June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

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FIG. 1A

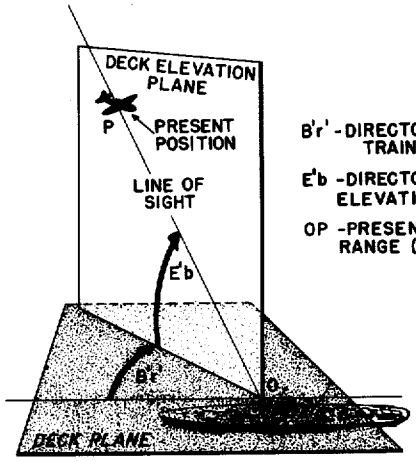
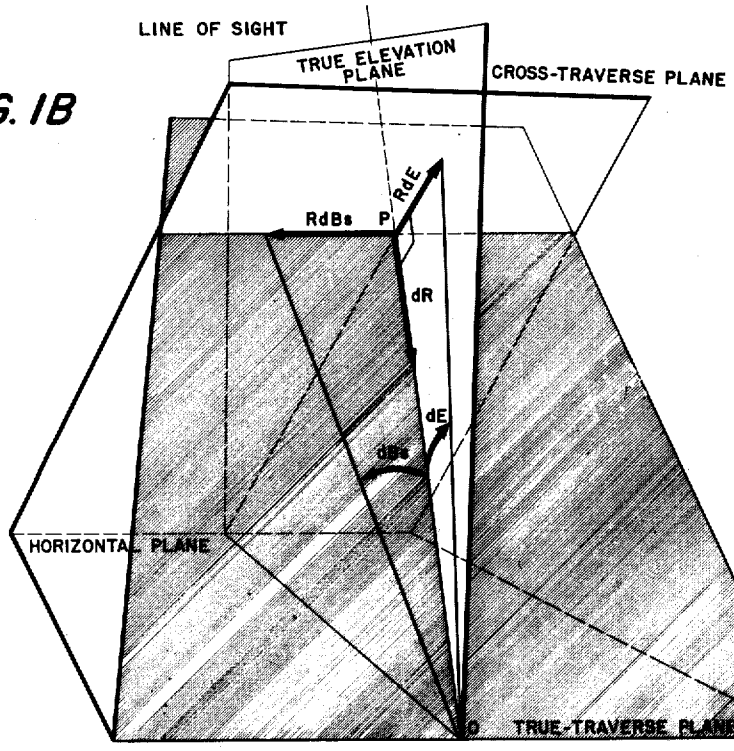


FIG. 1B



OP - PRESENT RANGE (R)
dE - INSTANTANEOUS ANGULAR ELEVATION RATE
dBs - INSTANTANEOUS ANGULAR TRAVERSE RATE
dR = INSTANTANEOUS RANGE RATE

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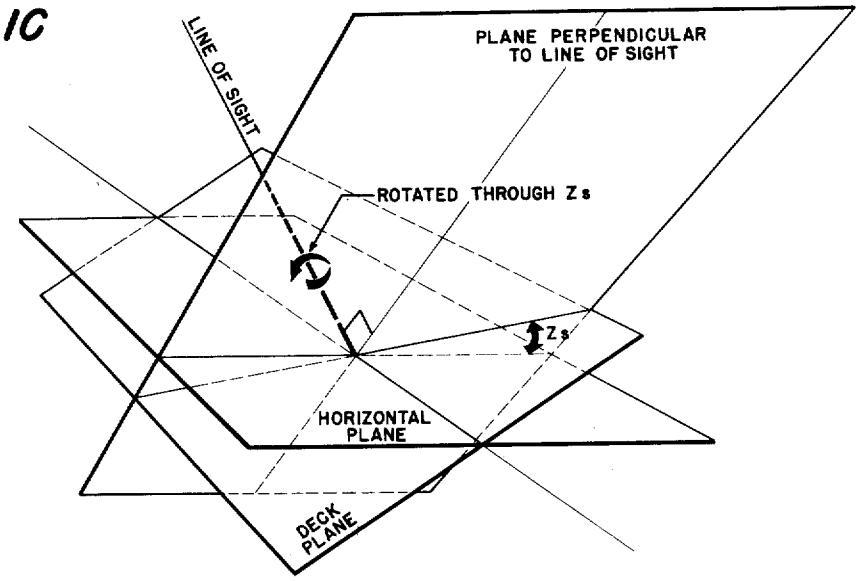
Attorney

June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

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FIG. IC



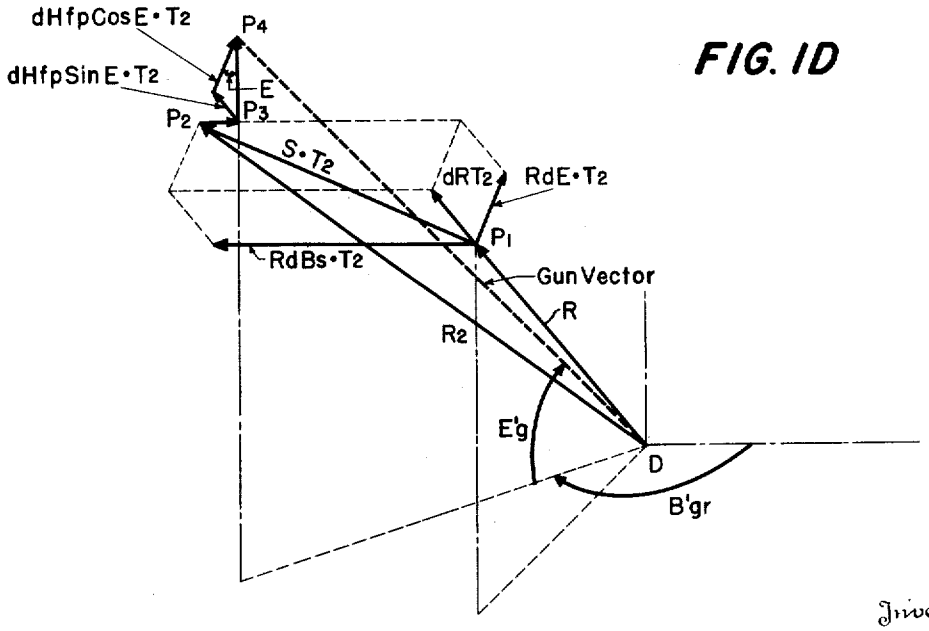


FIG. ID

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FIG. IE

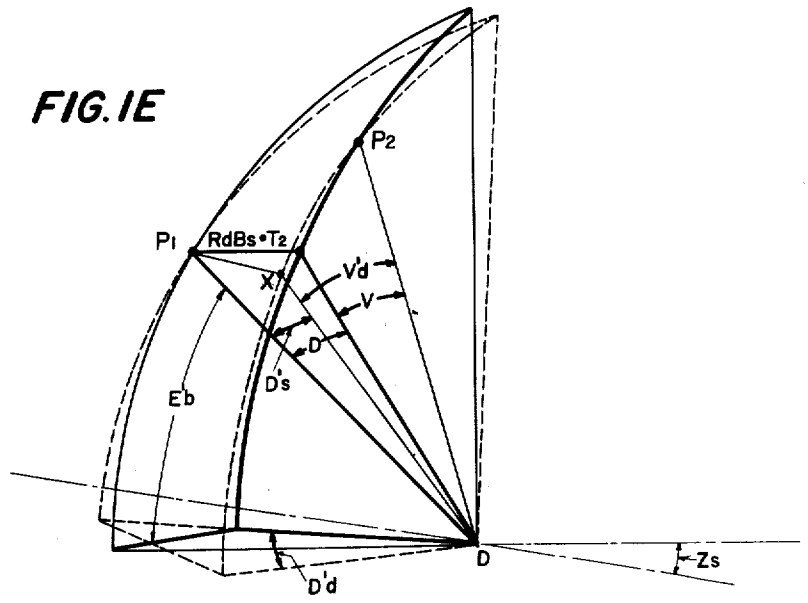


FIG. IF

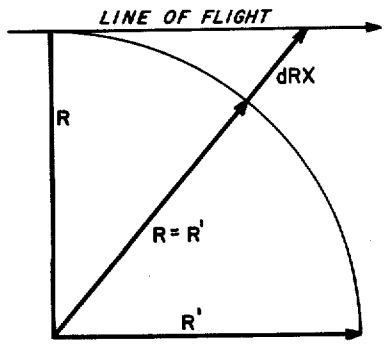
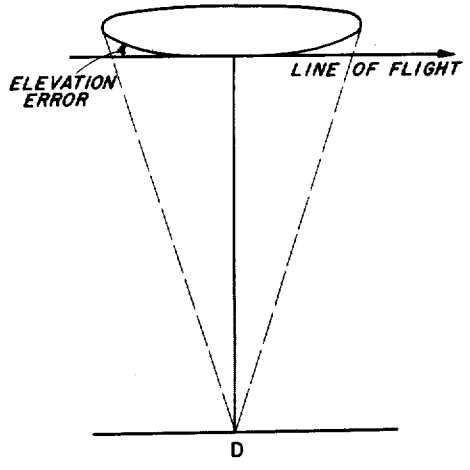


FIG. IG



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June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

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FIG. 1H

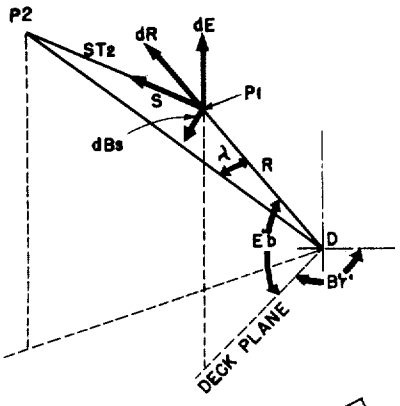
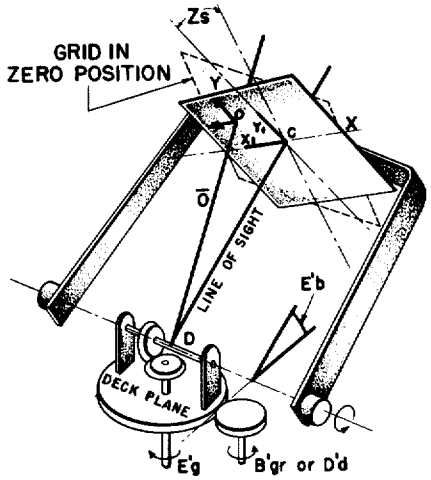


FIG. 1J



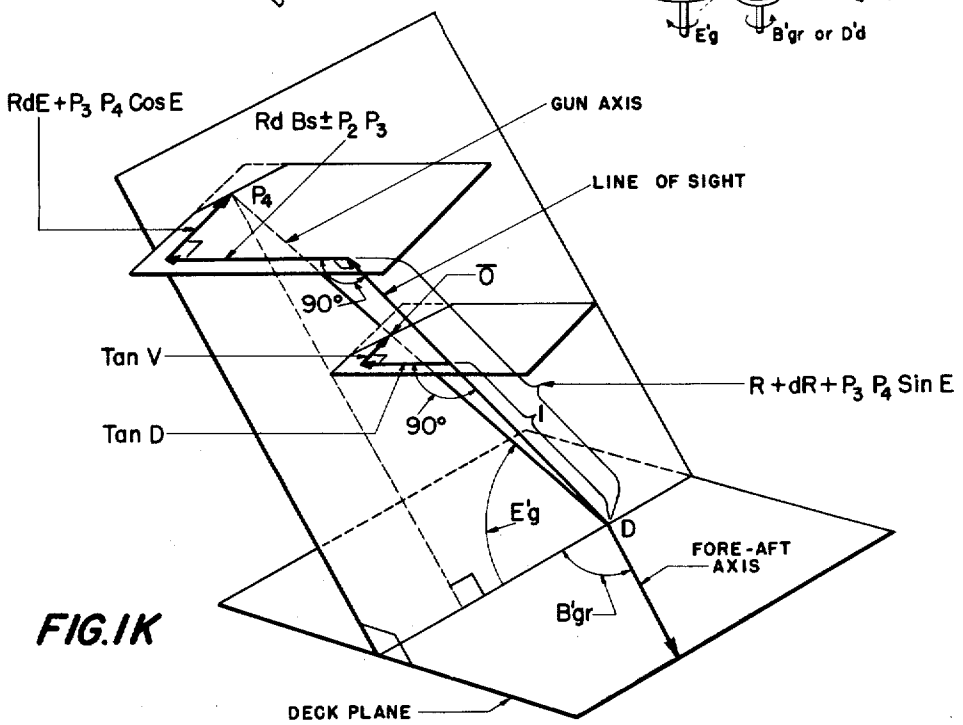


FIG. 1K

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June 11, 1957 C. H. DOWKER ET AL 2,795,379

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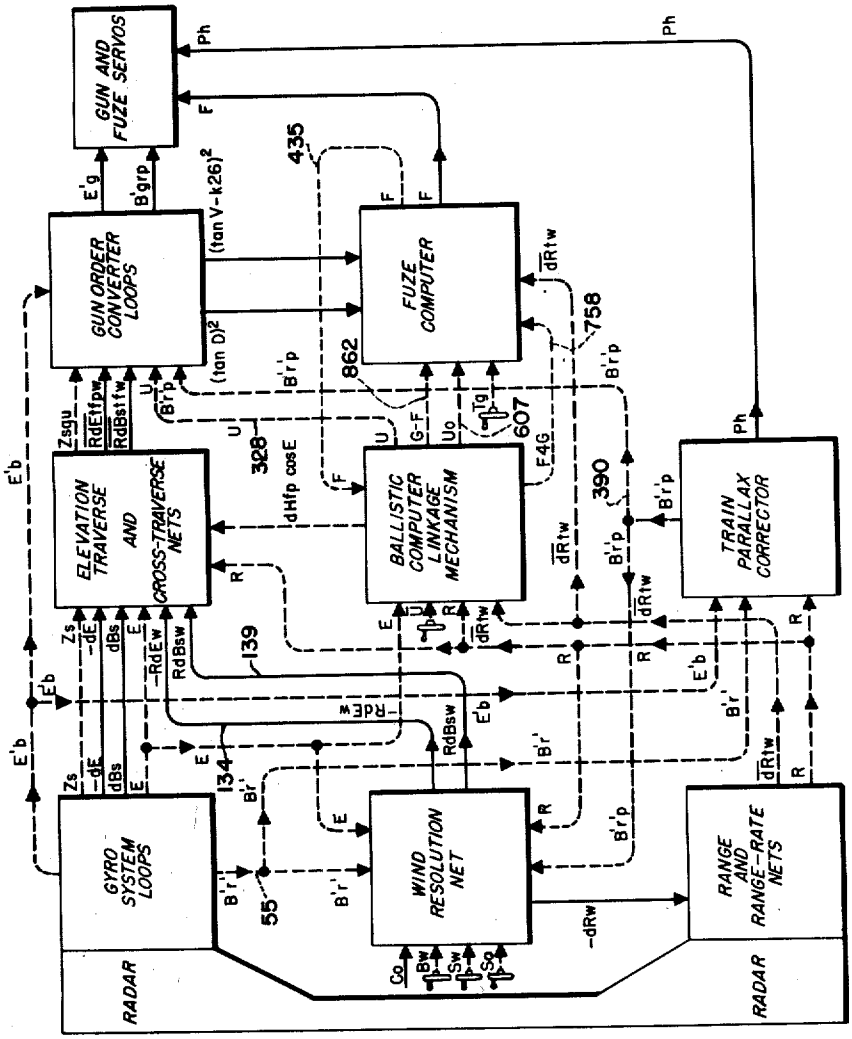


FIG. 2

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GUN ORDER CONVERTER

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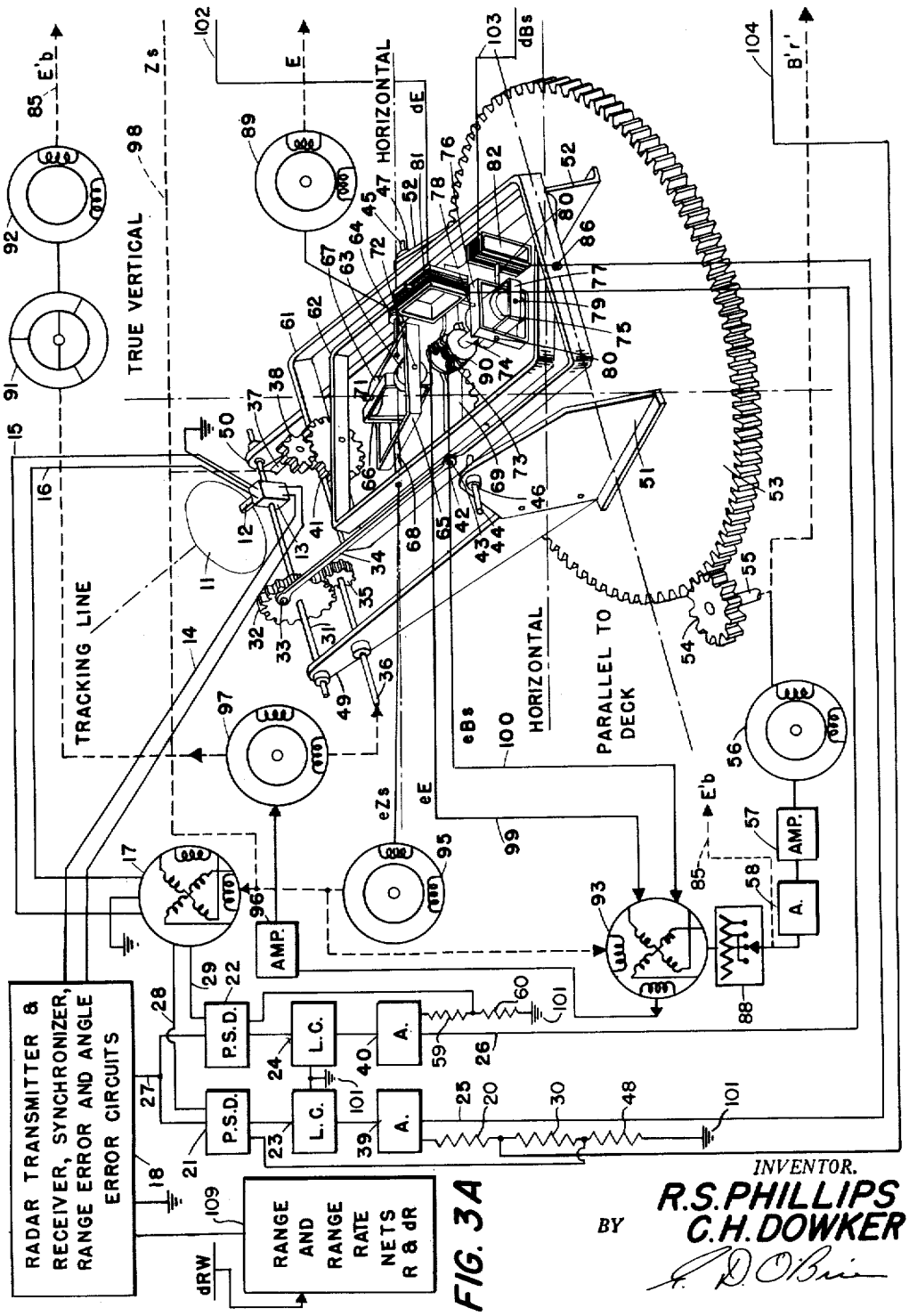


FIG. 3A

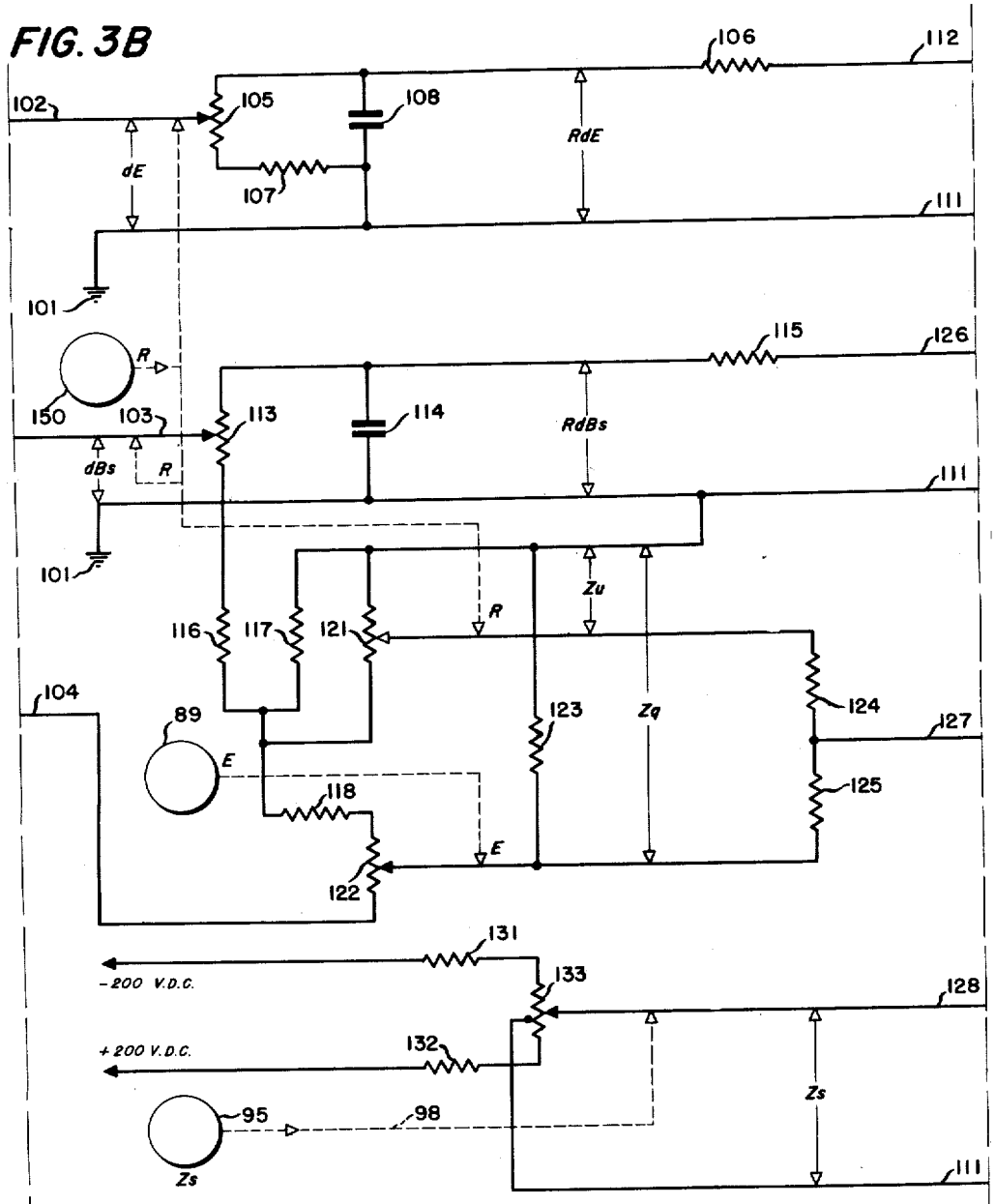
INVENTOR.
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June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

Filed June 1, 1949 18 Sheets-Sheet 7

FIG. 3B



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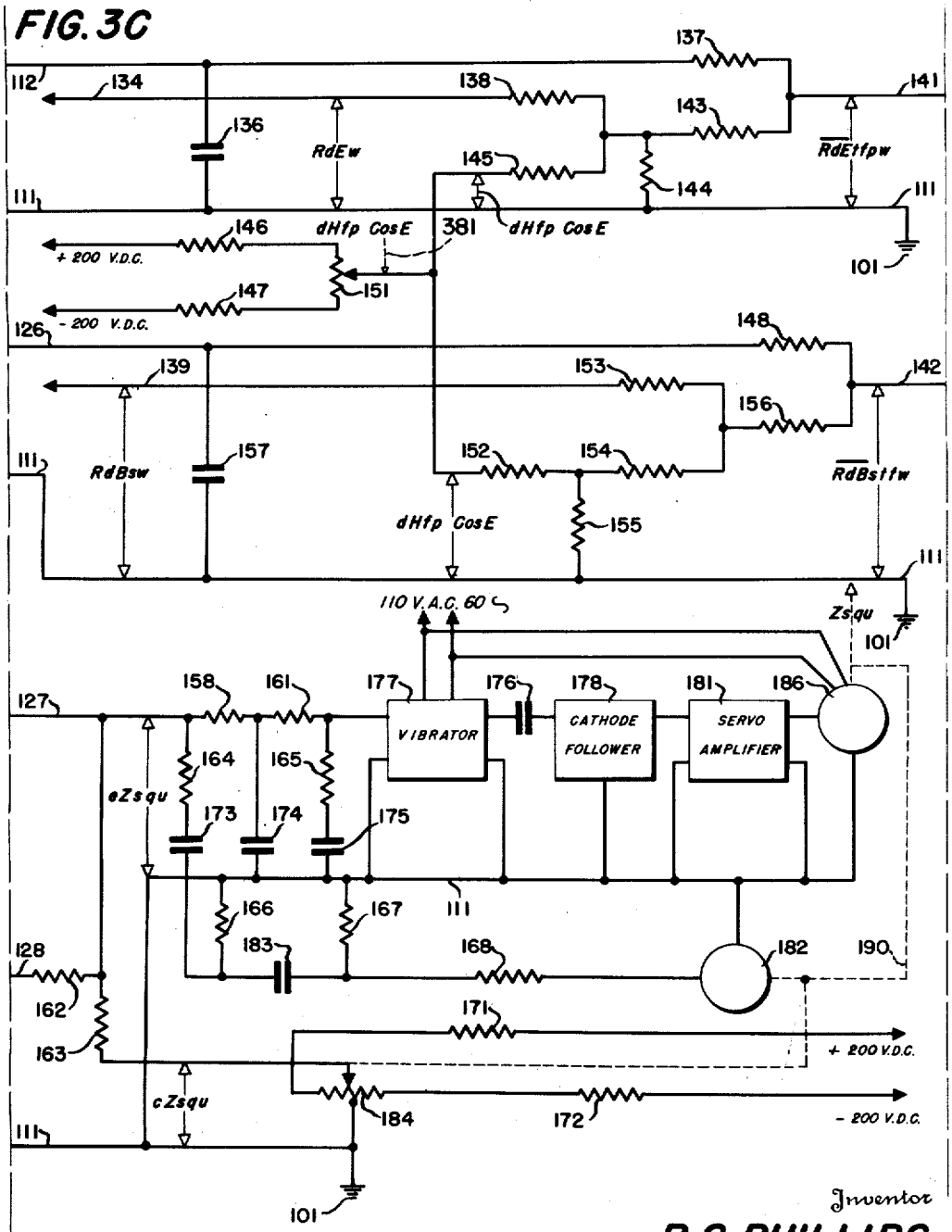
Attorney

June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

Filed June 1, 1949 18 Sheets-Sheet 8

FIG. 3C



Inventor

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GUN ORDER CONVERTER

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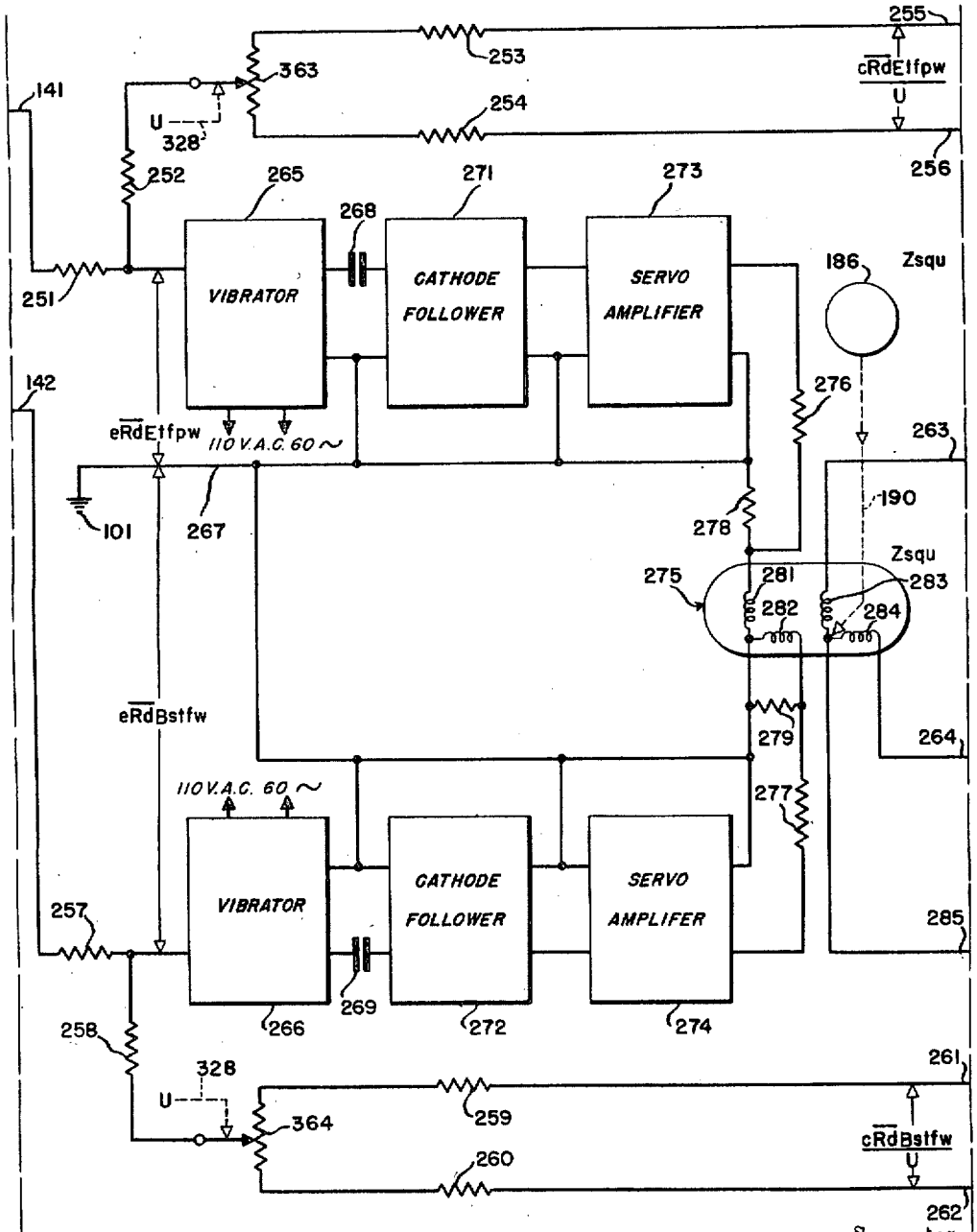


FIG. 3D

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GUN ORDER CONVERTER

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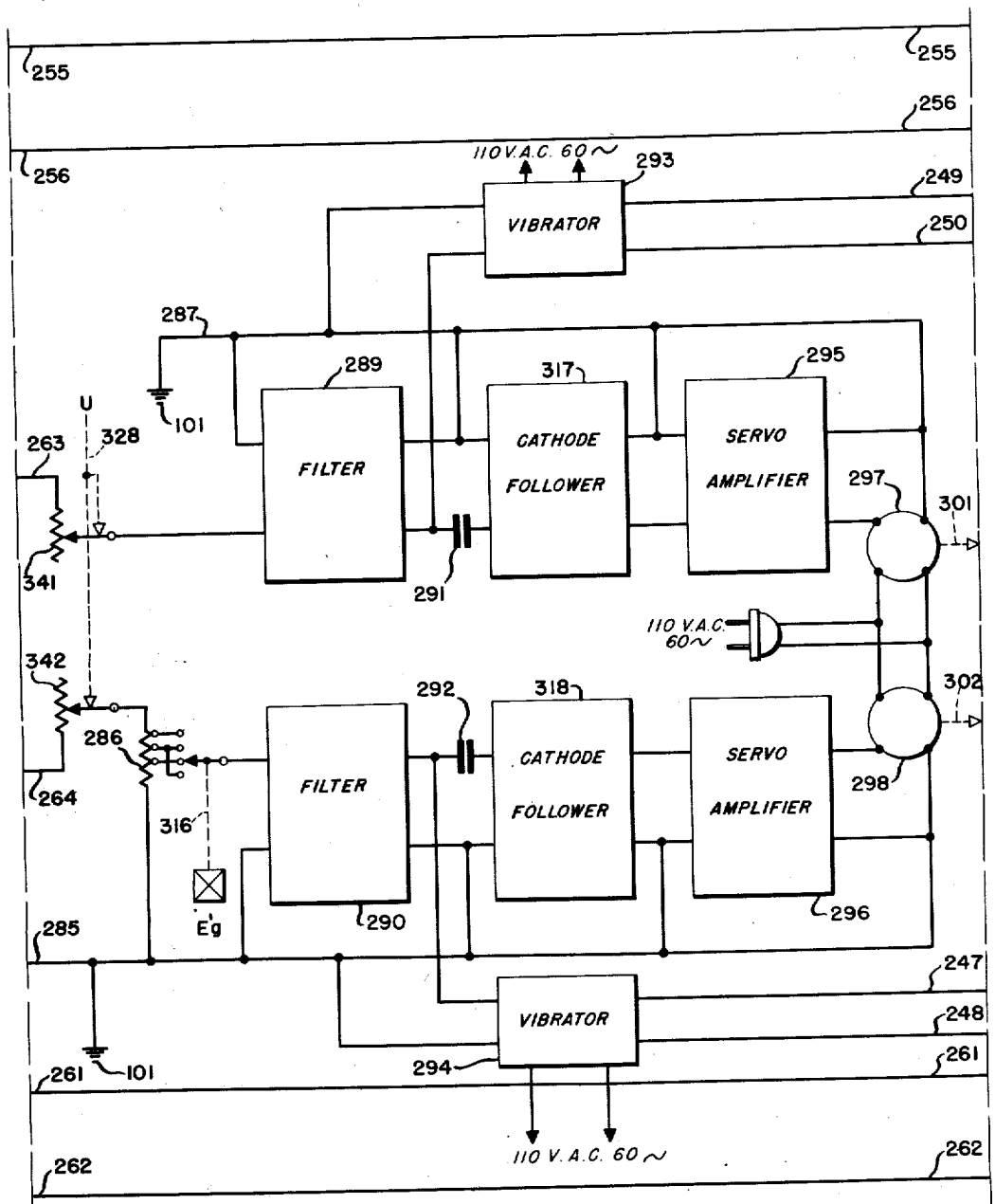


FIG. 3E

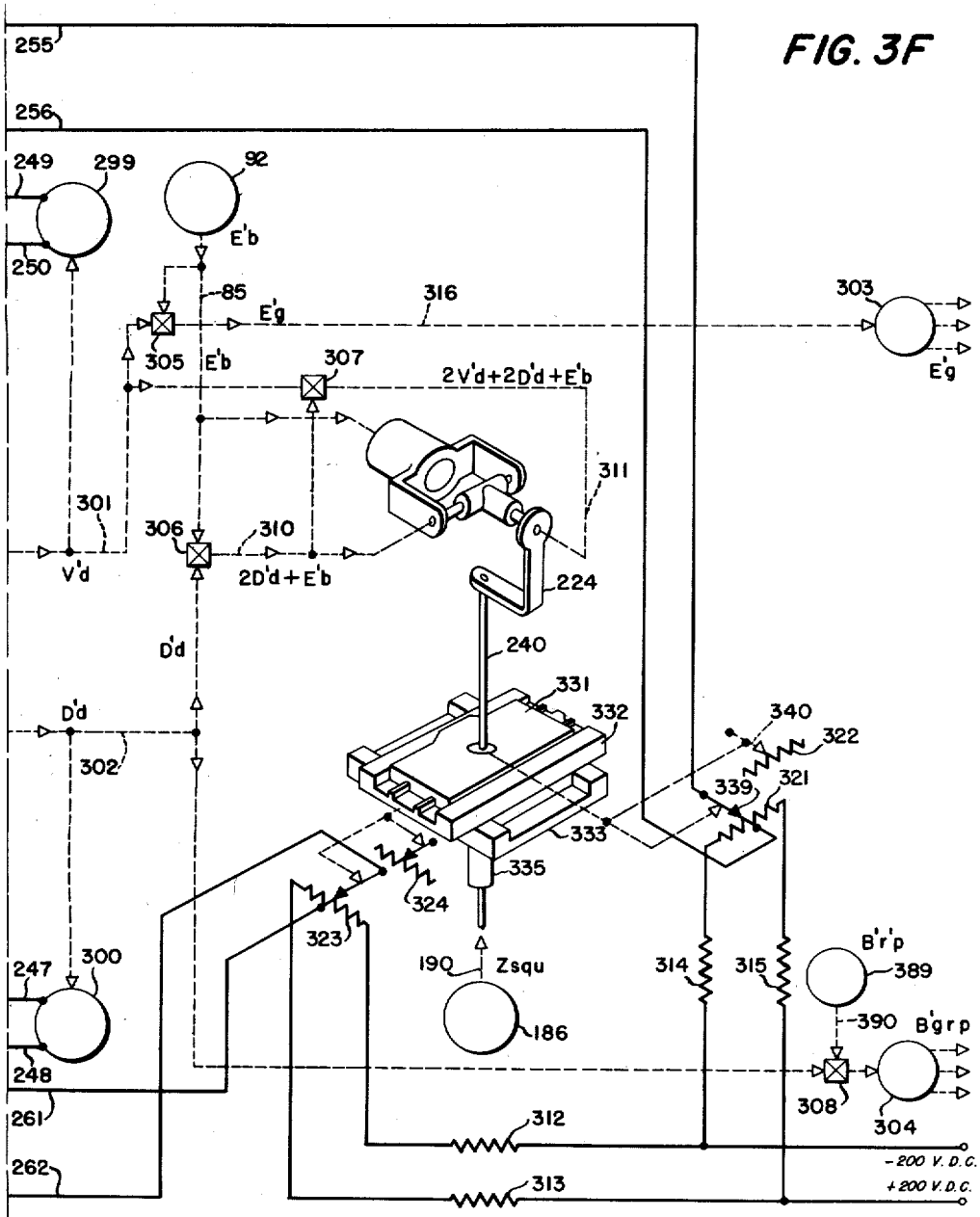
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GUN ORDER CONVERTER

Filed June 1, 1949 18 Sheets-Sheet 11

FIG. 3F



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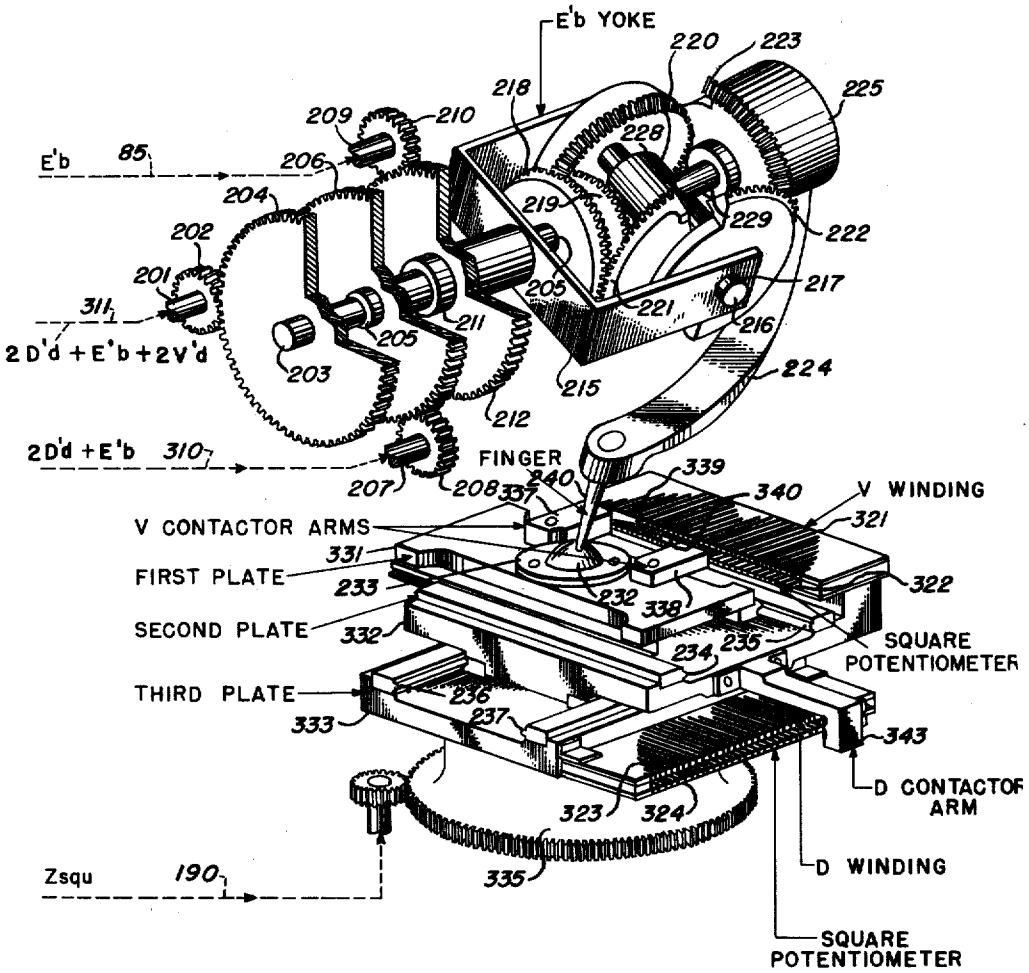
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GUN ORDER CONVERTER

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FIG. 4



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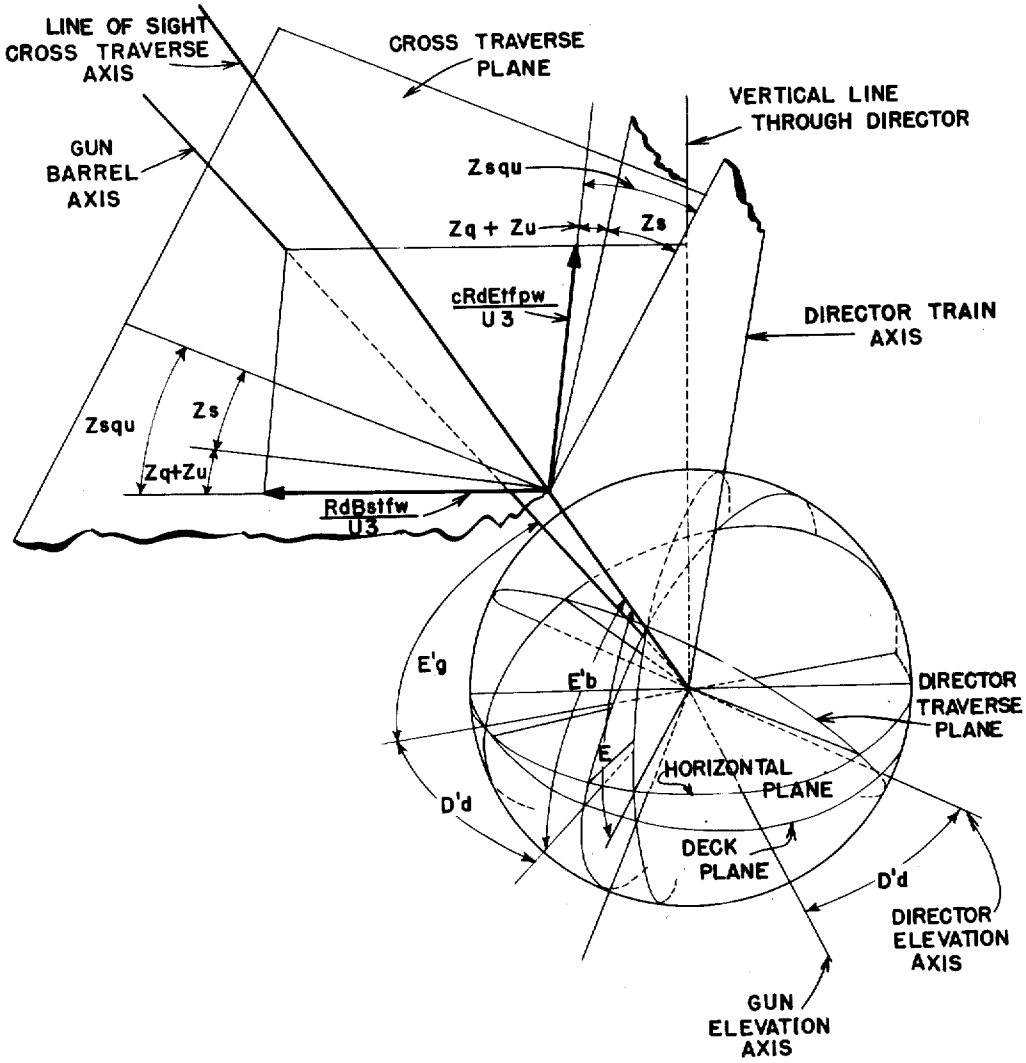
ATTORNEY

June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

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FIG. 5A



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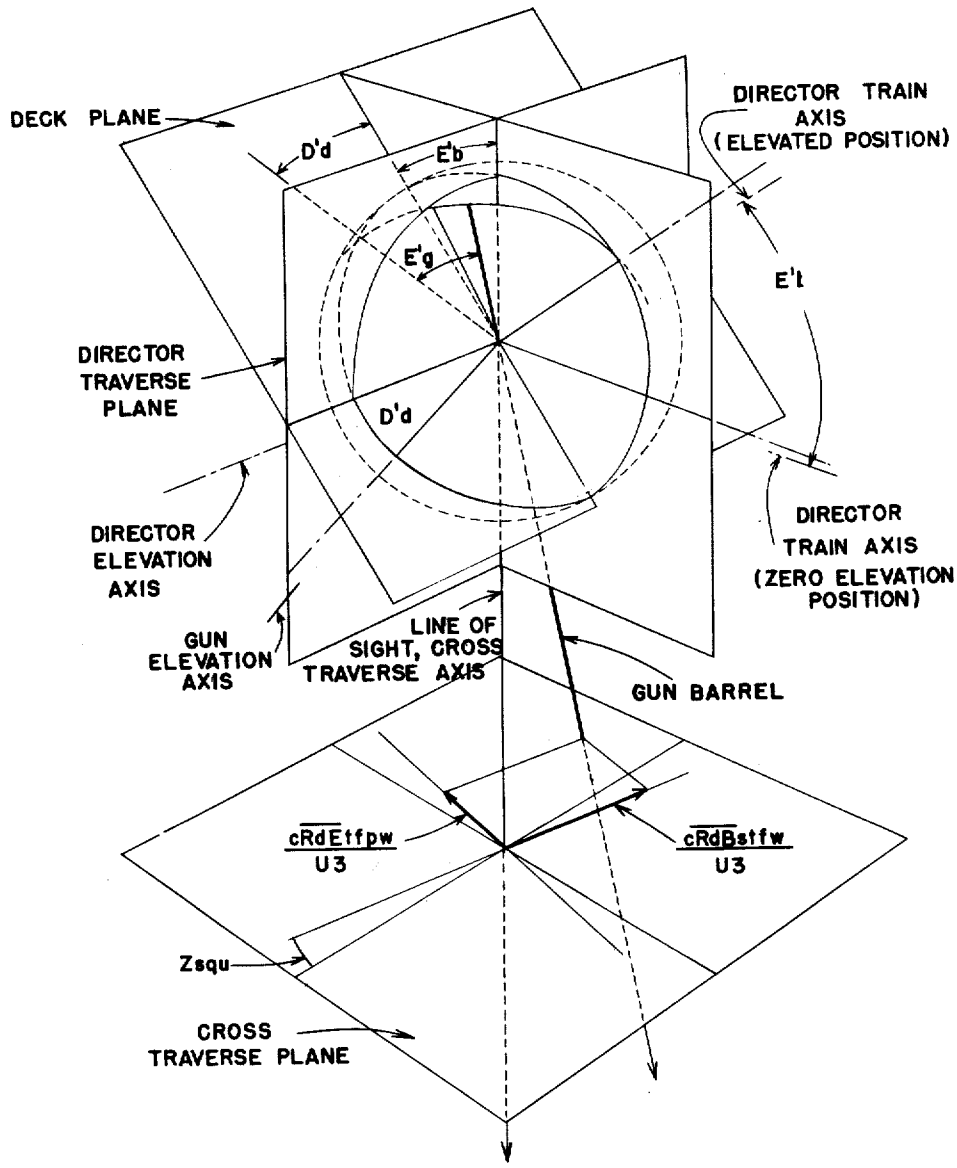
BY G. D. O'Brien ATTORNEY

June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

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FIG. 5B



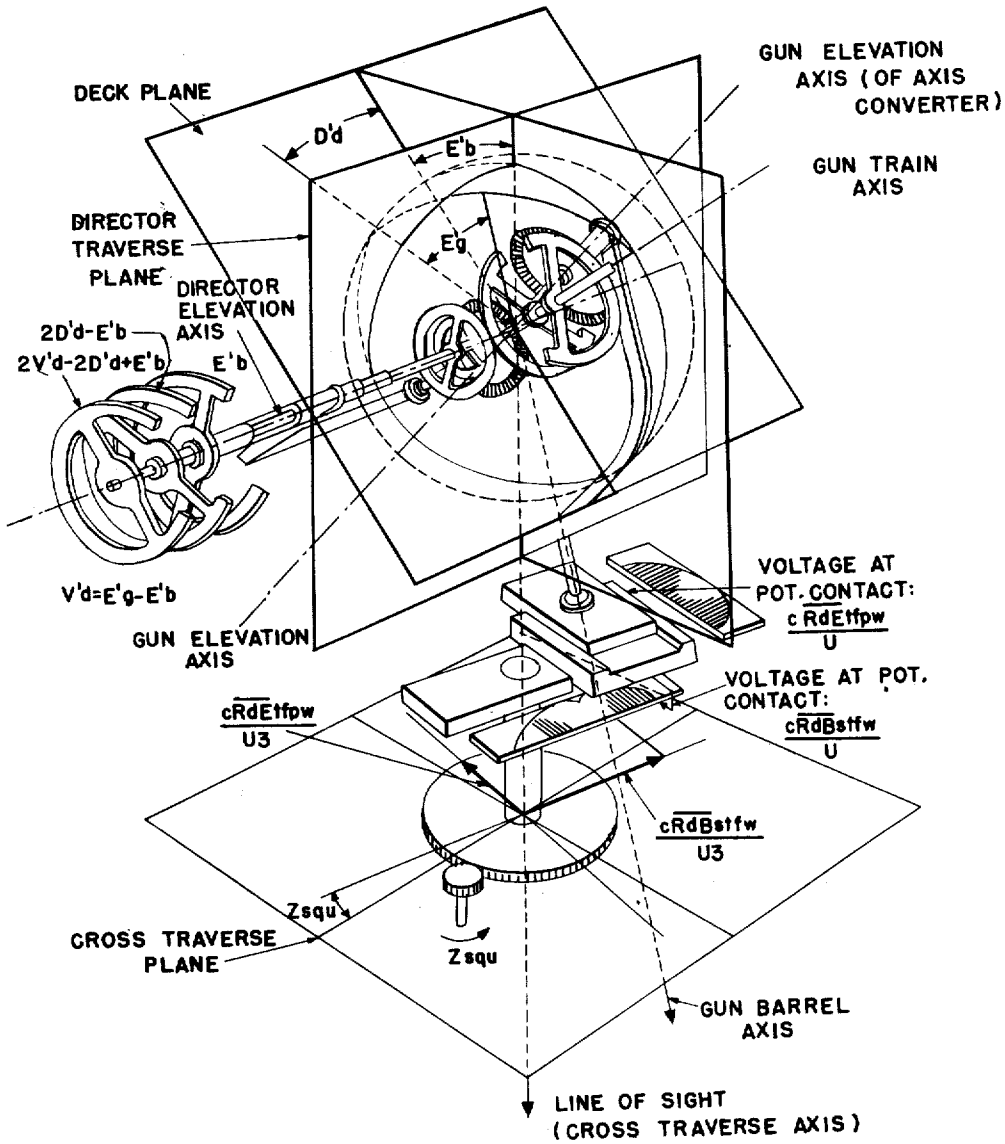
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June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

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FIG. 5C



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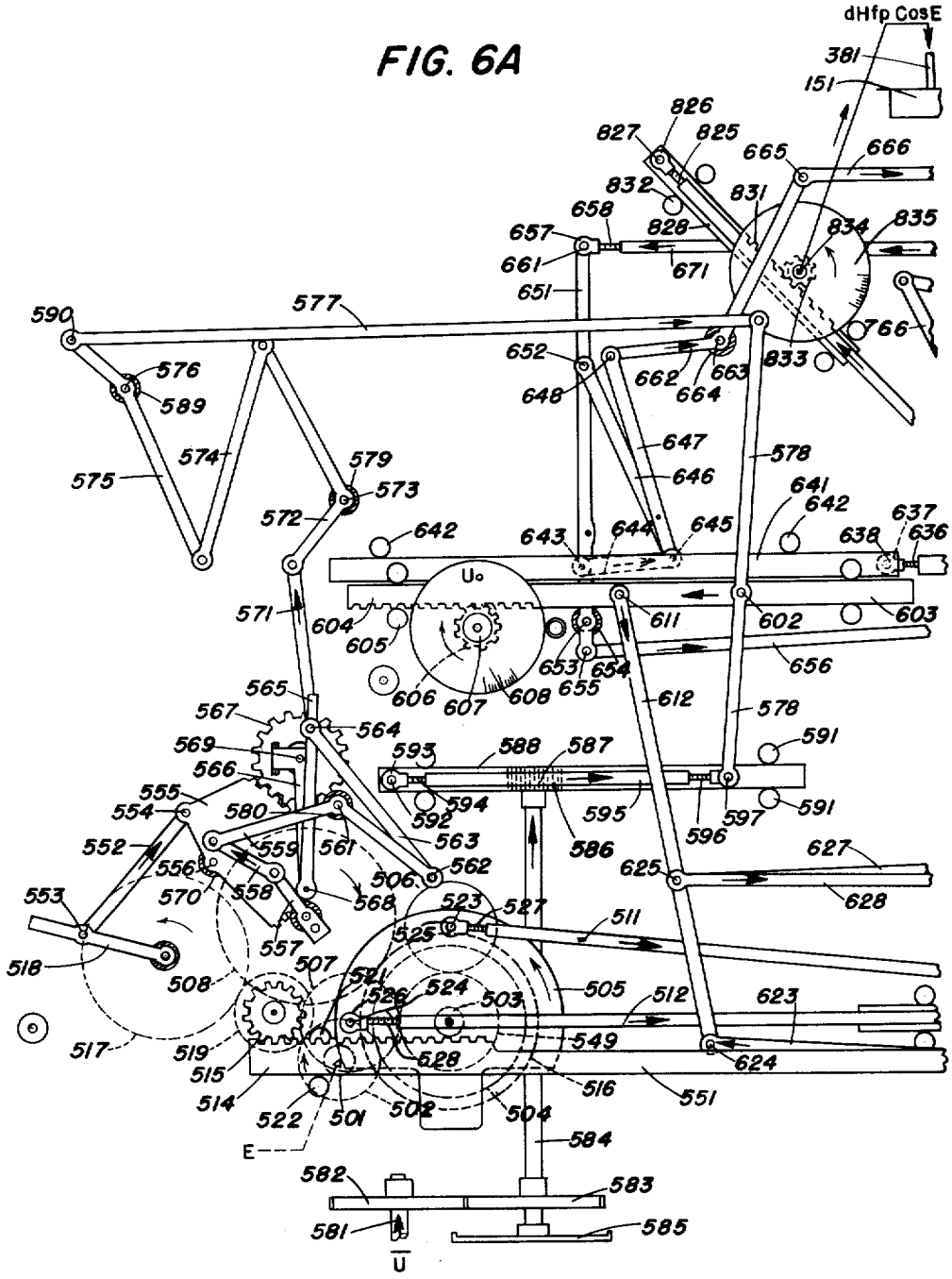
BY G. D. O'Brien ATTORNEY

June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

Filed June 1, 1949 18 Sheets-Sheet 16

FIG. 6A



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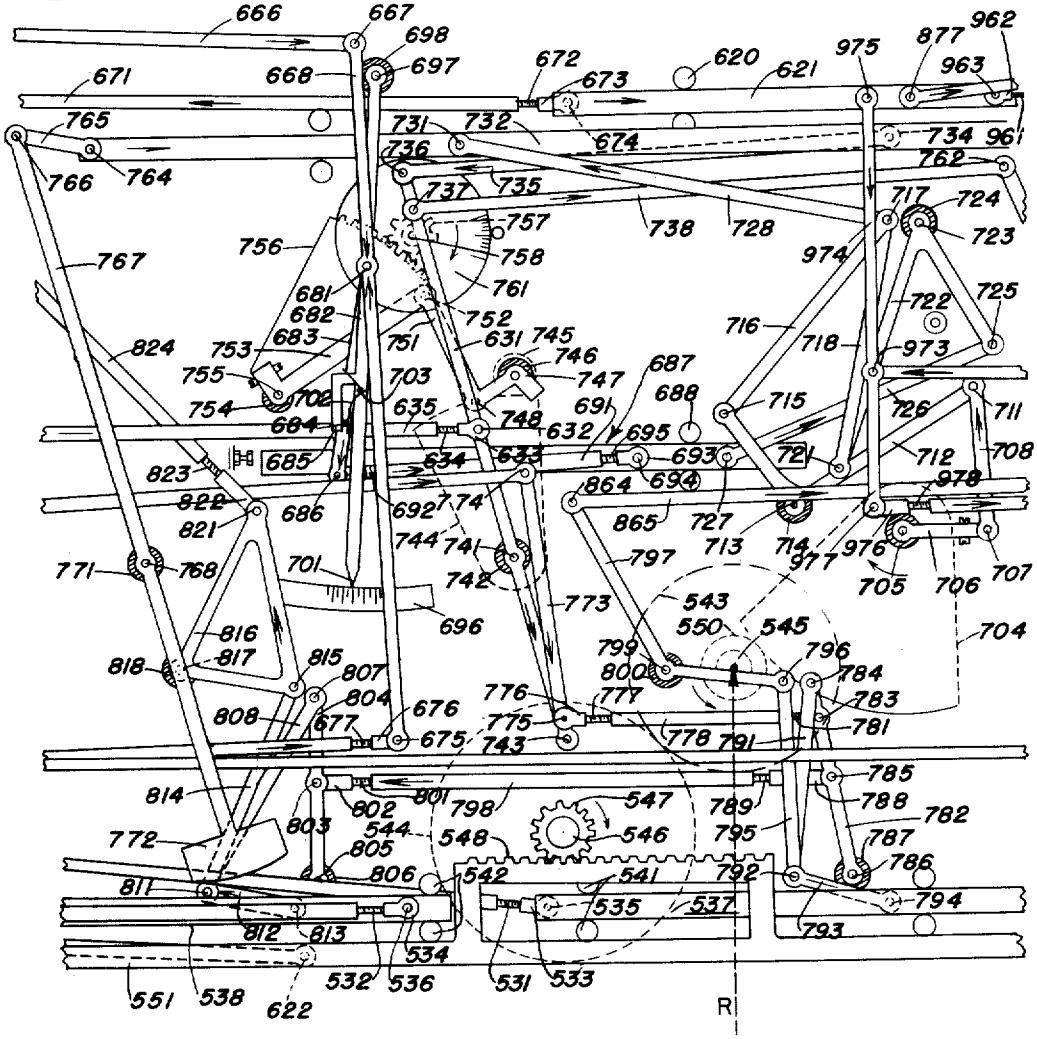
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ATTORNEY

June 11, 1957 C. H. DOWKER ET AL 2,795,379

GUN ORDER CONVERTER

Filed June 1, 1949 18 Sheets-Sheet 17

FIG. 6B



INVENTOR
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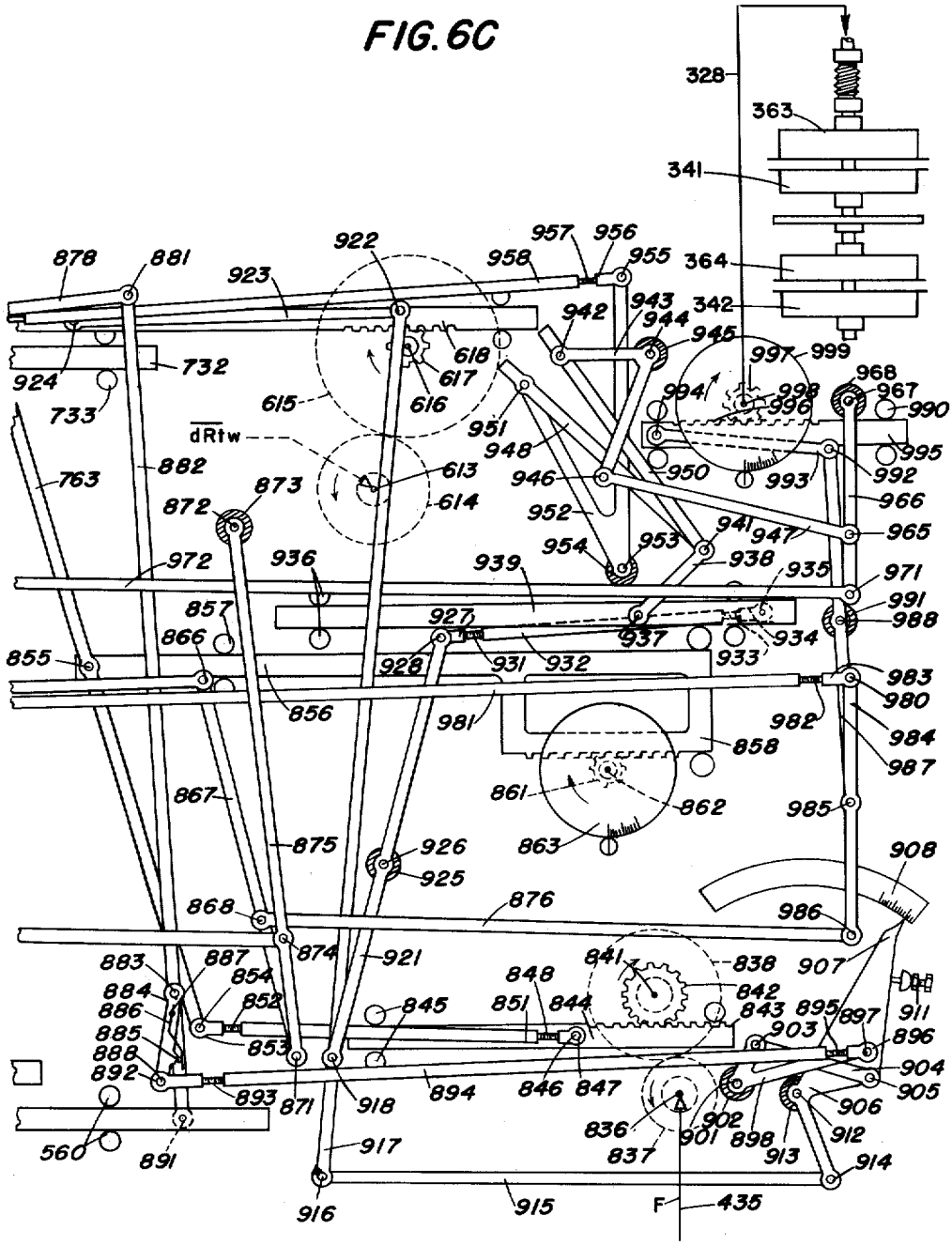
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GUN ORDER CONVERTER

Filed June 1, 1949 18 Sheets-Sheet 18

FIG. 6C



INVENTOR

R. S. PHILLIPS

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BY

A. D. O'Brien ATTORNEY

United States Patent Office 2,795,379 Patented June 11, 1957

2,795,379

GUN ORDER CONVERTER

Clifford Hugh Dowker, Princeton, N. J., and Ralph S. Phillips, Los Angeles, Calif., assignors, by mesne assignments, to the United States of America as represented by the Secretary of the Navy

Application June 1, 1949, Serial No. 96,516

23 Claims. (Cl. 235—61.5)

This invention relates to improvements in gun order converters for use in gun fire control systems employing a gun director for training and firing a gun at a moving target, and more particularly to gun order converters of the type in which a movable member is employed and moved in a manner simulating the movements of the target to thereby maintain the member in a position corresponding to the desired lead angles of target motion, and has associated therewith means for obtaining electrical signals representing said position.

In accordance with a preferred embodiment of the instant invention, a pair of rectangularly wound tapered potentiometers disposed in mutually perpendicular directions have their arms positioned in manners corresponding to the lead angles of the target in a pair of mutually perpendicular directions corresponding to true traverse and true elevation. Voltages derived from the potentiometers are employed in a pair of servo systems for positioning a finger to which the contact arms of the potentiometers are operatively connected, and are also employed, in conjunction with target present position information from the director, to obtain gun orders.

Apparatus embodying the instant invention also includes means for compensating for the roll and pitch of the vessel and means for compensating for the time by which target rate data is late due to smoothing.

The apparatus of the instant invention also provides for a fire control arrangement in which it is unnecessary to compute the quantity T2, or time of flight of the projectile to the future position of the target, and corresponding quantities U3 or $\tilde{U}$, shell average velocity along the range component of future position, quantities which it has been found difficult to compute, but permits a ballistic computed quantity U, or computational shell velocity, to be employed instead of U3 or $\tilde{U}$ in the computing circuits. This is accomplished by tapering the aforementioned potentiometers in a manner to be subsequently described.

The instant invention is particularly well adapted for use in the gun fire control system described and claimed in the copending application of Ivan A. Getting for Gun Fire Control Method and System, Serial No. 61,558, filed November 23, 1948.

An object of the invention is to provide new and improved gun order converter apparatus.

Another object is to provide new and improved gun order converter apparatus employing a finger which is continuously positioned in accordance with the lead angles of a moving target.

Another object is to provide new and improved gun order converter apparatus in which time of flight computation is eliminated.

Another object is to provide new and improved gun order converter apparatus for use aboard a vessel in which rotation of the deck as the vessel rolls and pitches is corrected for.

Another object is to provide new and improved gun order converter apparatus in which the effects of wind upon the projectile are corrected for.

Another object is to provide new and improved gun order converter apparatus in which the effect of gravity upon the projectile is corrected for.

Still another object is to provide new and improved gun order converter apparatus in which the effect of drift of the projectile is corrected for.

A further object of the invention is to provide new and improved gun order converter apparatus in which smoothed rate data is employed and the effects of smoothing corrected for.

Other objects and advantages of the instant invention will become more clearly apparent after perusal of the following specification, taken in conjunction with the accompanying drawings, in which:

Figs. 1A–1K inclusive are simplified geometrical diagrams illustrating the operation of the invention;

Fig. 2 is a block diagram of a gun fire control system utilizing the instant invention;

Figs. 3A through 3F inclusive taken together comprise a schematic diagram of electrical apparatus including a director and gun order converter embodying the instant invention;

Fig. 4 is a view of an angle converter constructed according to the instant invention;

Figs. 5A through 5C are geometrical diagrams illustrating the operation of the apparatus of the instant invention; and

Figs. 6A, 6B, and 6C taken together comprise a view of a mechanical ballistic computer suitable for use with the instant invention.

In the description of the invention, the following nomenclature is employed:

B′*gr*—Gun train. The angle between the fore and aft axis of own ship and the plane through the gun perpendicular to the deck, measured in the deck plane clockwise from the bow.

B′*grp*—Gun train order corrected for horizontal parallax of the director to the reference point of the ship.

B′*r*—Director train in slant plane parallel to deck.

B′*r*′—Director train. The angle between the fore and aft axis of own ship and the plane through the line of sight perpendicular to the deck, measured in the deck plane clockwise from the bow.

B′*r*′*p*—Director train corrected for horizontal parallax to the reference point of the ship.

B*w*—True direction of true wind. The angle between north and the direction from which the true wind is blowing, measured in a horizontal plane clockwise from north.

c—Before a quantity indicates a generated voltage corresponding to that quantity and used for nulling purposes or for obtaining an error signal.

C*o*—Own ship course. The angle between the north and south vertical plane and the vertical plane through the fore and aft axis of own ship measured in a horizontal plane clockwise from the bow.

D—Traverse deflection. The angle between the line of sight and the plane through the gun perpendicular to the traverse plane, measured in the traverse plane clockwise from the line of sight.

*d*B*s*—Angular traverse rate. The time rate of change of true target bearing measured in the traverse plane.

D′*s*—Deflection in the slant plane.

D′*d*—Deck deflection. Gun train order minus director train.

*d*E—Angular elevation rate. The time rate of change of target elevation.

*d*H*fp*—Gravity drop rate corrected for vertical parallax. $dHfp = k24.k25G + k4\overline{dR}tw.$

*d*R—Range rate. The time rate of change of range.

(Further distinguished by the subscript "*t*" as *d*R*t* when used in combination with range rate correction terms.)

$\overline{d\mathrm{R}}tw$—Computational range rate. Range rate for the computation of average shell velocity: the sum of the smoothed range rate $\overline{d\mathrm{R}}$ due to relative motion of the target *t* and a corrective term, *d*R*w*, applied to range rate *d*R to compensate for the effect on shell velocity due to the component of relative wind *w* which lies along the line of sight.

*d*R*w*—Range rate correction due to line of sight wind. A correction term applied to range rate to compensate for the effect on shell velocity due to the component of relative wind which lies along the line of sight.

e—Before a quantity denotes the instantaneous error in the quantity.

E—Target elevation. The elevation above the horizontal plane of the line of sight, measured in the vertical plane through the line of sight.

E'*b*—Director elevation. The elevation of the director line of sight above the deck, measured in a plane perpendicular to the deck, through the line of sight. The "'" indicates that the quantity is taken relative to the deck while the "*b*" refers to the director.

E'*g*—Gun elevation order. The elevation of the gun above the deck measured in a plane through the gun perpendicular to the deck, while the "'" indicates the quantity is taken relative to the deck and the "*g*" indicates that it refers to the gun.

F—Fuze setting. Fuze setting in seconds.

G—Computational time of flight. Time of flight to a hypothetical target which is following a radial path with a velocity equal to the range rate of the real target.

P*h*—Horizontal parallax. The angular correction to be applied to gun train order for a gun which is 100 yards fore of the reference point.

R—Range. The distance in yards from the director to the target (measured along the line of sight).

R2—Future range. The range at which the target will be when the projectile now being fired bursts, where the subscript "2" indicates the future position.

R*d*B*s*—Linear traverse rate. The component of the linear cross rate lying in the traverse plane, where "*s*" indicates the quantity as is taken relative to the line of sight. (Further distinguished by the subscript "*t*" as R*d*B*st* when used in combination with linear traverse rate correction terms to indicate motion relative to the target.)

R*d*B*sf*—Linear traverse rate correction due to drift. A correction term applied to linear traverse rate to compensate for the effect of drift of the projectile, where "*f*" indicates a movement relative to the standard trajectory. Such a movement is called drift.

$\overline{\mathrm{R}d\mathrm{B}}stfw$—Computational linear traverse rate. Linear traverse rate for the computation of lead angle: the sum of the smoothed linear traverse rate $\overline{\mathrm{R}d\mathrm{B}}s$ due to relative motion of the target *t*, a corrective term to compensate for the effect of drift R*d*B*sf*, and a corrective term to compensate for the effect of cross wind, R*d*B*sw*.

R*d*B*sw*—Linear traverse rate correction due to cross wind. A correction term applied to linear traverse rate to compensate for the effect on shell velocity due to the cross wind, where "R" is a range, "*d*B" is rate of traverse, "*s*" is relative to the line of sight, and "*w*" is due to the wind.

R*d*E—Linear elevation rate. The component of the linear cross rate lying in a vertical plane through the line of sight. (Further distinguished by the subscript "*t*" as R*d*E*t* when used in combination with linear elevation rate correction terms.)

R*d*E*fp*—Linear elevation rate correction due to gravity drop rate and vertical parallax. A correction term applied to linear elevation rate to compensate for the effect of gravity drop rate and vertical parallax.

$$RdEfp = dHfp \cos E$$

$\overline{\mathrm{R}d\mathrm{E}}tfpw$—Computational linear elevation rate. Linear elevation rate for the computation of lead angle: The sum of the smoothed linear elevation rate $\overline{\mathrm{R}d\mathrm{E}}$ due to relative motion of the target *t*, a corrective term *p* to compensate for the effect of gravity drop and vertical parallax, and a corrective term *w* to compensate for the effect of relative wind perpendicular to the line of sight in a vertical plane. $\overline{RdE}tfpw = \overline{RdE} + RdEw + RdEfp$.

R*d*E*w*—Linear elevation rate correction due to elevation wind. A correction term applied to linear elevation rate to compensate for the effect on shell velocity due to the component of relative wind perpendicular to the line of sight in a vertical plane.

S*o*—Own ship speed. The speed of own ship relative to the earth.

S*w*—True wind speed. The horizontal velocity of true wind with respect to the earth.

T2—Time of flight to future position of target.

T*g*—Dead time. The time in seconds between cutting a fuze and firing the projectile.

T*q*—Smoothing time. The time by which linear traverse rate and linear elevation rate may be considered to be late due to smoothing.

$\tilde{\mathrm{U}}$—Measured average shell velocity. The average shell velocity over the range interval 1,000 to 3,000 yards with zero gun elevation and no wind.

U—Average shell velocity for lead angle computation.

U*o*—A shell velocity employed in fuze computation.

U*t*—U prediction. The increment of U which must be included to take account of target motion during time of flight where the subscript "*t*" indicates that the motion is related to the target.

U1—Average shell velocity to present position of the target, where "1" indicates present position.

U2—Average shell velocity. The quotient of range to future position divided by time of flight, where "2" indicates the future position.

U3. $$U3 = \frac{R}{T2} + dR + dHfp \sin E$$

$\tilde{\mathrm{U}}$. $$\tilde{U} = \frac{R}{T2} + dR + dHf \sin E$$

U3 equals $\tilde{\mathrm{U}}$ corrected for parallax.

V—Vertical deflection angle. The angle between the line of sight and the plane through the gun perpendicular to the vertical plane through the line of sight measured in the vertical plane through the line of sight, positive when the gun is above the line of sight.

V'*d*—Elevation difference. Gun elevation order minus director elevation, where the "'" indicates that the quantity is taken relative to the deck and the "*d*" following the quantity indicates that the quantity is measured in plane perpendicular to the deck.

Z*q*—Smoothing rotation about the line of sight. A rotation increment of the grid of the gun order converter about the line of sight necessary to correct for the smoothing of the linear traverse and elevation rates. It is equal to $Tq \cdot dBs \cdot \tan E$, and is measured clockwise about the line of sight.

Z*s*—Cross traverse. The angle, measured in a plane perpendicular to the line of sight *s*, between a vertical plane through the line of sight and a plane perpendicular to the deck through the line of sight. (Positive for the purposes of computation if, when you face the target, the right hand side of the ship is up.)

Z*squ*—Computational rotation about the line of sight. The sum of cross traverse, smoothing rotation about the line of sight, and a corrective term.

Z*u*—A correction to cross traverse.

The following terms, when used to modify a basic

quantity such as elevation E or traverse B, have the following indicated meaning:

b—In reference to the director.
c—Before a quantity means the value of that quantity as generated by the mechanism, as opposed to the observed value of the same quantity. After a quantity means relative to rate control.
d—Before a quantity means a time rate of change of that quantity. After a quantity means in or relative to the deck plane or plane perpendicular to the deck.
e—Elevation.
f—Due to standard trajectory.
g—Of gun.
j—Before a quantity means a correction or partial correction to that quantity, usually generated by the mechanism. After a quantity means arbitrary correction (spot) to that quantity.
o—Own ship; of or due to.
p—Parallax; of or due to.
r—Relative to own ship.
s—Relative to the line of sight, or in a slant plane.
t—Of or due to target.
w—Of or due to wind.
z—Of or due to crosslevel.
f( )—Function of the quantity in parentheses.
'—Indicates that a quantity is measured in or with respect to the deck plane.
1—Present position.
2—After a quantity indicates that it is the predicted value of that quantity for advance position, i. e., for the position at time of flight seconds after firing, or at time of impact or burst.
3—After a quantity indicates that it is the predicted value of that quantity for the time of the burst, of a fuzed projectile, the fuze having been set dead time seconds before firing.
—Smoothing quantity. When used over the quantity. Where the term "K" is used in connection with some numeral it refers to some arbitrary constant.

Reference is made now to the drawings for a more complete understanding of the invention and in particular to Fig. 3A, thereof in which the arrangement of the more important elements of a suitable director are shown. The rotatable base of the gun fire control director, indicated by the reference numeral **53**, is adapted to rotate or pivot through an angle of 360° around an axis vertical to the deck of the vessel and has gear teeth meshing with the teeth of a driving gear **54**, which is driven by shaft **55** by means hereinafter to be more fully described, to position the gear or base **53** in train. Fixedly mounted upon member **53** are a pair of spaced upright supports **51** and **52** which have bearing journals **46** and **47** respectively mounted therein for receiving bearing shafts **44** and **45**.

Fixed to shafts **44** and **45**, to rotate therewith, is a rectangular frame member **61**, which is pivotally mounted to permit rotation about the axis of shafts **44** and **45**. Mounted within member **61** is a second somewhat smaller rectangular frame member **62** adapted to rotate about an axis perpendicular to the axis of shafts **44** and **45**, the bearing pin **86** being provided for this purpose, and gear **41** being fixed to rotate with frame member **62** and adapted to freely rotate about a suitable pin or other mounting member (not shown) mounted in frame member **61**. Gear **38**, driven from shaft **37**, meshes with gear **41** and positions the frame member **62** by the quantity *Zs*.

Mounted within the frame member **62** are: the aforementioned vertical and line-of-sight gyroscopes, the vertical gyroscope comprising rotor **67** which may rotate upon shaft **71**; inner gimbal ring **66** which may rotate with shaft **72** and having a pick-off transformer generally designated by the reference numeral **63** for obtaining a voltage proportional to the quantity *eZs*, in a manner to be subsequently more fully described; and, outer gimbal ring **65** which may be mounted to rotate with a shaft **68** pivoted for rotation in frame member **62**, which shaft **68** has thereon a pick-off transformer **64** for obtaining a voltage representative of the quantity E. The operation of the pick-off transformers **63** and **64** is conventional and need not be described in detail.

In the operation of the vertical gyroscope, the rotor **67** may be driven by any suitable means, not shown, for example, a synchronous motor energized from a power supply of stable amplitude and which has its frequency stabilized, as by a 400 cycle tuning fork.

The rotation of the rotor **67** maintains the shaft **71** in a true vertical position as the director trains and elevates, while outer gimbal ring **65** has the axis of rotation thereof determined by the position of the inner rectangular frame member **62**. As a result, transformer **64** supplies a voltage proportional to the quantity E and, since frame **62** is rotated by the quantity *Zs*, transformer **63** provides a voltage, *eZs*, representative of the cross-traverse angle, *Zs*. These voltages are utilized for purposes to be made apparent hereinafter. The generation of the signal voltage *eZs*, representative of the cross-traverse angle *Zs* is attributable, of course, to the inclination of the deck plane produced as the result of the roll and pitch of the vessel.

A second gyroscope, the aforementioned line-of-sight gyroscope, comprises a gyro rotor **75** which is rotated at constant speed by any convenient means, not shown. The rotation of the rotor **75** may take place about a shaft **79** supported in inner gimbal ring **77**. The inner gimbal ring may be fixed to a shaft **80** for rotation therewith within the outer gimbal ring **76**. Fixed to shaft **80** is a torque motor coil generally designated by the reference numeral **82**, for purposes to be hereinafter apparent. Fixed to shaft **78**, which may be fixed to ring **76**, is a second torque motor coil generally designated by the reference numeral **81**, these torque motor coils **82** and **81** being portions of torque motors which, when energized by currents from leads **25** and **26** respectively, precess the line-of-sight gyroscope in traverse and elevation.

The coils **81** and **82** have associated therewith respectively cores of permanently magnetic material, not shown. The cores may be mounted upon a housing, not shown, for the line-of-sight gyroscope, and may be connected to frame **62**. Whereas the line-of-sight gyroscope, for convenience of illustration, is shown as "floating," that is unsupported, it is understood that suitable supporting means is provided for mounting this gyroscope within frame **62** in a manner to allow freedom for precessive movements thereof.

Attached to the rectangular frame member **62** is a cross support **69** on which are mounted the primary and secondaries of a double E transformer **73** which may be of conventional design. A reluctance dome **90** is attached to shaft **74** which is attached to gimbal **77** and moves with movements of the axis of rotation of rotor **75**, and provides for the generation of two voltages in the secondaries of the double E transformer proportional to the displacement of the dome from its center position in two mutually perpendicular directions. These voltages are representative of the quantities *e*E and *eBs*, and are applied by way of leads **99** and **100** respectively to a resolver **93**.

The aforementoned trunnions **51** and **52** have extended arm portions **49** and **50** respectively. A shaft **31** is supported in bearings in arms **49** and **50** and has fixed thereto for rotation therewith a gear **32**, the teeth of which gear mesh with the teeth of a gear **35** fixed to shaft **36**, while the shaft **36** is connected to servomotor or servo system **97** and positions shaft **31** by the quantity E'*b*. Shaft **31** may have fixed thereto to rotate therewith a housing **13** for a scanning mechanism, which may be of conventional design, and which is operatively connected by means of a length of wave guide **12** or other means with an an-

tenna, not shown, which functions in conjunction with reflector **11**. The scanning mechanism, reflector, and antenna system associated therewith provide means for causing a recurrent series of overlapping conical patterns of radiation of a type to permit a range error signal and angle error signal to be produced by suitable radar apparatus, shown in block form at **18** and operatively connected by wave guide **14** to the housing **13**, member **12**, and reflector **11**. The radar apparatus may be of conventional design.

Gear **32** has a pin **33** fixed thereon, and frame **61** has a raised arm portion **43** having pin **42** affixed thereon. Pins **33** and **42** are operatively connected by link **34** for positioning frame member **61** by the quantity E'*b*.

The aforementioned scanning mechanism has associated therewith a reference generator, not shown, which may be of conventional design, for producing two reference voltages of the same frequency as the scanning frequency and 90° apart in phase. These reference voltages are applied by way of leads **15** and **16** to a resolver **17** which also may be of conventional design. Resolver **17** has the moving elements thereof positioned by the quantity Z*s* by suitable mechanical coupling to a Z*s* servomotor **95** operatively connected to the aforementioned *e*Z*s* pick-off transformer **63**, and converts the reference voltages from deck to true or stabilized coordinates.

After resolution at **17**, the reference voltages from the reference generator are applied by way of leads **28** and **29** to a pair of phase sensitive detectors **21** and **22** respectively, both of which also have applied thereto by way of lead **27**, the angle error signal from the aforementioned radar **18**. The phase sensitive detectors may be of conventional design and constructed and arranged to provide output voltages representative of the deviation of the target from the center of the pattern or main axis of radiation in two mutually perpendicular directions, in a manner readily apparent to those skilled in the art.

The outputs of the phase detectors **21** and **22** are applied to level changers **23** and **24** respectively, which may be of conventional design, and thence to amplifiers **39** and **40** respectively, whence two currents proportional to *d*B*s* and *d*E respectively are applied by way of leads **25** and **26** to the aforementioned torque motor coils **82** and **81** respectively, for precessing the aforementioned line-of-sight gyroscope in traverse and elevation.

Preferably the gyroscope precessing circuits contain antitumbling circuits, not shown, constructed and arranged to prevent too rapid precessing in response to large error signals.

The aforementioned *e*E and *e*B*s* voltages from "double E" or "crossed E" transformer **73** are applied by way of connections **99** and **100** to the resolver **93** which has the moving or control element thereof positioned by the quantity Z*s* by the suitable coupling shown to the Z*s* servomotor **95**. From the resolver **93**, which may convert from true to deck coordinates, two voltages are obtained, one representative of the quantity *e*E'*b*, the other representative of the quantiy *e*B'*r*. The *e*E'*b* voltage is applied to an amplifier and amplidyne **96** and thence to a drive motor **97** which is operatively connected to position aforementioned shaft **31** by the quantity E'*b*. The voltage representing the quantity *e*B'*r* is applied to a secant attenuator **88**, which has the movable element thereof positioned by the quantity E'*b* by mechanical coupling **85** and converts the voltage applied thereto from a B'*r* signal representing deflection in the slant plane to a B'*r'* signal representing deflection in the deck plane. The B'*r'* signal is applied to amplifier **58** and amplidyne **57** and thence to drive motor **56**, which is operatively connected to aforementioned shaft **55** for positioning the director base **53** in train.

Operatively connected to the aforementioned E pick-off transformer **64** is an E servomotor **89** for providing a shaft rotation representative of the quantity E. A shaft **98** operatively connected to shaft **37** provides a shaft rotation corresponding to the quantity Z*s*.

Operatively connected to motor **97** is generator **91** for producing an E'*b* signal, and responsive to this signal is a servomotor **92** for producing on shaft **85** a rotation corresponding to the quantity E'*b*. These E, Z*s*, and E'*b* outputs are provided for purposes to be presently described.

The range error signal from radar **18** is applied to the range and range rate networks, Fig. 2, for purposes to be hereinafter apparent.

It will be understood that a portion of the electrical circuit of Fig. 2 is diagrammatic.

The aforedescribed director and radar provide an arrangement in which a moving target is automatically tracked, and maintained gated in range by the radar, and the operation thereof is substantially as follows: The nutating mechanism in housing **13**, together with the antenna, not shown, and reflector **11**, provides for a conical pattern of radiation which is itself moving in a conical pattern at a convenient rate, for example 30 times per second; and the radar provides an angle error signal representative of the instant deviation of the target from the main axis of radiation of the antenna system.

The two reference voltages from the aforementioned reference generator, after resolution at **17**, are utilized by the phase sensitive detectors to resolve the aforementioned angle error signal into two angle error component signals representing the deviation of the target from the main axis of the pattern of radiation in a pair of mutually perpendicular directions, corresponding to true elevation and true traverse respectively.

These two signals are applied to the aformentioned torque motor coils **81** and **82** respectively and precess the gyroscope so that the reluctance dome **90** moves from its normal center position with respect to transformer **73**, thereby generating in the transformer **73** two *e*E and *e*B*s* voltages which are respectively measures of the precessions of the gyroscope in a pair of mutually perpendicular directions, and are also representative of the angle errors between the line of sight or major radiation axis of the reflector **11** and the straight line between reflector and target.

These two *e*E and *e*B*s* voltages or error signals are converted by the aformentioned Z*s* resolver **93** and E'*b* secant attenuator **88** from true to deck coordinates, and drive motors **97** and **56** in directions which tend to reduce the angle errors to zero.

The aforedescribed director in which member **61** is positioned by the quantity E'*b*, and member **62** is positioned by the quantity Z*s*, provides an arrangement in which the precessions of the line-of-sight gyroscope take place in planes corresponding to true elevation and true traverse, and the axis of shaft **74** associated with the line of sight gyroscope tends to be maintained in coaxial with the straight line between target and director. The currents or signals on leads **25** and **26** are substantially accurate representations of the aformentioned rates of target motion *d*E and *d*B*s*.

The aforementioned *d*E current on lead **102** is applied, Fig. 3B, to the arm of potentiometer **105**, the arm being further connected by way of a suitable mechanical coupling to an R servomotor **150** and positioned in accordance with changes in the range of the target. Potentiometer **105** may have a resistance of 20 kilohms. The upper terminal of potentiometer **105** is connected by way of resistor **106**, which may have a value of 150 kilohms, to lead **112**, and is further connected by way of capacitor **108**, which may have a value of 20 mfd., to lead **111**, which is connected to ground at **101**. The lower terminal of potentiometer **105** is connected by way of resistor **107**, which may have a value of 865.4 ohms, to lead **111**.

Lead **103** is also connected to the arm of a potentiometer **113**, and is also operatively connected to R servomotor **150**. Potentiometer **113** may have a value of 20 kilohms. The upper terminal, Fig. 3B, of potenti-

ometer **113** is connected by way of resistor **115**, which may have a value of 150 kilohms, to lead **126**, and is also connected by way of capacitor **114**, which may have a value of 20 mfd., to lead **111**. The lower terminal of potentiometer **113** is connected by way of resistors **116** and **117** to lead **111**, which is connected to ground **101**. Resistor **116** may have a value of 84 ohms and resistor **117** may have a value of 900 ohms. Resistor **117** has connected in parallel therewith the potentiometer **121**, which may have a value of 10 kilohms. The junction between resistors **116** and **117** is connected by way of resistor **118**, which may have a value of 12.38 kilohms, and potentiometer **122**, which may have a value of 13 kilohms, to lead **104**. The arm of aformentioned potentiometer **121** is connected by way of resistor **124**, which may have a value of 65 kilohms, and resistor **125**, which may have a value of 39.7 kilohms, to the arm of potentiometer **122**. Resistor **123**, which may have a value of 7.04 kilohms, is connected between the last named arm and ground. The junction between resistors **124** and **125** is connected to lead **127**.

As aforementioned, the current or signal between lead **102** and **101** represents the quantity *d*E, and after multiplication by R at the potentiometer **105**, the signal on lead **112** may represent the quantity R*d*E. The use of potentiometers for division and multiplication is old in the art, and does not include part of the present invention. Preferably, the resistance values of the potentiometer multiplier, and the input and output impedances associated therewith are related by the following equations:

$$E_o=\frac{R_L}{R_1+RpX+R_L}E$$

$$X=\frac{y-y_{min}}{y_{max}-y_{min}}$$

$$E_o=\frac{R_LE}{R_1+\frac{Rpy}{y_{max}-y_{min}}-\frac{Rpy_{min}}{y_{max}-y_{min}}+R_L}$$

Satisfy:

$$\frac{Rpy_{min}}{y_{max}-y_{min}}=R_1+R_L$$

$$E_o=\left[\frac{R_L}{Rp}(y_{max}-y_{min})\right]\frac{1}{y}E$$

in which E is the input voltage to a network in which R1 may be a resistor connected in series between one input terminal of the network and one terminal of the multiplying potentiometer R*p*, the arm of which is positioned in accordance with the quantity X is to be multiplied by, and which is connected to one output terminal of the network, and R_L is connected between the output terminals of the network, the other output terminal of the network being directly connected to the other input terminal. Eo is the output voltage developed across R_L.

Lead **112**, Fig. 3C, is connected to lead **111** by way of resistor **137**, which may have a value of 66.72 kilohms, resistor **143**, which may have a value of 51.94 kilohms, and resistor **144**, which may have a value of 42.72 kilohms, connected in series in the order named. The junction between resistors **143** and **144** is connected by way of resistor **138**, which may have a value of 170.6 kilohms, to lead **134**, which is operatively connected, Fig. 2, to a wind resolution network, and which computes and supplies to lead **134***a* wind correction signal R*d*E*w*, hereinbefore defined. A wind resolution network suitable for use with the instant invention is described and claimed in the copending application of Carlton W. Miller for Wind Resolution Apparatus, Ser. No. 74,442, filed February 3, 1949.

The junction between resistors **143** and **144** is also connected by way of resistor **145**, which may have a value of 122.7 kilohms, to the arm of potentiometer **151** which is operatively connected by a suitable mechanical coupling, to a ballistic computer hereinafter to be described and positioned by the quantity *dHfp* cos *E*, previously defined.

Potentiometer **151**, which may have a value of 10 kilohms, has one terminal thereof connected by way of resistor **146**, which may have a value of 39.837 kilohms, to a source of potential of plus 200 volts to ground, while the other terminal of potentiometer **151** is connected by way of resistor **147**, which may have a value of 30.163 kilohms, to a source of potential of minus 200 volts to ground. Accordingly, the arm of potentiometer **151** provides a voltage or signal representative of the quantity *dHfp* cos *E*.

The aforementioned R*d*E, R*d*E*w*, and *dHfp* cos *E* signals are added in the adding network comprising the aforementioned resistors **137**, **143**, **144**, **138**, and **145**, and develop on lead **141**, which is connected to the junction between resistors **137** and **143**, an R*d*E*tfpw* signal, previously defined, and which represents the linear elevation rate of target movement corrected for wind, superelevation or gravity drop, and parallax.

The aforementioned *dBs* signal on lead **103**, Fig. 3B is multiplied at **113** by the quantity R, with the result that the signal on aforementioned lead **126** represents the quantity R*d*B*s*. Lead **126**, Fig. 3C, is connected by way of resistor **148**, which may have a value of 66.72 kilohms, resistor **156**, which may have a value of 71.99 kilohms, resistor **154**, which may have a value of 7.548 kilohms, and resistor **155**, which may have a value of 1.697 kilohms, to lead **111**. The junction between resistors **154** and **156** is connected by way of resistor **153**, which may have a value of 49.67 kilohms, to lead **139**, which is connected to the aforementioned Wind Resolution Network, Fig. 2, and supplies to the circuit of Fig. 3C an aforedefined R*d*B*sw* wind signal.

The junction between resistors **154** and **155** is connected by way of resistor **152**, which may have a value of 198.3 kilohms, to the arm of the aforementioned *dHfp* cos *E* potentiometer **151**.

The adding network comprising resistors **148**, **156**, **153**, **154**, **155**, and **152** accordingly has applied thereto signals representing R*d*B*s*, R*d*B*sw*, and *dHfp* cos *E*, and provides a signal on lead **142**, which is connected to the junction between resistors **148** and **156**, representative of the aforedefined quantity R*d*B*stfw*, or linear traverse rate corrected for wind and drift.

The arm of the aforedescribed potentiometer **121** provides a signal thereon corresponding to the aforedefined quantity *Zu*, and the arm of the aforedescribed potentiometer **122** provides a signal thereon corersponding to the quantity *Zq*, which signals are added in the adding network comprising ersistors **124** and **125**, and the sum thereof applied to lead **127**.

Potentiometer **133**, Fig. 3B, may be tapered and may have a total value of 40 kilohms, and has one terminal thereof operatively connected by way of resistor **131**, which may have a value of 7.493 kilohms, to the negative terminal of a source of potential of 200 volts to ground. The other end terminal of potentiometer **133** is connected by way of resistor **132**, which may have a value of 7.493 kilohms, to the positive terminal of a source of potential of 200 volts to ground. The arm of potentiometer **133** is positioned by the quantity *Zs* by coupling **98** operatively connected to the aforementioned *Zs* servomotor **95**, while the tap of the potentiometer is connected by way of lead **111** to ground **101**. The voltage or signal developed between leads **128** and **111** corresponds to the quantity *Zs*.

Lead **128** is connected to lead **127** by way of resistor **162**, which may have a value of 71.123 kilohms, and lead **127** is connected by way of resistor **163**, which may have a value of 71.123 kilohms, to the arm of a potentiometer **184**, which may be tapered and have a value of 40 kilohms. The tap of potentiometer **184** is grounded at **101**. One end of potentiometer **184** is connected by way of resistor **171**, which may have a value of 7.493

kilohms, to the positive terminal of a source of potential which may be of the order of 200 volts D.-C. to ground, while the other end of potentiometer **184** is connected by way of resistor **172**, which may have a value of 7.493 kilohms, to the negative terminal of a source of potential of 200 volts D.-C. to ground.

Lead **127** is further connected by way of resistor **158**, which may have a value of 620 kilohms, and resistor **161**, which may have a value of 620 kilohms, to one input terminal of a vibrator **177**, which has the other input terminal thereof connected to ground by way of lead **111**.

Lead **127** is further connected by way of resistor **164**, which may have a value of 560 kilohms, a capacitor **173** which may have a value of 0.5 mfd., capacitor **183** which may have a value of 2.0 mfd., and resistor **168** which may have a value of 10 kilohms, to one terminal of a tachometer signal generator **182**, which has the other terminal thereof grounded, and which is driven by coupling **190** from *Zsqu* servomotor **186**. The junction between resistor **168** and capacitor **183** is connected to ground by way of resistor **167** which may have a value of 15 kilohms, while the junction between capacitors **173** and **183** is connected to ground by way of resistor **166** which may have a value of 120 kilohms.

The output of vibrator **177**, which changes the input thereto from D. C. to A. C. is coupled by way of capacitor **176**, which may have a capacity of 0.1 mfd., to a cathode follower stage **178** which energizes *Zsqu* servo amplifier **181** which in turn supplies the exciting signal to *Zsqu* servomotor **186**.

In the operation of the before described *Zsqu* circuit, the generated or *cZsqu* signal produced by potentiometer **184** is compared with the *eZsqu* signal on lead **127**, and motor **186** tends to drive the arm of **184** in a direction and in an amount such that the *eZsqu* signal is maintained substantially zero, in a manner well known to those skilled in the art of servo devices.

The aforementioned $\overline{R}dEtfpw$ signal on lead **141** is applied in Fig. 3D by way of a resistor **251**, which may have a value of 798.3 kilohms, to the input terminal of a vibrator device **265** which converts the input signal thereto from D. C. to A. C. The output of vibrator **265** is coupled by capacitor **268**, which may have a value of 0.1 mfd., to the input of a cathode follower **271**, the output of which excites servo amplifier **273**. The output of the servo amplifier **273** is applied by way of resistor **276**, which may have a value of 250 ohms, to one primary **281** of the *Zsqu* resolver generally designated by the reference numeral **275**, the other terminal of primary **281** being connected to ground **101** by way of lead **267**. Resistor **278**, which may have a value of 250 ohms, is connected in parallel with primary **281**.

The aforementioned $\overline{R}dBstfw$ signal on lead **142** is applied by way of resistor **257**, which may have a value of 798.3 kilohms, to the input of a vibrator **266**, which has the output thereof coupled by capacitor **269**, which may have a value of 0.1 mfd., to the cathode follower **272**, which supplies the output thereof to servo amplifier **274** which energizes primary **282** by way of resistor **277**, which may have a value of 250 ohms. Resistor **279** connected in parallel with primary **282** may have a value of 250 ohms.

The secondaries of resolver **275** are positioned by the quantity *Zsqu* by the coupling **190**, and the center tap therebetween is connected to ground **101** by way of lead **285**. The resolver **275** is constructed and arranged to resolve or convert the input signals thereto from true to deck coordinate values, in a manner well known to those skilled in the art.

Between lead **263** and ground is developed an *RdEtfpw* error signal, which is applied to the U divided potentiometer **341** (Fig. 3E) which has the arm thereof positioned in accordance with the value of U, and which is operatively connected by coupling **328** to the U computing apparatus of a ballistic computer hereinafter to be described.

The signal from resolver secondary **283**, after division by U, is applied to one input terminal of a filter **289** which may be of conventional design, and which has the other input terminal thereof connected to ground **101** by way of lead **287**.

The output of the filter **289** is applied by way of capacitor **291**, which may have a value of 0.1 mfd., to the cathode follower **317**, the output of which is applied to a servo amplifier **295** which energizes the *V'd* servomotor **297**, which also has applied thereto 110 v., A. C., 60 cycles, obtained from any convenient source, not shown. The servomotor **297** drives a shaft **301**, which is operatively connected to a tachometer signal generator **299** (Fig. 3F), which is provided for stabilizing purposes, and which has its output applied by way of leads **249** and **250** to a vibrator device **293** (Fig. 3E) which converts from D. C. to A. C. The output of the vibrator **293** is fed back into the servo control circuit in the manner shown.

The voltage output of the aforementioned resolver secondary **284** (Fig. 3D) is applied by way of lead **264** to the U division potentiometer **342** (Fig. 3E), and thence to the *E'g* secant attenuator **286**, which has the arm thereof positioned by the quantity *E'g* from the mechanical coupling **316**. The output of secant attenuator **286** is applied to the filter **290**, whence the output is coupled by capacitor **292**, which may have a capacity of 0.1 mfd., to the cathode follower **318**, the output of which is amplified by servo amplifier **296** and applied to *D'd* servomotor **298**, which also has applied thereto 110 v., A. C., 60 cycles.

Servomotor **298** drives a *D'd* shaft **302**, which drives a *D'd* tachometer **300** (Fig. 3F), the output of which is applied by way of leads **247** and **248** to the vibrator **294** (Fig. 3E) which converts from D. C. to A. C. The A. C. output of the vibrator **294** is fed back into the circuit in the manner shown for stabilizing purposes.

As aforementioned, the *E'b* servomotor **92** (Fig. 3F) positions the shaft **85** by the quantity *E'b*, which input is applied to a differential **306**. Differential **306** also has applied thereto a *D'd* shaft rotation **302** from *D'd* servomotor **298**. The differential **306** is constructed and arranged to provide a shaft rotation corresponding to the quantity $2D'd+E'b$, which is supplied as one input to the angle or gun order converter.

The *D'd* rotation of shaft **302** is also applied to differential **308**, which also has applied thereto a shaft rotation **390** corresponding to the quantity *B'r'p*, obtained from *B'r'p* servomotor **389** which may be located in the Train Parallax Corrector, Fig. 2. A Parralax Corrector suitable for use in the instant invention is described and claimed in the copending application of Carlton W. Miller for Parallax Computation Method and Apparatus, Ser. No. 74,442, filed February 3, 1949. The output of differential **308** is a *B'grp* rotation, controlling generator **304** which supplies the *B'grp* output to the gun and fuse servos, Fig. 2.

The aforementioned rotation of shaft **85** is applied to a differential **305**, to which the *V'd* shaft rotation on **301** is also applied. The differential **305** is constructed and arranged to provide on output coupling **316** and *E'g* rotation, corresponding to $E'b+V'd$, and which is applied to a generator **303**, the output voltage of which represents the gun elevation order and is applied to the gun and fuse servos, Fig. 2.

The *V'd* shaft rotation of **301** is also applied to a differential **307** which has applied thereto the aforementioned $2D'd+E'b$ rotation on shaft **310**. Differential **307** is constructed and arranged to provide a $2V'd+2D'd+E'b$ shaft rotation input to the gun order or angle converter, as shown. The third input to the angle converter is the quantity *E'b*, obtained from coupling **85**.

The angle converter is constructed and arranged by way of yoke member **224** to position finger **240** in accordance with the lead angles. Referring particularly now to Fig.

4 in which is shown an elevational view partly broken away of the angle converter, three shafts **203**, **205**, and **211** are shown concentrically aligned. Shaft **211** had fixed thereto on one end thereof to rotate therewith a gear **212**, which meshes with gear **210** fixed to shaft **209** to rotate therewith, the shaft **209** being positioned by the quantity E'*b* by coupling **85**. The other end of shaft **211** has fixed thereto to rotate therewith the E'*b* yoke **215**.

Shaft **205** has fixed thereto to rotate therewith the gear **206**, which meshes with gear **208** which is fixed to shaft **207** to rotate therewith, the shaft **207** being positioned by coupling **310** by the quantity $2D'd+E'b$.

Shaft **203** has fixed thereto to rotate therewith a gear **204**, which meshes with gear **202** which is fixed to shaft **201** to rotate therewith, shaft **201** being positioned by coupling **311** by the quantity $2D'd+E'b+2V'd$.

Gear **223** meshes with gear **222**. Gear **223** and member **225** are fixed together and both are rotatably mounted upon shaft **229**. Shaft **229** is secured to member or hollow shaft **228**. Gear **222** is fixed to shaft **216** to rotate therewith. Shaft **216** is mounted in bearings **217** in yoke **215**, and extends through member **228**, which is free to rotate thereon; shaft **216** has fixed thereon to rotate therewith gear **220**, which meshes with gear **219** which is fixed to shaft **203** to rotate therewith. Accordingly, rotation of gear **204** secured to shaft **203** tends to rotate gear **223** and arm **224** about the axis of member **229**. To clarify the foregoing, consider the effect of the rotation of gear **204**. Such a rotation rotates gear **219** through the common shaft **203** to which the two gears are affixed. The gear **219**, in turn, rotates gear **220** with which it meshes. Because shaft **216** is affixed to gear **220** and gear **222** is affixed to shaft **216** and meshes with gear **223**, the rotation of gear **220** produces a corresponding rotation of gear **223**. Gear **223** is coupled fixedly to member **225** and both are mounted for rotation on shaft **229**. As a result, the member **224**, fixedly coupled to member **225**, also rotates about the axis of shaft **229**.

Gear **218** is fixed to shaft **205** and rotates therewith. Rotation of gear **218** rotates gear **221** about the axis of shaft **216**. Gear **221** is fixed to member **228** to rotate therewith.

In the operation of the above described apparatus, assuming no rotation of the E'*b* yoke member **215**, the rotation of shafts **203** and **205** cause finger **240** to move in mutually perpendicular directions respectively. If the finger **240** is maintained in a position perpendicular to plate **331**, rotation of gear **212** causes counterrotation of gear **204** in the opposite direction, while gear **206** is carried with gear **212** in a substantially equal amount.

Gears **204** and **206** can be rotated without affecting **212**, but at the same time move the finger **240**.

It is understood that for clarity of illustration, supports for the yoke **215** and gear mechanism are not shown. The neck of shaft **211** adjacent yoke **215** is preferably mounted in a bearing support, not shown, so that the axis of **211** is maintained perpendicular to the axis of rotation of member **335**, which is rotatably mounted upon any convenient support which may in turn be mounted upon the deck of the vessel. If desired, yoke **215** may be extended around and beyond member **225**, and a second supporting bearing aligned with the axis of **211**, provided at that point.

The aforementioned finger **240** has secured to the end thereof a ball **232** disposed in socket **233**, which is mounted in a first plate **331**. The first plate **331** is disposed in guideways **234** and **235** in a second plate **332**, which is disposed in guideways **236** and **237** in a third plate **333**, the guideways **234** and **235** being substantially perpendicular to the guideways **236** and **237**. The third plate **333** is fixed to base member **335** to rotate therewith.

Plate **332** has mounted thereon a pair of potentiometer windings **321** and **322**, which have associated therewith respectively a pair of contact arms **337** and **338** respectively having wiping contacts **339** and **340** respectively. Potentiometer winding **321** is tapered to the function of a term in the quantity U3 which it has been found difficult to compute, for reasons hereinafter to be more fully stated. Potentiometer **322** is tapered to provide an output proportional to the square of the displacement of the arm, and is operatively connected to provide a voltage proportional to tan V^2-k26, which is utilized in the fuse computer, Fig. 2.

Plate **33** has mounted thereon a pair of potentiometer windings **323** and **324**, the winding **323** being tapered to the function of the aforementioned term in the quantity U3, the winding **324** being tapered to provide a voltage proportional to tan D^2 for use in the fuse computer, Fig. 2, the windings having a common contact support arm **343**.

The potentiometer winding **323**, which may have a value of 40 kilohms, has one terminal thereof connected by way of resistor **312**, which may have a value of 39.468 kilohms, to the negative terminal of a source of potential of 200 volts D. C. to ground, while the other end or terminal of potentiometer **323** is connected by way of resistor **313**, which may have a value of 39.468 kilohms, to the positive terminal of a source of potential of 200 volts D. C. to ground.

The center tap of potentiometer **323** is connected by way of lead **261** and resistor **259**, which may have a value of 5.051 kilohms, to one terminal of a potentiometer **364**, which may have a value of 4.375 kilohms. The arm of potentiometer **323** is connected by way of lead **262** and resistor **260**, which may have a value of 16.646 kilohms, to the other terminal of potentiometer **364**. Potentiometer **364** has the arm thereof positioned by the quantity U by mechanical coupling **328**, and the arm is connected by way of resistor **258**, which may have a value of 850 kilohms, to one terminal of aforementioned resistor **257** and the input terminal of vibrator device **266**.

The aforementioned potentiometer winding **321**, which may have a value 37.383 kilohms, has one terminal thereof connected by way of resistor **314**, which may have a value of 40.301 kilohms, to the negative terminal of a source of potential of 200 volts D. C. to ground. The other terminal of potentiometer winding **321** is connected by way of resistor **315**, which may have a value 37.788 kilohms, to the positive terminal of a source of potential of 200 volts D. C. to ground. The arm **339** of potentiometer **321** is connected by way of lead **255** and resistor **253**, which may have a value of 16.646 kilohms, to one terminal of a potentiometer **363** which may have a value of 14.375 kilohms. The tap of potentiometer **321** is connected by way of lead **256** and resistor **254**, which may have a value of 5.051 kilohms, to the other terminal of potentiometer **363**. The arm of this potentiometer **363** is positioned in accordance with the quantity U from coupling **328**, and is connected by way of resistor **252**, which may have a value of 850 kilohms, to resistor **251** and the input of vibrator **265**.

Reference is made now to Figs. 6A, 6B, and 6C which taken together comprise a schematic mechanical diagram of the linkage mechanism of the aforementioned computer, the console view of which is shown in Fig. 2.

As previously stated, the gun fire control system of the instant invention has available information as to the present position of the target, with respect to elevation E, previously defined as the elevation above the horizontal plane of the line-of-sight, measured in the vertical plane through the line-of-sight. Also available is information as to the measured average shell velocity, a quantity denoted by the symbol U. Accurate information as to the present range R is supplied by the radar apparatus of the aforementioned director. The fuse setting in seconds, F, is also supplied from the fuse computer. The computational range rate $d\overline{R}tw$ is also available from electrical networks within the apparatus which computes this quantity.

The linkage mechanism of Figs. 6A, 6B, and 6C is supplied information as to the quantities E, $\bar{U}$, R, F, and $d\bar{R}tw$, and from these computes five other quantities essential to the operation of the fire control system. These computed quantities, are U*o*, *dHfp* cos *E*, *f*4G, U and G–F, to be presently defined and the manner of computation thereof to be presently described in detail.

Referring now particularly to Fig. 6A, the shaft **501** is rotated by suitable mechanical coupling to the E servo system and positioned in accordance with the quantity E. Fixed to shaft **501** to rotate therewith is a gear **502** the teeth of which mesh with the teeth of a gear **504** fixed to shaft **503**. Shaft **503** also carries fixed thereto to rotate therewith a disc or plate **505**, in which are mounted 90° apart in suitable journals therein a pair of shafts, not shown. These shafts have fixed to the ends thereof to rotate therewith a pair of gears **506** and **507**, respectively, both of which mesh with a gear **549** fixed to shaft **503** to rotate therewith. Eccentrically mounted upon gears **506** and **507** at the ends of the shafts are pins **523** and **524**, having coupling yokes or terminals **525** and **526** connected thereto, with adjusting screws or studs **527** and **528** respectively attaching the yokes to coupling bars or push rods **511** and **512** which have at the other ends thereof adjusting screws **531** and **532** respectively having coupling yokes or terminals **533** and **534** respectively operatively connected to or coupled to pins **535** and **536** respectively which are attached to slides **537** and **538** respectively and which move these slides longitudinally in sets of guide rollers **541** and **542** respectively in amounts proportional to the sine and cosine of E respectively. The manner in which the sine and cosine functions of E are generated from the aforedescribed mechanism is well known in the art, and need not be described in detail.

The eccentrically mounted pins **523** and **524** provide means well known in the art, for correcting for errors introduced by the angular displacements of arms **511** and **512** which occur as the disc **505** rotates in response to changes in the value of E.

A shaft **545** is positioned in accordance with the value of R by suitable mechanical coupling to a range servomotor contained within the range and range rate nets, Fig. 2. Fixed to shaft **545** to rotate therewith are a pair of gears **550** and **543**, the latter meshing with gear **544** which is fixed to shaft **546** to rotate therewith, the shaft **546** having mounted thereon a gear **547** meshing with a rack **548** attached to R slide **551** which moves in roller guides **569** and is positioned longitudinally in accordance with the value of R.

Formed in the left hand end (Fig. 6A) of slide **551** is a rack **514**, the teeth of rack **514** meshing with gear **515** fixed to a shaft for rotation therewith, the same shaft having fixed thereto for rotation therewith the gear **519** which meshes with gear **517**. Gear **517** is fixed for rotation with a shaft which also has fixed for rotation therewith a crank **518**, having pivoted thereto at **553** link **552** having pivotally connected thereto at **554** a sector gear **555** pivoted for rotation at **556** about support **570**, the teeth of gear **555** meshing with those of a gear **567** pivoted for rotation at **569** and having fixed thereto for rotation therewith a crank **566**.

Crank **566** is coupled by pin **568** to one end of link **565**, near the other end of link **565** there being connected or coupled at **564** to two links **563** and **571**. Link **563** is connected at **562** to one end of bell crank **559** which is pivoted for rotation at **561**, about fixed support **580**, the other end of bell crank **559** being pivoted to one end of link **558** which has the other end thereof pivotally connected to one end of crank arm **557**, which is connected to rotate with a shaft which has fixed thereto to rotate therewith a gear **508**, which meshes with gear **516** fixed to shaft **503** to rotate therewith.

Aforementioned link **571** is pivotally connected to one end of bell crank **572** which is pivotally mounted at **573** upon fixed support **579**, the other end of bell crank **572** being pivotally connected to one end of link **574**, the other end of link **574** being pivotally connected to one end of bell crank **575** which is pivoted for rotation at **576** about fixed support **589**. The other end of bell crank **575** has pivotally connected thereto at **590** a link **577**.

As noted on the drawing, link **577** is positioned longitudinally by the quantity *f*2 (R, E), which is obtained by the aforedescribed linkage and gear mechanisms from the rotations of the E and R shafts **501** and **545** respectively. The manner in which the function is obtained need not be described in detail, the use of such mechanisms for the generation of functions having been described in detail in Svoboda: Computing Mechanisms and Linkages; McGraw-Hill Publishing Co., it being understood that the dimensions of the various elements are properly proportioned to insure that *f*2(R,E) has the correct value.

The aforementioned quantity $\bar{U}$, which is the measured average shell velocity, is put in by handknob and positions shaft **581** which has fixed thereto to rotate therewith gear **582** meshing with a gear **583** which is fixed to shaft **584** to rotate therewith. Shaft **584** also has fixed thereto a dial **585** for indicating the value $\bar{U}$ supplied to the computing mechanism.

Shaft **584** has fixed thereto to rotate therewith a gear, shown in dashed outline at **586**, meshing with the teeth, shown in dashed outline at **587**, of a rack formed on the underside, as viewed in Fig. 6A, of a slide **588** which is positioned longitudinally by the quantity $\bar{U}$, and moves in guide rollers **591**. Attached to slide **588** is a pin **592** which has connected thereto a coupling yoke **593** having adjusting screw **594** associated therewith, the screw being operatively connected to one end of push rod **595** having in the other end thereof adjusting screw **596** and a coupling yoke in which is a pin **597** to which is coupled one end of an adding lever **578**.

A coupling pin **602** connected to slide **603** couples the slide to lever **578**, and causes the slide **603** to be positioned in accordance with movement of the lever. Slide **603** has a rack portion **604** the teeth of which mesh with a gear **606** fixed to shaft **607** which also has fixed thereto a dial **608** calibrated in values of U*o*. The shaft **607** may position the finger of a U*o* potentiometer, not shown, located in the fuse computer, Fig. 2.

The equation for U*o* is $Uo=\bar{U}+f2(R,E)+K1Ro$. As previously stated link **577** coupled to one end of adding lever **578** is positioned by the quantity $f2(R,E)$. The other end of adding lever **578** is positioned by the quantity $\bar{U}$. K1 is a constant and *Ro* is a constant representing the value 3854 yards, so that the term $K1Ro$ is also a constant. As is well known this constant can be added to the equation of the movement of the slide by proper positioning of the slide with respect to the settings of **577** and **588** when $f2(R,E)$ and $\bar{U}$ are zero, so that the quantity $Uo= +f2(R,E)+K1Ro$ is obtained for positioning the slide **603** longitudinally by this quantity.

As aforementioned, another of the inputs of the computer mechanism is the quantity $d\bar{R}tw$, which is obtained as an input from a range-rate servomotor, not shown, located in the range and range rate nets, Fig. 2, and positions the shaft **613**. Fixed to shaft **613** to rotate therewith is a gear **614**, meshing with a gear **615** fixed to shaft **616** to rotate therewith, the shaft **616** also having fixed thereto to rotate therewith a gear **617** meshing with the rack portion **618** of slide **621** which is accordingly positioned longitudinally by the quantity $d\bar{R}tw$. The slide **621** has guide rollers **620** for controlling the movement thereof.

A quantity, employed in the subject computing mechanism, but one which does not appear as one of the final outputs of the computer, is the quantity **U1**, which is defined by the equation $U1=Uo-K1R$. U*o* has been computed in a manner previously described. Coupled to

the U*o* slide **603** at point **611** is one end of a subtracting lever **612** which has the other end thereof coupled at **624** to a link **623** which is coupled at **622** to the range slide **551**. The U1 output of lever **612** is taken from point **625** and positions two U1 links **627** and **628**, the functions of which will be hereafter explained in detail. It will be readily understood that the constant K1 may be inserted in the equation by proper proportioning the dimensions of the lever **612** and the connections thereto.

Another quantity employed in the computing mechanism, but which does not appear as an output thereof, is the quantity G, which is defined as the computational time of flight, that is, the time of flight to a hypothetical target which is following a radial path with a velocity equal to the range rate of the real target. G is further defined by the equation

$$G=\frac{R}{U1-\overline{dR}tw(K1G+1)}$$

In computing G, the subject computing mechanism computes the denominator and devides this into R.

The G denominator is obtained as follows: a G lever **631**, which is positioned by the quantity G in a manner to be presently described, has connected thereto at **632** a coupling yoke or terminal **633** having adjusting screw **634** connecting to one end of push rod **635** which has in the other end thereof screw **636** and coupling yoke **637** which at coupling pin **638** operatively connects to a slide **641** which is moved longitudinally in guide rollers **642** by the quantity $K1G+1$, it being readily understood that the constant K1 and the added term $+1$ may be added by suitable proportioning of the dimensions of the mechanism and proper positioning of the slide when $G=O$.

Attached to the $K1G+1$ slide **641** at pin **643** is one end of a link **644** which has the other end coupled at **645** to two links **646** and **647**. Link **646** has the other end thereof connected at point **652** to a $(K1G+1)\overline{dR}tw$ multiplying lever **651**. One end of lever **651** is connected at **661** to coupling yoke **657** having an adjusting screw **658** connecting the yoke to one end of push rod **671**. The other end of push rod **671** has connected therein adjusting screw **672**, having coupling yoke **673** connecting the push rod **671** to the $\overline{dR}tw$ slide **621** at point **674**. Accordingly the upper end of lever **651** is positioned by the quantity $\overline{dR}tw$. The lever **651** is pivoted at **653** for pivotal movement about support **654**.

Aforementioned link **647** is coupled at **648** to one end of a bell crank lever **662** pivoted at **663** for rotation about support **664**. The other end of bell crank **662** is coupled at **665** to a link **666** which moves in accordance with the quantity $(K1G+1)\overline{dR}tw$, which is obtained from the previously described multiplier comprising lever **651** positioned by $\overline{dR}tw$, slide **641** positioned by $K1G+1$, and the links **644**, **646**, **647** and bell crank **662**.

Link **666** is coupled at **667** to one end of subtracting lever **668**, which has the other end thereof coupled at **675** to yoke **676** having adjusting screw **677** connecting the yoke to the aforementioned link or push rod **627** positioned by the quantity U1.

Point **681** on lever **668** is coupled to two arms **682** and **683**. Arm **682** is pivoted at point **697** to fixed support **698**. The arm **682** has a pointer portion **701** cooperating with a scale **696** calibrated in values of the G denominator $U1-(K1G+1)\overline{dR}tw$. Arm **682** further has a member **685** fixed thereto which engages a pin **684** fixed in arm **683**, the member **685** being maintained in close engagement with pin **684** by pressure of a spring member **702** fixed in the pin or support **703** attached to arm **682**.

Operatively connected to arm **683** at point **686** are a yoke and adjusting screw **692** which is connected to one end of a push rod **691**, which has in the other end thereof an adjusting screw **695** having a loke **693** coupling the push rod at **694** to a G denominator slide **687** which moves in guide rollers **688** and is positioned longitudinally by the quantity $U1-(K1G+1)\overline{dR}tw$.

The G denominator having been obtained, the quantity G is obtained by dividing the quantity R by the G denominator. As aforementioned, the shaft **545** is positioned by R, and has fixed thereto for rotation therewith the gear **550**. Gear **550** meshes with a sector gear **705** fixed for rotation with a shaft, not shown, which extends through support **705** and has fixed thereto to rotate therewith the crank arm **706**. Coupled to arm **706** at point **707** is one end of a link **708** which has the other end thereof coupled at **711** to one end of a bell crank **712**, the bell crank being pivoted at **713** for rotation about the support **714**. The other end of the bell crank **712** has coupled thereto at **715** one end of a link **716**, the other end of the link **716** being coupled at **717** to two links **728** and **718**. The other end of link **718** is coupled at **721** to one end of a bell crank **722** which is pivoted at **723** for movement about fixed support **724**, the other end of the bell crank **722** being connected at **725** to one end of link **726**. The other end of link **726** is coupled at **727** to the G denominator slide **687**.

The aforedescribed couplings and linkages comprise a G divider, and the operation thereof will be readily understood by those skilled in the art. Aforementioned link **728** is coupled at **731** to the slide **732** which moves between guide rollers **733** and is positioned longitudinally by the quantity G.

Attached to slide **732** at **734** is a link **735** coupled to aforementioned G lever **631** at **736**. G lever **631** is pivoted at **741** to move about support **742**, and has the lower end thereof connected at **743** to one end of a link or lever **773**, the other end of the lever **773** being connected at **774** to the aforementioned link **656** which is connected at **655** to the lever **651** which is positioned by $\overline{dR}tw$.

The lefthand end, Fig. 6B, of the G slide **732** has connected thereto at **764** one end of a link **765** which has coupled thereto at **766** an arm or lever **767** which is pivoted for rotation at **768** about support **771**, the arm **767** having connected on one end thereof the balance weight **772**.

The G lever **631** has connected thereto at **741** by a shaft, not shown, mounted in support **742**, a sector gear **744**, which meshes with a gear **745** fixed to a shaft extending through support **746** and which shaft is fixed to lever **747** to rotate therewith. Lever **747** is pivoted at **748** to link **751** which is pivoted at **752** to a lever **753**, which has connected thereto at **755** to rotate therewith, by a shaft, not shown, journalled in support **754**, a sector gear **756**, the teeth of which mesh with gear **757** and drive shaft **758** by the quantity $f4G$, which is supplied to the fuse computer, Fig. 2. Dial **761** indicates the value of $f4G$.

The quantity G having been obtained, the manner in which the aforementioned computer output $dHfp\cos E$ is obtained may conveniently be described. $dHfp$ is computed from the formula $dHfp=K24\cdot K25G+K4\overline{dR}tw$, and is subsequently multiplied by the cos E to obtain $dHfp\cos E$. An aforementioned link or lever **773** has one end thereof positioned at **743** in accordance with the position of the G lever **631**, and the other end thereof positioned at **774** in accordance with the quantity $\overline{dR}tw$. At a suitable point **775** on arm or lever **773** a coupling yoke **776** is connected, the yoke having adjusting screw **777** between it and push rod **778** which is positioned longitudinally in accordance with the quantity $dHfp$, it being understood by those skilled in the art that the position of the various connections to the lever **773** provide for the intrduction of the constants K4, K24, and K25.

Arm or push rod **778** is operatively connected at **783**

by way of means including an adjusting screw **781** to a multiplying lever **782** which has one end pivoted at **786** for rotation about support **787**. Connected to lever **782** at **785** is a short arm or yoke **788** having connected thereto by way of adjusting screw **789** the push rod **798**, which is also positioned longitudinally by the quantity *d*H*fp*, but at a somewhat different scale factor than the arm **778**.

Arm or push rod **798** has connected thereto by way of screw **801** the short arm or yoke **802** which is operatively connected at **803** to a lever **804** having one end thereof pivoted at **805** for movement about support **806**, the other end of lever **804** having operatively connected thereto at **807** one end of the link **808**, the other end of link **808** being pivotally connected at **811** to two links **814** and **812**, the link **812** being pivotally connected at the other end thereof at **813** to an aforementioned slide **538** which is positioned longitudinally by the quantity cosine E.

Link **814** has the other end thereof pivotally connected at **815** to a linkage member **816** which is pivoted at **817** for rotation about support **818**, and which has pivotally connected thereto at **821** a short arm or coupling yoke **822**, the member **822** being connected by way of adjusting screw **823** to one end of push rod **824**. The other end of arm or push rod **824** is connected by way of adjusting screw **825** to coupling yoke **826**, the yoke being connected at **827** to a slide **828** having a rack portion **831**, the slide **828** moving between guide rollers **832** and being positioned by the quantity *d*H*fp* cos *E*, *d*H*fp* and cos E being multiplied in the mechanism comprising members **816**, **814**, **808**, **804**, and **812**.

The teeth of the rack **831** mesh with the teeth of a gear **833** which is fixed to shaft **834** to rotate therewith, the shaft **834** positioning the finger of a potentiometer **151**, Fig. 3C, and providing the aforementioned *d*H*fp* cos *E* output of the computer, the shaft **834** having fixed thereto a dial **835** calibrated to give information as to the value of *d*H*fp* cos *E*.

One of the aforementioned outputs of the ballistic computer to the fuse computer is the quantity G–F. As aforementioned, F is an input to the computer, is defined as the fuse setting in seconds, and is supplied to the computer from the fuse servo system. The shaft **836** is positioned from coupling **435** in accordance with the value of F, and has fixed thereto to rotate therewith a gear **837**. Gear **837** meshes with a gear **838** fixed to shaft **841** to rotate therewith. Shaft **841** also has fixed thereto to rotate therewith a gear **842** which meshes with a rack portion **843** of a slide **844**, the action of the gear and rack positioning the slide **844** longitudinally in accordance with the quantity F. The slide **844** has guide rollers **845**, and has operatively connected thereto at **846** a coupling yoke **847**, the terminal or yoke **847** being connected by way of adjusting screw **848** to one end of a connecting link or rod **851**, the other end of link **851** being connected by way of adjusting screw **852** to yoke **853** which is pivotally connected at **854** to one end of a lever **763**. This end of lever **763** is accordingly positioned in accordance with the value of F, while the upper end of lever **763** is positioned by the value of G through the medium of the link **738** coupled to the G lever at **737** and to lever **763** at **762**. From point **855** on subtracting lever **763**, the quantity G–F is taken, this point being operatively coupled to a G–F slide **856** which is positioned longitudinally in guide rollers **857**. The slide **856** has a rack portion **858**, the teeth of which mesh with the teeth of a gear **861** fixed to shaft **862** to rotate therewith. The shaft **862** positions the fingers of a G–F potentiometer, not shown, located in the fuse computer. Shaft **862** also has connected thereto for rotation therewith a dial **863** calibrated to indicate the output value of G–F.

The last of the outputs of the ballistic computer mechanism is the quantity U, where $U=U1+Ut+dHfp \sin E$ and $Ut=[f1(R-K5\overline{dR}tw)-K6\overline{dR}tw]\overline{dR}tw$.

The quantity sin E has been obtained in a manner previously described. Attached to the sin E slide **537** at **794** is one end of a link **793**, having the other end thereof coupled at **792** to two links **791** and **795**, the link **791** being coupled at **784** to aforementioned lever **782**, the link **795** being operatively connected at **796** to one end of a bell crank **797**, the bell crank being pivoted at **799** for rotation about support **800**, the other end of the bell crank being connected at **864** to link **865**. Link **865** is operatively connected at **866** to one end of adding lever **867**, the other end of lever **867** being operatively coupled at **871** to one end of lever **875** which has the other end thereof pivotally connected at **872** to support **873**. At point **874**, lever **875** is pivotally connected to aforementioned link **628**, which is positioned by U1. Accordingly aforementioned lever **867** has one end thereof positioned by *d*H*fp* sin *E* and the other end thereof positioned by U1, so that the quantity *d*H*fp* sin $E+U1$ may be taken from point **868** on lever **867**, and move the link **876** in accordance with this quantity.

In the computation of U*t*, a quantity corresponding in value to $Ut+k22\overline{dR}tw$ is first computed, and then has subtracted therefrom $k22\overline{dR}tw$ to leave a remainder U*t*.

The mechanism for the computation of the term $f1(R-K5\overline{dR}tw)$ employs a lever **882** coupled at **881** to one end of a link **878** having the other end thereof coupled at **877** to $\overline{dR}tw$ slide **621**. Lever **882** has the other end thereof coupled at **891** to range slide **551**. Coupled to lever **882** at **883** is arm **884** having an anchor pin **887** with a spring **886** mounted therein, the spring **886** bearing against a pin **885** attached to lever **882**. The other end of arm **884** is coupled at **888** to a yoke **892** which is attached by way of adjusting screw **893** to push rod **894**, which is positioned by the quantity $R-K5\overline{dR}tw$, it being understood that the constant K5 is introduced by suitable proportioning of the dimensions of the various sections of the levers.

Arm or push rod **894** is attached at the other end thereof by way of adjusting screw **895** to a coupling or terminal yoke **896** which is coupled at **897** to one end of a bell crank or lever **898**, the bell crank **898** being pivoted at **901** for rotation about support **902** and having the other end thereof coupled at **903** to one end of link **904**. The other end of link **904** is coupled at **905** to a bell crank **906**. Bell crank **906** is pivoted at **912** for rotation about **913**, and has one end thereof coupled at **914** to link **915**. The bell cranks **898** and **906** together with link **904** comprise a function generator, and position link **915** in accordance with the quantity $f1(R-K5\overline{dR}tw)$. The bell crank **906** has an extended tapered portion **907** forming a pointer which in cooperation with scale **908** indicates the value of $f1(R-K5\overline{dR}tw)$. Stop **911** is provided for limiting the movement of **907**.

Link **915** has coupled thereto at **916** one end of a lever **917** which has the other end thereof coupled at **922** to one end of link **923**. The other end of link **923** is coupled at **924** to slide **621** which is positioned by the quantity $\overline{dR}tw$. Lever **917** has coupled thereto at **918** a lever **921** which is pivoted at **926** for rotary movement about support **925**. The other end of lever **921** has coupled thereto at **928** a yoke **927** which is connected by way of adjusting screw **931** to one end of push rod **932**. The other end of push rod **932** is connected by way of adjusting screw **933** to a yoke **934** which is coupled at **935** to a slide **939** which moves in guide rollers **936**, the slide **939** being positioned by the quantity

$$f1(R-K5\overline{dR}tw)-K6\overline{dR}tw+K22$$

the constants having been introduced by suitable proportioning of the dimensions of the linkage mechanisms.

Slide 939 has coupled thereto at 937 one end of a link 938 which has the other end thereof coupled at 941 to two links 948 and 950. Link 950 has the other end thereof coupled at 942 to bell crank 943. Link 948 has the other end thereof operatively connected at 951 to one end of a bell crank 952. Bell crank 952 is pivoted at 953 for rotation about support 954 and has the other end thereof coupled at 955 to yoke 956 which is connected by way of adjusting screw 957 to one end of a push rod 958, the other end of the push rod or link 958 being connected by way of adjusting screw 961 to a coupling yoke 962 which is coupled at 963 to $\overline{dR}tw$ slide 621.

Aforementioned bell crank 943 is pivoted for rotation at 944 about support 945, and has one end thereof coupled at 946 to one end of link 947, the other end of link 947 being coupled at 965 to lever 966. Lever 966 has one end thereof pivoted at 967 for rotation about support 968 and the other end thereof coupled at 971 to link 972.

The aforementioned bell cranks 943 and 952, with their connecting links, comprise a U*t* multiplier, which, by suitable proportioning of the dimensions thereof, position the aforementioned link 972 by the quantity $[f1(R-K5dRtw)-K6dRtw+K22]\overline{dRtw}$, which is equal to $Ut+K22\overline{dRtw}$.

Link 972 is coupled at 973 to a subtracting lever 974 which has one end thereof coupled at 975 to $\overline{dR}tw$ slide 621, and the other end thereof coupled at 977 to coupling yoke 976, the yoke 976 being connected by way of adjusting screw 978 to push rod 981, positioning the link or push rod 981 by the quantity U*t*.

Link 981 is connected by way of adjusting screw 982 to coupling yoke or terminal 983, which is coupled at 980 to one end of lever 984, the other end of lever 984 being coupled at 986 to an aforementioned link 876 which is positioned by the quantity $dHfp \sin E+U1$.

Lever 984 has coupled thereto at 985 one end of a lever 987, which is accordingly positioned by the quantity $Ut+\overline{dH}fp \sin E+U1$, or U. Lever 987 is pivoted at 988 for rotation about support 991, and has the other end thereof pivotally connected at 992 to one end of link 993. Link 993 has the other end thereof pivotally connected at 994 to slide 995 which is positioned by the quantity U and moves between guide rollers 990.

Slide 995 has a rack portion 996 the teeth of which mesh with the teeth of gear 997. Gear 997 is fixed to shaft 998 for rotation therewith, the shaft 998 by coupling 328 positioning the fingers of a plurality of U potentiometers, Figs. 3D, 3E, connected in circuits elsewhere described, and which provide the aforementioned U output of the computer. Shaft 998 also has fixed thereto for rotation therewith a dial 999 calibrated to provide, in conjunction with an indicator, information as to the value of the U output of the computer.

As is well known in the fire control art, the ballistic problem is an involved one. The equations which describe the motion of a projectile are reached by making a number of approximations and assumptions. These approximations may result in certain variable terms of the equation being replaced by constants which provide sufficient accuracy for practical purposes. In the foregoing description of the computer mechanism, some constants are introduced for this reason and some are required as a result of the method of and apparatus employed in the computation. The constants mentioned hereinbefore may have the following values:

$K1=.0402$	$K22=1.1032$
$K4=.007$	$K24=6.5$
$K5=1.2$	$K25=3.958$
$K6=.00078$	$Ro=3854$

The function *f*1 is introduced to improve the approximation in the computation of U*t*. The output *f*4G is a ballistic quantity and is one of the functions of G employed by the fuse computer, Fig. 2.

Whereas certain of the elements of the computing mechanism have been described as links and certain others have been described as push rods, it is understood that these elements could in many instances be employed interchangeably.

The invention contemplates the use if desired, of aligning holes or marks on the various mechanisms, which, in cooperation with adjacent holes or scales, permit proper alignment of the apparatus by adjusting the numerous alignment screws previously mentioned.

Particular reference is made now to the geometrical diagrams for an understanding of the invention. Present range R is measured along the line of sight by radar apparatus. The director which is known in the art as a two-axis director, trains in the deck plane, and present target bearing in terms of director train, B′*r*′, is measured in the deck plane between the fore and aft axis of own ship, and a plane containing the line of sight perpendicular to the deck plane. Since, as a result of gyroscope action in holding on the line of sight, only the antenna elevates, present target elevation in terms of director elevation, E′*b*, is measured in a plane containing the line of sight perpendicular to the deck, between the deck plane and the line of sight. By means of the vertical gyro, true elevation of the target, E, is also measured, as the elevation of the line of sight above the horizontal plane, measured in the vertical plane through the tracking line.

Rates of target motion are measured in the vertical plane containing the line of sight and the cross traverse plane perpendicular to the line of sight. This stabilized reference system is pictured, Fig. 1B, as a set of mutually perpendicular coordinates at the target. The range rate vector *d*R lies along the line of sight; the elevation angular rate vector *d*E lies perpendicular to the line of sight in the vertical plane; and the horizontal angular rate vector *d*B*s* lies in a plane horizontally perpendicular to the line of sight. The rate angles *d*E and *d*B*s* when multiplied by the range R in their limit as time approaches zero become the vector coordinates which lie in the cross traverse plane. When the coordinates are rotated about the line of sight, they move in a cross traverse plane which is perpendicular to the line of sight.

The angular target rates are measured in this coordinate system by the precession of the line of sight gyroscope. While fastened on a fixed target, the line of sight gyroscope maintains its position independently of the roll, pitch, or yaw of the ship.

If, however, the target moves from its present position, radar error signals are generated which are substantially proportional to the displacement of the target from the antenna axis in elevation and true traverse directions. Two D.-C. currents proportional to the radar error signals are generated and passed through the elevation and true traverse torque motors 81 and 82, Figure 3A, on the line-of-sight gyroscope in the director. The precession rates introduced by these currents will be substantially proportional to the currents. Since the director antenna must follow the line-of-sight gyroscope, the antenna is made to move with angular rates proportional to the displacement between the line of sight and the gyroscope. If the error in the position of the line of sight is just sufficient to develop angular rates of the director equal to those of the target as viewed from the director, the director will smoothly follow the target. If the error between the line of sight and the target happens to be large for a given target rate the director system will move more rapidly until the error signals, and thus the currents passing through the gyroscope torque motors are proportional to the true target rates. Thus the currents through the torque motors are substantially proportional to the two components of the angular velocity of the target.

If the radar error signals were at all times exactly proportional to the displacement of the target from the

line of sight, the currents which measure the target rates would have high instantaneous accuracy with only very small errors resulting from the inaccuracies of servo followups. However, the radar error signal for a fixed error is far from constant. Fading, change of target aspect, and many other conditions cause the error signals to fluctuate rather widely. Consequently the currents controlling the angular rates of the director fluctuate about their proper values causing the director to jitter about its true position. Though the instantaneous values of the currents are not precise measures of the angular rates of the target, these currents must still, in a statistical sense, measure the target rates, since on the average the antenna does follow the target and the currents control the rates of angular motion of the antenna through the precessions of the gyroscopes.

As a result of the aforementioned fluctuations, a smoothing or averaging process is necessary. For purposes of smoothing, in the instant invention, the angular rates are averaged over a period of, for example, two seconds. As a result, it is desirable that the rates of target motion are measured in respect to a stabilized coordinate system.

The gyroscope system of the instant invention also measures the cross traverse angle *Zs*, the angle in the cross traverse plane between the vertical plane through the line of sight and a plane perpendicular to the deck through the line of sight.

Thus, present target position information is obtained in a combination of deck and stabilized coordinates and target rate information in stabilized coordinates. Since gun orders must be received in terms of deck coordinates, the system compensates for the different sets of coordinates in the process of solving for gun orders.

For the purposes of the invention, it is necessary to predict where the target will be after the time it takes a shell to reach it. Since it is impossible to predict accurately the target's future motion, the asumption is made that the target will maintain its course in a straight line at constant speed during the interval in which rate measurements are made.

The fire control problem can be conceived of simply as represented in Fig. 1H. P1 is the target's present position as defined by director D with reference to the plane of the deck in terms of B′*r*′, E′*b*, and R, where the "1" indicates that the deck plane is the reference plane. Vector S is the observed target velocity relative to the director measured in terms of range R, rate of change of range *d*R, rate of change in director bearing *d*B*s*, and rate of change in elevation, *d*E. At the end of time of flight of the projectile, T2, the target and shell are assumed to collide at point P2, the theoretical future position of the target.

In terms of the coordinate system chosen, it is necessary to determine the components of the vector along which the gun must be aimed. As seen in Fig. 1D, the distance *DP*2=vector *R*2, where R2 is the range to future position P2, which may be resolved into the sum of vectors R and ST2, and therefore has the components

$$R2=(R+dR\cdot T2,\ RdBs\cdot T2,\ RdE\cdot T2)$$

In the instant invention, the gun must be fired at a point above P2 to allow for the curved trajectory of the shell. To obtain gun elevation, the sight angle appropriate to future range and elevation (R2 and E2) must be added to E2. In the instant invention E2 is not computed explicitly and the superelevation effect is introduced through the addition of a vertical vector at P2. To overcome gravity effects on the shell, the gun must be pointed at a point above P2.

The drift effect is also introduced as a vector displacement from P2. The drift displaces the shell in a horizontal plane perpendicular to the vertical plane of fire shown in Fig. 1D. The vector displacement of the shell will have both true traverse and range components in the fundamental coordinate system. However, the drift has an extremely small effect and a sufficient approximation can be introduced as a true traverse displacement which is independent of the lead angle. The displacement is a function of future range and elevation.

The point P4, the "virtual future position" at which the gun must be aimed, can be obtained from P2 by the introduction of a displacement P2P3 along the negative traverse direction and the displacement P3P4 along the true vertical. It is noted that:

$$DP4=(R+dR\cdot T_2+P3P4\ \sin E,\ RdBs\cdot T_2-P2P3,\ RdE\cdot T_2+P3P4\ \cos E)$$

The gun must take up the position along the direction DP4. The deck coordinates of this position are called gun train B′*gr*, the angle between the fore and aft axis of own ship and the plane through the gun perpendicular to the deck measured in the deck plane clockwise from the bow, and gun elevation E′*g*, the elevation of the gun above the deck measured in a plane through the gun perpendicular to the deck.

Instead of DP4, the computations in the instant invention make use of another vector of different magnitude but with the same direction in space. The vector is obtained by first dividing the components of DP4 by T2. The resulting range component is then

$$\frac{R}{T2}+dR+dHf\ \sin E=\tilde{U}$$

where *d*H*f* is the gravity drop rate defined by

$$dHf=\frac{P3P4}{T2}$$

and $\tilde{U}$ is the magnitude of the new component.

Since P2P3 is proportional, to a sufficient approximation, to *P3P4* cos *E*, the following may be writen (where K8 is a constant of proportionality equal to 1/30): $P_2P_3=K8P_3P_4\ \cos E$ which when divided by T_2 gives

$$\frac{P2P3}{T2}=K8dHf\ \cos E$$

If DP4 is divided by $\tilde{U}$, after dividing by T_2 and substituting the above defined terms, the resulting gun order vector ($\bar{o}$), Fig. 1K, has the components

$$o=\left(1,\frac{RdBs-K8dHf\ \cos E}{\tilde{U}},\frac{RdE+dHf\ \cos E}{\tilde{U}}\right)$$

where

$$\frac{DP_4}{T_2G}=\bar{o}$$

For simplicity in handling, x_1 and y_1 are substituted for two components of the gun vector:

$$x_1=\frac{RdBs-K8dHfp\ \cos E}{\tilde{U}}$$

$$y_1=\frac{RdE+dHf\ \cos E}{\tilde{U}}$$

These quantities may be considered as the tangents of the two components, D and V, of the lead angle between the target and gun positions so that:

$$x_1=\tan D$$
$$y_1=\tan V$$

Accordingly, the data required to define the gun position are the quantities x_1, y_1, and the present orientation of the moving coordinate system.

DP4 is transformed into the form $\bar{o}$ for the following reasons: Division by T2 transforms the range component of DP4 into a velocity U2 which is approximately the range component of the average shell speed to future position (*R*2/*T*2). The average shell speed varies only from about 850 yards per second to 500 yards per sec-

ond, whereas the range component itself will vary from 500 yards to 12,000 yards. The slowly varying function can be more accurately computed especially since the range component $\tilde{U}$ can be computed without direct use of time of flight T2. In the traverse and elevation components, the time of flight T2 drops out of the principal terms making the computation of these terms simpler.

The division by $\tilde{U}$ which leads to the gun order vector $\bar{o}$ has the advantage of transforming the problem to one that is essentially two dimensional.

The quantities x_1 and y_1 are employed in the gun order converter of the instant invention to obtain the deck coordinates of the gun position. In addition to x_1 and y_1 the converter employs E'*b*, the deck elevation of the director, and Z*s*, the cross traverse angle. The latter two values are used to orient the coordinate system along the traverse and elevation directions in which the components x_1 and y_1 are measured.

The converter sets up a geometrical model of the fire control problem as shown schematically in Fig. 1J. For convenience of illustration it is considered as mounted on the deck and partaking of the deck's motion. D represents the director position. The finger DO is considered as having its initial position at the center C of the grid system which is mounted on the yoke in a plane perpendicular to the line DC. The line of sight is established by rotating the director through B'*r'* and elevating it through E'*b*. The distance from D to C can be taken as unity because of the choice of $\bar{o}$ as the gun order vector. Thus DC, which is oriented along the line of sight, represents the range component of the gun order vector $\bar{o}$ and the grid system establishes a plane which contains the traverse and elevation directions. As the deck rolls and pitches the yoke will rotate about the line DC. This rotation from its position in a horizontal deck plane is Z*s*. The displacements x_1 and y_1 are introduced along the directions CX_1 and CY_1 which are in true traverse and true elevation planes when the deck is horizontal. If the deck is tilted so that the yoke has effectively rotated about DC through Z*s*, it is necessary to rotate the card mounted on the yoke through the same angle in the opposite direction in order to bring the CX_1 and CY_1 axes back to the true traverse and elevation directions. This process substantially parallels the rotation of the gyro unit in the director through Z*s*.

In the process of training and elevating the yoke, the B'*gr* and E'*g* shafts are turned through the angles B'*r'* and E'*b* respectively. These shafts are given additional rotations so as to produce a displacement of the finger from the position DC to the gun position DO, so as to give the point O the coordinates x_1, y_1 in the rotated X_1, Y_1 coordinate system. Since the motions which position the finger are rotations in deck train and deck elevation the resultant shaft positions measure the gun orders B'*gr* and E'*g*.

The displacements x_1, y_1 are introduced into the converter as follows: Voltages proportional to the numerators of these quantities are generated from the director inputs by a computer elsewhere more fully described. Contacts are mounted on the arm DO so as to slide along potentiometer cards on the converter. The voltages from these potentiometers will be substantially proportional to the displacements of O along the directions CX_1 and CY_1; in operation these voltages will be approximately proportional to x_1 and y_1. The voltages are taken off, multiplied by U, and compared with those generated in the aforementioned computer. Servo systems drive through the B'*gr* and E'*g* shafts until the pairs of voltages from computer and converter are substantially equal.

The foregoing explanation is somewhat simplified, and the actual operation of the converter differs from that described above although the same angular relationships are maintained. In practice the converter is not rotated through B'*r'*. The train shaft marked B'*gr* in Fig. 1J is employed only to introduce a displacement of the finger from C. The resultant rotation of this shaft which takes the finger to O is then deck deflection D'*d*, the angle between the two planes perpendicular to the deck, one containing the line of sight and the other gun axis. This angle is measured clockwise from the plane containing the line-of-sight. Gun train is computed, therefore, through the use of the equation:

$$B'gr=B'r'+D'd$$

The principal part of the aforementioned quantity $\tilde{U}$,

$$\frac{R}{T2}+dR$$

is the range component of the average shell speed to future range R2.

$$\frac{R}{T2}+dR=\frac{R2}{T2}\cos\lambda=U2\cos\lambda$$

where lambda λ is the angle P1DP2, Fig. 1H, between present and future target positions, and $U2=R2/T2$. Since λ is generally small enough so that $\cos\lambda\sim 1$, $\tilde{U}$, apart from the gravity drop component, is a close approximation to the average shell speed to future position, U2.

An approximation to U2 in terms of R2 is obtained as follows: The retardation of the projectile, apart from the gravity component along the trajectory, is a function of the remaining velocity, *v*, and is proportional to the air density, rho, (ρ):

$$\frac{dv}{dt}=-2k\rho f(v)$$

where *k* is a constant and *t* is time. At short ranges and low elevation, the trajectory will be nearly straight and the gravity component along the trajectory will average out to almost zero. Using *r* for the range of the shell at time *t*:

$$v\sim\frac{dr}{dt}$$

$$\frac{dv}{dt}\sim\frac{d^2r}{dt^2}$$

Also, for *v* between 1,300 and 2,600 feet per second:

$$f(v)\sim v^{3/2}$$

Substituting:

$$\frac{dv}{dt}=\frac{dv}{dr}\cdot v$$

and

$$\frac{dv}{dr}\sim-2k\rho v^{\frac{1}{2}}$$

Integration and the introduction of the initial condition $v=a$ when $r=0$, where *a* is the intial velocity of the shell, gives:

$$v=\frac{dr}{dt}=\frac{(a-br)^2}{a}$$

where:

$$b=k\rho a^{1/2}$$

A further integration with the second initial condition $r=0$, when $t=0$, yields for the average shell speed to range *r*

$$\frac{r}{t}=a-br$$

This derivation is approximate. It has been found by empirical observation that the average velocity to a

point at range R and elevation E can be expressed approximately as

$$\frac{R}{t}=a-bR-f2(R,E)$$

where f_2 is an empirically determined function which is independent of initial velocity or ρ. This function is found by solving

$$f(R,E)=a-bR-\frac{R}{t}$$

where R, E, and t are taken from ballistic tables.

The ballistic input to the computer is $\bar{U}$, the measured average shell velocity between 1,000 and 3,000 yards, which is approximately the average speed to the range R_0=3,854 yards. More exactly

$$\bar{U}=a-bR_0$$

Here, b=0.0402 for an initial velocity of 825 yards per second and standard air density. Taking standard density as unity, and $\Delta\rho$ as the difference of density from standard, from ballistic tables:

$$b=\sqrt{\frac{a}{825}}(.0402+.043\Delta\rho)$$

Thus

$$\bar{U}=a-R_0\sqrt{\frac{a}{825}}(.0402+.043\Delta\rho)$$

The value of $\bar{U}$ may be found from the last stated equation with a knowledge of a and $\Delta\rho$.

For the average shell speed to future position;

$$U_2=\frac{R2}{T2}=\bar{U}-b(R_2-R_0)-f2(R_2,E_2)$$

This formula is utilized in the computation of $\tilde{U}$. To reduce the number of inputs and eliminate a multiplier, the quantity b is approximated by a constant:

$$K_1=0.0402 \text{ second}^{-1}$$

The approximation for U2 then becomes:

$$U_2=\bar{U}-K_1(R_2-R_0)-f2(R_2,E_2)$$

The error introduced by this approximation is $(b-K_1)(R_2-R_0)$, which, since $b-K_1$ rarely exceeds 0.002 second^{-1}, is generally less than two yards per second per 1,000 yards difference in R_2 from R_0.

The square of the magnitude of the vector R_2 is the sum of the square of its three components:

$$R_2^2=(R+dR\cdot T_2)^2+[(RdBs)^2+(RdE)^2]\cdot T_2^2$$

which can after some transformation be written:

$$R_2=(R+dR)\ (T_2+W\cdot T_2)$$

$$W=\frac{(RdBs)^2+(RdE)^2}{\frac{R2}{T2}+\frac{R}{T2}+dR}$$

Since W, in general, is a small rate by comparison with dR, an approximation may be made:

$$U_2=\frac{R2}{T2}\sim\frac{R}{T2}+dR\sim\tilde{U}$$

A further abbreviation is employed:

$$(RdBs)^2+(RdE)^2=(RdQ)^2$$

where RdQ is the target rate in the plane perpendicular to the line of sight, so that W becomes:

$$W\sim\tfrac{1}{2}\frac{(RdQ)^2}{\tilde{U}}$$

By substitution:

$$\frac{R}{T_2}+dR+W=\bar{U}-K_1(R+dR)(T_2+WT_2-R_0)-f2(R_2E_2)$$

Rearranging:

$$\frac{R}{T_2}+dR=\bar{U}-K_1(R-R_0)-K_1T_2dR-f(R_2E_2)-(1+K_1T_2)(W)$$

Because of their small values, the last three terms in the equations may be handled with sufficient accuracy by approximations. The T_2 in K_1T_2dR is replaced by a function of range.

For incoming and outgoing targets with dR large, the lead angle is relatively small, and errors in the K_1T_2dR and $f2$(RE) terms, even when large, result in relatively small lead angle errors. For $\tilde{U}$, therefore, the following expression may be used:

$$\tilde{U}=\bar{U}-K_1(R-R_0)-f(R_1E)-f_1(R)dR-(1+K_1T_2)W+dHf\sin E$$

Instead of $\tilde{U}$, a quantity U is computed in the ballistics computer:

$$U=\tilde{U}-(1+K_1T_2)W$$
$$U=U_1-f_1(R)dR+dHf\sin E$$

where U_1, the approximate average shell speed to present range, is

$$U_1=\bar{U}-K_1(R-R_0)-f(R,E)$$

The time of flight, T_2, is defined approximately by the following pair of simultaneous equations:

$$R_2=R+\mathrm{d}RT_2+WT_2$$

$$U_2-\frac{R_2}{T_2}=\bar{U}-K_1(R_2-R_0)-f2(R_2E_2)$$

Since W is not available for the mechanical computation of T_2, a new pair of equations are derived which approximate those above and no not involve W:

$$R_G=R+dRG$$

$$U_G=\frac{R_G}{G}=\bar{U}-K_1(R_G-R_0)-f2(R,E)$$

$$U_G=U_1-K_1GdR$$

R_G is the future range of a target having no cross rate (RdQ=0) and a range rate equal to that of the true target. The approximation $f2(R_2E_2)=f(R,E)$ has been introduced into the above equations. On the elimination of R_G:

$$G=\frac{R}{U_1-dR\cdot(1+K_1G)}$$

which is substantially the equation mechanized in the ballistics computer.

In the computer the combination of dHf and vertical parallax is designated as

$$dHfp=f5(T_2)=f5(K7G)$$

where $K7$=1.02.

As aforementioned

$$U=\tilde{U}-(1+K_1T_2)W$$

An approximation to $(1+K_1T_2)$ gives:

$$U_2\sim a-K_1R_2=(a-K_1U_2)T_2$$

Rearranging:

$$(1+K_1T_2)\sim\frac{a}{U_2}\sim\frac{a}{U_2}$$

As previously stated, W may be written

$$W\sim\tfrac{1}{2}\frac{(RdQ)^2}{\tilde{U}}$$

So that

$$(1+K_1T_2)W\sim\frac{a}{2}\left(\frac{RdQ}{\tilde{U}}\right)^2$$

and

$$\tilde{U}\sim U\left[1-\frac{a}{2U}\left(\frac{RdQ}{\tilde{U}}\right)^2\right]$$

In the event that $RdE=O$, so that $RdQ=RdBs$, neglecting the small drift term:

$$X_1=\frac{RdBs}{\tilde{U}}=\frac{RdBs}{U\left[1-\frac{a}{2U}\cdot\frac{(RdBs)^2}{\tilde{U}}\right]}$$

which may be written:

$$X_1\left[\left(1-\frac{a}{2U}\right)X_1^2\right]=\frac{RdBs}{U}$$

A sufficient approximation may be obtained by replacing

$$\frac{a}{2U}$$

with a constant $K15$, since X_1^2 is small comparison with 1, and the range of variation of

$$\frac{a}{2U}$$

is not great. When this is done the quantity

$$\frac{RdBs}{U}$$

is expressed in terms of the displacement alone.

The potentiometer along CX_1 is tapered so that for a displacement X_1, a voltage proportional to:

$$\frac{RdBs}{U}=X_1(1-K15X_1^2)$$

rather than to x_1 is obtained. In this event, the RdBs voltage from the computer can be compared with that obtained from the converter after multiplication by U, and the finger positioned by means of the D'd and E'g rotations until the voltages are equalized.

If $RdBs=0$, a condition somewhat similar to that described hereinbefore exists, except that the superelevation term, $dHf\cos E$, is too large to be neglected. Substituting the constant K16 for

$$\frac{a}{2U}$$

$$Y_1\left[1-K16\left(\frac{RdE}{\tilde{U}}\right)^2\right]=\frac{RdE+dHf\cos E}{U}$$

The right hand expression is obtained as a voltage in the computer; the left hand term is expressed as a function of y_1. From

$$Y_1=\frac{RdE\pm dHf\cos E}{\tilde{U}}$$

the following equation is obtained:

$$\frac{RdE}{\tilde{U}}=y_1-\frac{dHf\cos E}{\tilde{U}}$$

The second term of this equation is approximated by its average value K_{17}:

$$\frac{RdE+dHf\cos E}{U}=y_1[1-K_{15}(y_1-K_{17})^2]$$

The general case where both RdBs and RdE differ from zero cannot be precisely expressed. In general, in place of the aforestated equation:

$$X_1[1-K_{15}(X_1^2+y_1^2)]=\frac{RdBs}{U}$$

with a similar one for y_1.

The tapering of the potentiometer windings introduces some errors, which are compensated or corrected for by means hereinafter to be more fully described.

As previously stated, it is desirable to smooth the rate data in order to obtain gun orders of the desired accuracy. In the smoothing process, a weighted average of the rates supplied by the director over a small time in the past is computed. In determining the time, a compromise is effected because a long period permits more accurate rate data to be obtained but at the same time results in sluggishness of the system. In the instant embodiment of the invention, a settling or smoothing time of approximately 2 seconds is employed.

As previously stated, it is assumed that the target moves on a straight course with constant speed, and its motion may be represented by the constant vector S. The components of S, (dR, RdBs, and RdE) are functions of time as a consequence of the motion of the coordinate system with the target. After the smoothing of the components, the target velocity vector becomes $\overline{S(dR,\ RdBs,\ RdE)}$. The smoothed rates may be considered as approximations of the true rates at a time Tq in the past. From the point of view of the computer, $\overline{S}$ is a vector equal in magnitude to S but with a somewhat different orientation.

The Zq rotation of the potentiometers is directly introduced in the gun order converter. By turning the x_1, y_1 system through Zq (after proper cross traversing and laying off displacements proportional to $\overline{RdBs}$/M $\tilde{U}$ and $\overline{RdQ}$/M $\tilde{U}$) the correct gun order vector is established.

$$RdBs=RdQ\cos\alpha$$

$$RdE=RdQ\sin\alpha$$

where α is the angle between the vectors RdQ and RdBs and

$$\overline{RdBs}=\overline{RdQ}\cos\bar{\alpha}$$

$$\overline{RdE}=\overline{RdQ}\sin\bar{\alpha}$$

where $\bar{\alpha}$ is the angle between vectors $\overline{RdQ}$ and $\overline{RdBs}$. The smoothed RdQ is the vector $\overline{RdQ}=(\overline{RdBs},\ \overline{RdE})$ magnified by:

$$M=\frac{\overline{RdQ}}{RdQ}$$

and rotated through

$$Zq=\bar{\alpha}-\alpha$$

where Rm is the crossover range or the minimum range along the line of flight. Therefore

$$RdQ=\frac{C}{R},\text{ when } C=SRm$$

where C is a constant defined by target path and speed. Substituting:

$$RdBs=C\frac{\cos\alpha}{R}$$

$$RdE=C\frac{\sin\alpha}{R}$$

R and α are both functions of t. The smoothed rates may be obtained from:

$$\overline{RdBs}=C\int_0^\infty\frac{\cos\alpha(t-s)}{R(t-s)}L(S)ds$$

and a similar expression for RdE.

After some operations, the resulting vectors may be written

$$\overline{RdBs}=M[RdBs\sin Zq-RdE\sin Zq]$$

$$\overline{RdE}=M[RdBs\sin Zq+RdE\cos Zq]$$

The gun order vector $\bar{o}$ has the components (x_1y_1) along the X_1Y_1 directions of the converter grid

$$x_1=\frac{RdBs-\frac{1}{30}dHf\cos E}{\tilde{U}}$$

$$y_1=\frac{RdE+dHf\cos E}{\tilde{U}}$$

If the grid is rotated through Zq, in addition to Zs, the components of the gun order vector $\bar{o}$ is the resulting coordinate systems X, Y, become:

$$x=x_1\cos Zq-y_1\sin Zq$$

$$y=x_1\sin Zq+y_1\cos Zq$$

The substitution of x_1 and y_1 and the introduction of the smoothed rates gives:

$$x=\frac{\frac{1}{M}\overline{RdBs}-\frac{1}{30}dHf\cos E\cos Zq-dHf\cos E\sin Zq}{\tilde{U}}$$

$$y=\frac{\frac{1}{M}\overline{RdE}+dHf\cos E\cos Zq-\frac{1}{30}dHf\cos E\sin Zq}{\tilde{U}}$$

Using the approximations

$$RdBs\sim\overline{RdBs}/M$$

$$x\sim\frac{RdBs/M}{R/T_2}$$

$$dHf\sim4T_2$$

$$ZqdHf\cos E\sim4x\sin E$$

Substitution gives:

$$x=\frac{\frac{1}{M}\overline{RdBs}-\frac{1}{30}dHf\cdot\cos E}{\tilde{U}+4x\sin E}$$

The x and y displacements which may be introduced on the rotated grid system of the converter to establish $\bar{o}$:

$$x=\frac{\overline{RdBs}-\frac{MdHf}{30}\cos E}{M\tilde{U}}$$

$$y=\frac{\overline{RdE}+MdHf\cos E}{M\tilde{U}}$$

Expressions are developed which may be used in the computer for the quantities:

$$M\left(\frac{R}{T}+dR\right)\text{ and }MdHf$$

In arriving at the taper for the potentiometers:

$$x=\frac{\overline{RdBstf}}{U\left[1-\frac{a}{2u}\left(\frac{RdQ}{u}\right)^2\right]}$$

$$y=\frac{RdEtf}{U\left[1-\frac{a}{2u}\left(\frac{RdQ}{u}\right)^2\right]}$$

The actual formulas used in tapering are arrived at empirically by considering the various uses of the device as against level bombers, torpedo bombers, and dive bombers, and the tapering may be in a manner to solve the following equations:

$$\frac{RdBstf}{U}=x(1-0.75x^2)$$

$$\frac{RdEtf}{U}=y[1-0.80(y-0.04)^2]$$

In the operation of the aforedescribed apparatus, the radar **18** in Figure 3A provides on lead **27** an angle error

signal representing the instant deviation of the target from the line of sight of the director. A pair of reference voltages are generated by a reference generator, not shown, which may conveniently be located in aforementioned housing **13**, and which is operatively connected to the mechanism for producing a conical scan, and which produces two reference voltages of the same frequency as the scanning frequency, but displaced 90 degrees apart from each other in phase. These reference voltages, after resolution at **17** by the quantity Zs to convert from deck to true coordinates, are utilized by the phase detectors or phase discriminators **21** and **22**, in conjunction with the radar error signal, to provide two angle error signals representative of the deviation of the target in two mutually perpendicular directions. These signals, after amplification at **39** and **40**, are applied to the aforementioned torque motors, and provide on leads **102** and **103** the aforementioned dE and dBs currents. Resistors **59** and **60** provide a stabilizing network for amplifier **40**, and resistors **20**, **30**, and **48** provide a stabilizing network for amplifier **39**. Lead **104**, which is connected to the junction between resistors **20** and **30**, conducts a signal or current to the Zu and Zq computing network of Fig. 3B.

The dE signal on lead **102** is multiplied by R at **105** to provide an RdE signal, which is smoothed or filtered by the R–C network including resistor **106** and capacitor **136**, and which may have a time constant of 2 seconds, and provides on lead **112** a smoothed $\overline{RdE}$ signal.

The dBs signal on lead **103** is multiplied by R at **113** to provide an $RdBs$ signal, which is smoothed or averaged by the R–C network of resistor **115** and capacitor **157**, which may have a time constant of 2 seconds, to provide on lead **126** a smoothed $\overline{RdBs}$ signal.

The smoothing times are designated Tq, and result in the rate signals being late by this amount, which requires some correction in the angle converter, which is accomplished by rotating the potentiometer cards by an amount Zq, in a manner to be hereinafter more fully described.

From the signal on lead **104**, a quantity Zq, is computed according to the formula:

$$Zq=Tq\cdot dBs\cdot\tan E$$

and from the signal on lead **104** an additional quantity Zu is computed according to the formula:

$$Zu=\frac{R-1{,}000}{10{,}000}dBs$$

these formulas having been found suitable for the purpose, and the component values of the computing networks being suitably selected to provide for their accurate computation. As aforementioned, the potentiometers of the gun order converter are tapered to a function of a term it has been found difficult to compute. The tapering introduces an error, which is corrected for by rotating the potentiometers through the aforementioned additional amount Zu.

The Zu and Zq signals from potentiometers **121** and **122** respectively are added by the network comprising resistors **124** and **125**, are further added to the signal on lead **128** obtained from suitably tapered potentiometer **133** and corresponding to Zs, to provide on lead **127** an $eZsqu$ signal, which is applied by the apparatus shown to drive $Zsqu$ servomotor **186**, which generates at **184** a $cZsqu$ signal used for nulling in the servo loop, in a manner well known to those skilled in the art.

The total $Zsqu$ shaft rotation of **190** is utilized for rotating the potentiometers of the angle converter, and corrects for the roll and pitch of the vessel, the time by which the rate data is late, and the errors introduced by the tapering of the potentiometers. Figs. 5A–5C inclusive illustrate the geometry of the angle converter of Fig. 4.

The aforementioned $\overline{RdE}$ and $\overline{RdBs}$ signals on leads

112 and 126 respectively are corrected for wind, drift, gravity, and parallax in the network of Fig. 3C, to provide $\overline{RdEtfpw}$ and $\overline{RdBstfw}$ signals on leads 141 and 142 respectively. As aforementioned, the wind corrections R*d*E*w* and R*d*B*sw* are computed in a suitable wind resolution network shown in block form in Fig. 2. The network also computes a wind correction for range rate *dRw*, which is utilized in the range and range rate nets to obtain a corrected and smoothed range rate signal $\overline{dRtw}$. A range and range rate net suitable for the purpose is disclosed in the copending application of Ivan A. Getting for Gun Fire Control Method and System, Ser. No. 61,558, filed November 23, 1948.

It has been found by empirical observation that the drift of a 5"–38 caliber projectile, for which the instant apparatus was designed, is approximately 1/30 of the gravity drop rate, so that the quantity *dHfp* cos *E* may be utilized as shown for providing the drift and gravity corrections to the $\overline{RdBs}$ and $\overline{RdE}$ signals, Fig. 3C.

The aforementioned $\overline{RdEtfpw}$ signal on lead 141 is applied to an adding network comprising resistors 251 and 252, the output of which represents $e\overline{RdEtfpw}$. This last named signal is applied to vibrator 265 where it is converted to A. C., thence by way of cathode follower 271 and servo amplifier 273 to primary 281.

The aforementioned $\overline{RdBstfw}$ signal on lead 142, Fig. 3D, is applied to the adding network of resistors 257 and 258, and the output thereof applied by way of vibrator 266, cathode follower 272, and servo amplifier 274, to primary 282.

The resolver 275 converts from true to deck or slant coordinates. The outputs, after division by U at 341 and 342 to regulate the gains of the servo loops and after one signal passes through secant E'*g* attenuator 286, are filtered and amplified as shown, and used to drive V'*d* and D'*d* servomotors 297 and 298 respectively. Tachometers 299 and 300 generate stabilizing voltages which are fed back into the respective loops.

The V'*d* and D'*d* shaft rotations on shafts 301 and 302 are utilized to position finger 240 by the desired lead angles. Accordingly, the voltages from potentiometers 321 and 323 respectively represent the quantities

$$\frac{\overline{cRdEtfpw}}{U} \text{ and } \frac{\overline{cRdBstfw}}{U}$$

respectively, which, after multiplication by U at 363 and 364 respectively, are applied to the aforementioned adding networks.

