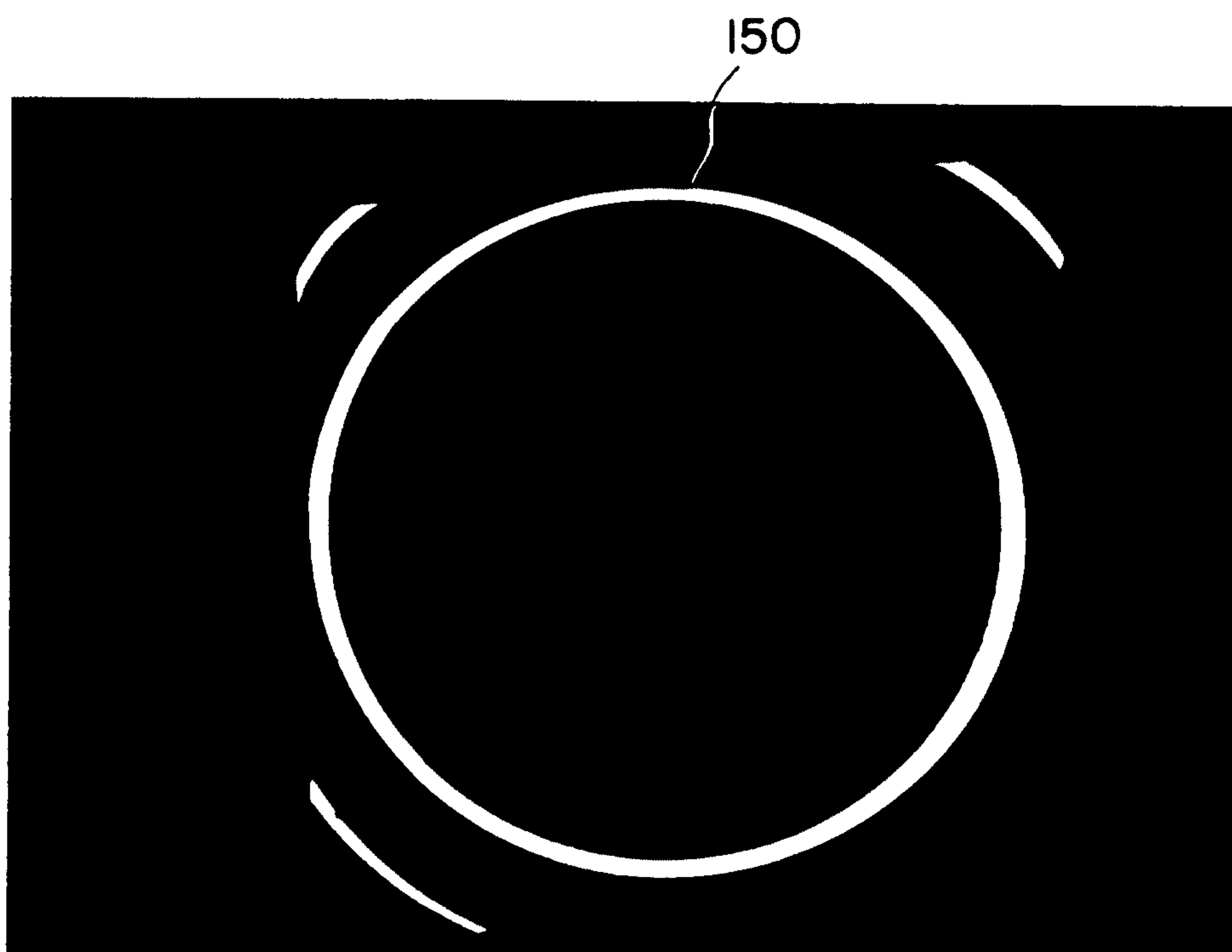


FIG. IIA

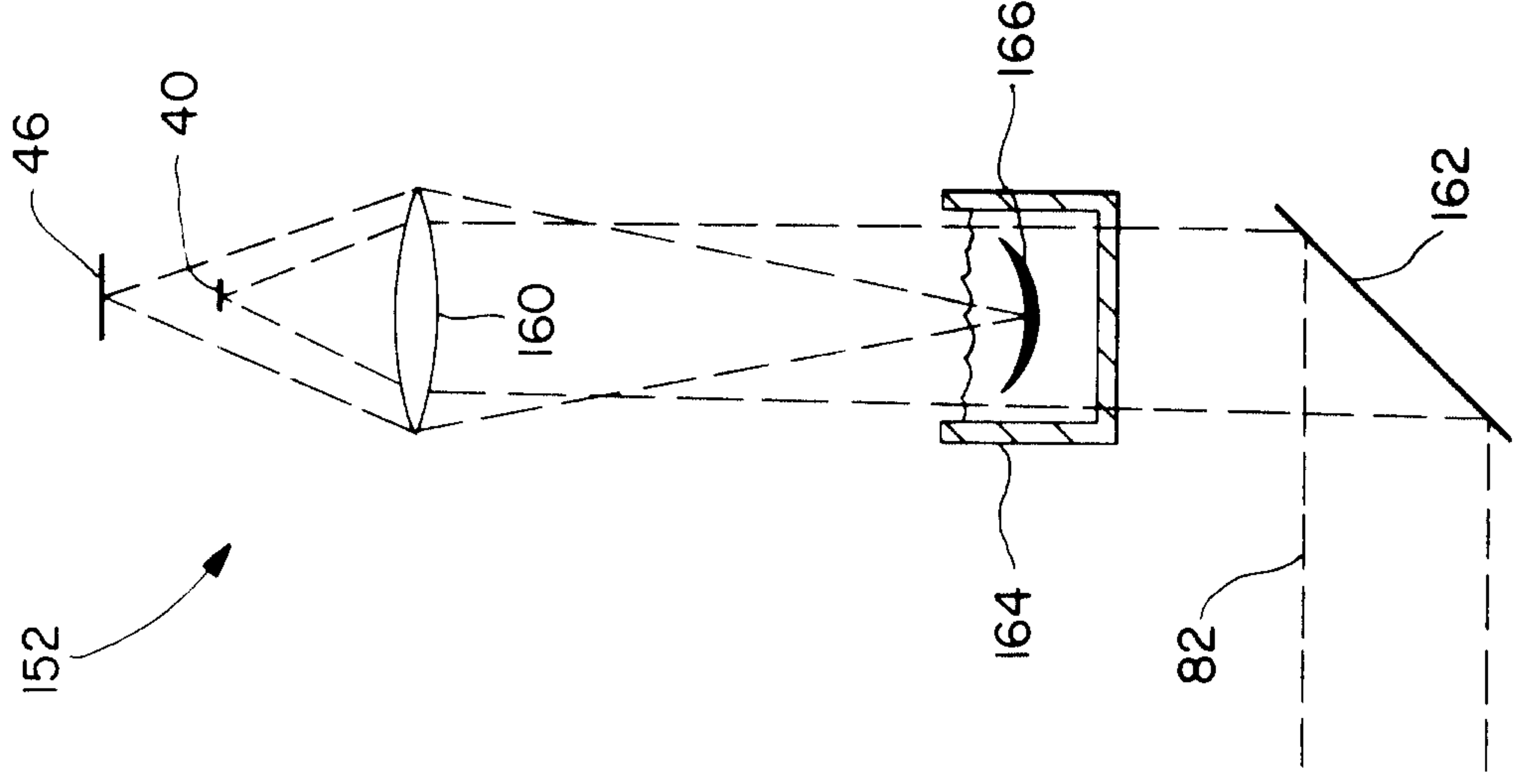


FIG. IIB

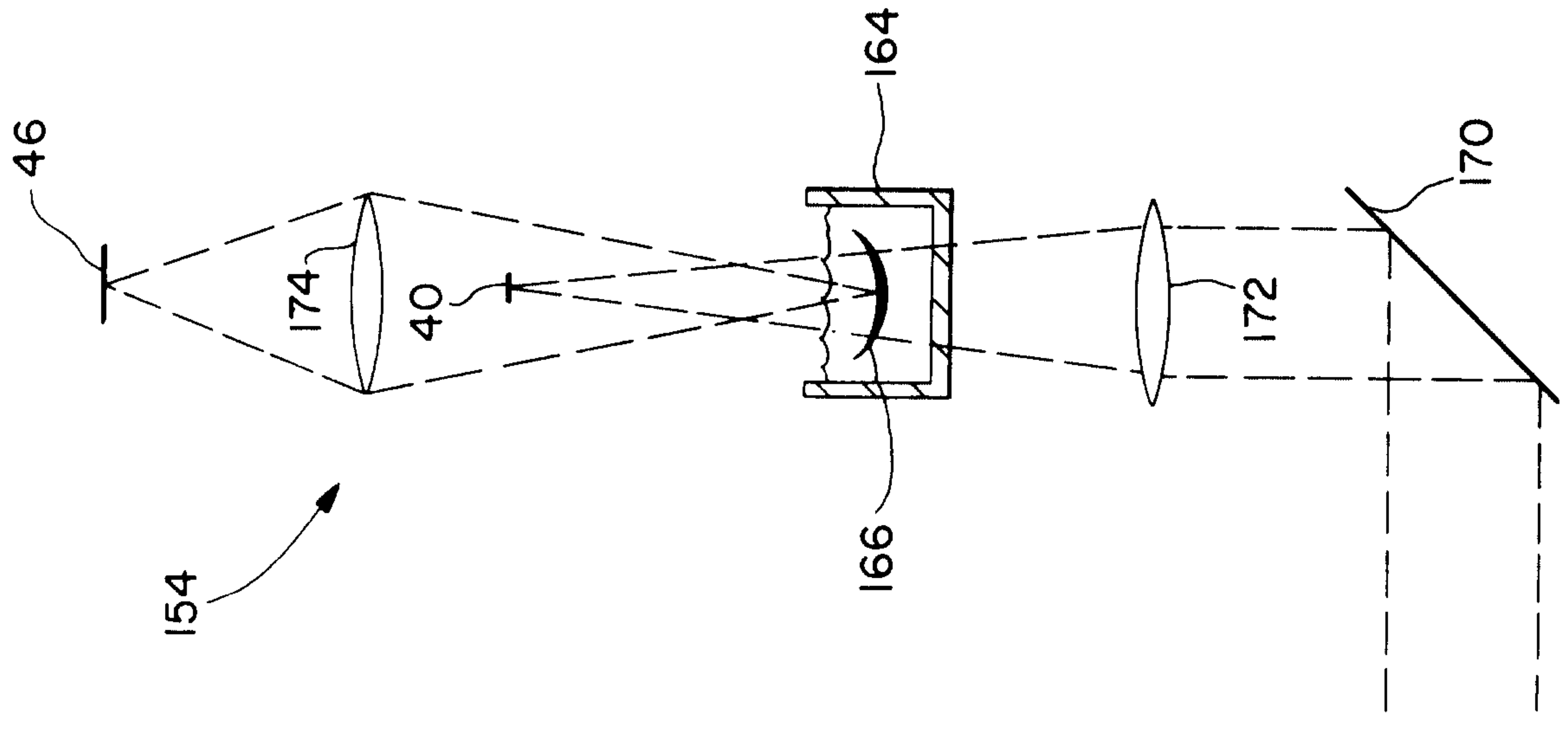
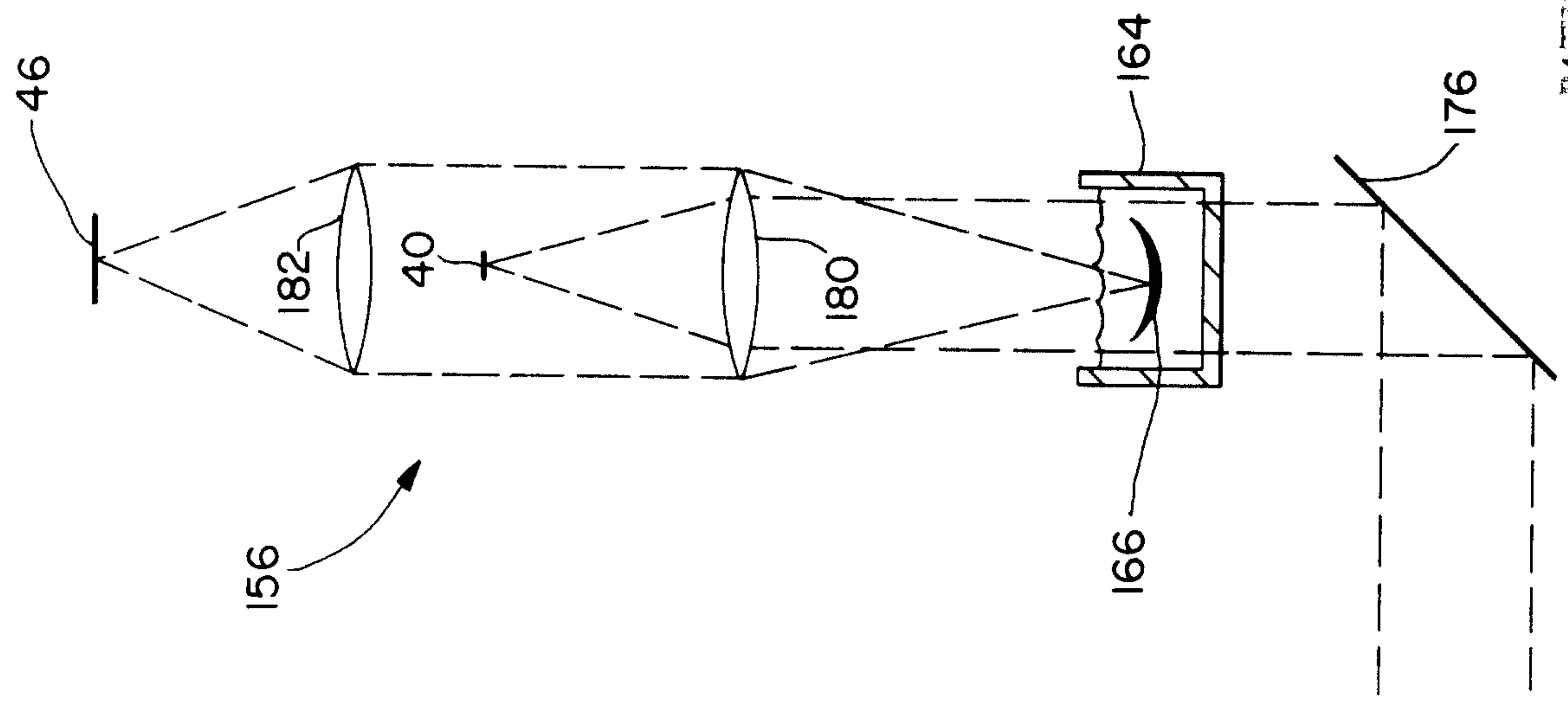


FIG. IIC



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FIG.12A

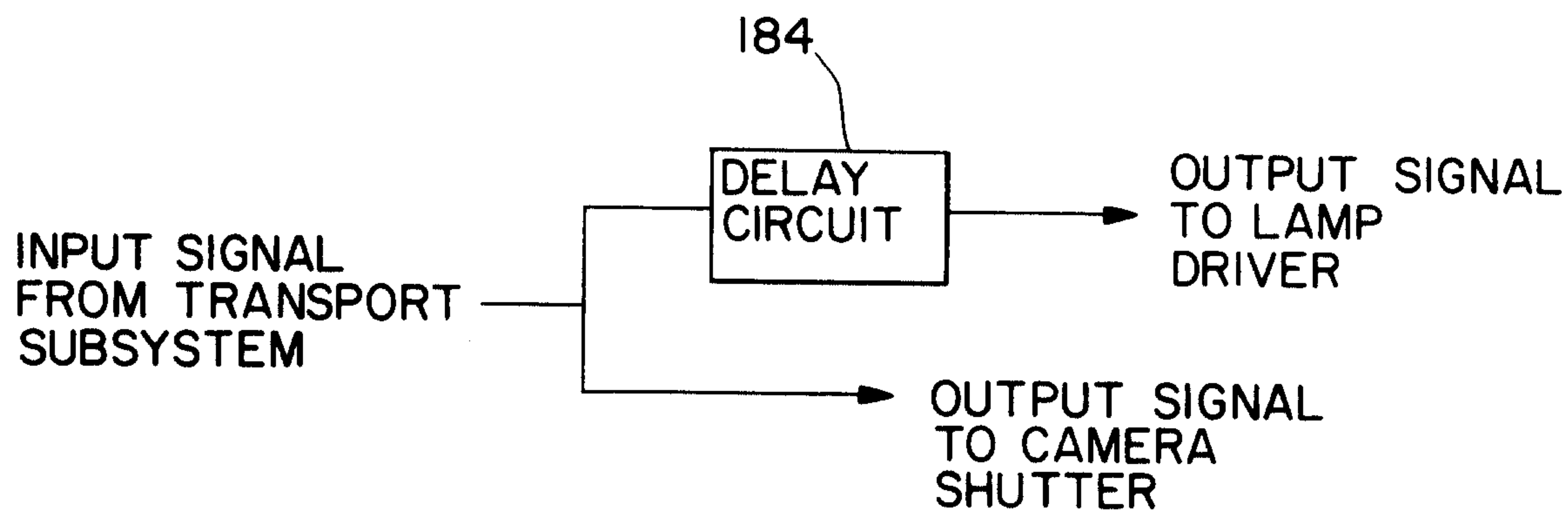
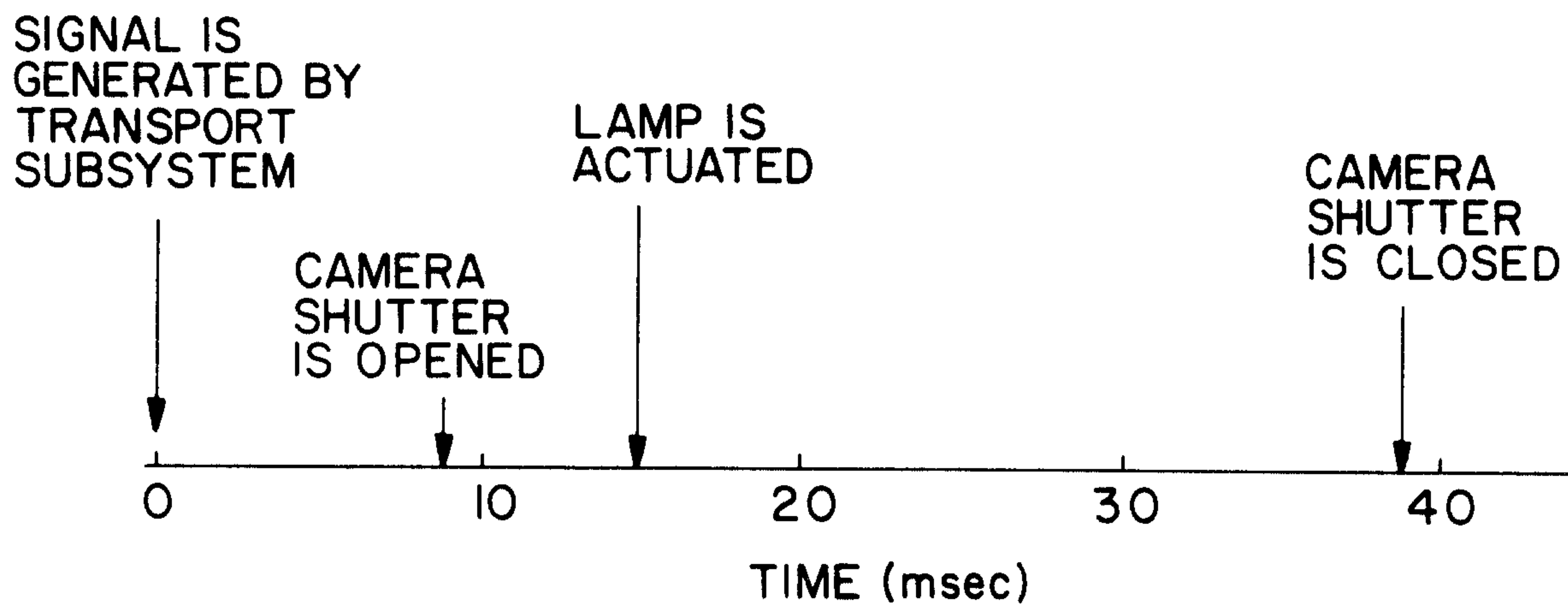


