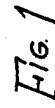


J. A. CRAWFORD ET AL

ALL-WEATHER PROJECTILE FIRE CONTROL SYSTEM - DIRECTOR MODE

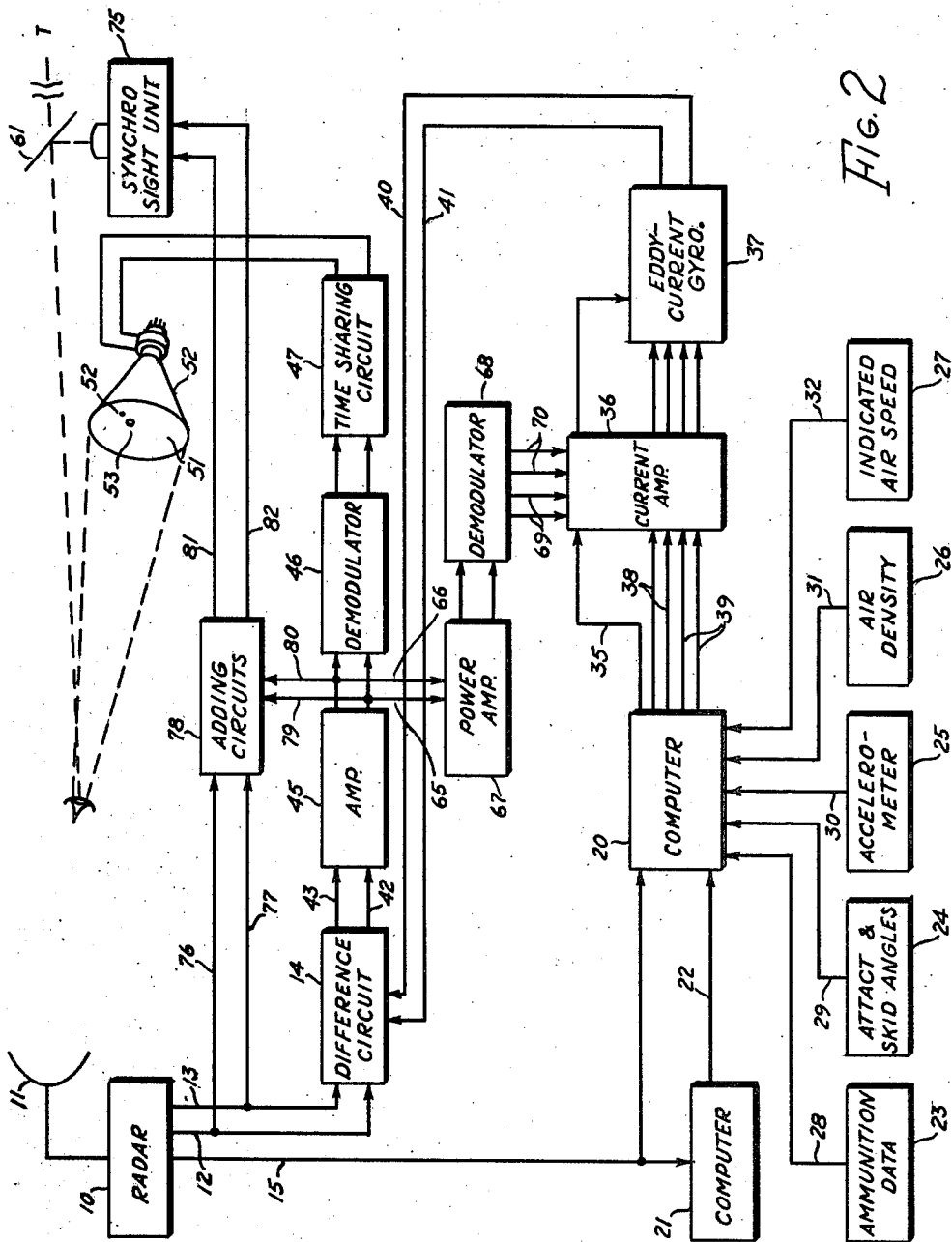
3 Sheets-Sheet 1



INVENTOR.
JACK A. CRAWFORD
JOHN H. GREGORY
BY *Richard H.
H. H. Loeche*
ATTORNEYS

3,181,147

3 Sheets-Sheet 2



INVENTOR.
JACK A. CRAWFORD
JOHN H. GREGORY
BY *J. H. Loecher*
H. H. Loecher
ATTORNEYS

April 27, 1965

J. A. CRAWFORD ETAL

3,181,147

ALL-WEATHER PROJECTILE FIRE CONTROL SYSTEM - DIRECTOR MODE

Filed March 15, 1962

3 Sheets-Sheet 3

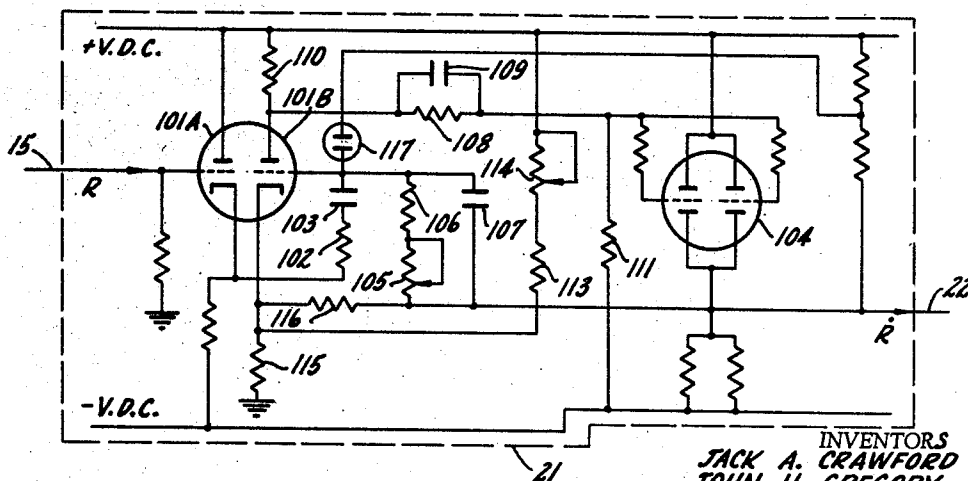
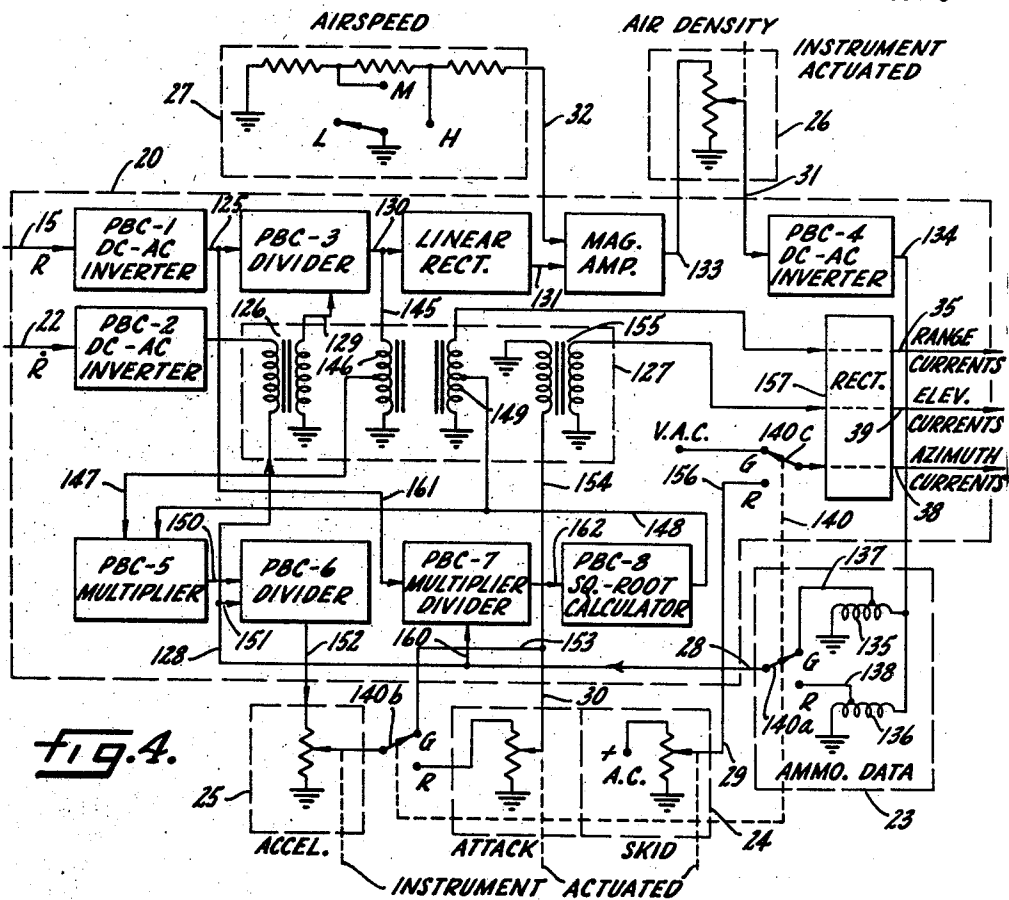


Fig. 3.

INVENTORS
JACK A. CRAWFORD
JOHN H. GREGORY
BY
H. H. Loebe
ATT'YS.

1

3,181,147

ALL-WEATHER PROJECTILE FIRE CONTROL SYSTEM—DIRECTOR MODE

Jack A. Crawford and John H. Gregory, China Lake, Calif., assignors to the United States of America as represented by the Secretary of the Navy

Filed Mar. 15, 1962, Ser. No. 181,229

9 Claims. (Cl. 343-7)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This is a continuation-in-part of our patent application Serial Number 673,748, filed July 23, 1957, for All-Weather Projectile Fire Control System—Director Mode, now abandoned.

This invention relates to an all-weather projectile fire control system for vehicles, as aircraft or the like, for computing projectile fire control problems and for displaying resulting projectile firing lead angles on a cathode ray tube and on a sight unit to enable firing personnel to effect projectile and target collision although either the vehicle, or the target, or both, are moving. More particularly, the invention relates to a circuit in the all-weather projectile fire control system for feeding back signal information between predetermined points of the computing circuits to decrease or speed up the response time of computation of the resulting lead angles thereby giving instantaneous and continuous displays of the lead angles for projectile and target collision to eliminate over-correction of the lead angle by operating personnel.

