

March 24, 1959

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2,879,502

COLLISION COURSE FIRE CONTROL SYSTEM

Filed Jan. 8, 1946

2 Sheets-Sheet 1

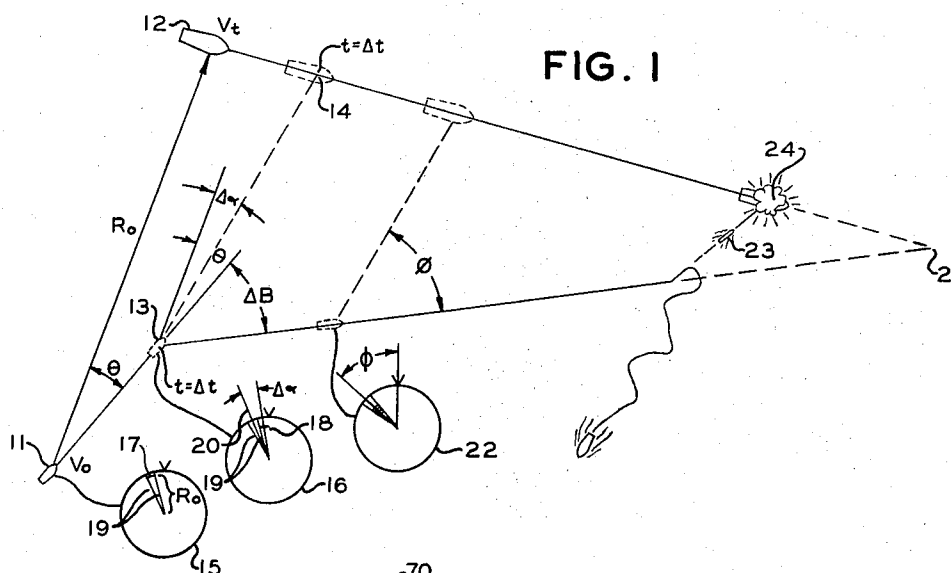


FIG. 1

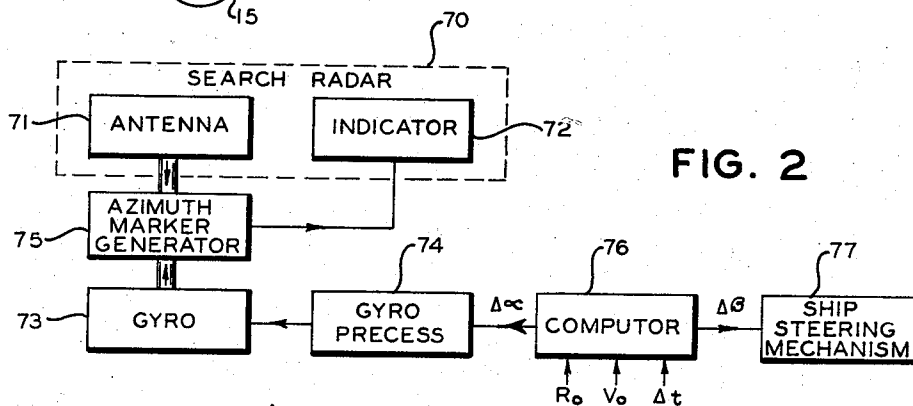


FIG. 2

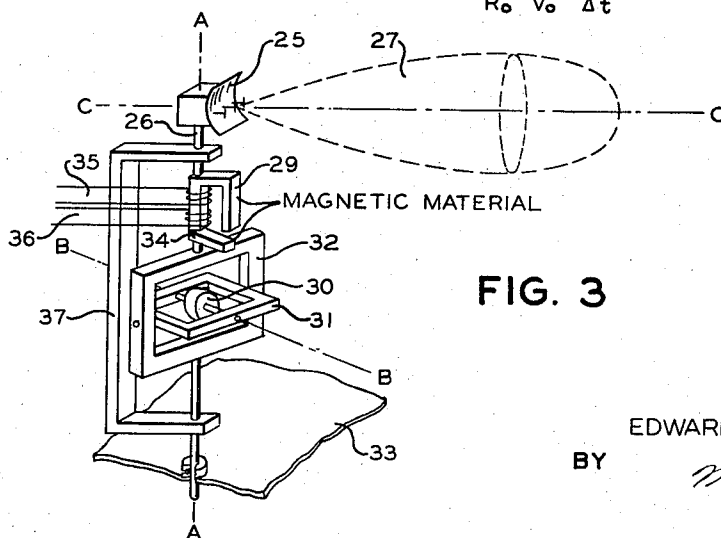


FIG. 3

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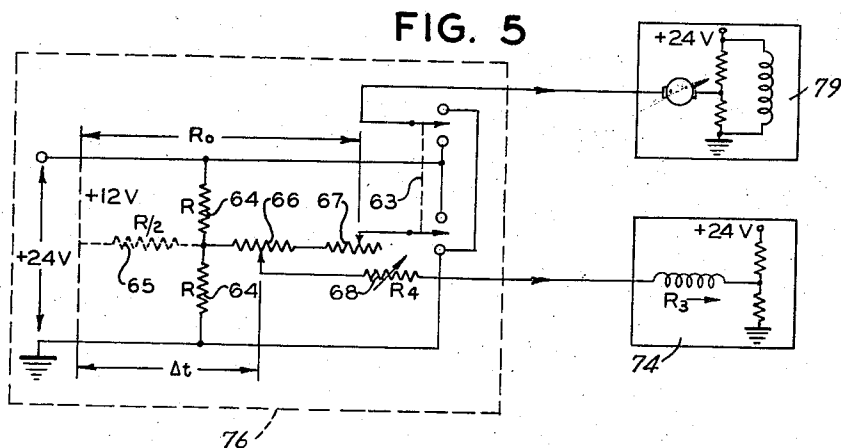
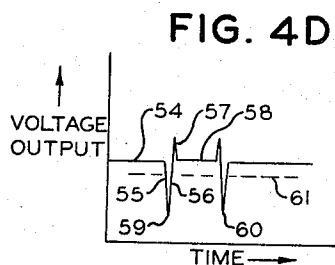
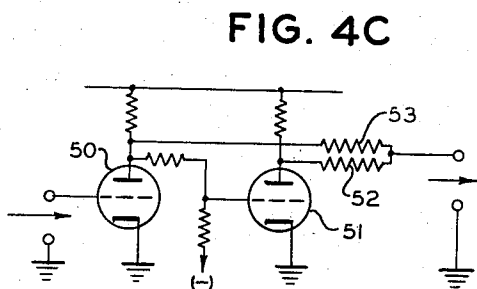
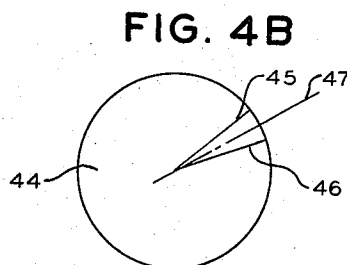
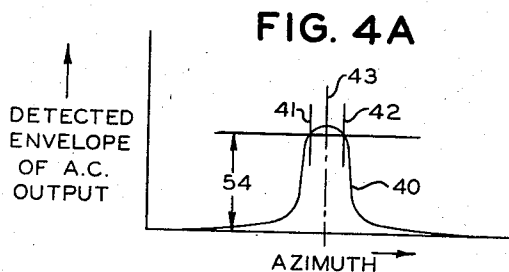
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COLLISION COURSE FIRE CONTROL SYSTEM

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Application January 8, 1946, Serial No. 639,896

7 Claims. (Cl. 343—7)

This invention relates to projectile laying systems and more specifically to the type for laying a projectile, such as a torpedo, at a moving target from a moving craft, such as a PT-boat.

A common firing technique and the one concerned in this invention is that employing the collision course principle, wherein the attacking craft places itself on such a course that, should the target and attacking vessels continue on their respective courses and maintain their velocities, the two vessels would collide. The collision course principle is employed because it offers to the attacking vessel the necessary velocity and azimuth heading information of the target vessel and because the collision course condition is one that is easily recognized.

Heretofore an attacking vessel got on a collision course by making a series of estimated course corrections, but this technique is time consuming requiring a long tracking time for a given degree of accuracy. The present invention describes a system which can place an attacking vessel on a collision course with a single correction in the azimuth heading of the attacking craft. The system can be adapted to both radar and visual tracking of the target vessel.