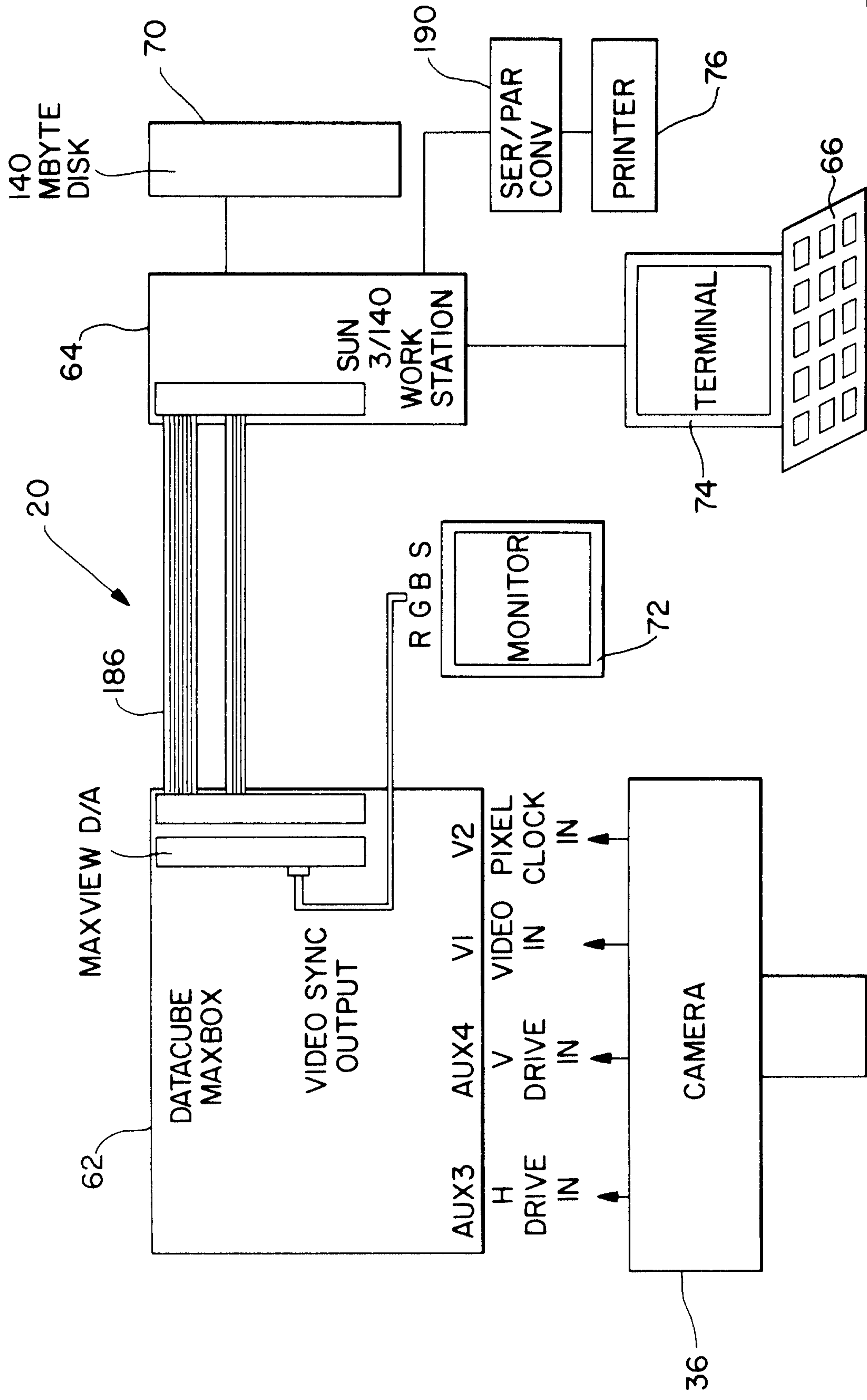
FIG.12B



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FIG. 13

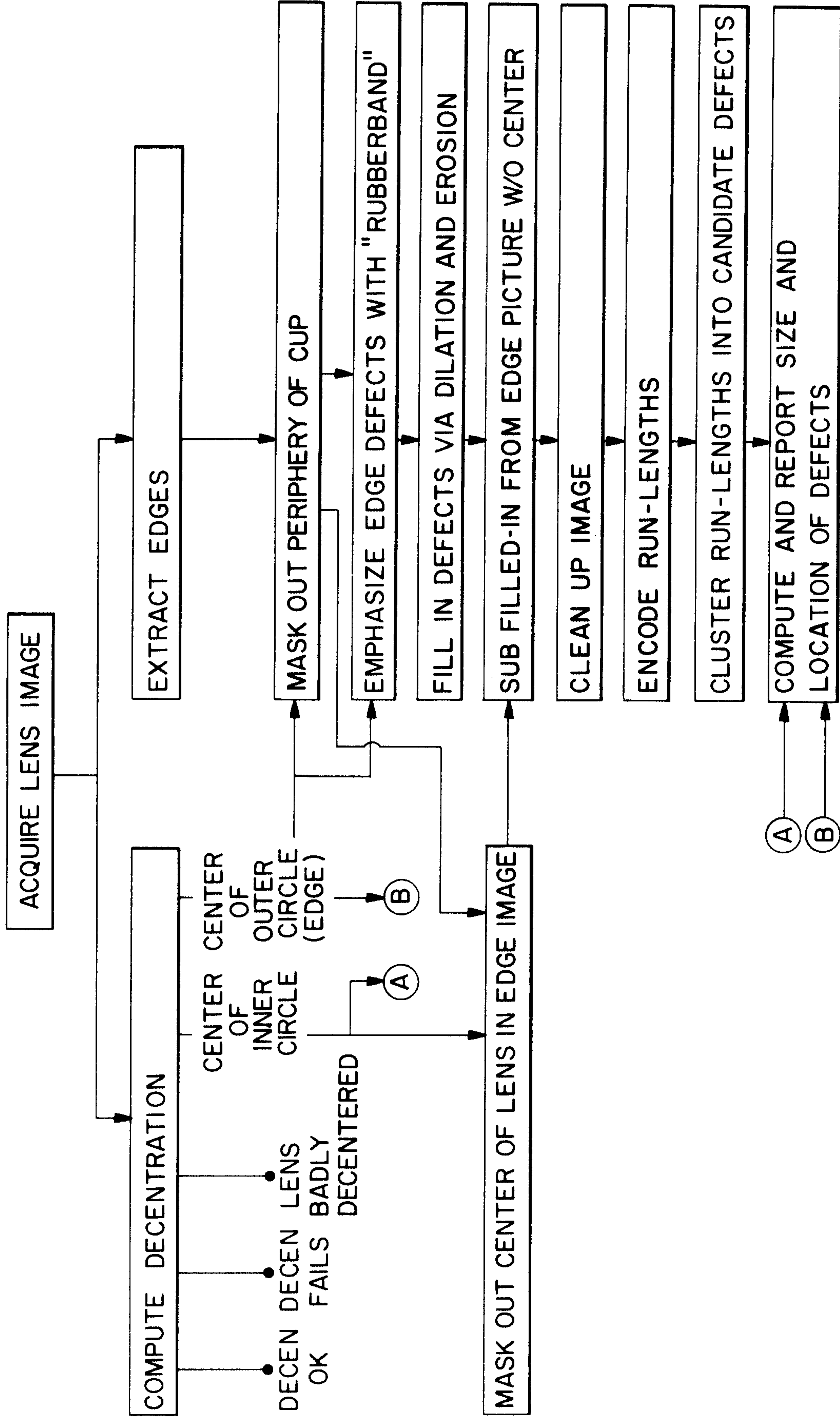


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FIG.14

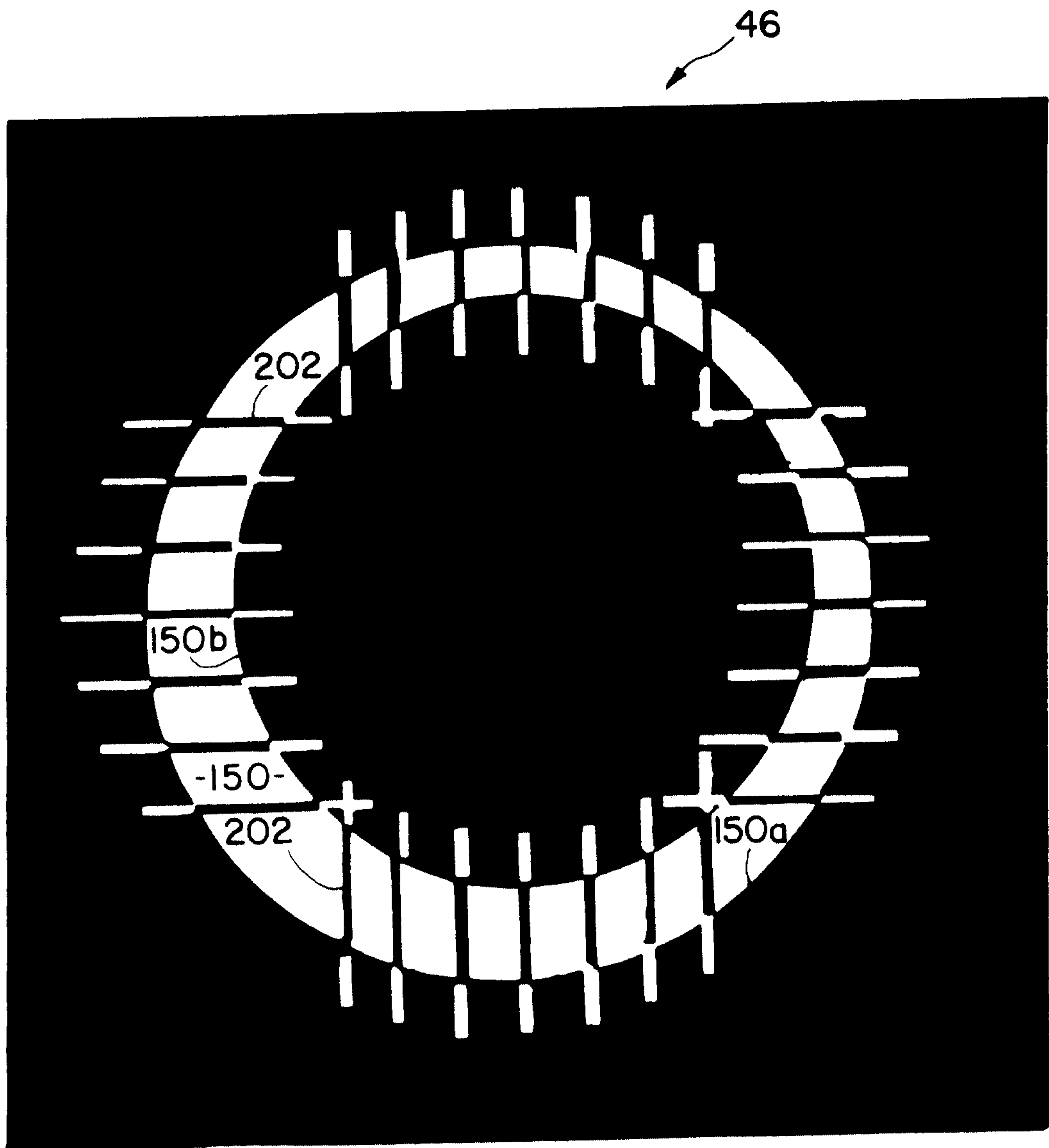


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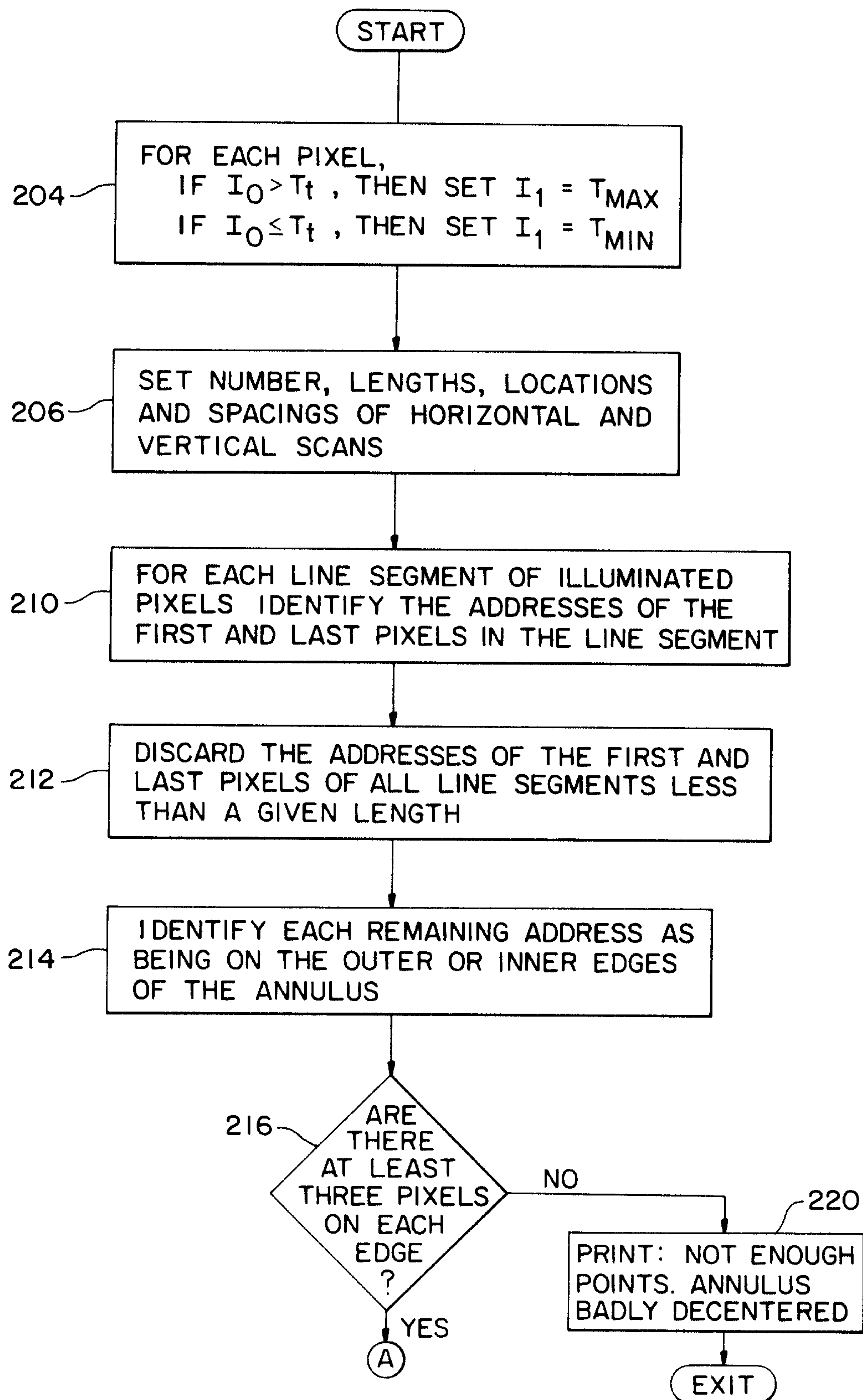
FIG. 15



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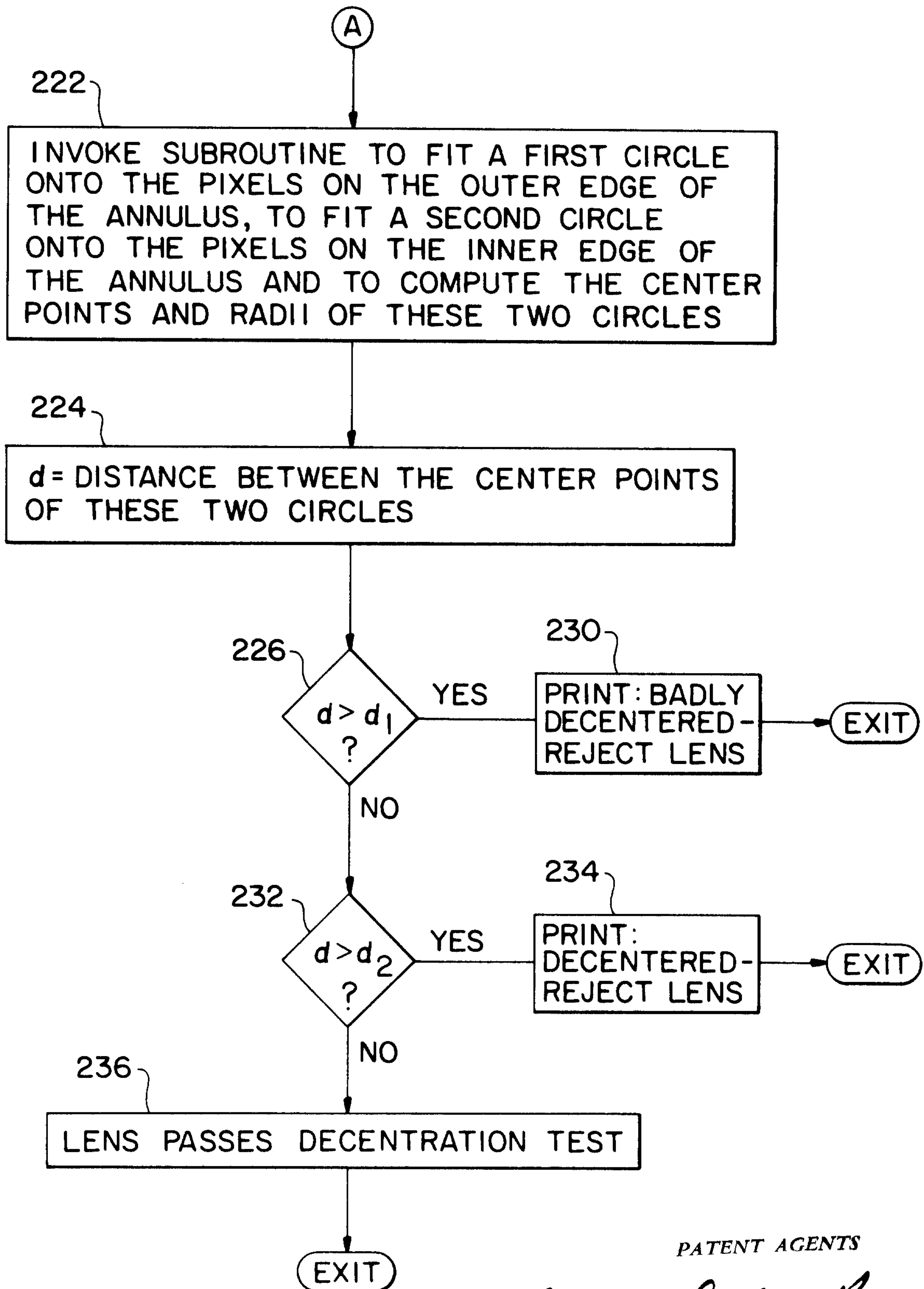
FIG. 16A



