FIRE CONTROL SYSTEM FOR AN ANTI-AIRCRAFT WEAPON CARRIER

Filed April 27, 1965 2 Sheets-Sheet 1

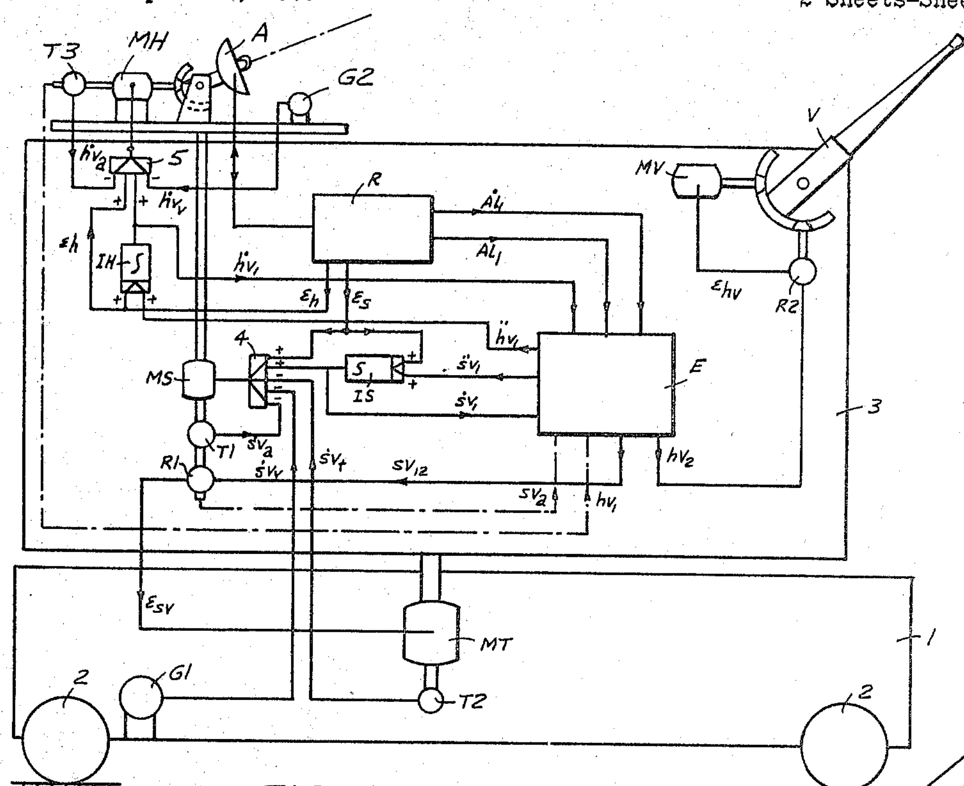


FIG. 1

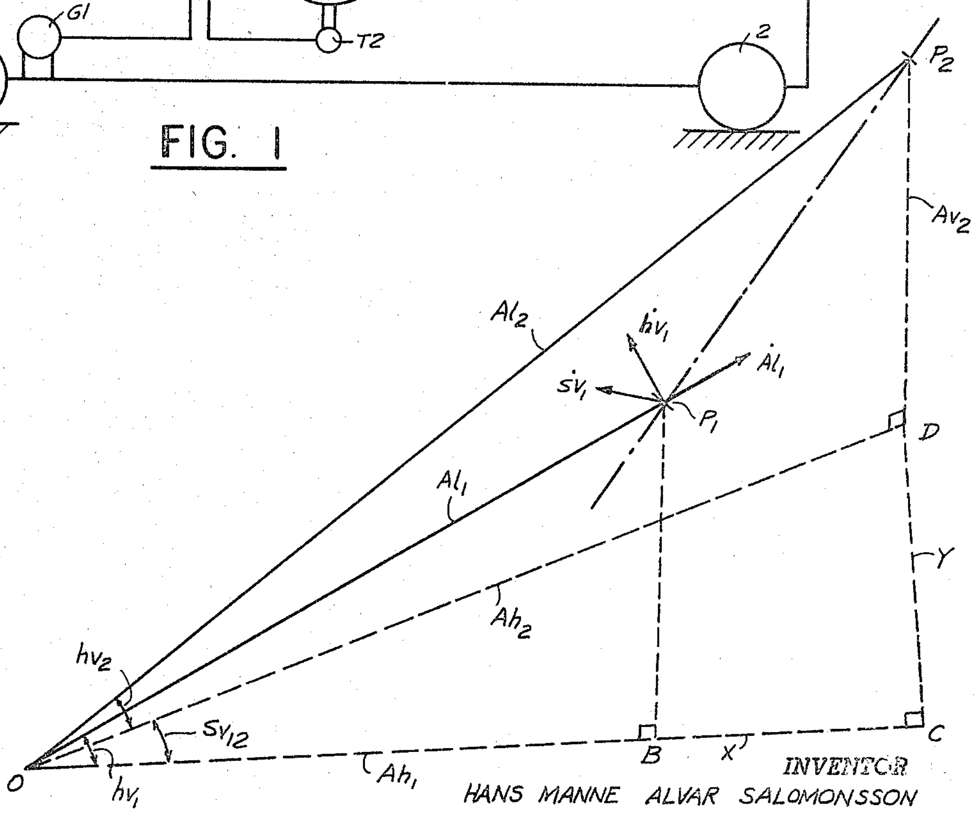


FIG. 3

INVENTOR
HANS MANNE ALVAR SALOMONSSON
BY Hane and Nydick
ATTORNEYS

FIRE CONTROL SYSTEM FOR AN ANTI-AIRCRAFT WEAPON CARRIER

Filed April 27, 1965



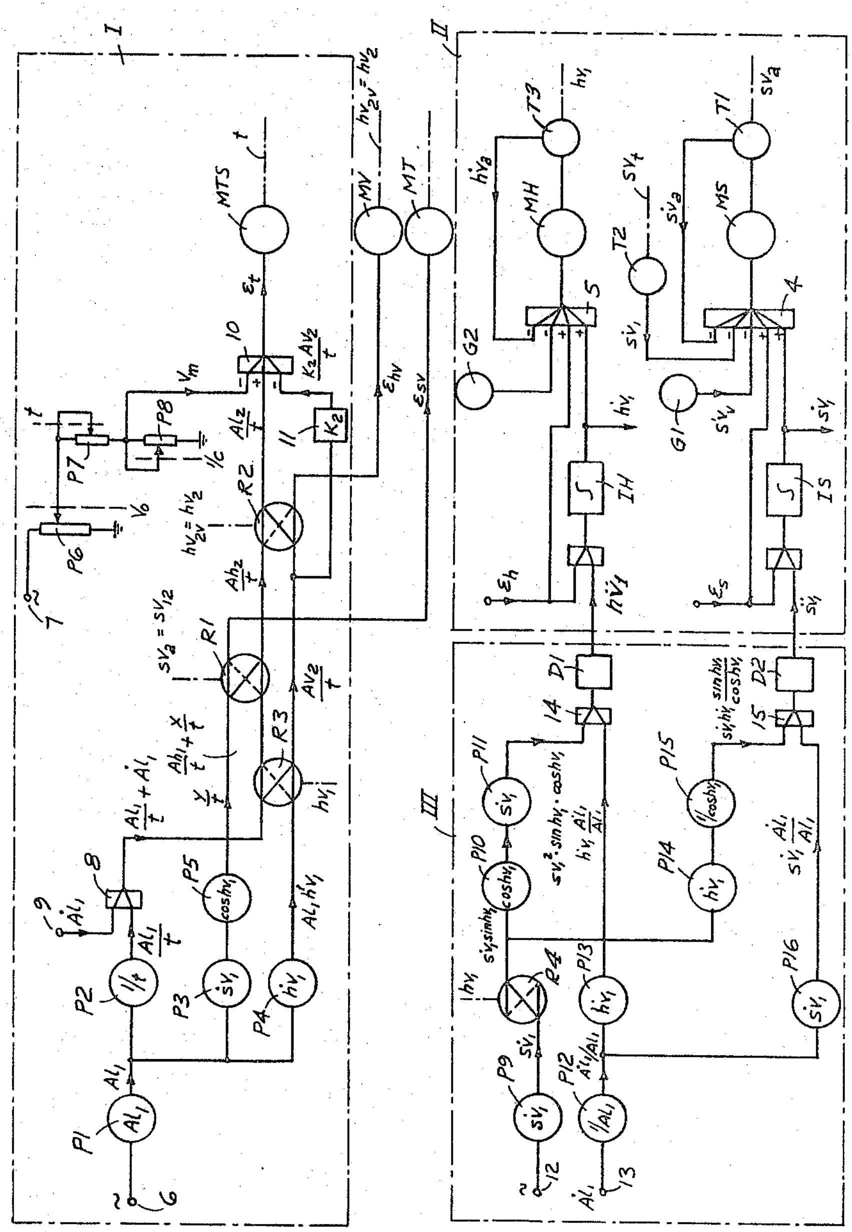


FIG. 2

INVENTOR
HANS MANNE ALVAR SALOMONSSON
BY Hane and Nydick
ATTORNEYS

United States Patent Office

3,309,963

Patented Mar. 21, 1967



3,309,963

# FIRE CONTROL SYSTEM FOR AN ANTI-AIRCRAFT WEAPON CARRIER

Hans Manne Alvar Salomonsson, Karlskoga, Sweden, assignor to Aktiebolaget Bofors, Bofors, Sweden, a Swedish company

Filed Apr. 27, 1965, Ser. No. 451,179
Claims priority, application Sweden, May 5, 1964, 5,582/64
8 Claims. (Cl. 89—41)

The present invention is related to an anti-aircraft weapon carriage or carrier, that is a vehicle, generally a track laying or endless track vehicle, which carries an anti-aircraft weapon, generally an automatic A.A. gun, which is mounted for elevation in a turret, which is mounted for rotation in traverse upon the mobile chassis of the vehicle. An anti-aircraft carriage of the type concerned is also provided with a complete fire control system for the weapon, comprising a radar sight for determining the position and the velocity in a spheric coordinate system for a target to be fired at and also a fire control computer adapted to compute from the target data determined by the radar sight the point of aim, upon which the weapon is to be laid to fire at the target. In a modern anti-aircraft carrier of this type the fire control must be completely automatic, which means that the radar sight is in a manner known per se provided with means for automatic target tracking, that is the radar antenna is laid in elevation and in transverse by servomotors, which are controlled by error signals received from the radar sight and representing the deviations between the true direction in elevation and in traverse respectively to the target and the actual direction in elevation and traverse respectively of the antenna so that the antenna is automatically brought to track the target. In the same way the range measuring unit of the radar sight is operated by a servomotor, which is controlled by an error signal produced by the radar sight representing the difference between the true slanting range to the target and the actual range, to which the range measuring unit is momentarily adjusted, so that the radar sight will track the target automatically also in range. Further the weapon is elevated in the turret of the carriage by a servomotor, which is controlled by an error signal produced by the fire control computer and representing the deviation between the elevation angle to the computed point of aim and the actual elevation angle of the weapon, whereas the weapon is laid in traverse by a servomotor rotating the turret, which servomotor is also controlled by an error signal produced by the fire control computer and representing the deviation between the azimuth angle to the computed point of aim and the actual angular azimuth position of the turret, that is of the weapon.

In an anti-aircraft carrier of the type defined above considerable difficulties arise however with respect to the design of the fire control system. These difficulties are primarily due to the fact that the radar antenna must be mounted upon the turret to obtain a free field of sight and to permit a rotation of the turret through 360°. Consequently the antenna can be positioned in elevation and in azimuth only with respect to the turret, and in principle the radar sight can therefore determine the azimuth angle and the elevation angle to the target and the azimuth angular velocity and the elevation angular velocity of the target only with respect to the turret of the anti-aircraft carriage. The turret is however rotated about a vertical axis, when the weapon is laid in traverse, and furthermore the complete carriage will move with respect to the ground in an undefined manner in its suspension system under the influence from the forces created by the rotation of the turret, the elevation of the weapon and the firing of the weapon. Consequently, the