In the projectile fire control problem, computations are necessary for effective projectile fire on moving targets, and particularly where both the target and the fire control system are moving as, for example, in the situation of pursuit and target aircrafts. The fire control problem may be compared with that of a hunter wherein the hunter must attempt to mentally compute a lead angle for his gun to hit a flying bird. The hunter must compensate for gravity effect, bird direction and speed, wind direction, range, bullet speed, etc., in order to ensure a hit. The hunter cannot expect to hit a flying bird by aiming directly at it. The hunter must learn to "lead" or aim ahead of the bird so that the bird and shot will collide with each other. The greater distances between pursuit aircraft and target aircraft in combat require solution by scientific means since man is incapable of solving these problems while under stress of self preservation and in the short space of time often times demanded in combat. The problem is further complicated by the condition that the pursuit aircraft is also moving which necessitates the solution to find the "kinematic lead" angle or the angle of offset necessary because of the relative motion of the pursuit and target aircrafts. This invention is therefore directed to the improvement of solving the "lead angles" for fire control problems in a substantially instantaneous and continuous manner.

The present invention is a modification of the all-weather gun fire control system shown and described in the patent application of E. Frank Echolds, Serial Number 848,873, filed October 26, 1959, which is a continuation-in-part application of Serial Number 585,589, filed May 17, 1956, for an Airborne Fire Control System, both applications now abandoned. The combination of the all-weather gun fire control system of the above-mentioned application is the basic combination of the present invention. The eddy-current gyroscope shown and described as a component in the present disclosure is fully shown and described in the patent of E. Frank

2

Echolds and Paul L. Brink, bearing the Patent Number 2,900,825 which issued August 25, 1959, for an Eddy-Current Force System for Constrained Gyroscopes.