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FIG. 16B



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FIG. 17A

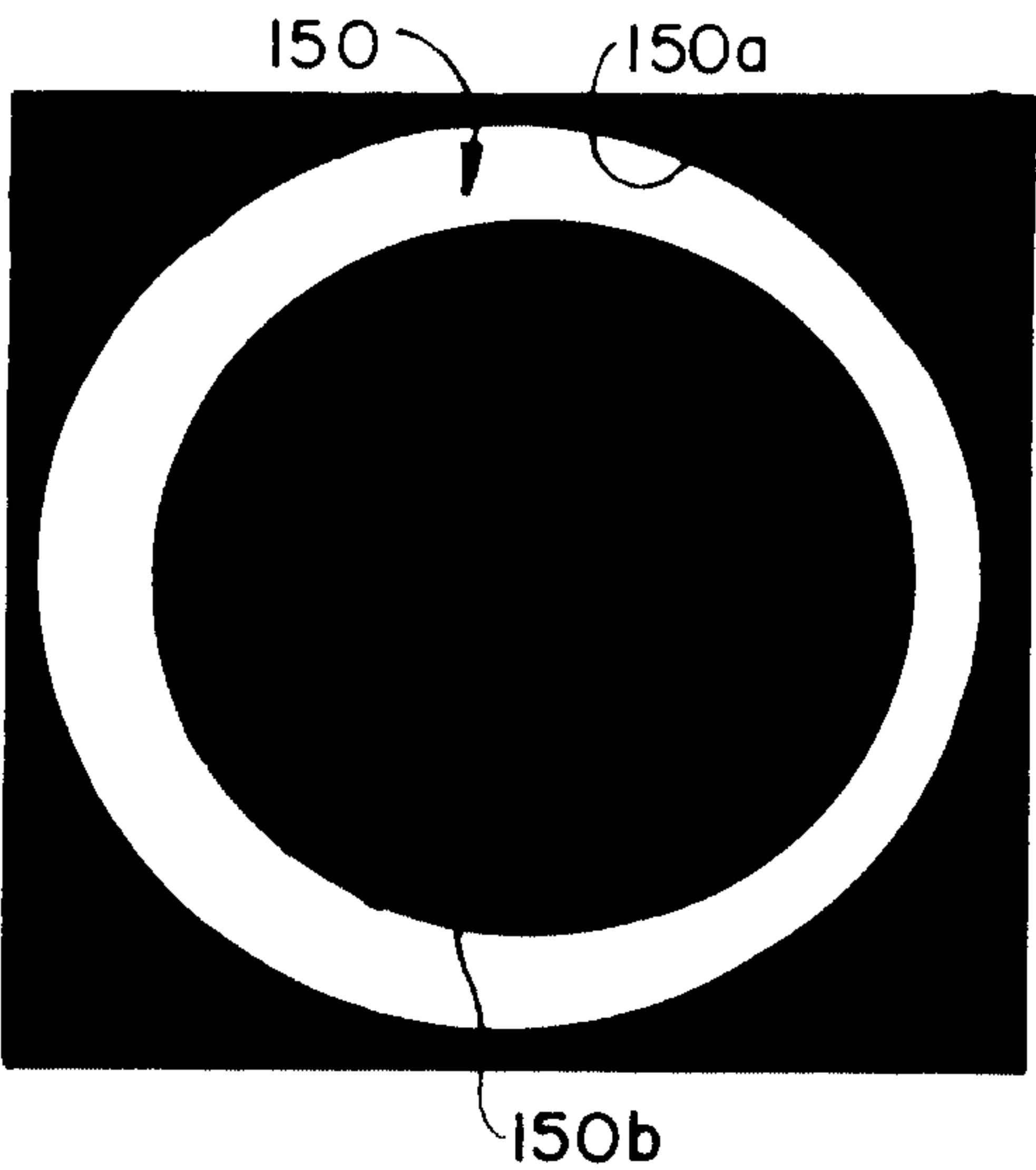


FIG. 17B

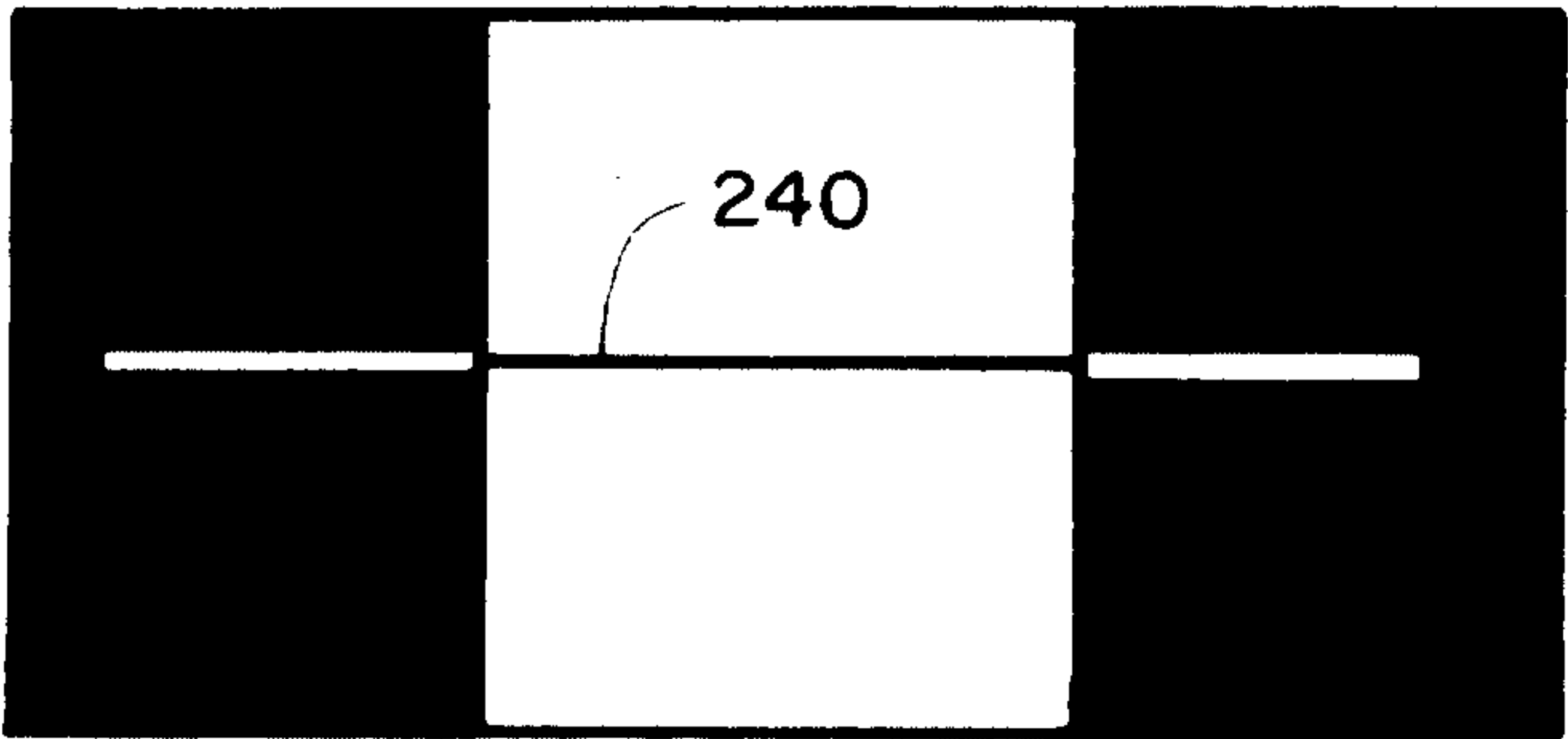


FIG. 17C



FIG. 17D

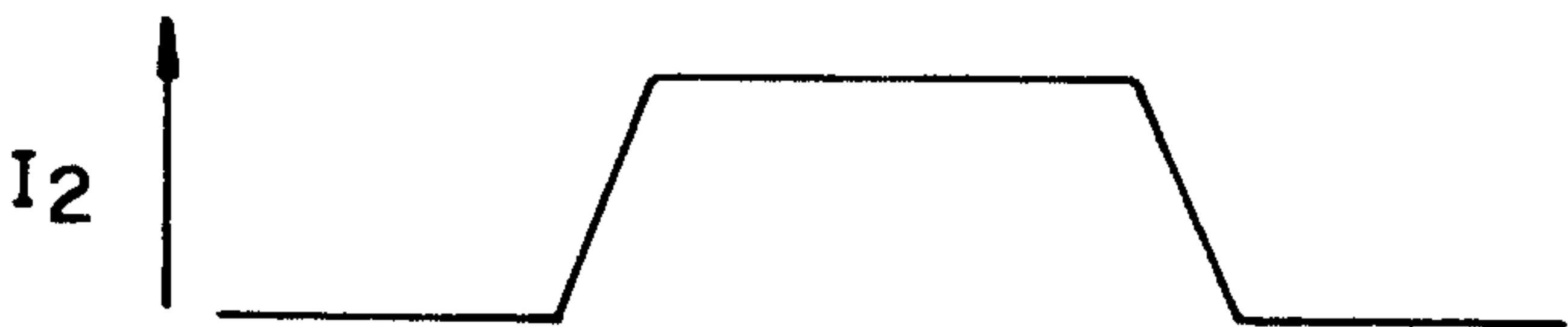
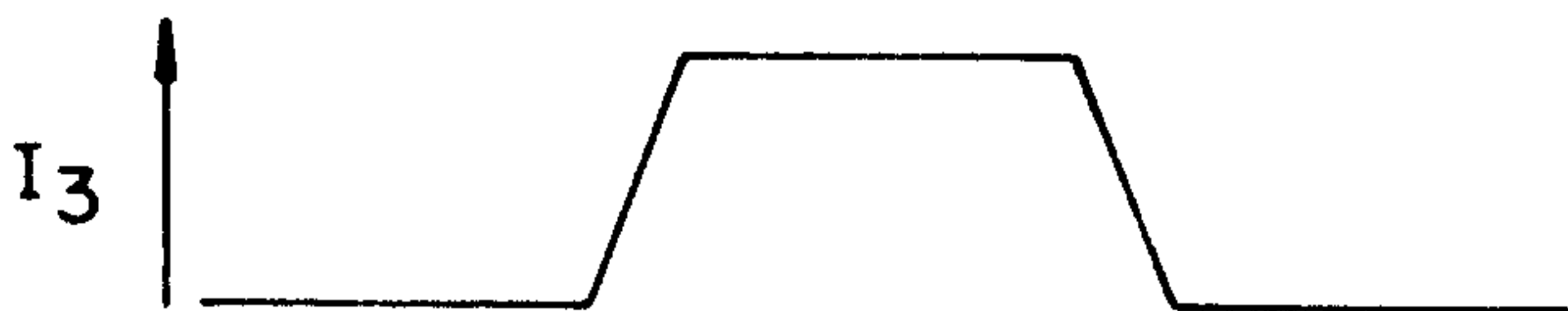


FIG. 17E



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FIG. 17F

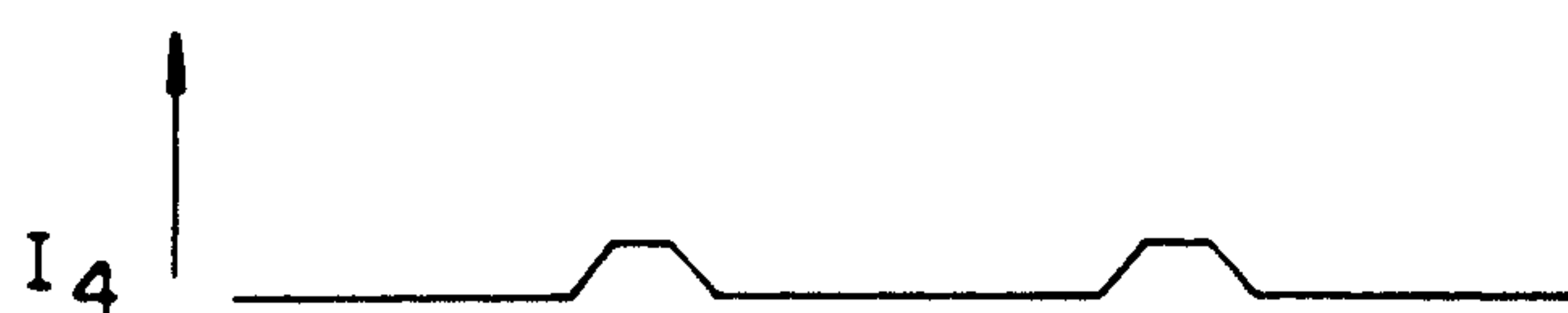


FIG. 17G

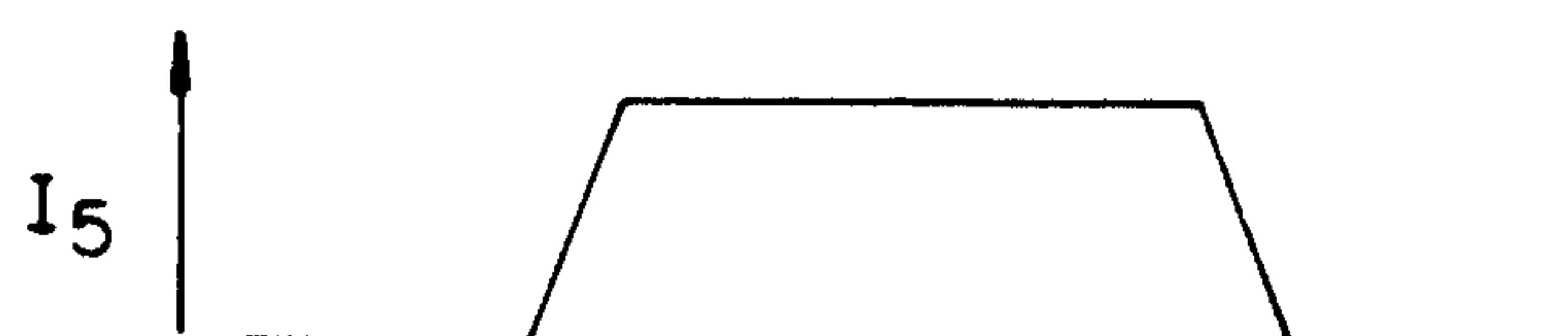


FIG. 17H



FIG. 17I

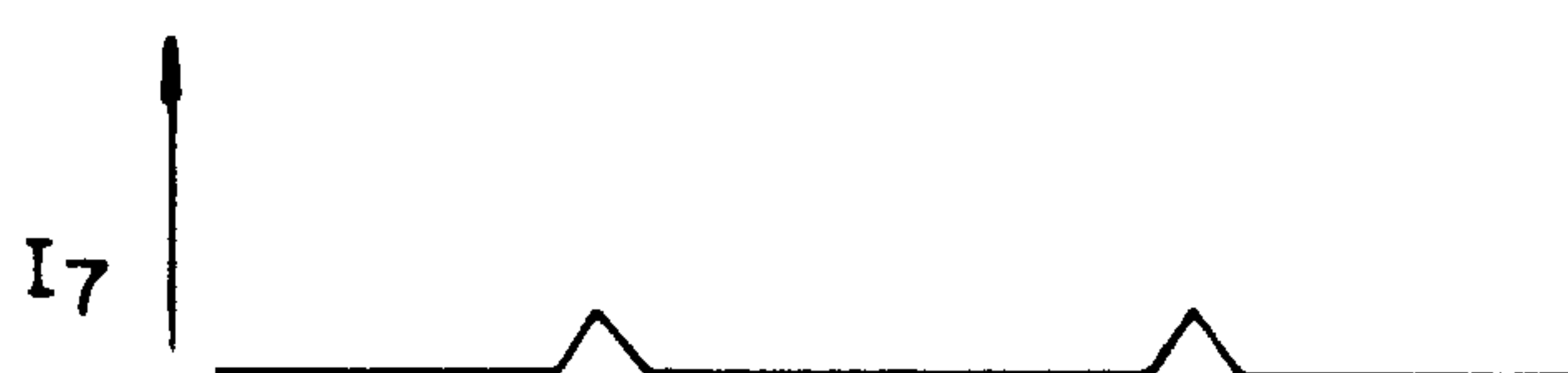
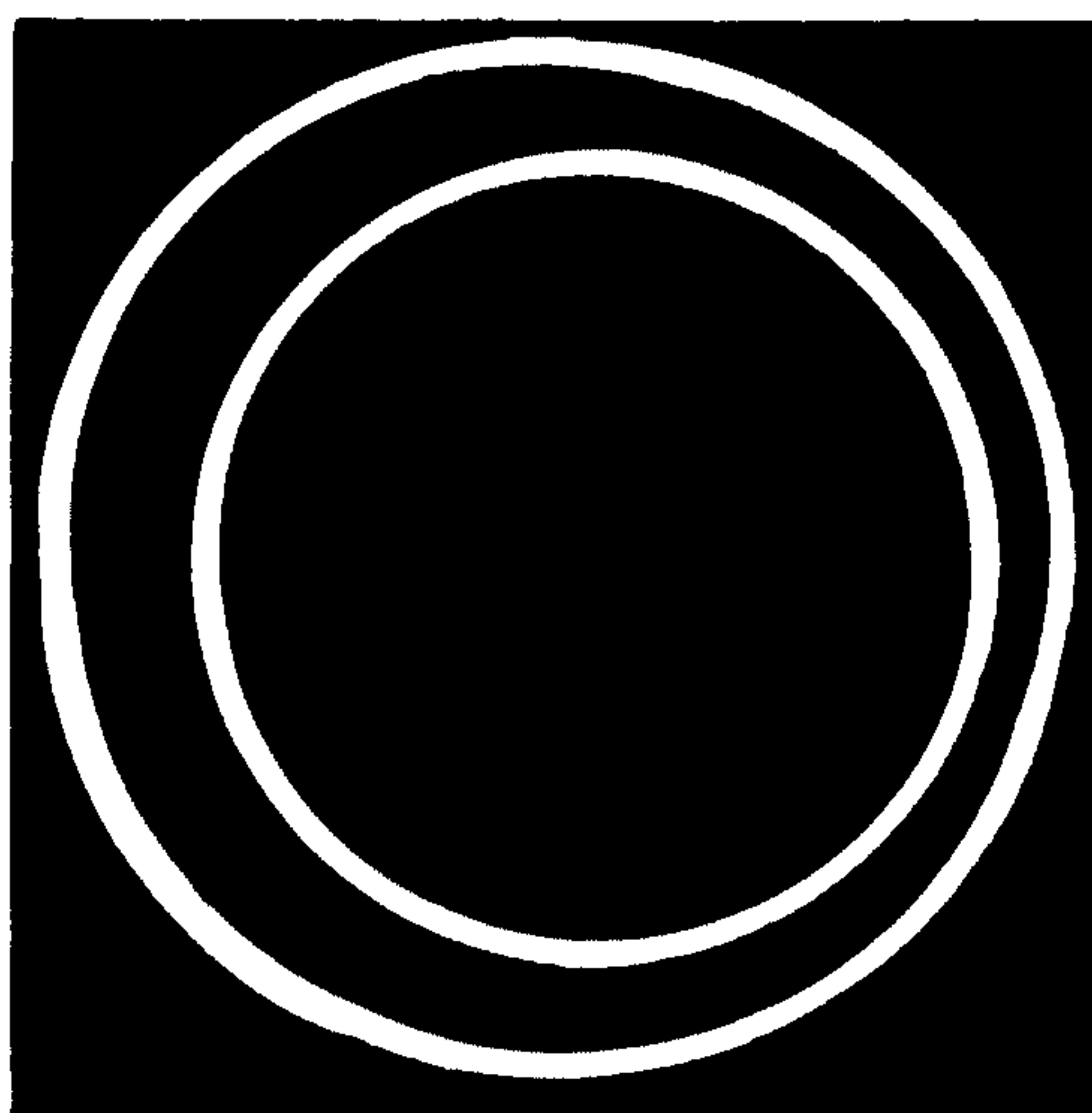