radar sight can not primarily determine the azimuth angular velocity and the elevation angular velocity of the target accurately with respect to the ground, which data, however, the fire control computer requires in order to calculate the point of aim. The rotation of the turret, when the weapon is laid in traverse, and also the suspension movements of the complete carriage with respect to the ground constitute furthermore very serious disturbances for the automatic target tracking of the radar antenna and these disturbances must be eliminated. The error signals, which are generated by the target tracking equipment of the radar sight and which are used as control signals for the servomotors laying the antenna in elevation and in traverse, contain, however, a substantial amount of radar noise, wherefore it is not possible to give these signals a sufficient amplification and use them in sufficiently rapid servo loops so as to obtain an elimination of the disturbances caused by the rotation of the turret and the suspension movements of the carrier. Due to this also the automatic target tracking of the radar antenna will be unsatisfactory or made impossible. An additional difficulty is caused by the fact that the weapon is laid in traverse by rotation of the turret with respect to the chassis of the carriage, whereas the azimuth angle to the target can primarily be determined by the radar sight only with respect to the turret and not with respect to the chassis of the carriage. There is also the additional requirement that a fire control system in an anti-aircraft carriage of the type defined must have the smallest possible weight and require the smallest possible space.

The main object of the present invention is therefore to provide for an anti-aircraft carrier of the type herein referred to as a fire control system having such a design, particularly with respect to the controlled laying of the radar antenna and the controlled rotation of the turret and the controlled elevation of the weapon, that the above-mentioned problems are satisfactorily solved with a simple design of the fire control system.

The anti-aircraft weapon carrier according to the invention is characterized in that it comprises means for determining the traverse angular velocity of the radar antenna relative to the ground and for generating a signal proportional thereto, which is fed back to the servomotor laying the antenna in traverse relative to the turret, and that the fire control computer is adapted to compute a quantity representing the deviation between the traverse angle between the direction to the target and the direction to the computed point of aim and the traverse angle between the antenna direction and the direction of the weapon, that is the traverse angle of the radar antenna relative to the turret, and to produce a signal proportional to said quantity, which signal is applied as a control signal to the servomotor rotating the turret. By feeding back a signal proportional to the traverse angular velocity of the antenna relative to the ground to the servomotor laying the antenna in traverse relative to the turret it becomes possible to determine the traverse angular velocity of the target relative to the ground accurately and simultaneously an elimination of those disturbances in the target tracking, which are caused by a rotation of the turret and the suspension movements of the carriage, is achieved, so that these disturbances do not have to be eliminated by the aid of the error signal from the target tracking equipment of the radar sight. Consequently, the laying and the position of the antenna in traverse relative to the ground will be completely independent of the rotation of the turret and the suspension movements of the carriage.

The means for determining the traverse angular velocity of the antenna relative to the ground consist preferably of a first tachogenerator coupled to the traverse laying shaft of the antenna, a second tachogenerator coupled to the rotation shaft of the turret and an angular velocity responsive gyro mounted in the chassis of the carriage so as to respond to the angular velocity of the chassis about an axis parallel to the axis of rotation of the turret. The sum of the signals from said two tachogenerators and the angular velocity responsive gyro will obviously represent the traverse angular velocity of the antenna relative to the ground.

The control signal for the servomotor rotating the turret is preferably produced in the following way. The fire control computer is adapted to compute two quantities and produce alternating voltages proportional thereto, representing the sine and cosine values respectively of the traverse angle between the direction to the target and the direction to the point of aim, said two alternating voltages being supplied to the two output windings of an electrical resolver, which is coupled to the traverse laying shaft of the antenna, whereby the voltage from an output winding of the resolver will constitute the required control voltage for a servomotor rotating the turret.