In the application of E. Frank Echolds, Serial Number 848,873, a radar device is used to seek out targets and, when one is found, the device will develop azimuth and elevation information signals which are transmitted by self-synchronous transmitters to circuits for use. The radar device also develops range information signals that are passed through computing means to provide range rate signal information which range and range rate signal information, together with signal information of factors pertinent to the solution of a gun fire or rocket control problem, are computed into range currents and deflection currents for a lead computing or eddy-current constrained gyroscope. The range and deflection currents actuate the eddy-current gyroscope to a precessed equilibrium position which position is sensed by a self-synchronous transmitter for each gyroscope gimbal axis. These self-synchronous transmitter signals, representative of lead angles in azimuth and elevation computed to cause projectile-target collision, are mixed in a difference circuit to which the azimuth and elevation information signals of the radar are applied to provide resulting error information signals. These error information signals are demodulated and applied to a cathode ray tube for display of the error of projectile-target collision. The use of the term "projectile" herein refers to gun missiles, rockets, or other types of projectiles that may be fired. By proper maneuvering of the vehicle the error can be reduced to zero at which time the guns or rockets may be fired and projectile-target collision assured. Some time must be allowed, however, after maneuvering the vehicle, to allow for computations to be made and a corrected error signal displayed. This system also anticipates the inclusion in the combination of a sight unit which is coupled to the computing circuitry to display fixed and movable reticles showing the gun reference line and the lead angle, respectively. The sight unit may be used when the target is visible to vehicle personnel.

In the present invention a circuit modification or addition is made to the all-weather gun fire control system which produces a rapid response of the computing circuitry so that gunnery personnel can maneuver the gun reference line rapidly to the zero error position by actual observance of the display on the scope or sight unit; that is, instead of mentally estimating the maneuvering necessary to correct the error in lead angle and awaiting confirmation by the computing circuits, the vehicle personnel can maneuver the vehicle to constantly reduce the error signal to zero by observance of the display on the cathode ray tube or the sight unit. The instantaneous visual display is accomplished by feeding back the output of the difference circuit to the eddy-current gyroscope to produce gyroscope output signal information to the difference circuit approaching the actual lead angle determined by the radar. This instantaneous visual display, by which operating personnel can maneuver the vehicle to reduce the error of the lead angle to zero for proper projectile-target collision, is considered herein as the director mode of operating the all-weather projectile fire control system. The sight unit may be operated as before or it may be coupled in the modified circuit to provide instantaneous movable reticle positions in the same manner as on the cathode ray tube screen. The present invention enables operating personnel to watch the results of their maneuvering of the vehicle into position for effecting projectile-target collision without hesitation. It is therefore an object of this invention to provide an all-weather projectile fire control system for a vehicle which produces instantaneous and continuous visual indications

of the error of lead angle on a target to enable operating personnel to rapidly maneuver the vehicle for projectile collision with the target whether the target is visible or invisible.

These and other objects, advantages, features and uses will become more apparent as the description proceeds when considered along with the drawing, in which:

FIGURE 1 illustrates in block diagram the flow of signal information for the all-weather gun fire control system, director mode;

FIGURE 2 illustrates a modification of this gun fire control system, director mode;

FIGURE 3 illustrates a schematic wiring diagram of computer 21 of FIGURES 1 and 2; and

FIGURE 4 illustrates a schematic wiring diagram of computer 20 of FIGURES 1 and 2.

Referring more particularly to FIGURE 1, there is shown a projectile fire control system which may be carried by a vehicle such as an aircraft, ship, or the like. For the purpose of illustration and explanation of the invention, let it be assumed that the fire control system is being carried by a fighter aircraft having fixed guns oriented with the gun lines parallel in alignment with the longitudinal center line of the aircraft and rocket launchers preset for proper angle of attack in the airstream from the aircraft. The fire control system includes a radar device 10 having a rotatable antenna 11 for seeking out targets. The radar 10 may be of any well known automatic tracking type which produces signal information outputs of azimuth and elevation of any target detected. The azimuth and elevation signal information is transmitted over the functional leads 12 and 13 to a difference circuit 14. The circuit 14 may be any difference circuit for producing the difference in alternating current (A.C.) signals, although a specifically designed difference circuit as disclosed in the application, Serial Number 848,873, may be used. The azimuth and elevation signal information is developed by resolvers within the radar device to produce alternating current voltage signals by way of self-synchronous transmitter means to produce specific fields representative of the azimuth and elevation of the target. The radar device 10 is also capable, as is well known, to produce a variable direct current voltage signal by way of the functional lead 15 representative of the target range. As is understood in the art, a predetermined number of yards may be represented as one volt in the range intelligence signal whereby the exact range from a known range voltage may be determined. The radar device 10 is preferably of the type to set the antenna in a rotating search mode and to automatically switch to a tracking mode when a target appears whereby the antenna follows the target, as is well understood in the art of radar detection systems.

In addition to the radar detection system, the all-weather fire control system includes circuitry which utilizes the information derived from the radar to compute proper lead angles so that the guns or rockets of the aircraft, or the like, may be fired to cause projectile and target collision. In this all-weather fire control system the range voltages conducted by the functional lead 15 are applied in parallel to a computer circuit 20 and to a computer circuit 21. The computers 20 and 21 will be described in detail in the description of FIGURES 3 and 4. The computer circuit 21 computes each range voltage into range rate or the rate at which the target and the vehicle are closing. This range rate voltage is also applied by the functional conductor 22 to the computer circuit 20. Several factors, which are necessary in making the computations of a fire control problem, are also applied to the computer circuit 20 and are shown in block diagram in FIGURES 1 and 2. The factors to be considered are the ammunition data represented by the block 23, the attack and skid angles represented by the block 24, the accelerometer measurements represented by the block 25, the air density represented by the block 26,

and the indicated air speed represented by the block 27. The ammunition data and the attack and skid angles may have voltage signals applied by way of the functional conductors 28 and 29 which voltages are developed and manually adjustable as will be described more fully in the description of FIGURES 3 and 4. The settings of these two informational devices are different for bullets and rockets and it will be necessary for operating personnel to make the proper settings for the type of projectile used. The accelerometer, air density, and indicated air speed voltage signals are usually developed from instrumentation in the aircraft and these voltage signals are automatically transmitted by way of functional conductors 30, 31, and 32, to the computer circuit 20. The computer circuit 20 accepts and utilizes the voltage signals of range, range rate, and the other abovementioned voltage information of factors necessary to solve the projectile firing problem to produce signal information in currents representative of range, azimuth, and elevation.

