Feb. 9, 1937. F. M. POTTENGER, JR., ET AL 2,070,178

AIRPLANE NAVIGATING APPARATUS

Filed June 6, 1934 8 Sheets-Sheet 1

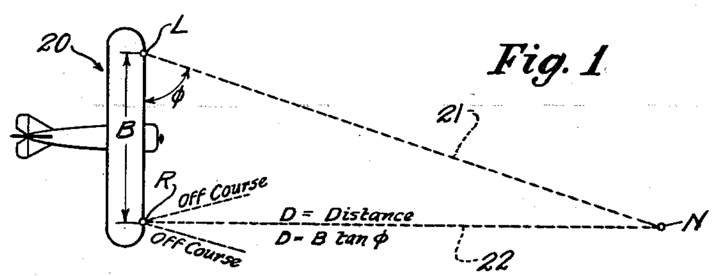

Fig. 1

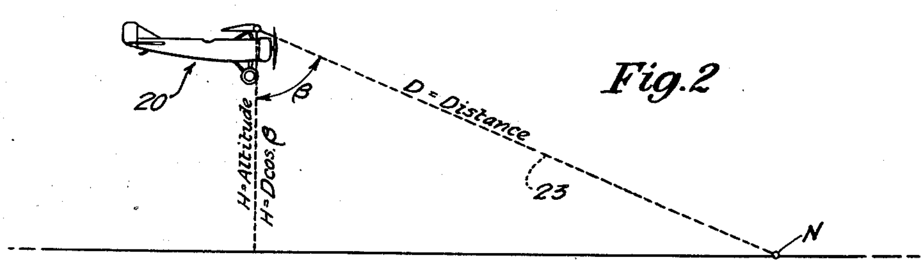

Fig. 2

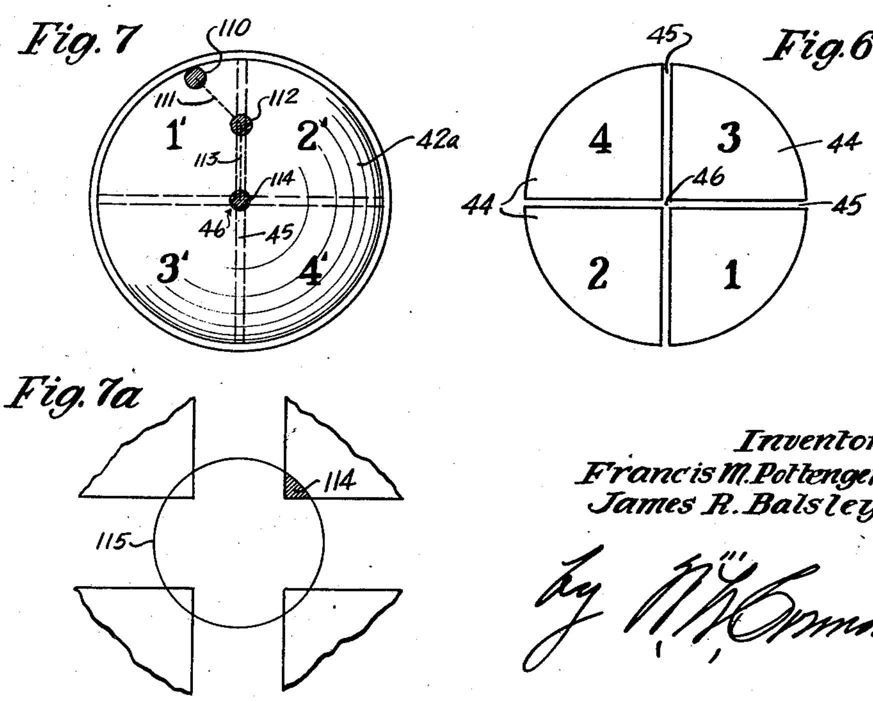

Fig. 7

Fig. 6

Fig. 7a

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AIRPLANE NAVIGATING APPARATUS

Filed June 6, 1934 8 Sheets-Sheet 2

Fig. 4

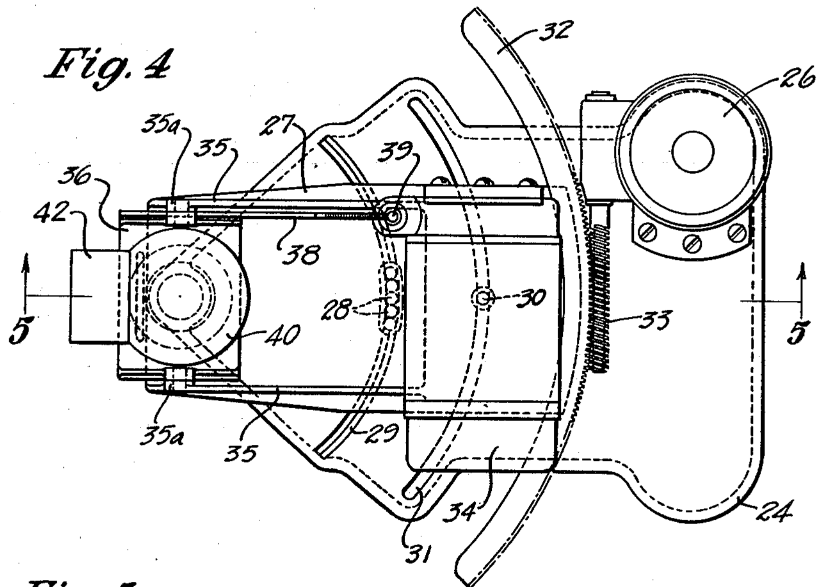
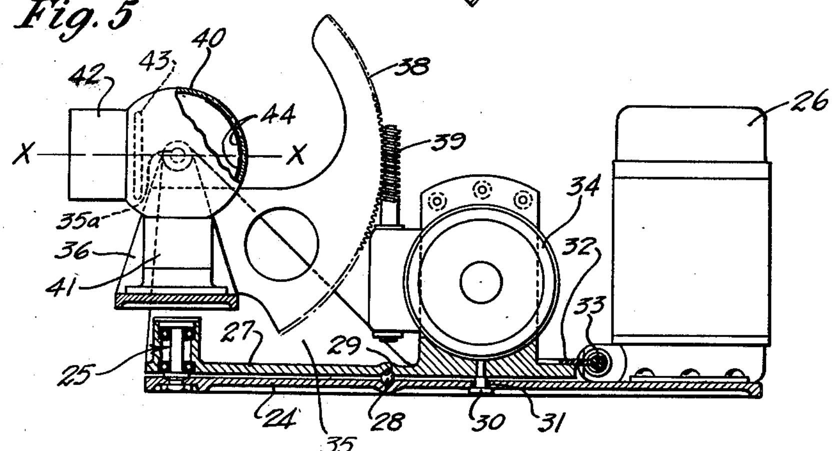


Fig. 5



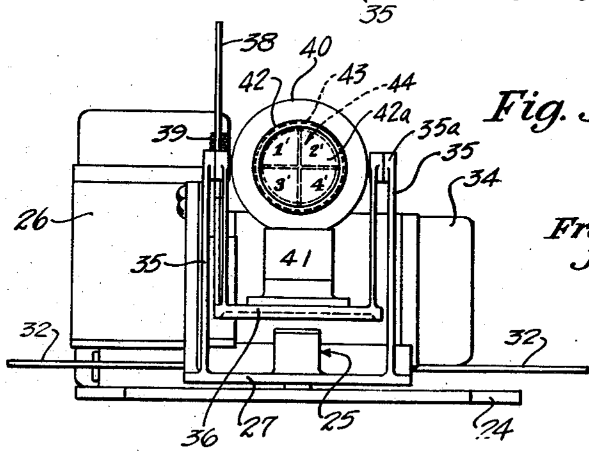


Fig. 3

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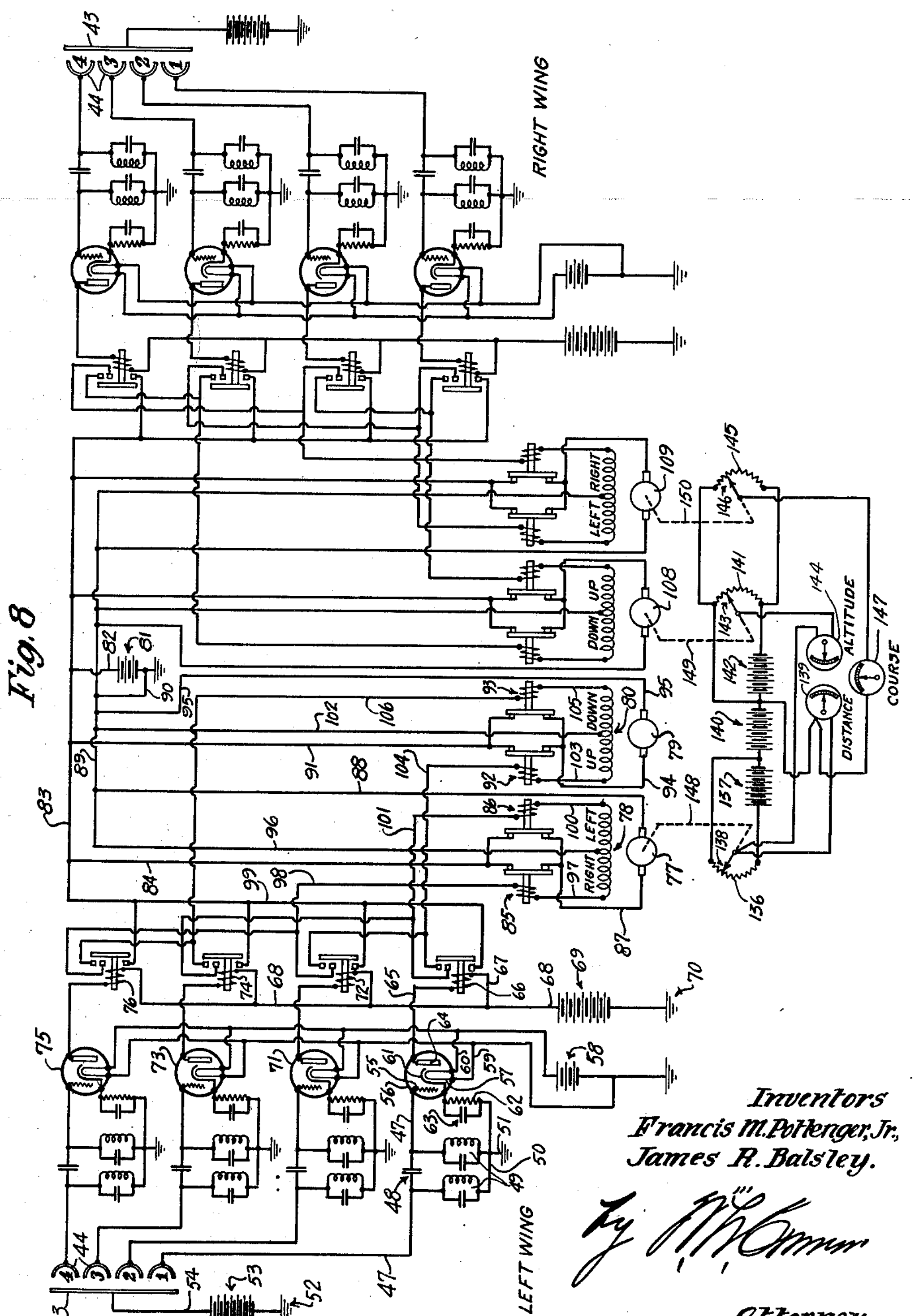
AIRPLANE NAVIGATING APPARATUS

Filed June 6, 1934 8 Sheets-Sheet 3



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Feb. 9, 1937. F. M. POTTENGER, JR., ET AL 2,070,178