The system for laying the antenna and the weapon respectively in elevation is in principle designed in the same way and comprises means for determining the elevation angular velocity of the antenna relative to the ground and for generating a signal proportional thereto, which is fed back to the servomotor laying the antenna in elevation relative to the turret, the fire control computer being adapted to compute a quantity and produce a signal proportional thereto, representing the deviation between the elevation angle to the point of aim and the elevation angle of the weapon, said signal being supplied as a control signal to the servomotor elevating the weapon. The means for determining the elevation angular velocity of the antenna relative to the ground consist preferably of a tachogenerator coupled to the elevation shaft of the antenna and an angular velocity responsive gyro mounted on a traversing but not elevating part of the antenna so as to respond to the angular velocity of the carriage in a plane through the traverse laying axis of the antenna and the antenna direction. The sum of the signals from the tachogenerator and the angular velocity responsive gyro will obviously represent the elevation angular velocity of the antenna relative to the ground and by feeding these signals back to the servomotor for the elevation of the antenna it becomes possible to determine the elevation angular velocity of the target relative to the ground accurately and furthermore the laying and the position of the antenna in elevation relative to the ground will become independent of the suspension movements of the carriage, so that the duration error signal from the automatic target tracking equipment of the radar sight does not have to be used for eliminating the disturbances in the elevation of the antenna caused by the suspension movements of the carriage. Preferably the fire control computer is adapted to compute two quantities and produce alternating voltages proportional thereto, representing the sine and cosine values respectively of the elevation angle to the point of aim, said two alternating voltages being supplied to the two input windings of an electric resolver, which is coupled to the elevation shaft of the weapon, whereby the voltage from an output winding of the resolver will constitute the required control voltage for the servomotor elevating the weapon.

In order to further improve the target tracking of the antenna and to make it possible to derive signals representing the traverse angular velocity and the elevation angular velocity respectively of the target relative to the ground directly from the servo loops of the antenna, it is preferable that the servo-ciruits for the servomotors laying the antenna in traverse and in elevation respectively are so designed that to each servomotor are supplied, in addition to the regenerative feedback signal representing the angular velocity of the antenna relative to the ground in the corresponding coordinate direction, also the error signal generated by the automatic target tracking equipment of the radar sight for said coordinate together with the output signal from an integrator, which is supplied with said error signal from the target tracking equipment of the radar sight and a signal from the fire control computer representing a value for the angular acceleration of the target in said coordinate direction as computed by the computer from the data determined by the radar sight regarding the position and the velocity of the target and with a predetermined assumption regarding the future movement of the target. The output signal from the integrator will then constitute an accurate value upon the angular velocity of the target relative to the ground in the associated coordinate direction and this signal can consequently be tapped and used as an input quantity for the fire control computer.



In the following the invention and its mode of operation will be further described with reference to the accompanying drawing, in which

FIG. 1 shows schematically and by way of example an anti-aircraft weapon carriage provided with a fire control system according to the invention,

FIG. 2 is a block diagram of the components in the fire control computer essential to the invention and of the servo-circuits for the positioning of the antenna, the elevation of the weapon and the rotation of the turret, and

FIG. 3 illustrates the basic geometric relations for the calculation of the point of aim.

The anti-aircraft carriage or carrier shown schematically in FIG. 1 comprises a chassis **1**, which is mobile, as indicated schematically in the drawing by wheels **2.** Normally, however, the carriage is a track laying vehicle. The chassis is in any conventional way, not shown in the drawing, connected to the wheels or the endless tracks through a suspension system. A turret **3** is mounted on the chassis **1** so as to be rotatable relative to the chassis **1** about a vertical axis. The turret can be rotated by a servomotor MT. An anti-aircraft weapon V, generally an automatic A.A. gun, is mounted for elevation in the turret **3**. The gun can be elevated by a servomotor MV. Further the carrier is provided with a radar station R for transmitting and receiving radar signals through a radar antenna A. The antenna is mounted upon the turret **3** and can be positioned in traverse relative to the turret about an axis parallel with the axis of rotation of the turret by a servomotor MS and positioned in elevation relative to the turret about an axis perpendicular to the traverse positioning axis and the antenna direction by a servomotor MH. The radar station R is in any conventional way provided with an equipment for automatic target tracking, which produces consequently a first error signal $\epsilon_s$ representing the traverse angular deviation between the true direction to the target and the antenna direction, and a second error signal $\epsilon_h$ representing the elevation angular deviation between the true direction to the target and the antenna direction. The target tracking system is also, as normal, designed for automatic range tracking in that the range measuring unit of the radar station is operated by a servomotor, which is controlled by an error signal produced by the radar station and representing the deviation between the true slanting range to the target and the slanting range momentarily set in the range measuring unit. Signals representing the slanting range $Al_1$ to the target and the radial velocity $A\dot{l}_1$ of the target can consequently be derived by means of potentiometers and tachogenerators coupled to the servomotor operating the range measuring unit. These signals are supplied as input data to a fire control computer E mounted in the carriage. As the fire control computer consists of an electric analog computer, as will be further explained in the following, in which the arithmetic operations are carried out by potentiometers and electric resolvers, which are to be set in accordance with the values of the input quantities or with predetermined functions of the input quantities, the value of the slanting range $Al_1$ to the target determined by the radar station R is preferably supplied to the fire control computer through mechanical connections between those potentiometers in the fire control computer, which are to be set in accordance with the value of the slanting range $Al_1$ or with certain functions of the slanting range, and the servomotor operating the range measuring unit of the radar station.

The servomotor MS for the traverse laying of the antenna A is supplied with a control signal from an adder circuit **4**. To the adder circuit **4** are supplied on the one hand the error signal $\epsilon_s$ from the target tracking equipment of the radar station R and on the other hand the output signal from an integrator IS as control signals for the servomotor MS. To the adder circuit **4** are further supplied a first signal from a tachogenerator T1 coupled to the traverse positioning shaft of the antenna, a second signal from a second tachogenerator T2 coupled to the positioning shaft of the turret **3** and a third signal derived from an angular velocity responsive gyro G1 mounted in the chassis **1** of the carriage so as to be responsive to the angular velocity of the chassis about a vertical axis. These signals from the tachogenerators and the gyro are supplied to the adder circuit **4** as regenerative feedback signals for the servomotor MS. The signal from the tachogenerator T1 will represent the traverse angular velocity $\dot{s}v_a$ of the antenna relative to the turret **3**, while the signal from the tachogenerator T2 will represent the traverse angular velocity $\dot{s}v_t$ of the turret **3** relative to the chassis **1** and the signal from the gyro will represent the traverse angular velocity of the chassis **1** $\dot{s}v_v$ relative to the ground. The sum of these signals will consequently represent the traverse angular velocity of the antenna A relative to the ground. To the integrator IS are supplied on the one hand the error signal $\epsilon_s$ from the target tracking equipment of the radar station R and on the other hand from the fire control computer E a signal proportional to a value for the traverse angular acceleration $\dot{s}\dot{v}_1$ of the target calculated by the fire control computer from the data regarding the position and the velocity of the target determined by the radar sight and a certain assumption regarding the future movement of the target, for instance that the target will continue to move in a straight course with constant velocity. If the error signal $\epsilon_s$ from the target tracking equipment of the radar station is zero and the signal $\dot{s}\dot{v}_1$ from the fire control computer E is also zero, that is the antenna A is positioned correctly in traverse towards a target, which is stationary or moving in a straight course towards or away from the antenna, the servomotor MS will obviously endeavour to rotate the antenna in traverse in such a way that the sum of the three regenerative feedback signals $\dot{s}v_a$, $\dot{s}v_v$ and $\dot{s}v_t$ becomes zero, that is so that the traverse angular velocity of the antenna relative to the ground becomes zero. The antenna will consequently be maintained stationary relative to the ground and directed towards the target independent of any rotation of the turret **3** or movement of the chassis **1**, and without the error signal $\epsilon_s$ from the target tracking equipment of the radar station R having to assist in the control of the antenna. If it is assumed, on the other hand, that the error signal $\epsilon_s$ from the radar station is still zero but that the traverse angular acceleration $\dot{s}\dot{v}_1$ of the target as calculated by the fire control computer is separated from zero, it is apparent that the servomotor MS will try to impart to the antenna a tranverse angular velocity relative to the ground corresponding to the calculated traverse angular acceleration $\dot{s}\dot{v}_1$. Consequently, the servomotor MS will rotate the antenna A to track the target in traverse, so long as the target is moving in the manner assumed by the fire control computer when calculating the traverse angular acceleration $\dot{s}\dot{v}_1$ of the target, that is, for instance, so long as the target is moving in a straight course with a constant speed, and no error signal $\epsilon_s$ from the target tracking equipment of the radar station has to be used for this control of the antenna. Consequently it is not necessary to make use of this error signal except for those corrections of the traverse positioning of the antenna, which will be necessary for a target not moving in the assumed manner that is for instance moving in a curved course, or with a varying velocity in its course, and for the compensation of any inaccuracies in the other control circuits for the laying of the antenna in traverse. The servo-loop for the servomotor MS containing the target tracking equipment of the radar station can consequently have a low amplification factor and be so slow that the radar noise in the error signal $\epsilon_s$ does not have any detrimental effect.