The output current signal information of range is transmitted by the functional conductor 35 through a current amplifier 36 to the range coils of an eddy-current gyroscope 37. The deflection or offset currents representative of azimuth and elevation are transmitted by way of the functional leads 38 and 39 through the current amplifier 36 to the offset or deflection coils of the eddy-current gyroscope 37. The eddy-current gyroscope with specific description of the range and offset coils is specifically shown and described in the aforementioned Patent Number 2,900,825, of E. Frank Echolds and Paul L. Brink, and will not be further described herein. The range signal currents transmitted by way of the functional lead 35 are obtained in the computer circuit 20 by computation using primarily the range, range rate, indicated air speed, air density, and ammunition data voltage signals. The elevational currents transmitted by way of the functional conductors 39 are derived primarily from voltage information of the accelerometer and the attack and skid angle devices, and from the range currents computed above. The deflection of offset currents for azimuth transmitted by way of the functional conductors 38 are derived in the computer circuit 20 primarily from the range voltage applied over the functional lead 15 and the attack and skid angle voltage applied over the functional lead 29 from the component 24. The range currents will produce a magnetic field in the eddy-current gyroscope range coils to cause a precessing force which allows a finite lead angle to be produced by the aircraft, or the like, whenever a turning rate is generated by maneuvering into a position of gun or rocket firing. The offset currents of azimuth and elevation presented by the conductors 38 and 39, respectively, deflect the gyroscope in the manner computed, together with the range current information, to effect a lead angle necessary for gun or rocket firing in accordance with the information submitted to the computer circuit 20 by the functional leads 15 and 22 and the data devices 23 to 27, inclusive.

The deflection intelligence of the eddy-current gyroscope is provided by alternating current voltage signals transmitted by a self-synchronous transmitter on each of the gimbaled axes of the eddy-current gyroscope as is more fully shown and described in the aforementioned Patent Number 2,900,825. These informational signals are transmitted by way of the conductors 40 and 41 to the difference circuit 14. The information signals coming by way of the functional leads 40 and 41 are representative of the computed lead angle to fire on a specific target while the information signals coming by way of the functional leads 12 and 13 from the radar are representative of the actual lead angle or angle of deviation of the target from the gun lines of the aircraft. The difference of these two informational signals, that is of the azimuth and of the elevation, produces co-ordinate voltage signals on the functional output leads 42 and 43 which represent the error lead angle or the angle of error both in azimuth and

elevation which the aircraft should fly, when corrected, to bring the gun lines into position to effectively cause projectile and target collision. These error voltage signals are amplified in amplifier 45 and demodulated in the demodulator 46 which may be of a phase sensitive rectifier type to produce error voltage signals in azimuth and elevation suitable for application to the deflection circuits of a cathode ray tube 50. For a desirable presentation, a time-sharing circuit may be used in the circuit between the demodulator 46 and the cathode ray tube 50 to present a plurality of informative signals on the screen 51 of the cathode ray tube. The time-sharing circuit 47 may be used to cause two simultaneous displays on the screen 51 of the cathode ray tube 50 to aid operating personnel in effectively firing on the target. The error signals coming from the difference circuit 14 will cause a fluorescent pip to be produced as a steering dot 52, and a second representation shown by a donut-shaped steering circle 53, which is usually approximately one-fifth of the distance from the steering dot 52 to the center of the cathode ray tube screen 51, may be created from the error signals at reduced amplitude. The screen 51 of the cathode ray tube 50 may be divided into quadrants by lines or by other grid means, as desirable. The steering circle 53 is produced in any well-known manner in the cathode ray tube electronics by applying two sine wave voltages in out-of-phase relation to the deflection circuits to produce this circular pattern commonly known as one of "Lissajous" figures. As described more fully in the above-mentioned patent application of the all-weather fire control system, the pilot or operating personnel need only to maneuver the aircraft to reduce the lead error angle to zero at which time the steering dot 52 is within the steering circle 53 and both are lying on the center of the cathode ray tube screen 51, this center representing the gun line or longitudinal reference line of the aircraft.

As also more fully described in the aforementioned patent application Serial Number 848,873 of the all-weather gun fire control system, information signals from the computer circuit 29 may likewise be applied to a gyroscope sight unit 60 which includes range coils and deflection or offset coils in a constructional manner similar to that of the constrained eddy-current gyroscope 37. The range current information will be supplied by the functional lead 35' and the azimuth and elevational signal information will be supplied by the functional leads 33' and 39'. While the deflection or offset current signals are coupled to leads 38 and 39, respectively, prior to current amplifier 36, it may be understood that the current signals 38' and 39' may be taken subsequent to current amplification, where desirable. The sight unit produces a fixed reticle and a movable reticle on a transparent plate 61 of the sight unit or the windshield of the aircraft as may be desired. As is well understood of the sight unit, the fixed reticle represents the gun line or longitudinal reference line of the aircraft whereas the movable reticle illustrates the lead angle for proper gun firing to cause projectile-target collision. As more clearly described in the prior-mentioned application Serial Number 848,873, of the all-weather gun fire control system, operating personnel may actually view the target and get proper bearing by bringing the target to the center of the movable reticle. At the time the target is at the center of the movable reticle on the sight unit glass plate 61, the steering dot and steering circle should be concentric over the center of cathode ray tube screen 51.

The above description sets out briefly the combination and advantages of the all-weather gun fire control system fully shown and described in the prior-mentioned patent application Serial Number 848,873, for that system. The description is repeated here to more fully provide a basis for the circuit modification to make the all-weather gun fire control system operate in the director mode which

