

[54] SCANNING INTERFEROMETER-BEAM RIDER GUIDANCE SYSTEM

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[58] Field of Search.....244/14, 77 B; 114/23; 343/7, 343/7.4

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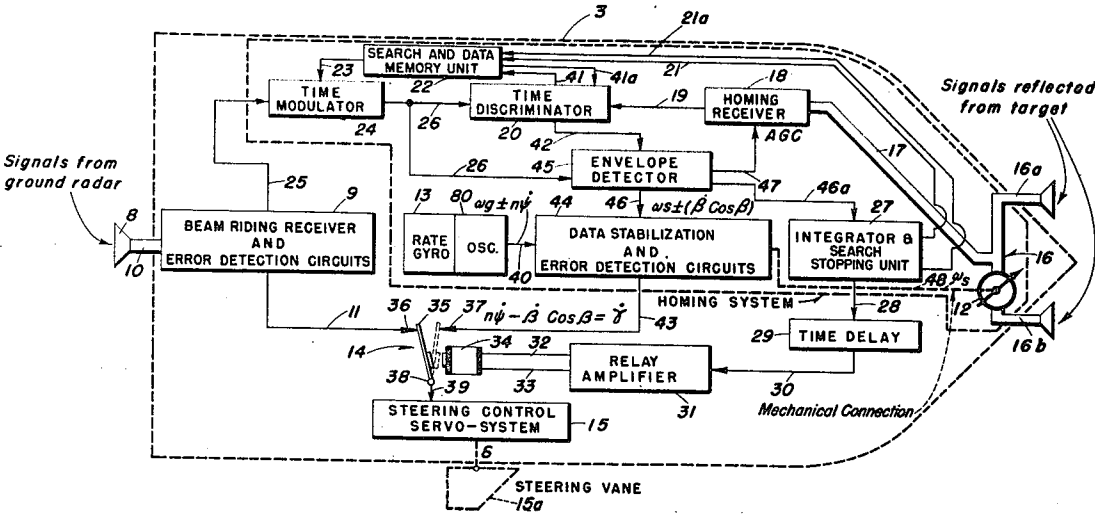
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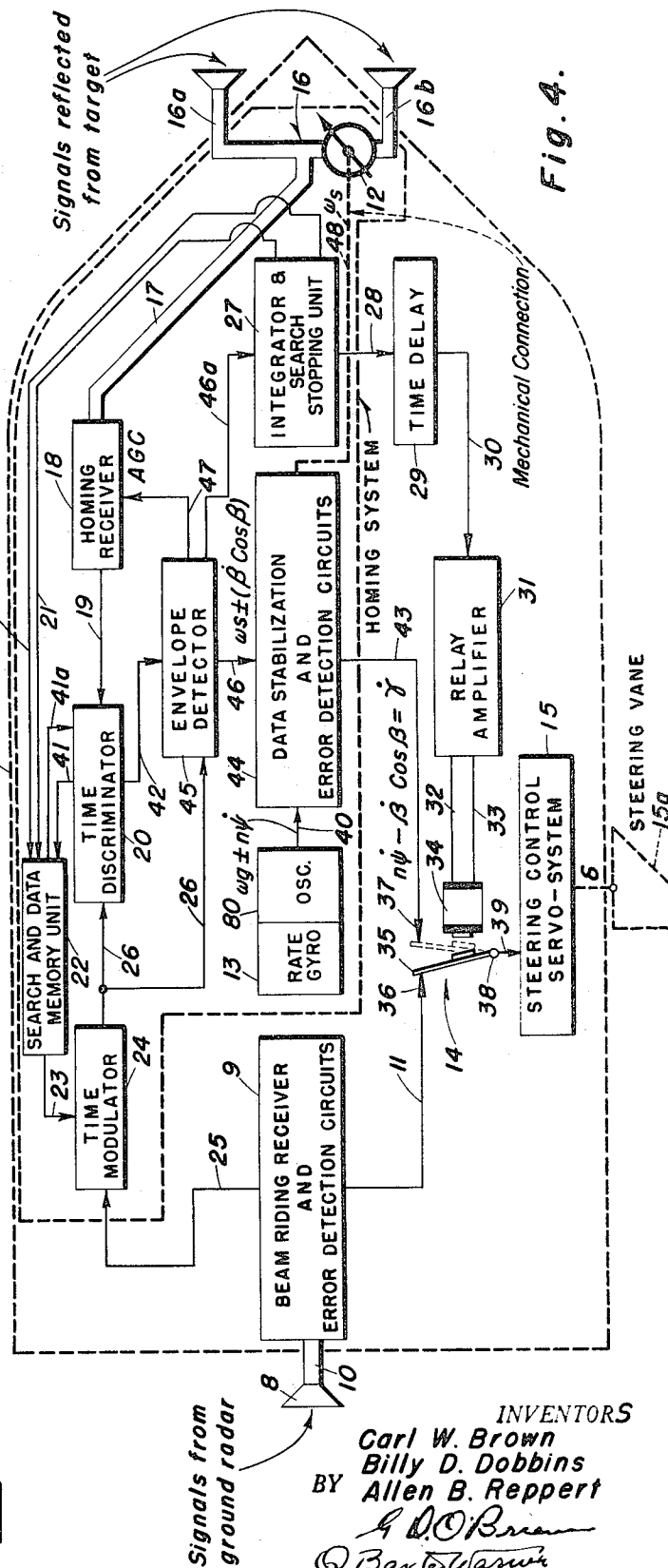
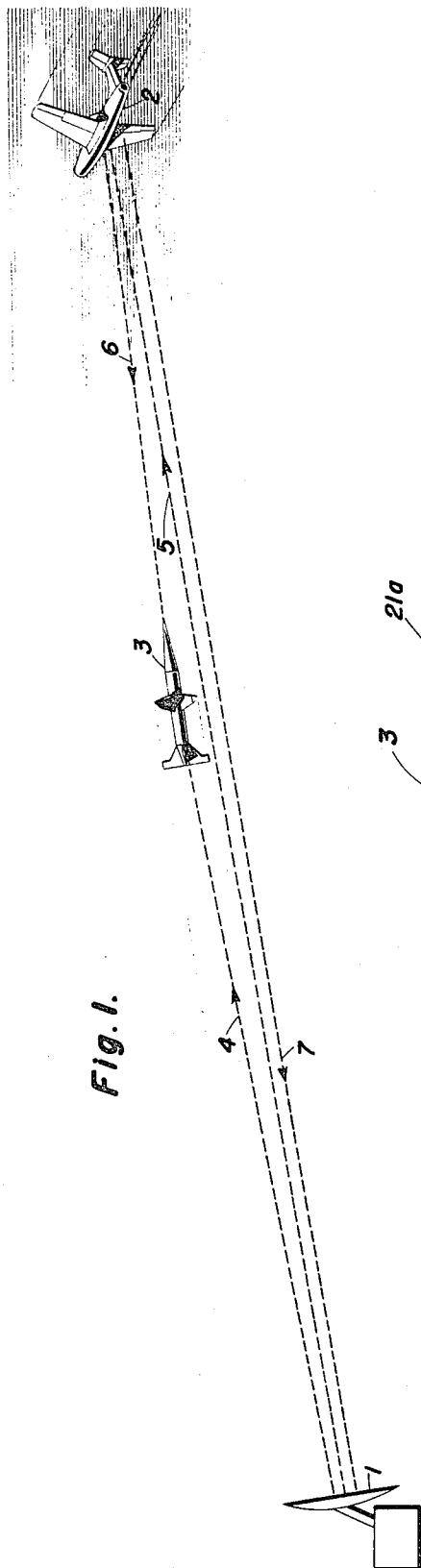
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EXEMPLARY CLAIM