It is particularly important that the input quantity for the fire control computer E representing the traverse angular velocity $\dot{s}v_1$ of the target relative to the ground is filtered with respect to the radar noise. The signal being in this respect the best representation of the traverse angular velocity $\dot{s}v_1$ is the output signal from the integrator IS. The transfer function from the radar noise, expressed as a traverse angular velocity, to the output of the integrator IS is

$$\frac{1}{1+T_1s+T_2^2s^2}$$

where $s$ is the Laplace operator and $T_1$ and $T_2$ are time constants for the slow control loop for the error signal $\epsilon_s$. It is also understood that the output signal from the integrator IS will constitute an accurate value for the traverse angular velocity of the antenna and thus also for the traverse angular velocity $\dot{s}v_1$ of the target, so long as the target is moving in the manner assumed by the fire control computer. This signal is, therefore, supplied to the fire control computer E as an input quantity.

It would of course also be possible to obtain a signal proportional to the traverse angular velocity of the antenna to be fed back to the servomotor MS by means of an angular velocity responsive gyro so mounted on a traversing part of the antenna as to respond to the traverse angular velocity of the antenna. In certain cases, however, the antenna has a considerable traverse angular velocity, wherefore it would be necessary to dimension such a gyro for a very large measuring range with the result that the gyro would become insensitive and inaccurate for small angular velocities. With the preferred system according to the invention, however, the tachogenerators T1 and T2, preferably consisting of direct voltage tachogenerators, can be given a large accuracy, and the angular velocity responsive gyro G1 can be dimensioned for the comparatively small traverse angular velocities of the chassis **1**, wherefore this gyro becomes accurate also for very small angular velocities. Due to its suspension the chassis **1** is also well damped for low frequent movements, wherefore the signals from the gyro G1 is preferably supplied to the adder circuit **4** through a high pass filter, preventing that any unbalance of the gyro G1 will affect the control of the servomotor MS.

The value of the traverse angle $sv_a$ of the antenna with respect to the turret, that is the traverse angle of the target with respect to the weapon, is transferred to the fire control computer E through mechanical connections between those potentiometers and resolvers in the fire control computer, which are to be set in agreement with the value of this traverse angle $sv_a$ or certain functions of this traverse angle, and the traverse positioning shaft of the antenna, as indicates in the drawing by a dash-dotted line.

The control circuit for the servomotor MH laying the antenna in elevation is designed fundamentally in the same way as the control circuit for the servomotor MS laying the antenna in traverse. The servomotor MH is consequently receiving its control signal from an adder circuit **5**, to which are supplied on the one hand the error signal $\epsilon_h$ from the target tracking equipment of the radar station R and on the other hand the output signal from an integrator IH as control signals for the servomotor. To the adder circuit **5** are further supplied a first signal from a tachogenerator T3 coupled to the elevation positioning shaft of the antenna and a second signal from an angular velocity responsive gyro G2 so mounted on a traversing but not elevating part of the antenna as to be responsive to the angular velocity in a plane through the traversing axis and the direction of the antenna. The signals from the tachogenerator T3 and the gyro G2 are supplied to the adder circuit **5** as regenerative feedback signals for the servomotor MH. The signal from the tachogenerator T3 will represent the elevation angular velocity $\dot{h}v_a$ of the antenna with respect to the carriage, whereas the signal from the gyro G2 will represent the elevation angular velocity $\dot{h}v_v$ of the carriage with respect to the ground. The sum of these two signals represents consequently the elevation angular velocity of the antenna with respect to the ground. To the integrator IH are supplied on the one hand the error signal $\epsilon_h$ from the target tracking equipment of the radar station and on the other hand a signal from the fire control computer E proportional to a value upon the elevation angular acceleration $\dot{h}\dot{v}_1$ of the target calculated by the fire control computer E with a certain assumption regarding the future movement of the target. The servo circuits will operate in the same way as the servo-circuits for the traverse laying of the antenna, that is the two regenerative feedback signals $\dot{h}v_a$ and $\dot{h}v_v$ provide that the antenna is maintained directed towards the target in elevation independently of the movement of the carriage and without any assistance of the error signal $\epsilon_h$ from the target tracking equipment, whereas the signal $\dot{h}\dot{v}_1$ from the fire control computer E provides that the antenna A is brought to follow the target in elevation without any assistance from the error signal $\epsilon_h$, so long as the target is moving in the assumed manner, for instance in a straight course with a constant velocity. Also in this case the gyro G2 and the tachogenerator T3 could be substituted by an angular velocity responsive gyro mounted on the elevating part of the antenna, in which case however it would be necessary to dimension this gyro for a large measuring range, whereby the gyro would become correspondingly less sensitive and less accurate for small angular velocities. Also the signal from the gyro G2 is preferably supplied to the adder circuit **5** through a high-pass filter eliminating any unbalance in the gyro.

The output signal from the integrator IH will consequently constitute an accurate and with respect to radar disturbances filtered value of the elevation angular velocity $\dot{h}v_1$ of the antenna, that is of the target, with respect to the ground and this signal is supplied to the fire control computer E as an input quantity. The elevation angle of the antenna and thus the elevation angle $hv_1$ to the target is transferred to the fire control computer through mechanical connections between those potentiometers and resolvers in the fire control computer, which are to be set in accordance with the elevation angle $hv_1$ to the target, and the elevation positioning shaft of the antenna, as indicated in the drawing by a dash-dotted line.