FIG. 17J

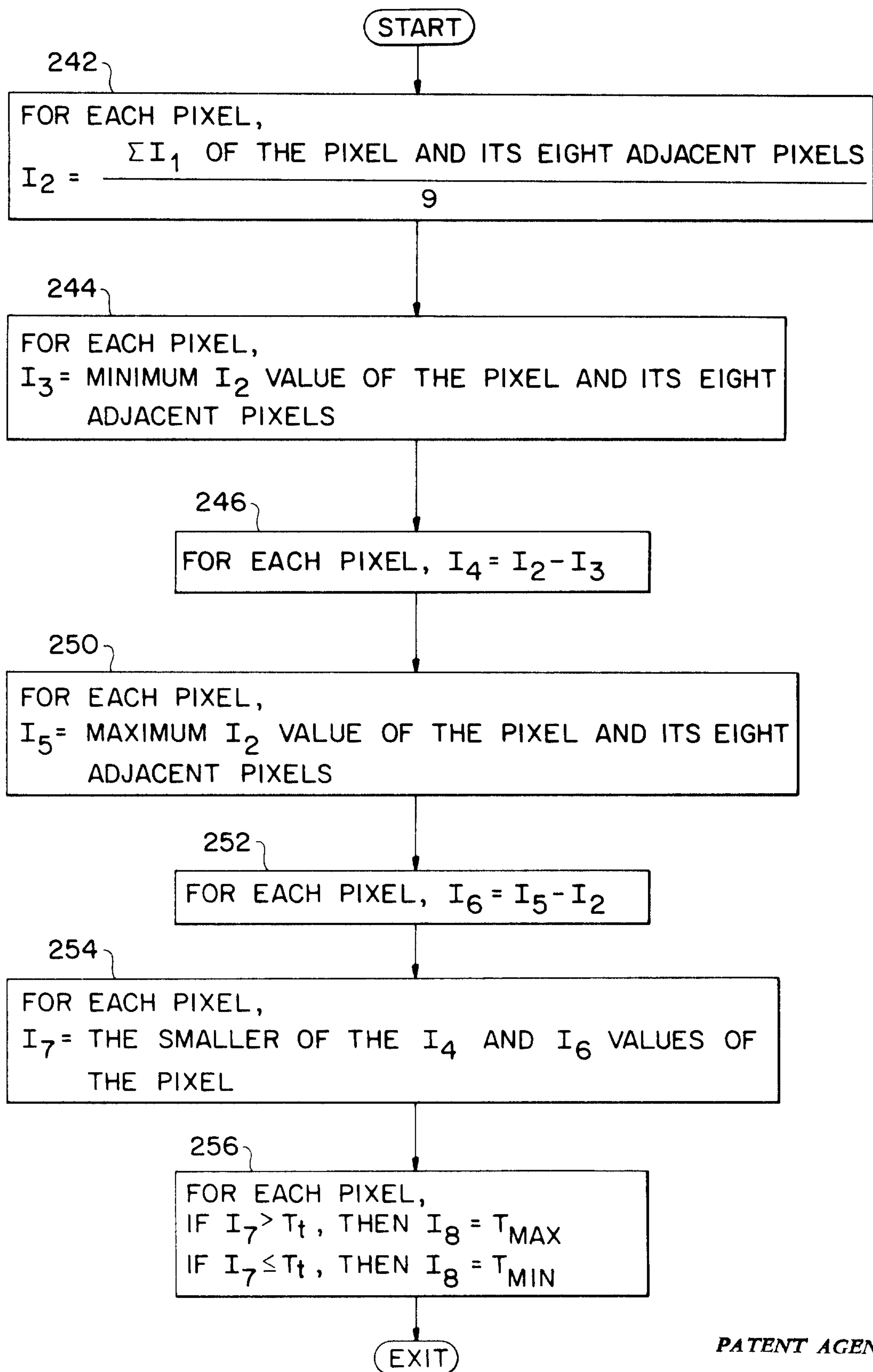


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FIG. 18



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FIG. 19A

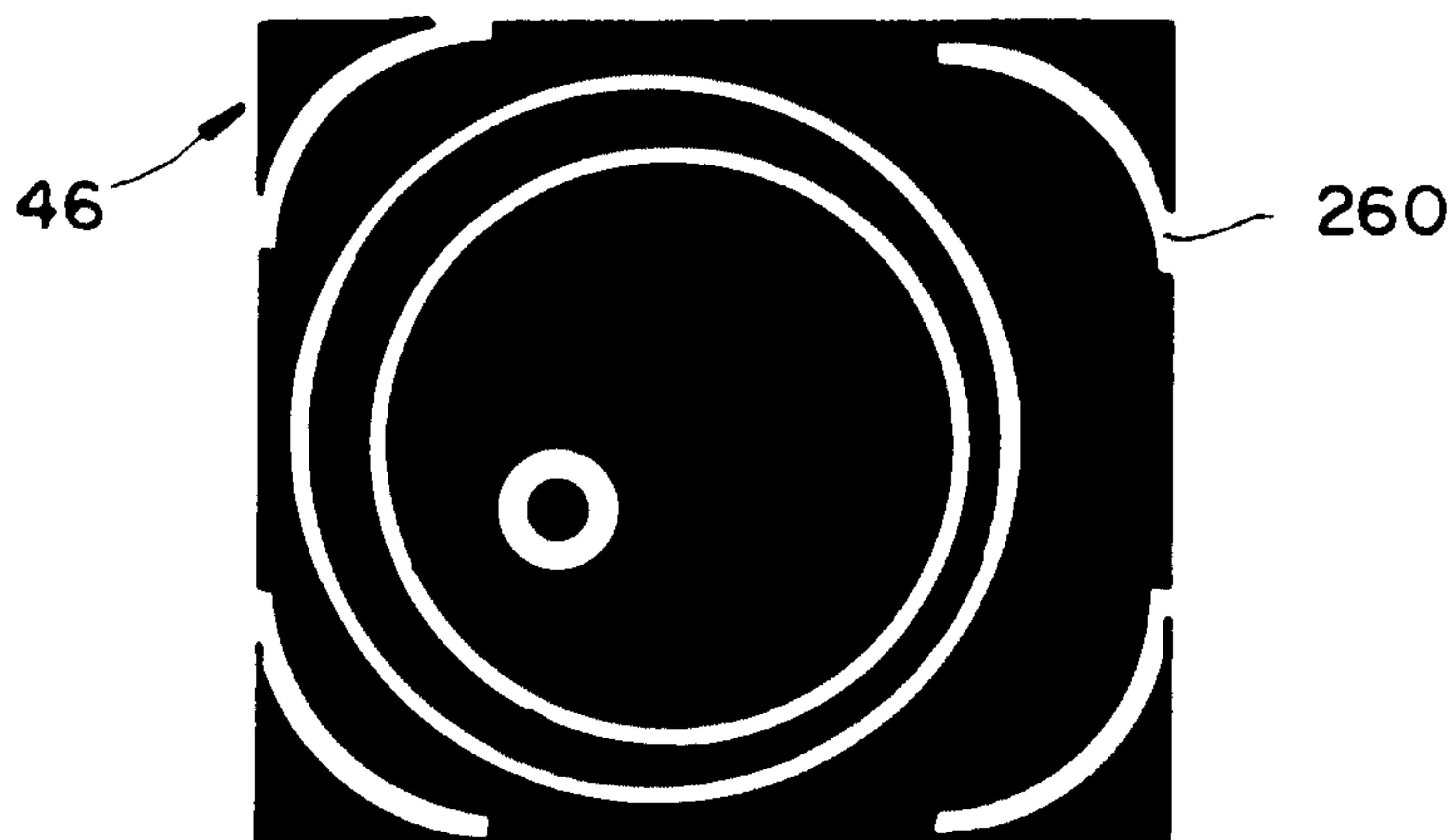


FIG. 19B

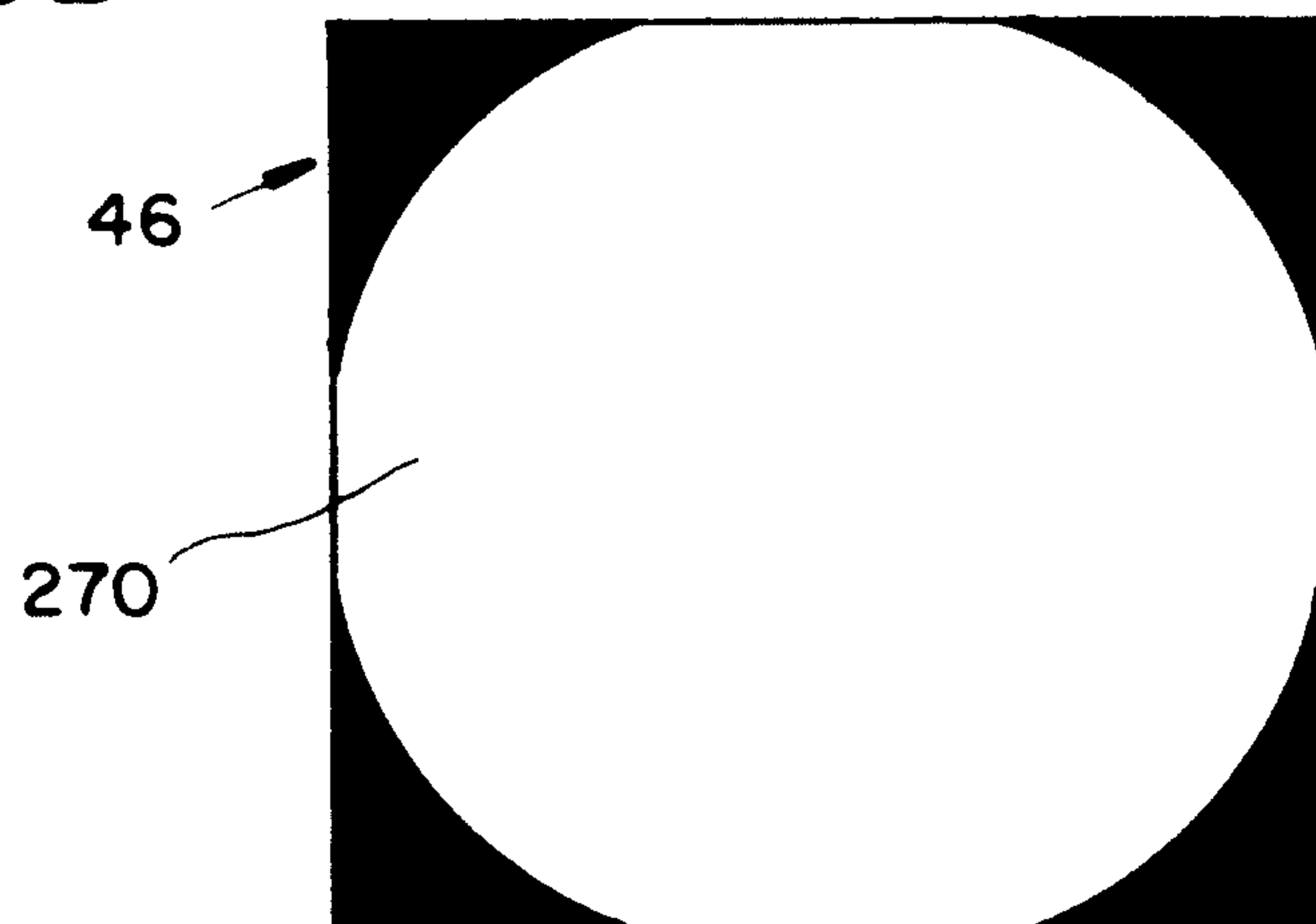
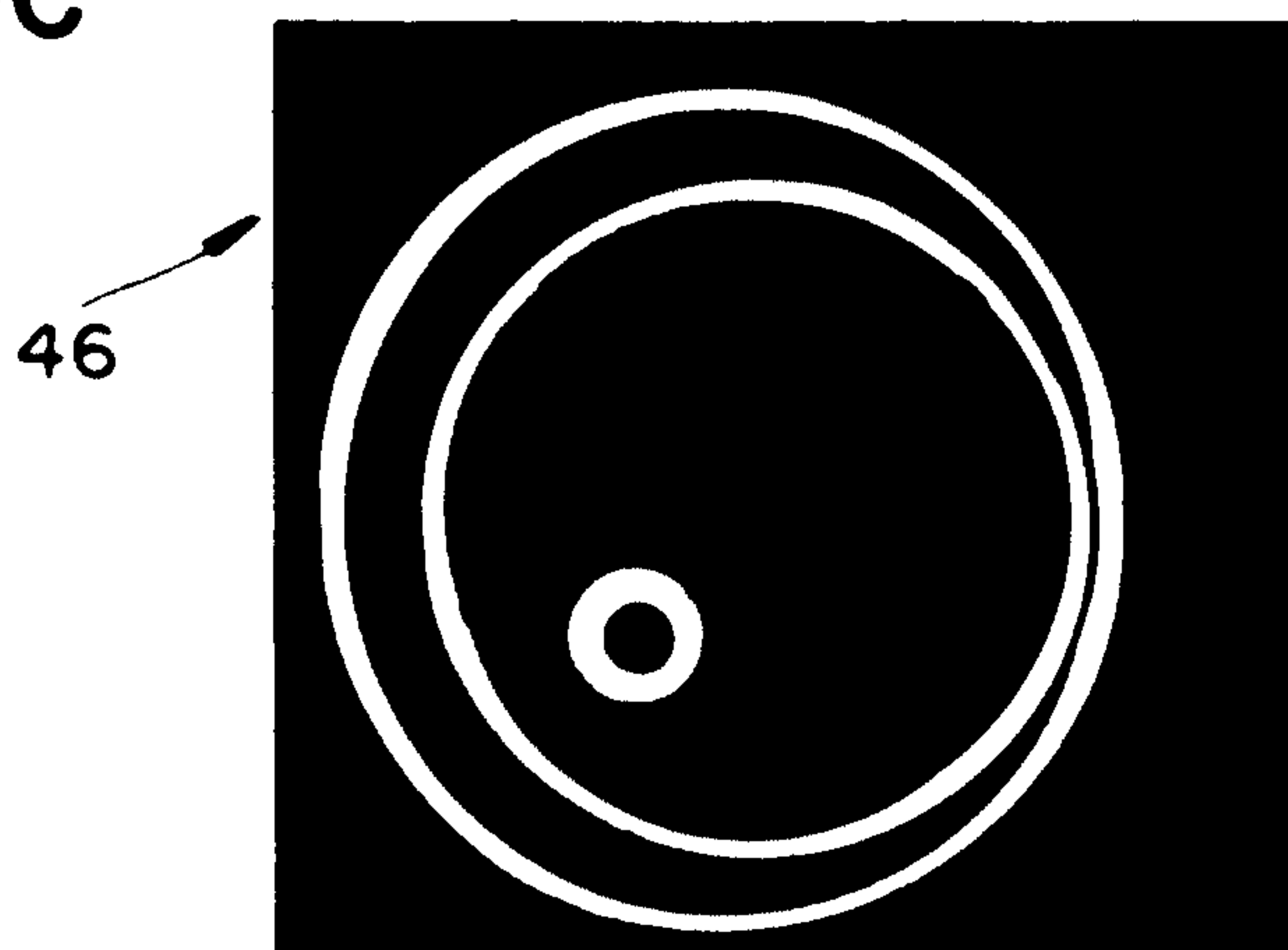


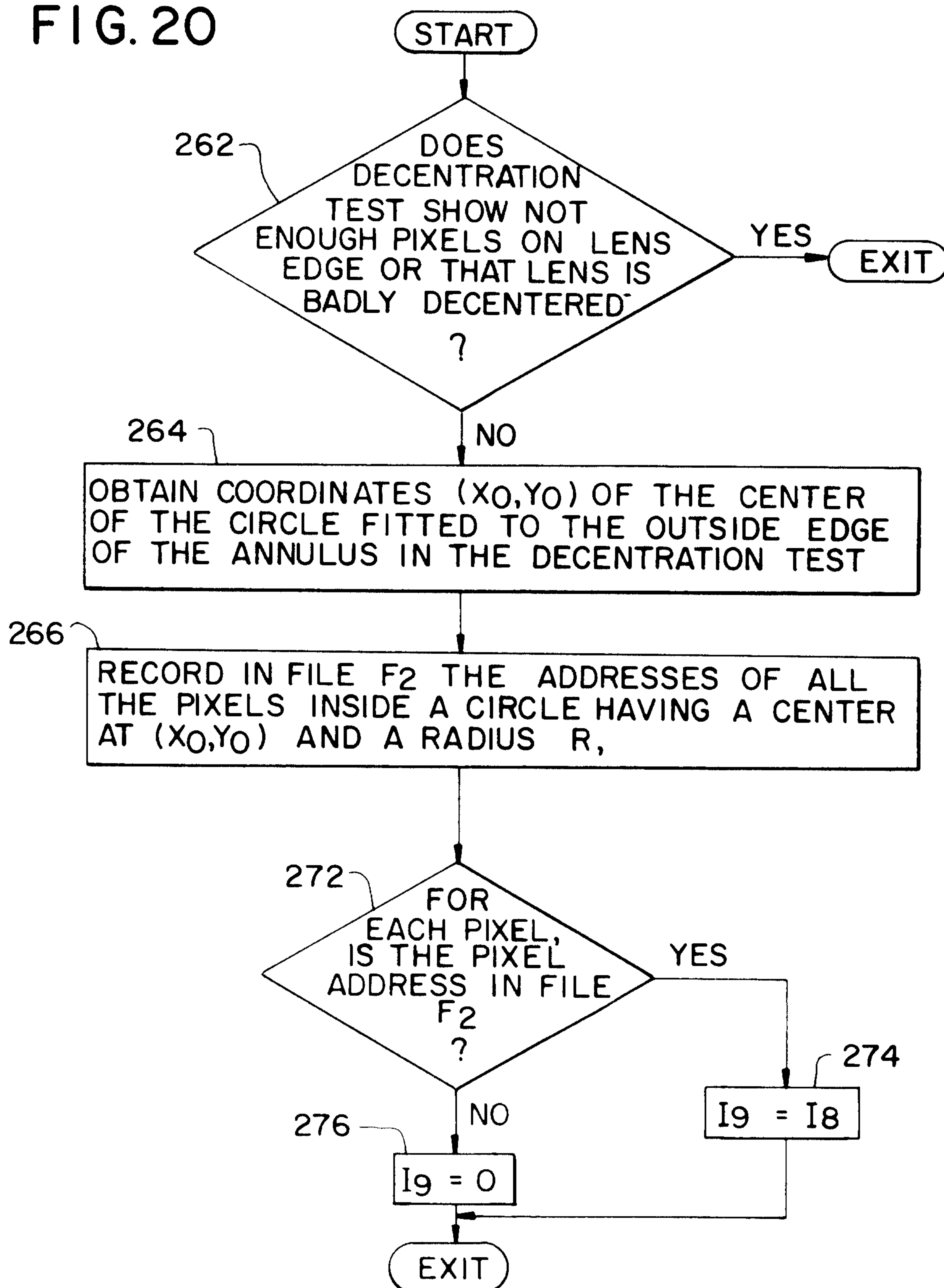
FIG. 19C



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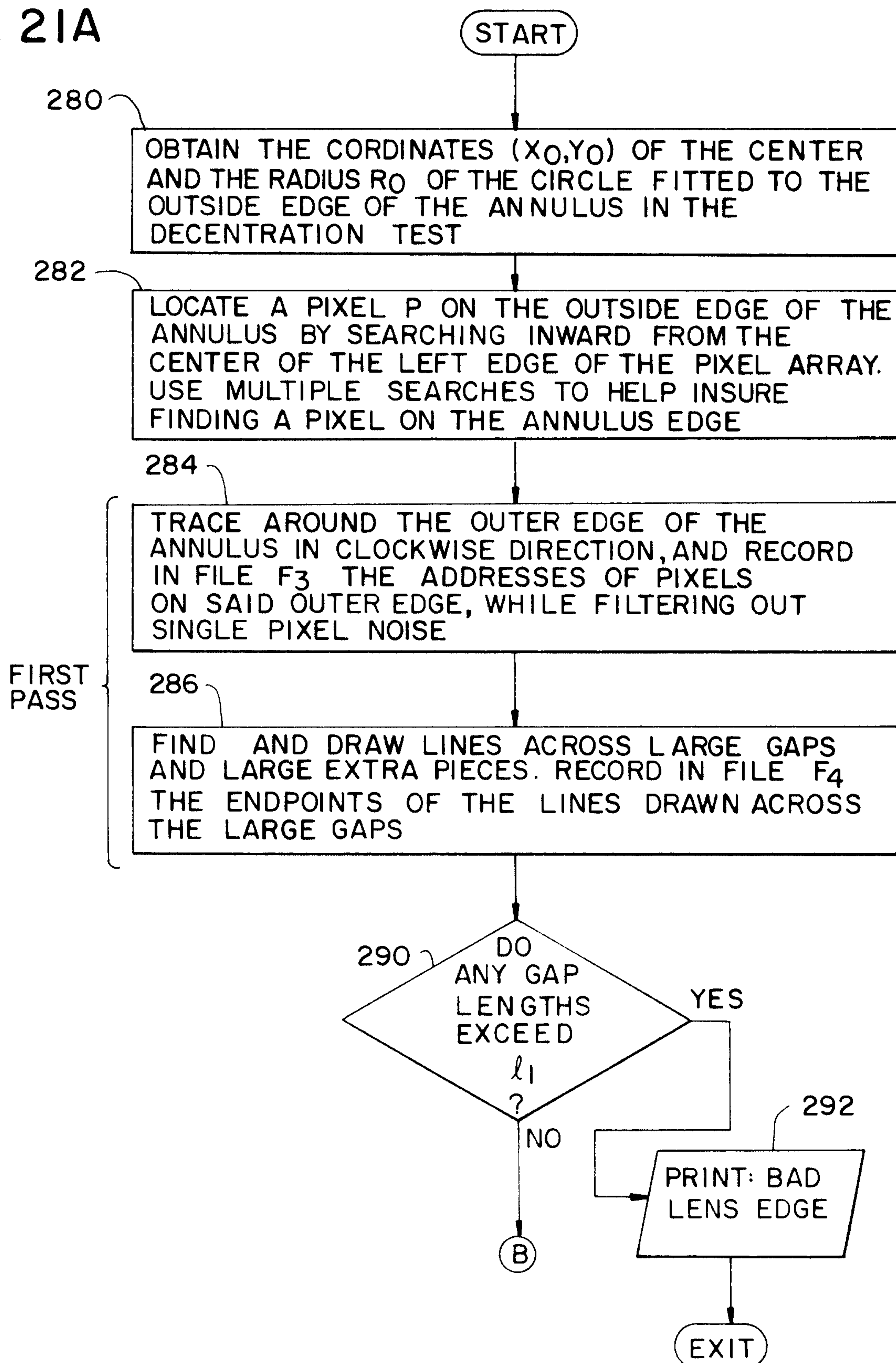
FIG. 20



