Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2367797 C 2009/10/06

(11)(21) **2 367 797**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

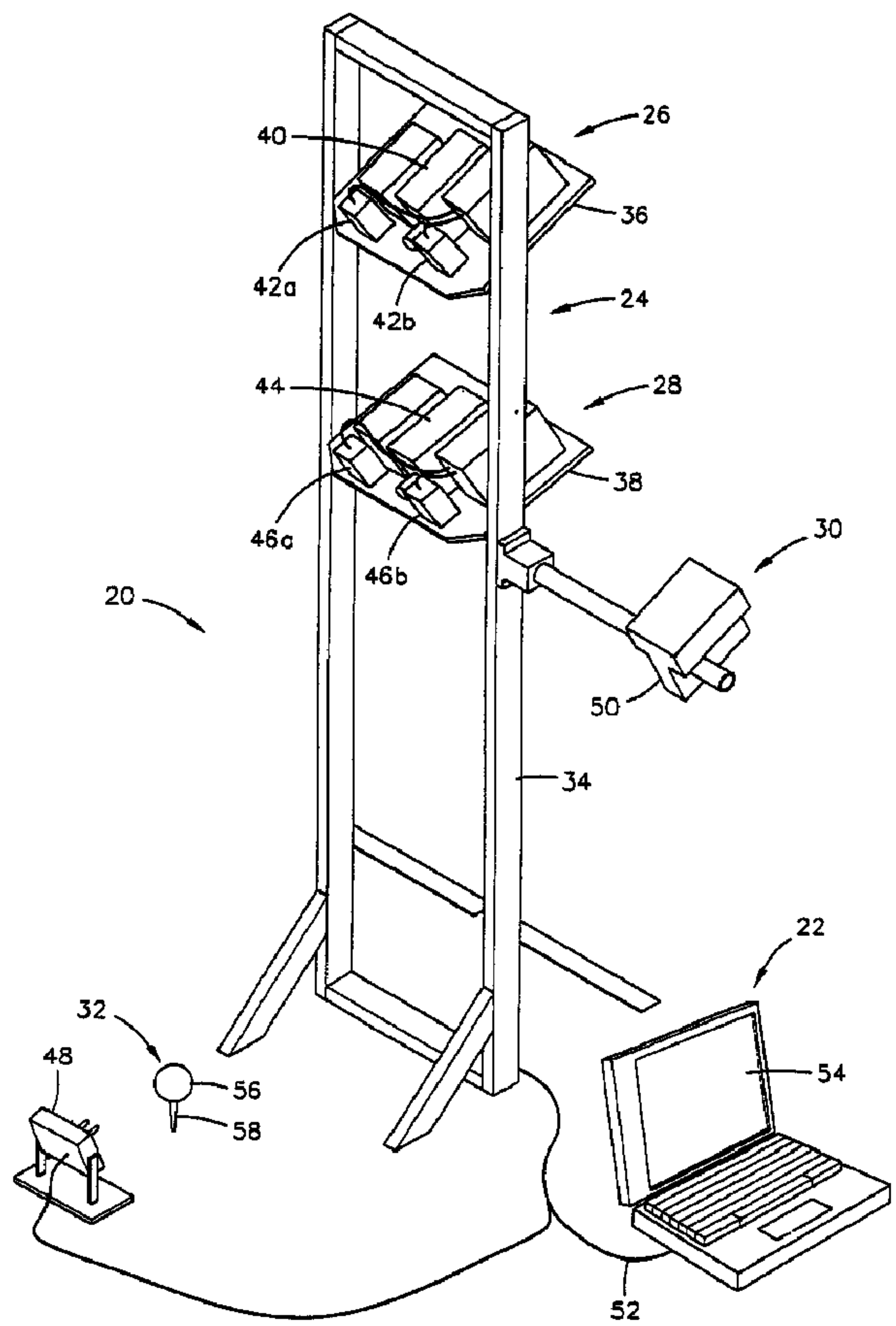
(22) **Date de dépôt/Filing Date:** 2002/01/15
(41) **Mise à la disp. pub./Open to Public Insp.:** 2002/07/19
(45) **Date de délivrance/Issue Date:** 2009/10/06
(30) **Priorité/Priority:** 2001/01/19 (US09/765,691)

(51) **Cl.Int./Int.Cl.** *A63B 71/02* (2006.01), *A63B 69/36* (2006.01), *A63B 69/00* (2006.01)
(72) **Inventeur/Inventor:**
MANWARING, SCOTT R., US

(73) **Propriétaire/Owner:**
CALLAWAY GOLF COMPANY, US

(74) **Agent:** GOWLING LAFLEUR HENDERSON LLP

(54) Titre : SYSTEME ET METHODE DE MESURE DES PARAMETRES DE FRAPPE D'UNE BALLE DE GOLFEUR
(54) Title: SYSTEM AND METHOD FOR MEASURING A GOLFER'S BALL STRIKING PARAMETERS



(57) Abrégé/Abstract:
A system (20) for capturing and analyzing golf club information and golf ball information during and after a golfer's swing is disclosed herein. The golf club information includes golf club head orientation, golf club head velocity, and golf club spin. The golf

(57) Abrégé(suite)/Abstract(continued):
club head orientation includes dynamic lie, loft and face angle of the golf club head. The golf club head velocity includes path of the golf club head, attack of the golf club head and downrange information. The golf ball information includes golf ball velocity, golf ball launch angle, golf ball side angle, golf ball speed manipulation and golf ball orientation. The golf ball orientation includes the true spin of the golf ball, and the tilt axis of the golf ball which entails the back spin and the side spin of the golf ball. The system includes camera units (26 and 28), a trigger device (30) and a computer (22).

Abstract of the Disclosure

A system (20) for capturing and analyzing golf club information and golf ball information during and after a golfer's swing is disclosed herein. The golf club information includes golf club head orientation, golf club head velocity, and golf club spin. The golf club head orientation includes dynamic lie, loft and face angle of the golf club head. The golf club head velocity includes path of the golf club head, attack of the golf club head and downrange information. The golf ball information includes golf ball velocity, golf ball launch angle, golf ball side angle, golf ball speed manipulation and golf ball orientation. The golf ball orientation includes the true spin of the golf ball, and the tilt axis of the golf ball which entails the back spin and the side spin of the golf ball. The system includes camera units (26 and 28), a trigger device (30) and a computer (22).

Title

SYSTEM AND METHOD FOR MEASURING A GOLFER'S BALL STRIKING PARAMETERS

Technical Field

The present invention relates to a system and method for measuring a golfer's launch parameters during a golf swing. More specifically, the present invention relates to a system and method for measuring club head information and golf ball information before and after impact of the golf club with the golf ball.

Description of the Related Art

For over twenty-five years, high-speed camera technology has been used for gathering information on a golfer's swing. The information has varied from simple club head speed to the spin of the golf ball after impact with a certain golf club. Over the years, this information has fostered numerous improvements in golf clubs and golf balls, and assisted golfers in choosing golf clubs and golf balls that improve their game. Additionally, systems incorporating such high-speed camera technology have been used in teaching golfers how to improve their swing when using a given golf club.

An example of such a system is U.S. Patent Number 4,063,259 to Lynch *et al.*, for a Method Of Matching Golfer With Golf Ball, Golf Club, Or Style Of Play, which was filed in 1975. Lynch discloses a system that provides golf ball launch measurements through use of a shuttered camera that is activated when a club head breaks a beam of light that activates the flashing of a light source to provide stop action of the club head and golf ball on a camera film. The golf ball launch measurements retrieved by the Lynch system include initial velocity, initial spin velocity and launch angle.

Another example is U.S. Patent Number 4,136,387 to Sullivan, et al., for a Golf Club Impact And Golf Ball Launching Monitoring System, which was filed in 1977. Sullivan discloses a system that not only provides golf ball launch measurements, it also provides measurements on the golf club.

Yet another example is a family of patent to Gobush *et al.*, U.S. Patent Numbers 5,471,383 filed on September 30, 1994; 5,501,463 filed on February 24, 1994; 5,575,719 filed on August 1, 1995; and 5,803,823 filed on November 18, 1996. This family of patents discloses a system that has two cameras angled toward each other, a golf ball with reflective markers, a golf club with reflective markers thereon and a computer. The system allows for measurement of the golf club or golf ball separately, based on the plotting of points.

Yet another example is U.S. Patent Number 6,042,483 for a Method Of Measuring Motion Of A Golf Ball. The patent discloses a system that uses three cameras, an optical sensor means, and strobes to obtain golf club and golf ball information.

Although the prior art has disclosed many useful systems, the prior art has failed to disclose a system that is capable of individualizing the calculations based on each individual golfer in order to provide information on the swing of the golfer and the launch of the golf ball subsequent to impact with the golf club. Further, the prior art has failed to disclose a system that allows for simultaneous imaging and analysis of the pre-impact golf club and post impact golf ball.

Disclosure of the Invention

The present invention provides a method and system for capturing and analyzing golf club information and golf ball information during and after a golfer's swing is disclosed herein. The golf club information includes golf club head orientation, golf club head velocity, and golf club spin. The golf club head orientation includes dynamic lie, loft and face angle of the golf club head. The golf club head velocity includes path of the golf club head and attack of the golf club head. The golf ball information includes golf ball velocity, golf ball launch angle, golf ball side angle, golf ball speed and golf ball orientation. The golf ball orientation includes the true spin of the golf ball, and the tilt axis of the golf ball which entails the back spin and the side spin of the golf ball.

One aspect of the present invention is a method for simultaneously measuring the golf club properties and the golf ball properties during a golfer's striking of a golf ball. The method begins with the swinging of a golf club toward a teed golf ball. Next, a detector is activated as the golf club is swung toward the teed golf ball. The detector transmits an estimated golf club head speed to an imaging system. The imaging system capable of compiling a plurality of exposures to generate a frame. Next, a first plurality of exposures of the golf club head are taken prior to the golf club head impacting the teed golf ball. The first plurality of exposures have a first time interval period between exposures. Next, the teed golf ball is struck with the golf club. Next, a second plurality of exposures of the golf ball are taken after the golf ball has been struck by the golf club head. The second plurality of exposures has a second time interval between exposures. The second time interval is different than the first time interval. A frame is generated that includes the first plurality of exposures of the golf club head prior to impact with the teed golf ball and the second plurality of exposures of the golf ball after impact with the golf club head. The method provides measurements of the golf club head and of the launched golf ball.

The first time interval for the first plurality of exposures may be less than second time interval for the second plurality of exposures. The first time interval for the first plurality of exposures may range from 750 milliseconds to 2000 milliseconds, and the second time interval for the second plurality of exposures may be greater than the first time interval. The imaging system of the method preferably includes a first camera and a second camera. Each frame preferably includes at least three exposures of the first plurality of exposures, and at least three exposures of the second plurality of exposures. The measurements of the golf club include golf club head orientation, golf club head spin and golf club head velocity, and the measurements of the golf ball include the golf ball velocity, the golf ball launch angle, the golf ball side angle, the golf ball orientation (spin) and the golf ball speed. The estimated golf club head speed is utilized to determine the first time interval of the first plurality of exposures and the second time interval of the second plurality of exposures. The method preferably uses a laser to activate the detector as the golf club is swung toward the teed golf ball.

Another aspect of the present invention is a system for simultaneously measuring the golf club properties and the golf ball properties during a golfer's striking of a golf ball. The system includes a pair of cameras, a golf club, a teed golf ball, a detector, a calculating means and an analysis means. The first and second cameras each have a lens focused toward a predetermined field of view. The golf club has at least one light contrasting area, and preferably three light contrasting areas. The teed golf ball is within the predetermined field of view. The detector is disposed prior to the teed golf ball along a path of a golf club swing, and it is capable of estimating the golf club speed. The calculating means calculates a first time interval between a first plurality of exposures of the golf club and a second time interval between a second plurality of exposures of the launched golf ball based on the estimated golf club speed. The analysis means determines the golf club swing properties and golf ball launch properties based on an image frame generated by the first and second cameras which includes the first plurality of exposures and the second plurality of exposures.

Another aspect of the present invention is another method for simultaneously measuring the golf club properties and the golf ball properties during a golfer's striking of a golf ball. The method begins with the swinging of a golf club toward a teed golf ball. Next, a detector is triggered as the golf club is swung toward the teed golf ball. The detector transmits an estimated golf club head speed to an imaging system. The imaging system capable of compiling a plurality of exposures to generate a frame. Next, a first plurality of exposures of the golf club head are taken prior to the golf club head impacting the teed golf ball. Each of the first plurality of exposures has a first exposure intensity. Next, the teed golf ball is struck with the golf club. Next, a second plurality of exposures of the golf ball are taken after the golf ball has been struck by the golf club head. Each of the second plurality of exposures has a second exposure intensity. The second exposure intensity is different than the first exposure intensity. A frame is generated that includes the first plurality of exposures of the golf club head prior to impact with the teed golf ball and the second plurality of exposures of the golf ball after impact with the golf club head. The method provides measurements of the golf club head and of the launched golf ball.

Brief Description of the Drawings

FIG. 1 is a perspective view of the monitoring system of the present invention.

FIG. 2 is a schematic isolated side view of the teed golf ball and the cameras of the system of the present invention.

FIG. 2A is a schematic isolated side view of the teed golf ball and the cameras of the system showing the field of view of the cameras.

FIG. 3 is a schematic isolated front view of the teed golf ball, trigger device and the cameras of the system of the present invention.

FIG. 4 is an image frame of a golfer's swing and subsequent launch of a golf ball composed of a multitude of exposures generated by the system of the present invention.

FIG. 5 is a partial image frame of a golfer's swing illustrating a first exposure of the highly reflective points on a golf club.

FIG. 5A is a graph of the time (x-axis) versus activation/deactivation for the exposure of FIG. 5.

FIG. 5B is a graph of time (x-axis) versus light intensity of the flash units to demonstrate the activation and deactivation points for the cameras.

FIG. 6 is a partial image frame of a golfer's swing illustrating first and second exposures of the highly reflective points on a golf club.

FIG. 6A is a graph of the time (x-axis) versus activation/deactivation for the exposures of FIG. 6.

FIG. 7 is a partial image frame of a golfer's swing illustrating first, second and third exposures of the highly reflective points on a golf club.

FIG. 7A is a graph of the time (x-axis) versus activation/deactivation for the exposures of FIG. 7.

FIG. 8 is a partial image frame of a golfer's swing illustrating first, second and third exposures of the highly reflective points on a golf club, and the initial impact golf ball exposure.

FIG. 8A is a graph of the time (x-axis) versus activation/deactivation for the exposures of FIG. 8.

FIG. 9 is a partial image frame of a golfer's swing illustrating first, second and third exposures of the highly reflective points on a golf club, the initial impact golf ball exposure, and a first exposure of a golf ball after impact with the golf club.

FIG. 9A is a graph of the time (x-axis) versus activation/deactivation for the exposures of FIG. 9.

FIG. 10 is a partial image frame of a golfer's swing illustrating first, second and third exposures of the highly reflective points on a golf club, the initial impact golf ball exposure, and first and second exposures of a golf ball after impact with the golf club.

FIG. 10A is a graph of the time (x-axis) versus activation/deactivation for the exposures of FIG. 10.

FIG. 11 is a partial image frame of a golfer's swing illustrating first, second and third exposures of the highly reflective points on a golf club, the initial impact golf ball exposure, and first, second and third exposures of a golf ball after impact with the golf club.

FIG. 11A is a graph of the time (x-axis) versus activation/deactivation for the exposures of FIG. 11.

FIG. 12 is an image frame of a low speed driver shot with a plurality of exposures of the golf club and the golf ball.

FIG. 13 is an image frame of a high speed driver shot with a plurality of exposures of the golf club and the golf ball.

FIG. 14 is a schematic representation of the highly reflective points of the golf club positioned in accordance with the first, second and third exposures of the golf club.

FIG. 15 is an isolated view of a golf ball striped for measurement using the present invention at a first exposure.

FIG. 15A is an isolated view of a golf ball striped for measurement using the present invention at a second exposure with a partial phantom of the first exposure with vector signs present to demonstrate calculation of angle Θ.

FIG. 16 is a partial image frame from only the first camera of a golfer's swing illustrating first, second and third exposures of the highly reflective points on a golf club, and the teed golf ball before determination of the threshold level on the grey scale.

FIG. 17 is a partial image frame from only the second camera of a golfer's swing illustrating first, second and third exposures of the highly reflective points on a golf club, and the teed golf ball before determination of the threshold level on the grey scale.

FIG. 18 is a partial image frame from only the first camera of a golfer's swing illustrating first, second and third exposures of the highly reflective points on a golf club, and the teed golf ball after determination of the threshold level on the grey scale.

FIG. 19 is a partial image frame from only the second camera of a golfer's swing illustrating first, second and third exposures of the highly reflective points on a golf club, and the teed golf ball after determination of the threshold level on the grey scale.

FIG. 20 is a partial image frame from only the first camera of a golfer's swing illustrating first, second and third exposures of the connected highly reflective points on a golf club, and the teed golf ball for the first find grouping of the highly reflective points.

FIG. 21 is a partial image frame from only the second camera of a golfer's swing illustrating first, second and third exposures of the connected highly reflective points on a golf club, and the teed golf ball for the first find grouping of the highly reflective points.

FIG. 22 is a partial image frame from only the first camera of a golfer's swing illustrating first, second and third exposures of the connected highly reflective points on a golf club, and the teed golf ball for the second find grouping of the highly reflective points.

FIG. 23 is a partial image frame from only the second camera of a golfer's swing illustrating first, second and third exposures of the connected highly reflective points on a golf club, and the teed golf ball for the second find grouping of the highly reflective points.

FIG. 24 is a partial image frame from only the first camera of a golfer's swing illustrating first, second and third exposures of the connected highly reflective points on a golf club, and the teed golf ball with repeated points eliminated and results of the find displayed.

FIG. 25 is a partial image frame from only the second camera of a golfer's swing illustrating first, second and third exposures of the connected highly reflective points on a golf club, and the teed golf ball with repeated points eliminated and results of the find displayed.

FIG. 26 is a chart of the processed final pairs giving the x, y and z coordinates.

FIG. 27 is an illustration of the thresholding of the exposures for the golf ball in flight.

FIG. 28 is an isolated view of the golf ball to illustrate determining the best ball center and radius.

FIG. 29 is a partial flow chart with images of golf balls for stereo correlating two dimensional points.

FIG. 30 is a partial image frame of the teed golf ball exposure and the first, second third and fourth exposures of the golf ball after impact, along with positioning information.

Detailed Description of the Invention

As shown in FIGS. 1-3, the system of the present invention is generally designated 20. The system 20 captures and analyzes golf club information and golf ball information during and after a golfer's swing. The golf club information includes golf club head orientation, golf club head velocity, and golf club spin. The golf club head orientation includes dynamic lie, loft and face angle of the golf club head. The golf club head velocity includes path of the golf club head and attack of the golf club head. The golf ball information includes golf ball velocity, golf ball launch angle, golf ball side angle, golf ball speed and golf ball orientation. The golf ball orientation includes the true spin of the golf ball, and the tilt axis of the golf ball which entails the back spin and the side spin of the golf ball. The various measurements will be described in greater detail below.

The system 20 generally includes a computer 22, a camera structure 24 with a first camera unit 26, a second camera unit 28 and a trigger device 30, a teed golf ball 32 and a golf club 33. The system 20 is designed to operate on-course, at a driving range, inside a retail store/showroom, or at similar facilities.

In a preferred embodiment, the camera structure 24 is connected to a frame 34 that has a first platform 36 approximately 46.5 inches from the ground, and a second platform 38 approximately 28.5 inches from the ground. The first camera unit 26 is disposed on the first platform 36 and the second camera unit 28 is disposed on the second platform 38. As shown in FIG 2, the first platform 36 is at an angle α_1 which is approximately 41.3 degrees relative to a line perpendicular to the straight frame vertical bar of the frame 34, and the second platform 38 is at an angle α_2 which is approximately 25.3 degrees relative to a line perpendicular to the straight frame vertical bar of the frame 34. However, those skilled in the relevant art will recognize that other angles may be utilized for the positioning of the cameras without departing from the scope and spirit of the present invention.

As shown in FIG. 2A, the platforms 36 and 38 are positioned such that the optical axis 66 of the first camera unit 26 does not overlap/intersect the optical axis 68 of the second camera unit 28. The optical view of the first camera unit 26 is bound by lines 62a and 62b, while the optical view of the second camera unit 28 is bound by lines 64a and 64b. The overlap area defined by curves 70 is the field of view of the system 20.

The first camera unit 26 includes a first camera 40 and flash units 42a and 42b. The second camera unit 28 includes a second camera 44 and flash units 46a and 46b. A preferred camera is a charged coupled device ("CCD") camera available from Wintriss Engineering of California under the product name OPSIS1300* camera.

The trigger device 30 includes a receiver 48 and a transmitter 50. The transmitter 50 is preferably mounted on the frame 34 a predetermined distance from the camera units 26 and 28. A preferred trigger device is a laser device that transmits a laser beam from the transmitter 50 to the receiver 48 and is triggered when broken by a club swung toward the teed golf ball 32. The teed golf ball 32 includes a golf ball 56 and a tee 58. Other trigger devices such as optical detectors and audible detectors may be used with the present invention. The teed golf ball 32 is a predetermined length from the frame 34, L_1, and this length is preferably 38.5 inches. However, those skilled in the pertinent art will recognize that the length may vary depending on the location and the placement of the first and second camera units 26 and 28. The transmitter 50 is preferably disposed from 10 inches to 14 inches from the cameras 40 and 44. The receiver 48 and transmitter 50, and hence the laser beam, are positioned in front of the teed ball 32 such that a club swing will break the beam, and hence trigger the trigger device 30 prior to impact with the teed ball 32. As explained in

* trade-mark

greater detail below, the triggering of the trigger device 30 will generate a command to the first and second camera units 26 and 28 to begin taking exposures of the golf club 33 prior to impact with the teed golf ball 32. The data collected is sent to the computer 22 via a cable 52 which is connected to the receiver 48 and the first and second camera units 26 and 28. The computer 22 has a monitor 54 for displaying an image frame generated by the exposures taken by the first and second camera units 26 and 28. The image frame 100 is the field of view of the cameras 40 and 44.

FIG. 4 is an image frame 100 of a driver shot of a golf ball. The image frame 100 includes a first plurality of exposures 102, an initial impact golf ball exposure 103 and a second plurality of exposures 104. The first plurality of exposures includes images of the golf club 33 prior to striking the teed golf ball 32. The second plurality of exposures 104 includes images of the golf ball 56 subsequent to being struck by the golf club 33. The first plurality of exposures 102 may be distinguished from the second plurality of exposures 104 by three different factors. First, the time interval between each of the first plurality of exposures 102 is shorter than the time interval between each of the second plurality of exposures 104. Second, the length of time of each exposure, or more precisely the time that the shutter of the camera is open, is shorter for each of the first plurality of exposures 102 than the time of exposure for each of the second plurality of exposures 104. Third, the intensity of each of the first plurality of exposures 102 is less than the intensity of each of the second plurality of exposures 104.

FIG. 5 is a first exposure 102a only illustrating the three reflective points on the golf club 33. The points 106a-c are positioned, respectively, on the shaft on the heel and on the toe of the golf club 33. As shown in FIG. 5A, the exposure 102a is taken at time 100 milliseconds from the triggering of the trigger device 30, and the exposure time is 1 millisecond. The exposure time need only be 1 millisecond since the reflective points 106a-c provide such an intense illumination. The Y axis in FIG. 5A, and similar figures, represents the activation and deactivation of the cameras 40 and 44. FIG. 5B illustrates the activation and deactivation of the cameras 40 and 44 on a graph of the intensity of the flash units 42 and 46 which are charged and increase in intensity where at point A the cameras 40 and 44 activated and then deactivated at point D while the intensity of the flash units 42 and 46 is beginning to fall.