AIRPLANE NAVIGATING APPARATUS

Filed June 6, 1934 8 Sheets-Sheet 4

Fig. 9

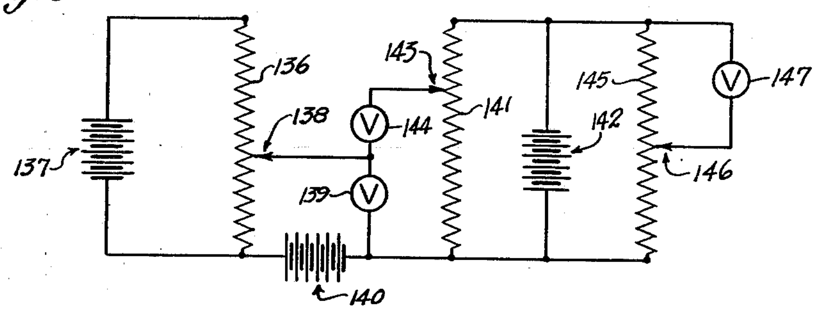

Fig. 11

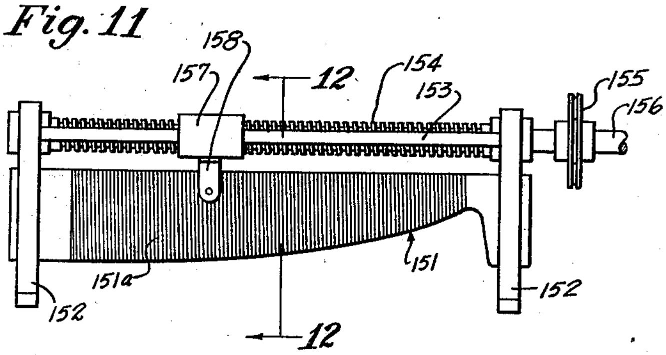

Fig. 12

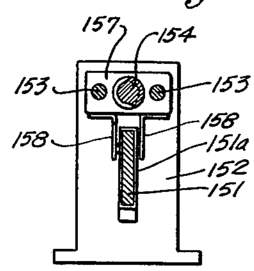

Fig. 13

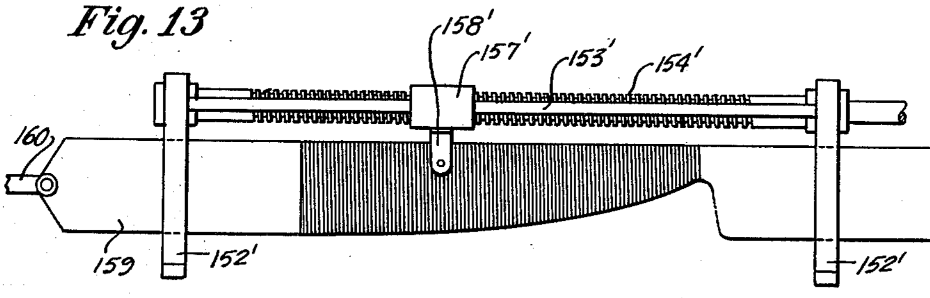

Fig. 10

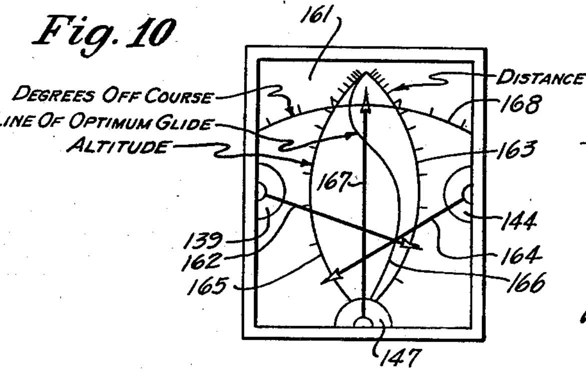

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Fig. 17

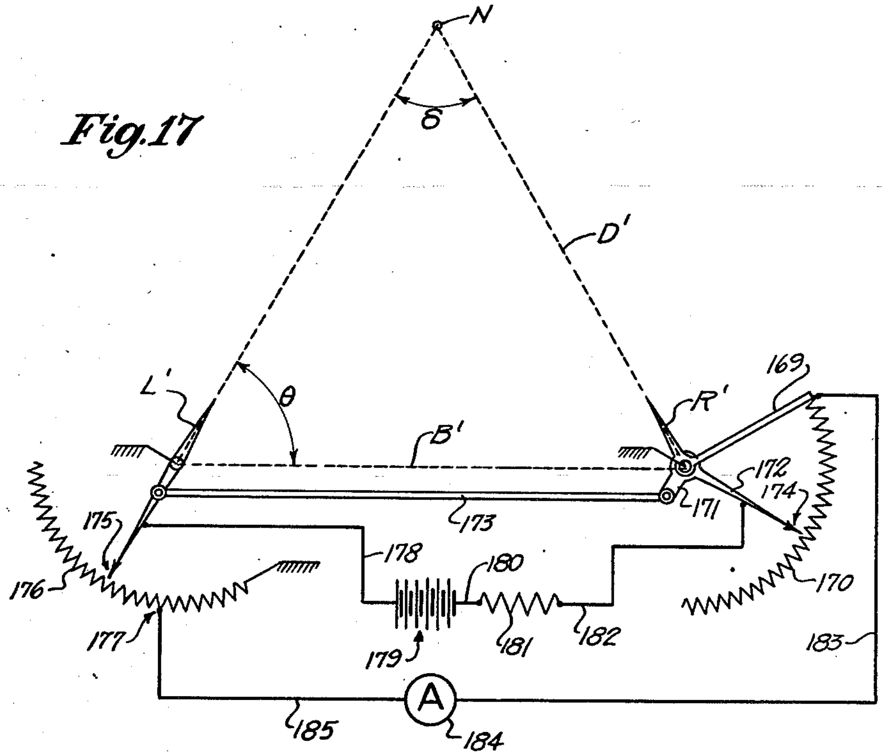


Fig. 14

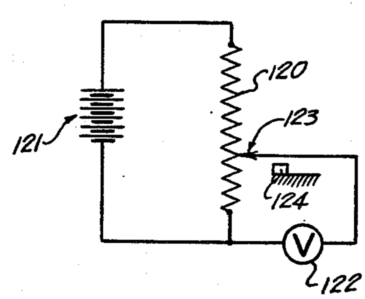


Fig. 15

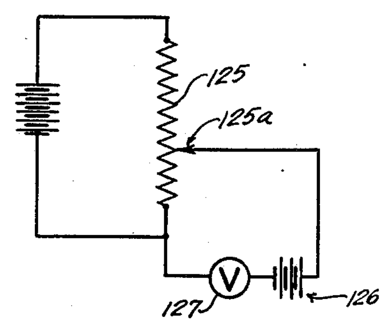
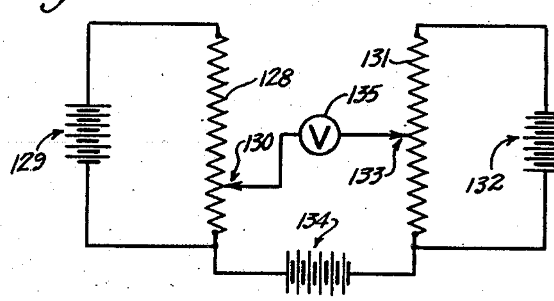


Fig. 16



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AIRPLANE NAVIGATING APPARATUS

Filed June 6, 1934 8 Sheets-Sheet 6

Fig. 18

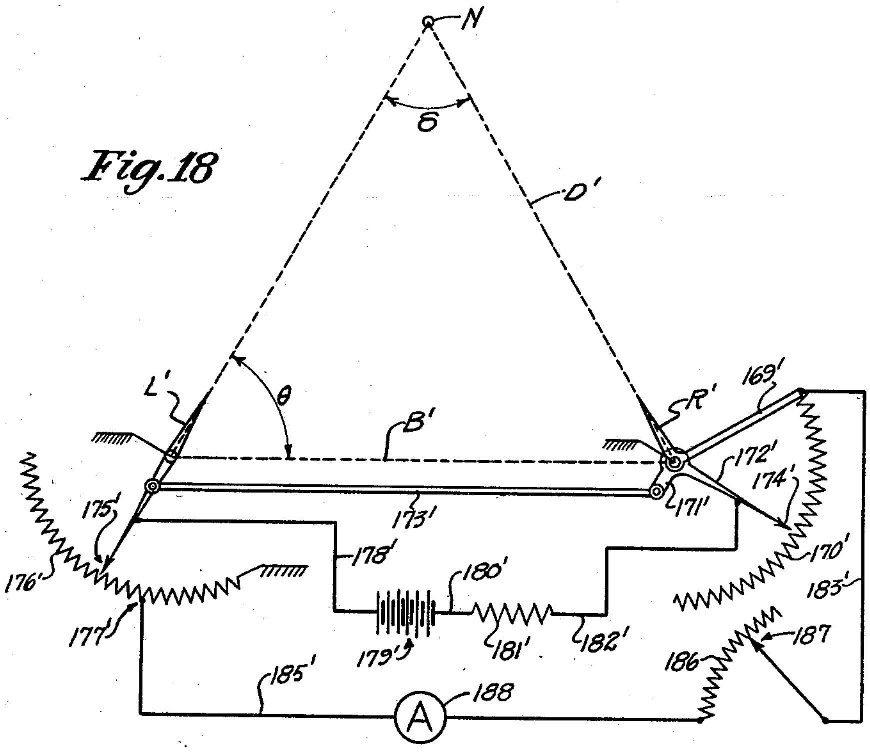


Fig. 20

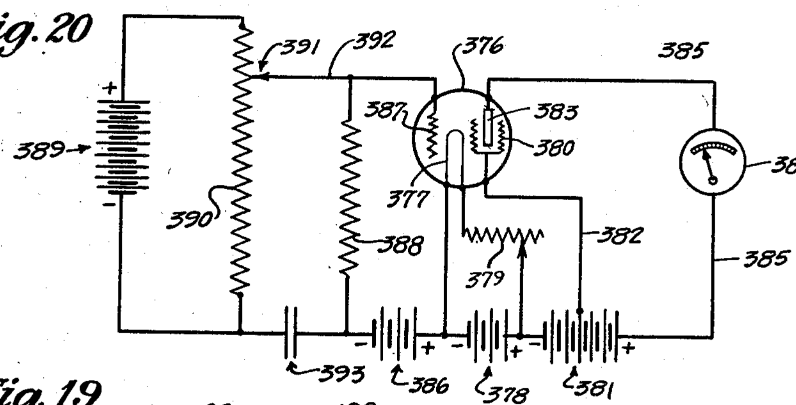
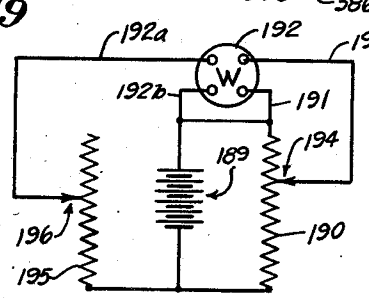


Fig. 19



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Feb. 9, 1937. F. M. POTTENGER, JR., ET AL 2,070,178

AIRPLANE NAVIGATING APPARATUS

Filed June 6, 1934 8 Sheets-Sheet 7

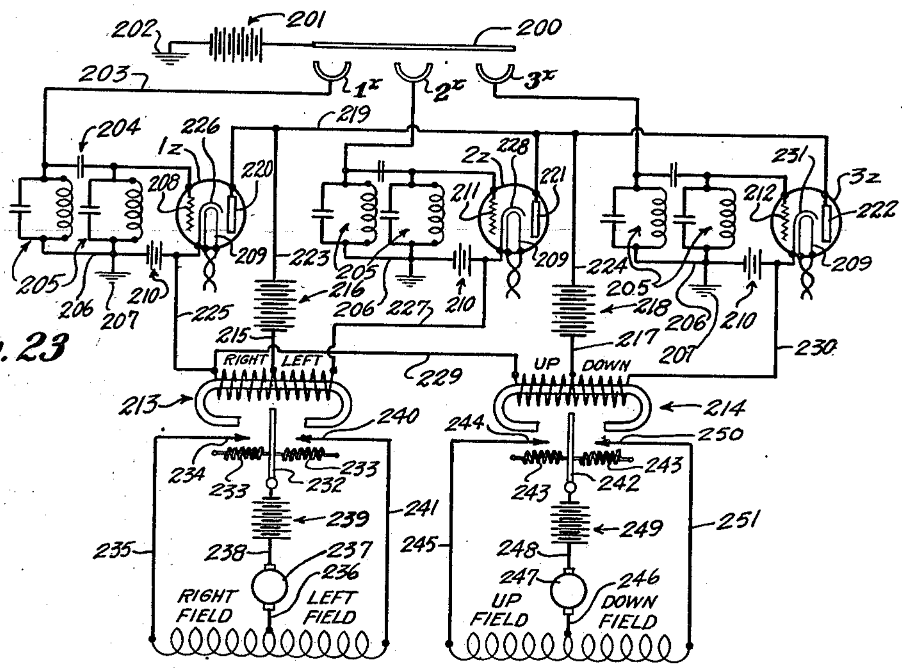


Fig. 23

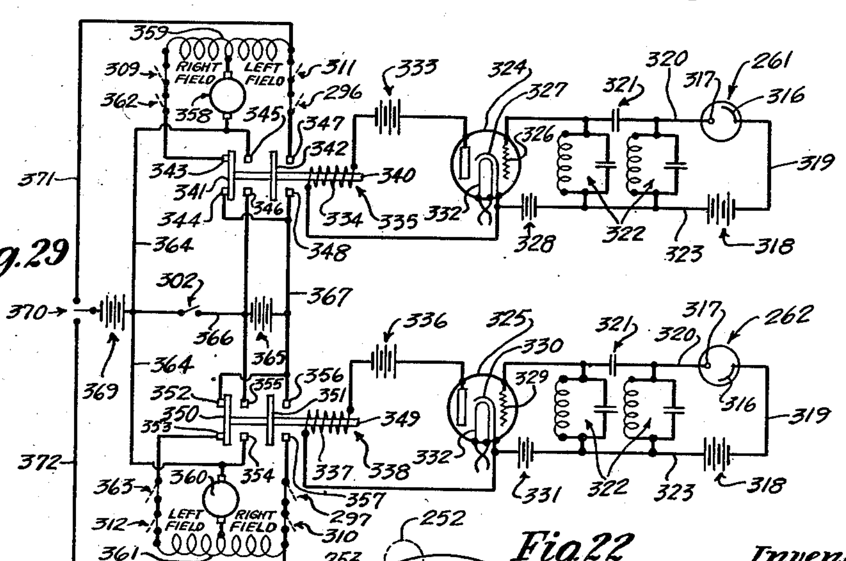


Fig. 29

Fig. 21

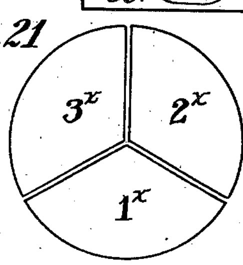
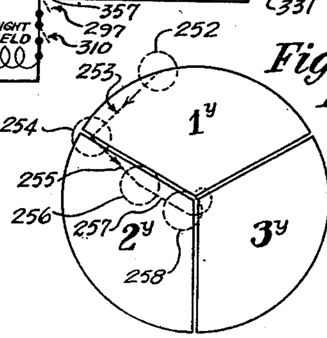