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FIG. 21A



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FIG. 2IB

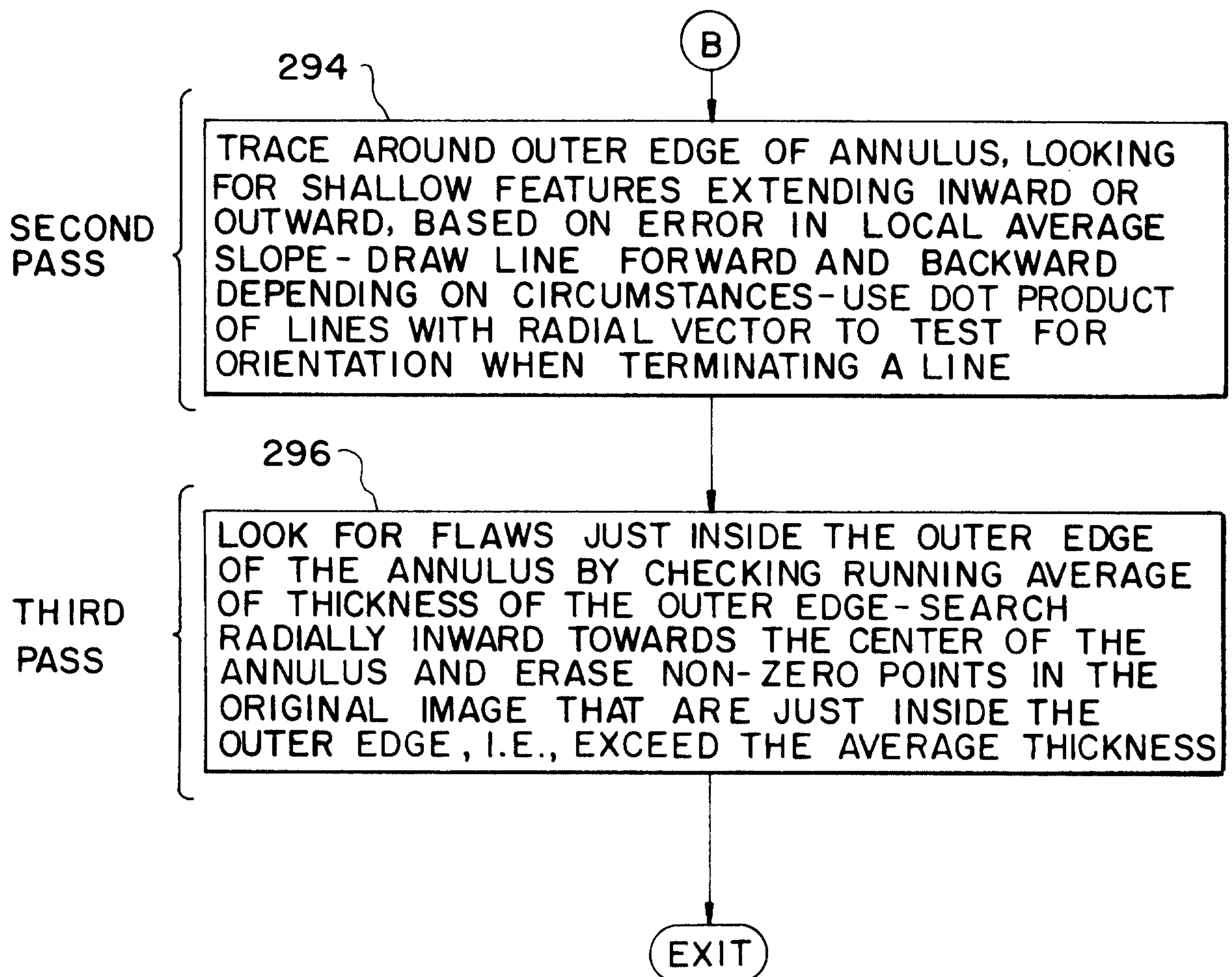
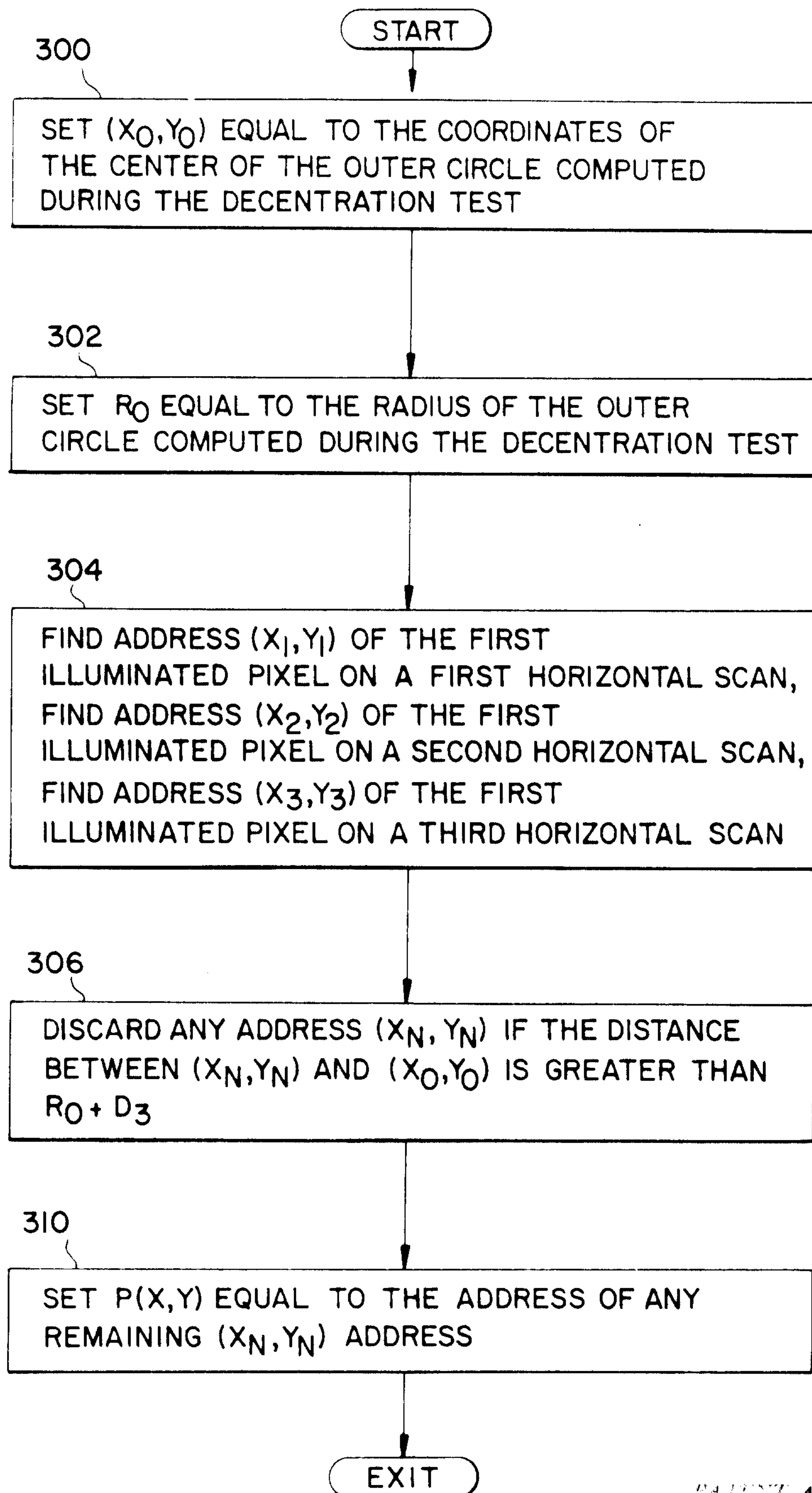


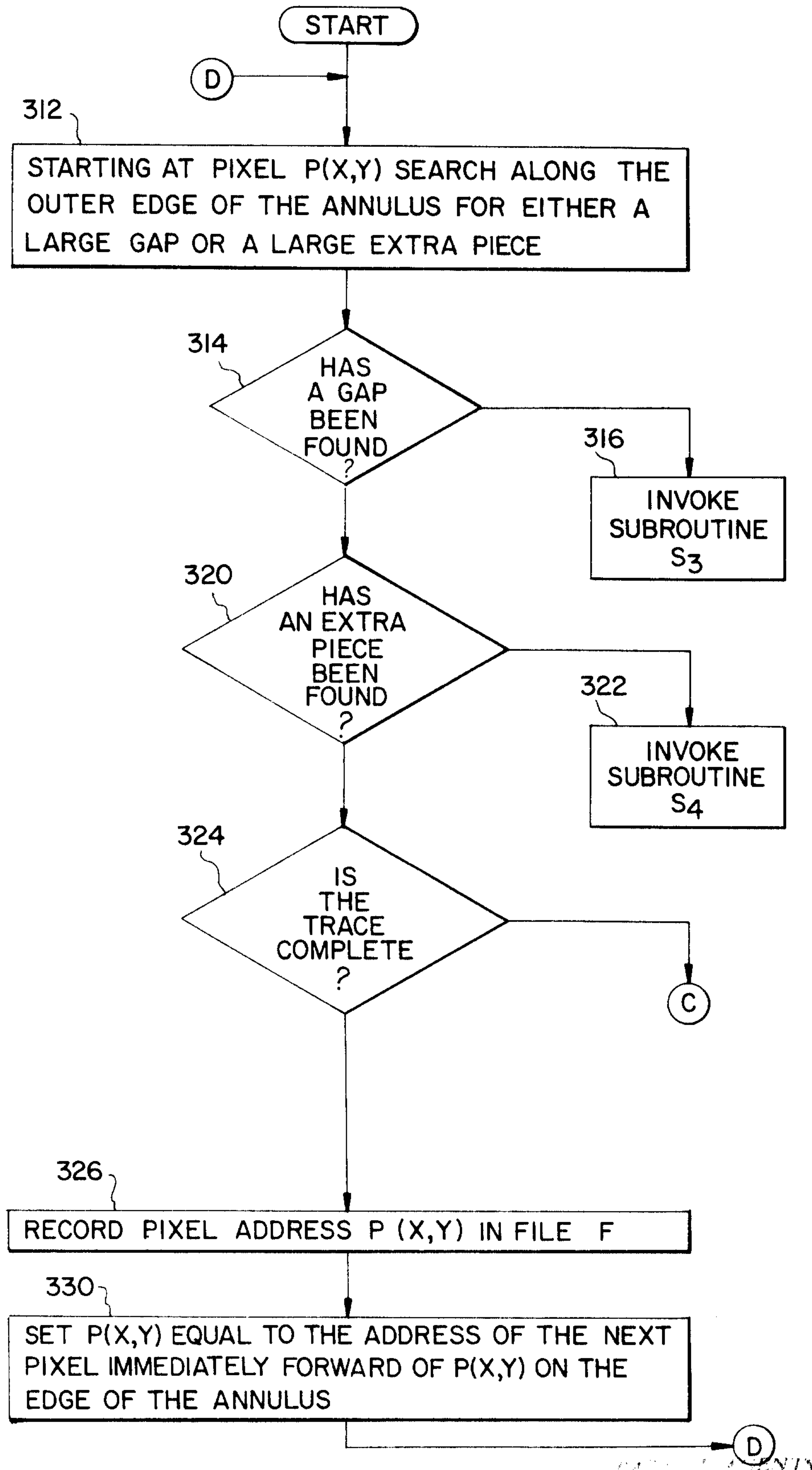
FIG. 22



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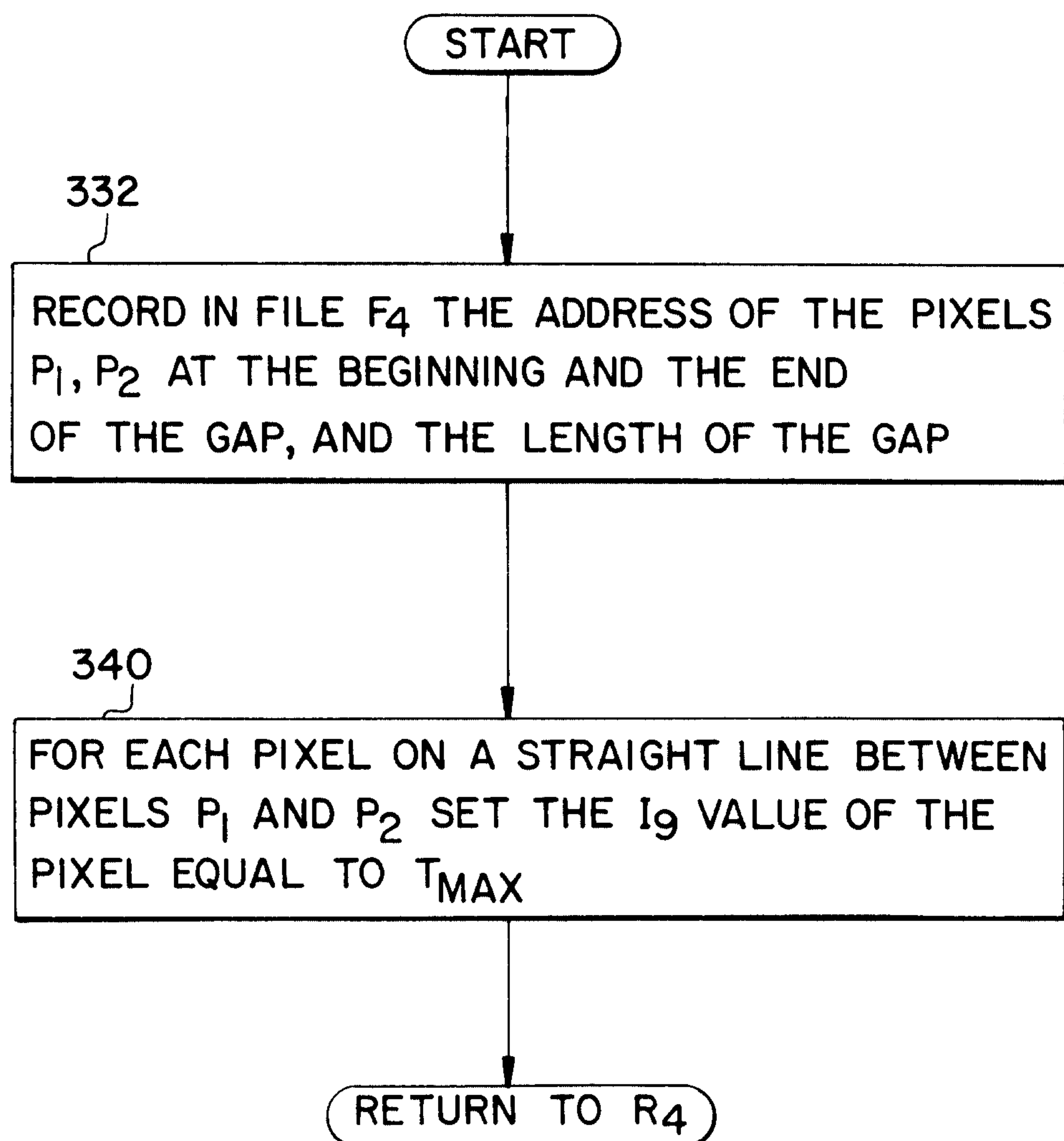
Swaney Ogilvy Renault