As will be further described in the following the fire control computer E is adapted to calculate the point of aim, towards which the weapon V is to be directed to fire at the target, from the data supplied from the radar sight and the antenna servos regarding the traverse angle $sv_a$, the elevation angle $hv_1$ and the slanting range $Al_1$ to the target and the traverse angular velocity $\dot{s}v_1$, the elevation angular velocity $\dot{h}v_1$ and the radial velocity $\dot{A}l_1$ of the target. More precisely, the fire control computer is adapted to calculate the traverse angle $sv_{12}$ between the direction to the point of aim and the direction to the target, that is the so-called traverse lead angle, and to produce a signal proportional to this traverse angle. This signal is supplied from the fire control computer E to a resolver R1 coupled to the traverse positioning shaft of the antenna, in which resolver the required traverse angle $sv_{12}$ between the direction to the target, that is the antenna direction, and the direction to the point of aim, that is the traverse direction of the weapon or the turret, is compared with the actual traverse angle $sv_a$ between the antenna and the turret, that is the weapon V. From the resolver R1 an error signal $\epsilon_{sv}$ is obtained, which represents consequently the deviation between the traverse angle between the target direction and the direction to the point of aim and the existing traverse angle between the weapon, that is the turret, and the target direction, that is the antenna direction. This error signal is connected as a control signal to the servomotor MT rotating the turret **3**, that is laying the weapon V in traverse. This servometer will consequently endeavour to rotate the turret **3** and thus lay the weapon V in traverse, until the weapon is directed in traverse towards the calculated point of aim. In the same way the fire control computer E is adapted to calculate the elevation angle $hv_2$ to the point of aim and produce a signal proportional thereto, which is connected to a resolver R2 coupled to the elevation positoning shaft of the weapon V. In the resolver R2, consequently, the calculated elevation angle $hv_2$ to the point of aim is compared with the actual elevation angle of the weapon so that from the resolver R2 an error signal $\epsilon_{hv}$ is obtained representing the deviation between the elevation angle $hv_2$ to the point of aim and the actual elevation angle of the weapon. This error signal is connected as a control signal to the servomotor MV elevating the weapon and this servomotor will consequently try to elevate the weapon V towards the calculated point of aim.

In FIG. 3, which illustrates schematically the basic geometric relations for the calculation of the point of aim for the weapon to be carried out by the fire control computer, $P_1$ designates the position of the target and $P_2$ the required point of aim for the weapon whereas O designates the site of the anti-aircraft carriage. As in the foregoing, $hv_1$ is the elevation angle to the target as determined by the radar sight, whereas $Al_1$ is the slanting range to the target as determined by the radar sight. The vectors $\dot{A}l_1$, $\dot{s}v_1$ and $\dot{h}v_1$ represent the radial velocity, the traverse angular velocity and the elevation angular velocity respectively of the target as determined by the radar sight. Also the traverse angle between the direction to the target $Pl_1$ and the direction to the point of aim $P_2$, that is the so-called lead angle, is designated with $sv_{12}$, as in the foregoing, and the elevation angle to the point of aim with $hv_2$. The horizontal range to the target is designated with $Ah_1$, whereas the slanting range to the point of aim is designated with $Al_2$, the horizontal range to the point of aim with $Ah_2$ and the vertical height to the point of aim with $Av_2$. Although, for the sake of simplicity, the ranges $Ah_1$ and $Ah_2$ have been called the horizontal ranges to the target and the point of aim respectively, it is to be observed that these ranges are not in reality necessarily lying in a horizontal plane but are lying in a traverse laying plane of the antenna, that is in a plane through the chassis of the carriage, which plane is horizontal only if the carriage is standing on a horizontal surface. As understood from the foregoing description, the radar sight is determining the position of the target in a spheric coordinate system having its origin in the carriage and its reference plane parallel with the traverse laying plane of the antenna and its reference direction coinciding with the direction of the antenna in traverse. This coordinate system is consequently rotating together with the antenna so that the reference direction of the coordinate system is always coinciding with the traverse direction to the target and the position of the point of aim is also calculated in this coordinate system. The velocity components $\dot{A}l_1$, $\dot{s}v_1$ and $\dot{h}v_1$ of the target are in any moment parallel to the coordinate direction in this spheric coordinate system, but their magnitudes are, as understood from the foregoing, determined relative to the ground and not relative to the moving coordinate system, which is rotating about the traverse laying axis of the antenna with the traverse angular velocity $\dot{s}v_1$ of the target. In the following it will be assumed for the sake of simplicity that the traverse laying plane of the antenna and thus the reference plane of the spheric coordinate system are horizontal.

Among the abovementioned quantities, shown in FIG. 3, the elevation angle $hv_1$, the slanting range $Al_1$ and the coordinate velocities $\dot{s}v_1$, $\dot{h}v_1$ and $\dot{A}l_1$ of the target are determined by the radar sight and supplied as input quantities to the fire control computer and the fire control computer has to calculate from these data the traverse angle $sv_{12}$ between the target and the point of aim and the elevation angle $hv_2$ to the point of aim.

For the calculation of the lead angle $sv_{12}$ an imaginary right-angled triangle OCD in the horizontal plane is used having the horizontal range $Ah_2$ to the point of aim $P_2$ as its hypotenuse and one of its smaller sides coinciding with the horizontal projection of the direction to the target $P_1$. This right-angled triangle gives

$$\frac{y}{Ah_1+x}=\frac{\sin sv_{12}}{\cos sv_{12}} \tag{1}$$

For a correct positioning of the weapon V, that is of the turret 3, in traverse towards the point of aim $P_2$ one has

$$sv_a=sv_{12} \tag{2}$$

where $sv_a$, as in the foregoing, is the traverse angle between the antenna direction, that is the direction to the target, and the traverse direction of the turret, that is of the weapon. For a correct positioning of the turret, that is of the weapon, in traverse one has consequently

$$y \cos sv_a-(Ah_1+x) \sin sv_a=0 \tag{3}$$

where the left-hand member obviously constitutes a measure of the deviation between the calculated traverse angle $sv_{12}$ between the direction to the target and the direction to the point of aim and the actual traverse angle $sv_a$ between the turret, that is the weapon and the antenna direction, that is the target direction, wherefore a signal corresponding to this expression could be used as an error signal $\epsilon_s$ for the control of the servomotor MT rotating the turret.

In the above relation 3 one has

$$Ah_1=Al_1 \cos hv_1 \tag{4}$$

According to FIG. 3 one has also

$$x=Al_1t \cos hv_1-Al_1\dot{h}v_1t \sin hv_1 \tag{5}$$

where $t$ is the time of flight of the projectile and consequently the first term is due to the radial velocity of the target, whereas the second term is due to the elevation angular velocity of the target. FIG. 3 gives in the same way with respect to the traverse angular velocity $\dot{s}v_1$ of the target that

$$y=Al_1\dot{s}v_1t \cos hv_1 \tag{6}$$

The point of aim is consequently calculated with the assumption that the target is moving in a straight course with constant speed during the time of flight of the projectile. If the Expressions 4, 5 and 6 are inserted in the left-hand member in the above Relation 3 which member represents the error in the traverse laying of the weapon, the following expression is obtained, after division with the time of flight $t$ of the projectile, for the error signal $\epsilon_{sv}$ controlling the servomotor MT rotating the turret, that is laying the weapon in traverse

$$sv=Al_1\dot{s}v_1 \cos hv_1 \cos sv_a - \left[\left(\frac{Al_1}{t}+\dot{A}l_1\right)\cos hv_1-Al_1\dot{h}v_1 \sin hv_1\right] \sin sv_a \tag{7}$$

The division with the time of flight $t$ of the projectile is made in order to make the error signal less dependent of the magnitude of the time of flight and in order to simplify the design of the fire control computer. In order to make the magnitude of the error signal less dependent of the elevation angle $hv_1$ to the target, it can in certain cases be preferable to divide the expression with $\cos hv_1$.