Fig. 22



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AIRPLANE NAVIGATING APPARATUS

Filed June 6, 1934 8 Sheets-Sheet 8

Fig. 24

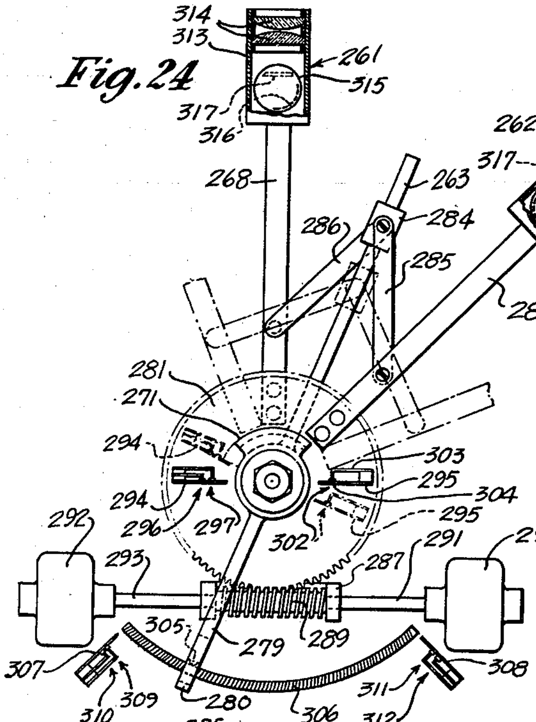


Fig. 28

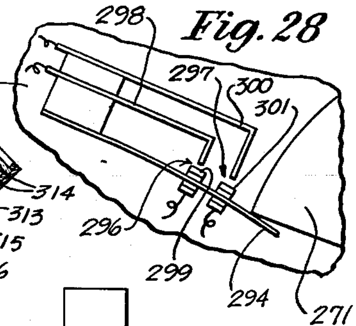


Fig. 25

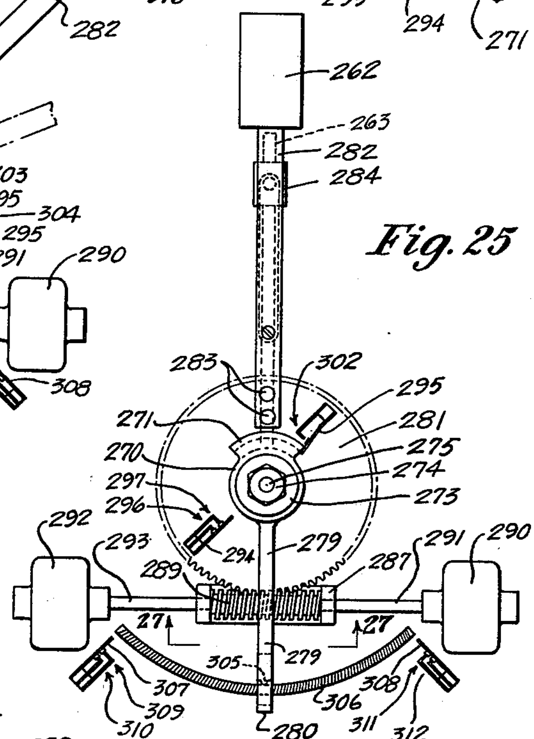


Fig. 27

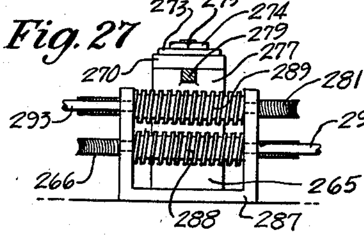


Fig. 26

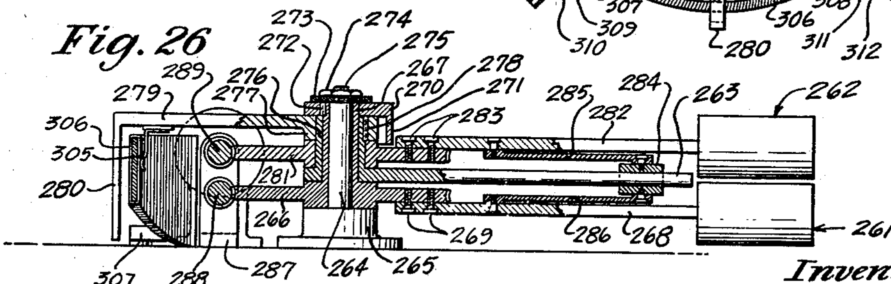
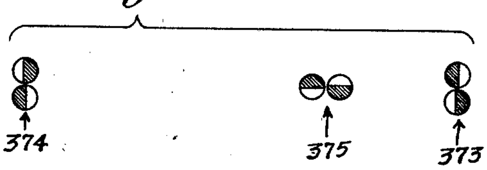


Fig. 30



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Patented Feb. 9, 1937 2,070,178

UNITED STATES PATENT OFFICE

2,070,178

AIRPLANE NAVIGATING APPARATUS

Francis M. Pottenger, Jr., Monrovia, and James R. Balsley, La Canada, Calif.; said Balsley assignor of twelve and one-half per cent to Paul Whittier and twelve and one-half per cent to Keith Scott, both of Los Angeles, Calif.

Application June 6, 1934, Serial No. 729,216

22 Claims. (Cl. 250—11)

Our invention relates to devices for ascertaining the position of one point in space with respect to a second point, having special reference to such devices incorporated in navigation apparatus, and is directed particularly to an automatic position-indicating system involving calculation by triangulation and providing guidance for the safe landing of aircraft under conditions of substantially no visibility.

The application of such a device to "blind flying" involves numerous difficulties, the solution of which demonstrates certain objects and advantages of our invention as will become apparent in our later detailed description.

In general, the requisites of such apparatus for successful application to airplane navigation are: first, that the apparatus be independent of weather and light conditions; second, that the apparatus be accurate within certain limits and be absolutely dependable; third, that the apparatus function with sufficient rapidity to keep pace with the continuous change in location of a speeding airplane; fourth, that the apparatus be fully automatic, requiring no manipulation or adjustment by the pilot; and, fifth, that the apparatus include a visual indicator that will clearly and conveniently reveal the position of the airplane either in units of distance from the landing field and altitude above the ground or reveal graphically the relation of the plane's position to a desired line of approach to the landing field, or both.

The disclosure of our invention may be approached by pointing out, in general terms, how we have met the above listed essentials.

First, we have made our apparatus independent of weather and light conditions by utilizing electromagnetic radiations such as infra-red rays, or other quasi-optical rays known to penetrate fog.

To meet the requirement of accuracy, we have provided for a relatively extensive base of triangulation; we have provided for electrical rather than mechanical interlocking connections; and, we have entirely eliminated the human equation from the functioning of the device. These provisions all have a bearing on the dependability of our system, and, in addition, we have provided for modulating the infra-red rays and making our apparatus selectively responsive to the modulated rays in order to avoid any possibility of interference from infra-red rays extraneous to our system.

Our apparatus keeps pace with the rapidly changing factors involved, because it functions electrically rather than mechanically.

To meet the fourth requirement, the characteristic of being automatic, in a system of measuration by triangulation involving electro-magnetic radiation, we have provided pointers that will automatically be trained on the source of the radiation and have further provided automatic means for deriving the distance in question from the angular positions of these pointers. We have made the pointers automatic by associating with them photoelectric cells having circuits selectively responsive to the electro-magnetic radiation, and we have provided automatic calculation by utilizing certain characteristics of electric circuits, as will be more fully disclosed hereafter.

Finally, the position continuously reckoned by our apparatus is continuously indicated to the pilot in a manner that reveals not only the altitude of the airplane and the distance from the airport, but also reveals the relation of the plane's position to a desired line of approach to the airport.

The objects and advantages of our invention, indicated by the above summary, will become more apparent in the detailed description to follow, as will certain other features illustrated by our preferred embodiment of the invention.

In the accompanying drawings:

Fig. 1 diagrammatically represents the plan view of an airplane approaching a beacon at an airport;

Fig. 2 diagrammatically represents the side view of an airplane approaching a beacon at an airport;

Fig. 3 is the front elevation of a pointer, with its associated photoelectric eye;

Fig. 4 is a plan view of Fig. 3;

Fig. 5 is a central longitudinal section taken as indicated by the line 5—5 of Fig. 4;

Fig. 6 diagrammatically presents the arrangement of quadrant cathodes in a photoelectric eye;

Fig. 7 is a diagram representing the outer lens of the photoelectric eye divided into quadrants for the purposes of description;

Fig. 7*a* is an enlarged central portion of Fig. 7;

Fig. 8 is a schematic arrangement of our system, showing the inter-relationships of the moving parts and the electric circuits involved;

Fig. 9 is a simplified diagram of certain circuits in Fig. 8;

Fig. 10 is a suggested arrangement of the indicating instruments on a panel or chart:

Fig. 11 is the side elevation of a typical resistor employed in our apparatus;

Fig. 12 is a transverse section taken as indicated by the lines 12—12 of Fig. 11;

Fig. 13 is the side elevation of a resistor arranged for compensating movement;

Figs. 14, 15 and 16 are diagrams of circuits arranged for calculation by voltage measurements;

Figs. 17 and 18 are diagrams of circuits arranged for calculation by current measurements;

Fig. 19 is a diagram of a circuit for calculation by both voltage and current measurements;

Fig. 20 is a diagram of an electrical arrangement for ground speed indication;

Fig. 21 indicates the arrangement of cathodes in a second form of photoelectric eye in a pointer construction;

Fig. 22 is a diagram of the outer lens of the eye as divided into sectors corresponding to the cathodes of Fig. 21;

Fig. 23 is a wiring diagram of the circuits involved in this second form of pointer;

Fig. 24 is a plan view of a third form of pointer involving two arms here shown spread apart;

Fig. 25 is a similar view showing the two arms closed together in their normal positions;

Fig. 26 is a longitudinal section through Fig. 25;

Fig. 27 is a fragmentary transverse section taken as indicated by line 27—27 of Fig. 25;

Fig. 28 is an enlarged view of a switch construction in this third form of pointer;

Fig. 29 is a wiring diagram showing the circuits used in this third form of eye; and

Fig. 30 is a diagram suggesting, as viewed from the front, the disposition on the airplane of three of this third form of pointer.

In applying our invention to the problem of navigating an airplane, we have the choice of establishing our base for triangulation either on the landing field or on the plane. The principal advantage of having the base on the landing field is that such a base may be of relatively great extent compared to a base established on the plane, with consequent greater permissible variation from absolute accuracy on the part of the calculating apparatus. One disadvantage of a base on the landing field arises from the fact that with changing wind conditions the airplane must approach the landing field from different directions, so that, if but one base is established on the field, the relation of the line of approach of the airplane to that base is not the same for each direction of approach. Such difficulties may be met by providing for a selection of bases on the landing field, or by providing for adjustments in the computing apparatus of the airplane to be made in accordance with the direction of approach. We prefer, however, to establish the base of triangulation at the airplane, so that only one radiating beacon is required at the airport.

Figs. 1 and 2 indicate the relations involved in the approach of an airplane having such a base line, to a single beacon on the landing field. On the airplane, generally designated **20**, are two pointers, L and R, the position of which and alignment of which with respect to beacon N are indicated by dotted lines **21** and **22**. In Fig. 2, dotted line **23** represents either or both lines **21** and **22** of Fig. 1. Beacon N may generate any type of electro-magnetic radiation, but, for the purposes of the preferred form of our invention, we contemplate employing quasi-optical waves, as, for example, an infra-red wave-length of approximately ten thousand angstrom units, and we further contemplate modulating to one hundred per cent (100%) such radiation with some desirable frequency, as five hundred (500) cycles per second. By arranging the eyes to be selectively responsive to such modulation, we avoid interference by stray infra-red radiation extraneous to our system.

The construction of pointers L and R may be understood by reference to Figs. 3 to 5. For each pointer a base plate **24** is fixed to the wing of the plane, with its longitudinal axis parallel with the longitudinal axis of the ship. The front end of the base plate supports a vertical bearing, generally designated **25**, and affixed to and supported by the rear of the base plate is an encased motor **26**. A horizontally movable turntable **27** is pivotally supported in parallel spaced relation to the base plate by bearing **25** and a series of steel balls **28** that are retained in a ball race **29** formed by complementary arcuate grooves in the turntable and base plate, respectively. To prevent the two parts from separating unduly, headed pin **30**, fixed to the under side of turntable **27**, extends through a suitable arcuate slot **31** in base plate **24**.

The rear edge of turntable **27** is provided with an arcuate rack **32** concentric to bearing **25**, the teeth of the rack being engaged by worm gear **33** driven by motor **26**. Mounted on turntable **27**, near the rear, is a second motor **34**. Integral with the forward portion of the turntable is a vertical pair of standards **35** presenting horizontal bearings **35a**, the axis of these bearings intersecting the extended axis of vertical bearing **25**. An underslung cradle **36**, pivotally supported by bracket **35**, is provided with a vertically disposed arcuate rack **38**, the teeth of which are engaged by worm gear **39** driven by motor **34**.