FIG. 23



Donald Ogilvy Renault

FIG. 24



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Awakey Ogilvy Renault

FIG.25A

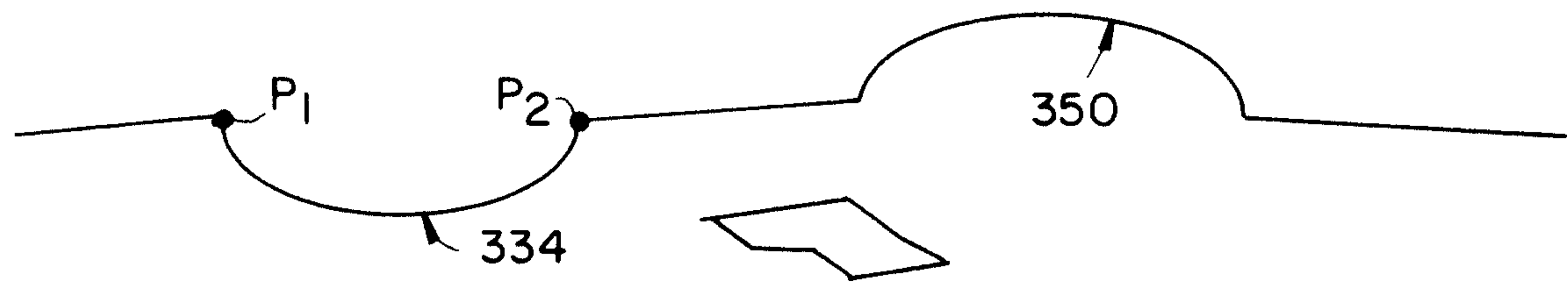


FIG.25B

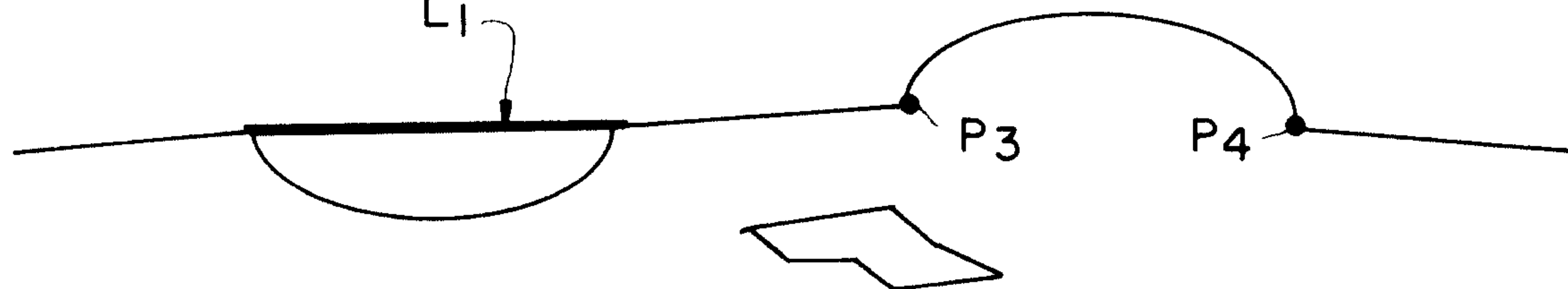


FIG.25C

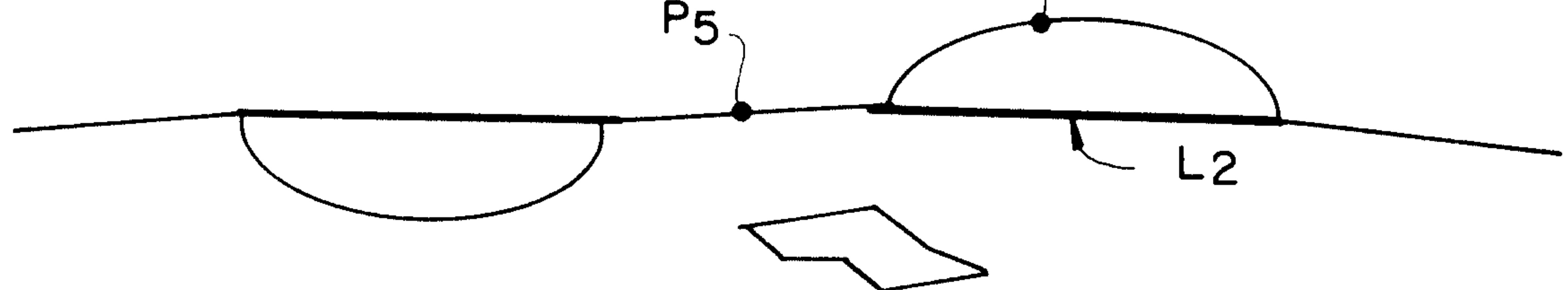


FIG.25D



FIG.25E

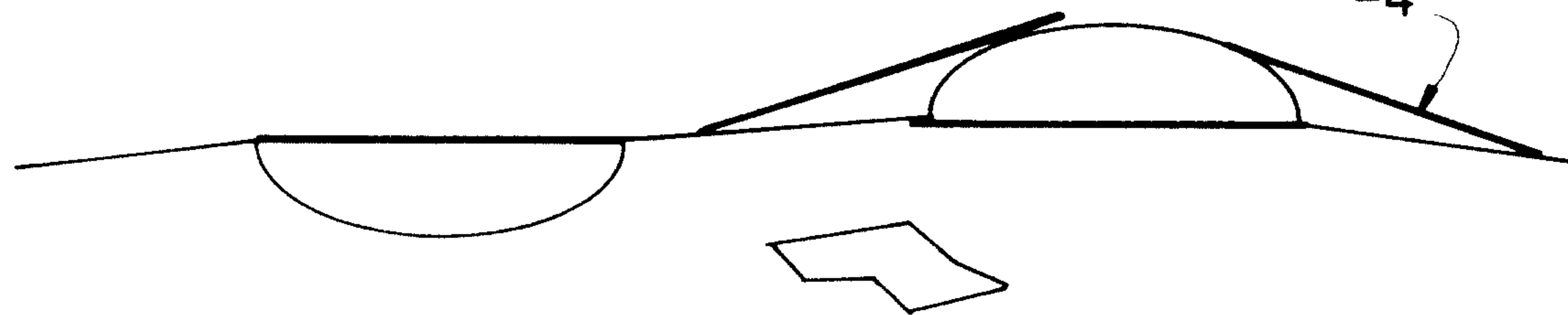
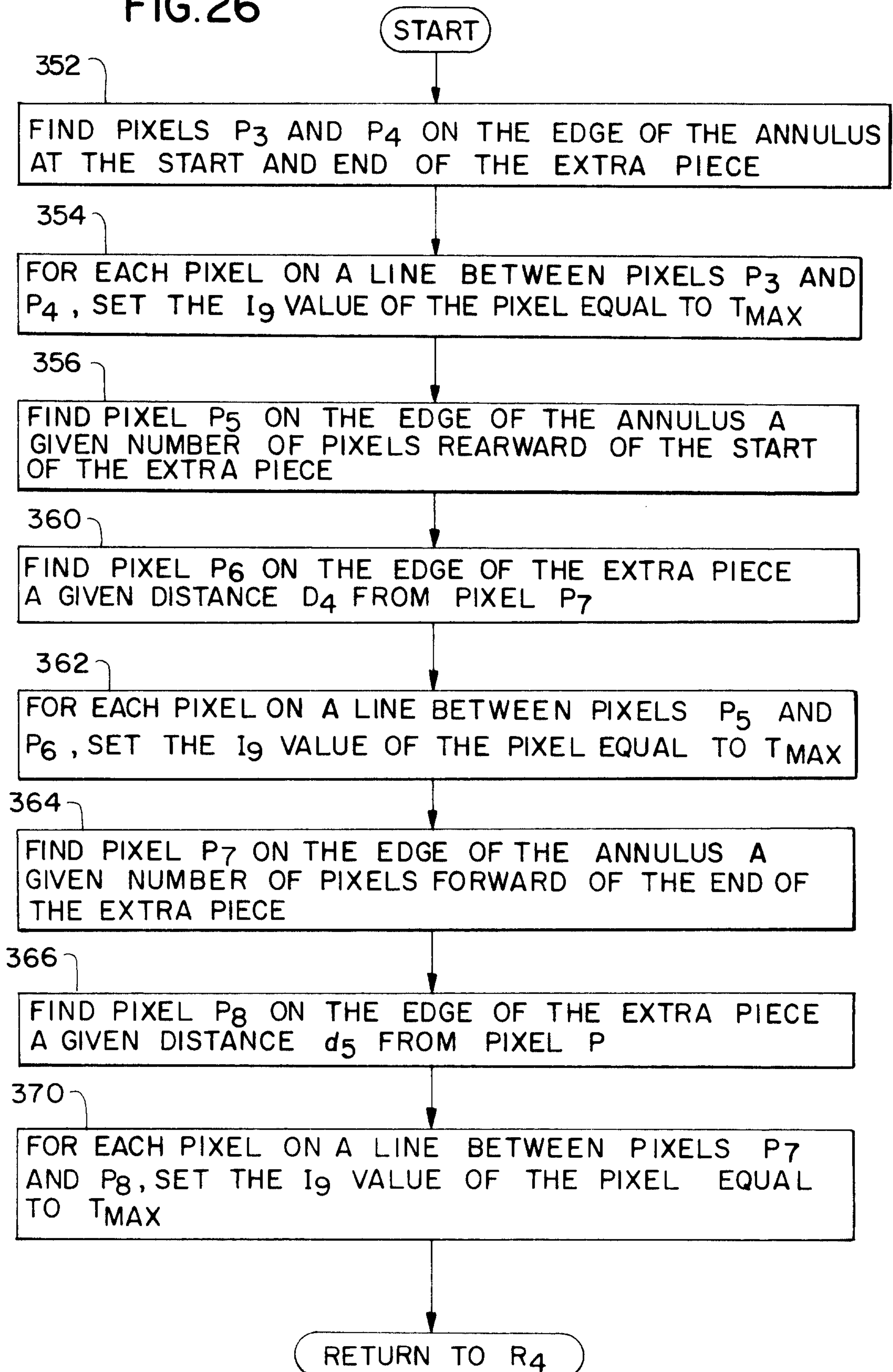


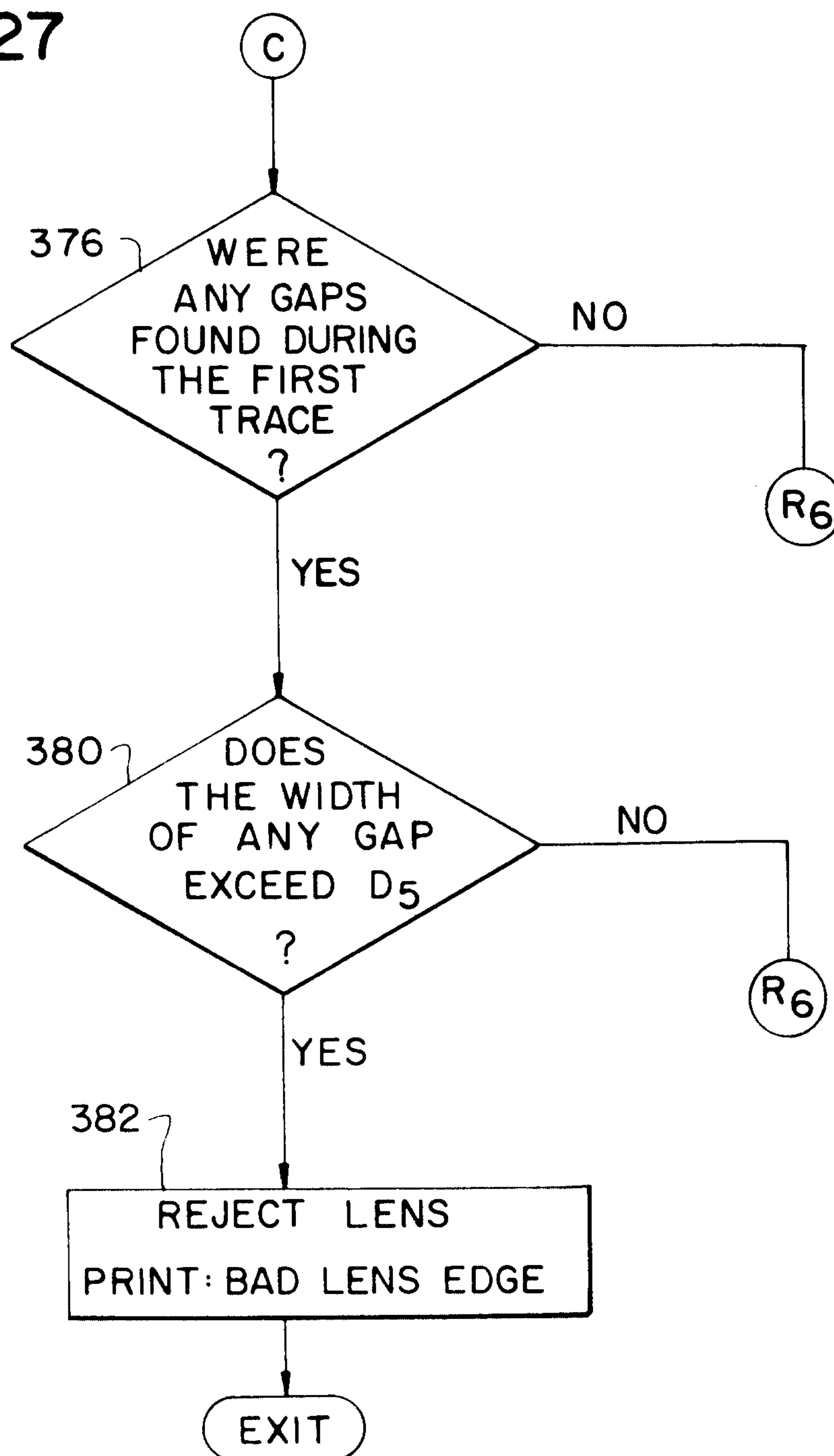
FIG.26



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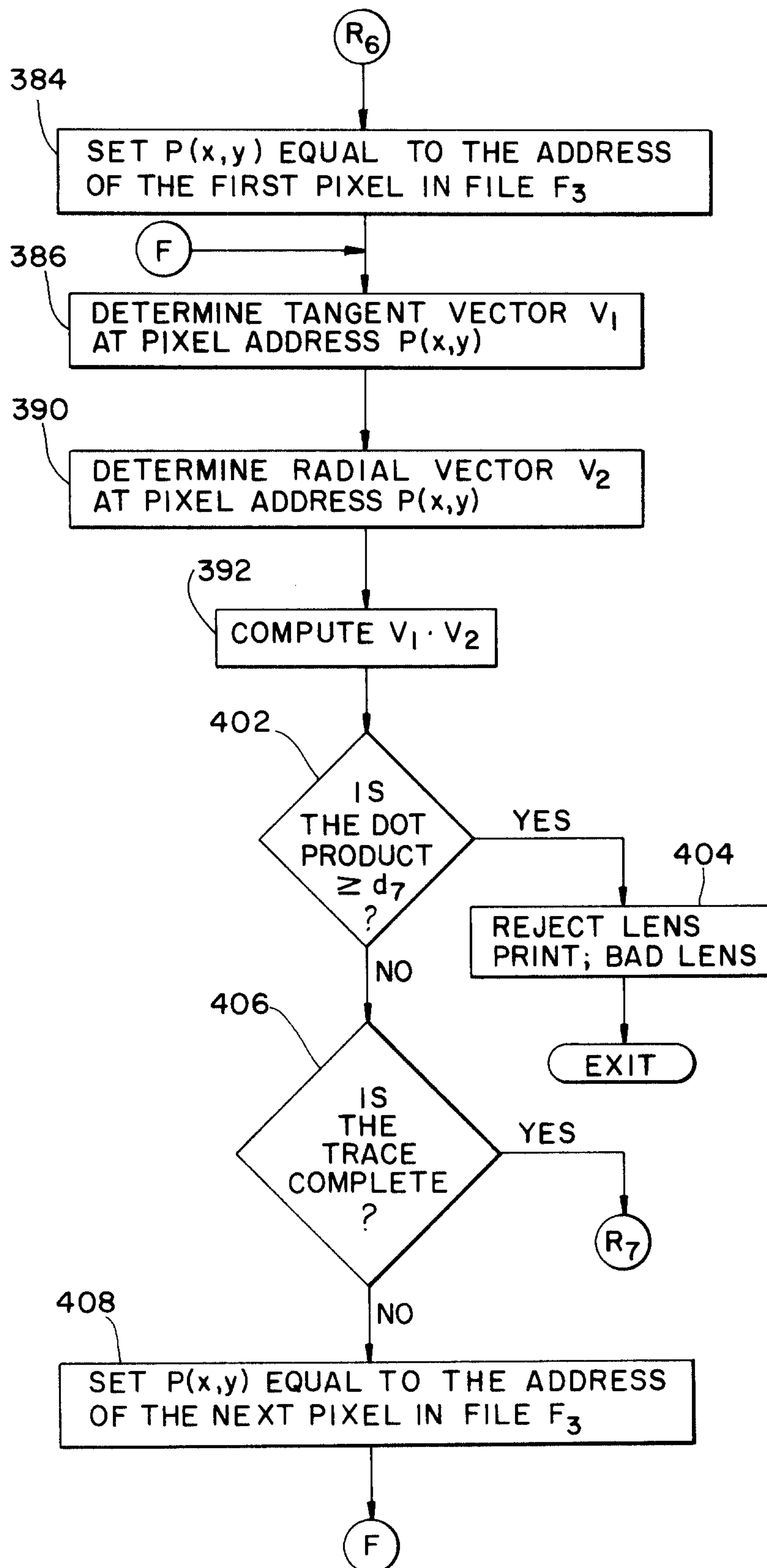
FIG. 27



PATENT AGENTS

Dwight G. G. G. G.

FIG. 28



PATENT AGENTS

Swatley Ogilvy & Associates

FIG.29

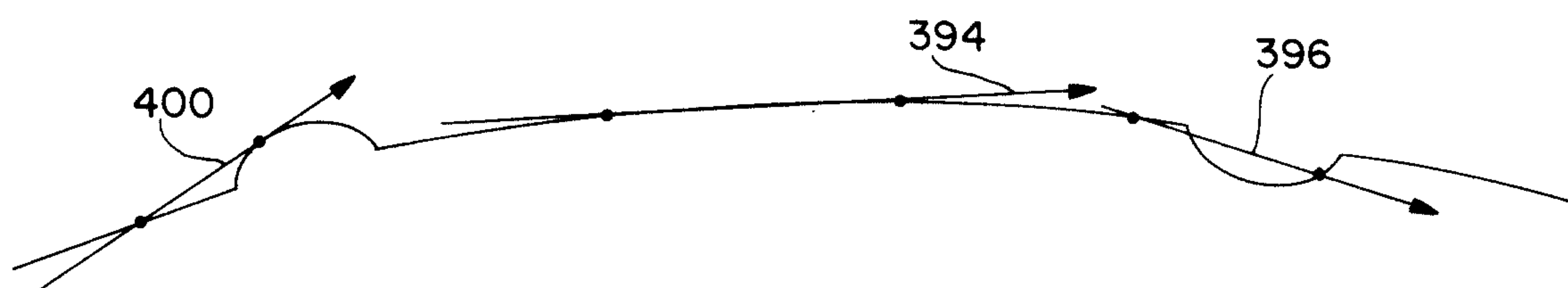


FIG.31

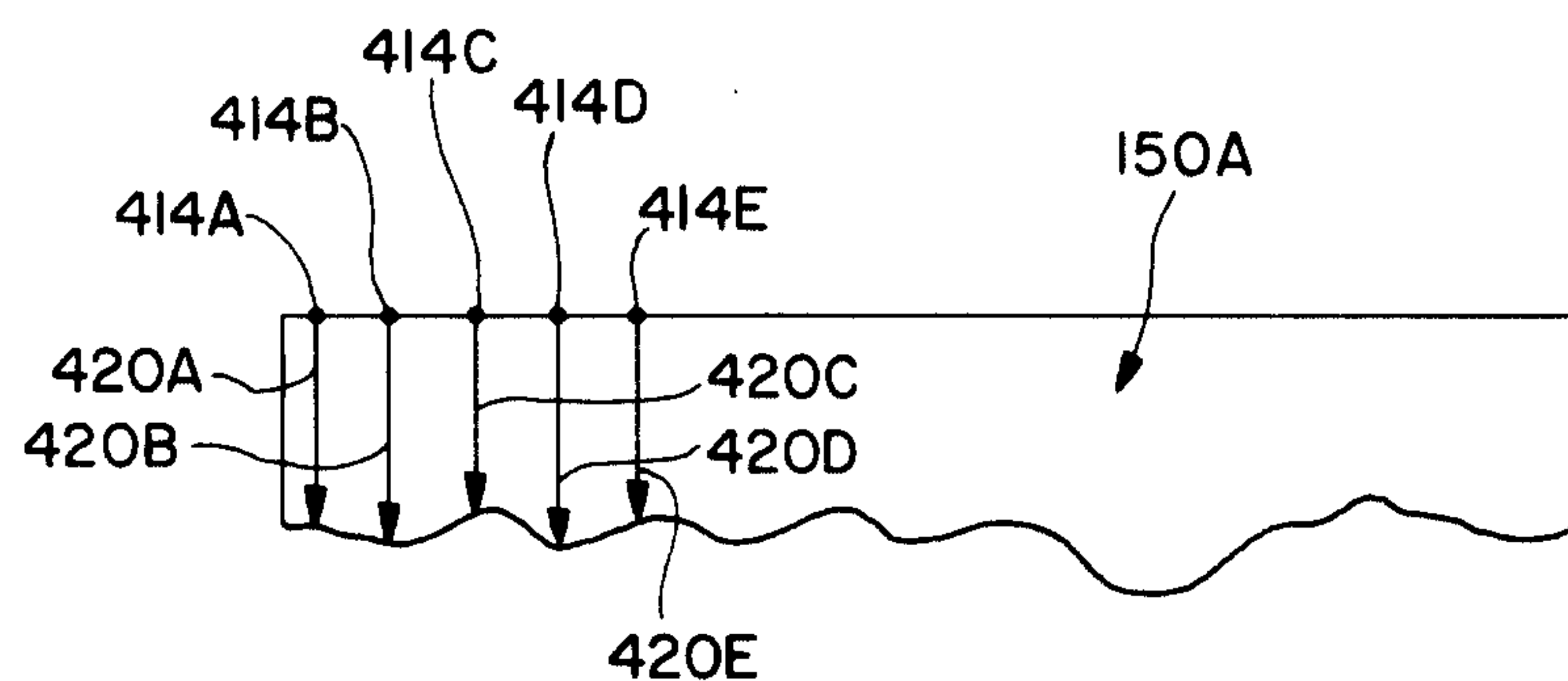
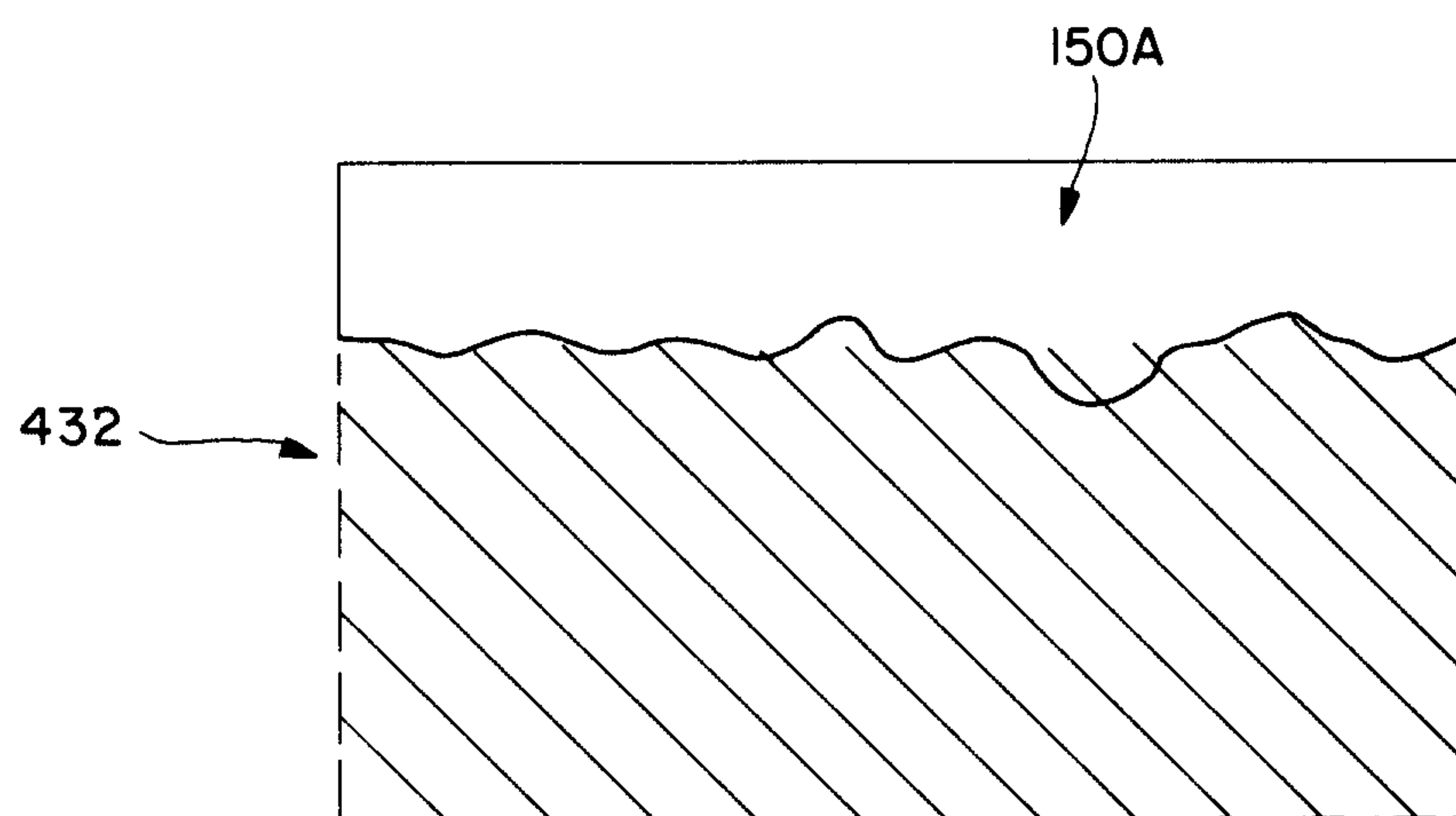