is the subject matter specifically of the present invention. The present invention contemplates feeding back the error azimuth and elevation signals transmitted by way of the functional conductors 42 and 43 on functional conductors 65 and 66 through a power amplifier 67 and a demodulator 68 to impress this azimuthal and elevational error voltage signal information on the deflection or offset currents applied to the azimuthal and elevational offset coils of the eddy-current gyroscope 37. The azimuth signal coming by way of the functional conductors 12, 42, and 65, is applied by the functional conductors 69 to the deflection or offset azimuth currents in the conductors 38. Likewise, the elevation signal information coming by way of the functional leads 13, 43, and 66, is applied by the functional leads 70 to the elevational deflection or offset currents in the functional leads 39. While it is shown and described that the azimuthal and elevational feedback voltages applied by way of 69 and 70, respectively, are coupled to the functional conductors 38 and 39 in the current amplifier 36, it is to be understood that this coupling may be made before or after the current amplifier with suitable results, it only being necessary to apply these error signals through isolating means as is well understood in the art. Four leads, that is, two leads 38, two leads 39, two leads 69, and two leads 70, are shown since the application of the currents to the deflection or offset coils of the gyroscope 37 is arranged to be additive in one offset coil and subtractive in the companion offset coil for each azimuthal or elevational plane, as better understood from the description in the prior-mentioned Patent Number 2,900,825 and application Serial Number 848,873 of the all-weather fire control system. Since the application of the azimuthal and elevational voltages in 69 and 70 is applied to substantially zero impedance circuits, the addition or subtraction of the feedback is equivalent to current feedback which decreases the offset of the eddy-current gyroscope to produce output information signals on the informational conductors 40 and 41 to more nearly correspond to the actual information signals coming from the radar by way of the functional conductors 12 and 13. This, in effect, produces a much more rapid response of computation which will be displayed upon the cathode ray tube screen 51 so that operating personnel can actually watch the maneuvering of their aircraft by the instantaneous and continuous response of the error lead angles represented by the steering dot 52 and steering circle 53. Without the benefit of the feedback circuit of this invention, operating personnel could only maneuver the aircraft to a position of orientation as a result of guessing the correction needed from the display shown and then wait to see if their new orientation was correct by watching the results of computations by the positioning of the steering dot and steering circle. By use of this invention, including the feedback circuit, the steering dot and steering circle would immediately respond to display the moving of the aircraft whereby aircraft personnel could readily and instantaneously determine when the error lead angle became zero at which time the aircraft would be in position to effect projectile-target collision. It may be noted that in this illustrated combination the feedback circuit would not disturb the results produced by the sight unit 60 but only decrease the response time for the display on the cathode ray tube which cathode ray tube display is used by operating personnel for unseen targets as when the target is concealed by inclement weather, darkness, smokescreen, or the like.

Referring more particularly to FIGURE 2, the same basic all-weather fire control system combination of components is used as shown and described for FIGURE 1 and these components bear like reference characters with those of the corresponding components of FIGURE 1. In this modification a sight unit 75 is used which is controlled by a self-synchronous or synchro motive means to position the movable reticle for azimuth and elevation.

7

The sight unit 75 casts fixed and movable reticles on the transparent plate 61 or windshield of the aircraft in the same manner as described for the sight unit 60 of FIGURE 1. The self-synchronous receivers of the sight unit 75 receive signal information from the radar 10, taking the information from the functional conductors 12 and 13 for the azimuthal and elevational information signals, respectively, over the functional conductors 76 and 77 to an adding circuit 78. A feedback from the difference circuit 14 by way of the functional leads 42 and 43 is also applied to the adding circuit 78 by way of the functional leads 79 and 80. The difference of the actual azimuth and elevation is added to or subtracted from the error signals coming by way of the feedback to produce resulting self-synchronous or synchro signals over the functional conductors 81 and 82 to the sight unit 75. By this construction it may be readily realized that the sight unit 75 will operate in the director mode the same as the director mode operation for the cathode ray tube 50. In this manner the operating personnel will redirect the aircraft to bring the steering dot 52 on the cathode ray tube 51 within the steering circle 53 overlaying the axis of the cathode ray tube 50 which, at the same time, will bring the movable reticle on the glass plate 61 to be superimposed over the target with equal rapidity. In the prior case where operating personnel redirect the aircraft for fire control on an unseen target the cathode ray tube 50 is used, but in the latter instance the sight unit is used for visible targets. The construction of FIGURE 2 has an advantage for operating personnel in that the displays on the cathode ray tube screen and on the sight unit glass plate are of equal speed in showing the correction caused by maneuvering.

While the computers 20 and 21 may be of any type to produce the output currents in range, azimuth, and elevation for the eddy-current gyroscope 37, the computers used in the basic all-weather fire control system of the above-mentioned patent application, Serial Number 848,873, will be shown and described herein for convenience in understanding the invention. Referring more particularly to FIGURE 3, where computer 21 is illustrated in broken lines, the radar range input signal coming by way of conductor 15 is applied to the grid of the vacuum tube section 101A. This is a cathode follower circuit and its purpose is to reproduce the input signal with negligible loading on the input circuit. The output of the cathode follower circuit is connected through a resistor 102 and a differentiating capacitor 103 to the grid of the amplifier tube section 101B. Negative feedback from the cathode of an output tube 104 through resistors 105 and 106 is also applied to the grid of tube section 101B, the resistor 105 being adjustable. Capacitor 107 with resistor 102 forms a filter circuit which tends to attenuate any extraneous high frequency inputs arising from noise pickup, hum, power supply ripple, et cetera, which may be present in the radar input signal.

The output of the amplifier 101B is connected through the circuit consisting of resistor 108 and capacitor 109 to the grids of the output tube 104. Capacitor 109 allows high frequencies, which are not stopped by resistance 102 and capacitor 107, to pass. Tube 104 is a cathode follower which reproduces its input signal.

Resistors 110, 111, and 108, form a voltage divider which establishes the anode voltage for tube section 101B and the grid voltage for tube 104. Resistors 113, 114, and 115, form a biasing circuit for the cathode of tube section 101B. The resistor 114 is variable and is used to be adjusted so that with zero input to the grid of tube section 101B there will be a zero potential at the cathode of tube 104. The presence of the resistance 115 causes a degenerative process which reduces the effective gain of the amplifier. This effect is eliminated by connecting the resistance 116 from the cathode of the output tube 104 to the cathode of the amplifier tube section 101B. This produces a regenerative effect and the value of resistance

8

116 is chosen to overcompensate, thus producing a net increase in gain.

The output slope factor is determined primarily by the value of the differentiating capacitor 103 and the resistors 105 and 106 since for any given range-rate the charging current depends on the value of this resistance. The accuracy and stability of the unit depends to a great extent on these components. The differentiating capacitor 103 must have negligible leakage over the entire range of operating temperatures. Accurate adjustment of the slope factor is made by adjusting the variable resistance 105.

Neon tube 117 permits quick recovery from overloading. Since all changes in range-volts input appear on the grid of tube section 101B, the circuit may overload since only a limited charging current is available through the resistance 106. A very rapid decrease in range could result in large negative voltages at the grid of tube section 101B and the computer might become inoperative for several seconds except for the presence of the neon tube 117 which breaks down during a negative overload and provides a low impedance path enabling the capacitor 103 to charge quickly to the required voltage. Other resistances in the circuit not particularly identified by reference character establish biasing voltages for the amplifier and output tubes in a manner well understood in the art and will not therefore be specifically described.