A globular photoelectric "eye" **40**, having a base portion **41**, is supported on cradle **36**, with its spherical center coincident with the aforesaid intersection of the horizontal pivotal axis of the cradle with the vertical axis of pivot bearing **25** of the turntable. It will be noted that by virtue of the described arrangement the center of the spherical photoelectric eye is the pivotal point for movement in two planes, and this assemblage may be considered, therefore, as, in effect, a pointer pivoted for universal movement about said center, the axis of the pointer being an imaginary line $x—x$ (Fig. 5), which line is also the longitudinal axis of photoelectric eye **40**. Motor **34**, through worm gear **39**, controls the disposition of this pointer through vertical arcs and motor **26**, through worm gear **33**, controls the angular disposition of the pointer through horizontal arcs. Preferably, one revolution of motor **26** produces the same degree of angular displacement of the pointer as is caused by one revolution of motor **34**, such provision being made by designing worm gear **33** as a double-pitch screw and worm gear **39** as a single-pitch screw.

Mounted on the front of photoelectric eye **40** is a lens cylinder **42**, coaxial with line $x—x$, incorporating lens **42a** and a filter or light screen (not shown) excluding all but a narrow band of the selected electromagnetic radiations. The photoelectric eye itself comprises, in effect, a plurality of photoelectric cells in a single bulb, there being a ring-shaped plate or anode indicated at **43**, common to all the cells, and four separate cathodes **44**, each being a semi-spherical quadrant in the rear hemisphere of eye **40**, as indicated in Figs. 5 and 6. These quadrants or sectors are insulated from each other by spaces or avenues **45**, the arrangement of the four cathodes being as shown in Fig. 6. It will be noted that these avenues intersect on axis $x—x$, so that the cathodes or photoelectric cells may be said to be arranged in pairs about said axis. It will be noted that avenues **45** intersect to form a central square space **46** having its center on axis $x—x$.

For convenience of explanation, the front lens **42** may be considered as divided into four quadrants, **1'**, **2'**, **3'**, and **4'**, respectively, as indicated in Figs. 3 and 7. The four cathodes, or cells, **44** will be considered as having corresponding numbers **1**, **2**, **3** and **4**, the numeral of the cell corresponding to the quadrant of the front lens through which light passes and eventually falls upon the cell. Obviously, the numerical arrangement of the cells will depend upon the type of lens system used. If a single convex lens is employed, the numerical arrangement of the cells will be as indicated in Fig. 6. Where in the appended claims the position of a cell is given relative to the axis of the pointer, it will be understood that reference is made to the apparent position of the cell indicated by **1'**, **2'**, **3'**, or **4'** in Fig. 7.

Cathodes **44** are of a material such as thalophide, having maximum sensitivity at 10,000 angstroms. It is also a requisite of the lens system that the electromagnetic radiations passed therethrough be focused to a sharp image point or circular spot of substantially unvarying magnitude as the airplane approaches the beacon.

The manner in which a photoelectric eye and the associated mechanisms may serve automatically to train the pointers L and R continuously upon beacon N will now be explained. The terms "upward", "downward", "right" and "left", used to describe movements of the pointer, will be understood as movements having such appearance to an observer facing the pointers from the front. It will be apparent, then, that because of the disposition of the photoelectric eye with respect to its associated pointer, when an image is projected on cathode or cell quadrant **1** (quadrant **1'** of the lens), thereby energizing the photoelectric circuit through that particular cell, the pointer should react by moving upward to the left, in a direction tending to center the image at neutral square **46**, thereby training axis $x—x$ of the pointer on the distant beacon. The arrangement of apparatus associated with the two pointers for providing such reaction to radiations from the distant beacon is set forth schematically in Fig. 8.

Each individual photoelectric cell, distinguished by a quadrant cathode **44**, controls a separate input circuit, the description of one of which will suffice for all. For example, consider cell **1** of the left wing. The input circuit may be traced as follows: cathode **1**, wire **47**, band pass filter comprising condenser **48** and two parallel tuned circuits **49**, wire **50**, ground **51**, ground **52**, battery **53**, wire **54**, and ring plate or anode **43**, previously mentioned. This circuit is tuned and filtered to the modulation frequency 500 cycles and controls the potential of grid **55** in amplifying vacuum tube **56**.

Tube **56** is a heater type, having heating element **57** energized by a suitable source conventionally indicated at **58**, the energizing circuit being through wires **59** and **60**. Cathode **61** of the tube is connected to wire **50** through grid-bias resistance **62**, of such a value as to operate the tube as a plate circuit rectifier, which is shunted by condenser **63**. Grid **55** controls the output or plate circuit, which may be traced as follows: plate **64**, wire **65**, solenoid coil of relay **66**, wire **67**, wire **68**, source of current conventionally indicated at **69**, ground **70**, ground **51**, wire **50**, resistor **62** and tube cathode **61**. Relay **66** is normally open, i. e., open when de-energized.

It is apparent from this arrangement that when cathode **61** is energized by the focused infra-red image modulated at the selected frequency, an alternating current voltage of the modulation frequency will be developed across tuned circuits **49** and the plate current of the tube will be increased sufficiently to close relay **66**.

In like manner, photoelectric cathode **2** is associated with vacuum tube **71** and normally open relay **72**; photoelectric cathode **3** is associated with tube **73** and normally open relay **74**; and photoelectric cathode **4** is associated with tube **75** and normally open relay **76**.

Numeral **77** indicates the armature of shunt-wound motor **26** associated with horizontal movements of the left pointer L. The field winding of that motor, generally designated by the numeral **78**, is center-tapped to offer the choice of a right-propelling electromagnetic field or a left-propelling field, the two halves of the field winding being, in effect, independent, thereby providing means to reversibly control the rotation of armature **77**. In the same way, armature **79** of shunt-wound motor **34** controlling the vertical position of the left pointer is reversibly controlled by similarly tapped field winding, generally designated **80**.

A source of electromotive force to energize the motors is indicated conventionally at **81**. The circuit through armature **77** may be traced: source **81**, wire **82**, wire **83**, wire **84**; either relay **85** or relay **86**, wire **87**, armature **77**, wire **88**, wire **89**, wire **90**, back to source **81**. A parallel circuit through armature **79** may be traced as follows: wire **91**, branching from wire **83**, either relay **92** or **93**, wire **94**, armature **79**, and wire **95** connecting with wire **89**.

The circuit through the right propelling field of motor **26** is: source **81**, wire **90**, wire **89**, wire **96** to the center tap of field winding **78**, the right-propelling half of field winding **78**, wire **97**, solenoid coil of relay **85**, wire **98** through either relay **72** or relay **76**, wire **99**, thence to wire **83** on the other side of source **81**. The circuit through the left propelling field is: wire **96** to the center tap of field winding **78**, the left-propelling half of field winding **78**, wire **100**, solenoid coil of relay **86**, wire **101**, through either relay **66** or relay **74** to wire **99** on the other side of source **81**.

The circuit through the upward propelling field is: wire **102** branching from wire **89**, center tap of field winding **80**, the up-propelling half of field winding **80**, wire **103**, solenoid coil of relay **92**, wire **104**, either relay **66** or relay **72**, to wire **99** on the other side of source **81**. The circuit through the downward propelling field is: wire **102** to center tap of field winding **80**, the down-propelling half of field winding **80**, wire **105**, solenoid coil of relay **93**, wire **106**, through either relay **74** or relay **76** to wire **99** as before.

Relays **85**, **86**, **92** and **93** are normally closed and open only when energized.

In the other half of Fig. 8 the parts corresponding to the above enumerated elements are correspondingly situated and need not be recited. Armature **108** controls the vertical movement of pointer R, and armature **109** controls the horizontal movement of that pointer.

The functional relation of a photoelectric eye to its associated pointer may be understood by describing the effect of an infra-red image at the selected modulation cast upon quadrant 1 of left eye L. To avoid confusion arising from any inversion in the order of the quadrants on the four cathodes with respect to the order of the quadrants on the front lens, the path of the image will be described with respect to the receiving quadrants 1', 2', 3', 4' on the lens, as may be understood by reference to Fig. 7.

When the infra-red image spot appears on quadrant 1' of the lens at the position 110 (Fig. 7), cathode quadrant 1 thereupon becoming activated discharges electrons that are attracted by anode 43 of the photoelectric eye. This action closes the input circuit associated with tube 56, which tube thereupon serves as an amplifying relay to close the circuit through the solenoid coil of relay 66, closing the relay. The closing of relay 66 energizes the up-propelling half of field winding 80 associated with armature 79, and also energizes the left-propelling half of field winding 78 associated with armature 77. The simultaneous movements of these two armatures move the eye upward and to the left so that the path of the image is a component of those two movements, the image moving diagonally, as indicated by dotted line 111. When the image spot has moved diagonally sufficiently to encroach upon quadrant 2' of the lens, as indicated at 112, cathode 2 also is energized, causing relay 72 to close. Both sides of field coil 78 are now energized and, being opposed, cancel each other as far as they affect armature 77. Since both relays 85 and 86 are now energized, the circuit through armature 77 is broken. Rotation stops in armature 77 of motor 26, but continues in armature 79 of motor 34, so that the image spot now moves vertically downward as indicated by dotted line 113. When the image arrives at the exact center of the lens, as indicated at 114, it bridges all four quadrants, thereby causing all four relays 66, 72, 74 and 76 to close and relays 85, 86, 92 and 93 to open, stopping movement of pointer L. At this position, pointer L is trained on beacon B. The same result will be attained if the image when centered clears all the quadrants or encroaches upon none of the quadrants sufficiently to operate any of relays 66, 72, 74 and 76.

It has been indicated above that when the image is centered on neutral square 46, the cathodes should be balanced, i. e., either that all four motor relays 66, 72, 74 and 76 be open, or that, as an alternate situation, all four said relays be closed, and that when the image shifts slightly from its position concentric to axis x—x, one or, at most, two of the relays be closed, while the remaining relays be open. The size of the image is, therefore, of great importance to the accuracy and promptness with which the pointers react to the distant beacon.

The size of the image required may be understood by reference to Fig. 7a. If the shaded area 114 represents the minimum area of image projection on a quadrant necessary to cause the motor relay associated with that quadrant to be energized sufficiently to close, then the diameter of the image should be approximately that of circle 115. If the image is slightly less in diameter than this circle, then the image at dead center will cause none of the relays to be actuated, and, if shifted from dead center, will cause one, or not more than two, relays to be actuated. If, on the other hand, the image diameter is slightly greater than that of circle 115, the image at dead center will cause all four relays to be actuated, with the result that neither of the associated motors will be energized, and when the slightly "oversized" image shifts from dead center, three of the four relays will be opened. If the image is made too large, however, it may be possible for the image to shift diagonally from dead center without deenergizing more than one relay, in which case the motors do not respond. Because of this possibility, it is advisable to focus the image at slightly less than the diameter of circle 115. Preferably, the image will be reduced to what is virtually a point, the avenues being correspondingly narrow. Obviously, the problem of accuracy is simplified by focusing to a minute image. Absolute control of the size of the image may be accomplished by using an iris diaphragm within the lens system.

From the above description, the automatic action of the pointers will be understood, the image of the beacon, in effect, seeking the center of the photoelectric eye that is fixed to the pointer. It will be noted that armature 77 rotates in direct proportion to the right and left movements of the left eye or pointer, and armature 79 moves in direct proportion to the up and down movements of the left eye or pointer; armature 108 moves in direct proportion to the up and down movements of the right eye or pointer; and armature 109 rotates in direct proportion to the right and left movements of the right eye or pointer.

There remains the problem of deriving the distance to the airport and the altitude of the airplane from the angular positions of the two pointers as represented by the rotary positions of their associated armatures.

An equation or formula for computing distance by triangulation involves a minimum of three factors in the case of an oblique triangle, or two factors in the case of a right-angle triangle, and one of these factors must be a side of the triangle. In the present arrangement, when the airplane approaches the beacon, one of these factors, the base line, represented by the distance between the pointers, is constant, while the other factor or factors are continuously variable.

Any of the formulas for triangulation may be employed. If, for instance, the right pointer, while trained on the beacon, is perpendicular to the base line B, as shown in Fig. 1, the distance to the beacon measured along the axis of the right pointer will equal B tan ϕ, ϕ being the angle of the left pointer with respect to the base line. In such a calculation, there is only one variable, angle ϕ. If one of the pointers is not perpendicular to the base line, a formula involving two variables is necessary.

After the distance has been derived, the altitude of the airplane can be computed from the angular position of one of the pointers with respect to the horizontal. In Fig. 2, for instance, the distance D and angle β being known, the altitude $H=D \cos \beta$.

We contemplate solving such equations by electrical means associated with the two pointers. In doing so, we have the choice of utilizing either the voltage characteristic or the current characteristic of an electric circuit, or both characteristics. In the preferred form of our invention we utilize the voltage characteristic, in a manner that will now be explained.

Fig. 14 shows a potentiometer in which resistor 120 shunts battery 121. A voltmeter 122 is in series with one terminal of resistor 120 and a movable resistor contact conventionally indicated at 123. A stop 124 limits the movement of contact 123 at a minimum voltage corresponding to the logarithmic value of a constant which is to be electrically multiplied by a variable. That portion of resistor 120 over which contact 123 is free to range is wound to vary in accordance with the logarithmic value of the said variable. The voltage registered by voltmeter 122 will represent the sum of these logarithmic values, and, if the voltmeter have a suitably calibrated logarithmic scale, the numerical product of the constant and the variable may be ascertained directly from the position of the indicating needle of the voltmeter with respect to that scale.