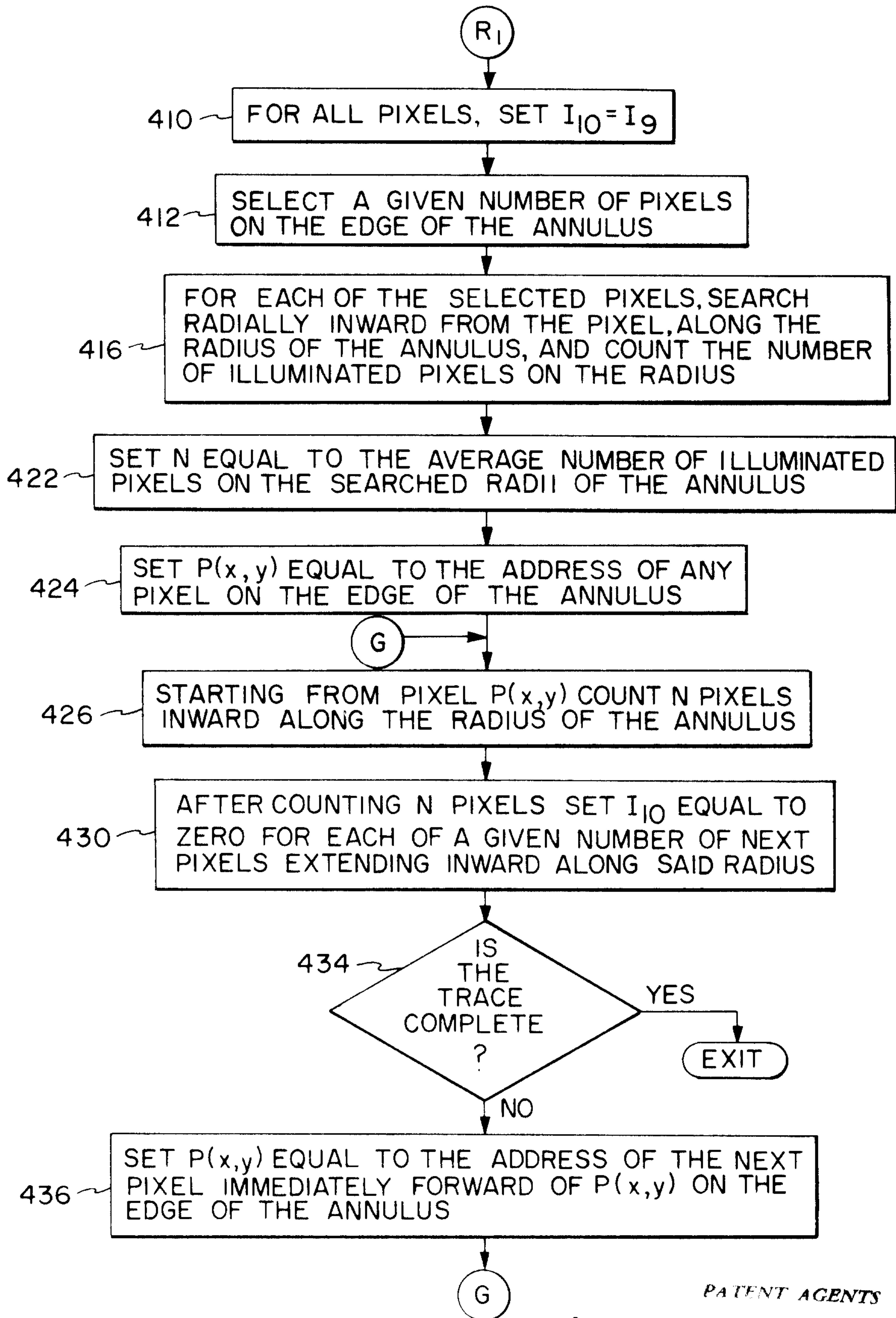
FIG.32



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FIG. 30



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FIG.33

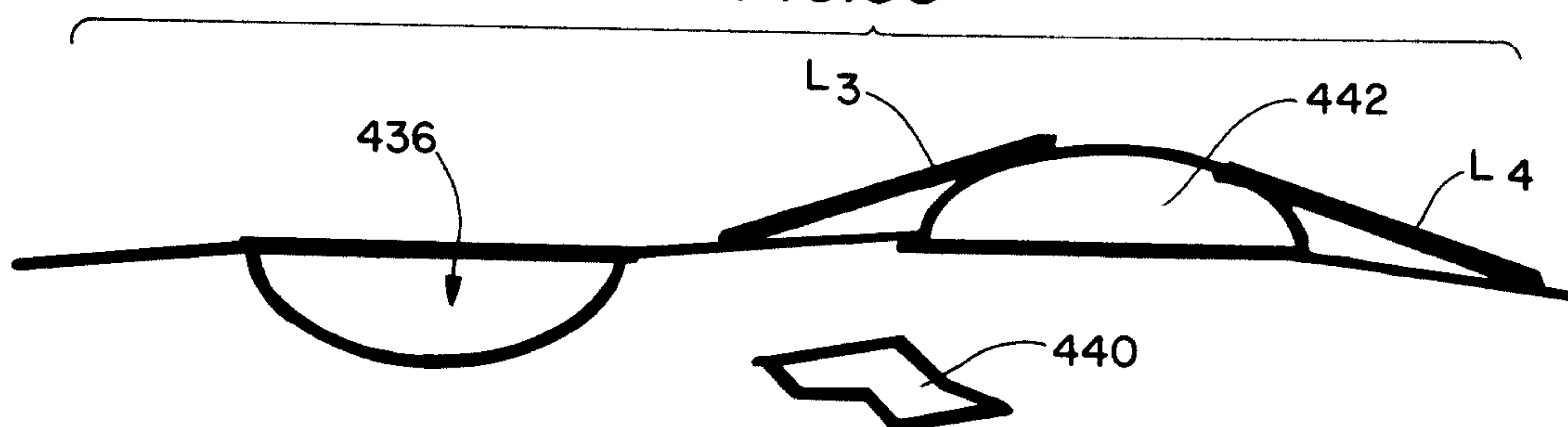


FIG.35

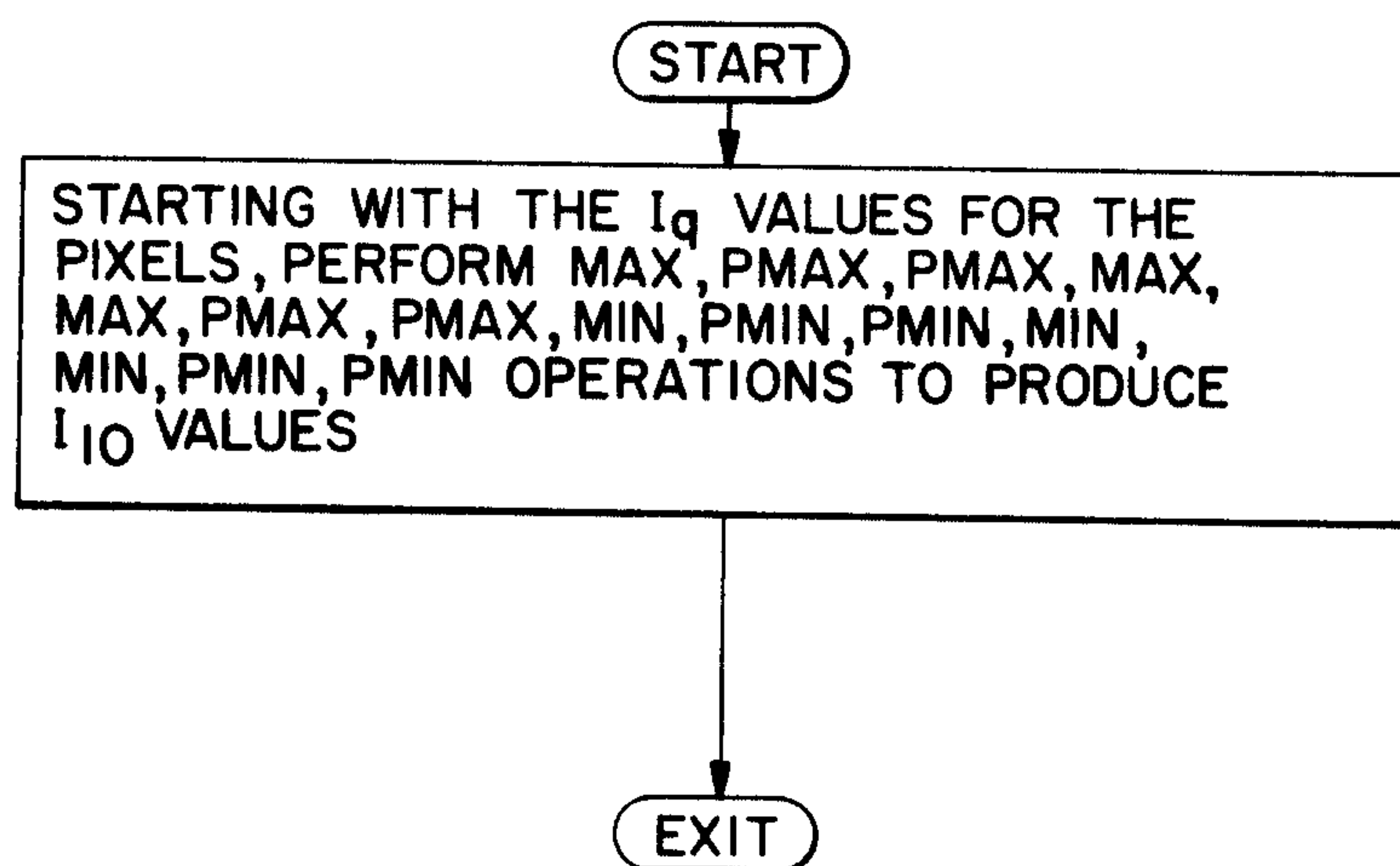
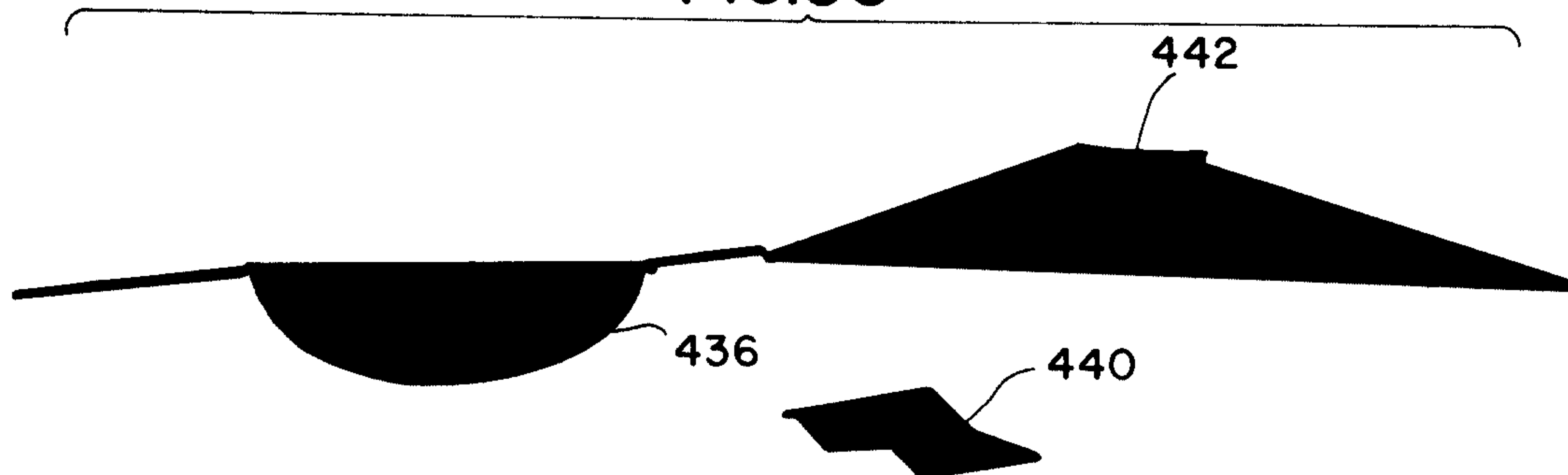


FIG.36



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FIG.34A

7	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
4	0	7	7	7	7	0	0
3	7	7	7	7	7	0	0
2	7	7	7	7	0	0	0
1	7	7	7	0	0	0	0
	1	2	3	4	5	6	7

FIG.34B

MAX

7	0	0	0	0	0	0	0
6	0	7	7	7	7	0	0
5	7	7	7	7	7	7	0
4	7	7	7	7	7	7	0
3	7	7	7	7	7	7	0
2	7	7	7	7	7	7	0
1	7	7	7	7	7	0	0
	1	2	3	4	5	6	7

FIG.34C

PMAX

7	0	0	0	0	0	0	0
6	0	0	7	7	0	0	0
5	0	7	7	7	7	0	0
4	7	7	7	7	7	7	0
3	7	7	7	7	7	7	0
2	7	7	7	7	7	0	0
1	7	7	7	7	0	0	0
	1	2	3	4	5	6	7

FIG.34D

MIN

7	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
3	0	0	7	0	0	0	0
2	7	7	0	0	0	0	0
1	7	7	0	0	0	0	0
	1	2	3	4	5	6	7

FIG.34E

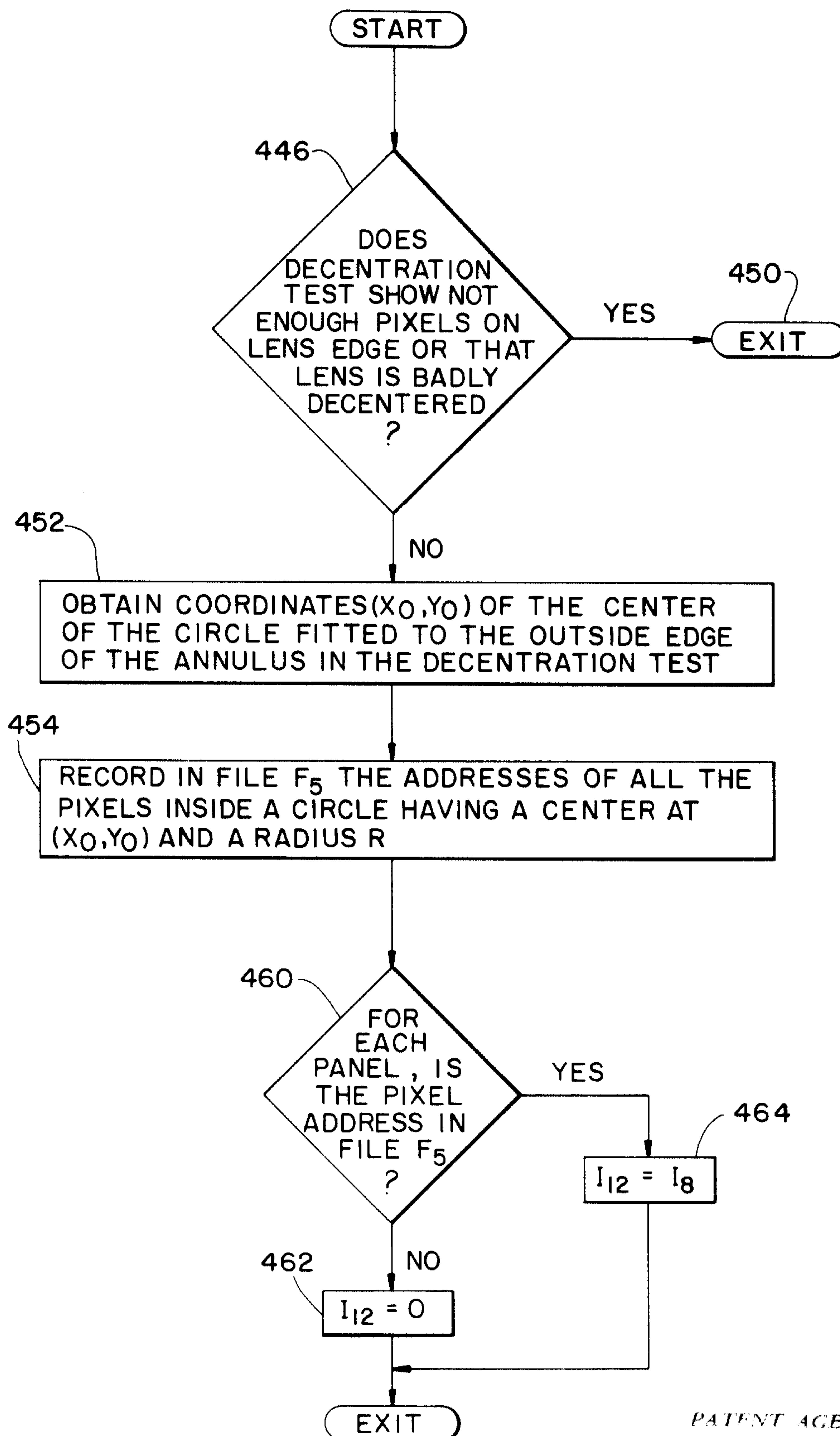
PMIN

7	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
4	0	0	7	7	0	0	0
3	0	7	7	7	0	0	0
2	7	7	7	0	0	0	0
1	7	7	0	0	0	0	0
	1	2	3	4	5	6	7