As shown in FIG. 6, a second exposure 102b of the first plurality of exposures 102 is added to the first exposure 102a of the first plurality of exposures 102. The second exposure 102b also only illustrates the three reflective points 106a-c of the golf club 33. As shown in FIG. 6A, the exposure 102b is taken at time 895.9 milliseconds from the triggering of the trigger device 30, and the exposure time is 1 millisecond. The time interval between the first plurality of exposures 102a and 102b is 795.9 milliseconds.

As shown in FIG. 7, a third exposure 102c of the first plurality of exposures 102 is added to the first exposure 102a and second exposure 102b of the first plurality of exposures 102. The third exposure 102c also only illustrates the three reflective points 106a-c of the golf club 33. As shown in FIG. 7A, the exposure 102c is taken at time 1691.8 milliseconds from the triggering of the trigger device 30, and the exposure time is 1 millisecond. The time interval between the first plurality of exposures 102b and 102c is 795.9 milliseconds. Thus, the time interval between the first plurality of exposures 102 is equal, and approximately 795.9 milliseconds.

FIG. 8 includes the previous exposures and an initial impact exposure 103 which is an exposure of the golf club and the golf ball 32 immediately after impact. As shown in FIG. 8A, the initial impact exposure 103 is taken at 3681.5 milliseconds from the triggering of the trigger device 30, and the exposure time is 15 milliseconds. The time interval between the initial impact exposure 103 and the first of the second plurality of exposures 104 allows for any image noise of the golf club 33 to be captured so not to "contaminate" the second plurality of exposures 104.

FIG. 9 is the first exposure 104a of the second plurality of exposures 104 of the golf ball 56 in flight added to the other exposures. The first exposure 104a only illustrates the golf ball 56. As shown in FIG. 9A, the exposure 104a is taken at time 6813.5 milliseconds from the triggering of the trigger device 30, and the exposure time is 15 milliseconds. The exposure time needs to be 15 milliseconds since the golf ball 56 is not as illuminating as the reflective points 106a-c.

FIG. 10 is the second exposure 104b of the second plurality of exposures 104 of the golf ball 56 in flight, added to the other exposures. The second exposure 104b only illustrates the golf ball 56. As shown in FIG. 10A, the exposure 104b is taken at time 7792.2 milliseconds from the triggering of the trigger device 30, and the exposure time is 15 milliseconds. The time interval between the second plurality of exposures 104a and 104b is 978.7 milliseconds.

FIG. 11 is the third exposure 104c of the second plurality of exposures 104 of the golf ball 56 in flight, added to the other exposures. The third exposure 104c only illustrates the golf ball 56. As shown in FIG. 11A, the exposure 104c is taken at time 8770.9 milliseconds from the triggering of the trigger device 30, and the exposure time is 15 milliseconds. The time interval between the second plurality of exposures 104b and 104c is 978.7 milliseconds.

Thus, the time interval between the second plurality of exposures 104 is equal, and approximately 978.7 milliseconds, which is a greater time interval than the time interval between the first plurality of exposures.

FIGS. 12 and 13 compare a low speed driver swing to a high speed driver swing. The triggering of the trigger device 30 by the golf club 33 is used to determine the speed of golf club swing. As the golf club 33 breaks the beam, the triggering device 30 sends a signal with an estimate of the golf club swing speed to the first and second camera units 26 and 28. The signal tells the first and second camera units 26 and 28 to take the first plurality of exposures 102 at certain times and predetermined intervals, to take the initial impact exposure 103 at a certain time, and to take the second plurality of exposures 104 of the golf ball 56 in flight at certain times and predetermined intervals. Thus, the system 20 will have individual exposure times for each individual golfer's swing thereby creating a more accurate system 20 to determine the swing properties of a particular golfer.

For example, the low swing speed image frame 100 of FIG. 12 has the first plurality of exposures 102a-c taken at 100 milliseconds from the triggering for exposure 102a, 1429.72 milliseconds from the triggering for exposure 102b, and 2759.44 milliseconds from the triggering for exposure 102c. The initial impact exposure 103 is taken at 5443.88 milliseconds from the triggering. The second plurality of exposures 104a-d are taken at 9793.93 milliseconds from the triggering for exposure 104a, 10775.15 milliseconds from the triggering for exposure 104b, 11756.37 milliseconds from the triggering for exposure 104c, and 12737.59 milliseconds from the triggering for exposure 104d.

For comparison, the high swing speed image frame 100 of FIG. 13 has the first plurality of exposures 102a-c taken at 100 milliseconds from the triggering for exposure 102a, 956.38 milliseconds from the triggering for exposure 102b, and 1091.62 milliseconds from the triggering for exposure 102c. The initial impact exposure 103 is taken at 2083.24 milliseconds from the triggering. The second plurality of exposures 104a-d are taken at 4091.48 milliseconds from the triggering for exposure 104a, 7335.83 milliseconds from the triggering for exposure 104b, 8799.44 milliseconds from the triggering for exposure 104c, and 9531.25 milliseconds from the triggering for exposure 104d.

The golf club speed of the low speed swing is 84.5 miles per hour ("MPH") compared to 114.5 MPH for the high swing speed. The golf ball speed of the low speed swing is 119.5 MPH compared to 168.0 MPH for the high speed swing. The back spin of the golf club is 1466 rotations per minute ("RPM") for the low speed swing compared to 1945 RPM for the high speed swing. The launch angle of the golf ball for the low speed swing is 17.7 degrees compared to 15.4 degrees for the high speed swing.

The system 20 may be calibrated using many techniques known to those skilled in the pertinent art. One such technique is disclosed in U.S. Patent Number 5,803,823. The system 20 is calibrated when first activated, and then may operate to analyze golf swings for golfers until deactivated.

As mentioned above, the system 20 captures and analyzes golf club information and golf ball information during and after a golfer's swing. The system 20 uses the image frame 100 and other information to generate the information on the golfer's swing. The golf club 33 has at least two, but preferably three highly reflective points 106a-c preferably positioned on the shaft, heel and toe of the golf club 33. The highly reflective points 106a-c may be inherent with the golf club design, or each may be composed of a highly reflective material that is adhesively attached to the desired positions of the golf club 33. The points 106a-c need to be highly reflective since the cameras 40 and 44 are programmed to search for two or three points that have a certain brightness such as 200 out of a grey scale of 0-255. The cameras 40 and 44 search for point pairs that have approximately one inch separation, and in this manner, the image of the golf club 33 is acquired by the cameras for data acquisition.

As shown in FIG. 14, which is similar to FIG. 7, the first row of acquired highly reflective points 106a (on the shaft) is designated series one, the second row of acquired highly reflective points 106b (on the heel) is designated series two, and the third row of acquired highly reflective points 106c (on the toe) is designated series three. The first row is the acquired highly reflective points 106a from the shaft, the second row is the acquired highly reflective points 106a from the heel, and the third row is the acquired highly reflective points 106a from the toe. The following equation is used to acquire the positioning information:

$$d = [(Ptx - Pnx)^2 + (Pty - Ptny)^2 \ldots]^{1/2}$$

where d is the distance, Ptx is the position in the x direction and Pty is the position in the y direction.

The system 20 may use a three point mode or a two point mode to generate further information. The two point mode uses V_{toe}, V_{heel} and $V_{clubtop}$ to calculate the head speed.

$$V_{toe} = [(Ptx_3 - Ptx_1)^2 + (Pty_3 - Pty_1)^2 + (Ptz_3 - Ptz_1)^2]^{1/2} [1/\Delta T]$$

$$V_{heel} = [(Ptx_3 - Ptx_1)^2 + (Pty_3 - Pty_1)^2 + (Ptz_3 - Ptz_1)^2]^{1/2} [1/\Delta T]$$

$$V_{clubtop} = [V_{toe} + V_{heel}][1/2]$$

$$Vy = [(y_{3heel} - y_{1heel})^2 + (y_{3toe} - y_{1toe})^2]^{1/2}[1/(2 * \Delta T)]$$

$$Vz = [(z_{3heel} - z_{1heel})^2 + (z_{3toe} - z_{1toe})^2]^{1/2}[1/(2 * \Delta T)]$$

This information is then used to acquire the path angle and attack angle of the golf club 33. The Path angle = $\sin^{-1}(Vy/[V])$ where [V] is the magnitude of V.

The attack angle = $\sin^{-1}(Vz/[V])$, and the dynamic loft and dynamic lie are obtained by using Series one and Series two to project the loft and lie onto the vertical and horizontal planes.

The two point mode uses the shaft highly reflective point 106a or the toe highly reflective point 106c along with the heel highly reflective point 106b to calculate the head speed of the golf club, the path angle and the attack angle. Using the shaft highly reflective point 106a, the equations are:

$$V_{heel} = [(Ptx_3-Ptx_1)^2 + (Pty_3-Pty_1)^2 + (Ptz_3-Ptz_1)^2]^{1/2}\ [1/\Delta T]$$

$$V_{shaft} = [(Ptx_3-Ptx_1)^2 + (Pty_3-Pty_1)^2 + (Ptz_3-Ptz_1)^2]^{1/2}\ [1/\Delta T]$$

$$V_{center} = 1.02 * (V_{shaft} + V_{heel})$$

$$Vy = [(y_{3heel}-y_{1heel})^2+(y_{3shaft}-y_{1shaft})^2]^{1/2}[1/(2*\Delta T)]$$

$$Vz = [(z_{3heel}-z_{1heel})^2+(z_{3shaft}-z_{1shaft})^2]^{1/2}[1/(2*\Delta T)]$$

The Path angle = $\sin^{-1}(Vy/[V])$ where [V] is the magnitude of V.

The attack angle = $\sin^{-1}(Vz/[V])$.

Using the toe highly reflective point 106c, the equations are:

$$V_{toe} = [(x_3-x_1)^2 + (y_3-y_1)^2 + (z_3-z_1)^2]^{1/2}\ [1/\Delta T]$$

$$V_{heel} = [(x_2-x_1)^2 + (y_2-y_1)^2 + (z_2-z_1)^2]^{1/2}\ [1/\Delta T]$$

$$V_{clubtop} = [V_{toe} + V_{heel}][1/2]$$

The path angle = $\sin^{-1}(Vy_{clubtop}/[\ V_{clubtop}]\ )$ where [$V_{clubtop}$] is the magnitude of $V_{clubtop}$.

The attack angle = $\sin^{-1}(Vz_{clubtop}/[\ V_{clubtop}]\ )$ where [$V_{clubtop}$] is the magnitude of $V_{clubtop}$.

The golf ball 56 information is mostly obtained from the second plurality of exposures

104. First, the best radius and position of the two dimensional areas of interest are determined from the exposures 104. Next, all of the combinations of the golf ball 56 centers in the exposures 104 are matched and passed through a calibration model to obtain the X, Y, and Z coordinates of the golf ball 56. The system 20 removes the pairs with an error value greater then 5 millimeters to get acceptable X, Y, Z coordinates. Next, the strobe times from the flash units 42a-b and 46a-b are matched to the position of the golf ball 56 based on the estimated distance traveled from the exposures 104. Next, the velocity of the golf ball 56 is obtained from Vx, Vy and Vz using a linear approximation. Next the golf ball speed is obtained by calculating the magnitude of Vx, Vy and Vz.

The launch angle = $\sin^{-1}$ (Vz/golf ball speed),

and the spin angle = $\sin^{-1}$ (Vy/golf ball speed).

Next, the system 20 looks for the stripes 108a-b, as shown in FIGS. 15 and 15A, on the golf ball 56 by using a random transformation searching for the spot of greatest contrast. X, Y and Z coordinates are used with the arc of stripe 108a and the arc of stripe 108b to orient the arc on the golf ball. Then, the system 20 determines which arc is most normal using $(x^2 + y^2)^{1/2}$.

Next, the Θ angle of the golf ball 56 is measured by taking the first vector and the second vector and using the equation :

$\Theta = \cos^{-1}$ [(vector A1)(vector A2)] /($[V_1][V_2]$) where $[V_1]$ is the magnitude of V_1 and $[V_2]$ is the magnitude of V_2.

As the golf ball 56 rotates from the position shown in FIG. 15 to the position shown in FIG. 15A, the angle Θ is determined from the position of vector A at both rotation positions. This allows for the spin to be determined. The back spin is calculated and applied to the first set of axis with a tilt axis of zero. The resultant vectors are compared to those of the next image and a theta is calculated for each of the vectors. This is done for each tilt axis until the Theta between the rotated first set of axis and the second set of axis is minimized.

The following is an example of how the system captures and analyzes golf club information and golf ball information during and after a golfer's swing. The golf club information includes golf club head orientation, golf club head velocity, and golf club spin. The golf club head orientation includes dynamic lie, loft and face angle of the golf club head. The golf club head velocity includes path of the golf club head, attack of the golf club head and downrange information. The golf ball information includes golf ball velocity, golf ball launch angle, golf ball side angle, golf ball speed manipulation and golf ball orientation. The golf ball orientation includes the true spin of the golf ball, and the tilt axis of the golf ball which entails the back spin and the side spin of the golf ball.

First the golf club 33 information is obtained by the system 20 with the assistance of an operator in inputting some preliminary data. The size of the highly reflective points 106, separation of the highly reflective points 106, and threshold setting are inputted into the computer 22 by the operator. Next, as shown in FIGS. 16 and 17, a bounding area 120 is set about the teed golf ball 32 before the determining the threshold level on a grey scale of 0 to 255 which is a measurement of the light intensity. An appropriate setting of the threshold is 200 for the first plurality of exposures 102. The operator inputs a mark, which designates the location of the teed ball 32. The bounding area 120 is determined to be the area to the left of this mark in order to analyze the first plurality of exposures 102. The system 20 then sets a threshold level to the left of the teed golf ball 32 looking for areas, which are brighter then the threshold value. The system 20 then extracts the points from those greater than the threshold value. The threshold level of the bounding area 120 is set, as shown in FIGS. 18 and 19, which shows an absence of the golf ball 56 within the bounding area 120 since its brightness does not meet the threshold value.

Next, the system 20 pairs the points 106a-c, verifying size, separation, orientation and attack angle. Then, the system 20 captures a set of six points (three pairs) from a first find as shown in FIGS. 20 and 21. Then, the system 20 searches above and below the three pairs for a second find, as shown in FIG. 22 and 23. The repeated points 106 are eliminated and the results are displayed from the find, as shown in FIGS. 24 and 25. The points of the final pairs are processed by the computer 22 and displayed as shown in FIG. 26.

Next the speed of the head of the golf club 33 is determined by the system 20 using the equations discussed above.

Next the path angle and the attack angle of the golf club 33 is determined by the system 20. Using the methods previously described, the attack angle is determined from the following equation:

$$\text{Attack angle} = -\text{atan}(\Delta z/\Delta x)$$

Where Δz is the z value of the midpoint between $106a_1$ and $106b_1$ minus the z value of the midpoint between $106a_3$ and $106b_3$. Where Δx is the x value of the midpoint between $106a_1$ and $106b_1$ minus the x value of the midpoint between $106a_3$ and $106b_3$.

The path angle is determined from the following equation:

$$\text{path angle} = -\text{atan}(\Delta y/\Delta x)$$

Where Δy is the y value of the midpoint between $106a_1$ and $106b_1$ minus the y value of the midpoint between $106a_3$ and $106b_3$. Where Δx is the x value of the midpoint between $106a_1$ and $106b_1$ minus the x value of the midpoint between $106a_3$ and $106b_3$.

Next, the golf ball 56 data is determined b the system 20. First, the thresholding of the image is established as shown in FIG. 27, at a lower grey scale value, approximately 100 to 120, to detect the golf ball 56. Next, well-known edge detection methods are used to obtain the best golf ball 56 center and radius, as shown in FIG. 28. Next, the stereo correlation of two dimensional points on the golf ball 56 is performed by the system 20 as in FIG. 29, which illustrates the images of the first camera 40 and the second camera 44.

Next, based on the partial image frame 100 shown in FIG. 30, with the positioning information provided therein, the speed of the golf ball 56, the launch angle of the golf ball 56, and the side angle of the golf ball 56 is determined by the system 20. The speed of the golf ball is determined by the following equation:

Golf ball speed = $[\Delta X^2 + \Delta Y^2 + \Delta Z^2]^{1/2} / \Delta T$. For the information provided in FIG. 30, the speed of the golf ball =

$[(-161.68 + (-605.26))^2 + (-43.41 + (-38.46))^2 + (-282.74 + (-193.85))^2]^{1/2} / (13127-5115)$,

which is equal to 126 MPH once converted from millimeters over microseconds.

The launch angle of the golf ball 56 is determined by the following equation:

Launch angle = $\sin^{-1}$(Vz/ golf ball speed) where $Vz = \Delta Z/\Delta T$.

For the information provided in FIG. 30, $Vz = [(-282.74 + (-193.85)]/(13127-5115) = 11.3$ MPH.

Then, the launch angle = $\sin^{-1}(11.3/126.3) = 11.3$ degrees.

The side angle of the golf ball 56 is determined by the following equation:

Side angle = $\sin^{-1}$(Vy/ golf ball speed) where $Vy = \Delta Y/\Delta T$. For the information provided in FIG. 30, $Vy = [(-43.41 + (-38.46)]/(13127-5115) = 1.4$ MPH.

Then, the side angle = $\sin^{-1}(1.4/126.3) = 0.6$ degrees.

The ball spin is calculated by determining the location of the three striped on each of the acquired golf balls. Matching each axis in the field of view and determine which of the axis is orthogonal to the vertical plane. The spin is then calculated by:

Θ= acos((vectorA1 dot vector A2)/mag(v1)*mag(v2)) as discussed above.

What is claimed is:

1. A method for simultaneously measuring golf club properties and golf ball properties during a golfer's striking of a golf ball, the method comprising:

swinging a golf club toward a teed golf ball;

activating a trigger device as the golf club is swung toward the teed golf ball, the trigger device being capable of transmitting an estimated golf club head speed to an imaging system when the trigger device is activated; the imaging system capable of compiling a plurality of exposures to generate a frame;

taking a first plurality of exposures of the golf club head prior to the golf club head impacting the teed golf ball, the first plurality of exposures having a first time interval between exposures;

striking the teed golf ball with the golf club;

taking a second plurality of exposures of the golf ball after the golf ball has been struck by the golf club head, the second plurality of exposures having a second time interval between exposures, the second time interval different than the first time interval;

generating a frame that includes the first plurality of exposures of the golf club head prior to impact with the teed golf ball and the second plurality of exposures of the golf ball after impact with the golf club head; and

providing measurements of the golf club head and of the launched golf ball based on the generated frame including the first plurality of exposures of the golf club head and the second plurality of exposures of the golf ball.

2. The method according to claim 1 wherein the first time interval for the first plurality of exposures is shorter than the second time interval for the second plurality of exposures.

3. The method according to claim 1 wherein first time interval for the first plurality of exposures ranges from 750 milliseconds to 2000 milliseconds, and the second time interval for the second plurality of exposures is greater than the first time interval.

4. The method according to claim 1 wherein the imaging system comprises a first camera and a second camera.

5. The method according to claim 1 wherein the measurements of the golf club comprise golf club head orientation, golf club head spin and golf club head velocity, and the measurements of the golf ball comprise the golf ball velocity, the golf ball launch angle, the golf ball side angle, the golf ball orientation and the golf ball speed.

6. The method according to claim 1 wherein the estimated golf club head speed is utilized to determine the first time interval of the first plurality of exposures and the second time interval of the second plurality of exposures.

7. The method according to claim 1 wherein each of the first plurality of exposures have a first exposure time, and each of the second plurality of exposures have a second exposure time, wherein the second exposure time is greater than the first exposure time.

8. A system simultaneously measuring golf club properties and golf ball properties during a golfer's striking of a golf ball, the system comprising:

a first camera and a second camera, each of the first and second cameras focused toward a predetermined field view;

a golf club having at least one light contrasting area thereon;

a golf ball teed within the predetermined field of view;

a trigger device disposed prior to the teed golf ball along a path of a golf club swing, the trigger device capable of estimating the golf club speed;

means for calculating a first time interval between a first plurality of exposures of the golf club and a second time interval between a second plurality of exposures of the launched golf ball based on the estimated golf club speed; and

means for determining golf club swing properties and golf ball launch properties based on an image frame generated by the first and second cameras, the image frame comprising the first plurality of exposures and the second plurality of exposures.

9. A method for simultaneously measuring golf club properties and golf ball properties during a golfer's striking of a golf ball, the method comprising:

swinging a golf club toward a teed golf ball;

triggering a trigger device as the golf club is swung toward the teed golf ball, the trigger device being capable of transmitting an estimated golf club head speed to an imaging system when the trigger device is activated, the imaging system capable of compiling a plurality of exposures to generate a frame;

taking a first plurality of exposures of the golf club head prior to the golf club head impacting the teed golf ball, the first plurality of exposures having a first time interval for each exposure;

striking the teed golf ball with the golf club;

taking a second plurality of exposures of the golf ball after the golf ball has been struck by the golf club head, the second plurality of exposures having a second time interval for each exposure, the second time interval different than the first time interval;

generating a frame that includes the first plurality of exposures of the golf club head prior to impact with the teed golf ball and the second plurality of exposures of the golf ball after impact with the golf club head; and

providing measurements of the golf club head and of the launched golf ball based on the generated frame including the first plurality of exposures of the golf club head and the second plurality of exposures of the golf ball.

10. A method for simultaneously measuring golf club properties and golf ball properties during a golfer's striking of a golf ball, the method comprising:

swinging a golf club toward a teed golf ball;

triggering a trigger device as the golf club is swung toward the teed golf ball, the trigger device being capable of transmitting an estimated golf club head speed to an imaging system when the trigger device is activated, the imaging system capable of compiling a plurality of exposures to generate a frame;

taking a first plurality of exposures of the golf club head prior to the golf club head impacting the teed golf ball, the first plurality of exposures having a first exposure intensity;

striking the teed golf ball with the golf club;

taking a second plurality of exposures of the golf ball after the golf ball has been struck by the golf club head, the second plurality of exposures having a second exposure intensity, the second exposure intensity different than the first exposure intensity;

generating a frame that includes the first plurality of exposures of the golf club head prior to impact with the teed golf ball and the second plurality of exposures of the golf ball after impact with the golf club head; and

providing measurements of the golf club head and of the launched golf ball based on the generated frame including the first plurality of exposures of the golf club head and the second plurality of exposures of the golf ball.

11. A method for simultaneously measuring golf club properties and golf ball properties during a golfer's striking of a golf ball, the method comprising:

activating a trigger device as a golf club is swung toward a teed golf ball;

transmitting a signal with an estimated golf club head speed to an imaging system when the trigger device is activated; the imaging system capable of compiling a plurality of exposures to generate a frame;

taking, by the imaging system, a first plurality of exposures of the golf club head prior to the golf club head impacting the teed golf ball, the first plurality of exposures having a first time interval between exposures;

taking, by the imaging system, a second plurality of exposures of the golf ball after the golf ball has been struck by the golf club head, the second plurality of exposures having a second time interval between exposures, the second time interval different than the first time interval;

generating a frame that includes the first plurality of exposures of the golf club head prior to impact with the teed golf ball and the second plurality of exposures of the golf ball after impact with the golf club head; and providing measurements of the golf club head and of the launched golf ball based on the generated frame including the first plurality of exposures of the golf club head and the second plurality of exposures of the golf ball.

12. The method according to claim 11 wherein the first time interval for the first plurality of exposures is shorter than the second time interval for the second plurality of exposures.

13. The method according to claim 11 wherein first time interval for the first plurality of exposures ranges from 750 milliseconds to 2000 milliseconds, and the second time interval for the second plurality of exposures is greater than the first time interval.

14. The method according to claim 11 wherein the imaging system comprises a first camera and a second camera.

15. The method according to claim 11 wherein the measurements of the golf club comprise golf club head orientation, golf club head spin and golf club head velocity, and the measurements of the golf ball comprise the golf ball velocity, the golf ball launch angle, the golf ball side angle, the golf ball orientation and the golf ball speed.

16. The method according to claim 11 wherein the estimated golf club head speed is utilized to determine the first time interval of the first plurality of exposures and the second time interval of the second plurality of exposures.

17. The method according to claim 11 wherein each of the first plurality of exposures have a first exposure time, and each of the second plurality of exposures have a second exposure time, wherein the second exposure time is greater than the first exposure time.

18. A system simultaneously measuring golf club properties and golf ball properties during a golfer's striking of a golf ball, the system comprising:

a first camera and a second camera, each of the first and second cameras focused toward a predetermined field view;

a trigger device for being triggered by a golf club being swung toward a golf ball teed within the predetermined field of view, the trigger device capable of estimating the golf club speed upon being triggered;

means for calculating a first time interval between a first plurality of exposures of the golf club and a second time interval between a second plurality of exposures of the launched golf ball based on the estimated golf club speed; and

means for determining golf club swing properties and golf ball launch properties based on an image frame generated by the first and second cameras, the image frame comprising the first plurality of exposures and the second plurality of exposures.

19. The system according to claim 18 further comprising a first flash device for the first camera and a second flash device for the second camera.

20. The system according to claim 18 wherein the trigger device is a laser detector.

21. The system according to claim 18 wherein the trigger device is an audible detector.

22. The system according to claim 18 wherein the trigger device detects the golf club being swung based on at least one light contrasting area on the golf club.

23. The system according to claim 22 wherein the golf club has three highly reflective markers thereon.

24. The system according to claim 18 wherein the calculating means calculates the first time interval and the second time interval such that the first time interval is less than the second time interval.

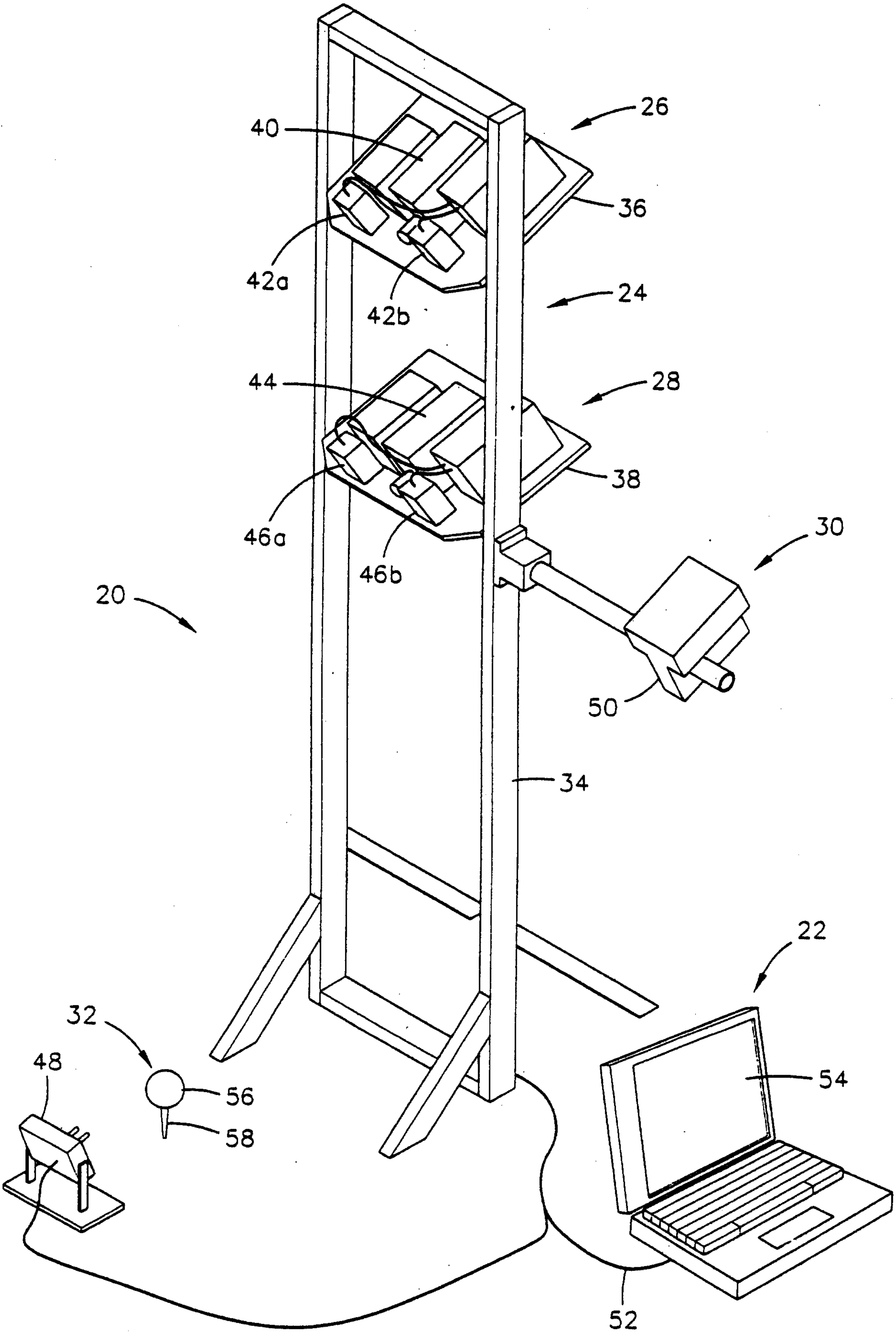


FIG. 1

Gowling Lafleur Henderson LLP

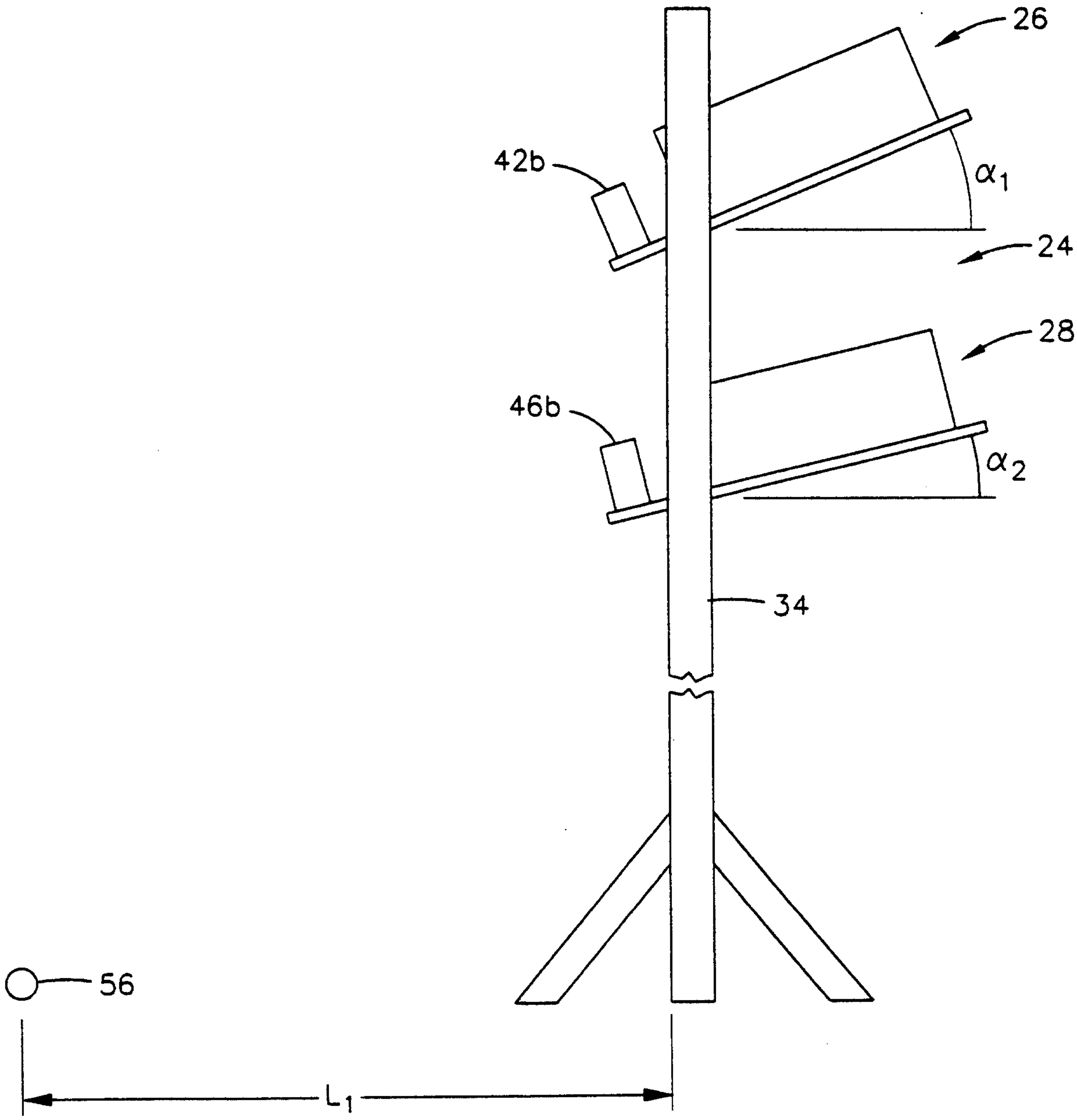


FIG. 2

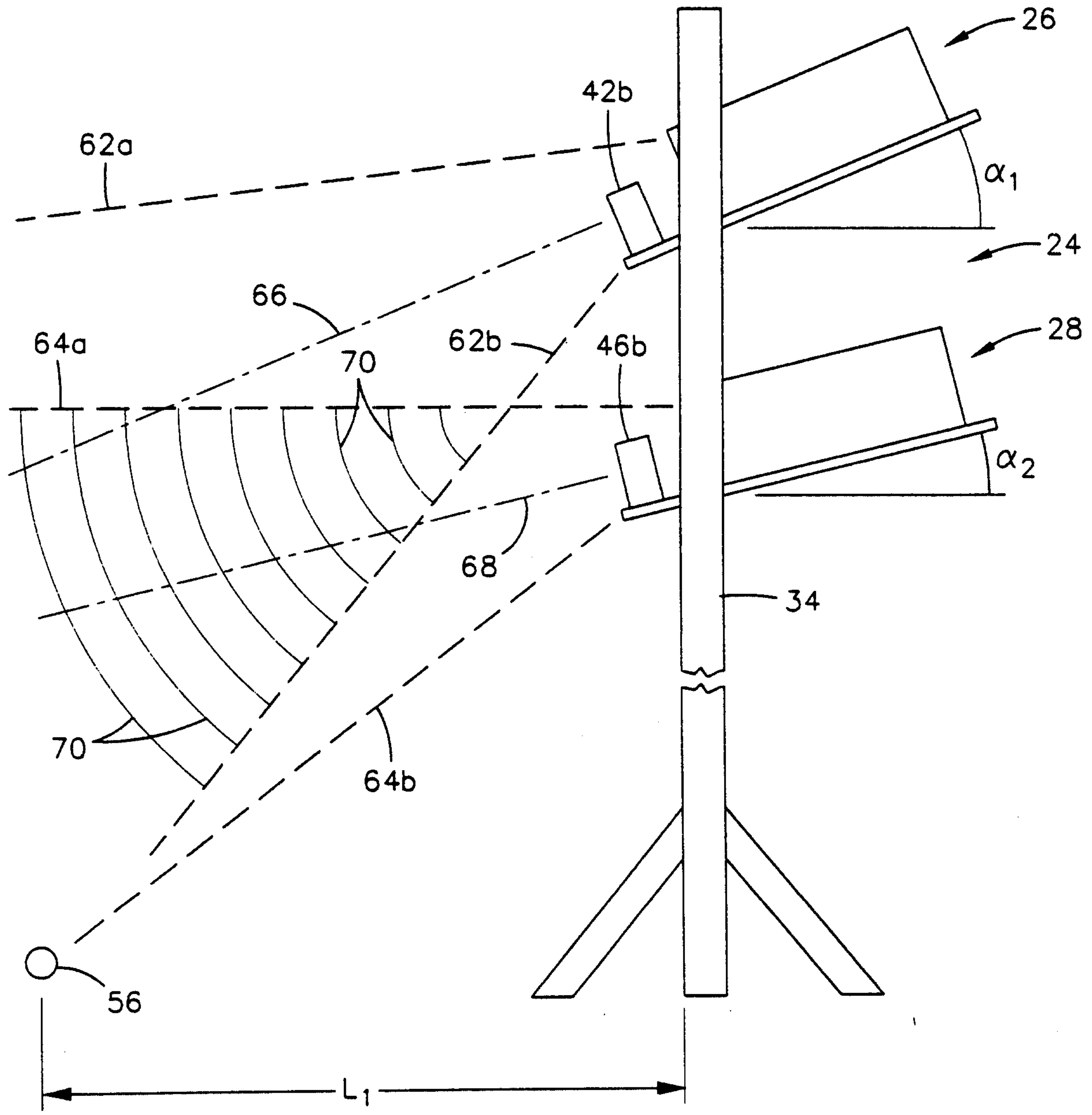

26
42b
62a
α_1
24
66
28
64a
70
62b
46b
α_2
68
34
70
64b
56
L_1

FIG. 2A

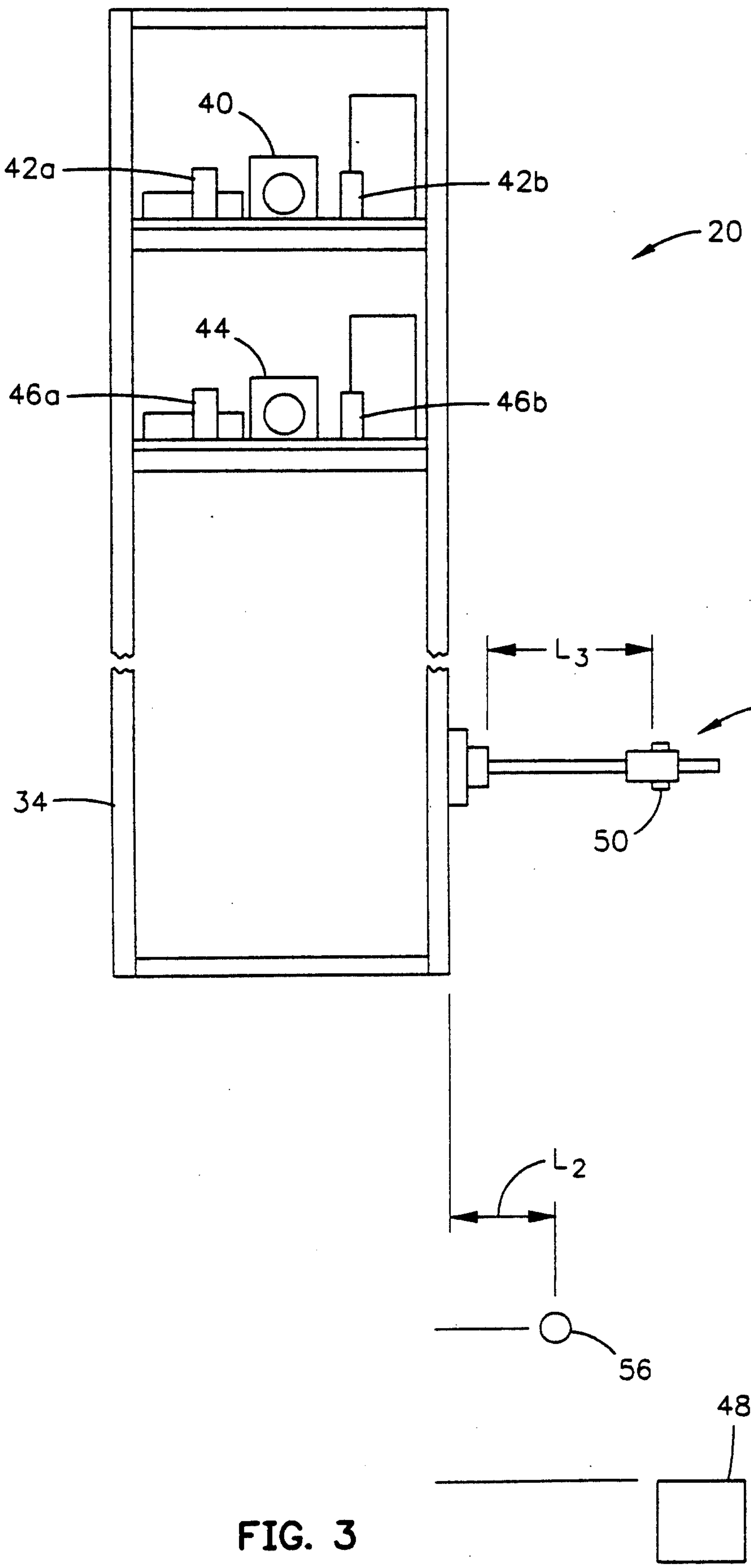


FIG. 3

Gowling Lafleur Henderson LLP

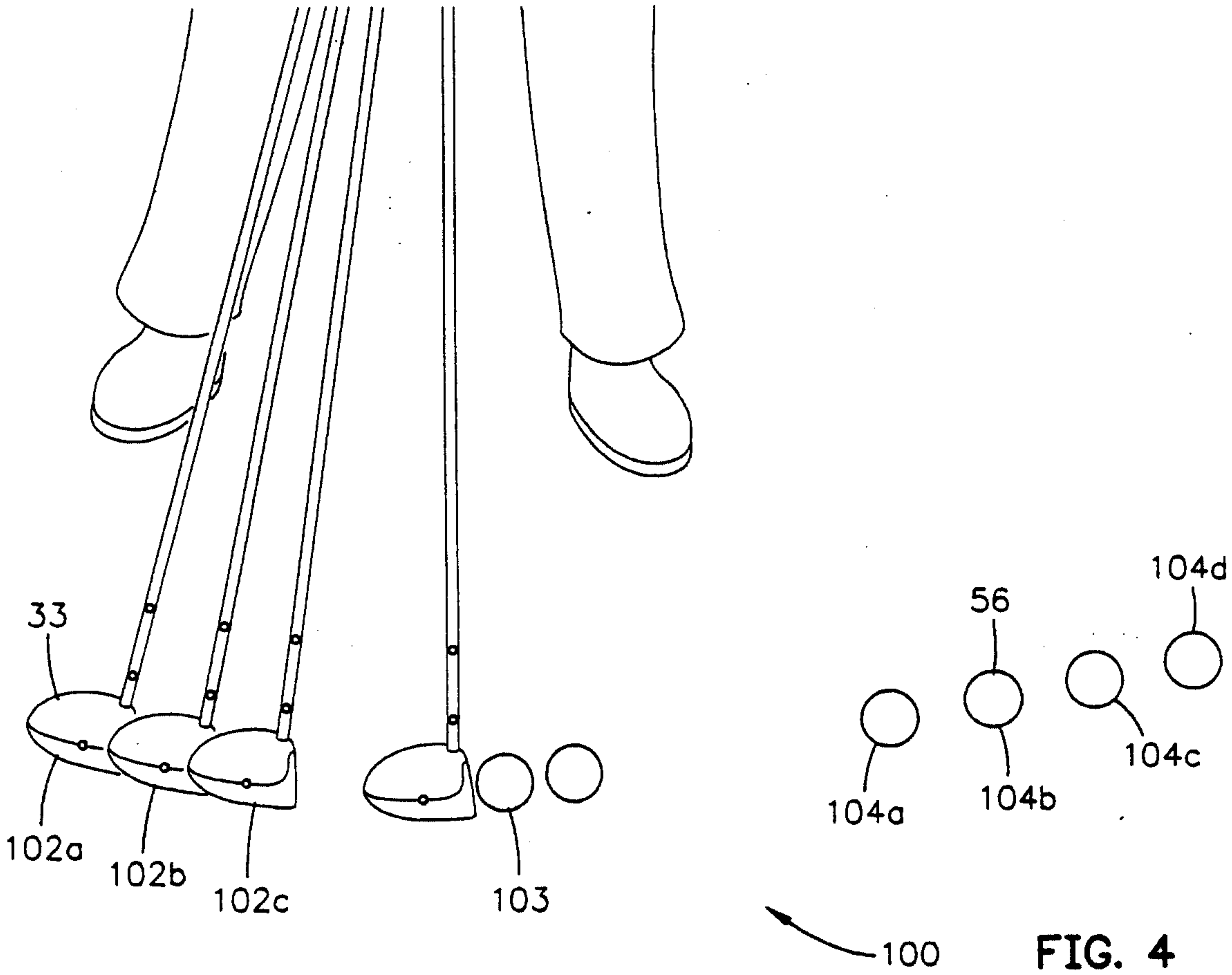
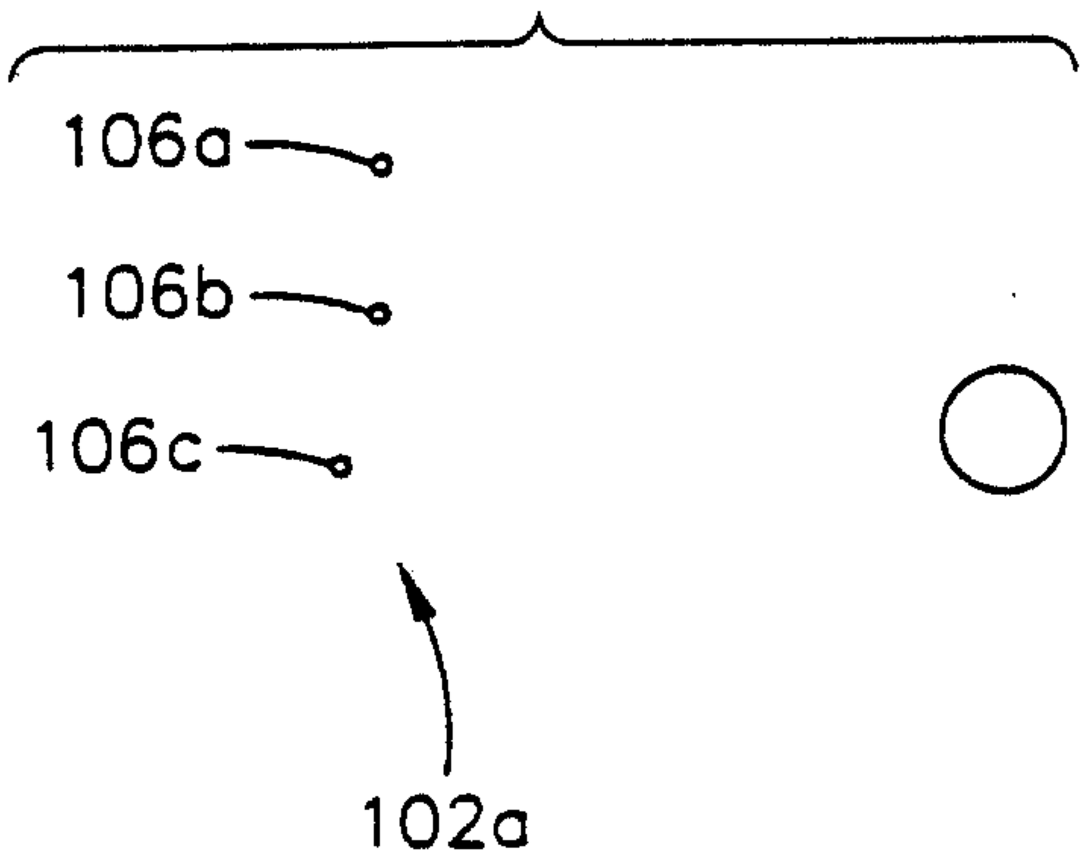


FIG. 4

FIG. 5



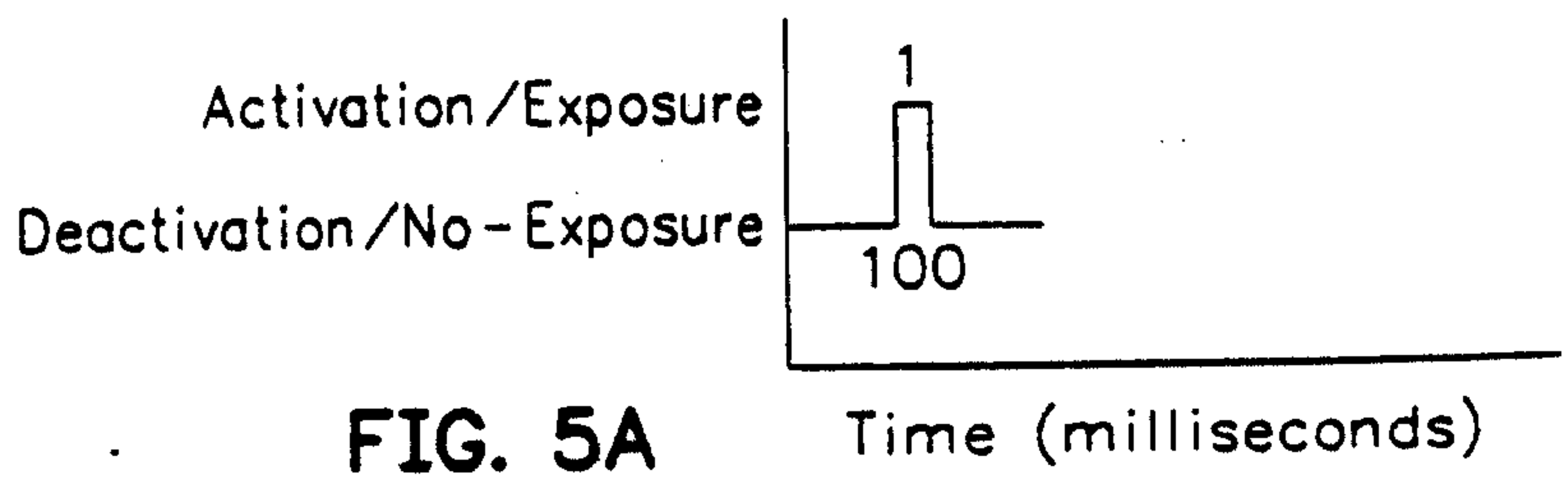


FIG. 5A

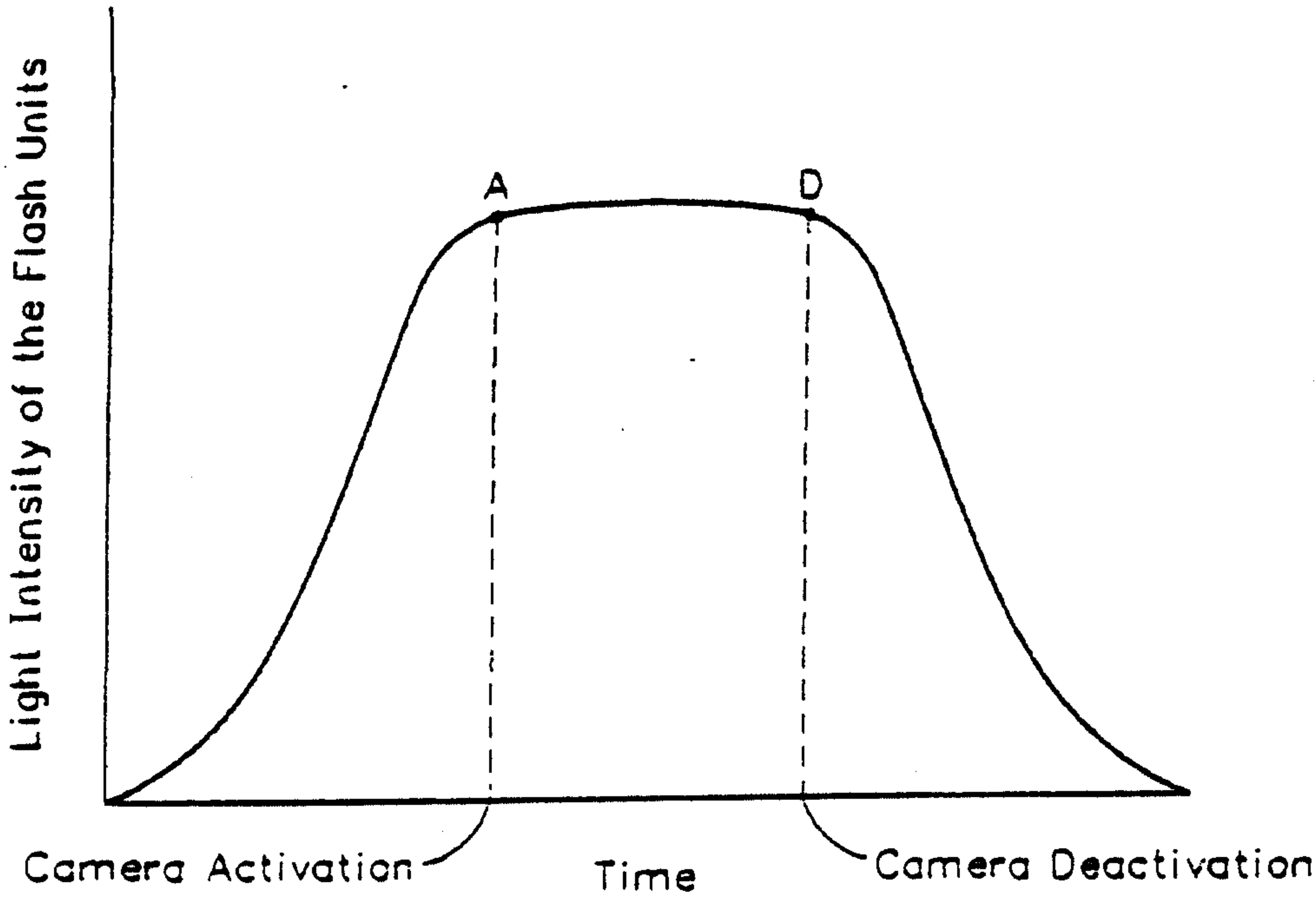
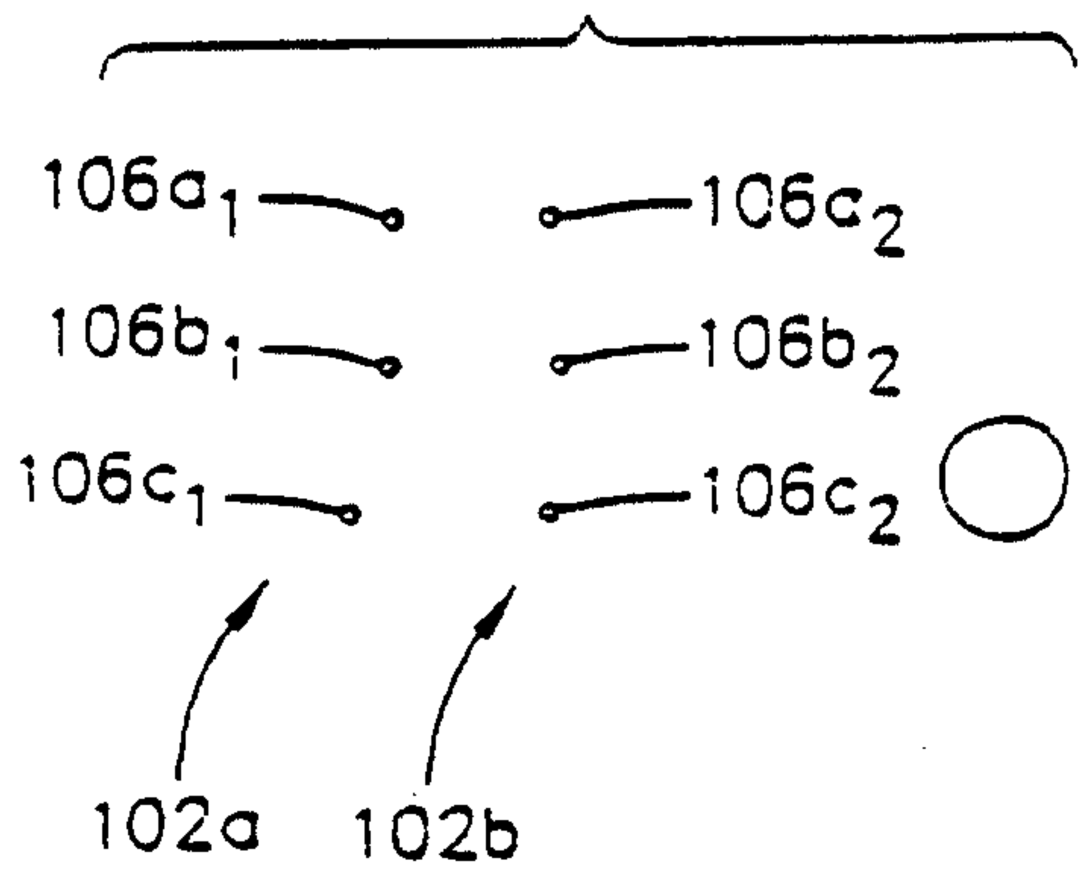


FIG. 5B

FIG. 6



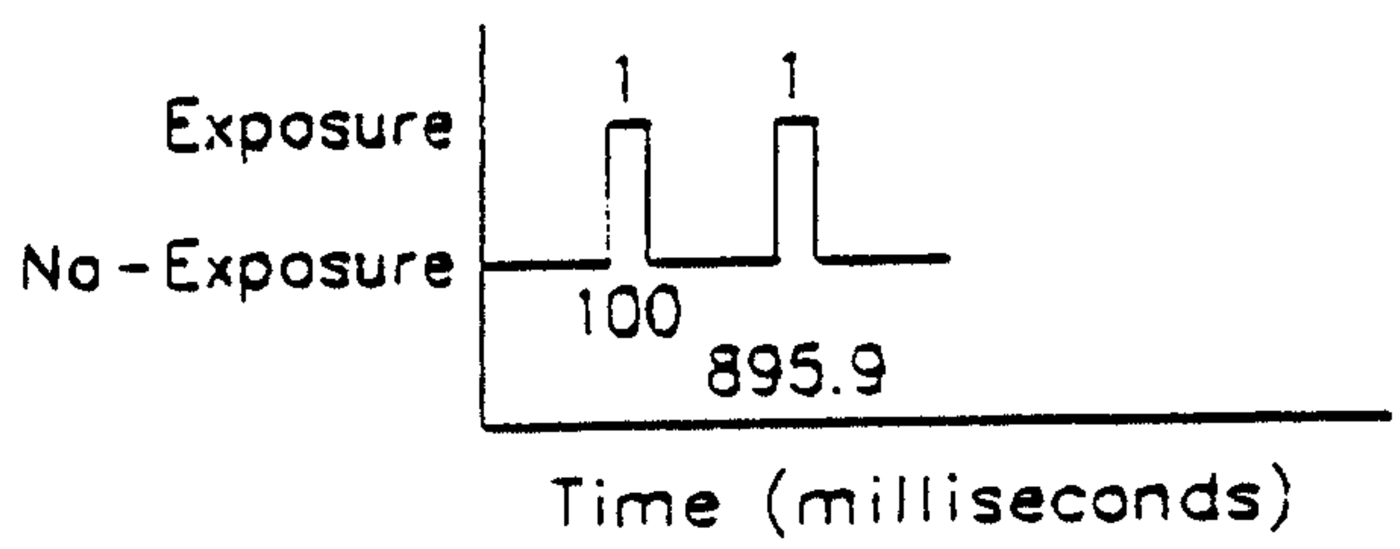
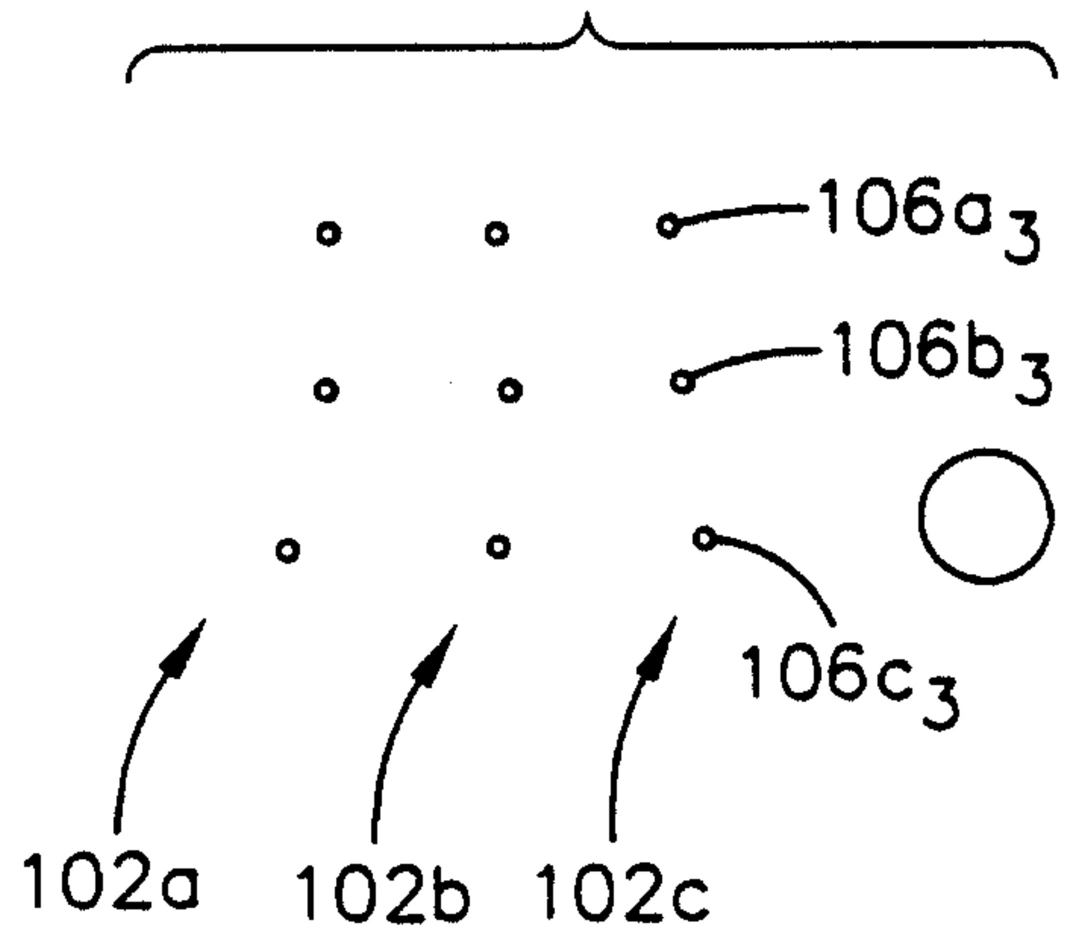


FIG. 6A

FIG. 7



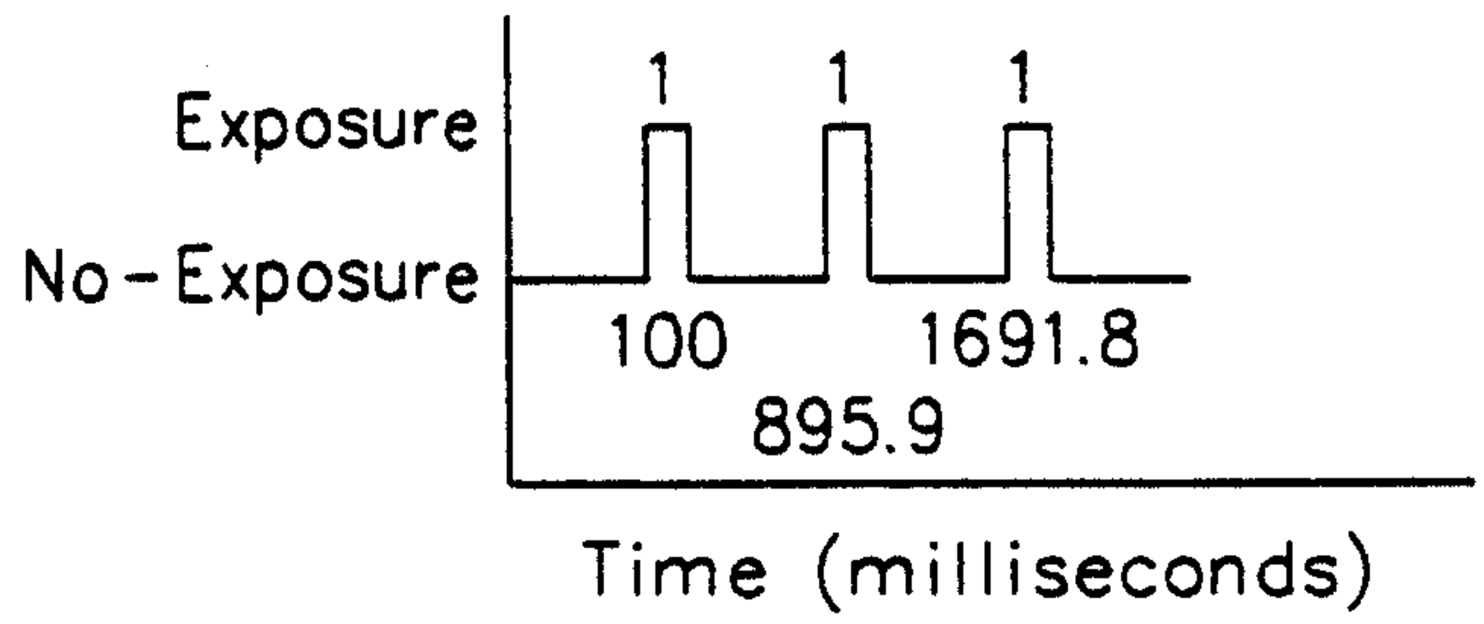
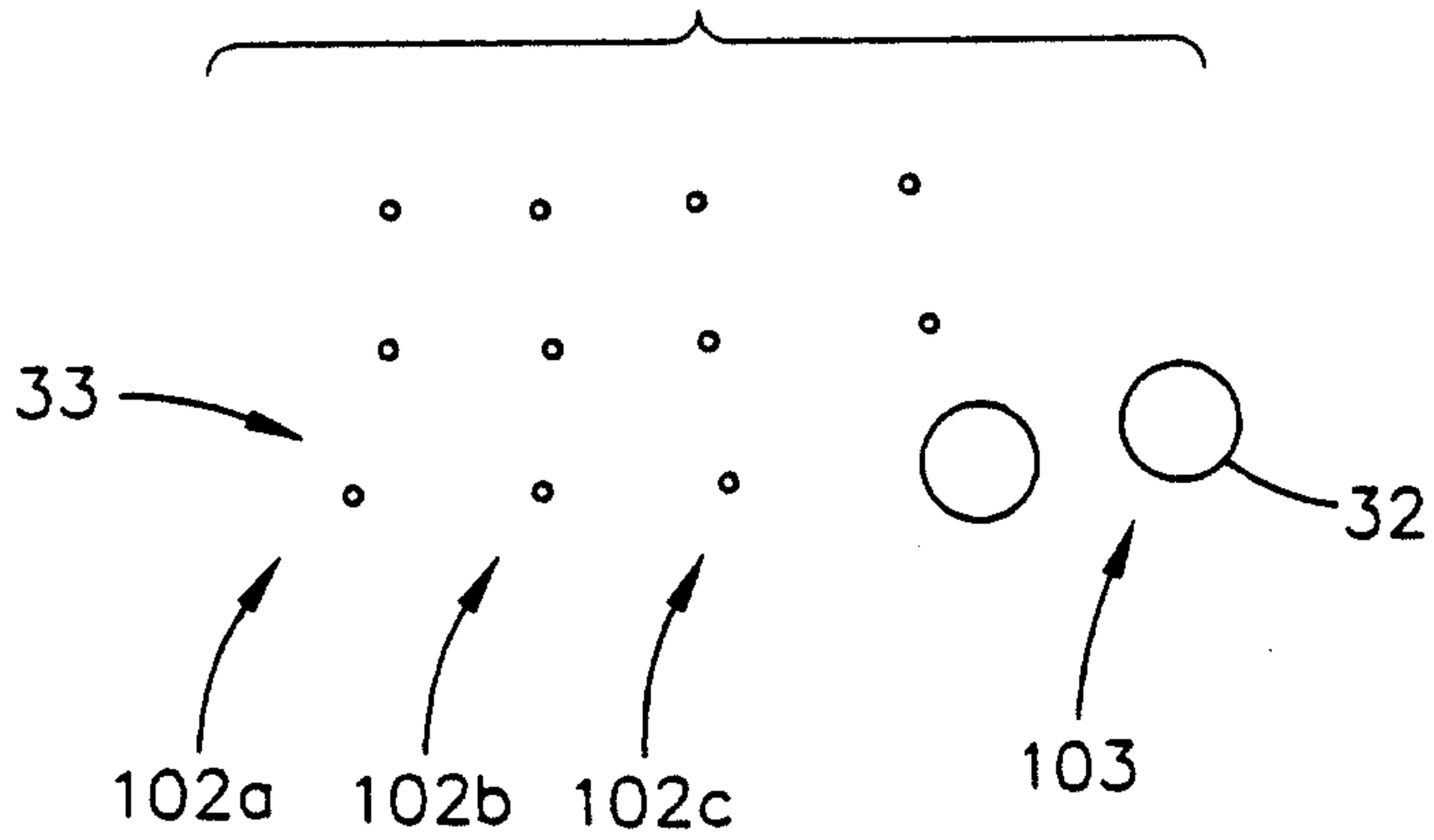


FIG. 7A

FIG. 8



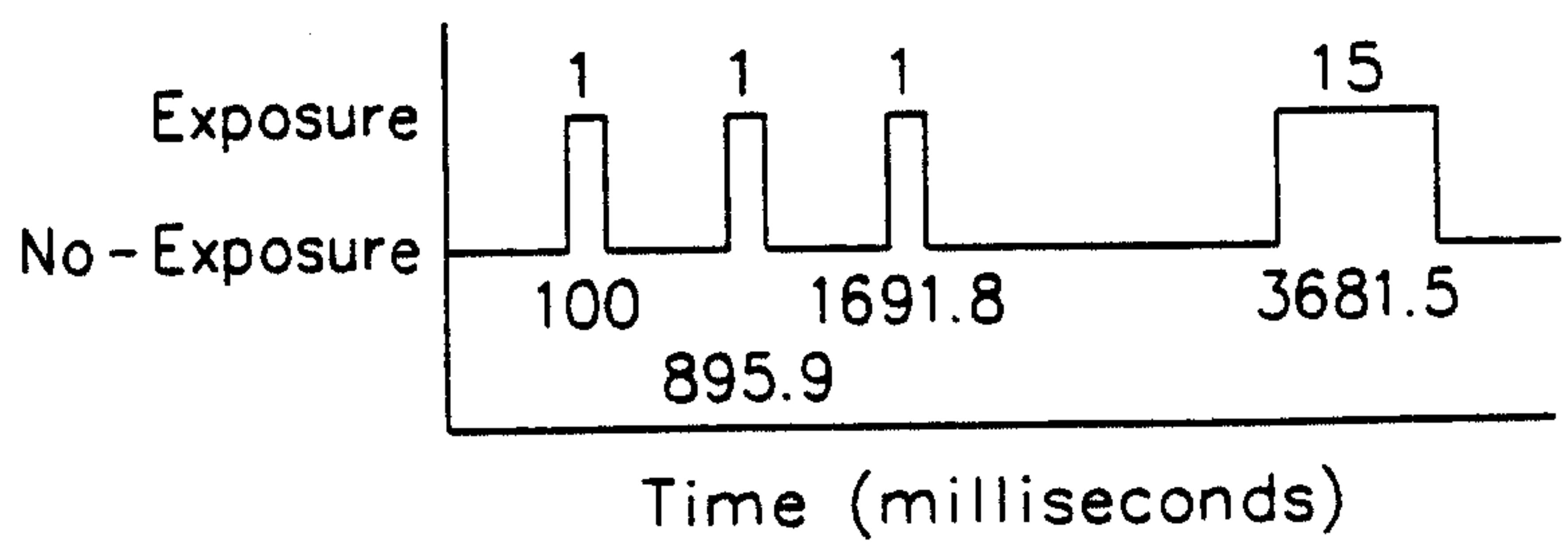
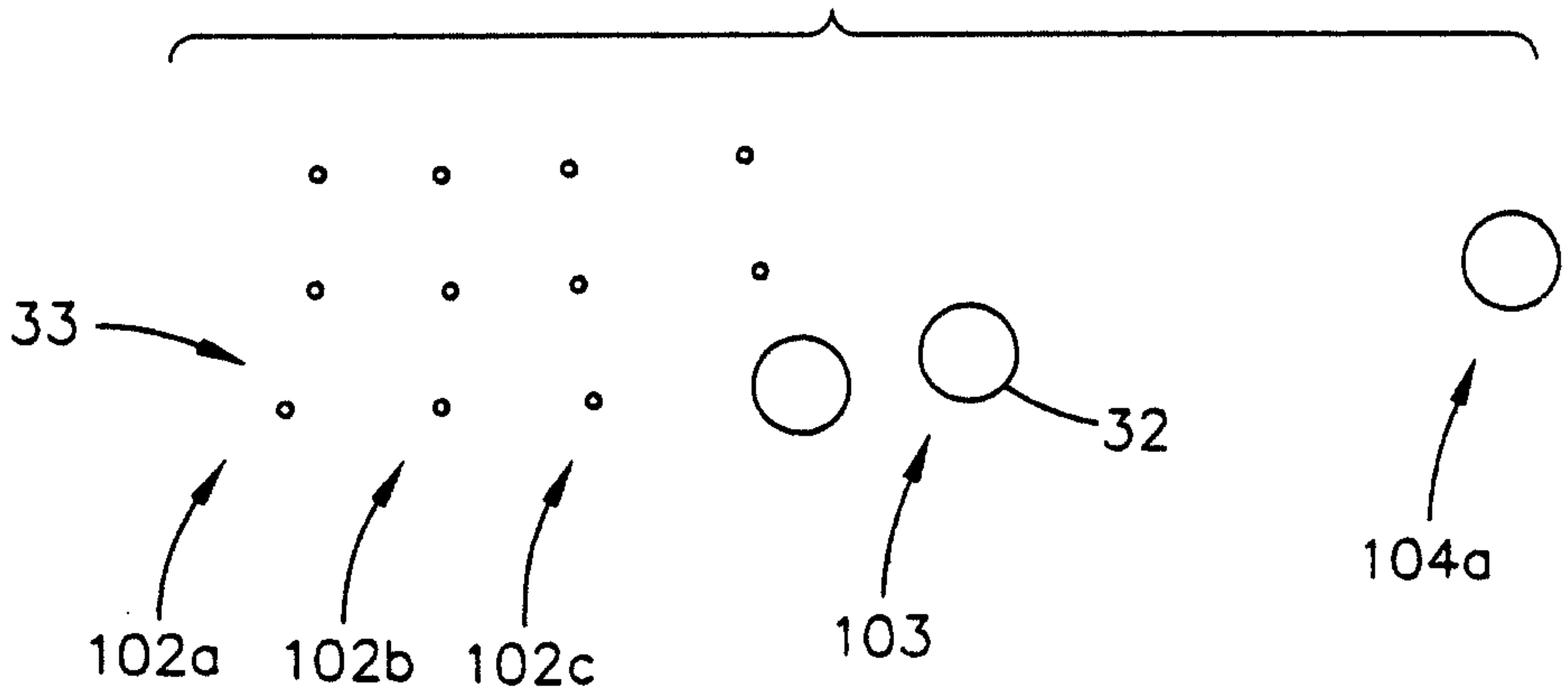


FIG. 8A

Gowling Lafleur Henderson LLP

FIG. 9


33
32
102a
102b
102c
103
104a

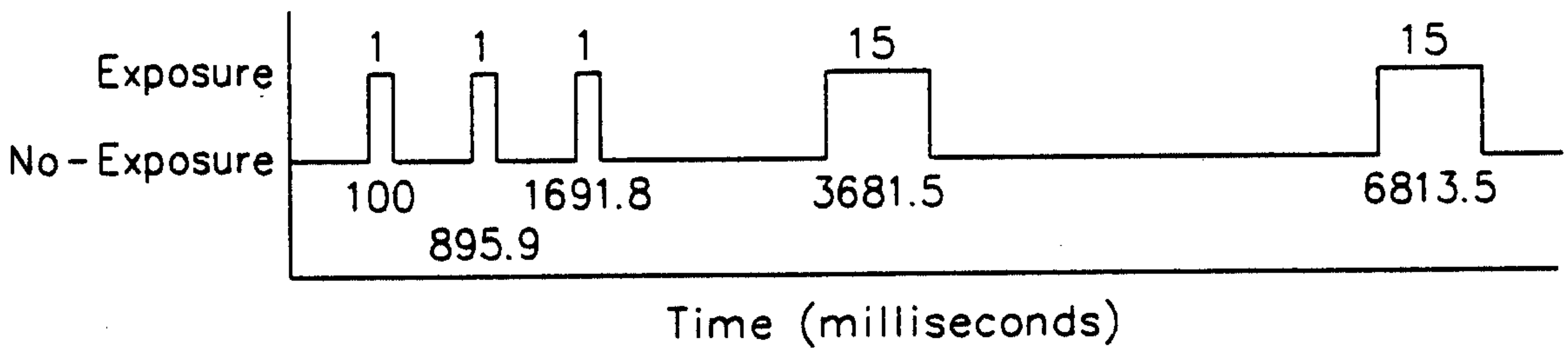
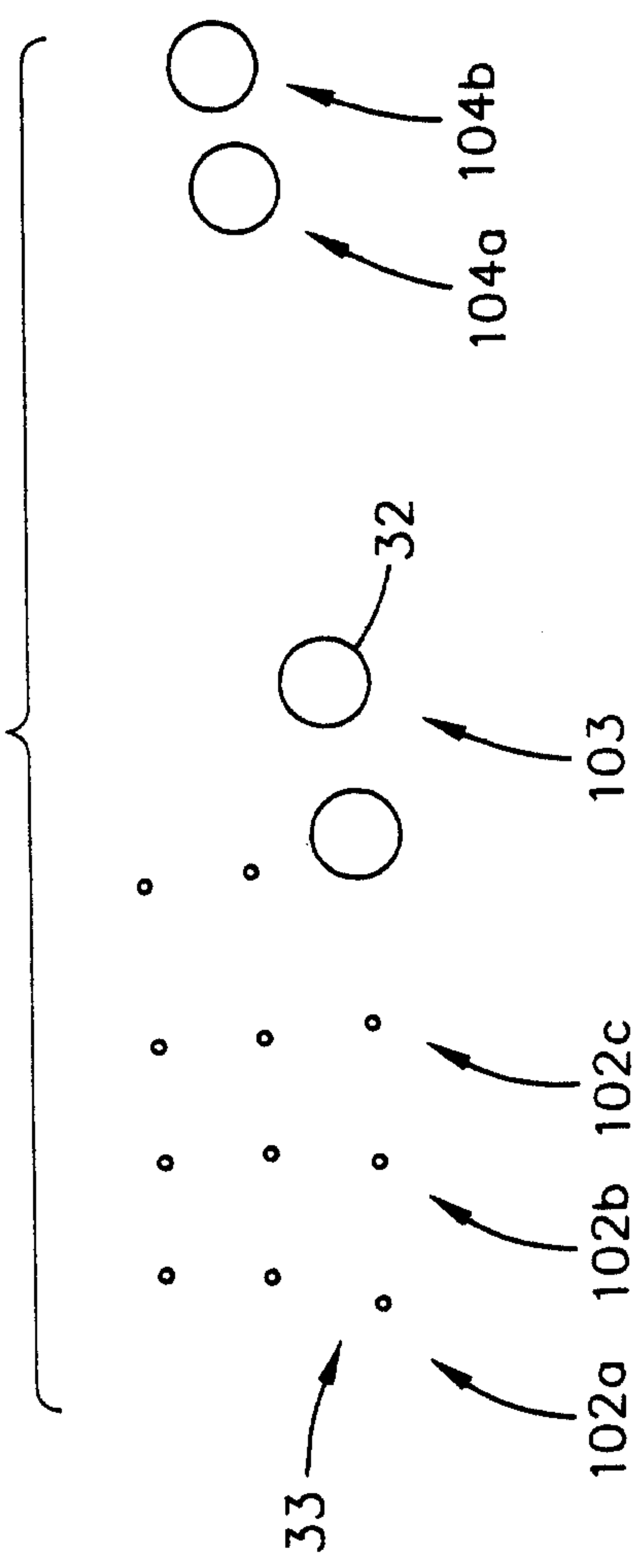

Exposure
No-Exposure
1
1
1
15
15
100
895.9
1691.8
3681.5
6813.5
Time (milliseconds)

FIG. 9A

FIG. 10



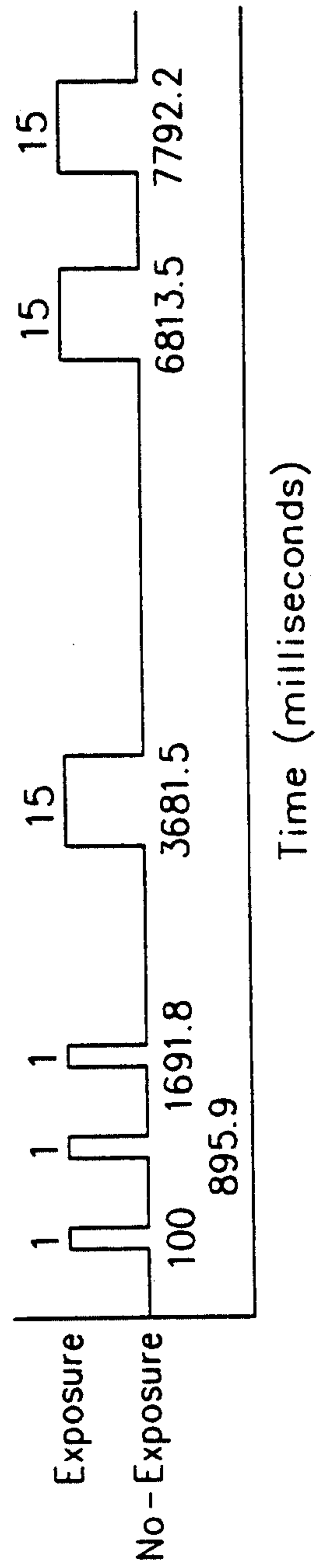
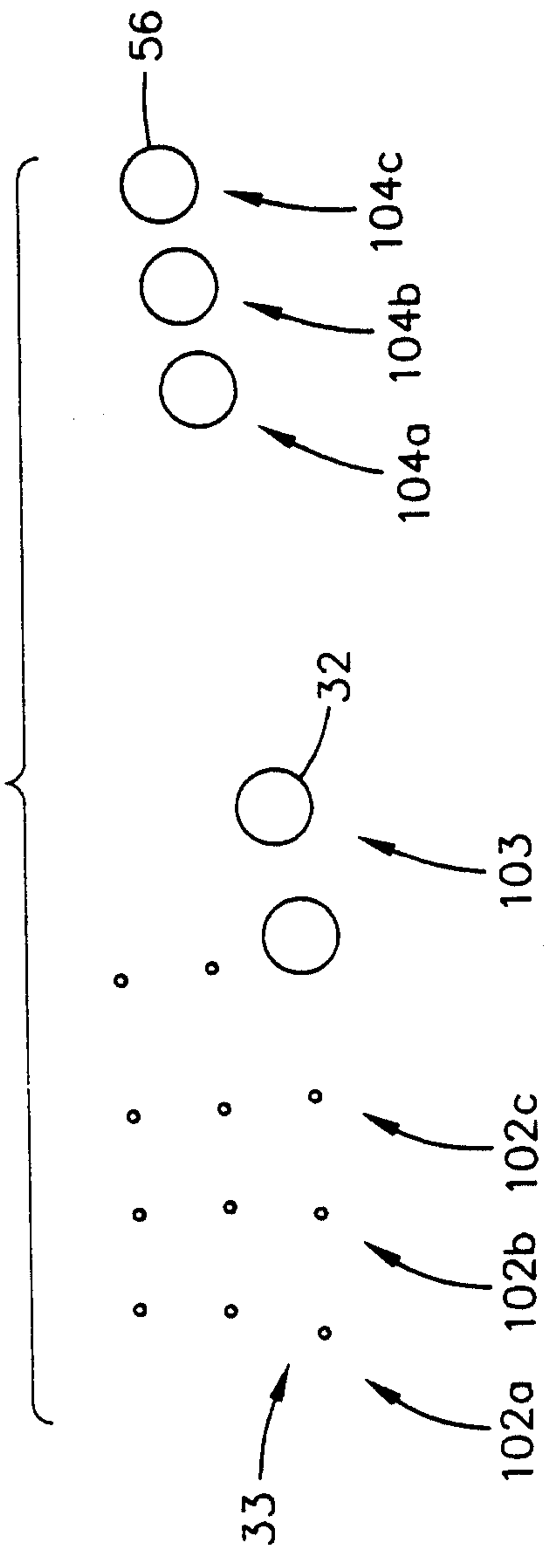


FIG. 10A

FIG. 11



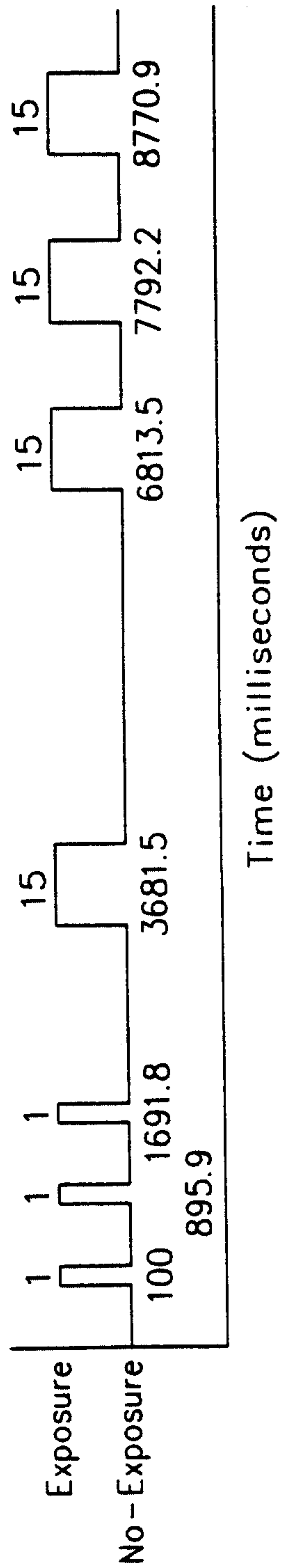


FIG. 11A

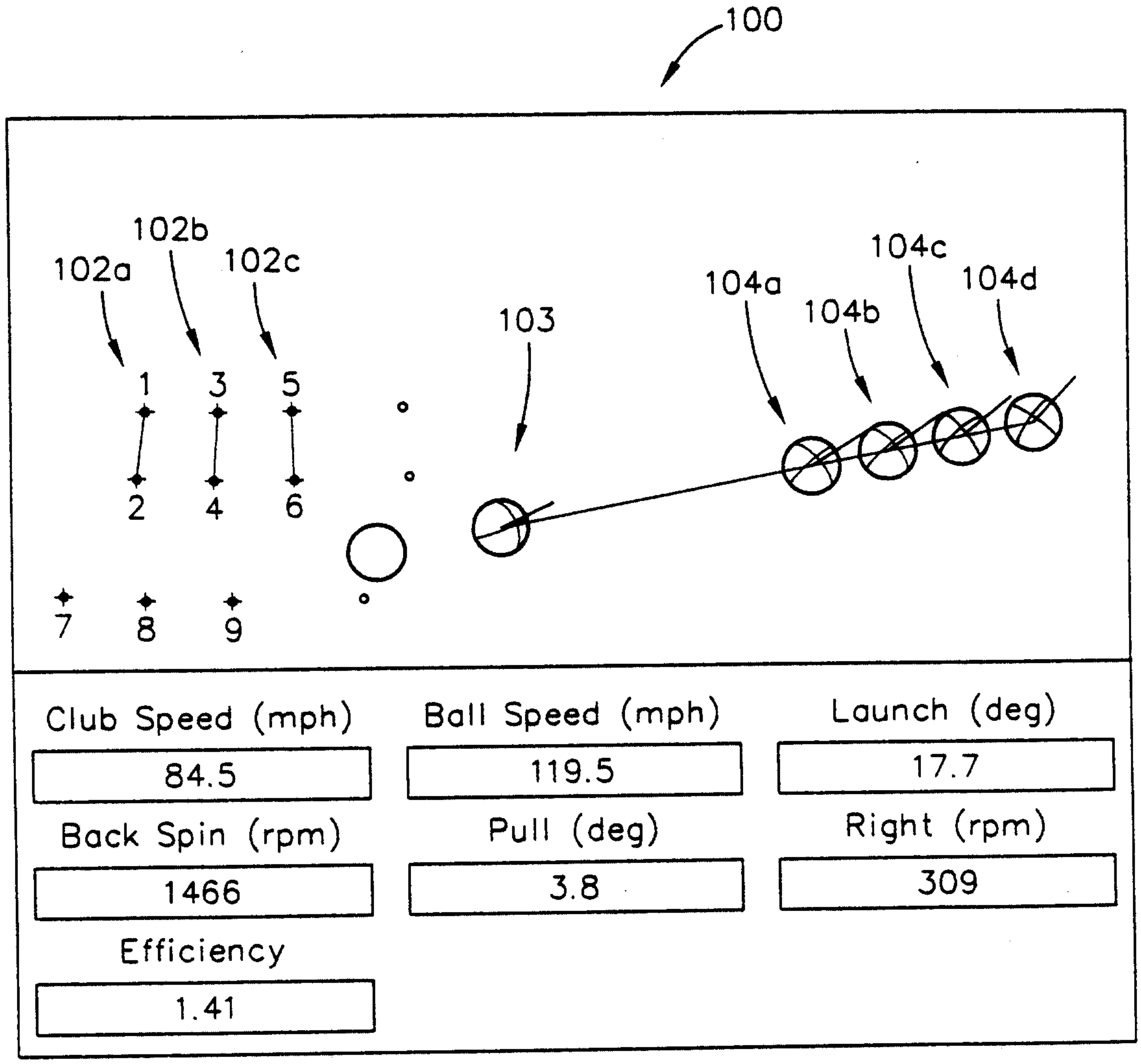

100
102a
102b
102c
1
3
5
2
4
6
7
8
9
103
104a
104b
104c
104d
Club Speed (mph)
84.5
Ball Speed (mph)
119.5
Launch (deg)
17.7
Back Spin (rpm)
1466
Pull (deg)
3.8
Right (rpm)
309
Efficiency
1.41

FIG. 12

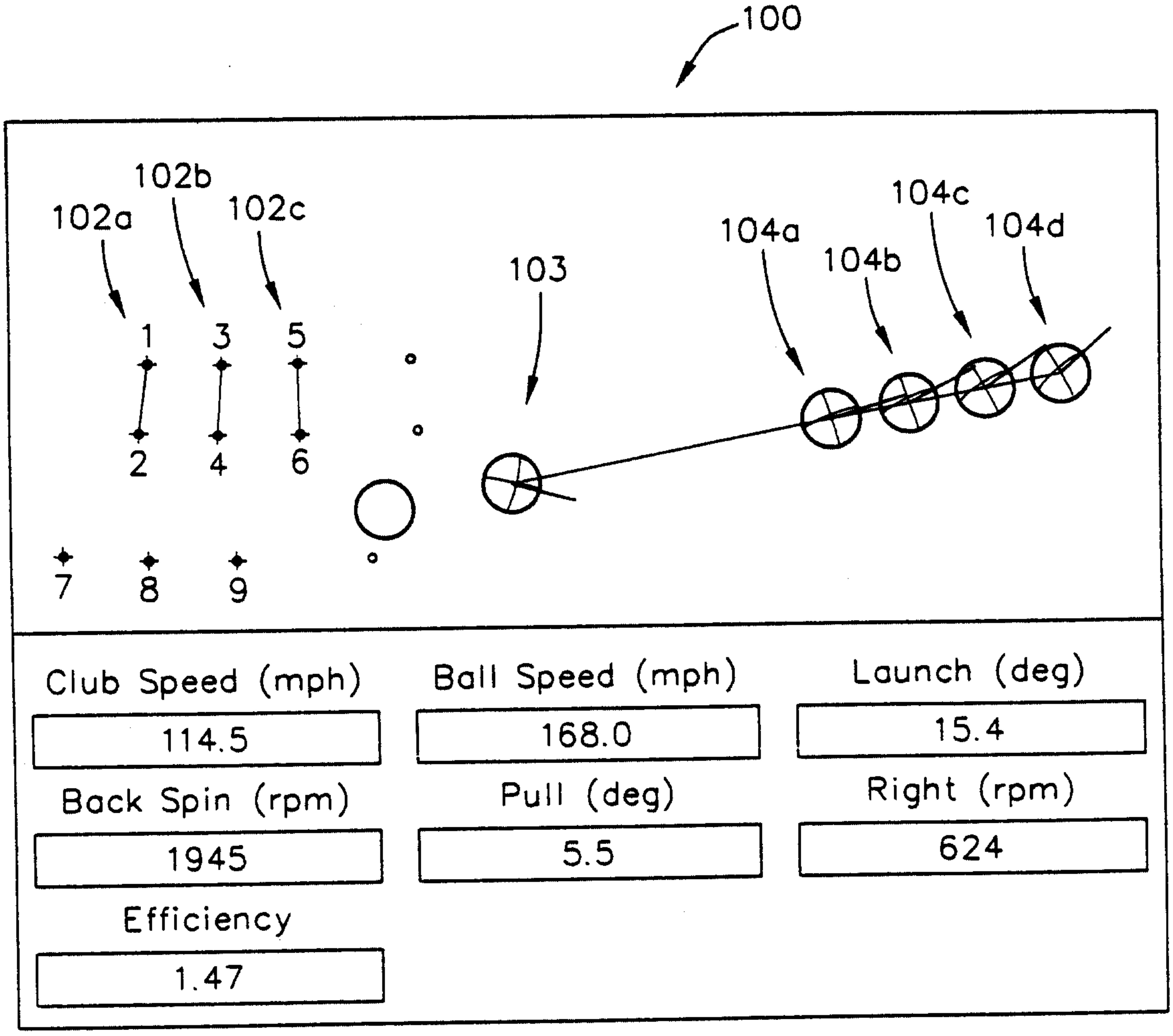

100
102a
102b
102c
1
3
5
2
4
6
7
8
9
103
104a
104b
104c
104d
Club Speed (mph)
114.5
Ball Speed (mph)
168.0
Launch (deg)
15.4
Back Spin (rpm)
1945
Pull (deg)
5.5
Right (rpm)
624
Efficiency
1.47