The elevation angle $hv_2$ to the point of aim $P_2$ can be calculated from the right-angled triangle $ODP_2$, which gives

$$\frac{Av_2}{Ah_2}=\frac{\sin hv_2}{\cos hv_2} \tag{8}$$

If the actual elevation angle of the weapon V is designated with $hv_{2v}$, one obtains consequently for a correct positioning of the weapon in elevation towards the point of aim $P_2$, that is when $hv_{2v}=hv_2$, that

$$Av_2 \cos hv_{2v}-Ah_2 \sin hv_{2v}=0 \tag{9}$$

where obviously the left-hand member is a measure of the deviation between the elevation angle $hv_2$ to the point of aim $P_2$ and the actual elevation angle $hv_{2v}$ of the weapon, wherefore this expression can be used as an error signal for the control of the servomotor MV laying the weapon in elevation. The triangle OCD gives also

$$Ah_2=(Ah_1+x) \cos sv_{12}+y \sin sv_{12} \tag{10}$$

FIG. 3 gives further

$$Av_2=Al_1 \sin hv_1+\dot{A}l_1t \sin hv_1+Al_1\dot{h}v_1t \cos hv_1 \tag{11}$$

where the first term is the vertical height to the target $P_1$, the second term is the vertical movement of the traget due to the radial velocity $\dot{A}l_1$ of the target and the third term is the vertical movement of the target due to the elevation angular velocity $\dot{h}v_1$ of the target. If the Expressions 10 and 11, with the values of $Ah_1$, $x$ and $y$ given by the Expresions 4, 5 and 6, are inserted in the left-hand member of the Relation 9, which is representing the error signal $\epsilon_{hv}$ for the servomotor MV of the weapon, one obtains, after division with the time of flight $t$ of the projectile, the following expression for the error quantity $\epsilon_{hv}$

$$\epsilon_{hv}=\left[\left(\frac{Al_1}{t}+\dot{A}l_1\right) \sin hv_1+Al_1\dot{h}v_1 \cos hv_1\right] \cos hv_{2v} - \left\{\left[\left(\frac{Al_1}{t}+\dot{A}l_1\right) \cos hv_1-Al_1\dot{h}v_1 \sin hv_1\right] \cos sv_{12} + Al_1\dot{s}v_1 \cos hv_1 \sin sv_{12}\right\} \sin hv_{2v} \tag{12}$$

As already mentioned, the above described calculations of the point of aim $P_2$ and the required error signals $\epsilon_{sv}$ and $\epsilon_{hv}$ have been carried out in a spheric coordinate system, which is coupled to the anti-aircraft carriage and has its reference plane coinciding with the plane of the chassis of the carriage, which of course can be tilted with respect to the horizontal plane due to the slope of the ground. To make the calculation in this spheric coordinate system can of course be permitted, as the turret is rotated in traverse in said plane and the weapon is elevated with respect to said plane. Furthermore, the point of aim $P_2$ has been calculated without any consideration to the necessary gravity elevation, that is to the curved trajectory of the projectile, and to the deflection of the projectile from its course due to the wind. Necessary corrections for the gravity elevation and the wind can be obtained by correction signals, which are added in the fire control computer to the signal representing $Ah_2$ and the error signals $\epsilon_{sv}$ and $\epsilon_{hv}$. The magnitudes of these corrections can be determined or calculated in any conventional manner, which will not be described in detail here, as it is of no fundamental importance for the invention. When calculating these corrections, due regard must, however, of course be paid to any tilted attitude of the carriage relative to the horizontal plane, as the gravity elevation as well as the wind deflection of the projectile is dependent of the angle, with which the projectile is fired relative to the horizontal plane.

In the above expressions for the error signals $\epsilon_{sv}$ and $\epsilon_{hv}$ all quantities except the time of flight $t$ of the projectile are known. It should be noted that in the expressions for the error signal $\epsilon_{hv}$ for the laying of the weapon in elevation the traverse angle $sv_{12}$ between the direction to the target and the direction to the point of aim is a known quantity, as it is presumed that the servomotor MT rotating the turret maintains the error signal $\epsilon_{sv}$ zero, so that $sv_{12}=sv_a$, where $sv_a$ is the known traverse angle of the antenna relative to the turret **3**.

The time of flight $t$ can be determined from the expression

$$Al_2=V_mt+k_2Av_2 \quad (13)$$

in which $V_m$ is the average velocity of the projectile and the term $k_2Av_2$ is a measure of the difference between the slanting range $Al_2$ to the point of aim and the length $V_mt$ of the projectile trajectory, which difference is due to the curvature of the trajectory. It is obvious that this difference is dependent of the vertical height $Av_2$ to the point of aim, $k_2$ being a constant. The average velocity $V_m$ of the projectile can be expressed as

$$V_m=\frac{V_0}{1+ct} \quad (14)$$

where $V_0$ is the known initial velocity of the projectile and $c$ is a constant dependent of the air density. The slanting range $Al_2$ to the point of aim can be determined from the expression

$$Al_2=Av_2 \sin hv_2+Ah_2 \cos hv_2 \quad (15)$$

in which $Av_2$ and $Ah_2$ can be obtained from the Relations 11 and 10 and $hv_2$ is equal to the known elevation angle $hv_{2v}$ of the weapon relative to the turret, provided that the elevating servomotor MV of the weapon is elevating the weapon so that the controlling error signal $\epsilon_{hv}$ is zero. The fire control computer comprises a servo circuit for the time of flight $t$, which circuit comprises a servomotor rotating its shaft in accordance with the actual time of flight. Consequently, those potentiometers in the fire control computer, which are to be set in accordance with the time of flight, can be coupled to the shaft of said servomotor. This servomotor requires a control signal $\epsilon_t$, which represents the deviation between the correct calculated time of flight and the time of flight represented by the rotation of the servomotor and which consequently becomes zero, when the servomotor has been rotated through an angle correctly corresponding to the calculated time of flight. From the above Relation 13 the following expression can be obtained for this error signal $\epsilon_t$

$$Al_2-V_mt-k_2Av_2 \quad (16)$$

If the Relations 14 and 15 are inserted in the above Expression 16 and the expression is divided with the time of flight $t$, the following expression is obtained for the error signal $\epsilon_t$

$$\epsilon_t=\frac{Av_2 \sin hv_2+Ah_2 \cos hv_2}{t}-\frac{V_0}{1+ct}-\frac{k_2Av_2}{t} \quad (17)$$

In FIG. 2 the dash-dotted frame I is enclosing those parts of the fire control computer, which are used for the calculation of the two error signals $\epsilon_{sv}$ and $\epsilon_{hv}$ for the traversing servomotor MT for the turret **3** and the elevating servomotor MV for the weapon V respectively. As already mentioned, the fire control computer consists of an electric analogue computer, which is supplied at the terminals **6** and **7** with a constant reference alternating voltage, assumed, for the sake of simplicity, to have the amplitude value 1. The reference voltage supplied to the terminal **6** is connected to a potentiometer P1, which is coupled to the range servo previously described in such a way that its potential division corresponds to the slanting range $Al_1$ to the target. The voltage from the potentiometer P1 is connected to an additional potentiometer P2, which is coupled to the above-mentioned time-of-flight-servo, which will be further described in the following, in such a way that the potential division of the potentiometer corresponds to $1/t$. The voltage from the potentiometer P2 is connected to an adder circuit **8** together with an alternating voltage supplied to the terminal **9** having an amplitude proportional to the radial velocity $\dot{A}l_1$ of the target. The alternating voltage proportional to $Al_1$ is obtained from the range servo, for instance from an alternating voltage tachogenerator coupled to the range servomotor. The voltage from the potentiometer P1 is also connected to a potentiometer P3 and a potentiometer P4. The potential division of the potentiometer P3 corresponds to the traverse angular velocity $\dot{s}v_1$ of the target, whereas the potential division of the potentiometer P4 corresponds to the elevation angular velocity $\dot{h}v_1$ of the target. These two potentiometers are operated by two servomotors in the fire control computer (not shown in the drawing), which servomotors are controlled by the signals proportional to the traverse angular velocity $\dot{s}v_1$ and the elevation angular velocity $\dot{h}v_1$, respectively supplied to the fire control computer, as previously described, from the integrators IS and IH respectively in the servo circuits for the traversing and the elevation respectively of the antenna. The voltage from the potentiometer P3 is connected to an additional potentiometer P5, which is coupled to the elevation positioning shaft of the antenna and has such a characteristic or gearing with respect to the elevation positioning shaft that its potential division corresponds to cos $hv_1$. The voltages from the adder circuit **8** and the potentiometer P4 are connected to the two input windings of an electric resolver R3, which is coupled to the elevation positioning shaft of the antenna in such a way that its rotor position corresponds to the elevation angle $hv_1$ to the target. The one output voltage from the resolver R3 will consequently correspond to $Av_2/t$ according to the Relation 11 given above, whereas the other output voltage will correspond to

$$\frac{Ah_1}{t}+\frac{x}{t} \quad (18)$$

according to the Relations 4 and 5 above.