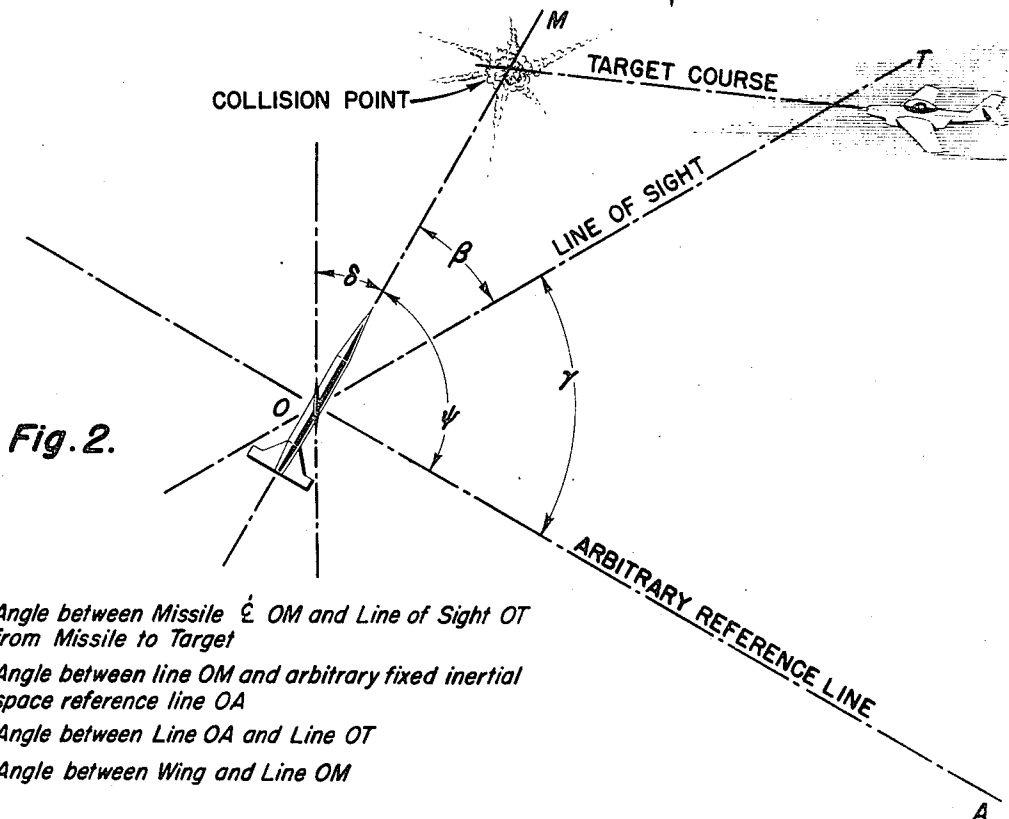
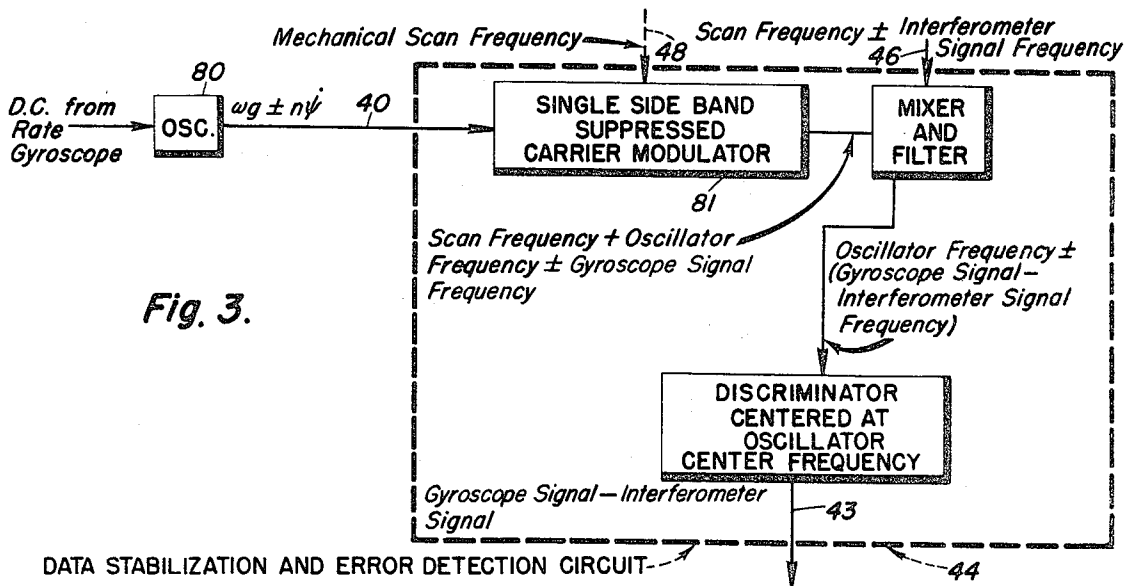
1. A missile guidance system including, in combination with a missile and a source of electromagnetic energy, said source being remote from the missile and projecting a guiding beam, means for maintaining the missile in and under the control of said beam, said means including an antenna mounted on the missile and a receiver connected to the antenna, a steering vane on the missile, a servo for controlling the vane, said servo being responsive to signals entering the receiver through the antenna from the beam, switching means between the receiver and the servo, means in the missile for searching for a target, and means controlled by said last mentioned means and operable in response to a signal reflected from an acquired target for actuating said switching means whereby operation of the servo will be transferred from the first-mentioned means to the reflected-signal operated means for controlling the vane for guiding the missile into the target.

20 Claims, 8 Drawing Figures

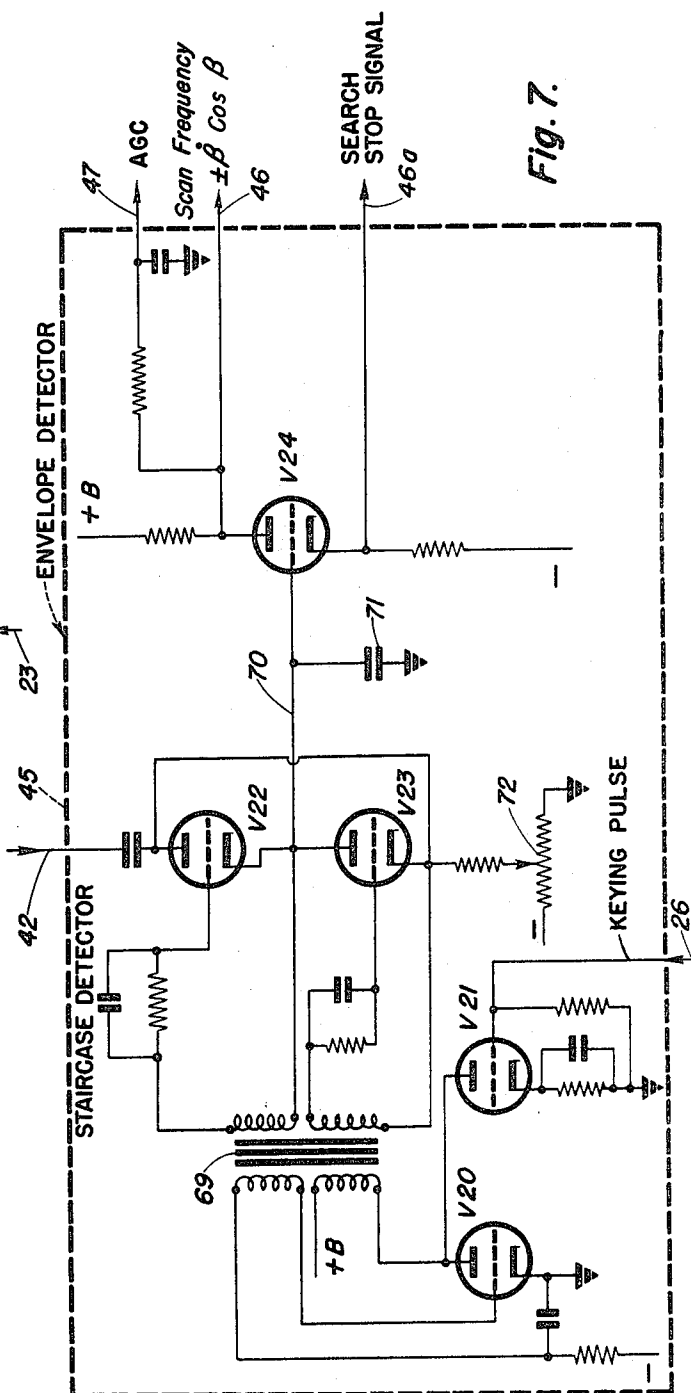
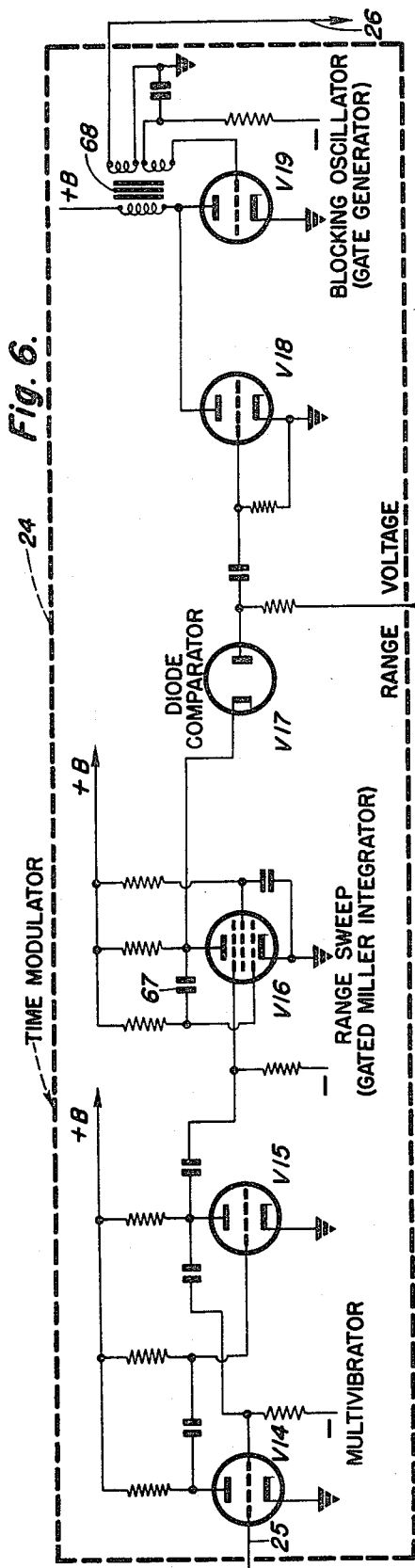




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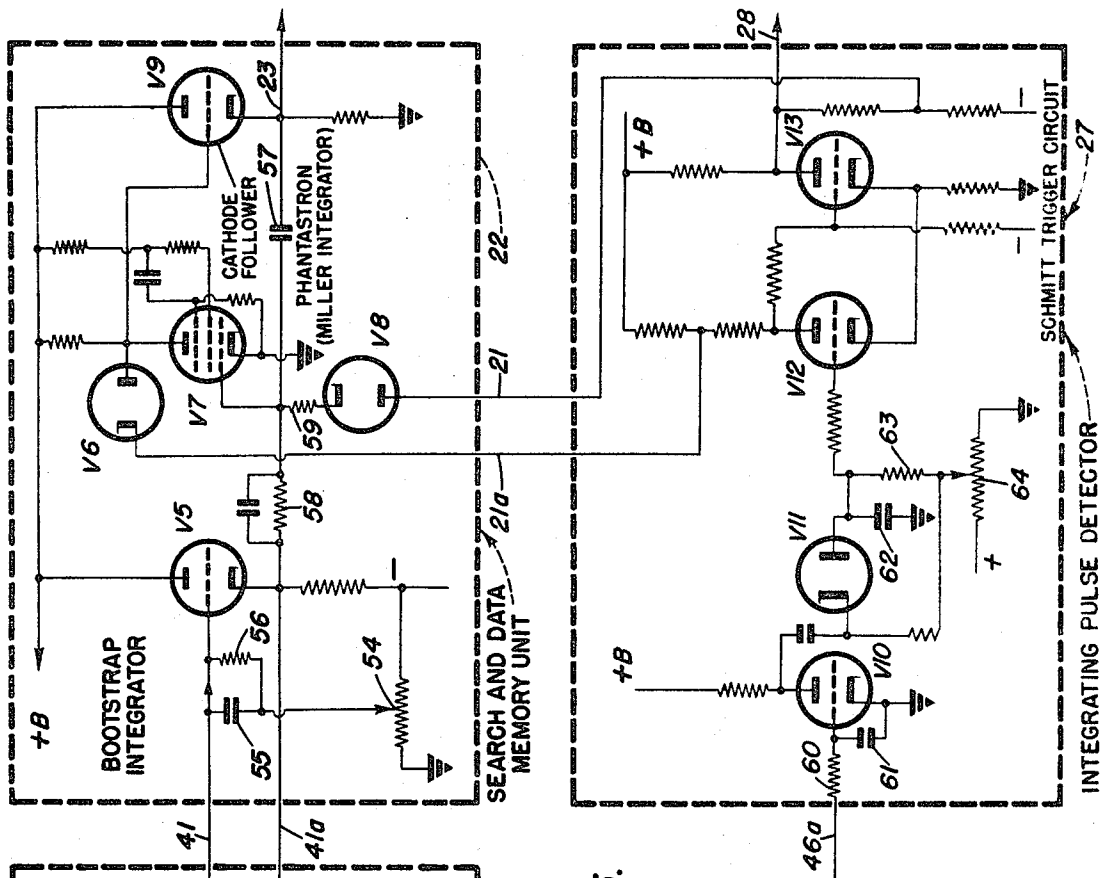


Fig. 5.

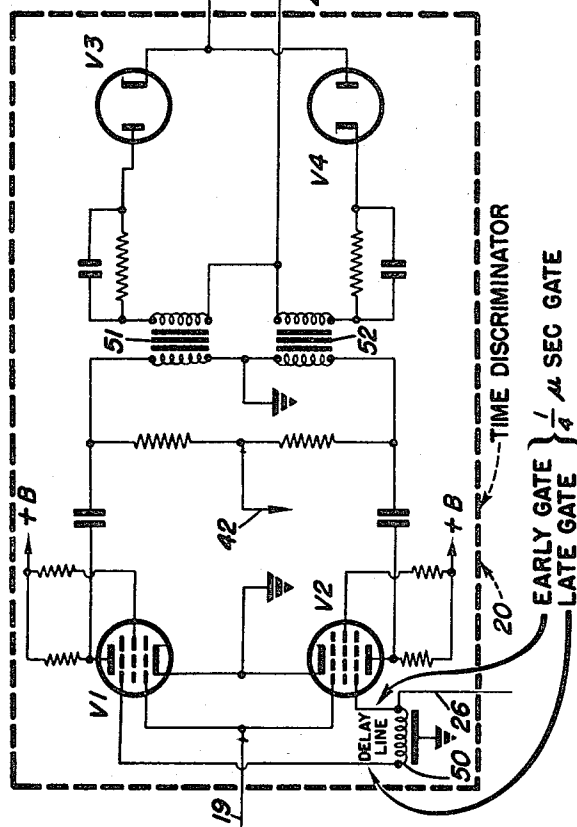
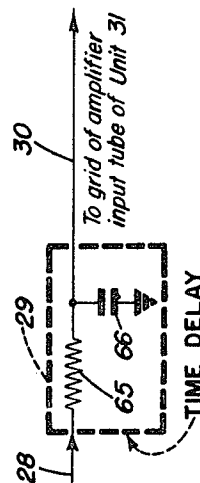


Fig. 8.



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SCANNING INTERFEROMETER-BEAM RIDER GUIDANCE SYSTEM

The present invention relates generally to guidance systems for airborne missiles; more particularly the invention relates to an improved guidance system operable for causing a missile to shift from a condition wherein it is initially guided by electromagnetic signals transmitted directly from a radar station, to a condition wherein, after the missile reaches a point near the target, it will be guided to said target by signals reflected from the target itself.

It has been established that missile warheads have a substantially fixed lethal radius. It is therefore essential that missile guidance error be reduced to an absolute minimum, to effect maximum target damage.

One of the most advanced of the missile guidance systems developed up to the present time is that which employs radar apparatus for tracking a target with a nutating beam of electromagnetic energy, the missile after launching being captured by the beam and guided to the vicinity of the target. This is known as Beam-Rider guidance and is described in U.S. Pat. Application Ser. No. 162,902, filed May 19, 1950, Parkinson et al, inventors, and now U.S. Pat. No. 3,126,172. Inasmuch as the accuracy of such a guidance system depends upon the width of the guiding radar beam, it becomes evident that even with a constant unavoidable minimum angular error of direction, the actual linear error increases proportionally to the distance from the guiding radar. It therefore becomes obvious that the Beam-Rider guidance system is not very effective for long range work.

Moreover, Beam-Riding systems have a fixed angular accuracy with respect to the beam axis, as seen at ground radar. Therefore, the effective area of defense is limited to ranges where the linear error of beam-riding equals the lethal radius of the warhead, in spite of the fact that a missile can be steered by the beam-riding technique, with this constant percentage of error, to points well beyond this useful range.

Missile homing, or target seeking systems, however, receive their intelligence from the target and the error is, like the beam-rider, a function of the range from the target, but because the range to target decreases toward zero, the effectiveness of the missile is increased by the use of a homing system. Missile effectiveness is also independent of the range of the target from the illuminating ground radar, as long as the illuminating energy is of sufficient intensity to provide useable signals to the homing antennas at a range adequate for the necessary corrections in missile trajectory. This minimum range is also a function of the dynamics of the missile and its associated intelligence and control system. It should be noted that a reflected signal from a target is too weak to be usable in a missile until said missile nears the target, because of limited missile antenna size. Thus, the missile cannot "home" on a target all the way from the missile launcher.

By the combination of the beam-rider and the homing guidance systems it is possible to defend many times the area which either system alone could defend. Such a combination of systems imposes new problems, however, and one of these involves the automatic selection of targets for the "homing" phase; another concerns the problem of switch-over from beam-riding operation to guidance by homing intelligence.

Broadly stated, the principal object of the present invention is to provide an improved system for guiding missiles accurately to prospective targets. More specifically, it is an object of the invention to provide a missile guidance system which initially utilizes a beam of electromagnetic energy to guide a missile into the vicinity of one or more targets, then employs means to resolve upon the target or, in the event of the presence of a number of targets, to search for, acquire and resolve upon a single target, and finally effects switching to control by intelligence reflected from the selected target.

Another object of the invention resides in the provision of a missile guidance system by the use of which it will be possible to defend much larger areas than could be protected by missiles controlled by other known types of missile guidance arrangements.

And as another object, the invention provides a guidance system which combines the best features of beam-riding and homing systems, for producing a highly effective means for guiding a missile accurately to a target.

Other objects and many of the attendant advantages of this invention will be appreciated readily as the same becomes understood by reference to the following detailed description, when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a diagrammatic representation showing a missile being guided to a target by the improved guidance system;

FIG. 2 is a diagram illustrating geometrical relationships between a target aircraft and a missile being guided, by the system of the present invention, to collide with the target aircraft;

FIG. 3 is a block diagram of the data stabilization and error detection unit of the system;

FIG. 4 is a block diagram showing the equipment of the system carried by the missile;

FIG. 5 is a circuit diagram showing details of certain units of the equipment illustrated in FIG. 4 namely, the time discriminator, the search and data memory unit, and the integrator and search stopping unit, and their interconnections;

FIG. 6 is a circuit diagram of the time modulator which, with the time discriminator and search and data memory unit, constitutes the automatic range tracking unit of the system;

FIG. 7 is a circuit diagram of the envelope detector unit; and

FIG. 8 is a circuit of the time delay unit of the system.

Referring first to FIG. 1, there is shown a ground radar transmitter-receiver 1 which by means of a directed energy beam is tracking a target 2, here shown as an airplane. A missile 3 is also in the radar energy beam and is receiving guidance signals therefrom. That is, the missile is functioning as a beam-rider. As pointed out hereinabove, such beam-riders have been developed sufficiently to make them adequate for the purposes of the present invention.

The arrows 4, 5 diagrammatically indicate portions of a beam of electromagnetic radiation directed as the missile 3 and at the target 2. The arrow 6 designates radiation reflected from the target 2 and received by missile 3, while arrow 7 indicates radiation reflected from the target 2 and returning to the radar apparatus 1. In general, the beam 4 of electromagnetic radiation emitted by the radar apparatus 1 serves to provide guidance signals to the beam-riding unit in the missile 3, and other radiation of the beam also serves to track the target 2, as indicated by arrows 5 and 7. It will be understood that while for clearness of illustration the lines 4, 5, 6, and 7 are shown spread apart and directed at slightly different angles, in actual service all of said lines would constitute a single beam, during beam-riding guidance of the missile.

Thus, in following the target the radar beam also provides the guidance signals to the missile, to guide the latter in the direction of the target. Reflected radiation 7 is received by the receiver of radar apparatus 1 and thereby permits tracking the target in the usual way. It should be understood, of course, that the missile need not follow the same beam as that which tracks the target, provided that, if two separate beams are used, they are brought into coincidence shortly before homing becomes effective.