A specific object of this invention is to provide apparatus for rapidly and accurately laying a projectile at a moving target from a moving craft.

Another object is to place an attacking craft on a collision course with a target vessel by means of a single adjustment in the azimuth heading of the attacking craft.

Another object is to provide projectile laying apparatus whose operation is totally independent of the pitch, roll, or yaw of the vessel on which it is mounted.

Another object is to provide projectile laying apparatus having incorporated therein means for indicating when two coaxial and abutting, mechanically independent shafts are in proper alignment.

Another object is to provide a projectile laying system having incorporated therein means for providing a stabilized azimuth marker on a radar indicator scope.

A further object is to provide a projectile laying apparatus having incorporated therein a simple computer for turning one shaft by an amount mathematically related to the motion of a second shaft.

A further object is to provide a projectile laying system which may be operated from either radar or optical data.

Another object is to provide a radar projectile laying system which is operative with either a stabilized or an unstabilized tracking indicator.

To achieve these and other objects, apparatus is employed which is described in detail in the following specification and shown in the accompanying figures, of which:

Fig. 1 is an illustration of the collision course principle and the manner in which the present invention is adapted to this firing technique;

Fig. 2 is a block diagram of the system of the present invention;

Fig. 3 is a perspective drawing showing schematically

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the correlation between the radar, the azimuth marker, and the gyro of the present invention;

Fig. 4A is a graph of the detected output of the azimuth marker of the present invention;

Fig. 4B shows a plan position indicator, or P.P.I., with the azimuth reference lines placed thereon;

Fig. 4C is a circuit which may be employed to produce the azimuth reference lines shown in Fig. 4B.

Fig. 4D shows the waveform of the output of the circuit of Fig. 4C.

Fig. 5 shows the resistance network computer associated with the gyro-precess means and the ship steering mechanism.

In the accompanying drawings and more specifically in Fig. 1 are shown an attacking craft 11 moving with a constant velocity C_0 , and a target vessel 12 traveling at a constant velocity V_0 , initially displaced from one another by a range R_0 . In a time Δt , the attacking craft 11 travels to a position 13, and the target vessel 12 moves up to a position 14. From the figure it can be seen that the two vessels shown are not on a collision course and that the attacking vessel 11 will fall astern of the target vessel 12. The condition which indicates to the attacking vessel 11 that the two vessels 11 and 12 are not on a collision course is that the original relative azimuth angle θ changes in a time Δt by an angular amount $\Delta\alpha$. If the two vessels 11 and 12 were on a collision course, the relative azimuth angle θ would remain unchanged as the two vessels approach one another.

To get on the proper collision course at the time

$$t = \Delta t$$

the attacking vessel 11 must alter its course by an angle $\Delta\beta$, and the present invention is based upon the fact that $\Delta\beta$ is determined from the known quantities, range R_0 , velocity V_0 , and time interval Δt , and the easily measurable angle $\Delta\alpha$. These quantities are related by the approximate mathematical expression

$$\Delta\beta \cong \frac{R_0}{V_0 \Delta t} \Delta\alpha$$

The approximation improves as the angle $\Delta\alpha$ diminishes, and $\Delta\beta$ corrections of greater precision can be made if necessary during the course of attack.

Considering the use of a search radar system with a plan position indicator for giving position information of the target vessel 12, initial range R_0 can be measured directly on the indicator presentation 15 of Fig. 1. The knowledge of own velocity V_0 is obvious, and the time interval Δt may conveniently be chosen as the time for an integral number of complete rotations of the radar antenna. The angle $\Delta\alpha$ can be measured if an azimuth reference line is maintained. Such an azimuth reference is provided by a gyro which is initially uncaged with its axis pointing directly at the target vessel and which presents on the radar azimuth indicator 15 a stable azimuth marker consisting of two adjacent radial lines 19. The oscilloscope radar presentation 15 of Fig. 1 shows the initial tracking condition with the radar echo 17 at a range R_0 , bracketed by the two radial lines 19 of the gyro stable azimuth marker. Indicator picture 16 at a time $t = \Delta t$ shows $\Delta\alpha$ as the easily measurable angle between the center line 20 of the stable azimuth markers 19 and the radar echo 18.

To solve for the azimuth heading correction angle $\Delta\beta$ which is ultimately desired, the gyro originally mentioned is precessed so that the stable azimuth marker line 20 controlled thereby is brought into azimuth alignment with the radar echo 18 at time $t = \Delta t$. By so precessing the gyro, the rotation axis thereof is again pointed directly at the target vessel now in position 14. A computer receives quantities R_0 , V_0 and Δt and is operated for a time dependent upon R_0 , V_0 , Δt and $\Delta\alpha$. Out of this

computer comes the angle $\Delta\beta$ which may either go to a helmsman indicator on the attacking vessel or serve to turn the attacking craft directly.

After turning the attacking craft 11 through an angle $\Delta\beta$, the attacking and target vessels 11 and 12 lie on relative courses which will cause them to collide at point 21. An indication that the two are on collision course is that the new relative azimuth angle ϕ remains constant as the two vessels approach one another. This condition is indicated on indicator picture 22 by the successive radar echoes of the target vessel falling within the stable azimuth marker of that indicator. It will be noticed that the indicator shown in Fig. 1 is unstabilized, with the top of the scope representing dead ahead.

Before the two vessels 11 and 12 reach the collision point 21, the attacking craft 11, which in the particular situation considered is making a torpedo attack, swerves in toward the target vessel by an angle determined by the relative velocity of the torpedo and the attacking vessel 11, and releases its projectile 23. The final point of impact of the torpedo with the target vessel is indicated by point 24. The apparatus brought into use after the attacking and target vessels are on a collision course is not a part of the present invention.

Refer now to Fig. 2 which is a block diagram. A search radar system 70 is employed having an antenna 71 that is sufficiently directive to provide accurate azimuth information and an indicator 72 for presenting both range and azimuth information. The gyro 73 shown, having an associated precess mechanism 74, provides the desired stabilized reference azimuth information. Both the antenna 71 and one of the gyro supporting frames or gimbals are coupled to an azimuth marker generator 75. It is the latter unit which places the aforementioned stable azimuth lines on the radar indicator 72. A computer 76 has its operation dependent on R_0 , V_0 , Δt , and $\Delta\alpha$ information and solves for the azimuth heading correction angle $\Delta\beta$ which is finally transmitted to the ship's steering mechanism 77. The arrows on Fig. 2 indicate the direction of flow of information.

Refer now to Fig. 3, which shows schematically the correlation between the radar, the gyro, the azimuth marker generator and the deck of the ship itself. A radar system having an antenna 25 rotatable about the axis A—A of shaft 26 is shown with its beam pattern having a plane of maximum radiation intensity which contains axis A—A. Mounted also on shaft 26 or synchro-coupled thereto is the U-shaped bar 29 which is made of magnetic material and which lies in the first plane defined.

A gyroscope having a rotor 30 is mounted on two supports or gimbals 31 and 32, the outer gimbal 32 being mounted on the deck plane 33 of the ship and being rotatable about an axis A—A which is perpendicular to the deck plane 33. The gyro thus has complete freedom of motion, allowing the rotor axis B—B to be positioned as desired. Rigidly attached to the outer gimbal 32 of the gyro is magnetic coupling bar 34 which is so located that the end of the first coupling bar 29 can sweep closely by and form a closed magnetic loop or circuit without any friction forces being transmitted by the driven bar 29 to upset the gyro alignment. Primary and secondary coils 35 and 36 are wound on coupling bar 29, and it can be seen that with an alternating signal on the primary winding 35, a maximum output signal will appear at the secondary winding 36 when the magnetic bars 29 and 34 are in such rotational alignment that they form a closed magnetic circuit. It is this output signal that is employed to produce the stable azimuth marker on the radar indicator, as will later be discussed.

It should be emphasized that Fig. 3 is a schematic representation of apparatus of this invention. In an actual system, all of the components may not conveniently line up on a single reference axis A—A, but this fact does not cause operation of the actual system to deviate appreciably from that of the simplified one shown in Fig. 3.

Supporting member 37 also does not actually exist, but represents all of the rigid structure on the ship which holds the various components and their associated parts in alignment.

One of the most important features of the system of this invention is that the coincidence between the gyro stable azimuth marker and the target vessel echo on the radar indicator is entirely independent of any roll, pitch or yaw of the attacking vessel. This aspect of the invention can be shown in terms of the structure of the Fig. 3.