In this manner finger 240 is maintained in a position with respect to the axis of 335 corresponding to the desired lead angles. E'*b* is also applied to the aforementioned gear mechanism to establish or define the line of sight, and provide for complementary error corrections, as illustrated in Fig. 1G. Figs. 1E and 1F additionally illustrate the operation of the subject invention.

Differentials 305 and 308 add the lead angles in deck coordinates V'*d* and D'*d* to the target present position in deck coordinates E'*b* and B'*r'p* respectively, and their outputs are shaft rotations corresponding respectively to gun orders in deck coordinates E'*g and* B'*grp*, which may be converted to electrical signals by the generators 303 and 304.

The squaring potentiometers 322 and 324 provide voltages for use in a fuse computer shown in block form, Fig. 2, which comprises no part of the present invention, for computing a fuse setting.

The invention contemplates the use of gears of the desired diameters and ratios in the mechanism of Fig. 4 to give the desired operation.

The invention contemplates the use of component values and potential values throughout to provide for operation in the desired manner.

It will be understood that whereas the quantity $\tilde{U}$ or

$$\frac{R}{T_2}+dR+dHf \text{ sine } E$$

is used in the computations, the quantity U3 or

$$\frac{R}{T_2}+dR+dHfp \text{ sine } E$$

which is $\tilde{U}$ corrected for parallax, may be employed if desired, the parallax correction providing for the introduction of no substantial errors.

Whereas certain mathematical formulas are stated as an aid in describing the theory of operation of the apparatus embodying the invention, it will be understood that the invention exists independently of these mathematical computations involved therein, and that other and different formulas could be utilized if desired.

Whereas certain constants have been stated as having prescribed values, it will be understood that other values may be used. Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States of America is:

1. In gun order converter apparatus of the character disclosed for use aboard a vessel including a source of a pair of angular rate signals corresponding to the angular rates of target motion in a pair of mutually perpendicular planes and corresponding respectively to the true elevation and true traverse coordinates of target motion, and a source of output signal corresponding to the instant range, R, of the target converter apparatus comprising in combination, means operatively connected to said source of signals for converting said pair of angular rate signals to a pair of linear rate signals in true elevation and true traverse respectively, designated R*d*E and R*d*B*s*; a pair of resistance-capacitance networks for smoothing said last named pair of signals respectively; means including a pair of adding resistance networks for correcting said pair of smoothed linear rate signals for wind, drift, gravity drop, and parallax and thereby obtaining a pair of signals designated $\overline{RdEtfpw}$ and $\overline{RdBstfw}$ respectively; a pair of rectangular potentiometer windings disposed in mutually perpendicular directions; means for rotating said potentiometer windings about a common axis and in an amount corresponding to the rotation of the vessel about the line of sight as a result of roll and pitch; means for obtaining from said potentiometer windings a pair of voltages corresponding to a calculated lead angle in true elevation designated

$$\frac{\overline{cRdEtfpw}}{\tilde{U}}$$

and a calculated lead angle in true traverse designated

$$\frac{\overline{cRdBstfw}}{\tilde{U}}$$

respectively; means for multiplying both said last named pair of voltages by the average shell velocity quantity U; means for respectively comparing said last named pair of voltages after multiplication by U with said $\overline{RdEtfpw}$ and $\overline{RdBstfw}$ voltages to produce a pair of difference voltage means for utilizing the said pair of difference voltages to position the arms of said potentiometer windings in a manner which tends to reduce the difference voltages to zero; and means operatively connected to said last named means for generating gun order signals in deck elevation and deck train in response to the said difference voltages and a signal representative of target elevation.

2. In gun order converter apparatus of the character

disclosed for use aboard a vessel including a source of a pair of *d*E and *d*B*s* signals corresponding respectively to the angular rates of target motion in a pair of mutually perpendicular directions in true elevation and true traverse, a source of signal representative of supply information as to the rotation of the deck about the line of sight as a result of roll and pitch, and a source of signal representative of the instant range of the target R: means for utilizing said range output to convert said *d*E and *d*B*s* signals from angular rate to linear rate signals, designated R*d*E and R*d*B*s* respectively; means for smoothing said pair of linear rate signals; means for correcting said smoothed pair of signals for wind, drift, and parallax to produce an additional pair of signals corresponding to the computational linear rate components of target motion in the true elevation and true traverse planes, designated $\overline{Rd\mathrm{E}}tfpw$ and $\overline{Rd\mathrm{B}}stfpw$ respectively; an angle converter including a pair of potentiometer windings disposed in mutually perpendicular directions; a movable finger operatively connected to the pickoff arms of said potentiometer windings; means coupled to the said moveable finger for positioning said arms to pickoff signals representative of the instantaneous lead angles to the target future position; means for multiplying the signals from said potentiometers by the average shell velocity quantity U; means for comparing the respective elevation and traverse components of the said last named pair of signals, after multiplication, with the $\overline{Rd\mathrm{E}}tfpw$ and $\overline{Rd\mathrm{B}}stfpw$ signals to produce difference voltages; means for utilizing the said difference voltages between the corresponding elevation and traverse signals of said pairs to position said finger; and means operatively connected to said last named means and to said source of deck-rotation signal for generating gun orders in deck elevation and deck train in response to the aforesaid signal differences, the said deck-rotation signal, and a signal representative of target elevation.

3. In gun order converter apparatus of the character disclosed for use aboard a vessel including a source of a plurality of signals representing respectively the instantaneous deck elevation of the line of sight, the angular rate of movement of the target in the true elevation plane, the angular rate of movement of the target in the true traverse plane, the present range of the target, and the rotation of the deck of the vessel about the line of sight as a result of roll and pitch, said signals being designated E'*b*, *d*E, *d*B*s*, R, and Z*s*, respectively: means operatively connected to said source of signals for generating a pair of signals corresponding respectively to the linear elevation rate and linear traverse rate of motion of the target and designated R*d*E and R*d*B*s* respectively; a pair of similar potentiometer windings disposed in mutually perpendicular positions, each of said potentiometers having a voltage pickoff arm; a movable finger operatively connected to said arms; means including means for generating signals representative of the lead angles in elevation and traverse to the future position of the target operatively connected to said finger, to the said R*d*E and R*d*B*s* signal generating means, and to said source of signals for positioning said finger; means operatively connected to said last named means, the said source of signals, and to said potentiometer pickoff arms for repositioning said finger in a manner which tends to maintain the signals from said potentiometer pickoff arms at predetermined values with respect to the values of said R*d*E and R*d*B*s* signals; and means operatively connected to said last named means and to said source of signals for producing gun order-signals in deck elevation and deck train.

4. In gun order converter apparatus of the character disclosed for use aboard a vessel including a source of a plurality of signals corresponding respectively to the instantaneous deck elevation of the target, the angular rates of target, motion in true elevation and true traverse, the range of the target and the rotation of the deck about the line of sight to the target: means for generating a pair of gun order signals in deck train and deck elevation including means for simulating the position of the target and means responsive to signals from the said source of signals for controlling said simulating means.

5. In gun order converter apparatus of the character disclosed for use aboard a vessel including means for generating a pair of rate signals corresponding respectively to the rates of movements of a target in a pair of mutually perpendicular directions: means operatively connected to said rate-signal generating means for smoothing both said rate signals to eliminate undesirable fluctuations resulting from change of target aspect and other factors; means operatively connected to said rate-signal generating means and to said last named means for providing a simulated target; means for continually positioning said simulated target in accordance with movements of the real target in response to the said rate-signals, a signal representative of the target elevation, and a signal representative of the rotation of the deck of the vessel about the line of sight, said last named means including means for correcting the said deck rotation signal for the time by which the said rate signals are late due to smoothing; and means operatively connected to said positioning means and to said rate-signal generating means for producing gun order signals.

6. In a gun fire control system for firing at a target moving in a predetermined three dimensional coordinate system, said gun fire control system including means for obtaining a first pair of rate signals corresponding to the rates of movement of said target in two dimensions, gun order converter apparatus comprising means including an angle converter for generating a second pair of rate signals corresponding to the position of a simulated target; means for multiplying said second pair of rate signals by a shell velocity signal to produce a third pair of signals corresponding to the future position of the target at which the gun is to be aimed; and means for generating signals representative of the differences between corresponding signals of said first and third pairs; means responsive to said difference signals and to a signal representative of the target elevation for generating gun order signals.

7. In a gun fire control system for firing at a target moving in a predetermined three dimensional coordinate system, gun order converter apparatus comprising; means for generating a first pair of rate signals coresponding to the rates of movement of said target in two dimensions; means including an angle converter for generating a second pair of rate signals corresponding to the instantaneous motion of a simulated target, said angle converter including a pair of potentiometers and a movable finger for controlling the said potentiometers to produce signals representative of the position of the said simulated target; means for multiplying said second pair of rate signals by a shell velocity signal to produce a third pair of signals corresponding to the future position of the target at which the gun is to be aimed; means for generating signals representative of the differences between corresponding signals of said first and third pairs; means responsive to the said difference signals for positioning the said finger; and means for generating gun order signals coupled to the said last named means.

8. In a gun fire control system for firing at a target moving in a predetermined three dimensional coordinate system, gun order converter apparatus comprising; means for generating a first pair of rate signals coresponding to the rates of movement of said target in two dimensions; means including an angle converter for generating a second pair of rate signals corresponding to the position of a simulated target, said angle converter including a movable finger and a pair of potentiometers having pickoff arms coupled to the said movable finger; means for adjusting the position of the said movable finger to establish the position of the simulated target, such that the said second pair of signals derived from said pickoff arms

will represent the position of the said simulated target; means for multiplying said second pair of rate signals by a shell velocity signal to produce a third pair of signals corresponding to the future position of the target at which the gun is to be aimed; means for generating signals representative of the respective differences between corresponding signals of said first and third pairs; means responsive to the said difference signals and to signal representative of the target elevation to position said finger; means for producing signals representing the instant position of the real target in deck elevation and deck train; and means including servo motors operatively connected to said difference-signal generating means for producing gun order signals.

9. In a gun fire control system for use aboard a vessel to fire at a target moving in a predetermined three dimensional coordinate system including means for generating a first pair of rate signals corresponding to the rates of movement of said target in two dimensions, means for stabilizing said coordinate system against roll and pitch of the vessel, and means to track the target, gun order converter apparatus comprising; means including an angle converter having a movable finger coupled to a pair of potentiometers for generating a second pair of rate signals corresponding to the position of a simulated target, means for multiplying said second pair of rate signals by a shell velocity signal to produce a third pair of signals corresponding to the future position of the target at which the gun is to be aimed; means for generating a pair of signals representative of the respective differences between corresponding signals of said first and third pairs of signals; means responsive to the said difference signals and to a signal representative of the target elevation to position said finger; and means operatively connected to said difference-signal generating means, the said stabilizing means, and the said tracking means for generating gun order signals.

10. In gun order converter apparatus of the character disclosed, in combination, a rotatable base, a support member secured to said base to rotate therewith, a first pair of potentiometer windings secured to said support member, said support member having a first pair of guideways mounted thereon, a first movable plate mounted upon said support member and movable in said first pair of guideways, a pair of contact means mounted on said first plate and cooperating with said first pair of windings respectively, a second pair of windings mounted upon said first plate, said first movable plate having a second pair of guideways mounted thereon, a second movable plate mounted upon said first movable plate and movable in said second pair of guideways, a second pair of contact means for said second pair of windings respectively and secured to said second movable plate, and means for moving said first and second movable plates.

11. Gun order converter apparatus according to claim 10 wherein said means for moving said first and second movable plates comprises a finger positioned in accordance with the future position of a moving target, and including in addition means connected to some of said contact means for obtaining order signals for positioning a gun to fire at the target.

12. Gun order converter apparatus of the character disclosed for receiving signals from a director means constructed and arranged to track a moving target comprising; means providing a pair of target rate signals; means for averaging said rate signals over a time Tq to eliminate fluctuations due to change of target aspect wherein Tq denotes smoothing time to smooth rate data by computing a weighted average of the rates supplied by the director over a small time in the past; and means including an angle converter utilizing said rate signals for computing gun order signals, said angle converter including means for correcting the said gun order signals by a factor Zq, where Zq is computed according to the formula

$$Zq=Tq\cdot dBs\cdot\tan E$$

wherein dBs represents the angular rate of target motion in true traverse, and E represents the angular rate of target motion in true elevation.

13. In gun order converter apparatus of the character disclosed for use aboard a vessel for receiving signals from a director means constructed and arranged to track a moving target and to provide a pair of target rate signals, and further including means for stabilizing the coordinates of motion of the target at the director to an extent determined by the crosstraverse angle; means for averaging said rate signals over a time Tq to eliminate fluctuations due to apparent changes of target aspect not attributable to target motion and wherein Tq denotes smoothing time to smooth rate data by computing a weighted average of the rates supplied by the director over a small time in the past; means including an angle converter utilizing said rate signals for computing gun order signals, said angle converter including means for correcting gun order signals by an amount determined by the sum of a signal representative of the cross-traverse angle and a signal representative of the factor Zq, where Zq is computed according to the formula

$$Zq=Tq\cdot dBs\cdot\tan E$$

wherein dBs represents the angular rate of target motion in true-traverse, and E represents the true target elevation.

14. Gun order converter apparatus according to claim 13 in which said angle converter means includes means for correcting gun orders by an additional factor Zu to compensate for errors in computation, Zu being computed according to the formula

$$Zu=\frac{R-1000}{10{,}000}dBs$$

wherein R represents range and dBs represents angular rate of target motion in true-traverse.

15. In gun order converter apparatus including a source of signals representing, relative to a point of observation, the instantaneous angular rates of motion of a moving target in true elevation, dE, true traverse, dBs, and instantaneous range, R: means coupled to the said source for multiplying the said elevation and traverse rate signals by the value of range to produce a linear elevation rate signal, RdE, and a linear traverse rate signal, RdBs; means coupled to the said multiplying means for smoothing the said RdE and RdBs signals; means coupled to the said smoothing means for modifying the smoothed RdE and RdBs signals so that the said smoothed signals also will incorporate pertinent effects of wind, drift, parallax, and gravity on the said linear elevation and traverse rates; means including a dual potentiometer actuated by a movable finger for developing a pair of signals, each of the last-named signals representing a separate one of the instantaneous coordinates of a displacement of the movable finger from the origin of a two-dimensional coordinate system; means comparing one of the said pair of signals with the said modified RdE signal to produce a first error signal; means comparing the other one of the said pair of signals with the said modified RdBs signal to produce a second error signal; means responsive to the said first and second error signals for displacing the said movable finger in a direction tending to reduce the said error signals to zero; and means coupled to the said signal source and the said finger displacing means for producing signals representing gun orders in gun elevation and gun train.

16. Gun order converter apparatus as represented in claim 15 wherein the said dual potentiometer comprises a pair of windings having tapering electrical resistance characteristics and including means for compensating for errors attributable to the said tapered windings.

17. Gun order converter apparatus for use aboard a vessel in conjunction with an automatic-tracking gun director generating signals representative of target position and motion components in a stabilized space coordinate system comprising: means including an angle converter having a pair of potentiometers for generating signals representative of the components of future target position relative to the present target position; means coupled to the said gun director and to the said angle converter for stabilizing the said angle converter in the space-coordinate system of the said gun director signals; and means coupled to the said future-target-position-signal-component generating means and the said gun director for utilizing the said potentiometer signals to produce gun-order signals.

18. In gun order converter apparatus including a source of independent signals representing the instantaneous angular rate of target motion in true elevation *d*E, the instantaneous angular rate of target motion in true traverse *d*B*s*, and the instantaneous range R respectively: a first channel coupled to the said source comprising means for combining the said *d*E signal with the said R signal to produce a signal representing the linear elevation rate, R*d*E, means coupled to the said combining means for smoothing the said R*d*E signal to eliminate the effects of spurious and erratic variations in target aspect, means coupled to the said smoothing means for incorporating into the said smoothed R*d*E signal other signals representative respectively of the effective components of gravity drop, wind, drift, and parallax in the true elevation plane to produce a resultant computational linear elevation rate signal, designated $\overline{R\dot{d}E}tfpw$; a second channel coupled to the said source comprising means for combining the said *d*B*s* signal with the said R signal to produce a signal representing the linear traverse rate, R*d*B*s*, means coupled to the said combining means for smoothing the said R*d*B*s* signal to eliminate the effects of spurious and erratic variations in target aspect, means coupled to the said smoothing means for incorporating into the said smoothed R*d*B*s* signal other signals representative respectively of the effective components of drift and wind in the true traverse plane to produce a resultant computational linear traverse rate signal, designated $\overline{R\dot{d}B}stfw$; and means coupled to the aforesaid first and second channels for generating two signals representative of the gun elevation order and the gun train order respectively, said apparatus including a source of signal representative of the average shell velocity, U, and wherein the said means for generating gun-order representative signals comprises: first means for generating signals representative of calculated traverse and elevation lead angles; second means coupled to the said first means and to the said source of average shell velocity signal, U, for changing the said calculated traverse and elevation lead-angle signals into signals representative respectively of the calculated linear traverse rate and linear elevation rate; third means coupled to the said second means and the said first and second channels for developing two error signals representative respectively of the instantaneous difference between the said computational and calculated linear traverse rates and the instantaneous difference between the said computational and calculated linear elevation rates; fourth means coupled to the said third means and the said source of average shell velocity signal, U, for changing the said linear-rate error signals into error signals representative of the error in the traverse and elevation lead angles respectively; fifth servo system means coupled between the said fourth and first means for modifying the said calculated traverse and elevation lead-angle signals in such a manner that the said error signals are minimized; means to generate signals representative of train and elevation angle signals; and sixth means coupled to the said fourth means for generating a gun-train order signal in response to the said traverse lead-angle error signal and the signal representative of the train angle; and seventh means coupled to the said fourth means for generating a gun elevation order in response to the said elevation lead-angle error signal and the signal representative of the elevation angle.

19. A gun order converter as represented in claim 18 wherein the said means for generating gun-order representative signals further includes apparatus for incorporating into the said gun-order signals further signals representative of the traverse and elevation components of the inclination of the deck plane of a vessel with respect to a horizontal plane in response to signals representing, respectively, the cross-traverse angle, Z*s*, range, R, elevation, E, and angular traverse rate, *d*B*s*, the said deck-inclination compensating apparatus comprising: means responsive to the aforesaid Z*s*, R, E, and *d*B*s* signals for generating a signal representative of the computational rotation, Z*squ*, of the deck about a line of sight between the said vessel and a target, the said computational rotation consisting of the summation of the instantaneous effects of the cross-traverse angle, Z*s*, attributable to the roll and pitch the vessel, the correction factor, Z*q*, required to compensate for the time lag inherent in the said smoothing means for linear traverse and elevation rate signals, and a correction factor Z*u* compensating for an error inherent in the electrical response of the said first means; means coupled to the said Z*squ*-signal generating means and to the said third means for developing two signals representative respectively of the instantaneous traverse and elevation components of the said Z*squ* signal and for incorporating the said Z*squ* component signals into the said traverse and elevation linear-rate error signals such that the said error signals represent the traverse and elevation lead-angle errors relative to the said deck plane; and means coupled to the said first means and to the said Z*squ*-signal generating means for removing the said instantaneous traverse and elevation components of the Z*squ* signal from the said calculated traverse and elevation lead angle signals.

20. A gun order converter as represented in claim 19 wherein the said means for generating gun-order representative signals also includes a closed-loop servo system comprising: means producing a calculated Z*squ* signal in response to the said Z*squ*-signal generating means; means developing an error signal representing the instantaneous difference between the said generated Z*squ* signal and the said calculated Z*squ* signal; and means responsive to the said Z*squ* error signal for correcting the said generated Z*squ* signal.

21. A gun order converter as represented in claim 19 wherein the said first means for generating signals representing calculated lead angles in traverse and elevation respectively includes a potentiometer assembly comprising: first and second potentiometers having windings tapered in resistance value per unit length; means including a potentiometer pickoff arm for the said second potentiometer movably mounting the said first potentiometer in perpendicular relation to the said second potentiometer such that the said first potentiometer may be moved along a path parallel to the longitudinal axis of the said second potentiometer; means mounting a pickoff arm for the said first potentiometer slidably engaging the said movable mounting means; means including a finger having one end coupled to the said pickoff-arm mounting means and shiftable in a two-dimensional rectangular coordinate system for positioning the said pickoff arms in response to the said deck elevation and the said train and elevation lead-angle signals; and means coupled to the said second potentiometer for rotating the said potentiometer assembly in response to the said Z*squ* signal such that the respective deck inclination components of the said traverse and elevation lead-angle signals are removed and, as a result, the signal voltages on the said pickoff arms are representative of the said calculated true traverse and true elevation lead angles.

22. In gun order converter apparatus for use aboard a vessel against a target including a source of signals representing, relative to a point of observation, the instantaneous deck elevation of the target E'*b*, the angular elevation rate of target motion in the true elevation plane *d*E, the angular rate of target motion in the true traverse plane *d*B*s*, the instantaneous range to the target R, and the instantaneous rotation of the deck, *Zs*, about a line of sight between the said point of observation and the target: a pair of resistance multipliers; means coupling the said multipliers to the said source of signals to generate a pair of signals representing respectively the linear elevation rate R*d*E and linear traverse rate R*d*B*s* in response to input signals from the said source representative *d*E, *d*B*s*, and R; means coupled to the said multipliers for smoothing the said R*d*E and R*d*B*s* signals to minimize the effects of spurious and erratic variations in target aspect; means coupled to the said smoothing means for modifying the said smoothed R*d*E and R*d*B*s* signals to compensate for the pertinent effects of wind, parallax, gravity, and drift, and thereby produce signals representative of the computational linear elevation rate $\overline{Rd\text{E}}tfpw$ and the computational linear traverse rate $\overline{Rd\text{B}}stfw$ respectively; means including two potentiometers disposed in mutually perpendicular relationship for supplying a pair of output signals representative of the respective positions of the pickoff arms of the said potentiometers; a finger having a pointable end coupled to the pickoff arms of the said potentiometers; means coupled to the said potentiometer pickoff arms for multiplying each of the said pair of output signals by a signal representative of shell velocity to produce two signals representing the calculated linear elevation rate, $c\overline{Rd\text{E}}tfpw$, and the calculated linear traverse rate, $c\overline{Rd\text{B}}stfw$, respectively; means coupled to the said shell-velocity multiplying means for comparing the said $c\overline{Rd\text{E}}tfpw$ signal with the aforesaid $\overline{Rd\text{E}}tfpw$ signal and the said $c\overline{Rd\text{B}}stfw$ signal with the aforesaid $\overline{Rd\text{B}}stfw$ signal to produce elevation and traverse difference signals respectively; means coupled to the said comparing means for resolving the said difference signals by a signal, *Zsqu*, representative of the computational rotation of the deck about the line of sight, to produce two error signals representing the error in linear elevation rate in the true elevation plane and the error in linear traverse rate in the true traverse plane respectively; means coupled to the said *Zsqu* resolving means for transforming the said true linear-traverse-rate error signal into a signal representing the true linear bearing rate; means including a pair of servo systems coupled to the said resolving means, the said source of signals, and the said transforming means for pointing the said movable finger in response to the said error signals; and means coupled to the said last-named means and the said signal source for generating gun elevation and gun train order signals.

23. In gun order converter apparatus of the character disclosed for use aboard a vessel including first means for generating a pair of signals corresponding to the linear elevation rate and linear traverse rate of a moving target: means simulating target motion including means for generating a pair of voltages corresponding to the linear elevation rate and linear traverse rate of motion of the simulated target; means for comparing said last named pair of voltages with the corresponding elevation and traverse rate voltages obtained from said first means; and means operatively connected to said last named means for positioning said simulated target and developing gun order signals in deck elevation and deck train.

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