The latter output voltage and the voltage from the potentiometer P5, which corresponds to $y/t$ according to the Relation 6 above, are connected to the input windings of a resolver R1, which is coupled to the traverse laying shaft of the antenna so that its rotor has an angular position corresponding to the traverse angle $sv_a$ between the antenna direction and the direction of the turret **3**, that is of the weapon V. The one output winding of the resolver R1 will consequently produce a voltage, which according to the Relations 3 and 7 given above corresponds to the required error signal $\epsilon_{sv}$ for the servomotor MT rotating the turret **3** and thus laying the weapon V in traverse. The servomotor MT will consequently rotate the turret so that the error signal $\epsilon_{sv}$ is maintained zero, that is so that the traverse angle between the direction of the weapon V and the antenna direction, that is the direction to the target, corresponds to the calculated lead angle $sv_{12}$ between the direction to the target and the direction to the point of aim.

The second output voltage from the resolver R1 will correspond to $Ah_2/t$ according to the Relation **10** above. This voltage and the voltage from the resolver R3 corresponding to $Av_2/t$ are connected to the input windings of an electric resolver R2, which is coupled to the elevating shaft of the weapon, so that its rotor has an angular position corresponding to the elevation angle $hv_{2v}$ of the weapon relative to the turret. The one output winding of the resolver R2 produces consequently a voltage, which according to the Relations 9 and 12 corresponds to the required error signal $\epsilon_{hv}$ for the servomotor MV laying the weapon V in elevation. This servomotor endeavours consequently to elevate the weapon V, until the control signal $\epsilon_{hv}$ becomes zero, that is until the elevation angle $hv_{2v}$ of the weapon corresponds to the calculated elevation angle $hv_2$ to the point of aim.

The second output voltage from the resolver R2 will according to the Relation 15 correspond to $Al_2/t$. This voltage is connected to an adder circuit **10**. The voltage from the one output winding of the resolver R3 corresponding to $Av_2/t$ is also connected to a potential divider **11** having the potential division $k_2$. The voltage from the potential divider **11** is consequently $k_2Av_2/t$ and is connected to the adder circuit **10**. The reference voltage supplied to terminal **7** is connected to a potentiometer **P6** having a setting corresponding to the known muzzle velocity $V_0$ of the projectile so that its potential division corresponds to the muzzle velocity $V_0$ of the projectile. The voltage from the potentiometer **P6** is connected to two potentiometers **P7** and **P8** connected in series. The potentiometer P7 is operated by the time-of-flight-servo so that its effective resistance value corresponds to the time of flight $t$, whereas the potentiometer P8 is set in relation to the prevailing air density so that its effective resistance value corresponds to $1/c$. The voltage derived from the junction between the potentiometer P7 and P8 corresponds consequently, according to the Relation 14 given above, to the average velocity $V_m$ of the projectile and this voltage is also connected to the adder circuit **10**. The circuit **10** adds the voltages supplied thereto with the signs indicated in the drawing and the output voltage from the adder circuit corresponds consequently, according to the Relation 17 given above, to the required error voltage $\epsilon_t$ for the control of the time-of-flight servomotor MTS. As the servomotor MTS endeavours to maintain the error signal $\epsilon_t$ zero, the shaft of the servomotor will assume a rotation angle corresponding to the calculated time of flight $t$. It may be preferable to multiply the error signal $\epsilon_t$ with the time of flight $t$, by means of the potentiometer operated by the servomotor MTS, before the error signal is connected as a control signal to the servomotor MTS.

As already mentioned, the necessary corrections for the gravity elevation and the wind deflection of the projectile can be made by means of correction voltages, which are added on the one hand to the voltage corresponding to $Ah_2/t$ from the one output winding of the resolver **R1** and on the other hand to the error signals $\epsilon_{sv}$ and $\epsilon_{hv}$ derived from the resolvers R1 and R2 respectively and connected to the servomotors MT and MV respectively.

The part of FIG. 2 enclosed by the dash-dotted frame II shows the servo-circuits for the laying of the antenna in traverse and in elevation. These servo-circuits are also shown in FIG. 1 and have been described with reference to this figure. The signals corresponding to the calculated traverse angular acceleration $\ddot{s}v_1$ and the elevation angular acceleration $\ddot{h}v_1$ respectively of the target, which are required for these servo-circuits, are obtained from the circuits in the fire control computer, which are enclosed by the dash-dotted frame III in FIG. 2.

Assuming that the target is moving in a straight course with a constant velocity, the traverse angular acceleration $\ddot{s}v_1$ of the target is obtained from the expression

$$\ddot{s}v_1 = -2\dot{s}v_1\frac{\dot{A}l_1}{Al_1} + 2\dot{s}v_1\dot{h}v_1\frac{\sin hv_1}{\cos hv_1} \qquad (19)$$

and the elevation angular acceleration $\ddot{h}v_1$ of the target from the expression

$$\ddot{h}v_1 = -\dot{s}v_1^2 \sin hv_1 \cos hv_1 - 2\dot{h}v_1\frac{\dot{A}l_1}{Al_1} \qquad (20)$$

The circuits within the frame III in the fire control computer are supplied with a constant reference alternating voltage on the terminal **12** and with an alternating voltage having an amplitude proportional to the radial velocity $\dot{A}l_1$ of the target on the terminal **13**. The latter voltage is derived from the range servo, as previously described. The reference voltage supplied to the terminal **12** is connected to a potentiometer **P9**, which is operated in a manner previously described by a servomotor, not shown in the drawing, in such a way that its potential division corresponds to the traverse angular velocity $\dot{s}v_1$ of the target. The voltage from the potentiometer **P9** is connected to the one input winding of a resolver **R4**, which is coupled to the elevation positioning shaft of the antenna in such a way that the angular position of its rotor corresponds to the elevation angle $hv_1$ to the target. The output voltage from the resolver R4 is connected to a potentiometer **P10**, which is also coupled to the elevation positioning shaft of the antenna and has such a characteristic or such a gearing to the elevation positioning shaft that its potential division corresponds to $\cos hv_1$. The voltage from the potentiometer **P10** is connected to a potentiometer **P11**, which is operated in the same way as the potential division corresponds to the traverse angular velocity $\dot{s}v_1$ of the target. The voltage from the potentiometer **P11** is connected to an adder circuit **14**. The voltage proportional to the radial velocity $\dot{A}l_1$ of the target supplied to the terminal **13** is connected to a potentiometer **P12**, which is coupled to the range servo and so designed that its effective resistance value is proportional to $1/Al_1$. The voltage from the potentiometer **P12** is connected to a potentiometer **P13**, which is operated in the manner previously described by a servomotor in such a way that its potential division corresponds to the elevation angular velocity $\dot{h}v_1$ of the target. The voltage from the potentiometer **13** is connected to the adder circuit **14**, which adds the two voltages supplied to the circuit in such proportions and with such polarities that the output voltage from the adder circuit corresponds to the value of the Expression 20 given above for the calculated elevation angular acceleration $\ddot{h}v_1$ of the target. The output alternating voltage from the adder circuit **14** is connected to a demodulator **D1** so that a direct voltage signal is obtained as a control signal for the servo-circuit for the elevation of the antenna.