With the operating voltages placed on the circuitry, as illustrated in FIGURE 3, let it be assumed that a constant range-volts input signal exists on input 15. The grid of the amplifier 101B and the cathode of the output tube 104 will then be at zero potential. Now assume that the range voltage decreases (range voltage is always positive). The cathode of tube section 101A becomes negative and the differentiating capacitor 103 discharges through resistances 105 and 106. The rate at which this capacitor discharges is proportional to the rate of change of the applied voltage or, mathematically speaking, it is proportional to the derivative of the applied voltage. Thus a negative voltage proportional to the rate of change of the input signal is applied to the grid of the amplifier tube section 101B. Current flow through tube section 101B decreases, causing the anode of tube section 101B and the grids of tube 104 to become more positive. This causes the current flow through tube 104 to increase and the cathode of this tube to become positive. The potential at the cathode of tube 104 is the range-rate signal conducted to the output thereof over a conductor 22. It is also fed back to the grid of the amplifier, thus decreasing the initial effect of the positive voltage. The range-rate out signal is positive for decreasing range signals on the input 15 and negative for increasing range signals on the input 15, and proportional to the rate at which range is changing.

Referring to FIGURE 4, the computer shown in block by the reference character 20 in FIGURES 1 and 2 is included within the block enclosed by broken lines in this figure. The inputs 23 to 27, inclusive, are shown within dotted lines outside the main block 20 with the circuitry within these small blocked areas representative of the general circuit means for developing the respective input signals to the computer 20. The computer 20 is shown partly in block diagram and partly in circuit diagram with functional leads having arrows thereon representative of the direction that information is traveling through the computer to provide the three-output informational intelligence of elevational currents, range currents, and azimuthal currents for the lead computing gyroscope 37. The computer utilizes a number of phase-balance computers, which are referred to herein as PBC-1, PBC-2, et cetera, by legends thereon in preference to reference characters since it is believed such identification will make the diagram of this computer more readily understandable. As is well understood in the art, phase-balance computers have magnetic amplifiers therein which make them readily adaptable for use as multipliers, in-

verters, dividers, summing circuits, or square root calculators, depending on the manner in which they are connected. The phase-balance computers used herein are of the type shown and described in United States Patent Number 2,733,004, of John E. Richardson, entitled "Electrical Computers," and in the United States Patent Number 2,870,960, of John E. Richardson, entitled "System for Analog Computing Utilizing Detectors and Modulators."

The range signal coming by way of the functional lead 15 is applied to the phase-balance computer, PBC-1, and the range rate signal coming by way of the functional lead 22 from the computer 21 is applied to PBC-2. PBC-1 and PBC-2 are coupled and operated as direct-current to alternating-current (D.C. to A.C.) inverters. The output of PBC-1 is applied through the functional lead 125 to the PBC-3 which is circulated to operate as a divider circuit. The output of PBC-2 is coupled to a transformer 126 in a transformer unit 127 through a primary winding, which primary winding is also coupled by functional lead 128 coming from the ammunition data input 23. The information coming from the ammunition data means 23 is the average velocity of the projectile used, as will be more fully described later, which average velocity represented by an A.C. voltage signal is summed with the A.C. voltage signal, or range rate signal, from PBC-2. The summed average velocity and range rate A.C. voltage signals are applied from the secondary of transformer 126 through the functional lead 129 to PBC-3 where division of the range by the sum of average velocity and range rate is accomplished to produce a time of flight A.C. voltage signal on the output conductor means 130. The time of flight signal is rectified in the linear rectifier and applied to a magnetic amplifier over functional lead 131 as a D.C. voltage signal where it is summed with the D.C. signal applied over conductor means 32 from the air speed input 27. While the air speed signal is developed from one of three D.C. signals representative of the aircraft speed, either as low, medium, or high speeds, shown herein by the taps designated as L, M, and H, it is to be understood that this air speed signal may be developed by potentiometer or other means which is instrument actuated. The summed D.C. components are multiplied by the air density factor coming from the air density block 26. This is represented as having the output of the magnetic amplifier on the functional lead 133 as passing through a potentiometer to PBC-4, the latter of which is a D.C. to A.C. inverter. The potentiometer of the air density block 26 is illustrated as being instrument actuated to clarify the manner in which this multiplication factor, or proportional factor, is provided. The output of PBC-4 is applied by way of functional lead 134 to two coils 135 and 136 in the ammunition data device 23. Each coil is tapped at a point providing an A.C. output representative of the average muzzle velocity factor for guns or the burnt-velocity factor for rockets which result in an output of the average velocity. For the purpose of illustration, the coil 135 is tapped by a functional lead 137 to a switch contact identified by the letter G which is representative of the ammunition data for guns. The coil 136 is tapped at a point representative in A.C. voltage signal of the burnt-velocity factor for rockets which is conducted by the functional lead 138 to the switch contact, herein designated by the letter R. The switch gang 140a of a composite switch is shown in position on the gun tap G to provide the average velocity for gun projectiles over the conductor means 128 which, as hereinbefore stated, is applied to one end of the transformer primary 126.

PBC-5 is arranged to produce multiplication. To PBC-5 is applied the A.C. time of flight voltage signal coming from the output 130 of PBC-3 through the functional lead 145 and a portion of a transformer winding 146 which is tapped by the functional lead 147 to PBC-5. The tap on the winding 146 is at a point representing a constant, equivalent to $\frac{1}{2}$ times gravity, whereby the

multiplication takes place in this winding 146, applying the product over the functional lead 147 to PBC-5. The other multiplication factor is an A.C. current representative of the range current produced as an output of PBC-3, hereinafter more fully described, over the functional lead 148 to PBC-5. This range current from functional lead 148 is also applied to a transformer winding 149 by a tap thereon, the winding of which has an output 35 being the range current applied to the range coils of the lead computing gyroscope 37. The output of PBC-5 is applied by the functional lead 150 to PBC-6, which is connected as a divider. The output of PBC-5 is an A.C. voltage signal representative of the product of $\frac{1}{2}$ gravity times the time of flight which is equivalent to the product of the average velocity times the gravity drop angle. This product coming by way of functional lead 150 is divided by the average velocity A.C. voltage signal coming by way of functional lead 128 which is applied by the functional lead 151 to PBC-6 producing on the output functional lead 152 the product of range current and the gravity drop angle. This output is multiplied by the voltage signal of the accelerometer 25, illustrated herein as an instrument actuated potentiometer. The output of the accelerometer is coupled to the switch blade of the switch gang 140b and is shown herein as being connected to the gun tap G which applies this voltage signal through the functional leads 153 and 154 to the primary winding of a transformer 155. The secondary of transformer 155 transmits this voltage signal by way of the functional lead 39 to the elevational control coils in the lead computing gyroscope 37. In order to produce the range current on the output 148 of PBC-8, the average velocity coming by way of the functional lead 128 from the ammunition data means 23 is applied by the functional lead 160 to PBC-7, which average velocity is divided by the range signal coming by way of functional lead 161 which is tapped on the output functional lead 125 of PBC-1. PBC-7 produces a time factor signal on the output 162 applied to PBC-8 where the square root of this time factor signal is taken to produce the range current.