FIG. 2 shows the geometry of constant bearing collision trajectory in one plane. In this diagram $\psi = \beta = \gamma$, where ψ equals the angle between the missile trajectory OM and an arbitrary reference line OA, β equals the angle between the missile 0 and the line-of-sight OT from missile to target, and γ equals the angle between the line-of-sight from the missile to the target and arbitrary reference line OA. That is, γ is a space angle which must be held constant for perfect steering. The angle γ is determined by measuring the angle ψ off the missile axis, by gyroscopic means, and by determining the angle β by the use of an interferometer or other radio direction finding system.

Adequate instrumentation may also be provided by measuring the rates of change of ψ and β , since unequal rates of change of these two angles is accompanied by a change in γ .

Referring again to FIG. 1, reflected radiation is received from the target at the missile. While the missile is still very far from the target, the radiation 6 is too weak to affect the control mechanism of the missile. This is due to a considerable extent to the fact that a missile cannot carry an antenna of sufficient size to provide adequate long-range response. However, as the missile travels toward the target, the amplitude of the received reflected radiation 6 increases. By an automatic target search and acquisition unit and automatic switch-over apparatus, both to be described hereinafter, the control of the missile switches from the beam-riding to homing.

The above concludes the general description of the operation of the invention, which will now be disclosed in detail.

It will be understood that not all the units designated by the "blocks" of FIG. 4 are disclosed in detail herein, for the reason that certain of said units are merely conventional. It will also be understood that in most cases only the basic circuits of the units are disclosed and that in actual practice the units will also contain additional electronic equipment, such as amplifiers, power supplies, etc., which has been omitted to emphasize the essential basic components.

Referring to FIG. 4, it will be noted that the missile has two electronic systems leading to the same mechanical servo system 15 that controls the missile wings.

One of these electronic systems deals with the operation of the missile as a beam-rider, and has an antenna 8 at the rear end of the missile. This system includes a beam-rider microwave receiver 9 connected to antenna 8 by waveguide 10. This beam-rider receiver ordinarily will include a microwave pulse receiver, a decoder and error detection circuits.

When the missile is beam-riding, the steering signal from the ground radar is proportional to the missile's angular displacement (error) from the axis of the radar beam and is also a function of the rate of change of said error. In the homing condition the steering signal is proportional to the rate of turn of the line of sight from missile to target.

The error output of the receiver 9 is fed through conductive means 11 to a fixed contact 36 of a relay 14 and through movable armature 35 of said relay, pivoted at 38, and conductor 39 to the steering control servo system 15. The system 15 operates appropriate steering means of the missile 3, such as a vane 15a, in such ways as to minimize the angular position error of the missile with respect to the beam centerline. Thus, while the relay armature 35 is in the full line position shown in FIG. 4, the missile 3 is maintained in beam-riding condition, wherein the direct beam 4 from radar 1 has exclusive control of the path of said missile.

It may be noted here briefly that a tap 25 is taken off the beam-riding receiver 9 and delivers reference timing pulses to one of the units of the second electronic system of the missile; the purpose of this will be described in the following discussion of said second system, which relates to the operation of the missile as a homing device.

As seen in FIG. 4, at the forward end of missile 3 there is an antenna system 16 connected by waveguide 17 to a homing microwave receiver 18. This antenna system comprises two antennas 16a and 16b connected to a common waveguide 17 wherein an interference effect results. In series with one of the antennas 16b, there is shown a phase shifter 12, whereby the interference pattern of the combined received radiation of the two antennas 16a and 16b jointly is scanned in angular space. The antenna system 16 thus constitutes a part of a scanning interferometer. The signal output of receiver 18 is fed by suitable electrical connecting means 19 to the time discriminator 20. This time discriminator is shown schematically in FIG. 5 and may be a conventional split-gate and difference detector circuit. The discriminator includes a pair of electronic gate tubes operated in such a manner that signal current may be caused to flow in its output circuit whenever a gating pulse is

received from a time modulator 24 (FIG. 4) through conductor 26, if the gating pulse and signal are time coincident.

Referring to FIG. 5, the time discriminator 20 comprises the pentodes V_1 and V_2 and diodes V_3 and V_4 , connected as shown. A signal arriving through conductor 19 passes to the control grids of said pentodes V_1 and V_2 . In order to determine the time position of this signal, gate pulses of equal durations but sequential in time are applied to the No. 3 grids of V_1 and V_2 from conductor 26. A delay line 50 has one terminal connected to conductor 26 and to the No. 3 grid of V_2 and its other terminal connected to the No. 3 grid of V_1 , thus providing a delay between these two grids equal to that of the delay line, which delay in turn is equal to the length of gating pulse delivered over line 26.

The summation output of V_1 and V_2 is delivered through conductor 42 to a detector unit 45, to be discussed hereinafter. The circuit further includes a pair of transformers 51 and 52 with their primary windings connected to the output leads of pentodes V_1 and V_2 and their secondary windings to the diodes V_3 and V_4 which yield a difference output to the conductors 41 and 41a, connected to a search and data memory unit 22 to be described hereinafter.

The output of the discriminator 20 represents the misalignment of the gating pulse and the signal from receiver 18 and is fed to the unit 22 through a conductive path 41. A component representing the sum of the outputs of the two electronic gate pentodes V_1 and V_2 is fed to the detector unit 45 through the conductive path 42.

It may be observed that each reference timing pulse delivered by the beam-rider receiver 9 through conductive means 25 will cause the time modulator 24 to emit a corresponding but delayed gating pulse to the time discriminator 20. The amount of delay is determined by the amplitude of a control voltage applied to said modulator 24 from the search and data memory unit 22. Further, this reference timing pulse occurs at the exact instant the main radar pulse energy passes the missile on its trip up the beam toward the target and thus serves as the beginning of time for the measurement of the travel time of the radar pulse from the missile to the target and the echo return; i.e., the measurement of the range to the target. The action here described is that of the well known single-scaled time modulation circuit and may be secured by various conventional means.

In the present embodiment, this time modulation circuit, FIG. 6, comprises a multivibrator including the tubes V_{14} and V_{15} which will deliver a pulse of square wave types whenever the grid of V_{14} is triggered. V_{16} is normally biased to cut-off, and becomes conductive when the pulse is received on its No. 3 grid, from the multivibrator. While the tube is at cut-off, the anode is at full +B potential while grid No. 1 is essentially at cathode potential. When anode current starts to flow, the potential of No. 1 grid will gradually become more negative, since this grid is coupled to the anode through capacitor 67. This action continues only until a stable condition is reached, with the No. 1 grid a few volts negative with respect to the cathode of tube V_{16} . The anode voltage now falls linearly for an interval equal to the length of the square pulse. This produces a corresponding gradual drop in the potential of the cathode of a comparator tube V_{17} , a diode. When the potential of the cathode of V_{17} falls below its anode voltage, provided through conductor 23 from unit 22, said diode V_{17} becomes conducting and then its anode drops in voltage with its cathode. As this voltage drop is coupled to the grid of a triode V_{18} , it cuts off V_{18} and trips a blocking oscillator tube V_{19} , to start its oscillation. The blocking oscillator includes, in addition to tube V_{19} , a transformer 68 having a primary and two secondaries. The blocking oscillator output consists of a single pulse of a duration which in this case is one-fourth microsecond and is determined by the characteristics of the transformer 68. This blocking oscillator, the generates the delayed gate pulse which is delivered through conductor 26 to unit 20.

The search and data memory unit 22 performs a dual function. Before a target echo appears in the gate of the time discriminator 20, the unit provides a signal to the time modulator 24 by conductive means 23 to systematically vary the delay of the time modulator output gating pulse with respect to the reference timing pulse from receiver 9, and thus positions the time discriminator gate for successive incremental ranges of possible target position beyond the missile. This is the range search process. A distinctive feature in this unit 22 is that it is designed for the high closing velocities between guided missiles and their targets. Therefore, the first several thousand feet of range ahead of the missile is not searched because the times of response and maneuverability of the missile are inadequate to permit making a useful correction in the missile trajectory if a target were encountered within this range. Further, within his internal false signals may be received because of side lobe illumination of large objects in the vicinity of the radar.

The second function of this search and data memory unit 22 is to receive by conductive means 41 the difference component of the gate output of the time discriminator 20 and to recognize the presence of a signal passing through the gate and thereafter to maintain the alinement of the gate with the signal by the aforementioned conductive means 23.

FIG. 5 shows the circuit of this unit 22, as well as those of units 20 and 27, the latter being an integrator and search stopping unit, to be described in more detail hereinafter. In unit 22, tube V_5 is a triode connected to provide a "bootstrap" integrator, that is, an integrating circuit of the RC type wherein the error that is characteristic of the simple RC type integrator is reduced by keeping the voltage difference between two terminals constant by feedback from one terminal to the other. In such circuits, the input current may be made independent of the voltage on the integrating capacitor by adding the capacitor voltage to the source voltage. The difference component from the time discriminator 20 is impressed between its grid and cathode through conductors 41, 41a respectively, if the signals coming from receiver 18 are time-coincident with gating pulses from the time modulator 24. Capacitor 55 and resistor 56 provide the RC time constant.

When signals from receiver 18 are absent or are not time-coincident with the gating pulses from time modulator 24, there will be no difference output from the time discriminator 20 and the grid of V_5 will remain at some preset bias level, as determined by a voltage divider 54. In FIG. 5, tubes V_7 and V_9 constitute a "phantastron" sweep generator. This circuit has the characteristic of producing a voltage of sawtooth wave form at the cathode of tube V_9 . The return sweep or "fly-back" time is determined primarily by the value of a capacitor 57 and the output impedance of tube V_9 , operating as a cathode follower, while the linear rundown rate has a slope determined by the capacitor 57, resistors 58 and 59, and the voltages present at the cathode of tube V_5 and upon conductor 21 from the integrator and search stopping unit 27.

The integrator and search stopping unit 27 includes triodes V_{10} , V_{12} and V_{13} , and a diode V_{11} . The output of an envelope detector 45, shown in FIG. 7 and to be described hereinafter, is fed to the grid of triode V_{10} through a resistor 60. The resistor 60, with a capacitor 61, forms a filter circuit having a time constant equal to several pulse intervals, so that the output of the envelope detector is integrated over several pulse intervals. Thus, true time-coherent received signals may be more readily distinguishable from random noise, the latter tending to integrate to zero or a constant low level, while said true, time-coherent signals vary in amplitude only as a function of signal strength and interferometer scan modulation percentage.

In the unit 27, triode V_{10} is an amplifier; diode V_{11} , capacitor 62 and resistor 63 constitute a peak detector having a charging time constant sufficiently short to follow the output of the filter 60, 61, but having a much longer discharge time constant so that capacitor 62 will retain a sufficient amount of

its charge even though the signal may fade briefly from time to time. The unit 27 also includes a two-way comparator Schmitt trigger circuit) for indicating whether a waveform approaches a reference voltage from larger or smaller values. The comparator is a bi-stable multivibrator consisting of two triodes V_{12} and V_{13} (FIG. 5) whose conducting position is determined by the polarity of the control signal with respect to a predetermined threshold. Here triode V_{12} is biased from a voltage divider 64 to such voltage that it is normally conducting. Under these conditions triode V_{13} will be cut off. Appearance of a signal of sufficient magnitude from the peak detector drives the grid of triode V_{12} negative and this triode is cut off, and triode V_{13} becomes conducting. This action is regenerative and occurs very rapidly after a threshold voltage has been reached at the grid of triode V_{12} . This regenerative action also takes place in the reverse manner when the voltage at the grid of triode V_{12} is raised. The action of triodes V_{12} and V_{13} produces the required voltage changes on conductors 21 and 21a, the voltage on conductor 21 becoming negative when a sufficient signal appears at the output of the envelope detector on conductor 46a (the voltage on conductor 21a simultaneously becoming positive). The negative step in voltage appearing at the anode of tube V_{13} at this time is fed, by suitable conductive means 28, to a time delay unit 29.

The time delay unit 29 is shown in FIG. 8, and consists simply of a resistor 5 and a capacitor 66. The time delay unit 29 functions for converting the step function change in voltage supplied from the integrator and search stopping unit 27 to an exponential decay of voltage, to feed relay amplifier 31 (FIG. 4) through conducting means 30.

A sawtooth voltage at the cathode of tube V_9 is fed to the time modulator 24 (FIG. 6) by the conductor 23, to control the delay time of the gating pulses produced in the said time modulator, resulting in the above-mentioned range search procedure. The diode V_6 in the search and data memory unit (FIG. 5) has a bias impressed upon its cathode through conductor 21a from unit 27, of such value that the voltage on the anode of pentode V_7 cannot rise above the bias level of the cathode of said diode V_6 . By suitable adjustment of this bias, the first several thousand feet of range ahead of the missile will be unsearched, as mentioned hereinbefore.

The action that occurs during the range search procedure will now be understood. Upon the appearance of signals from the receiver 18 which are time-coincident with the gating pulses from the time modulator 24, the action is changed by suitable signals supplied through the conductive means 21 and 21a from the integrator and search stopping unit 27. When such coincidence occurs, the voltage at the anode of diode V_8 is made much more negative than the normal operating bias of the control grid of pentode V_7 and thus diode V_8 becomes non-conducting.

The phantastron "rundown rate", in the unit 22, is now controlled only by capacitor 57, resistor 58 and the voltage at the cathode of V_5 . This last-named voltage has up to this point been determined by the grid bias as set by means of voltage divider 54, but now a difference component of voltage from the time discriminator 20 is applied between conductors 41 and 41a, so that the rate of anode voltage change of the phantastron is now controlled by this difference component. Tubes V_5 , V_7 and V_9 now function as a conventional double-integrator circuit, to maintain the alinement of the gating pulses with the received signals. At the same time, the voltage at the cathode of diode V_6 is raised by the action of the integrator and search stopping unit 27, through conductor 21a, so that the anode voltage on pentode V_7 of the phantastron is no longer restricted, thus removing the minimum range restriction which prevails during the range-search procedure.

The envelope detector 45 is shown in FIG. 7. In its circuits, transformer respectively, triodes last the triode V_{20} , in conjunction with the transformer 69, constitutes a blocking oscillator which delivers a single short pulse whenever the companion triode V_{21} receives a keying pulse through conductor 26, from the oscillator 19 in the time modulation unit 24 (FIG.

6). This transformer 69 has two input windings connected, respectively to the triode V_{20} and V_{21} as indicated, and two output windings from which it delivers a single pulse to the grids of triodes V_{22} and V_{23} , rendering said last named pair of triodes conductive for the duration of said pulse.