The voltage from the resolver R4 is also connected to a potentiometer **P14**, which is operated in the same manner as the potentiometer **P13** so that its potential division corresponds to the elevation angular velocity $\dot{h}v_1$ of the target. The voltage from the potentiometer **P14** is connected to a potentiometer **P15**, which is coupled to the elevation positioning shaft of the antenna and has such a characteristic or such a gearing to said shaft that its potential division corresponds to $1/\cos hv_1$. The voltage from the potentiometer **P15** is connected to an adder circuit **15**. The voltage from the potentiometer **P12** is also connected to a potentiometer **P16**, which is operated in the same manner as the potentiometers **P9** and **P11** so that its potential division corresponds to the traverse angular velocity $\dot{s}v_1$ of the target. The voltage from the potentiometer **P16** is also connected to the adder circuit **15**, which adds the two input voltages supplied to the circuit in such mutual proportions and with such polarities that the output voltage from the circuit corresponds to the Expression 19 given above for the calculated traverse angular acceleration $\ddot{s}v_1$ of the target. The output alternating voltage from the adder circuit **15** is connected to a demodulator D2 so that a direct voltage is obtained as a control voltage to the servo-circuit for the traverse laying of the antenna.

I claim:

1. An anti-aircraft weapon carrier comprising, in combination, a mobile chassis; a turret mounted on said chassis for rotation about a vertical axis; an anti-aircraft weapon mounted for elevation in said turret; a first servomotor for rotating said turret relative to said chassis and a second servomotor for elevating said weapon relative to said turret; a fire control system including a radar sight including a radar antenna layable in traverse and elevation for determining the position and the velocity of a target in a spheric coordinate system and for generating a first error signal representing the traverse angular devia-

tion between the antenna direction and the direction to the target and a second error signal representing the elevational angular deviation between the antenna direction and the direction to the target; a fire control computer supplied from said radar sight with data with respect to the position and the velocity of the target and arranged to calculate a point of aim for said weapon for firing at the target, said radar antenna being mounted on said turret so as to be layable in traverse and in elevation relative to said turret; a third servomotor for traversing said antenna relative to said turret; a fourth servomotor for elevating said antenna relative to said turret, said first error signal being supplied as a control signal to said third servomotor and said second error signal being supplied as a control signal to said fourth servomotor; a first tachogenerator coupled to said third servomotor; a second tachogenerator coupled to said first servomotor; an angular velocity responsive gyro mounted in said chassis so as to be responsive to the angular velocity of said chassis about an axis parallel to the axis of rotation of said turret, the sum of output signals from said first and second tachogenerators and said angular velocity sensitive gyro being supplied as a negative feedback signal to said third servomotor, said fire control computer being arranged to calculate the traverse angle between the direction to the target and direction to said point of aim; and comparison means for comparing said traverse angle with the traverse angle betwen the antenna direction and the direction of the weapon and producing a signal representing the difference between said two traverse angles, said signal being supplied as a control signal to said first servomotor.

2. An anti-aircraft weapon carrier, comprising in combination, a mobile chassis; a turret mounted on said chassis for rotation about a vertical axis; an anti-aircraft weapon mounted for elevation in said turret; a first servomotor for rotating said turret relative to said chassis and a second servomotor for elevating said weapon relative to said turret; a fire control system comprising a radar sight including a radar antenna layable in traverse and in elevation for determining the position and the velocity of a target in a spheric coordinate system and for generating a first error signal representing the traverse angular deviation between the antenna direction and the direction to the target and a second error signal representing the elevational angular deviation between the antenna direction and the direction to the target; a fire control computer supplied from said radar sight with data regarding the position and the velocity of the target and arranged to calculate from said data a point of aim for said weapon for firing at said target, said radar antenna being mounted on said turret so as to be layable in traverse and in elevation relative to said turret, a third servomotor for traversing said antenna relative to said turret; a fourth servomotor for elevating said antenna relative to said turret, said first error signal being supplied as control signal to said third servomotor and said second error signal being supplied as a control signal to said fourth servomotor; means for determining the traverse angular velocity of said antenna relative to the ground and generating a signal proportional thereto, said signal being supplied as a negative feedback signal to said third servomotor, said fire control computer being arranged to calculate the traverse angle between the direction to the target and the direction to said point of aim; comparison means for comparing said traverse angle with the traverse angle between the antenna direction and the direction of the weapon and for producing a signal representing the difference between said two traverse angles, said signal being supplied as a control signal to said first servomotor, said fire control computer being also arranged to calculate the traverse angular acceleration of the target on the basis of a predetermined assumption regarding the future movement of the target and to produce a signal proportional to said traverse angular acceleration; and an integrator circuit having an input and an output, said signal proportional to the calculated traverse angular acceleration of the target and said first error signal being supplied to the input of said integrator circuit, the output signal from said integrator circuit being supplied to said third servomotor as an additional control signal therefor.

3. An anti-aircraft weapon carrier as claimed in claim 2, wherein said comparison means comprises a first electric resolver having two input windings and an output winding and a rotor mechanically coupled to the traversing system of said antenna, said fire control computer being further arranged to calculate two quantities proportional to the length of the shorter sides respectively of an imaginary right-angled triangle in the horizontal plane having the horizontal distance from the carrier to the point of aim at its hypotenuse and one of its shorter sides coinciding with the horizontal projection of the direction to the target and to produce alternating voltages proportional to said two quantities, said alternating voltages being supplied to said input windings of said electric resolver, the output voltage from the output winding of said resolver being supplied as said control signal to said first servomotor.

4. An anti-aircraft weapon carrier as claimed in claim 2, comprising means for determining the elevational angular velocity of said antenna relative to the ground and producing a signal proportional thereto, said signal being supplied as a negative feedback signal to said fourth servomotor, said fire control computer being arranged to calculate the elevational angular acceleration of the target on the basis of a predetermined assumption regarding the future movement of the target and to produce a signal proportional to said calculated elevation angular acceleration, and a second integrator circuit having an input and an output, said signal proportional to the calculated elevational angular acceleration and said second error signal being supplied to the input of said second integrator circuit, the output signal from said second integrator circuit being supplied to said fourth servomotor as an additional control signal therefor.

5. An anti-aircraft weapon carrier as claimed in claim 4, wherein said means for determining the elevational angular velocity of said antenna relative to the ground comprise a third tachogenerator coupled to said fourth servomotor, and a second angular velocity responsive gyro mounted on a traversing part of said antenna so as to be responsive to the angular velocity in a plane through the traversing axis and the direction of the antenna, the sum of output signals from said third tachogenerator and said second angular velocity responsive gyro being supplied as said negative feedback signal to said fourth servomotor.

6. An anti-aircraft weapon carrier as claimed in claim 4, comprising a second electric resolver having two input windings and an output winding and a rotor coupled to the elevating system of said weapon, said fire control computer being arranged to calculate two quantities proportional to the horizontal distance and the vertical height respectively to said point of aim and to generate alternating voltages proportional to said quantities, said alternating voltages being supplied to the input windings of said second electric resolver, the output voltage from the output winding of said second electric resolver being supplied as a control voltage to said second servomotor.

7. An anti-aircraft weapon carrier as claimed in claim 4, wherein the output signal from said second integrator circuit is supplied to said fire control computer as an input signal therefor representing the elevational angular velocity of the target.

8. An anti-aircraft weapon carrier as claimed in claim 2, wherein the output signal from said integrator circuit is supplied to said fire control computer as an input signal therefor representing the traverse angular velocity of the target.

(References on following page)

**References Cited by the Examiner**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 2,617,982 | 11/1952 | Holschuh et al. | 89—41 |
| 2,660,793 | 12/1953 | Holschuh et al. | 89—41 |
| 2,968,997 | 1/1961 | Newton et al. | 89—41 |
| 3,019,711 | 2/1962 | Bailey et al. | 89—41 |
| 3,086,425 | 4/1963 | Huey | 89—41 |
| 3,135,053 | 6/1964 | Newman et al. | 89—41 |

BENJAMIN A. BORCHELT, *Primary Examiner.*

SAMUEL FEINBERG, *Examiner.*

S. C. BENTLEY, *Assistant Examiner.*