Fig. 15 represents a similar arrangement, in which contact 125*a* is free to traverse the length of resistor 125, the minimum voltage that represents the constant involved in the equation being supplied by auxiliary battery 126 in series with voltmeter 127.

The arrangement shown in Fig. 16 provides for multiplying two variable factors by a constant. Resistor 128, wound to vary as the logarithmic value of one factor, bridges battery 129 and is traversed by movable contact 130. In like manner, resistor 131, wound to vary as the logarithm of the second variable, shunts the terminals of battery 132 and is traversed by a second contact 133. A third battery, 134, having its terminals connected respectively to the lower ends of resistors 128 and 131, has a voltage corresponding to the logarithm of the constant involved. Voltmeter 135, calibrated to indicate the product of the three factors, has one terminal connected with contact 130 and the second terminal connected with contact 133, so that it is in series with battery 134 and variable portions of resistors 128 and 131.

Figures 14, 15 and 16 are offered to illustrate the principles of calculation by electric circuits. How these principles may be applied to our specific problem, as contemplated in the preferred form of our invention, may be understood by considering Fig. 9 together with Figs. 1 and 2.

Resistor 136 of Fig. 9, wound to vary in accordance with the logarithmic tangent of an angle, shunts battery 137, and is traversed by a movable contact 138. Contact 138 is controlled by movements of pointer L with respect to base line B (Fig. 1). In series with contact 138 and the lower end of resistor 136 are voltmeter 139 and a battery 140, having a voltage corresponding to the logarithm of base line B. From the foregoing explanation, it will be clear that if pointer R, of Fig. 1, is perpendicular to base line B, voltmeter 139, having a properly calibrated logarithmic scale, will indicate the instant value of distance D.

A second resistor 141, wound to vary as the logarithmic cosine of an angle, shunts the terminals of a third battery 142 and is traversed by movable contact 143. Contact 143 is controlled by vertical movements of either pointer L or pointer R. One terminal of a second voltmeter 144 is connected with contact 138, and the second terminal is connected with contact 143, with the result that the indicating needle of voltmeter 144 will take a position corresponding to the voltage registered by voltmeter 139 plus a voltage corresponding to the logarithmic cosine of angle β. This second voltmeter is calibrated to give the instantaneous value of altitude H in Fig. 2.

For the purpose of indicating to the pilot of the airplane the deviation of pointer R from the desired disposition perpendicular to base line B, one of the three batteries, for instance battery 142, may be shunted by resistor 145, the resistor being the usual type wound to vary linearly and being traversed by a movable contact 146. Contact 146 is controlled by horizontal movements of pointer R. Voltmeter 147 is in series with contact 146 and one end of resistor 145. This third voltmeter is so calibrated that at a given point, as, for instance, the midpoint of resistor 145, pointer R is 90° from base line B and the indicating needle shows zero deviation.

It is apparent that if contact 138 is suitably connected with pointer L, or the mechanism associated with the horizontal movement of pointer L, contact 143 connected to either pointer, or the mechanism controlling the vertical movement of either pointer, and contact 146 properly connected with pointer R, or the mechanism controlling the horizontal movement of pointer R, the system will function automatically, voltmeter 139 indicating the distance to the beacon, voltmeter 144 indicating the altitude of the airplane, and voltmeter 147 indicating the deviation of the flying axis of the ship from the line of approach necessary for triangulation involving a right triangle.

The circuit shown in elementary form in Fig. 9 may be recognized in the schematic arrangement of Fig. 8, corresponding numbers indicating corresponding parts. Dotted line 148 indicates an operative connection between armature 77 and contact 138; dotted line 149 indicates an operative connection between armature 108 and contact 143; and dotted line 150 likewise indicates an operative connection between armature 109 and contact 146.

How the pointers may be mechanically associated with the various resistors, may be understood by considering the construction of a typical resistor as illustrated in Figs. 11 and 12. Resistor form 151 wound transversely with wire 151*a* is supported at each end by spaced standards 152, the assembly being reinforced by two spaced rods 153 fixed to the standards above and parallel with the top edge of form 151. Form 151 may be of any suitable insulating material, preferably of sheet material, such as fibre board. Wire 151*a* is of uniform resistance, and, if it is desired that the resistor vary linearly in resistance, the upper and lower edges of the form will be parallel. If, however, the resistance is to follow the values of a variable, the lower edge of the form will be cut to follow the curve of the variable, as indicated by Fig. 11.

Journalled in standards 152, parallel with the top edge of form 151, is a worm or screw 154 operatively connected, as by coupler 155, with a shaft 156 of one of the four armatures. Screw-threadedly engaging screw 154 and slidingly engaging rods 153 is a carrier 157, from which one or more contacts 158 extend downward to slide upon the windings of resistor wire 151*a*. Obviously, since the pointer associated with a given armature and the contact carrier 157 are both driven directly by the armature, the position of the movements of the carrier will be in direct proportion to the movements of the pointer. The ratio of movement of carrier 157 to movement of the associated pointer will be made as large as necessary to obtain accurate changes of resistance commensurate with small changes in the angular position of the pointer.

Fig. 13 shows a modification of such a resistor to provide for compensating movements of the resistor winding as required, for instance, in resistor 141 of Fig. 8. Angle β in Fig. 2 is measured from the true vertical; therefore, resistor 141 must have a fixed relation to the vertical regardless of the inclination of the ship. Therefore, resistor winding 141, is movably mounted and controlled by suitable means such as a gyroscope, pendulum, or other similar device. The resistor shown in Fig. 13 is similar to that shown in Figs. 11 and 12, identical parts having corresponding prime numbers, but resistor form 159 is slidably mounted in brackets 152' and is operatively connected with some vertical-seeking device (not shown), as by pivotally connected rod 160.

The voltmeters may be simply independent indicating devices on a panel, as shown in Fig. 8, or the indicators may be mounted on a panel or calibrated chart 161 (Fig. 10). Such a chart graphically indicates the position of the ship. Voltmeter 139 on one side of the chart has an indicating needle 162 positioned to traverse a distance-reading scale 163. Similarly positioned on the opposite edge of the chart is voltmeter 144, having its indicating needle 164 movable along altitude-reading scale 165.

The position of the intersection of needles 162 and 164 relative to chart 161 will vary with the position of the airplane in space, and, obviously, lines may be drawn on the chart to aid in the visualization of the position of the airplane in space. For instance, a line 166 may be drawn to correspond to the movement of the intersection of the needle across the chart, as the airplane follows a desirable gliding angle or line of optimum glide to the landing field (no significance is to be attached to the specific disposition of line 166 in Fig. 10). By such an arrangement the aviator can be informed continuously of his position in space relative to such a line of optimum glide, as well as his position relative to the beacon. It will be noted that the accuracy of our system increases as the beacon is approached.

The third voltmeter 147 may be arranged at the bottom of chart 161 with its indicating needle 167 having a normal vertical position at the middle of a scale 168 calibrated in degrees of deviation from the desired course. Such an arrangement has the advantage of confining the pilot's attention to a relatively small area on the chart, and reveals the maximum amount of information at a glance.

The resistors may be standard, battery 140 and the calibration of the voltmeter varying with the base line that a given airplane can accommodate.

The operation of the preferred form of our invention will be readily understood from the foregoing explanation. As the airplane approaches the desired airport, pointers L and R are automatically trained on the beacon at the airport, and the electrical arrangement described calculates the instant position of the ship in distance to the airport and altitude above the ground. The calculations are continuously and automatically corrected to give the successive instant positions of the ship, such corrections being made at a rate commensurate with the flying speed of the ship. The photo-electric eyes respond only to infra-red rays, and only to infra-red rays modulated to the predetermined frequency.

The pilot watches needle 167 to keep the ship head-on towards the beacon, and watches the intersection of needles 162 and 164 to keep his ship at the proper gradient of approach. The intersection of the needles moving along line 166 advises the pilot of his approximate speed and his distance from the landing field. It will be obvious that where the beacon itself is at a substantial elevation above the ground, scale 165 associated with needle 164 and the disposition of line 166 may be arranged to compensate for such elevation.

The specific form of our invention selected for the purposes of illustration and disclosure suggests a wide range of possible changes and structural modifications, and we reserve the right to all such changes and modifications that properly come within the scope of our appended claims.

For instance, our invention may be arranged to utilize the current characteristics of an electric circuit for the purpose of calculating the position of the airplane automatically. In view of our disclosure above, such a modification may be understood by considering diagrams given in Figs. 17 and 18.

L' and R' are pointers corresponding respectively to L and R of Fig. 1. Pointer R' controls, as by arm 169, movable winding 170 of a resistor. Pivoted to the same axis as arm 169 is a right-angle bell crank having arms 171 and 172, arm 171 being connected as by link 173 or other means with pointer L', so that pointer L' and arm 171 are always parallel. By virtue of this arrangement, the angle between arm 169 and arm 172 will always be equal to angle δ at beacon N, and contact 174 on arm 172 will measure on winding 170 a distance corresponding to the magnitude of angle δ.

Operatively connected with pointer L is a movable contact 175 associated with a fixed resistor 176, the resistor being taped at an intermediate point 177 and being free at the ends. The base line for calculation by triangulation is represented by dotted line B' and the arrangement is such that when pointed L' is perpendicular to line B', contact 175 is at tap 177 of resistor 176.

The formula to be used here for the distance measured along one length of the triangle is distance

$$D'=B' \sin \theta \operatorname{cosec} \delta, \text{ or}$$

$$\log D'=\log B'+\log \sin \theta+\log \operatorname{cosec} \delta.$$

The electric circuit may be traced as follows: contact 175, wire 178, battery 179, wire 180, limiting resistance 181, wire 182, contact 174, resistor 170, wire 183, ammeter 184, wire 185, and resistor 176. When both pointers are trained ninety degrees from base line B', no part of either resistor winding 176 or resistance winding 170 is included in the calculating circuit, at which positions of the pointers the current in the circuit as determined by battery 179 and the resistance of the circuit plus limiting resistance 181 will correspond in value to the logarithm of approximately the maximum distance from the beacon at which it is desired the apparatus become operative, say, a distance of ten thousand feet. This value may be termed the "normal" amperage of the system. Resistor 176 varies in resistance as the logarithmic sine of an angle, the purpose of the arrangement being that as far as resistance 176 is concerned, the maximum current will flow when contact 175 is at center tap 177 and the current at other positions of contact 175 will be decreased in according with the logarithmic sine of angle θ. Similarly, contact 174, cooperating with winding 170, will further reduce the current of the circuit in accordance with the logarithmic cosecant of δ. Ammeter 184 has a logarithmic scale in units of distance and is so calibrated that the position of the ammeter needle will indicate the true distance to beacon N. Whereas, in the preferred form of our invention, the electrical calculating circuit in effect adds logarithms electrically, in the present arrangement the calculating circuit in effect subtracts logarithms electrically, the end being the same.

Fig. 18 is a duplicate circuit associated with the pointers L' and R' in the same manner as the circuit shown in Fig. 17, having prime numbers corresponding to numbers in Fig. 17. This duplicate circuit has, additionally, a movable resistor 186 controlled by a vertical-seeking device, as before described (Fig. 13), the resistance being associated with a movable contact 187 controlled by armature 108. Resistor 186 will be recognized as corresponding to resistor 141, and contact 187 as corresponding to contact 143 in Fig. 8. This duplicate circuit is arranged to have a minimum current corresponding to the maximum value of the sum of the four logarithms involved in the equation:

Log of altitude

$$H=\log B'+\log \sin \theta+\log \operatorname{cosec} \delta+\log \cos \beta.$$

Ammeter 188 in this duplicate circuit is calibrated to read in units required, and corresponds to voltmeter 144 in Fig. 10 just as ammeter 184 in Fig. 17 corresponds to voltmeter 139 in Figs. 8 and 10.

Fig. 19, indicating an electrical arrangement for calculation in which both current and voltage are utilized, serves to further illustrate the scope of our invention. Battery 189 is shunted by resistor 190. The positive end of resistor 190 is connected by wire 191 with a voltage terminal of indicating wattmeter 192, the other voltage terminal of the wattmeter being connected by wire 193 with a contact 194 movable along resistor 190. Battery 189 also energizes a parallel circuit through resistor 195, a movable contact 196, wire 192a, the current coils of wattmeter 192, and wire 192b back to battery 189.

Battery 189 represents the base line of the triangle, resistor 190 is wound to vary as a desired function of one angle; and resistor 195 is wound to vary as the desired function of another angle. Inasmuch as a wattmeter multiples current by voltage, it will be clear that the scale of wattmeter 192 may be calibrated to read in units of the product of these factors. It will be noted that this arrangement multiples directly, instead of, as in the case of the previous arrangements, by adding or subtracting logarithmic values and then translating the sum of the logarithmic values into an arithmetic product. In view of the detailed explanations of the earlier described arrangement, it will be clear that a wattmeter associated with the arrangement shown in Fig. 19 may be arranged to indicate distance to the beacon and a second wattmeter associated with a second and similar arrangement of circuits may be utilized to calculate the altitude of the airplane.

In the apparatus heretofore described, the relation of the size of the image to the spacing of the quadrant cathodes, as affects the accuracy of the pointer action, is critical, because it is contemplated that the motor-controlling relays will be operated whenever even a minute portion of the image is projected over the edge of a quadrant. Hence, the incorporation of a diaphragm in the lens system of the preferred form of our invention heretofore described.