In the intervals between pulses, triodes V_{22} and V_{23} are biased to cut-off by reason of the grid leak, grid capacitor circuits shown, and as a result of the grid current that flowed during the preceding pulse. A bias adjusting voltage divider is shown at 72. When a pulse enters, the cut-off is terminated, and current flows, thus readjusting the potential of the conductor 70 to become equal to that then existing on conductor 42, and this in turn establishes the voltage of the capacitor 71. Said last-named voltage is applied to the grid of triode V_{24} which tube provides the final output of the envelope detector 45.

The envelope detector 45 receives, through conductive means 42, the sum component of the output of the time discriminator 20 (FIG. 5). This sum component consists of pulses occurring at the ground radar repetition rate, a pulse appearing each time the electronic gate pentodes V_1 and V_2 in said time discriminator 20 are gated "on" by a gating pulse through conductor 26 from the time modulator 24. In the absence of time-coincidence between the gating pulses and a signal from the homing receiver 18, these output pulses have random amplitudes corresponding to the noise output of the homing receiver. Should a signal appear from the homing receiver which is time-coincident with the gating pulses, then the pulses being fed to the envelope detector 45 are proportional in amplitude to the signal amplitude which varies in manner determined by the scanning interferometer action.

The purpose of the envelope detector 45, then, is to reproduce the amplitude modulation present on the pulses coming into it through conductor 42. It is typically a "staircase" detector or recycling detector in which the output rises to a value proportional to the input pulse amplitude and remains at this level until the next pulse appears, when the output immediately rises or falls to a value corresponding to this new pulse amplitude. The keying pulse which is required for this type of circuit is supplied, as previously stated, from the time modulator 24, through conductive means 26. The various outputs through conductors 46, 46a and 47 from the envelope detector differ only in the degree of filtering applied. Thus, one component of the output is suitably filtered and returned to the homing receiver 18 through conductor 47 as an automatic gain control voltage AGC, while another component after suitable filtering passes through conductor 46 to the data stabilization and error detection circuits unit 44. A third component is passed through 46a to the unit 27, for three purposes, namely, (1) to stop the searching operation (to complete the acquisition of the target); (2) to remove the minimum range restriction which prevails during the range-search procedure; (3) provide a signal for operation of switch-over mechanism from beam-riding to homing.

The data stabilization and error detection circuit 44, shown in block diagram in FIG. 3, comprises an oscillator 80 which receives a signal from the rate gyroscope 13 (FIG. 4), whereby the oscillator output frequency is deviated by an amount corresponding to the rate gyroscope precession. The direction of the frequency deviation is determined by the direction of the gyroscope precession. This composite or frequency modulated oscillator signal then enters a single side band suppressed carrier modulator 81 where it is mixed with the mechanical scan frequency corresponding to that of the phase shifter 12 (FIG. 4), as transmitted through a mechanical connection, shown as a broken line 48.

The resultant is thus the scan frequency plus the oscillator frequency plus or minus the gyroscope signal frequency deviation and this resultant is passed to the combined mixer and filter unit. Here enters also, through conductor 46, the frequency which is equal to the scan frequency plus or minus the interferometer signal frequency deviation derived from interferometer 16, 17. The mixing process utilizes the difference

of these two inputs and so yields as an output the oscillator frequency plus or minus the gyroscope signal frequency deviation minus the interferometer signal frequency deviation. This output passes to the discriminator centered at the oscillator center frequency and through 43 yields the final output $\dot{\gamma}$ representing $n\dot{\psi} - \beta \cos \beta$ which is the "error signal" for entry into the steering control servo-system 15. The factor n is introduced to equate the space degrees of the gyroscope to the electrical degrees of the interferometer.

The above describes the function of the apparatus necessary to provide a homing signal. The operation of the switch-over means, by which the missile steering is converted from a beam-riding to a homing device, will now be described.

Upon growth of sufficient output from the delay unit 29, the relay amplifier 31, which receives said output through conductor 30, will cause an amplified current to flow through conductors 32 and 33 and winding 34 of the relay 14. Energization of the winding 34 will cause the free end of armature 35 of said relay, which is pivoted at 38, to leave the contact 36 and move to the contact 37, thereby switching the control of the missile to the homing circuit. The purpose of the delay unit 29 is to defer switch-over of missile control from beam-riding to homing until after the homing system has demonstrated that the signal reflected from the target is of adequate strength and continuity to ensure successful operation.

The actual switching occurs in that now the signals from homing receiver 18, after passing through time discriminator 20, travel through path 42 to the envelope detector 45. From the envelope detector 45 signals are fed through path 46 to the data stabilization and error detector circuits unit 44. These signals consist of the scanning frequency, determined by the motor driven phase shifter 12 plus or minus the interferometer rate signals $\beta \cos \beta$ of the relative target and missile motions. The rate gyroscope 13 provides a signal output $\omega g \pm n\dot{\psi}$ to unit 44 through the conductive path 40, when the missile turns in space, and thus permits the relative motion component due to the missile yaw (motion of the missile about its center of gravity which includes its longitudinal axis and the target in the same plane) to be eliminated, thus leaving only the signal due to true target motion. This signal produces a single side-band suppressed carrier output frequency from the oscillator in gyro 13. The direction of frequency deviation is determined by the direction of turn of the missile while the magnitude of the frequency deviation is proportional to the rate of missile turn. The oscillator output frequency is then added to the scanning frequency by electromechanical means. The connection 48 introduces the scan frequency into unit 44 by mechanical means, although it will be understood that alternatively wholly electronic means may be substituted. The resulting signal frequency is then combined with the signal frequency from the envelope detector 45 to produce a new signal frequency containing the interferometer signal frequency, corrected by the gyroscope signal frequency for missile motion. The resulting intelligence signal frequency is measured by a discriminator centered at the oscillator frequency. The discriminator output is the steering signal. It is fed through conductive means 43 to the relay contact 37 and finally through path 39 to the steering control servo system 15, which initially was operatively connected to the beam riding circuit. It should be understood, of course, that for operation in two planes, two homing systems must be used, although only one range unit and one beam-riding system are needed for such two plane operation.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A missile guidance system including, in combination with a missile and a source of electromagnetic energy, said source being remote from the missile and projecting a guiding beam, means for maintaining the missile in and under the control of

said beam, said means including an antenna mounted on the missile and a receiver connected to the antenna, a steering vane on the missile, a servo for controlling the vane, said servo being responsive to signals entering the receiver through the antenna from the beam, switching means between the receiver and the servo, means in the missile for searching for a target, and means controlled by said last mentioned means and operable in response to a signal reflected from an acquired target for actuating said switching means whereby operation of the servo will be transferred from the first-mentioned means to the reflected-signal operated means for controlling the vane or guiding the missile into the target.

2. In combination with a guided missile, a guidance system including a receiver carried by the missile, a steering vane-operating servo system carried by the missile and controlled by said receiver, whereby beamed signals impinging on said receiver will cause the receiver to actuate the servo system to maintain the missile in the beam, a second receiver carried by the missile and responsive to signals reflected from a target being tracked by the beam, and means for switching the control of the servo system to the second receiver when said reflected signals exceed a predetermined amplitude, said last mentioned means including target search and acquisition apparatus controlled by pulses from the first receiver.

3. In a missile guidance system, a missile, a beam-riding receiver, an antenna system carried by said missile and connected to said receiver, a steering vane controlling servo, means connected with the receiver whereby said receiver actuates said servo in response to signals beamed on a target, to keep the missile in the beam, a homing receiver in the missile, a second antenna system in the missile and connected to said homing receiver, said homing receiver being responsive to signals reflected from the target, and means for switching said servo from control by the beam-riding receiver to control by the homing receiver upon increase of the amplitude of the reflected signals to a value above a preset level, for guiding the missile into the target.