FIG. 13

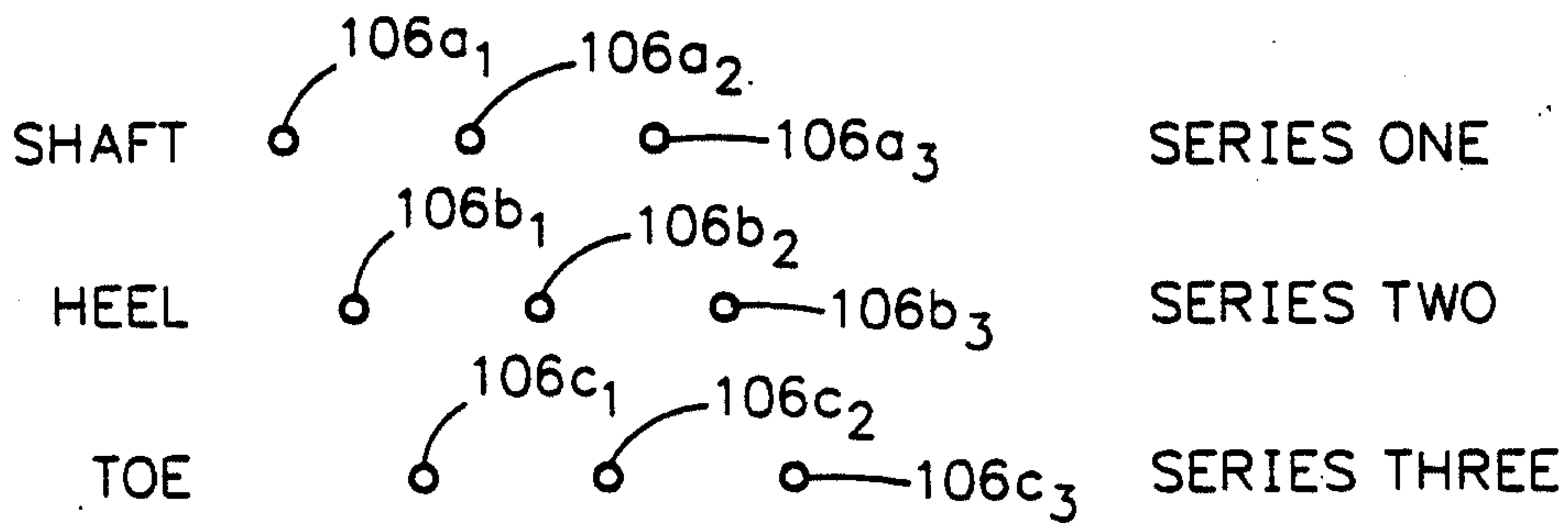


FIG. 14

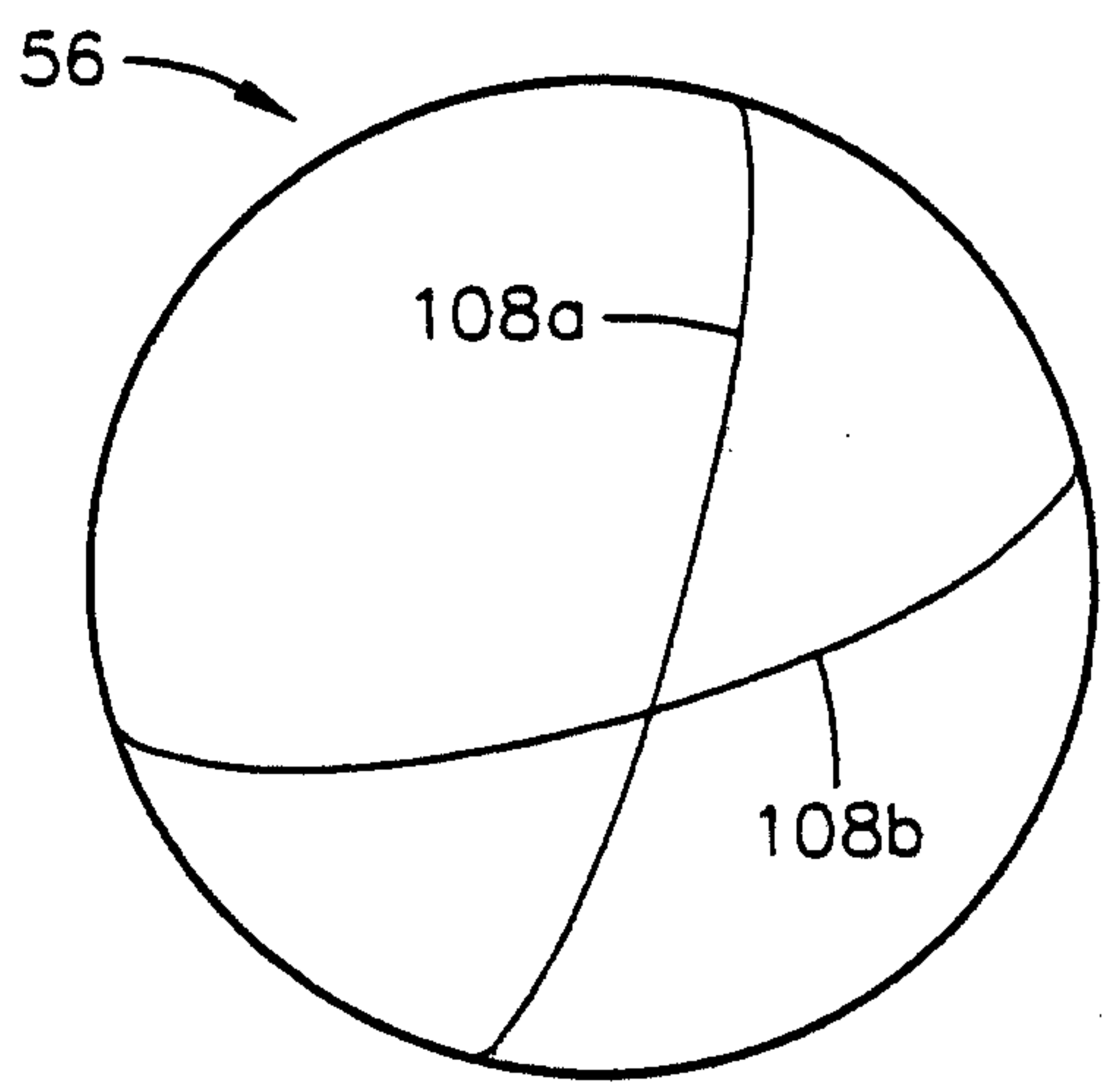


FIG. 15

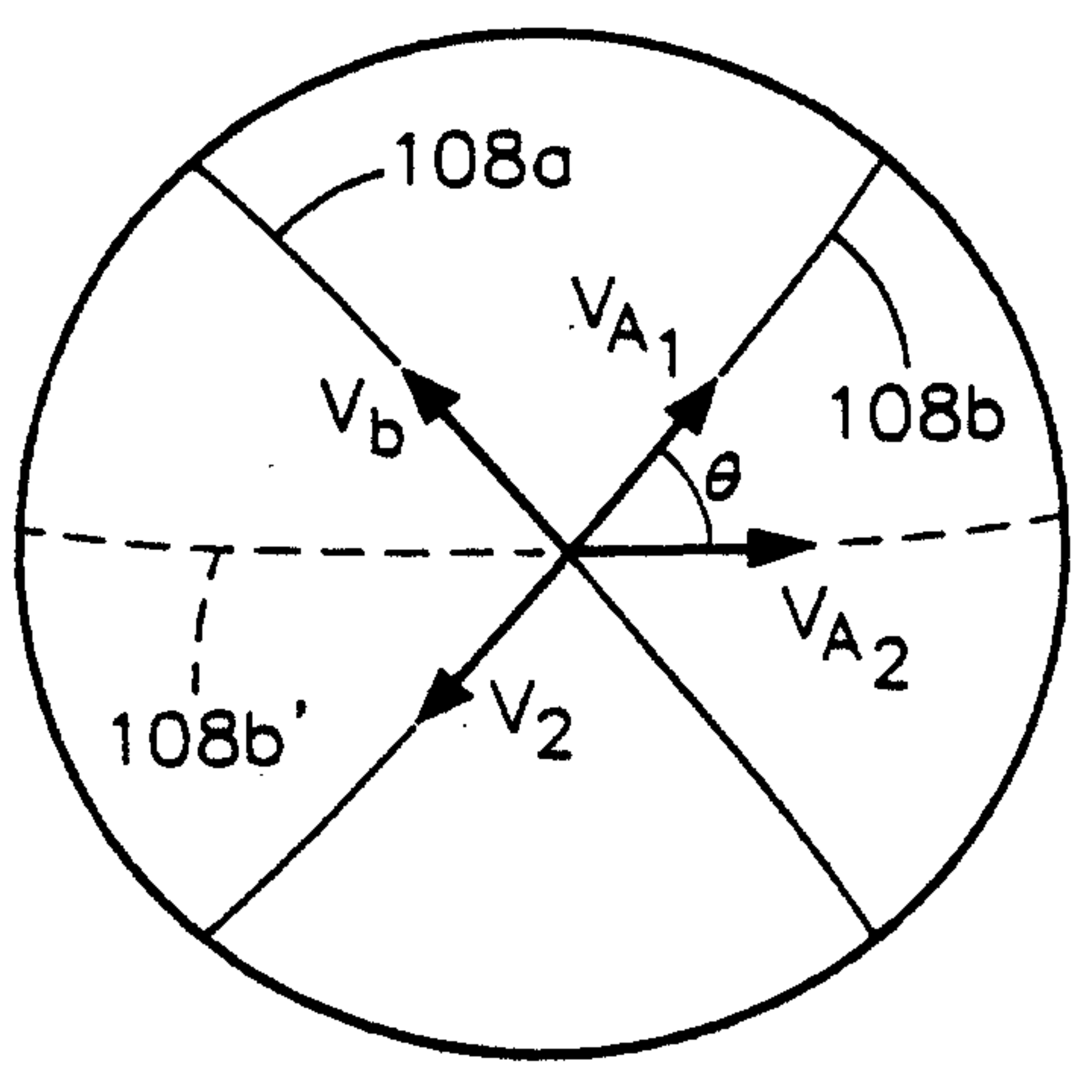


FIG. 15A

FIG. 16

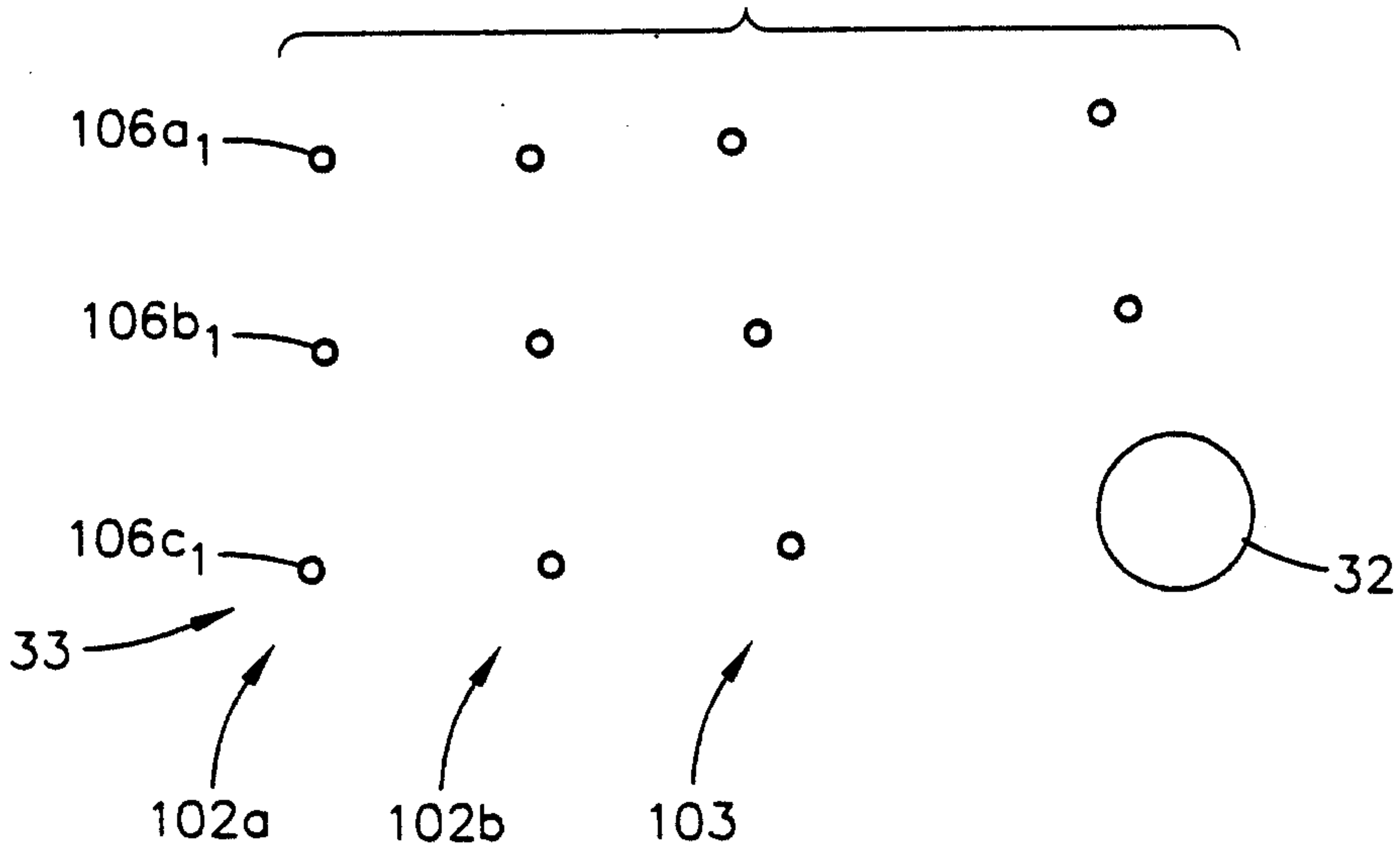

106a1
106b1
106c1
33
102a
102b
103
32

FIG. 17

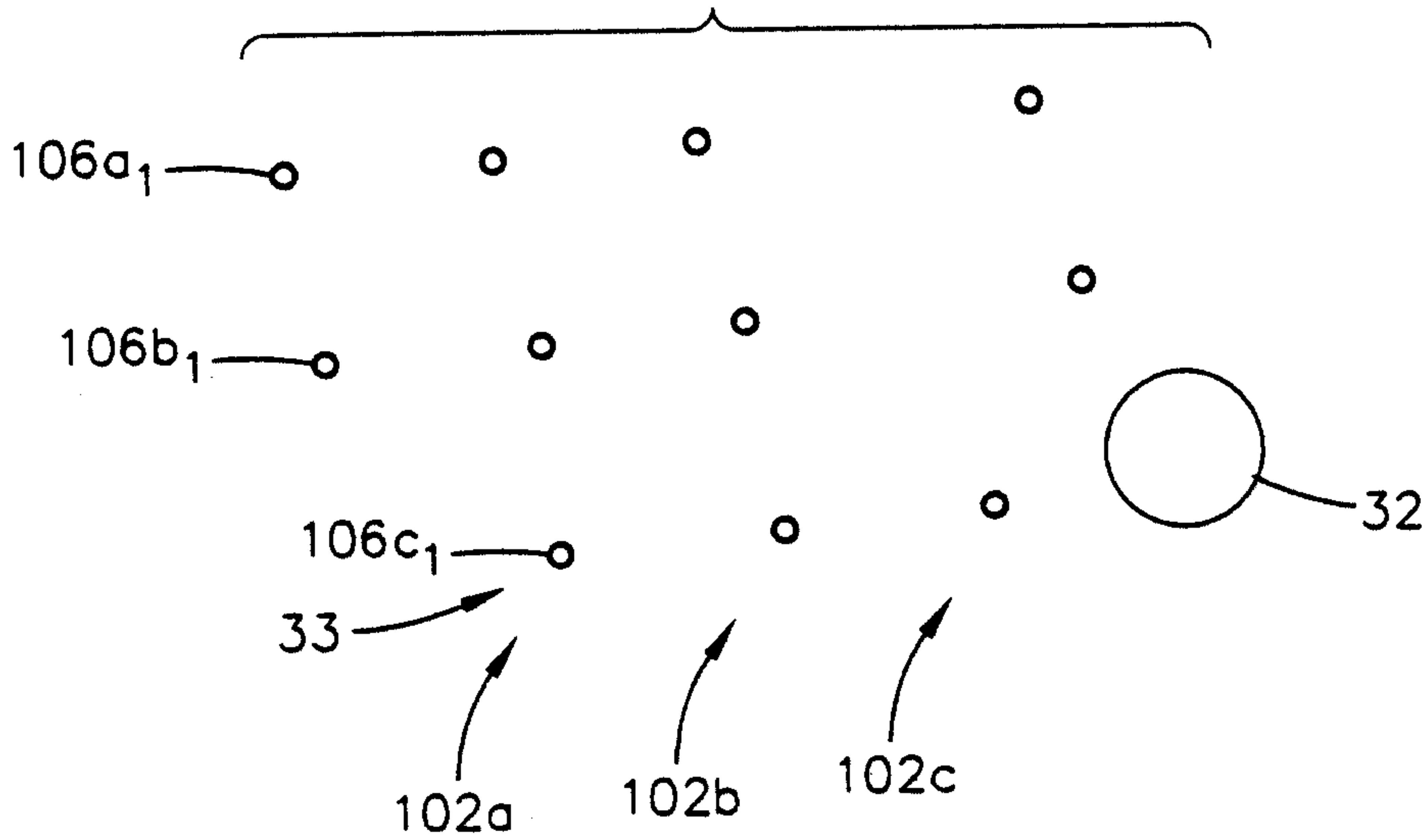

106a1
106b1
106c1
33
102a
102b
102c
32

FIG. 18

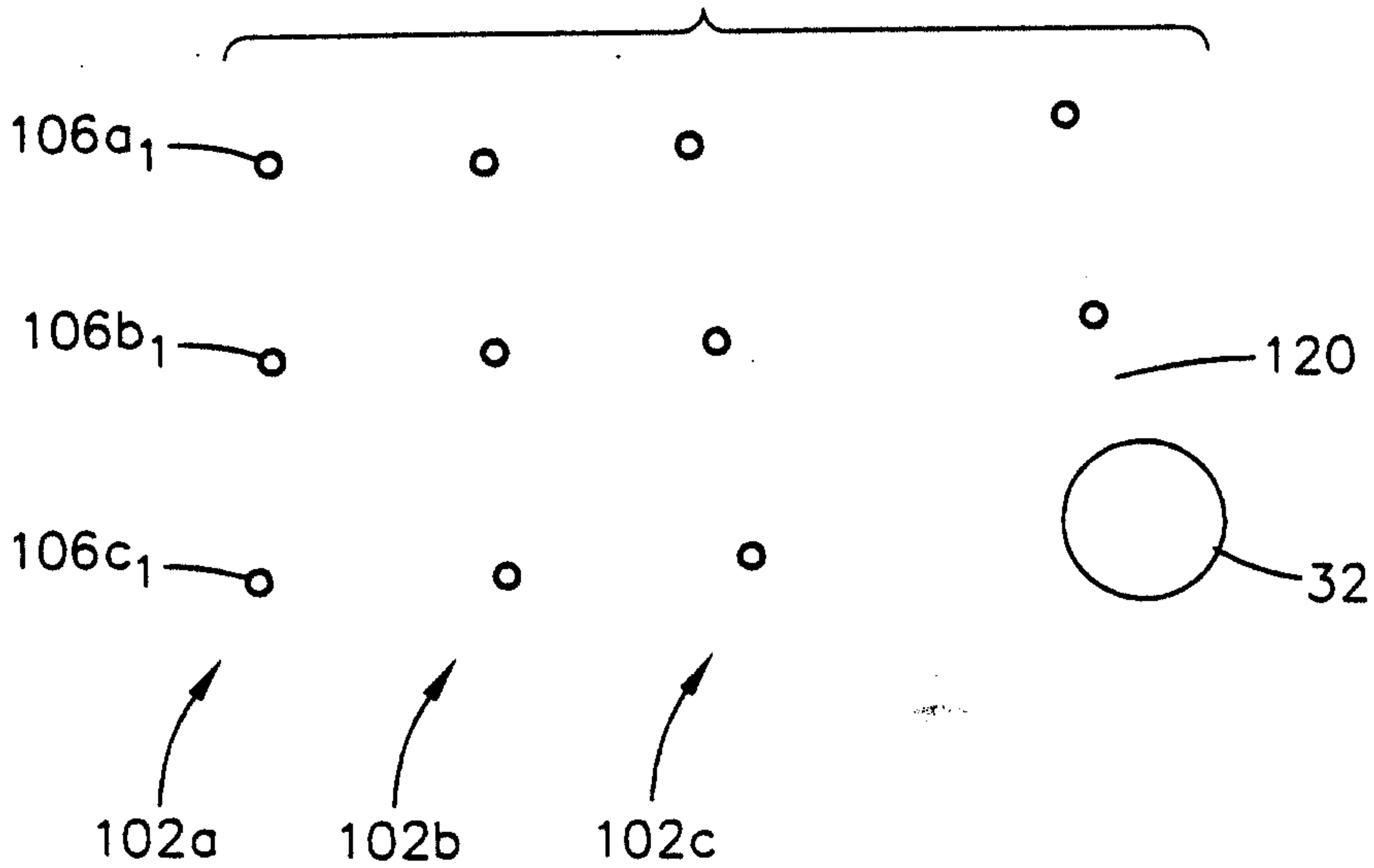

106a1
106b1
106c1
120
32
102a
102b
102c

FIG. 19

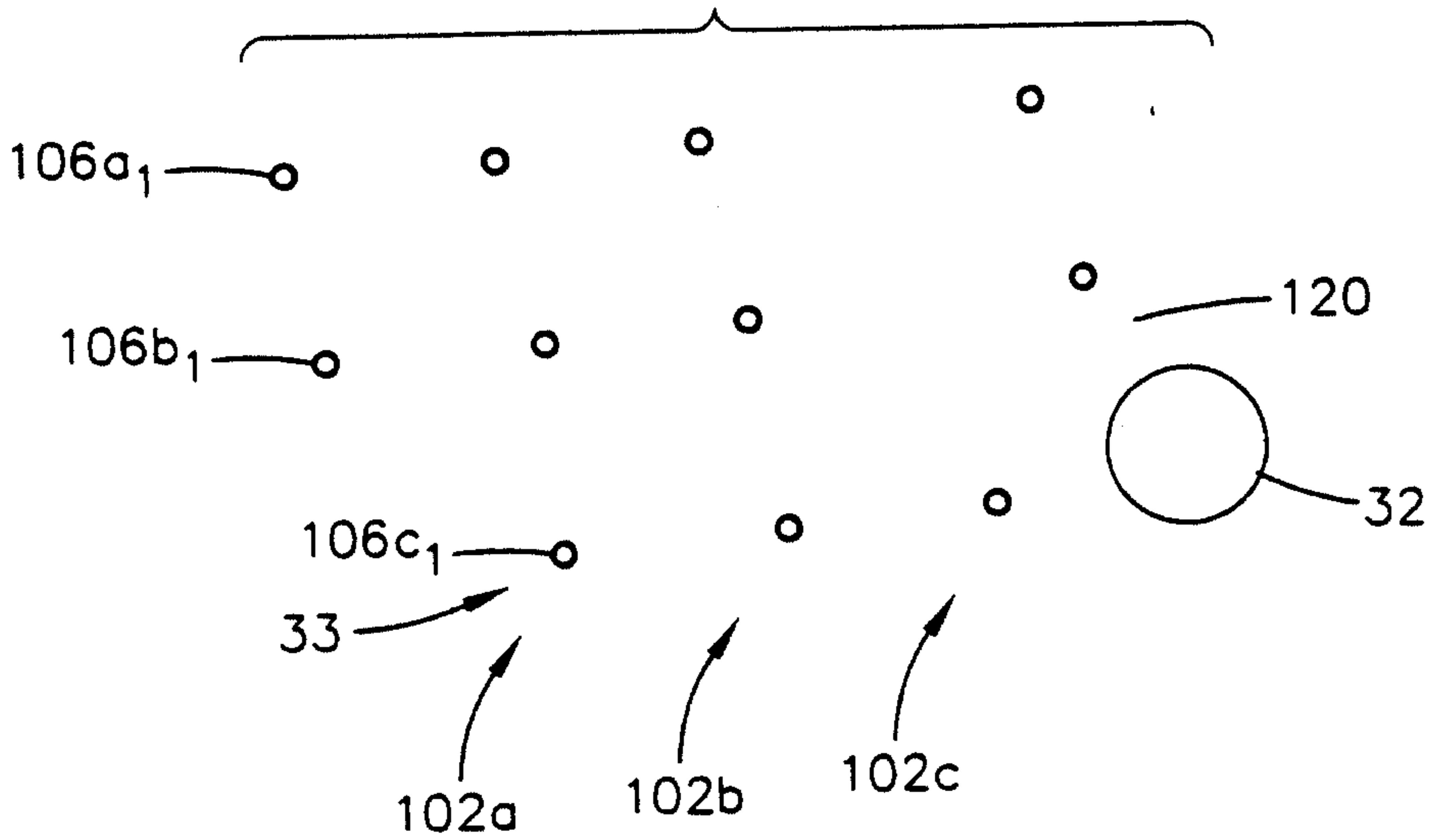