The reference axis A—A, which is perpendicular to the deck plane 33, and the gyro axis B—B define a first plane which is perpendicular to the deck plane and which contains the magnetic bar 34. A second plane is defined by the axis A—A and the radar beam central radiation axis C—C. This plane, also perpendicular to the deck plane, contains a plane of maximum radiation intensity of the radar and the magnetic bar 29. By the related action of magnetic bars 34 and 29, an azimuth marker is placed on the radar P.P.I. scope when these two planes coincide.

In operation, the first plane is made to initially contain the target by pointing gyro axis B—B directly at the target. For a collision course, it is necessary that the target remains at the same relative azimuth bearing with respect to the attacking craft as the two vessels close. Thus, if the attacking craft is on collision course, the gyro axis B—B continues to point at the target and the first plane contains the target no matter how much the attacking vessel pitches, rolls, or yaws. Under this circumstance, the second plane passes through the first plane and the target simultaneously and the target radar echo remains centered on the P.P.I. azimuth marker regardless of how much the marker swings on the radar indicator due to the attacking ship's instability. Should the attacking vessel be off its collision course, however, the relative azimuth bearing of the target will shift and the first plane will no longer contain the target. As a result, the second plane will coincide with the first either before or after the second plane passes through the target, and the radar echoes and the azimuth marker will not be coincident on the indicator.

Another way to analyze this stabilization scheme is to consider that the gyro axis B—B and the radar axis C—C are both projected perpendicularly down onto the deck plane. It is these deck projections that are referred to the indicators by the antenna synchro and the magnetic coupling bar. By so referring both the B—B and C—C axes to the same reference plane, motion of this plane does not affect the relation between the two projected axes.

The manner in which the double line, stable azimuth marker is formed by the output signal of the magnetic coupling structure previously described is shown in Figs. 4A, 4B, 4C and 4D. Fig. 4A shows the detected envelope 40 of the alternating signal which is produced on the secondary coupling winding 36 of Fig. 3 as the two magnetic coupling bars 29 and 34 of that figure sweep past and couple with one another. From this envelope, it is desired to produce two pulses, symmetrically related to the peak of the curve, which may be used to intensify the radar indicator beam. On the P.P.I. cathode ray indicator, as illustrated in Fig. 4B, two radial lines 45 and 46 are formed and these are symmetrically disposed about an axis 47 which corresponds to the center line 43 of Fig. 4A.

One of a number of circuits which may be used for producing two intensifier pulses at points 41 and 42 of the curve of Fig. 4A is shown in Fig. 4C. The detected envelope of Fig. 4A is placed on the grid of a first amplifier stage 50 whose plate is D.C. coupled through a resistance voltage divider to the grid of a second amplifier stage 51. A high impedance averaging network comprising resistors 52 and 53 is tied across the plates of stages 50 and 51. Stage 50, which is quiescently biased

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far beyond cut off (biasing means not shown), starts to conduct when its grid voltage rises to the value 54 of Fig. 4A. Stage 51 is quiescently held in saturation by the high plate voltage of stage 50 and continues to remain saturated as the conduction of stage 50 increases. Fig. 4D shows the voltage output wave 54 of the circuit of Fig. 4C, having an initial drop 55 caused by stage 50 starting conduction and stage 51 remaining saturated.

With the input grid voltage still increasing, stage 50 conducts more strongly and stage 51 starts to cut off. As the result of this action, the output voltage has a sharp rise 56.

Stage 51 finally cuts off, with the conduction of stage 50 still increasing, and the output voltage falls (57) to the level 58 where stage 50 is finally saturated. The circuit of Fig. 4C has thus been flipped over, producing a large voltage pulse 59 at the point 41 of Fig. 4A. A similar pulse 60 is produced at the point 42 of Fig. 4A as the input voltage to stage 50 falls to its initial value. After inverting and clipping the wave of Fig. 4D at some level 61, the two resulting pulses are placed directly on the intensifier grid of the radar indicator cathode ray tube (P.P.I.). Any number of other types of circuits may be adapted by those skilled in the art to perform this pulse generating function.

Referring now to Fig. 5, the computer for solving the relation between the azimuth deviation angle $\Delta\alpha$ and the azimuth heading correction angle for collision course $\Delta\beta$ is shown. This apparatus comprises a $\Delta\alpha$ gyro-precess means 74 having an input resistance R_3 and adapted to precess the gyro of the system at a rate proportional to the voltage which said precess means receives, a constant speed, rapid start-stop, reversing motor 79 which directs $\Delta\beta$ information to the turning mechanism of the attacking craft, and a control box 76 having included therein a switch for operating the $\Delta\beta$ motor 79 in either direction and for operating the gyro-precess means 74, and a resistive network for controlling the voltage, and thus the rate of precession, of the $\Delta\alpha$ gyro-precess mechanism 74.

As previously discussed, the equation which relates $\Delta\beta$ and $\Delta\alpha$ is

$$\Delta\beta \cong \frac{R_0}{V_0 \Delta t} \Delta\alpha$$

Since $\Delta\beta$ is introduced by a constant rate device (motor 79) and $\Delta\alpha$ by a variable rate device (gyro-precess means 74), and since the same switch is used for on and off control of both rate devices, the relation between the angle of rotation $\Delta\beta$ and the angle of precess $\Delta\alpha$ can be controlled entirely by adjustment of the variable gyro-precess rate. The latter rate control is simply achieved by the resistive network shown, which determines the voltage that precess means 74 receives.

A 24-volt supply is provided across a resistive network in the control box 76 and either the ground or the 24-volt point of this supply may be tied directly to $\Delta\beta$ motor 79 by the switch 63. In the network itself two equal resistances 64 are placed in series directly across the 24-volt supply and these are changed by conventional transformation to an equivalent resistance 65 having a magnitude

$$\frac{R}{2}$$

led to a fictitious +12 voltage point. As a result, resistors 65, 66 and 67 can be effectively placed across a +12 or -12 volt supply by switch 63.

Computation is done by the hand set taps on resistors 66, 67 and by variable resistor 68, and to correlate adjustment of these with the computation which they perform, it must be noted that increasing the control voltage to the $\Delta\alpha$ gyro-precess means 74, increases the rate of precess thereof and thus decreases the angle $\Delta\beta$ generated by the constant speed motor 79. Thus increasing the

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R_0 tap on resistor 67 decreases gyro-precess rate, while increasing the Δt tap on resistor 66 causes an increase in gyro-precess rate. This is all in keeping with the above equation. Velocity V_0 is introduced to the resistive network by control of the magnitude R_4 of resistance 68. The R_0 and Δt resistance controls are linear, while the introduction of V_0 by resistance R_4 is determined by the equation

$$R_4 = \frac{1}{V_0} - R_3$$

R_3 being the input resistance of the gyro-precess circuit.

The apparatus of the present invention has been described with respect to a projectile laying system whose operation is based on the collision course principle. However, it will be obvious to those skilled in the art that the technique involved might easily be adapted to other types of fire control or navigation and with other than seacraft. Since radar replaces optical systems when darkness, fog, smoke, etc. make the latter inoperative, it will be obvious that an optical tracking means might well be used under circumstances favorable thereto instead of the radar described above. The scope of this invention should further be interpreted to encompass the use of combined optical and radar systems with one serving as a check upon the other. Furthermore the simple technique of fully stabilizing the tracking apparatus of the present invention against ship's pitch, roll, and yaw is adaptable to any number of other types of systems requiring similar stabilization.

The invention described in the foregoing specification need not be limited to the details shown, which are considered to be illustrative of one form the invention may take. What I desire to secure by Letters Patent and claim is:

1. Apparatus for laying a projectile at a moving target from a moving craft, said apparatus comprising a radio echo detection and ranging system including a rotary scanning antenna and a range-azimuth indicator, a gyro, precess means for causing said gyro to precess, means mechanically coupled to said antenna and said gyro for producing a stable azimuth marker on said indicator, a computer, said computer being coupled to said precess means for controlling the rate at which said gyro precesses, and constant speed reversible motor means controlled by said computer for determining an azimuth heading correction angle mathematically related to a gyro precess angle.

2. Apparatus for laying a projectile at a moving target from a moving craft, said apparatus comprising a radio echo detecting and ranging system including a rotary scanning antenna and a range-azimuth indicator, a gyro having precess means associated therewith, a computer coupled to said precess means for controlling the rate at which said gyro is caused to precess, constant-speed reversible motor means controlled by said computer for determining an azimuth heading correction angle mathematically related to a gyro precess angle, and means for producing a stable azimuth marker on said indicator, said marker producing means including magnetic coupling bars mounted on two shafts respectively representing the azimuthal position of the antenna and the rotor of said gyro, said bars being so shaped that they communicate with one another without touching to form an essentially closed magnetic circuit when said antenna and gyro rotor are in a predetermined azimuthal relationship means for inducing a magnetic field in said bars, and a signal coil associated with one of said bars for conveying an output signal to said indicator.

3. In a fire control system of the type wherein an attacking craft maneuvers to close on a moving target along a collision course, the combination of a radio pulse echo detecting and ranging system carried by said attacking craft, said system having as components thereof a rotating directional antenna which periodically radiates

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search pulses and receives echo pulses reflected from remote target and a synchronized plan position indicator for displaying the azimuth and range of targets so detected, means for producing on the face of said plan position indicator a pair of angularly disposed, illuminated radial traces during each cycle of rotation of said directional antenna, said radial traces defining a sector on said plan position indicator which delineates a predetermined search area covered by said system, means for initially locating said sector so that it is centrally disposed about the representation on the plan position indicator of the azimuth bearing of said moving target, means operative a predetermined time later for shifting the location of said sector so that it is again centrally disposed about the representation of the azimuth bearing of said moving target, and means for correcting the steering of said attacking craft in accordance with the amount and direction through which said sector shifts.

4. In a fire control system of the type wherein an attacking craft maneuvers to close on a moving target along a collision course, the combination of a radio pulse echo detecting and ranging system carried by said attacking craft, said system having as components thereof a rotating directional antenna which periodically radiates search pulses and receives echo pulses reflected from remote targets and a synchronized plan position indicator for displaying the azimuth and range of targets so detected, a generator for producing a pair of spaced pulses during each cycle of rotation of said directional antenna, means for supplying said spaced pulses to the intensity control electrode of said plan position indicator whereby a pair of angularly disposed radial traces are produced on the face of said plan position indicator, said radial traces defining a sector on said indicator which corresponds to a predetermined amount of search area, means for initially setting the time of occurrence of said space pulses whereby said sector is symmetrically disposed about a first azimuth bearing on said plan position indicator of said moving target, and means for varying at a given time later the time of occurrence of said pair of pulses so that said sector progressively shifts its location until it reaches a position on said plan position indicator at which it again is symmetrically disposed about a second azimuth bearing of said moving target, the angular distance through which said sector shifts providing a measure of the amount of steering correction that is needed to bring said attacking craft on a collision course to said moving target.

5. In a fire control system of the type wherein an attacking craft maneuvers to close on a moving target along a collision course, the combination of a radio pulse echo detecting and ranging system carried by said attacking craft, said system having as components thereof a ro-

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tating directional antenna which periodically radiates search pulses and receives echo pulses reflected from remote targets and a synchronized plan position indicator for displaying the azimuth and range of targets so detected, means for producing on the face of said plan position indicator a pair of angularly disposed, illuminated radial traces during each cycle of rotation of said directional antenna, said radial traces defining a sector on said plan position indicator which delineates a predetermined search area covered by said system, means for initially adjusting the time of occurrence of said space pulses during each cycle of rotation of said directional antenna so that said sector is symmetrically disposed about the azimuth bearing on said plan position indicator of said moving target, and means for subsequently varying the time of occurrence of said pairs of pulses during successive cycles of rotation of said directional antenna until said sector shifts to a position at which it again is symmetrically disposed about the latest azimuth bearing of said moving target, the angular distance through which said sector shifts identifying the azimuth heading correction angle for the collision course.

6. In a system as defined in claim 5, means for regulating the rate at which said means for changing the time of occurrence of said pairs of pulses functions, whereby the time required to shift the position of said sector is controllable.

7. In a system as defined in claim 5, a constant speed motor for driving the steering mechanism of the attacking craft, and means for energizing said motor for a length of time equal to that required for said selector to shift its position and in a direction corresponding to that in which said sector moves on said plan position indicator.

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