Such a diaphragm is omitted and a more simple lens system is used in a second type of eye we have developed. This eye, by virtue of its associated control circuit, automatically centers a relatively large image, and, having centered the image, thereafter responds to minute displacements of the image from the desired central position. Such response to minute displacements of the image is accomplished, as will be further explained, by what may be described as electrically balancing the energized areas of opposed cathodes in the eye.

The cathodes of an eye, in this second form of the pointer construction, are arranged as three spaced sectors of a circle, $1x$, $2x$ and $3x$, as shown in Fig. 21, the corresponding areas of the lens of the pointer eye being indicated as $1y$, $2y$ and $3y$ in Fig. 22.

The manner in which such a tri-cathode photoelectric eye controls an associated pointer may, in view of the complete description of the first form of our invention above, be readily understood by referring to the wiring diagram of Fig. 23.

Each eye is incorporated in a pointer construction in the same manner as heretofore described, reference being made to Figs. 3, 4 and 5 of the drawings. This modification of our invention shows the use of series-wound motors to illustrate that either type of motor may be used by employing a suitable relay arrangement.

In each photoelectric eye, cathode sectors $1x$, $2x$ and $3x$ have a common plate 200, which plate or anode is maintained at a positive potential by battery 201, the negative pole of the battery being grounded at 202. Cathode sectors $1x$, $2x$ and $3x$, respectively, of the photoelectric eye control the input circuits of corresponding amplifying tubes $1z$, $2z$ and $3z$.

For example, current through the photoelectric eye affecting tube $1z$ may be traced in the following circuit; ground 202, battery 201, photoelectric plate or anode 200, cathode sector $1x$, wire 203, band pass filter comprising condenser 204, and two parallel tuned circuits 205, wire 206 and ground 207. This circuit is tuned and filtered to the modulation frequency and controls the potential of grid 208 in tube $1z$.

The three amplifying tubes are of the heater type, each having a heating element 209 suitably energized (source not shown), and each having a grid-bias battery 210. Current through photoelectric cathode $1x$ will affect the potential of grid 208, thereby causing a proportional current to flow through the plate circuit of tube $1z$. In similar manner, cathode $2x$ associated with grid 211 controls the plate circuit of tube $2z$, and cathode $3x$ associated with grid 212 controls the plate circuit of tube $3z$.

The output circuits of these three tubes control two split-wound polarized relays, relay 213 controlling the horizontal movements of the pointer, and relay 214 controlling the vertical movements of the pointer. The center tap of relay 213 is connected by wire 215 to the negative pole of battery 216, and the center tap of relay 214 is connected by wire 217 to the negative pole of battery 218. Wire 219 is connected to plate 220 of tube $1z$, plate 221 of tube $2z$, and plate 222 of tube $3z$. Wire 219 is connected to the positive pole of battery 216 by wire 223 and the positive pole of battery 218 by wire 224. The end terminal in relay 213 associated with the half of the relay coil marked Right, is connected by wire **225** to cathode **226** of tube **1z**, and the other terminal associated with the left portion of the relay coil, is connected by wire **227** to cathode **228** of tube **2z**. The end terminal in relay **214** at the up side of the relay coil is connected by wire **229** and wire **225** to cathode **226** of tube **1z**, and the opposite terminal of relay **214** at the down end of the relay coil is connected by wire **230** to cathode **231** of tube **3z**.

Again, the terms right, left, up and down are used as occurring to a spectator viewing the pointer from the front.

Pivoted armature **232** of relay **213** is normally held at a central position by a pair of opposed springs **233**, and maintains its central position both when neither the right coil nor the left coil is energized and also when both of the coils are equally energized. If the right coil alone is energized, or, both coils being energized, if the right coil carries the greater current, armature **232** will swing against contact **234**, thereby closing the circuit through wire **235**, the right field in the field winding of the motor that controls the horizontal movement of the pointer, wire **236**, armature **237** of the motor, wire **238**, motor-energizing battery **239**, and relay armature **232**.

When the left coil of relay **213** alone is energized, or when both coils of the relay are energized but the greater current flows through the left coil, relay armature **232** will swing against contact **240**, thereby closing a circuit through wire **241**, the left field of the motor controlling the horizontal movements of the pointer, wire **236**, armature **237**, wire **238**, battery **239**, and relay armature **232**.

Pivoted armature **242** of relay **214** is normally held in a central position by opposed springs **243**, and maintains its central position both when neither the up nor down coil is energized and also when both coils are equally energized. When only the up coil is energized, or when, both the up coil and down coil being energized, the more current flows through the up coil, relay armature **242** will swing against contact **244**, thereby completing a circuit through wire **245**, the up field of the field winding of the motor that controls the vertical movements of the pointer, wire **246**, armature **247** of the motor, wire **248**, motor-energizing battery **249**, and relay armature **242**.

When only the down coil of relay **214** is energized, or, both coils of the relay being energized, if greater current flows through the down coil, relay armature **242** will swing against contact **250**, thereby closing the circuit through wire **251**, the down field of the motor controlling the vertical movements of the pointer, wire **246**, armature **247**, wire **248**, battery **249** and relay armature **242**.

In the arrangement being described, the total current through the photoelectric eye is proportional to the total areas of the three cathode sectors energized by the image from the distant beacon, and may change with the size of the image in accordance with changes of distance to the beacon. But the response of the pointer itself, i. e., the action of the two pointer motors, depends upon the distribution of the energized areas among the three cathode sectors, the response being such that the pointer automatically seeks a position at which the energized areas are in equilibrium and at which the axis of the pointer is directed at the distant beacon. It is apparent, then, that changes in the size of the image will not affect the accuracy of this form of pointer construction.

An image appearing on the periphery of a sector of the photoelectric eye will be caused to travel by a somewhat spiral path to a central position at which the same proportion of the image will overlie each of the three sectors of the photoelectric eye. The reaction of the pointer to an image on the photoelectric eye may be illustrated by considering what happens when an image appears, for instance, at dotted position **252** as indicated in Fig. 22. A current being set up across the plate circuit of amplifying tube **1z**, the right coil of relay **213** and the up coil of relay **214** will be energized simultaneously, causing the pointer to move to the right and up, thereby shifting the image left and downward at an angle of forty-five degrees, as indicated by the arrow **253** of Fig. 22.

When the image first touches sector **2y** there will be no change in the movement of the pointer because, while current controlled by tube **2z** will flow through the left coil of relay **213**, that current will be less than the current flowing through the right coil of relay **213**. Momentarily, at dotted position **254**, the up coil, right coil and left coil will be equally energized. The right and left coils cancelling the effect of each other, only the up coil will be effective and the image will move downward. Immediately thereafter, however, the greater area of the image will lie on the **2y** sector, causing a greater flow of current through the left coil than through the right coil, with the result that the pointer will move up and left, causing the image to move downward and to the right, as indicated by dotted line **255**.

Since the image is moving at forty-five degrees from the vertical, whereas the line of division between sectors **1y** and **2y** is disposed at sixty degrees vertical, the image will clear sector **2y** at position **256**. As sector **1y** is cleared, however, all relay coils except the left coil are deenergized and the image moves to the right into sector **2y** again. The result is that the image progresses in the general direction indicated by dotted line **257**, alternating between movements to the right towards sector **2y** and movements downward away from sector **2y**.

As soon as the image touches sector **3y** at the dotted position **258**, the image will move horizontally to the right until a larger portion of its area overlies sector **3y** than overlies sector **2y**, at which time the image will turn diagonally upward to the right. Subsequently, the image will change to movement vertically upward, followed by horizontal movement to the left above the midpoint of the eye, and continue in the somewhat spiral path of progression to the center of the eye. While the image does not move directly to the center of the eye, the response of the pointer is sufficiently rapid to complete the spiral within the short time interval required for the navigation of a rapidly flying plane.

A third form of pointer construction, shown in Figs. 24—29, is based on the principle of "bracketing" the image of the beacon by a pair of eyes. One photoelectric eye **261** seeks the margin of the image at one side, and a second photoelectric eye **262** seeks the margin at the opposite side of the image, so that the pointer proper, a pivotally mounted rod **263** mechanically held exactly midway between the two eyes, is continuously directed at the center of the image.

This combination of two photoelectric eyes and an intermediate pointer is pivotally mounted on a stub shaft **264** extending from fixed base **265**. A lower gear **266** rotatably mounted on shaft **264** has a sleeve portion 267 extending to the top of shaft 264. An arm 268 secured at its inner end to gear 266, as by screws 269, carries at its outer end photoelectric eye 261, the axis of the eye being radially disposed with reference to the axis of the shaft 264. A collar 270 embraces sleeve 267 at the top and is provided with a depending arcuate flange 271, for a purpose to be described later, the angular relation of flange 271 to arm 268 being fixed by virtue of a suitable key 272 between the collar and sleeve 267. These members may be retained on shaft 264 by a suitable washer 273, the washer being retained in turn by a nut 274 threaded to the reduced end 275 of stub shaft 264.

Pointer 263 is rotatably mounted on sleeve 267, the pointer being provided with an integral sleeve 276 rotatably embracing the first mentioned sleeve 267 and extending upward to collar 270. A second collar 277 keyed to the upper end of this second sleeve by key 278 is integral with a radially extending contact arc 279. This contact arm terminates in a downwardly extending finger 280. Rotatably mounted to sleeve 276 between pointer arm 263 and collar 277, is a second and upper gear 281 for controlling the second eye 262. This eye, also radially disposed relative to the axis of shaft 264, is at the outer end of arm 282, secured to the gear as by screws 283.

Pointer 263, near its forward end, is embraced by a free-running slide 284, to which are pivotally connected ends of links 285 and 286 of equal length, the other end of link 285 being pivotally connected to arm 282, and the other end of link 286 being pivotally connected to arm 268, as shown. By virtue of slide 284 and the two links, pointer 263 will always bisect the angle between arms 268 and 282, so that if eye 261 is directed at one edge of the beacon and eye 262 is directed at an opposite edge, the axis of pointer 263 will be directed at the center of the beacon.

Journalled in a suitable bracket 287 are a worm gear 288 meshing with lower gear 266, and worm gear 289 meshing with gear 281 (Fig. 27). Gear 288, controlling eye 261, is in turn controlled by motor 290, being connected therewith by shaft 291. In a similar manner, motor 292 is connected by shaft 293 to worm gear 289 to control the movements of eye 262.

To deenergize either motor, if it tends to move its associated photoelectric eye so far from the other eye as to make the pointer linkage inoperative, and again, to deenergize either, or both, motors when the two arms are closed together in the normal position shown in Fig. 25, certain mechanical switching arrangements are necessary.

For such purpose, the previous identified arcuate flange 271, controlled by gear 266, overhangs upper gear 281. Relative movement of flange 271 with respect to gear 281 in a direction to separate the two eyes will, at a desired limit, deflect a flexible switch-member 294 (Fig. 24) and relative movement in the opposite direction tending to bring the two arms together will, at a desired limit, deflect a second suitably positioned flexible switch-actuating member 295 (Fig. 25). Deflection of member 294 opens two switches, generally designated by numerals 296 and 297. The construction of such a switch may be readily understood by referring to Fig. 28, where it is seen that switch 296 comprises a fixed contact 298 and a second contact 299 mounted on member 294 and switch 297 also comprises a fixed contact 300 and a contact 301 carried by member 294.

When switch-member 295 is deflected by the opposite end of flange 271, a switch generally designated 302 is opened, the switch comprising a fixed contact 303 and a complementary contact 304 mounted on member 295.

It is apparent that contact arm 279, being virtually an extension of pointer 263, will move with the pointer. An electric contact 305 of suitable construction is mounted on arm 279 to press continuously against a resistor 306, the resistor being curved concentric to the axis of stub shaft 264. This resistor is wound to vary in accordance with the functions or the logarithm of a function of an angle. For example, if this pointer construction is substituted for pointer L of Fig. 1, resistor 306 will be wound to vary as the logarithm of a function angle ϕ of the pointer with respect to the base line defined by the two pointers on the airplane.

To prevent pointer contact 305 being carried past the ends of resistor 306, means should be provided to break the energizing circuits of motors 290 and 292 when the desired limits of pointer movements are reached. For this purpose, a flexible switch member 307 is positioned near one end of resistor 306 in a position to be deflected by the overhanging end or finger 280 of the pointer, and a similar flexible switch member 308 is positioned near the opposite end of resistor 306. Deflection of member 307 opens two switches, designated generally by the numerals 309 and 310. Similarly, deflection of member 308 opens two switches, generally designated by numerals 311 and 312. The construction of these switch mechanisms is similar to that shown in Fig. 28.

It will be apparent that when the pointer assembly is in the normal closed position, directed straight ahead, as shown in Fig. 25, switches 296, 297, 309, 310, 311, and 312 are in their normal closed positions, while switch 302 is in its normal open position.

Each of the two photoelectric eyes comprises a suitable casing 313 housing a lens system 314 at the front and a suitable photoelectric cell 315 at the rear, each photoelectric cell having cathode 316 and a ring-shaped anode 317.