106a1
106b1
106c1
120
32
33
102a
102b
102c

FIG. 20

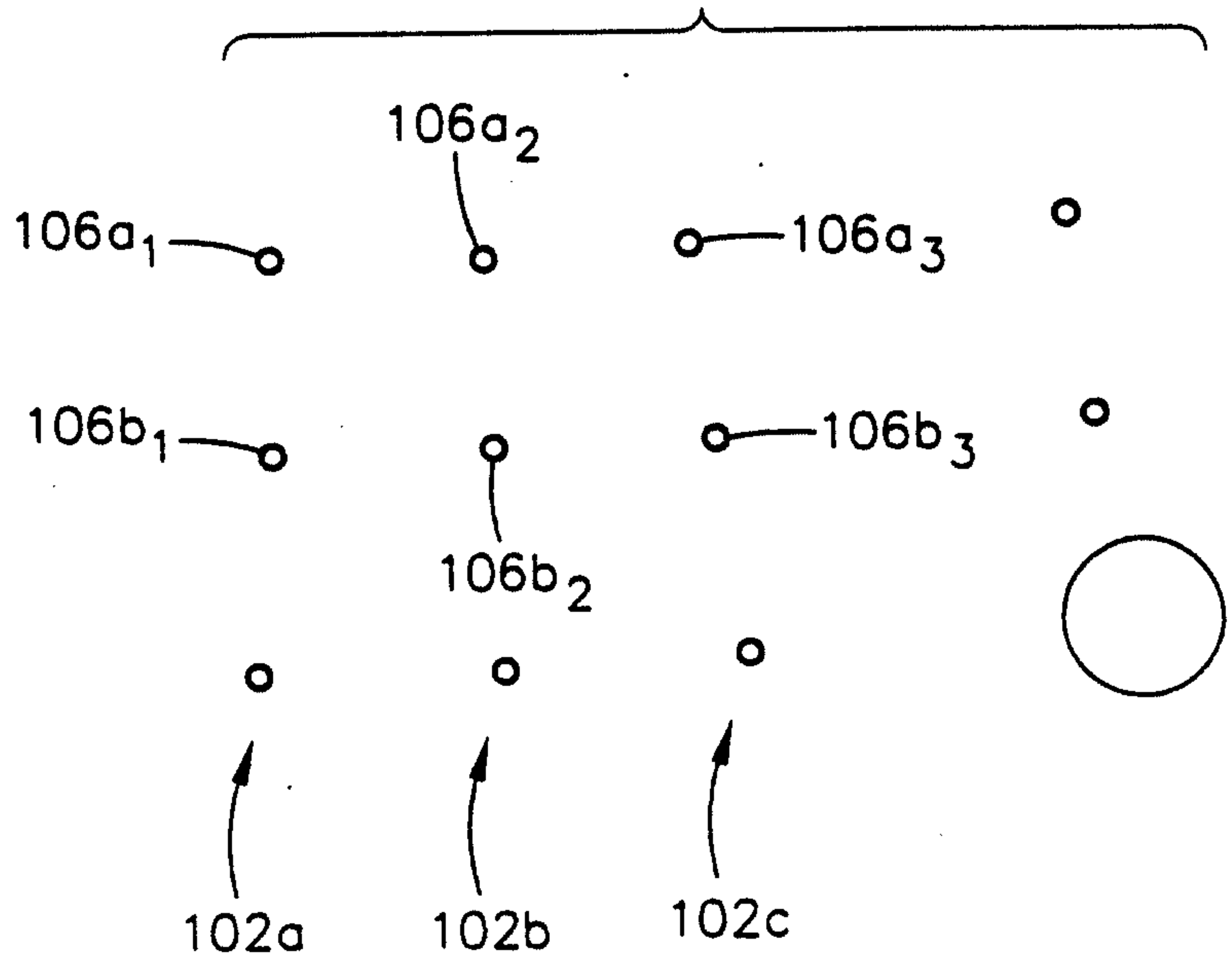
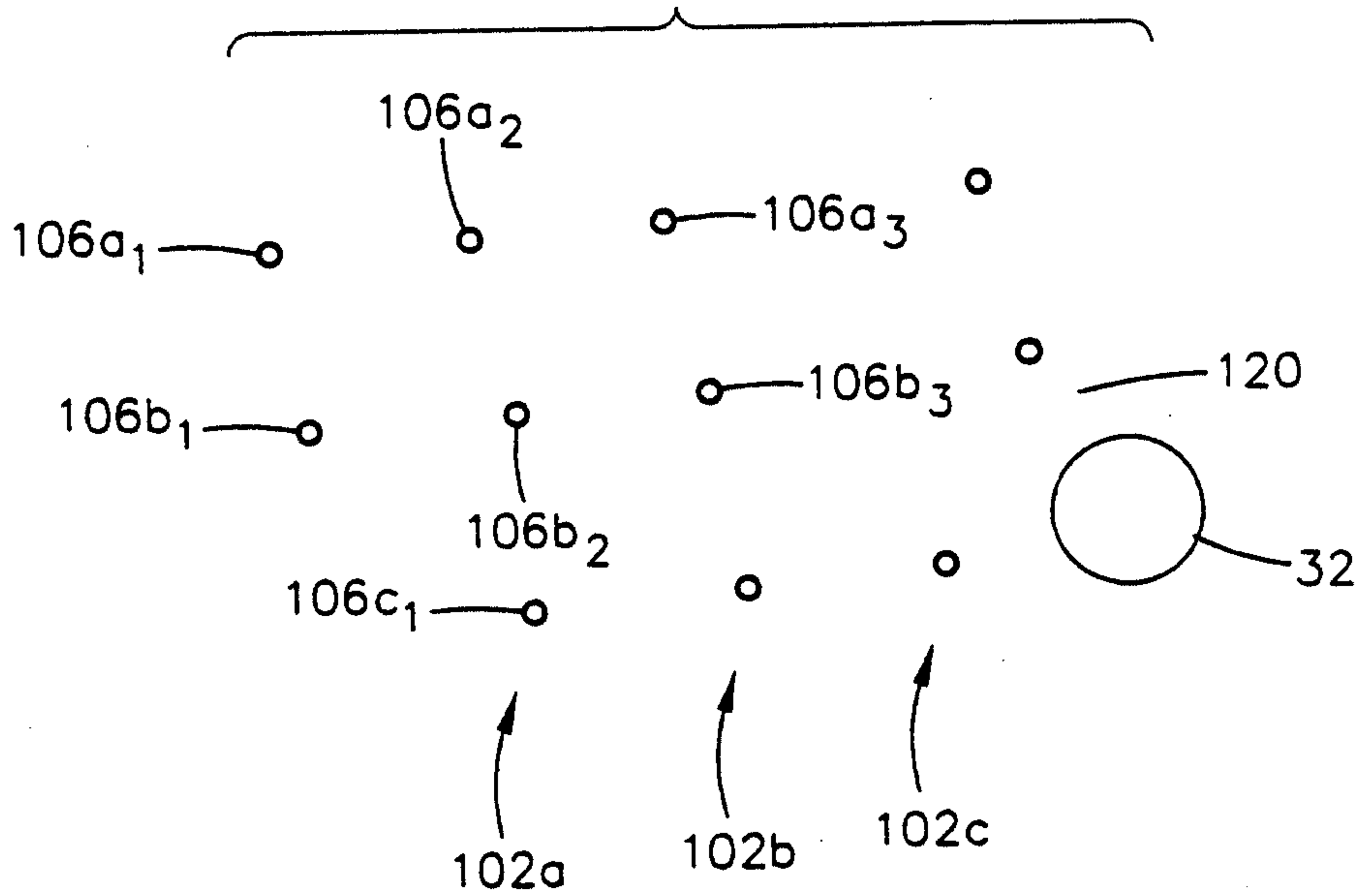

106a2
106a1
106a3
106b1
106b3
106b2
102a
102b
102c

FIG. 21


106a2
106a1
106a3
106b1
106b3
120
106b2
32
106c1
102a
102b
102c

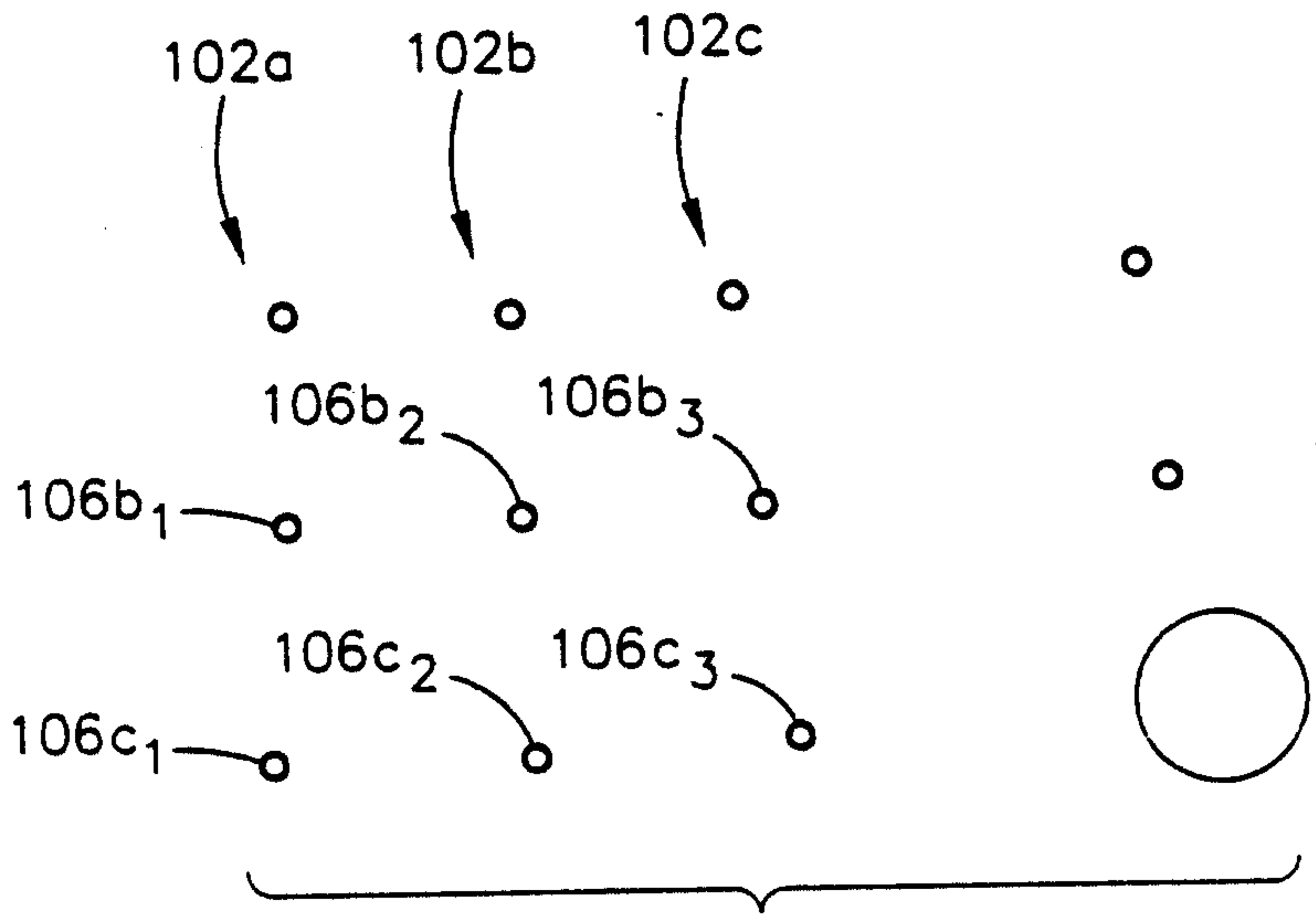

102a
102b
102c
106b1
106b2
106b3
106c1
106c2
106c3

FIG. 22

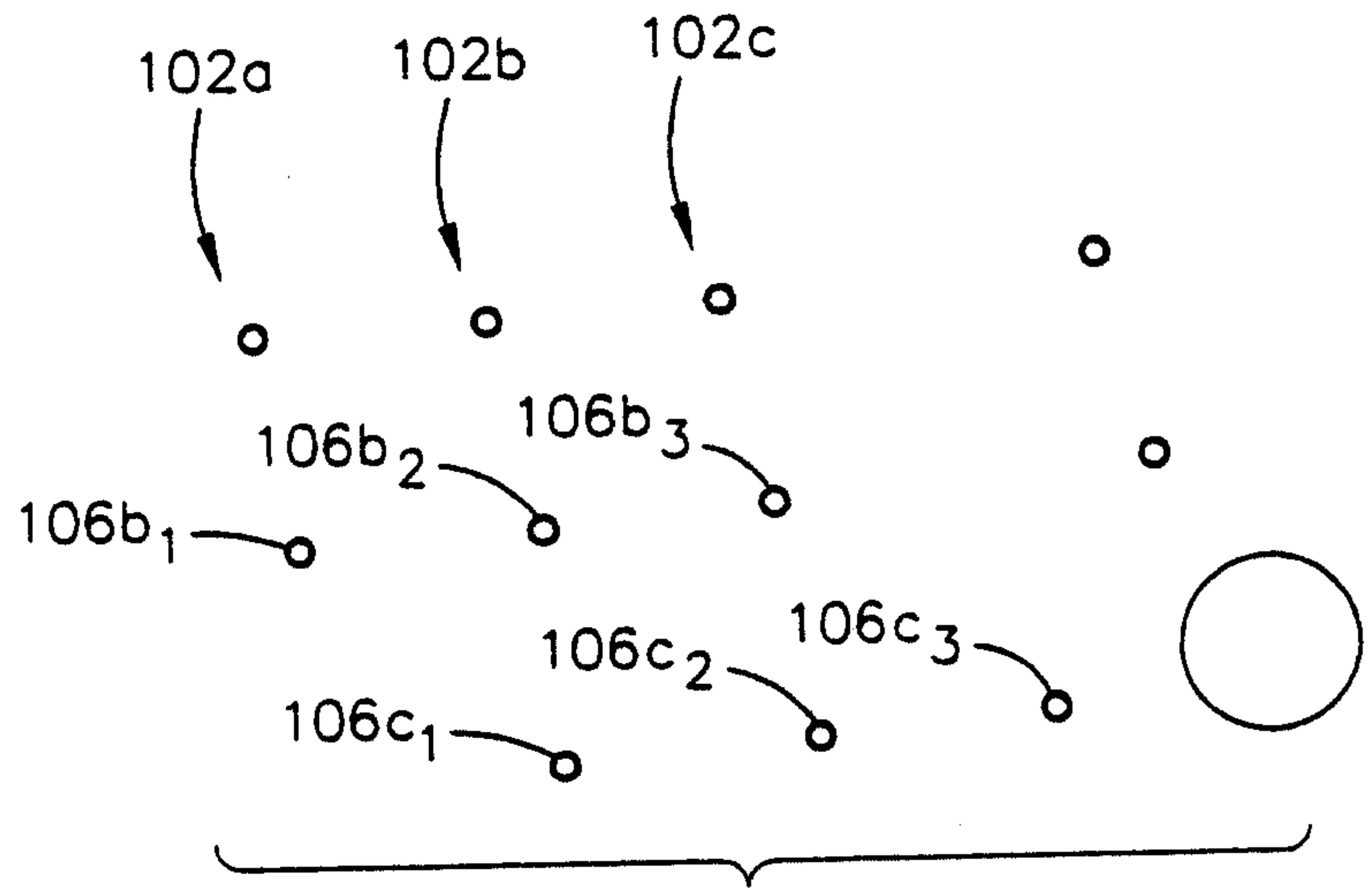
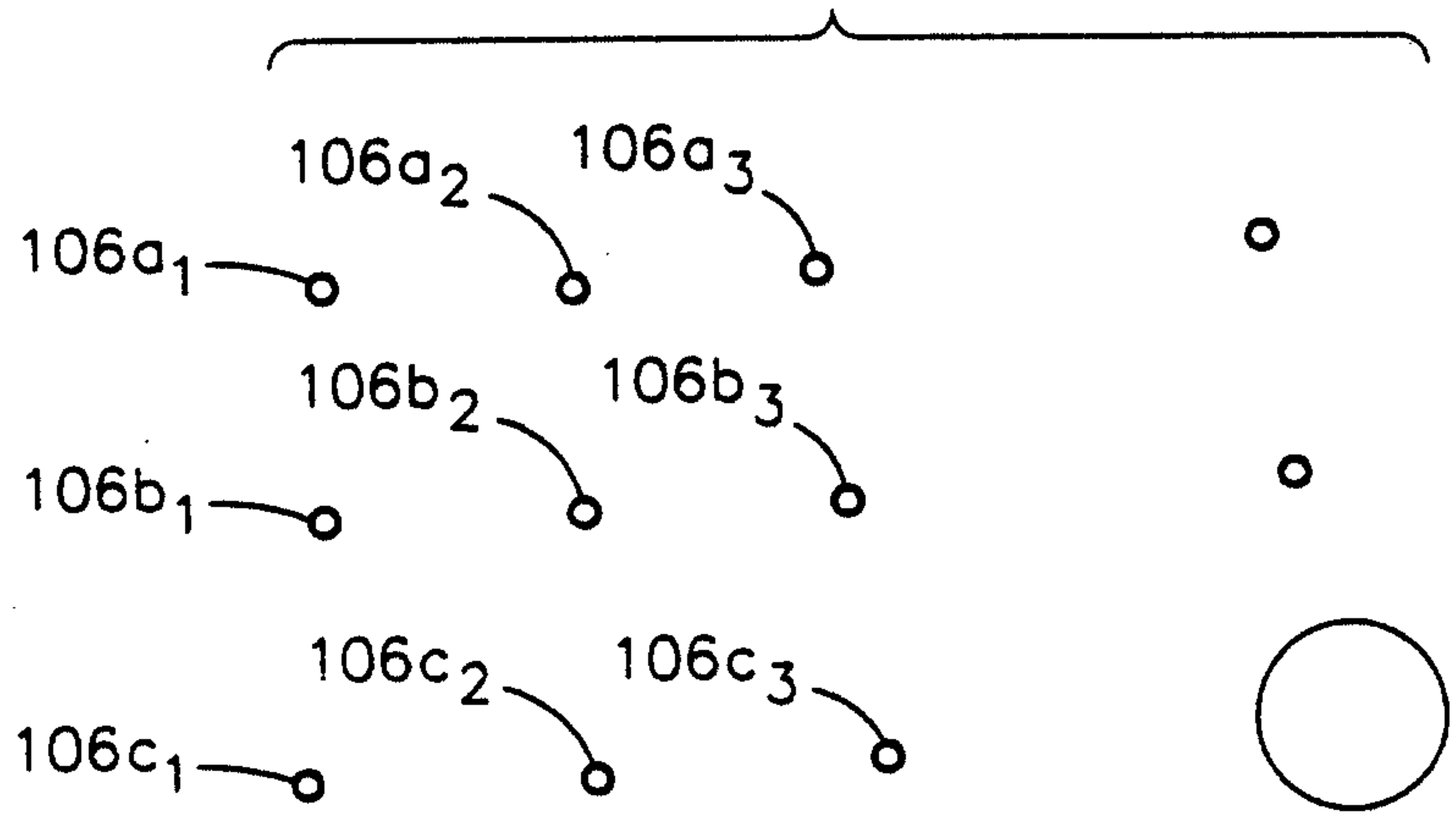

102a
102b
102c
106b1
106b2
106b3
106c1
106c2
106c3

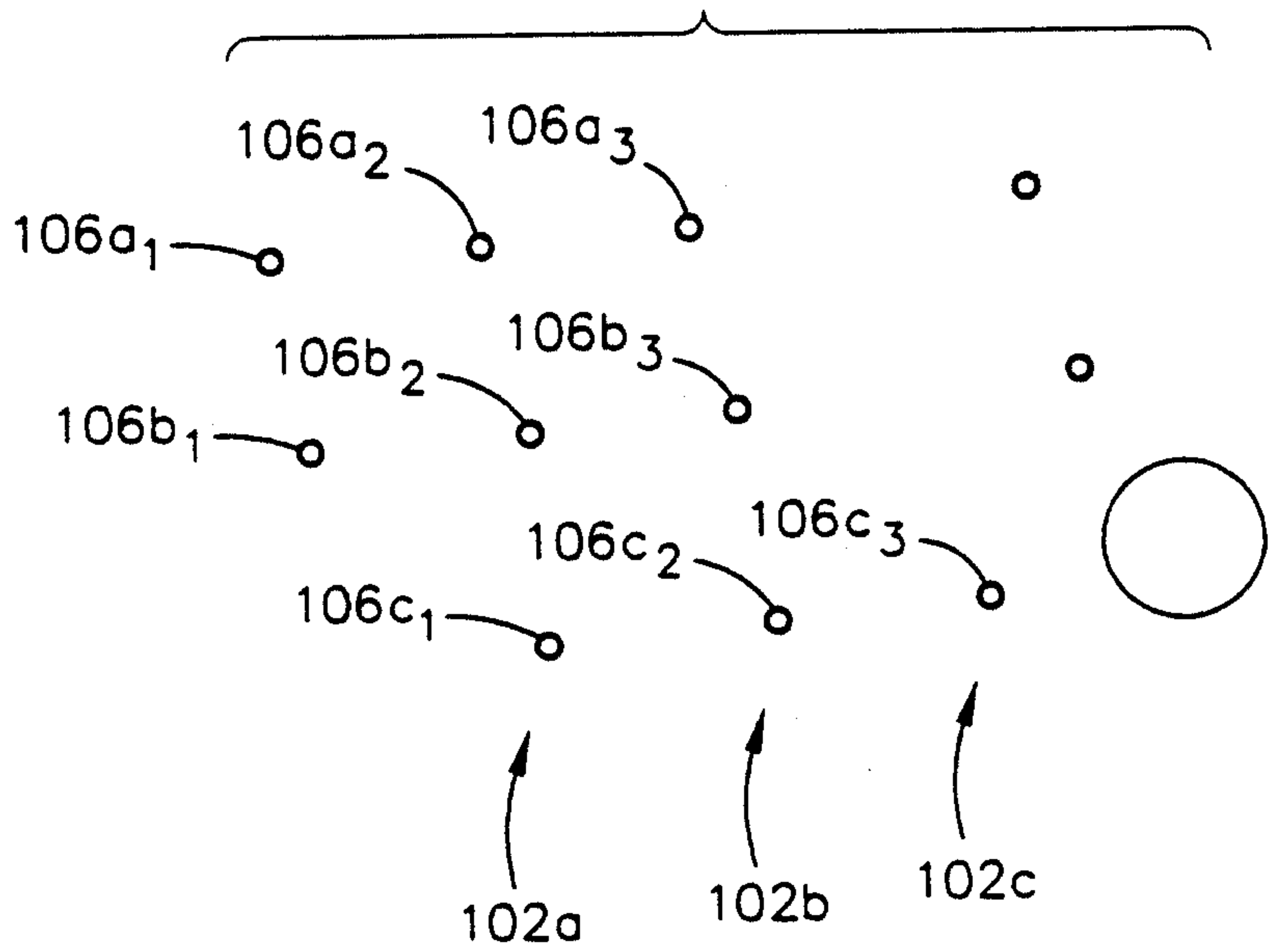
FIG. 23

FIG. 24



$106a_1$
$106a_2$
$106a_3$
$106b_1$
$106b_2$
$106b_3$
$106c_1$
$106c_2$
$106c_3$

FIG. 25



$106a_1$
$106a_2$
$106a_3$
$106b_1$
$106b_2$
$106b_3$
$106c_1$
$106c_2$
$106c_3$
102a
102b
102c

Point	World X	World Y	World Z	Error
1	29.450	-103.307	-233.802	1.038
2	30.831	-85.566	-265.861	1.256
3	-6.378	-103.560	-234.665	1.051
4	-6.133	-85.495	-266.727	1.239
5	-42.418	-104.266	-234.779	1.099
6	-43.248	-86.050	-266.888	1.226
7	46.192	14.770	-290.289	0.201
8	5.158	15.938	-291.271	0.005
9	-35.937	16.234	-291.519	0.121

FIG. 26

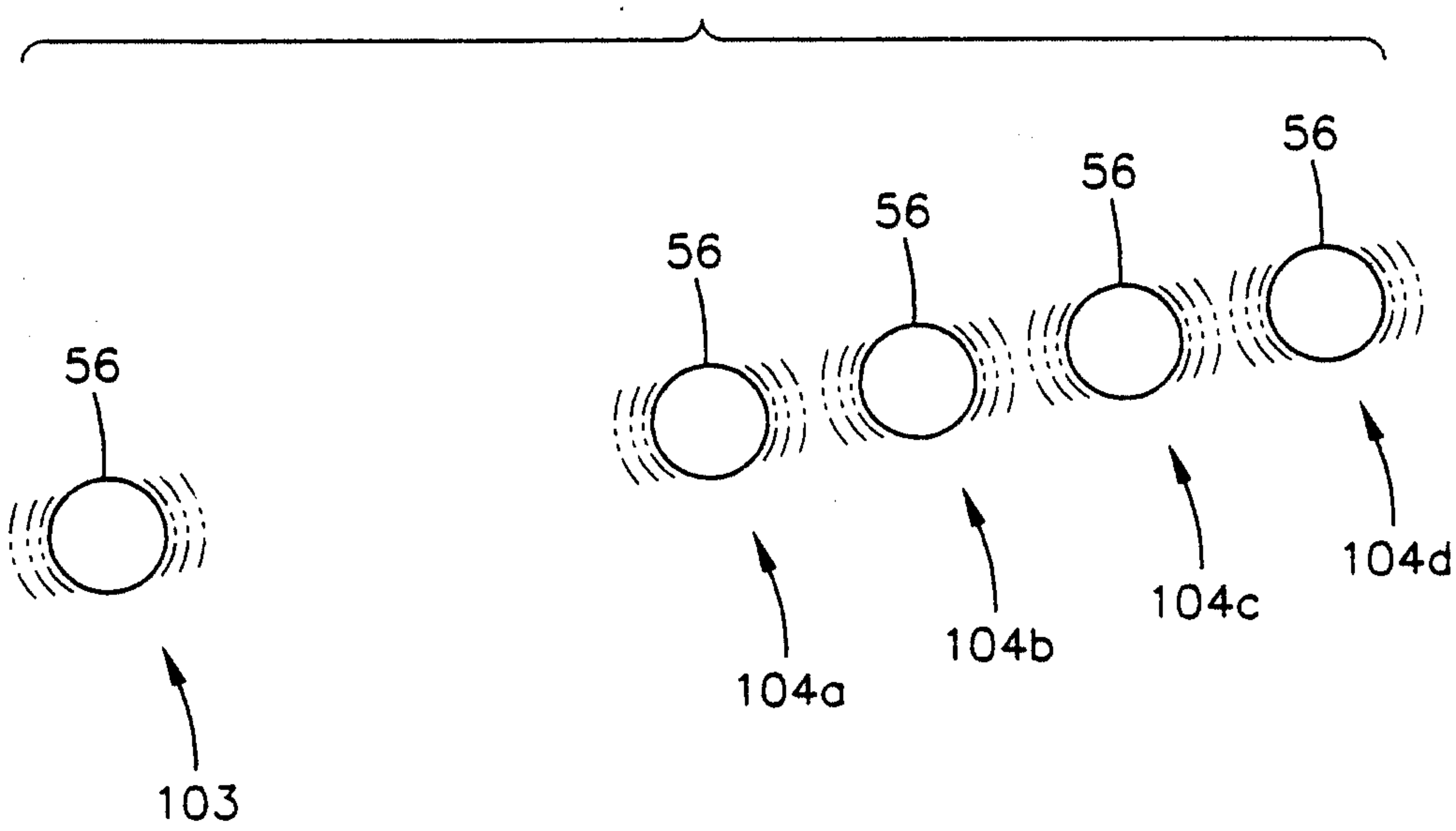


FIG. 27

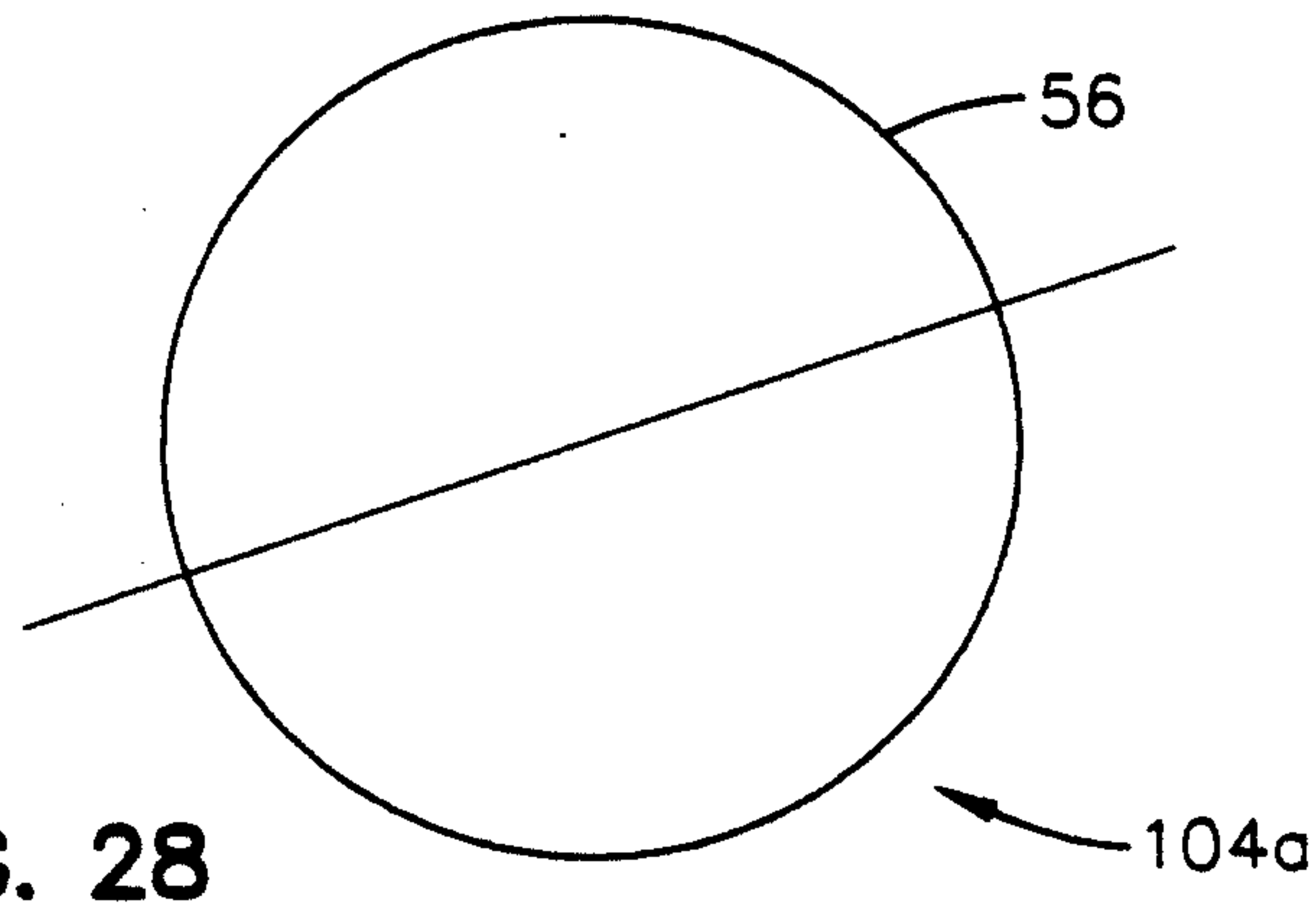

56
104a

FIG. 28

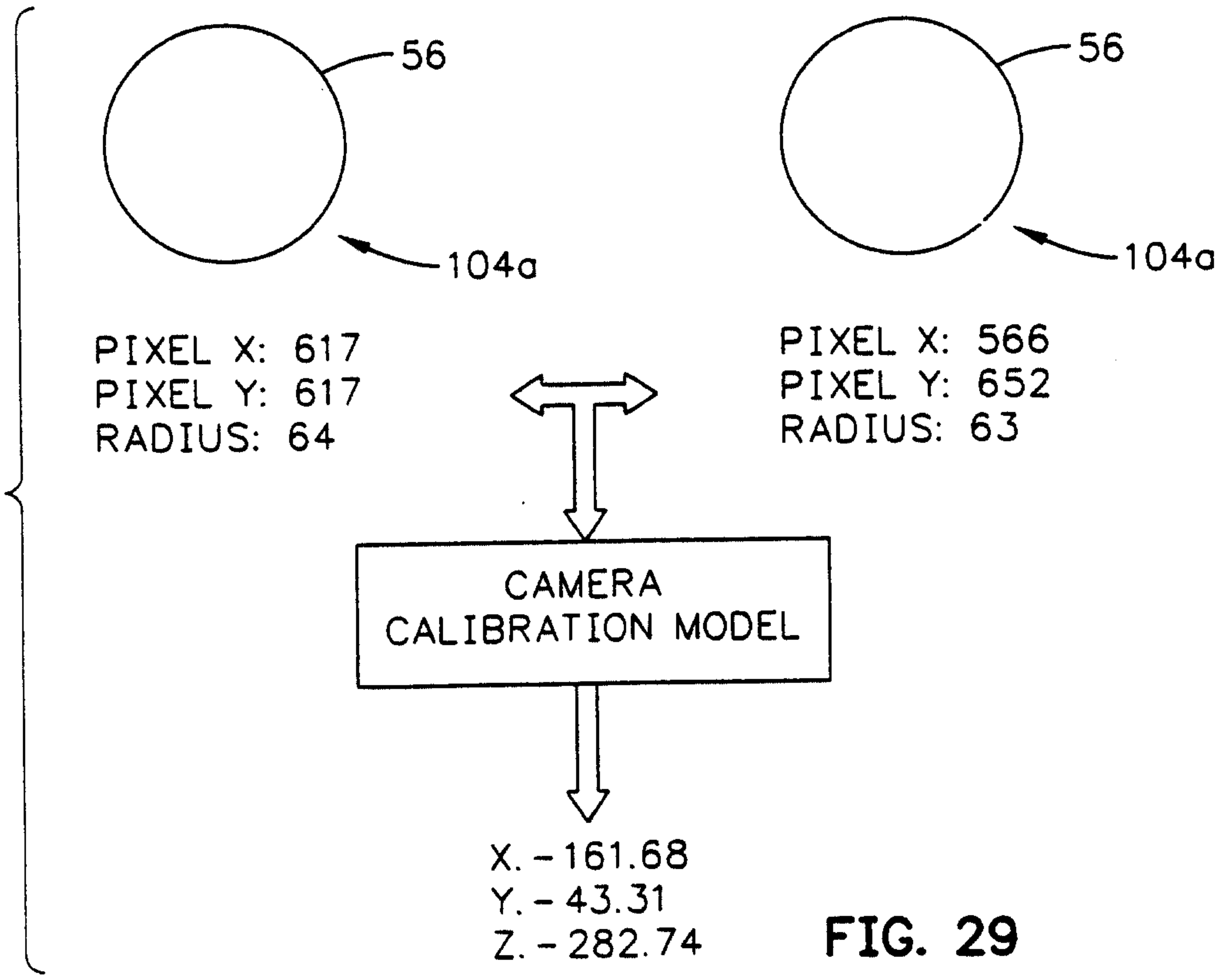
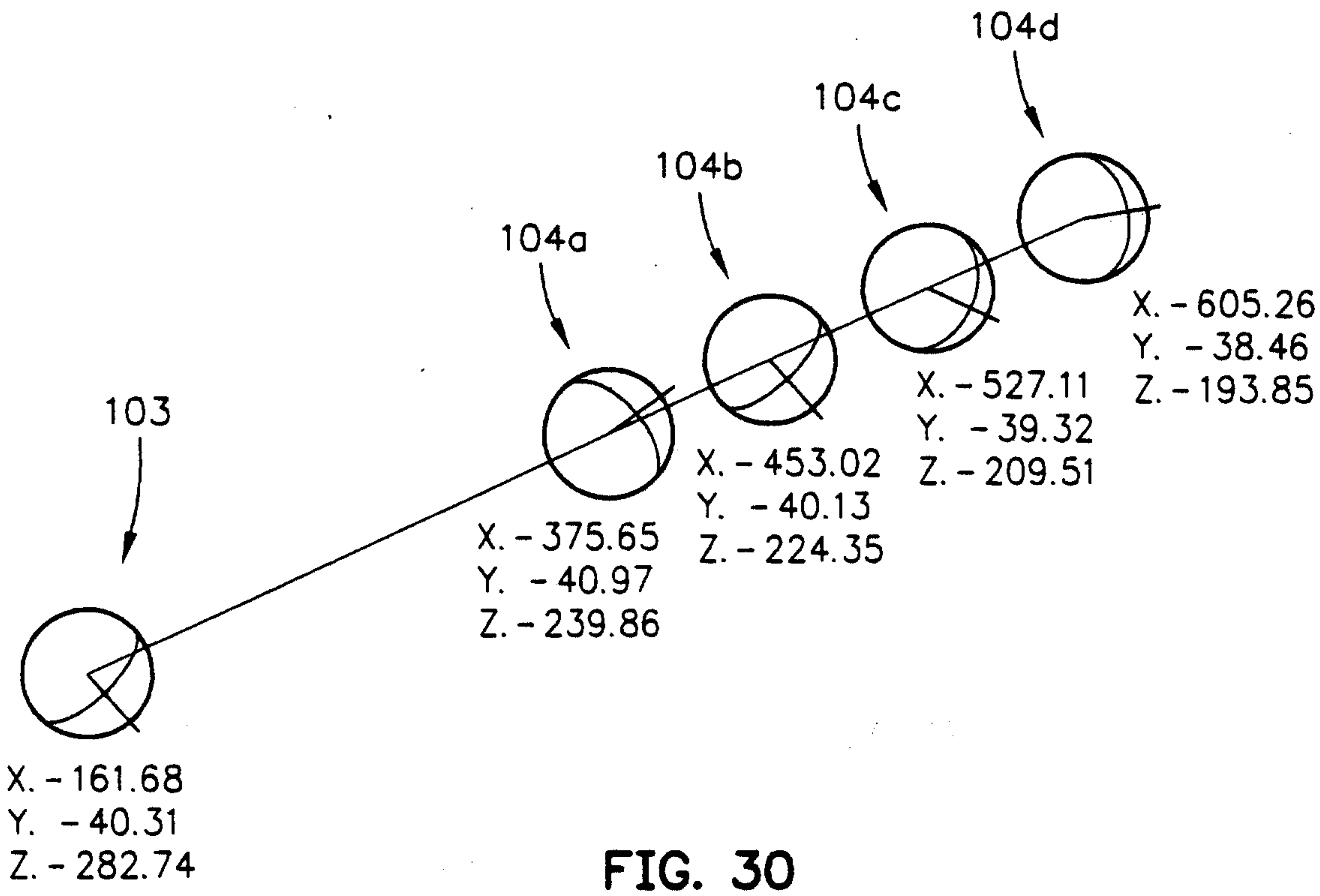
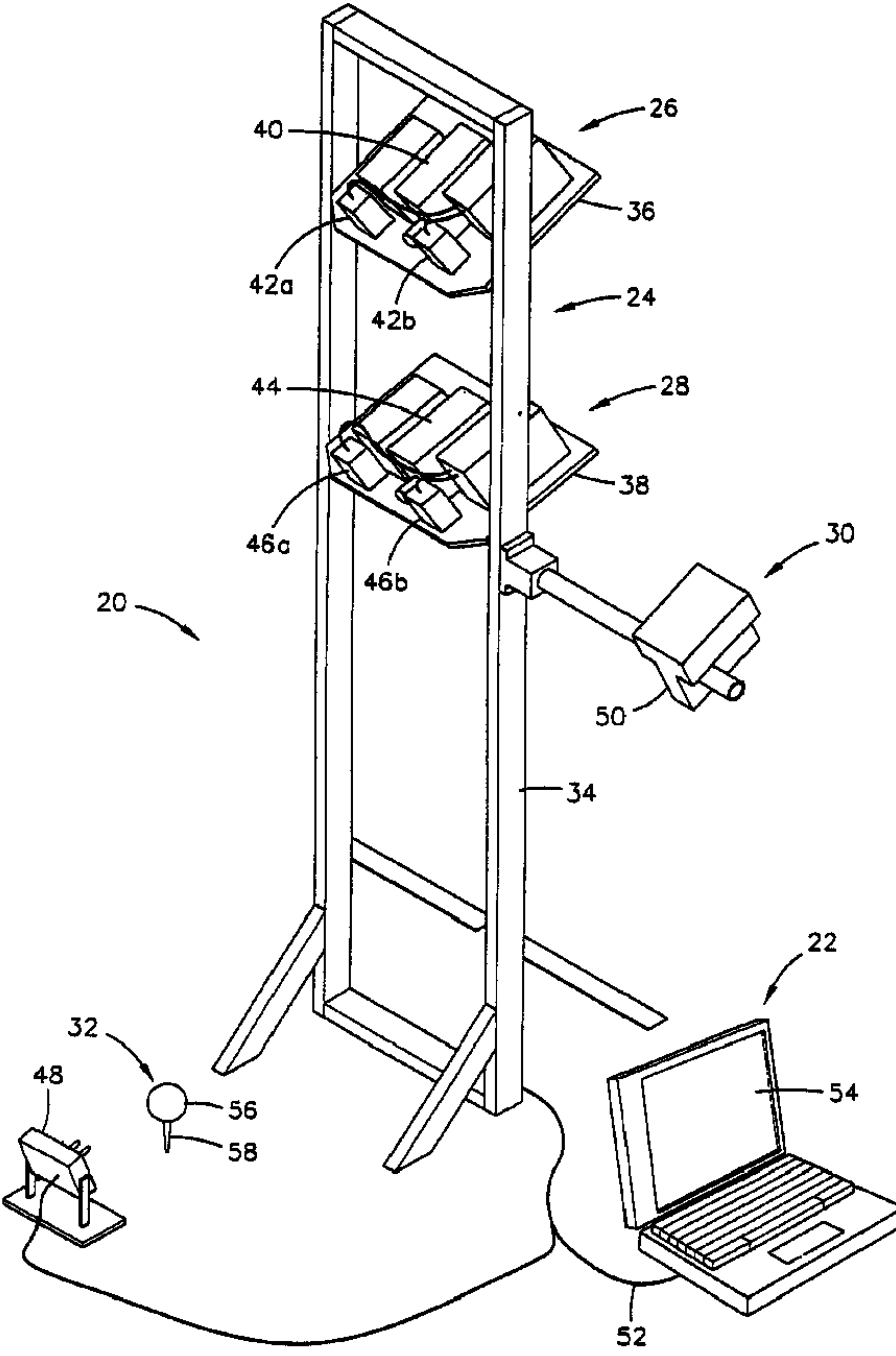

56
104a
PIXEL X: 617
PIXEL Y: 617
RADIUS: 64
56
104a
PIXEL X: 566
PIXEL Y: 652
RADIUS: 63
CAMERA
CALIBRATION MODEL
X. - 161.68
Y. - 43.31
Z. - 282.74

FIG. 29



104d
104c
104b
104a
103
X. - 605.26
Y. - 38.46
Z. - 193.85
X. - 527.11
Y. - 39.32
Z. - 209.51
X. - 453.02
Y. - 40.13
Z. - 224.35
X. - 375.65
Y. - 40.97
Z. - 239.86
X. - 161.68
Y. - 40.31
Z. - 282.74

FIG. 30


26
40
36
42a
42b
24
44
28
38
46a
46b
30
20
50
34
22
32
48
56
54
58
52