4. In a missile guidance system, a missile, a beam-riding receiver carried by the missile, an antenna system connected to said receiver, a vane-operating servo system carried by the missile and controlled by the receiver, said servo system functioning to maintain the missile in a beam of electromagnetic energy tracking a target, a homing receiver carried by the missile, a second antenna on the missile and connected to the homing receiver, said homing receiver being responsive to signals reflected by the target, and apparatus operated by an impulse from the first receiver for switching control of the servo system to operation in response to target-reflected signals, whereby the missile will be guided into the target.

5. In a missile guidance system as recited in claim 4, wherein said apparatus includes means on the beam-riding receiver for providing timed pulses, and means utilizing said pulses for determining the optimum time for switching control of the servo system.

6. In a missile guidance system as recited in claim 5, wherein said last mentioned means includes a search unit, a time modulator, and a time discriminator including a gate, said search unit, time modulator and time discriminator being interconnected and said time discriminator being connected to the homing receiver.

7. In a missile guidance system, a missile, a receiver carried by the missile and providing reference impulses, an antenna system carried by the missile and connected to the receiver, a vane controlling servo system connected to the receiver, said servo system being operated by the receiver upon receipt by said receiver of energy from an electromagnetic beam, homing guidance apparatus including a homing receiver carried by the missile, a pair of antennas on the missile and connected to the homing receiver, a phase shifter connected between the last mentioned antennas and providing interferometer scanning action of signals in a target area, means operated by an impulse from the first-mentioned receiver for searching for and acquiring a target in the area, means for stopping opera-

tion of said last-mentioned means upon acquisition of a target, and means for switching the servo system from the first mentioned receiver to said homing guidance apparatus upon target acquisition for guiding the missile into the target.

8. A missile guidance system including, in combination with a missile having a receiver, an antenna on the missile and connected to the receiver, said antenna conducting to said receiver signals from a beam of electromagnetic energy searching a target area, a steering control servo system having a steering vane, and means connecting the receiver to the servo system and including a relay, said receiver producing reference timing pulses and said receiver and servo system maintaining the missile in the beam; missile homing guidance apparatus comprising a homing receiver, an antenna on the missile for conducting to said homing receiver signals reflected from a target, a time discriminator, a time modulator receiving pulses from the first mentioned receiver and feeding delayed pulses to the time discriminator, said discriminator including a gate, a search and data memory unit coupled to the discriminator and to the modulator and operable for positioning the gate for sampling target-reflected signals from the homing receiver, whereby the range ahead of the missile will be searched for an acceptable target, an envelope detector coupled to the time modulator, time discriminator and receiver, means coupled to the envelope detector and operable for arresting operation of the searching process upon acquisition of an acceptable target, means coupled to said detector and to said last mentioned means for providing homing control signals, and means including said last mentioned means and said relay for switching control from said first mentioned receiver to said missile homing guidance apparatus, whereby the missile will be guided into the accepted target.

9. In a missile guidance system, a missile, means on the missile for maintaining said missile in a beam of electromagnetic energy searching a target area, said means including a receiver producing reference timing pulses and a steering vane controlling servo system; homing guidance apparatus including a time modulator receiving reference timing pulses from said receiver and generating delayed gating pulses, a time discriminator including a gate, a homing receiver supplying target-reflected signals to the gate, a search and data memory unit cooperating with said modulator and discriminator for searching the range ahead of the missile for a target, search stop apparatus for stopping the search process upon target acquisition, an envelope detector for operating the search stop apparatus upon target acquisition, in response to a signal passing through the gate, and means for switching operation of the servo mechanism to respond to signals from the homing receiver after target acquisition.

10. In a missile guidance system, a missile, means on the missile and initially maintaining said missile in a beam of electromagnetic energy searching a target area, and means on the missile and responsive to signals reflected from a target in the area for guiding the missile into said target after said missile has reached the vicinity thereof, said last mentioned means including a servo system initially under the control of said first mentioned means, apparatus under control of said first-mentioned means and operative for searching for and acquiring the target, means for stopping operation of said apparatus upon target acquisition, and means for switching servo system control to said second mentioned means after target acquisition.

11. A missile guidance system as recited in claim 10, wherein said last mentioned means includes a homing receiver, an interferometer antenna system connected to the homing receiver, a relay for operating the servo system control switching, and apparatus operated by the homing receiver for actuating the relay.

12. A missile guidance system as recited in claim 11, wherein said relay actuating apparatus includes a detector connected with the homing receiver, and stabilization and error detection circuits connected between the detector and the relay.

13. A missile guidance system as recited in claim 11, wherein said relay actuating apparatus includes an amplifier and a time delay circuit connected between the relay and the means for stopping operation of the target search and acquisition apparatus.

14. A missile guidance system as recited in claim 9, wherein said envelope detector includes means for supplying a pulse constituting a homing guidance signal, means for providing an automatic gain control voltage for the homing receiver, and means for supplying a voltage for operating the search stop apparatus.

15. A missile guidance system as recited in claim 9, wherein said time modulator includes a multi-vibrator coupled to the first mentioned receiver and receiving the reference timing pulses therefrom, an integrator coupled to the multivibrator, a blocking oscillator, and a diode comparator connected between the blocking oscillator and the integrator, said comparator supplying range voltage to the search and data memory unit and said blocking oscillator supplying a gate control voltage to the time modulator.

16. A missile guidance system including, in combination with a missile having a receiver, and a steering control servo system connected with the receiver, said receiver initially cooperating with the servo system for keeping the missile in a beam of electromagnetic energy searching a target area, said receiver having a source of reference pulses, means for searching the range ahead of the missile for a target in the area, said means including a homing receiver, a gate and apparatus operable partially by said reference pulses for intermittently opening the gate, and apparatus for utilizing a signal reflected from an acceptable target and passing the gate for assuming control of the missile from the first mentioned receiver when the missile approaches the vicinity of said acceptable target, whereby said missile will be guided into the target.

17. A missile guidance system as recited in claim 16, wherein said last mentioned apparatus includes a time modulator emitting delayed gating pulses, a search and data memory unit comprising a double integrator, and a time discriminator, said search and data memory unit setting said time discriminator for successive ranges of target position and aligning the gate to a target signal, said time modulator, time discriminator and search and data memory unit being interconnected.

18. A missile guidance system as recited in claim 17, including additionally an envelope detector consisting of a blocking oscillator and a cathode follower, means for stopping operation of the range search means, and means supplying a homing signal pulse for operating the missile servo system, said envelope detector supplying a search stop signal to the range search stopping means, automatic gain control voltage to the homing receiver and a keying pulse to the homing signal pulse supply means.

19. In a missile guidance system, means for searching the range beyond a predetermined minimum distance ahead of a traveling missile for a target, and means operable by said first mentioned means for removing the minimum range restriction from the range searching means upon target acquisition, said first mentioned means being actuated by a pulse signal emitted from a point remote from the missile.

20. In a guided missile, a guidance system including means for causing the missile to follow a target-tracking beam of electromagnetic energy emitted from a point remote from the missile until said missile reaches the vicinity of a target, said beam containing a reference signal, and means on the missile and operated by said reference signal and by signals reflected from the target for causing the missile to be guided into the target.

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