Preferably, the cathode of each eye is semicircular, as viewed from the front, and, in a pair of eyes, the cathodes are oppositely disposed, as indicated in Fig. 24, and, again, in Fig. 30, the latter figure showing diagrammatically the disposition of three pairs of eyes on an airplane as viewed from the front. In such an arrangement, each cathode takes in approximately half the field of vision of an eye, so that a pair of eyes having complementary cathodes, as shown, will, together, cover the entire field of vision of one eye of the type shown in Fig. 6 or the type shown in Fig. 22. To preclude any possibility of there being a gap in the field of vision covered by the complementary cathodes, switch 302 is arranged to close only when the two cathodes are moved into definitely overlapping relation, such relationship being the normal relationship of the two eyes when not affected by the distant beacon.

The electric circuits incorporated in this third form of pointer construction may be understood by referring to the wiring diagram, Fig. 29. In either of the two eyes, 261 and 262, the circuit through the photoelectric cell may be traced as follows: negative pole of battery 318, wire 319, photoelectric cathode 316, anode 317, wire 320, band pass filter comprising condenser 321 and two parallel tuned circuits 322, wire 323, and positive pole of battery 318.

An amplifying tube 324 is associated with eye 261, and a similar tube 325 is associated with eye 262. Grid 326 of tube 324 is connected to the photoelectric anode side of the associated band pass filter and cathode 327 of tube 324 is connected through grid bias battery 328 to the opposite side of the band pass filter.

In like manner, grid 329, of tube 325, is connected to the photoelectric anode side of the associated band pass filter, and cathode 330 of tube 325 is connected to the opposite side of the associated band pass filter through grid bias battery 331.

Each of the amplifying tubes is a heater type, having a heating element 332 energized from a suitable source (not shown).

The plate circuit of tube 324 includes a suitable battery 333 and the solenoid coil 334 of a relay that is generally designated by numeral 335. Similarly, the plate circuit of tube 325 includes battery 336 and solenoid coil 337 of a second relay generally designated by numeral 338.

Armature 340 of relay 335 carries two spaced insulated contact members 341 and 342. In the normal deenergized position of armature 340, contact member 342 is free of any contacts, and contact member 341 electrically connects spaced contacts 343 and 344. When relay 335 is energized by current through coil 334, armature 340 moves contact member 341 to a second position free of contacts 343 and 344, contact member 341 in this second position electrically connecting a second pair of spaced contacts 345 and 346. This same movement of armature 340, when the relay is energized, carries contact member 342 from its normal free position to a second position electrically connecting contacts 347 and 348.

In like manner, armature 349 of relay 338 carries two spaced insulated contact members 350 and 351. When relay 338 is energized by current through coil 337, armature 349 moves contact member 350 from a normal position electrically connecting contacts 352 and 353 to a second position electrically connecting contacts 354 and 355, and simultaneously moves contact member 351 from a normal position free of all contacts to a second position electrically connecting contact members 356 and 357.

In describing this third form of pointer construction and its action, the words right and left will be used as occurring to a person looking outward over the pointer from a position at the rear. This direction of reference is the opposite of that suggested in connection with the previously described forms of pointers, but is believed to favor clarity of explanation.

Relay 335 controls the action of motor 290, thereby controlling the movements of the lower photoelectric eye 261, covering the left half of the field of vision; and relay 338 controls the action of motor 292, thereby controlling movements of upper photoelectric eye 262 responsive to the right half of the field of vision. The armature and the split field coil of motor 290 are generally designated by numerals 358 and 359, respectively; and, on the other side of the diagram, the armature and the split field coil of motor 292 are generally designated by numerals 360 and 361, respectively.

Contact 347 is connected to the left field of the motor associated with eye 261, the connection being through switches 296 and 311, previously described, the switches being in series. Contact 343, associated with left relay 335, is connected to the right field half of field coil 359 of the same motor, the connection being through switch 309, previously described, and in series therewith, a second switch 362, the purpose of which second switch will be described later.

Contact 357, associated with right relay 338, is connected with the right field of the motor controlling the right eye 262, the connection being through the two switches 297 and 310, previously mentioned, the switches being in series. Contact 353 is connected to the left field of the motor controlling the right eye 262, the connection being through two switches in series, switch 312, previously mentioned, and a switch 363, the purpose of which will be described later.

Connection is made from the center tap of field coil 359 of the motor controlling the left eye through armature 358 of that motor to contact 345 of left relay 335. In a similar manner, connection is made from the center tap of field coil 361 of the motor controlling the right eye through armature 368 of that motor to contact 354 of the right relay 338.

Wire 364 interconnects contact 345 of the left relay and contact 354 of the right relay, and is connected to one terminal of motor-energizing battery 365 by a branch wire 366, this branch wire being controlled by switch 302, previously described, (Fig. 24). The second terminal of battery 365 is connected to wire 367, which wire interconnects contacts 344 and 348 of the left relay and contacts 356 and 352 of the right relay.

Suppose, the pointer and eyes being in the normal position shown in Fig. 25, the airplane is approaching the distant beacon, the beacon being at the left extremity of the combined field of vision of the two eyes 261 and 262. This image, energizing cathode 316 of the left eye at the selected modulated frequency, will cause the left relay 335 to be energized, whereupon a circuit through the motor associated with the left eye will be established as follows: battery 365, wire 367, contact 348, contact member 342, contact 347, switches 296 and 311, left field of coil 359, armature 358, contact 345, contact member 341, contact 346, back to battery 365. Motor 290 will cause eye 261 to move to the left, and the eye will continue to be so moved until the image passes over the inner straight edge of the semicircular cathode 316. This same action may be described as a movement of the eye towards the outside edge of the image of the distant beacon.

At the beginning of this leftward movement of eye 261, switch 302 will automatically close. Whenever relay 335 is deenergized while switch 302 is closed eye 261 will move to the right because of the circuit: battery 365, wire 366, switch 302, wire 364, motor armature 358, right field of coils 359, switches 309 and 362, contact 343, contact member 341, contact 344, and wire 367 back to the battery. Therefore, as soon as eye 261 moves sufficiently to the left to cause the image to traverse the cathode of the eye to a position clearing that cathode, the eye will automatically reverse to the right. As a result of such an arrangement, left eye 261 will tend to hover at a position where the straight edge of its cathode will be approximately tangential to the left edge of the image.

When switch 302 first closes at the beginning of the leftward movement of the left eye, the movement described above, the right eye will also move to the left following the first eye, because of the following circuit: battery 365, wire 366, switch 302, wire 364, motor armature 360, left field of coils 361, switch 312, switch 363, contact 353, contact member 350, contact 352, and wire 367 back to battery 365.

As soon as the right eye moves sufficiently to the left to cause the image to be positioned on its cathode, right relay 338 will be energized and the eye will reverse to the right because of the following circuit: battery 365, wire 367, contact 356, contact member 351, contact 357, switches 297 and 310, right field of coil 361, armature 360, contact 354, contact member 350, contact 355, back to battery 365. Because these last two described circuits alternate, the right eye will hover at a position at which the straight edge of its cathode will be approximately tangential to the image of the beacon, the eye being moved automatically to the left when the image does not touch the cathode and being moved automatically to the right when the image does touch the cathode.

Because each eye thus moves outward when energized and inward when deenergized, it may be said that the two eyes "bracket" the image. Whenever the beacon disappears from the field of vision of the two eyes, the two eyes will automatically close together until switch 302 automatically breaks the two motor circuits.

After a landing is made, the two eyes will usually come together and be deenergized with the pointer directed to one side. For this and other reasons, it is desirable that there be independent means conveniently operable by the pilot to move each pointer to a position straight ahead. For this purpose, an auxiliary motor-energizing battery 369 (Fig. 29) is connected by one terminal to wire 364, the other terminal being connected to a switch 370. This switch is movable to one position connecting with wire 371 to the left field of the motor controlling the left eye, and is movable to a second position establishing connection through wire 372 with the right field of the motor controlling the right eye 262, the normal position being an intermediate neutral position. Switch 370 is mechanically connected to switch 362 to open that switch when connection is made with wire 371, and is likewise mechanically connected to switch 363 to open that switch when connection is made to wire 372.

Suppose it is desirable to move pointer 263 to the left in order to direct it straight ahead. The pilot will move switch 370 from the normal central position indicated in Fig. 29 to the left, establishing the following circuit: battery 369, wire 364, armature 358, left field of coil 359, wire 371, and switch 370, back to battery 369. This circuit will cause eye 261 to move to the left, thereby opening switch 302, and causing right eye 262 to follow this leftward movement.

It will be apparent that switch 362 is necessary, because otherwise the closing of switch 302 would energize the right field of the motor associated with the left eye.

As soon as left eye 261 has moved leftward the desired distance, the pilot will return switch 370 to its normal disconnected position, whereupon the two eyes will close together until switch 302 is opened automatically. In the same manner, if switch 370 is moved to the right, a circuit will be closed as follows: battery 369, wire 364, armature 360, right field of coil 361, wire 372, switch 370, back to battery 369. Switch 363 being opened automatically when switch 370 connects with wire 372, energization of the left field of coil 361 will be prevented.

This third pointer construction has several advantages. It will accommodate itself to an image of any diameter, the two eyes spreading apart to accommodate the dimensions of the image while the pointer proper is automatically directed at the center of the image. The eye construction itself is relatively simple, there being no critical relationship between cathode spacing in an eye and the size of the image. It is important to note, also, that in the case of the previously described pointer constructions, the image may conceivably vibrate so fast across two opposed cathodes as to have the same effect as an inordinately large image simultaneously overlying the two opposed cathodes. In the case of the present construction, however, the two eyes would automatically spread apart to the opposite limits of such vibration, and the pointer, seeking the center of the range of vibration, would thereby be directed to the center of the beacon. A further advantage of this third type of pointer construction is the rapidity with which the pointer is centered on the beacon. In the other constructions, the pointers move circuitously to the desired position directed at the center of the image, whereas in the present construction the pointer movement is more nearly direct, there being no diagonal lines described by the path of the image. Another advantage is that the area of image necessary to establish an effective current through the eye is immaterial.

It is suggested that three pairs of such eyes be arranged on an airplane, as indicated by Fig. 30, showing the arrangement of the eyes as viewed from the front. The pointer controlled by the pair of eyes on the left wing, the pointer designated by numeral 373, will correspond to pointer L of Fig. 1 and will, therefore, control contact 138 of Fig. 8. The pointer controlled by the pair of eyes designated by numeral 374 on the extremity of the right wing of the plane corresponds to pointer R of Fig. 1 and will, therefore, control contact 146, indicated in Fig. 8. The third pair of eyes 375 is mounted to bracket the image vertically to ascertain angle β of Fig. 2. The pointer associated with this third pair of eyes will, therefore, control contact 143 of Fig. 8. It is apparent that, with such a hook-up, the instruments designated in Fig. 8 will indicate the distance, altitude and course, as previously described.

For the further guidance of the pilot, we have devised a ground speed indicator, the construction of which may be understood by reference to the circuit shown in Fig. 20.

Vacuum tube 376 is shown here as a battery-operated screen grid tube, although other types may be employed. Filament 377 is heated by an "A" battery 378, the current being controlled by rheostat 379. In the usual manner, screen 380 of the tube is connected to a central cell of "B" battery 381 by wire 382. Plate 383 of the tube is connected to ammeter 384 by wire 385, the ammeter, in turn, being connected to the positive pole of battery 381 by wire 385 to complete the plate circuit.

The negative pole of "C" battery 386 is connected to grid 387 of the tube through a relatively high resistance 388.

An independent circuit comprises a suitable battery 389, shunted by a suitable resistor 390 wound to vary directly as the tangent of an angle. This resistor is provided with a movable contact 391, the construction of the resistor and contact being similar either to that indicated by Figs. 11 and 12 or that shown in Figs. 24 and 25.

This contact is mechanically controlled by pointer L of Fig. 1 in a manner heretofore suggested, as, for instance, in the manner that contact 138 of Fig. 8 is controlled. The movements of the contact are synchronized with the pointer so that the potential of the contact as determined by its position on the resistor will correspond to the tangent of angle ϕ of Fig. 1. Since, as previously stated, $D=B \tan \phi$ (see Fig. 1), the tangent of ϕ will vary directly as distance D and the potential of contact 391 will also vary directly as distance D.

Contact 391 is connected by wire 392 to grid 387 and, therefore, to the grid end of resistance 388. A suitable condenser 393 is inserted between the low potential end of resistor 390 and the negative pole of "C" battery 386. It is suggested that the condensor have a capacity of one microfarad and that resistance 388 have a rating of 10^6 ohms, if a time constant of approximately one second is desirable. It is apparent that charges on opposite sides of condensor 393 will balance at values determined by the position of contact 391 on resistor 390, and that any change in the value of the balanced charges occasioned by a change in position of contact 391 will cause a compensating flow of current through resistor 388 for a duration of approximately one second.

This compensating current is dependent solely upon changes in potential of contact 391, dying away whenever the contact is stationary for more than a second, and is directly proportional to the rate of such changes in the potential of the contact. Now the potential of contact 391 at any given moment corresponds to distance D, as heretofore stated, and, therefore, the value of the compensating current through resistance 388 is proportional to the rate of change of that distance, i. e., the speed with which the ship approaches the beacon.

Ammeter 384 is indexed to serve as a speed indicator, being set to show zero speed at normal amperage in the plate circuit as determined by normal potential of grid 387. As the airplane approaches the distant beacon, angle ϕ becoming progressively more acute, contact 391 moves towards the positive end of resistance 390, as indicated by the arrow, thereby causing compensating current to flow from the contact through resistance 388 to condensor 393. This transitory compensating current, by making grid 387 less negative, causes a proportionate increase in the current through the plate circuit of tube 376, so that ammeter 384, being properly calibrated, will indicate the instantaneous speed with which the airplane approaches the beacon.

It is true that the ammeter, strictly spreaking, does not measure the ground speed, because distance D is measured in an air line at an angle from the horizontal, but this "air line" speed approximates ground speed so closely that, for practical purposes, it is not deemed necessary to complicate the apparatus with further means to correct for the angle of the air line.

Having described our invention, we claim:

1. Apparatus for computing the distance between two points, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; and means operatively connected to at least one of said pointers to automatically derive the distance between the two points from the angular disposition of said pointers with respect to said base line.

2. Apparatus for computing the distance between two points, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; an electric circuit having a variable energy characteristic determined by two factors, said characteristic corresponding in value with the distance between the two points to be measured, said factors corresponding in value with factors in an equation for computing the distance by triangulation; means interconnecting the pointers and circuit whereby the pointers control said characteristic through at least one of said factors in accordance with said equation; and means controlled by the circuit to indicate the instant value of said characteristic, said means being adapted to express the value as distance between the two points.

3. Apparatus for computing the distance between two points, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiations; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; an electric circuit; at least one voltage-regulating means associated with the circuit corresponding with two or more factors in a triangulation equation and adapted to vary the voltage of said circuit in accordance with said factors, one of said pointers being operatively connected to said voltage regulator; and a voltmeter in said circuit calibrated in units of distance.

4. Apparatus for computing the distance between two points, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiations; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; an electric circuit having a minimum voltage corresponding in value to the logarithm of a constant in a triangulation equation; at least one voltage regulator in the circuit corresponding to a variable in said triangulation equation and adapted to vary the voltage of the circuit above said minimum in accordance with the values of the logarithm of said variable, one of said pointers being operatively connected to said voltage regulator, whereby the instant voltage of said circuit corresponds to the instant value of the logarithm of the distance between said two points; and a voltmeter

in said circuit having a logarithmic scale calibrated to indicate said distance.

5. Apparatus for computing the distance between two points, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiations; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; an electric circuit having a minimum voltage corresponding in value to the logarithm of a constant in a triangulation equation; at least one voltage regulator associated in the circuit, said regulator including a resistor wound to vary as the logarithm of a function of an angle figuring in said triangulation equation, said regulator being operatively connected with a corresponding pointer whereby the instant voltage of said circuit corresponds to the instant value of the logarithm of the distance between said two points; and a voltmeter in said circuit having a logarithmic scale calibrated to indicate said distance.

6. Apparatus for computing the distance between two points, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation, one of said pointers being normally perpendicular to the base line and the other pointer forming an acute angle with the base line; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; an electric circuit having a minimum voltage corresponding in value to the logarithm of the length of said base line; voltage-regulating means associated with the circuit incorporating a resistor wound to vary as the logarithm of the tangent of said acute angle; an operative connection between the pointer forming the acute angle and said voltage regulator whereby the voltage of the circuit varies as the value of the logarithm of the distance between the two points; and a voltmeter in said circuit having a logarithmic scale calibrated to indicate said distance.

7. Apparatus for computing the distance between two points, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations, one of said pointers having a normal position perpendicular to said base line, the other pointer forming an acute angle with the base line varying with the distance to be computed; an electric circuit having a minimum voltage corresponding in value to the logarithm of the length of said base line; voltage-regulating means operated by the acute-angle pointer adapted to add to said minimum potential a voltage value corresponding to the logarithm of the tangent of said acute angle whereby the resultant voltage of the circuit will correspond in value to the logarithm of the distance between the two points; a voltmeter in said circuit having a logarithmic scale calibrated in units of distance; a second circuit; a voltage regulator operatively connected with the normally perpendicular pointer and adapted to control the potential of said second circuit; and a voltmeter in said second circuit calibrated to indicate the angular variance of said pointer from its normal perpendicular position.

8. Apparatus for indicating the altitude of one point above a plane through a second distant point, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation means connected with each pointer responsive to said electro-magnetic radiation to automatically train each pointer on the source of the radiation; distance-calculating means associated with said pointers responsive to changes in the angles of the pointers with respect to said base line; an electric circuit; a voltage regulator controlled by said distance-calculating means to maintain the potential of said circuit at a minimum corresponding in value to the logarithm of the airline distance between the two points; a second voltage regulator connected to one of the pointers, said second voltage regulator being responsive to changes in the angle of said pointer with respect to said plane, said second voltage regulator being adapted to raise the potential of the circuit above said minimum potential by a value corresponding to the logarithm of a function of said angle, whereby the resultant voltage of the circuit will correspond in value to the logarithm of said altitude; and a voltmeter in said circuit having a logarithmic scale calibrated to indicate said voltage in units of altitude.

9. Apparatus for indicating the altitude of one point above a plane through a second distant point, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiation to automatically train each pointer on the source of the radiations; distance-calculating means associated with said pointers responsive to changes in the angles of the pointers with respect to said base line; an electric circuit; a voltage regulator controlled by said distance-calculating means to maintain the potential of said circuit at a minimum corresponding in value to the logarithm of the airline distance between the two points; a second voltage regulator adapted to raise the voltage of the circuit above said minimum potential, said second regulator incorporating a resistor wound to vary as the value of the logarithmic cosine of an angle; means connected with one of the pointers to control said second regulator in accordance with the angle of said pointer with respect to a perpendicular from said plane; and a voltmeter in said circuit having a logarithmic scale calibrated to indicate said voltage in units of altitude.

10. Apparatus for computing the distance from one point to a second point and the altitude of the first point above the plane of the second point, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; means operatively connected to at least one of said pointers to automatically derive the airline distance between the two points from the angular disposition of said pointers with respect to said base line; and means operatively connected to one of said pointers to automatically derive the altitude of the first point from said distance and the angle of said airline with respect to said plane.

11. Apparatus for computing the distance from one point to a second point and the altitude of the first point above the plane of the second point, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; means operatively connected to at least one of said pointers to automatically derive the airline distance between the two points from the angular disposition of said pointers with respect to said base line; an indicating needle controlled by said distance-deriving means; means operatively connected to one of said pointers to automatically derive the altitude of the first point from said distance and the angle of said airline; an indicating needle controlled by said altitude-deriving means positioned to intersect the first needle; and a chart associated with said arms calibrated to indicate by the position of said intersection of the needles the position in space of the first point with respect to the second point.

12. Apparatus for computing the distance from one point to a second point and the altitude of the first point above the plane of the second point, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; means operatively connected to at least one of said pointers to automatically derive the airline distance between the two points from the angular disposition of said pointers with respect to said base line; an indicating needle controlled by said distance-deriving means; means operatively connected to one of said pointers to automatically derive the altitude of the first point from said distance and the angle of said airline; an indicating needle controlled by said altitude-deriving means positioned to intersect the first needle; and a chart associated with said arms adapted to indicate graphically by the position of said intersection of the arms the position of the first point relative to a desired line of travel to the second point.

13. Apparatus for computing the distance from one point to a second point and the altitude of the first point above the plane of the second point, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations: an electric circuit; means associated with the pointers to regulate the voltage of said circuit at a value corresponding to the sum of the logarithms of factors in an equation expressing the distance in an airline between the two points; a second circuit connected with the first circuit to receive the regulated potential thereof; means associated with one of said pointers to add to said transferred voltage in the second circuit a value corresponding to the logarithmic function of an angle associated with said airline and plane, whereby the resultant voltage of the second circuit corresponds to the sum of the logarithms of factors in an equation expressing the altitude of the first point above the plane of the second point; a voltmeter in the first circuit having a logarithmic scale calibrated in units of distance; and a voltmeter in the second circuit calibrated in units of altitude.

14. Apparatus for computing the distance from one point to a second point and the altitude of the first point above the plane of the second point, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations, one of said pointers having a normal position perpendicular to said base line, the other pointer forming an acute angle with the base line varying with the distance to be computed; an electric circuit having a minimum potential corresponding in value to the logarithm of the length of said base line; voltage-regulating means operated by the acute-angle pointer adapted to add to said minimum potential a voltage value corresponding to the logarithm of the tangent of said acute angle, whereby the resultant voltage of the circuit will correspond in value to the logarithm of the distance in an airline between the two points; a voltmeter in said circuit having a logarithmic scale calibrated in units of distance; a second circuit; a voltage regulator operatively connected with the normally perpendicular pointer and adapted to control the potential of said second circuit; a voltmeter in said second circuit calibrated to indicate the angular variance of said pointer from its normal perpendicular position; a third circuit associated with the first

circuit to receive the regulated potential thereof; means connected with one of said pointers to add to said transferred potential in the third circuit a value corresponding to the logarithmic function of an angle associated with said airline, whereby the resultant voltage of said third circuit corresponds to the logarithm of the altitude of said first point above the plane of said second point; and a voltmeter in said third circuit having a logarithmic scale calibrated in units of altitude.

15. Apparatus for computing the distance between two points, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; an electric circuit; means operated by said pointers to vary the voltage of said circuit in accordance with the distance between the two points; and a voltmeter in said circuit having a scale calibrated in units of distance.

16. Apparatus for computing the distance between two points, comprising, in combination: means generating electro-magnetic radiations from one of said points, the other being the receiving point; means at the receiving point for receiving said generated electro-magnetic radiation; two pointers associated with the receiving point spaced to define a base line for computing distance by triangulation; means connected with each pointer responsive to said electro-magnetic radiations to automatically train each pointer on the source of the radiations; an electric circuit; means operated by said pointers to vary the amperage of said circuit in accordance with the distance between the two points; and an ammeter in said circuit having a scale calibrated in units of distance.

17. In a device of the class described, a direction indicator reactive to a beacon generating electro-magnetic radiations, said indicator comprising, in combination: a pointer mounted for angular movement through two planes; a reversible motor for moving the pointer in one plane; a motor circuit adapted to energize the motor in one direction in said plane; a motor circuit adapted to energize the motor in the opposite direction in said plane; a second motor for moving the pointer in the second plane; a motor circuit adapted to energize said second motor in one direction; a motor circuit adapted to energize said second motor in the opposite direction; a pair of diametrically opposed photoelectric cells connected with the pointer and aligned with the plane of pointer-movement associated with the first motor means, said cells being responsive to said radiations; a second pair of diametrically opposed photoelectric cells aligned with the plane of pointer-movement associated with the second motor means; means associated with said receivers to focus said radiations to an image spot at the range of said cells; a normally open switch in each of said motor circuits; four switch operating means, each operatively connected with one of said switches and controlled by one of said cells, whereby the image point on a given photoelectric cell causes the pointer to turn towards said beacon; and means to deenergize either of said motors when both of its associated photoelectric cells are energized.

18. In a system for indicating direction, the combination of: a pivotally mounted pointer, motor means for pivotally moving the pointer; a distant beacon radiating modulated quasi-optical waves; lens associated with the pointer to focus said waves to an image spot; and photoelectric means connected with the pointer and lens responsive to said waves, said photoelectric means having plate circuits filtered to such modulation, and adapted to control said motor means, said cells and output circuits being so constructed and arranged that the motor keeps the pointer trained on said beacon.

19. In a system for indicating direction, the combination of: a pivotally mounted pointer; motor means for pivotally moving the pointer; a distant beacon radiating modulated quasi-optical waves; lens associated with the pointer to focus said waves to an image spot; and a plurality of photoelectric cells responsive to said waves connected with the pointer and disposed around the axis thereof to receive said image spot, said cells having plate circuits selectively tuned to the modulation of the waves, and adapted to control said motor means and arranged to move the pointer to a position centering the image spot on the axis of said cells, thereby training the pointer on said beacon.

20. In a device of the class described, a direction indicator reactive to a distant source of electromagnetic radiations, said indicator comprising: a pivotally mounted pointer; reversible motor means to move the pointer through two dimensions; reversible motor means to move the pointer through the third dimension; three photoelectric cathodes on the pointer grouped about the axis of the pointer, responsive to said electromagnetic radiations; means on the pointer to direct an image of said radiations towards said cathodes; a plurality of relays controlling the first motor means; a plurality of relays controlling the second motor means; and three plate circuits controlled respectively by said photoelectric cathodes and controlling in turn said relays, said plate circuits being energized in proportion to the energization of their respective photoelectric cathodes, said relays being responsive to plate circuits having preponderant current, said relays and plate circuits being arranged to cause the pointer to move to a position directed at said source.

21. In a device of the class described, a direction indicator responsive to a distant source of electromagnetic radiations, said indicator comprising; a pivotally mounted pointer; a photoelectric eye mounted to pivot on the same axis as the pointer; a reversible motor to move said eye; a second photoelectric eye on the other side of the pointer pivoted on the same axis as the pointer; a reversible motor to move said second eye, each of said photoelectric eyes having plate circuits controlling the circuits of said motors, said circuits being arranged to move each eye towards the pointer when de-energized and away from the pointer when energized; linkage interconnecting the pointer and the two eyes to maintain the pointer at a position bisecting the angle between the two eyes; and a switch to de-energize said motors when the two eyes close together.

22. In a direction indicator responsive to a distant beacon radiating electromagnetic waves, the combination of: two photoelectric eyes responsive to said beacon, said eyes being pivoted on a common axis; two reversible motors to move the two eyes respectively, each of said eyes having a plate circuit controlling the associated motor whereby each eye is moved away from the other eye when energized by the beacon and towards the other eye when de-energized; and mechanical means to de-energize both motors when the two eyes close together.

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