The azimuthal currents for rockets applied on the output functional lead 38 come by way of the switch gang 140c and the functional lead 156 from the skid angle instrument represented by 24 in FIGURES 1 and 2. The generation of an A.C. signal is illustrated herein merely as an instrument actuated potentiometer to which is applied a predetermined A.C. voltage. Since all of the outputs of the computer 20 are A.C. signals, these signals are rectified to D.C. currents by the rectifier means 157 which, for the purpose of simplicity, is shown as being within the computer 20 herein.

In the case of rocket firing, the angle of attack of the aircraft carrying the subject matter of the invention must be added to the output signal of the accelerometer 25, which summed A.C. signal is applied by way of functional lead 154 to the primary of the transformer 155 to produce the proper elevational currents for such rocket firing. Also for rocket firing the skid angle signal is used and is therefore switched in by the switch gang 140c to skid angle element 24, thereby providing the proper azimuthal currents for rocket firing. For gun firing, switch gang 140c rests on G, which G contact is coupled to an A.C. voltage source of predetermined amplitude. The composite switch gangs 140a, 140b, and 140c have the two positions for gun and rocket firing, these positions being represented on the switch contacts as G and R, respectively. The switch gang 140a switches in the proper winding 135 or 136 to introduce the proper muzzle velocity factor or burnt-velocity factor for average velocity; the switch gang 140b switches in the attack angle signal for rockets and bypasses the attack angle signal for guns; and the switch gang 140c switches the skid angle signal out for guns and in for rockets.

The computer 20 therefore receives the range signals from the automatic tracking radar 10 over functional lead

15 and the range rate signals from the computer 21 over the functional lead 22 together with the input signals coming from the elements 23 to 27, inclusive, to compute all of these input signals into the range currents, elevational currents, and azimuthal currents, produced on the outputs 35, 39, and 38, respectively, for the lead computing gyroscope 37.

The operation of the computers 20 and 21 is believed to be clear and apparent from the description of FIGURES 3 and 4 together with their operative relation in the all-weather fire control system. Operating procedures heretofore included to describe the all-weather fire control system, director mode, are believed to be clear but a brief description of operation will be given for the purpose of clarity. The radar 10 being of the automatic tracking type will become fixed on a target thereby to produce range, azimuth, and elevation signals as hereinbefore disclosed. If the target is invisible to the operating personnel for the reason of cloud formation, darkness, or otherwise, the operating personnel will watch the display on the cathode ray tube screen 51 in either embodiment of FIGURE 1 or FIGURE 2. The steering dot and steering circle will display the relative position of the target and the reference line of the aircraft embodying this fire control system and operating personnel will redirect the aircraft to reduce the error signal for fire control to zero. That is, by redirecting the aircraft to cause the steering dot and steering circle to approach and ultimately be superimposed over the axis of the cathode ray tube screen, the error for projectile and target collision is reduced to zero. The steering circle 53 gives a coarse indication of target position while the steering dot 52 is a vernier indication of error of target position. In the director mode of this fire control system, operating personnel can view instantaneously the results of their aircraft redirection by the display on the screen 51 thus avoiding overshooting or overcorrection. When the error signal is reduced to zero, the gun projectile or rocket may be fired with the assurance of projectile-target collision since all computations of the fire control problem have been computed as hereinabove shown and described and these computed results are accounted for on the screen 51 presentation unless errors have been introduced by manual adjustment of the ammunition data device 23 or attack and skid angle device 24 or by some error of the elements 25, 26, or 27, which caused the computer 20 to produce erroneous range, azimuth, or elevation current signals to be applied to the eddy-current gyroscope 37. It is a natural thing for operating personnel, as the pilot or gunners, to direct the guns or rockets toward visual targets utilizing equipment necessary to solve the lead angle for projectile-target collision. Where the target is visible, operating personnel will, in all probability, utilize the sight unit 60 or 73 to effect this projectile-target collision. In the operation of the sight unit of FIGURE 1, operating personnel will redirect the aircraft to superimpose the movable reticle over the visible target before firing. Since the sight unit 60 is not operating under the director-mode, some delay may be experienced in awaiting changes of the movable reticle on the sight unit. Where time is of the essence, operating personnel may refer to the cathode ray tube screen occasionally to see that they do not overshoot or overcorrect the redirection of the aircraft for proper projectile-target collision. The sight unit in FIGURE 2 is operating under the director mode and where the target is visible there is no necessity for the operating personnel to view both the glass plate 61 and screen 51 since there should be no overshooting or overcorrection by following the movable reticle and superimposing it over the target. The movable reticle will give instantaneous and continuous indications of lead angle for projectile-target collision, the same as the indications on the screen 51. This enables the operating personnel to get a "fix" on a target and to fire the projectile for target destruction in the minimum of time without fear of over-

shooting or overcorrection of the lead angle. Where the target may be visible part of the time and invisible part of the time, as by the target passing through cloud formations or smokescreens, operating personnel may watch both displays of the cathode ray tube and the sight unit to effect projectile-target collision. The location of the cathode ray tube and the sight unit should be such that operating personnel should not have to make any substantial head or eye movement in viewing these two visible displays.

While many modifications and changes may be made in the constructional details and the operation of the system, it is to be understood that the two embodiments herein are illustrative of the preferred forms of the invention and are not intended to limit the invention except that it be limited only by the appended claims.

We claim:

1. In an all-weather projectile fire control system having a radar target detection means providing actual azimuth, elevation, and range signal information with respect to a reference line, the actual azimuth and elevation signal information being conducted through one circuit to the deflection circuits of a cathode ray tube to provide actual azimuth and elevation signal information for the cathode ray tube co-ordinate display, and the range signal information together with signal information representing factors affecting projectile trajectory being conducted to computing circuits for computing said range and factor information into computed range, azimuth, and elevation signal information with respect to said reference line, said computed range, azimuth, and elevation signal information being applied to an eddy-current constrained gyroscope to produce lead angle azimuth and elevation information signals, said lead angle azimuth and elevational signal information being applied to said one circuit to modify said actual azimuth and elevational signal information to error lead angle azimuth and elevation information signals for co-ordinate display on the cathode ray tube to show the lead angle error between said reference line and the target, the invention which comprises:

a feedback circuit coupling each error lead angle azimuth and elevation information signal from points in said one circuit between said application of said lead angle azimuth and elevation information signals and said cathode ray tube to points in said coupling between said computer and said eddy-current gyroscope to apply same to the respective computed azimuth and elevation information signals thereby adjusting said error lead angle azimuth and elevation information signals to provide instantaneous display on said cathode ray tube all relative movements of the target and the fire control system.