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Awake Agilny Result

FIG. 37



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FIG. 38A

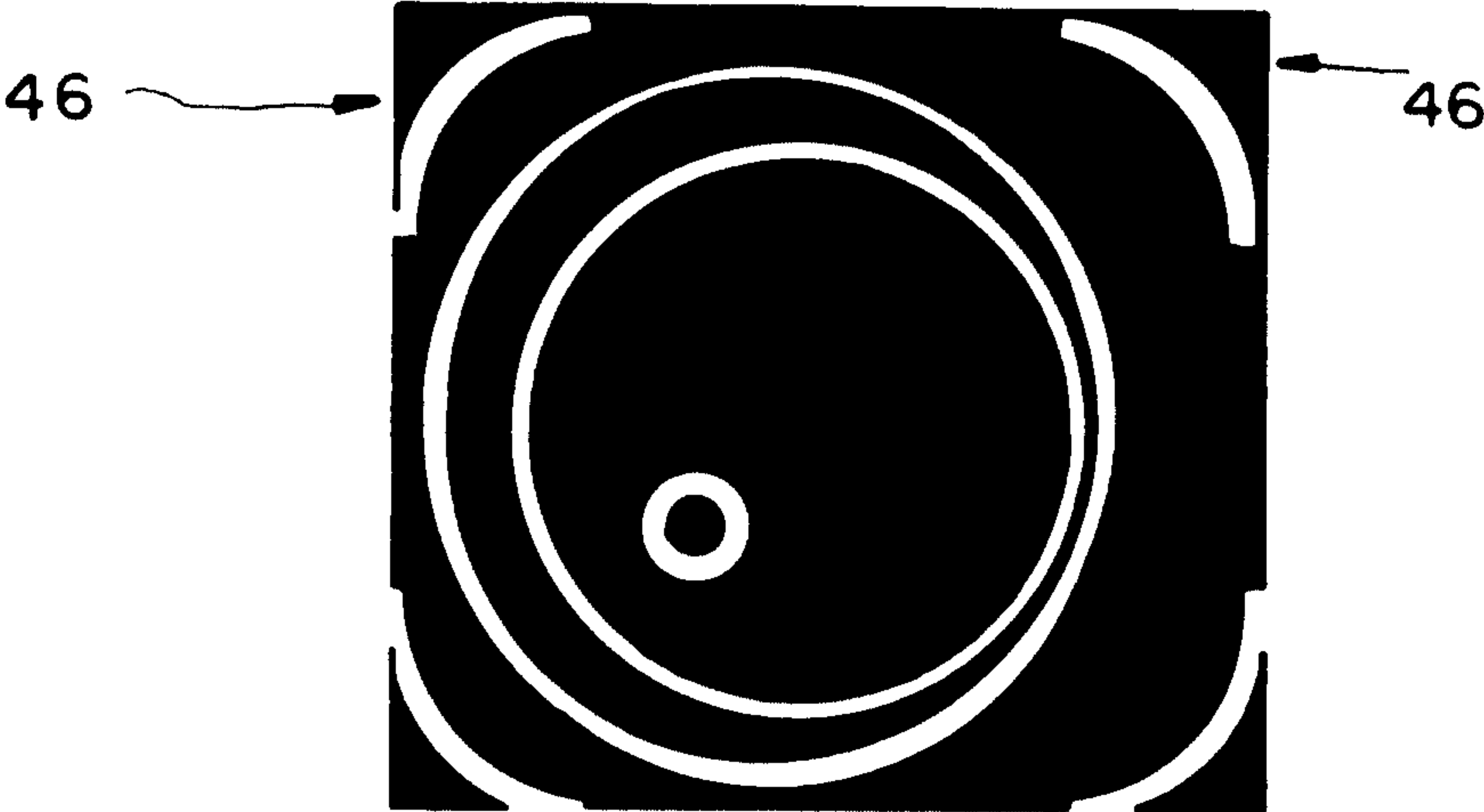


FIG. 38B

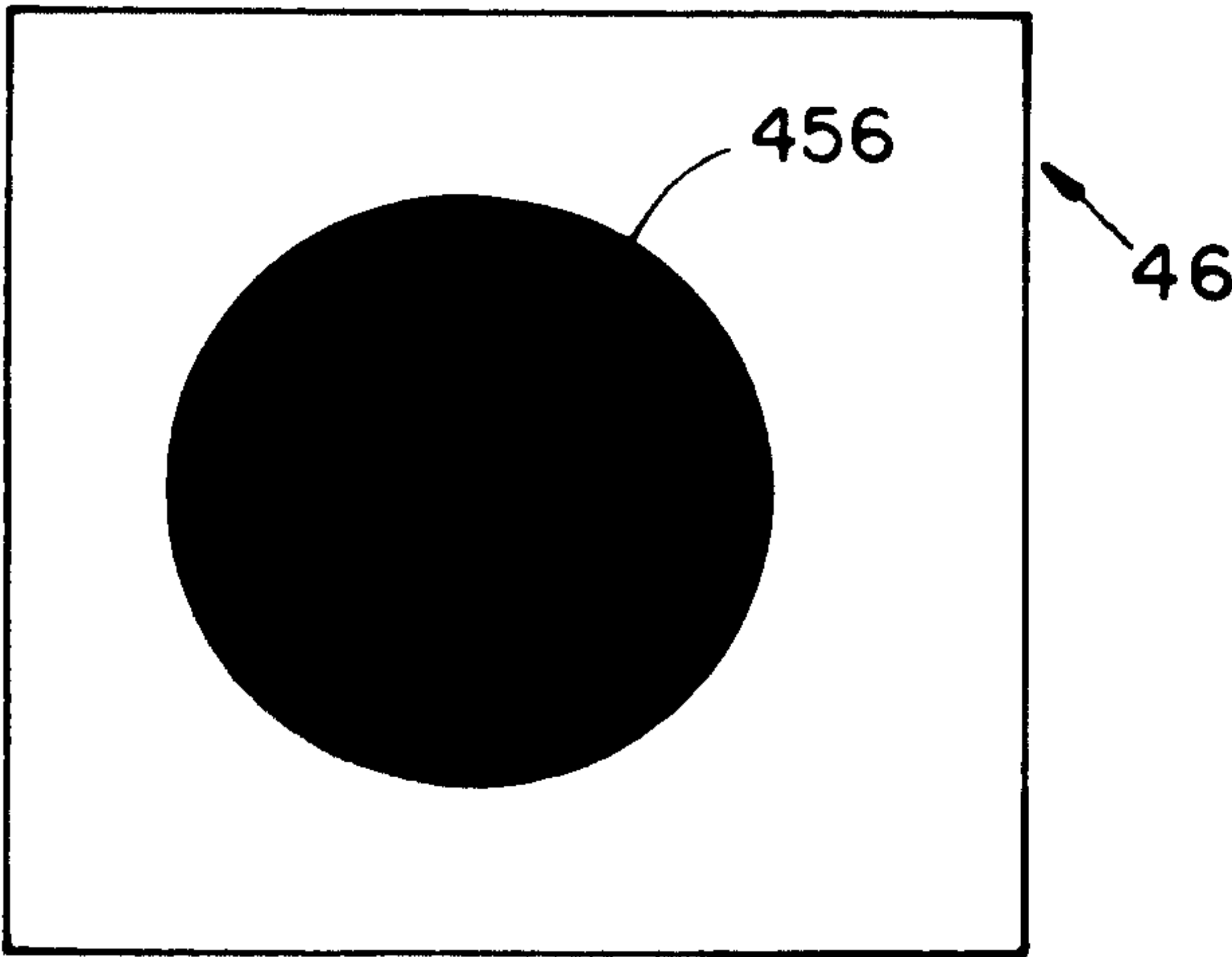
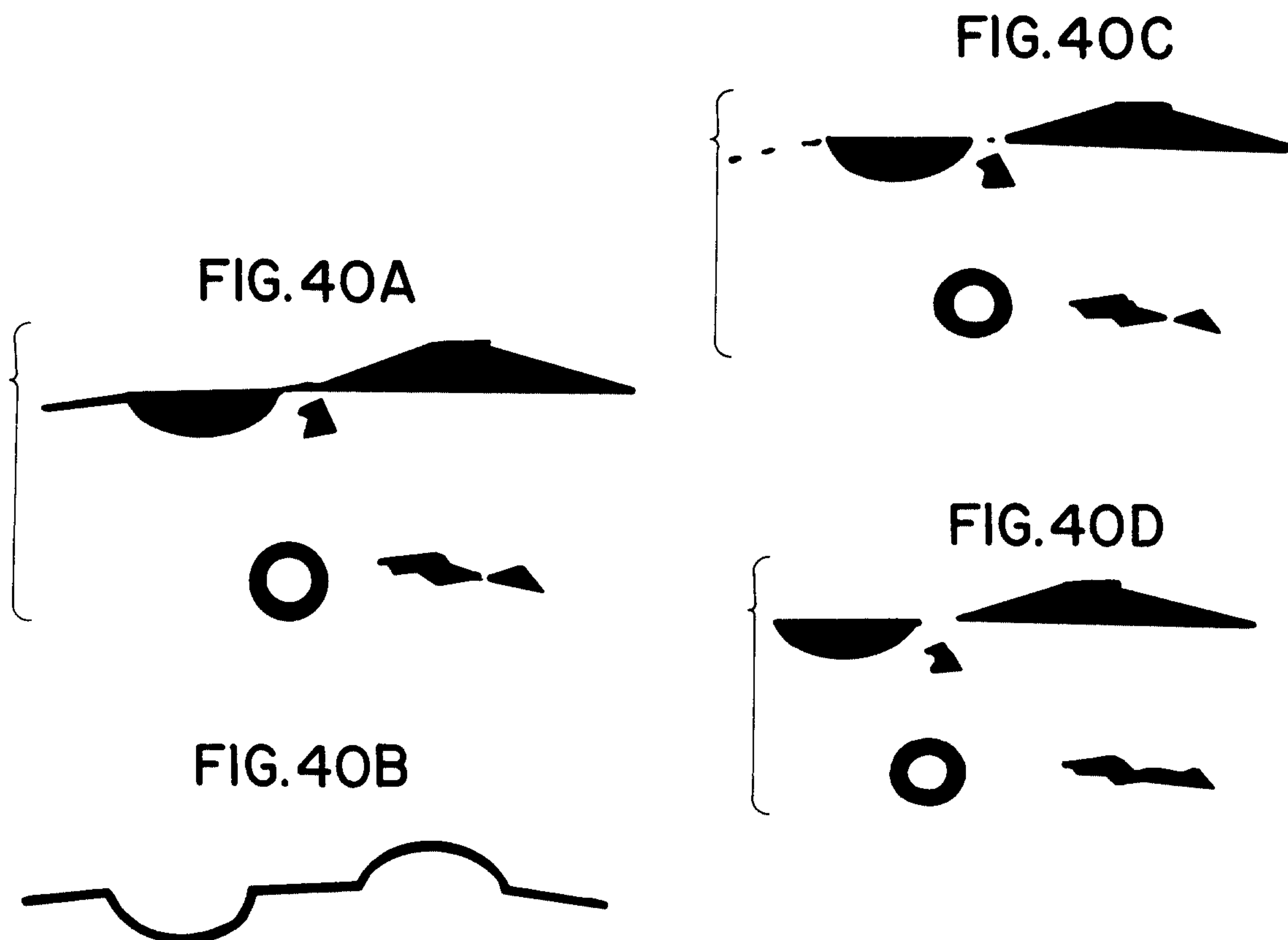
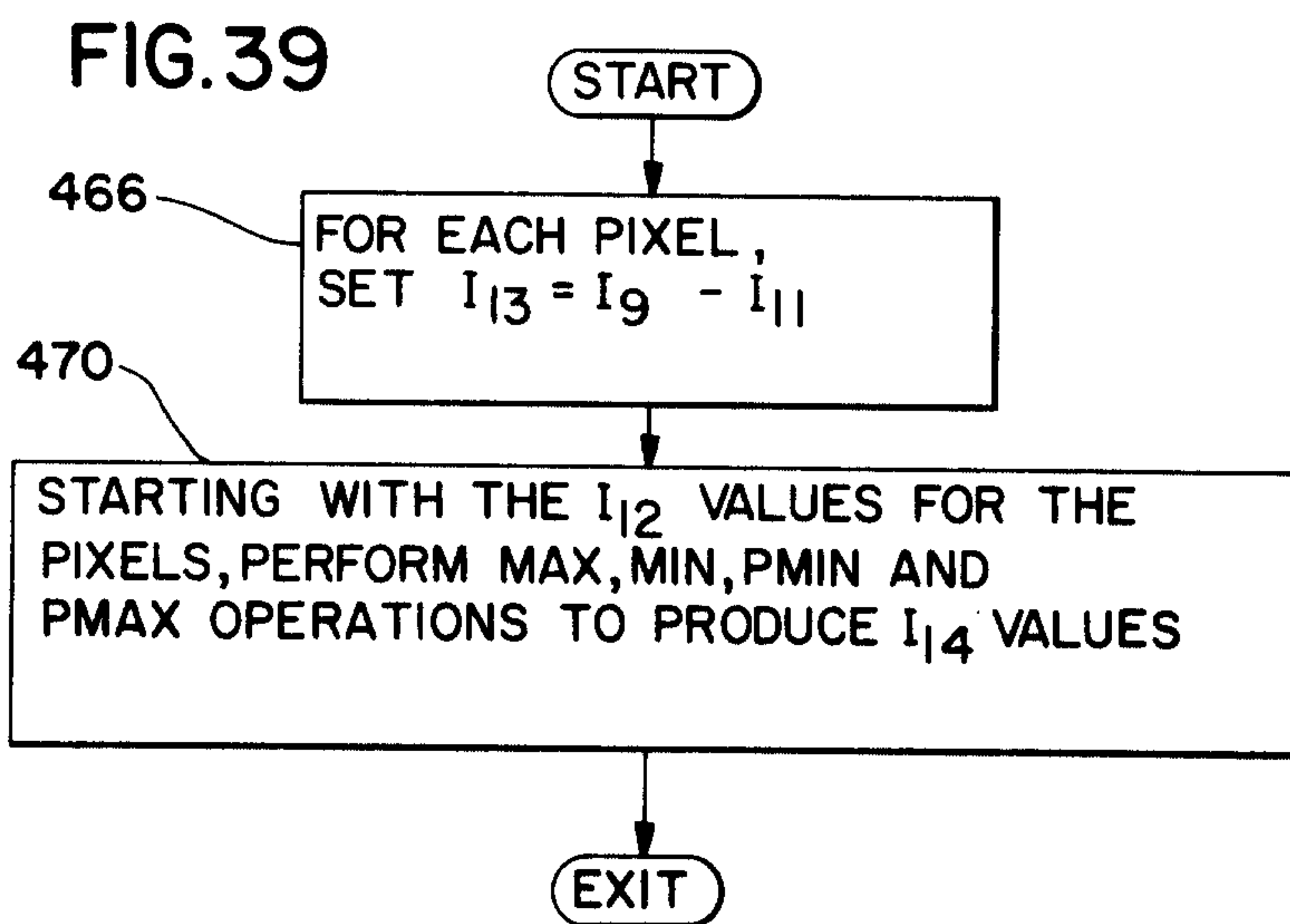


FIG. 38C



PATENT AGENTS

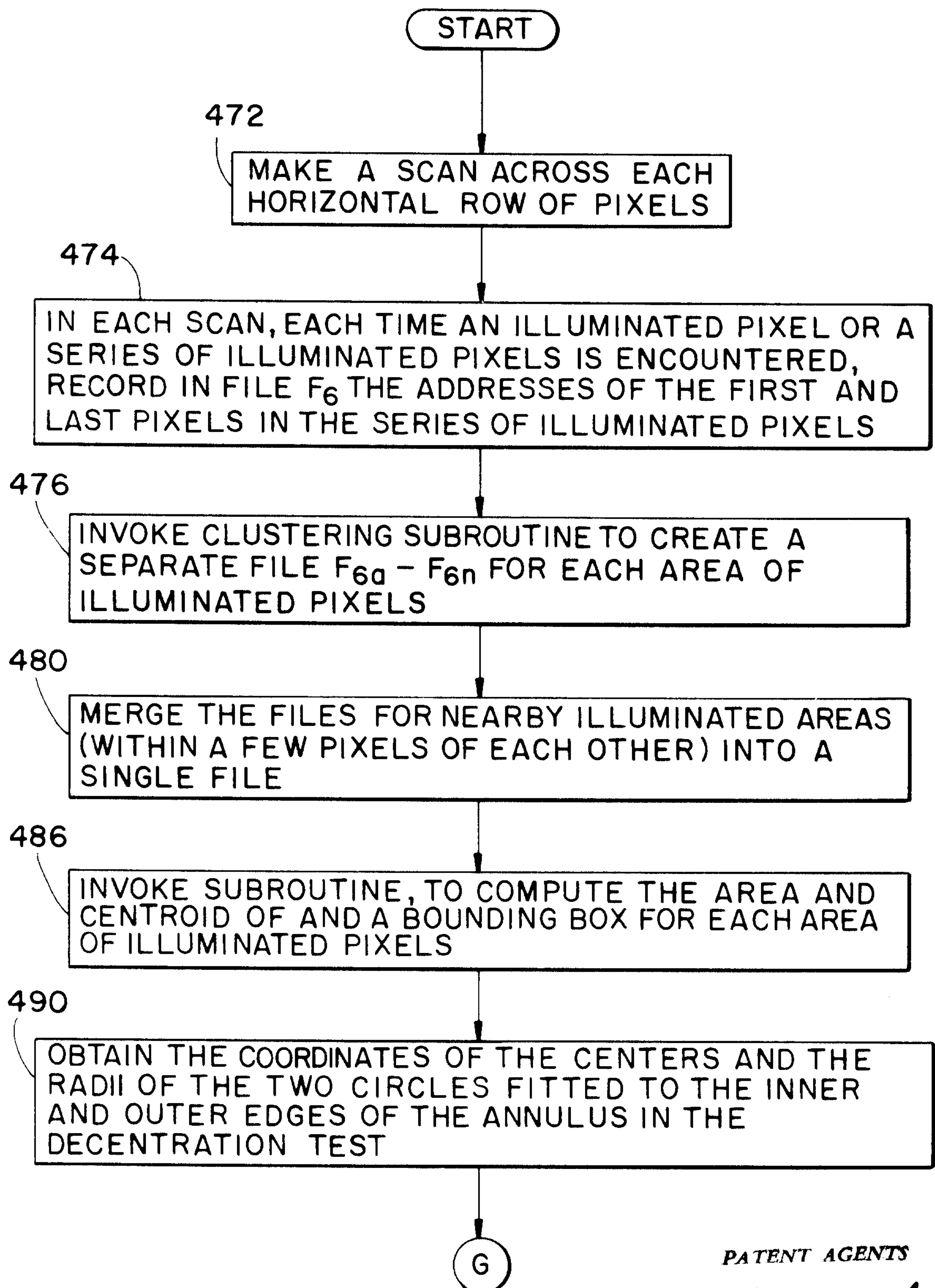
Dwight Ogilvy Renault



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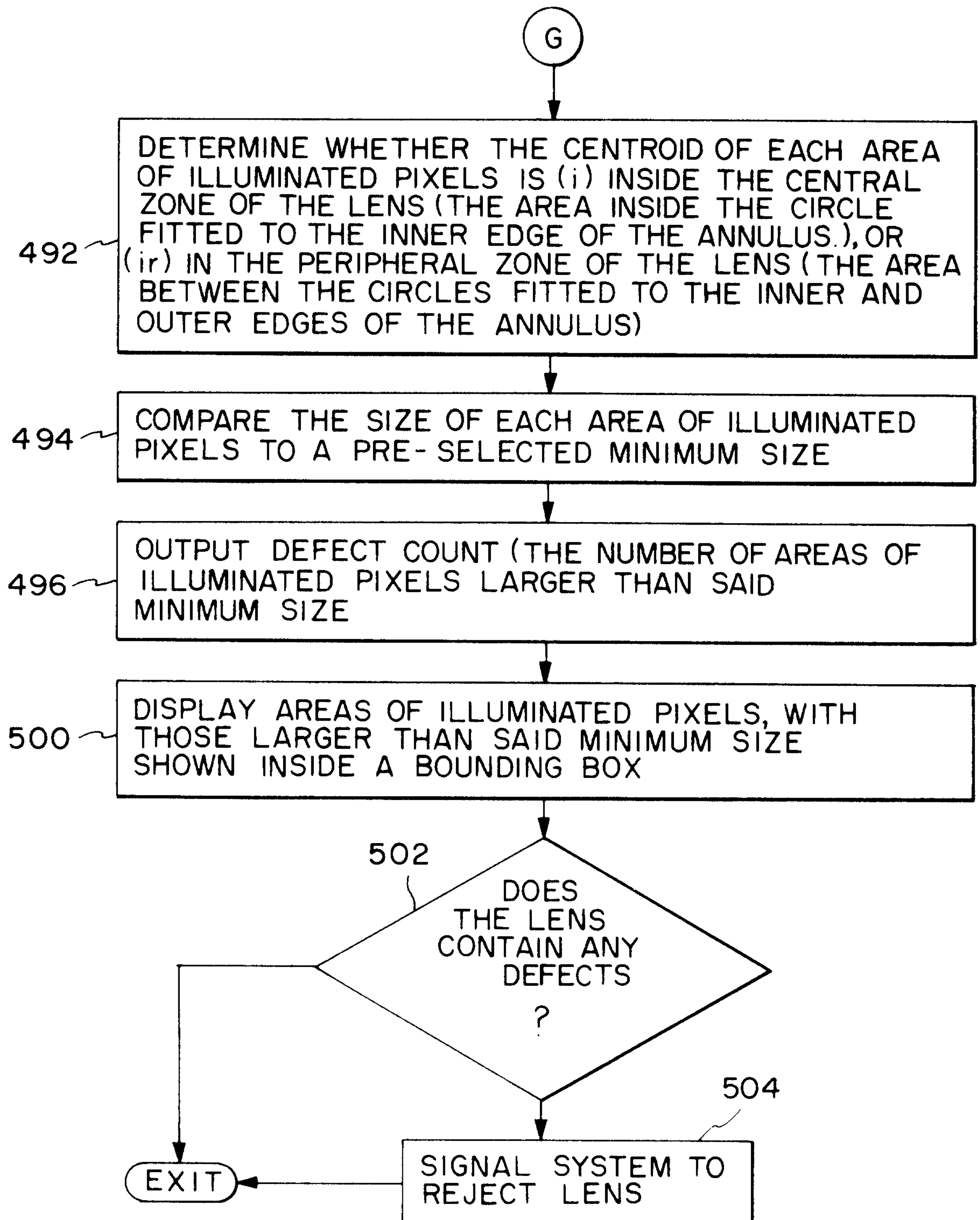
FIG. 41A



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FIG. 41B



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FIG. 42