2. In an all-weather projectile fire control system having a radar target detection means providing actual azimuth, elevation, and range signal information with respect to a reference line, the actual azimuth and elevation signal information being applied to a difference circuit the output of which is through a demodulator providing actual azimuth and elevation signal information applied to the deflection circuits of a cathode ray tube, the range signal information, together with signal information representing factors to effect projectile and target collision, being conducted to computing means for producing computed azimuth and elevation signal information on the output thereof with respect to said reference line calculated to effect projectile target collision, this computed azimuth and elevation information output being applied to an eddy-current constrained gyroscope to produce lead angle azimuth and elevation information signals, said lead angle azimuth and elevation signal information being applied to the difference circuit to modify said actual azimuth and elevation signal information to produce error azimuth and elevation signal information for display on the cathode ray tube, and a sight unit coupled to receive the computed azimuth and elevation

signal information for positioning a sighting reticle, the invention which comprises:

a feedback circuit coupling points between the difference circuit and the cathode ray tube to the eddy-current constrained gyroscope to feed back the error azimuth and elevation signal information from the difference circuit to the eddy-current constrained gyroscope for producing adjusted azimuth and elevation information signals to speed up the response time of computation and of the display on the cathode ray tube and to position the sighting reticle of the sight unit in response to computed azimuth and elevation information signals whereby a continuous display and rapid signal response of the misalignment of the target from said reference line for projectile fire control to effect projectile and target collision is presented on said cathode ray tube and whereby a continuous display and slow signal response of the misalignment of the target from said reference line for projectile fire control to effect projectile and target collision is presented on said sight unit.

3. In an all-weather gun fire control system as set forth in claim 2 wherein said feedback circuit coupling a point between said difference circuit and said cathode ray tube is between said difference circuit and said demodulator.

4. In an all-weather gun fire control system as set forth in claim 3 wherein said feedback circuit includes an amplifier and a demodulator in series to demodulate the error azimuth and elevation signal information applied to the eddy-current constrained gyroscope.

5. In an all-weather projectile fire control system having a radar target detection means providing actual azimuth, elevation, and range signal information, the actual azimuth and elevation signal information being applied to a difference circuit the output of which is fed through a demodulator to a cathode ray tube providing signal information for actual azimuth and elevation co-ordinate voltages for target display, the range signal information together with signal information representing factors affecting projectile trajectory for projectile-target collision being applied to computing circuits to produce computed azimuth and elevation signal information to effect target hit by the projectile which computed azimuth and elevation signal information is applied to the difference circuit for producing error azimuth and elevation signal information to display on the cathode ray tube, and the first-mentioned actual azimuth and elevation signal information being coupled to a sight unit for positioning a sight reticle for effective gun firing on a visible target, the cathode ray tube and the sight unit providing information for the firing of a projectile to effect projectile and target collision of visible and invisible targets, the invention which comprises:

a feedback circuit coupling the output of the difference circuit with the output of the computing circuits and with the coupling of the actual azimuth and elevation signal information to the sight unit for applying the error azimuth and elevation signal information respectively to the computed azimuth and elevation signal information and respectively to the actual azimuth and elevation signal information to the sight unit whereby signal response is rapid to display relative movements of the fire control system with respect to the target.

6. In a fire control system as set forth in claim 5 wherein said feedback circuit coupling the output of said difference circuit with the output of said computing circuits includes an amplifier and a demodulator in series.

7. In a fire control system as set forth in claim 6 wherein said feedback circuit coupling the output of said difference circuit with the output of said computing circuits is through a low impedance coupling.

8. In an all-weather projectile fire control system for target pursuit vehicles providing a director mode of operation comprising:

a radar target detection device for providing actual azimuth, elevation, and range information signals of a detected target;

a demodulator and a cathode ray tube;

a difference circuit coupled to receive the actual azimuth and elevation information signals from the radar device, having the output thereof coupled through said demodulator to the deflection circuits of said cathode ray tube for displaying error lead angles for correction to effect projectile-target collision;

devices representing factors affecting projectile trajectory

computer circuits coupled to receive the actual range signal information from said radar device and voltage signal information from said devices representing factors affecting projectile trajectory to produce range current signal information and computed azimuth and elevation current signal information representative of the lead angle for firing a projectile at the target;

an eddy-current constrained gyroscope coupled to receive said current signals for producing computed azimuth and elevation voltage signal information of the lead angle coupled to said difference circuit, the difference in the actual azimuth and elevation signal information from said radar and said computed azimuth and elevation signal information respectively producing azimuth and elevation error signals of lead angles for said display on said cathode ray tube;

and a feedback circuit coupling the azimuth and elevation error signals of lead angle to the respective computed azimuth and elevation couplings from said computing circuits to said eddy-current constrained gyroscope to apply said azimuth and elevation error signals of lead angle, respectively, to said computed azimuth and elevation current signal information whereby the error signals of lead angles are rapidly computed with changes of relative position and orientation of the fire control system and the target to enable vehicle personnel to acquire fire control system attitude for projectile-target collision.

9. An all-weather projectile fire control system as set forth in claim 8 wherein said coupling of said feedback circuit includes a power amplifier and a demodulator for feeding back unidirectional current signals corresponding to said error signals, said coupling between said computer circuits and said eddy-current constrained gyroscope being of substantially zero impedance.

References Cited by the Examiner

UNITED STATES PATENTS

2,737,652	3/56	White et al.	343—7
2,819,461	1/58	Bryan	343—7
3,034,116	5/62	Shelley	343—7
3,044,056	7/62	Bloch	343—7.4

CHESTER L. JUSTUS, *Primary Examiner.*

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,181,147

April 27, 196

Jack A. Crawford et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 13, line 8, after "adjusted" insert -- lead angle

Signed and sealed this 19th day of October 1965.

(SEAL)

Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents