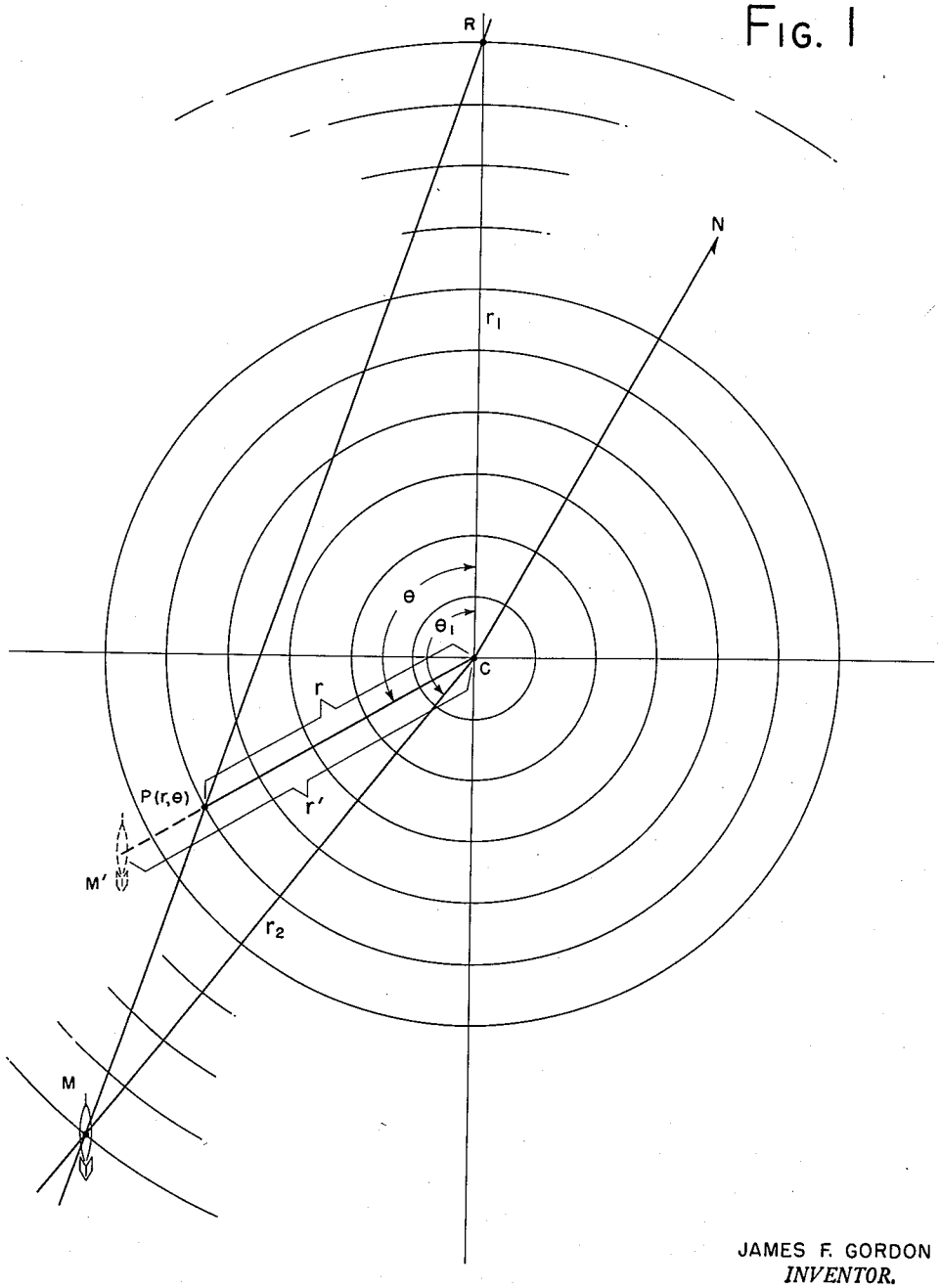
Feb. 2, 1960 J. F. GORDON 2,923,496

SINGLE CONTROL MISSILE GUIDANCE

Filed July 25, 1952

5 Sheets-Sheet 1

FIG. 1



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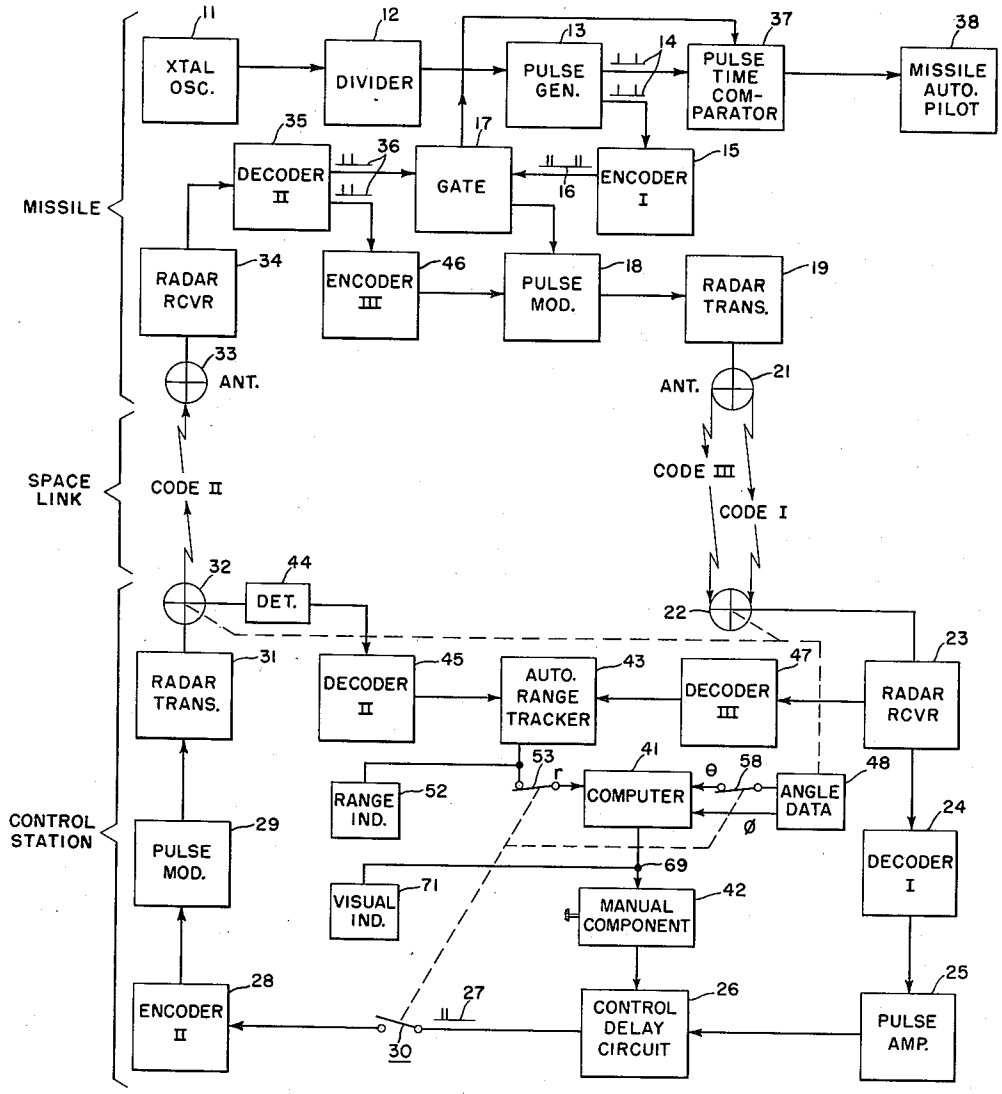
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SINGLE CONTROL MISSILE GUIDANCE

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FIG. 2



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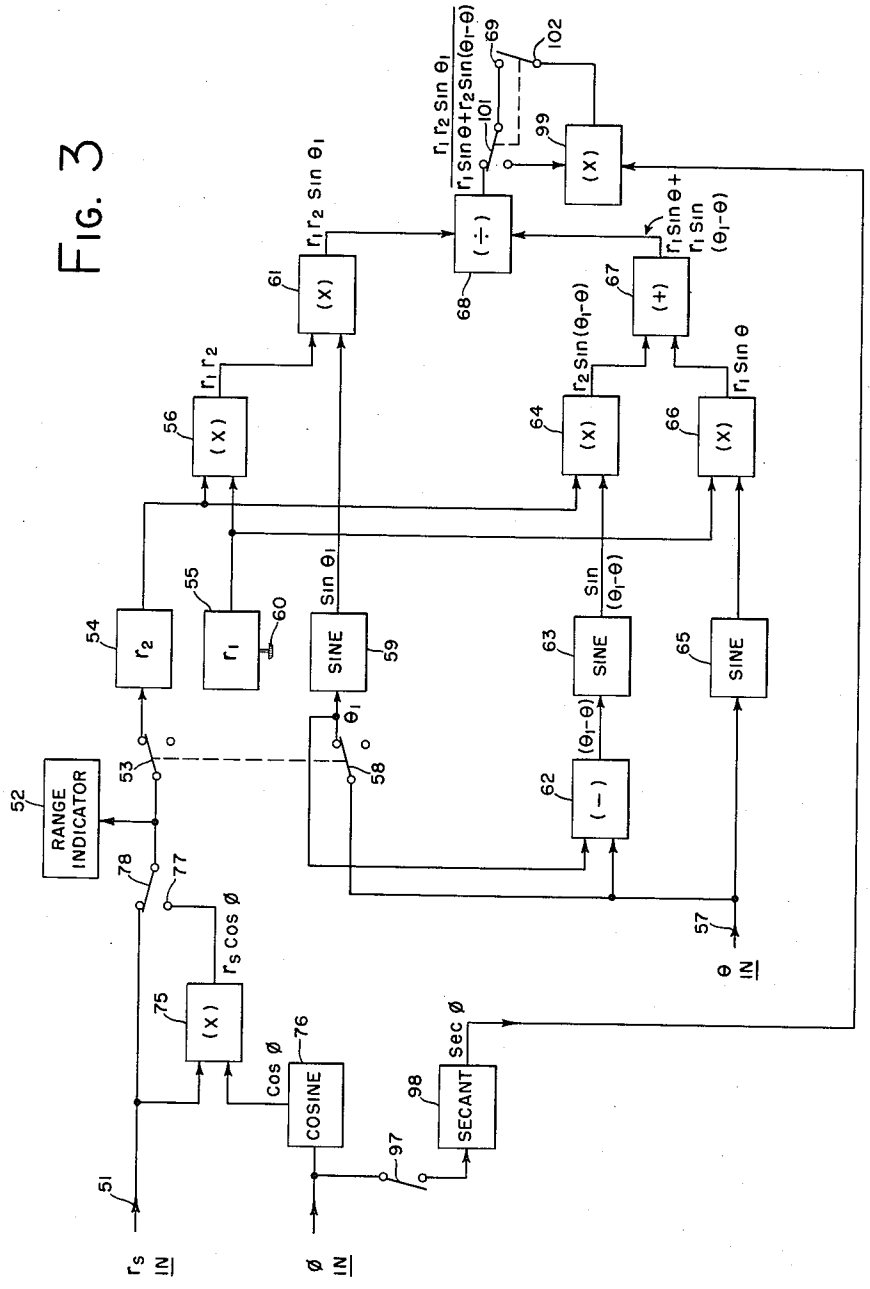
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FIG. 3



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Filed July 25, 1952

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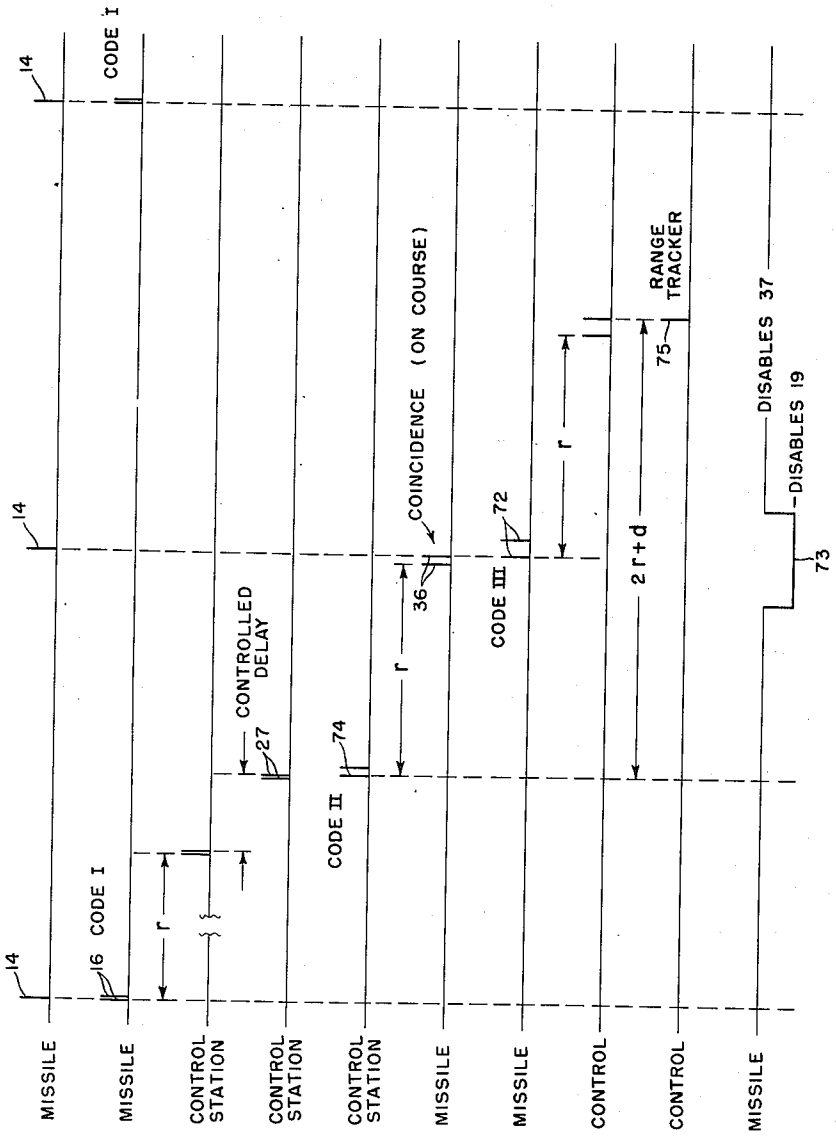


FIG. 4

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FIG. 5

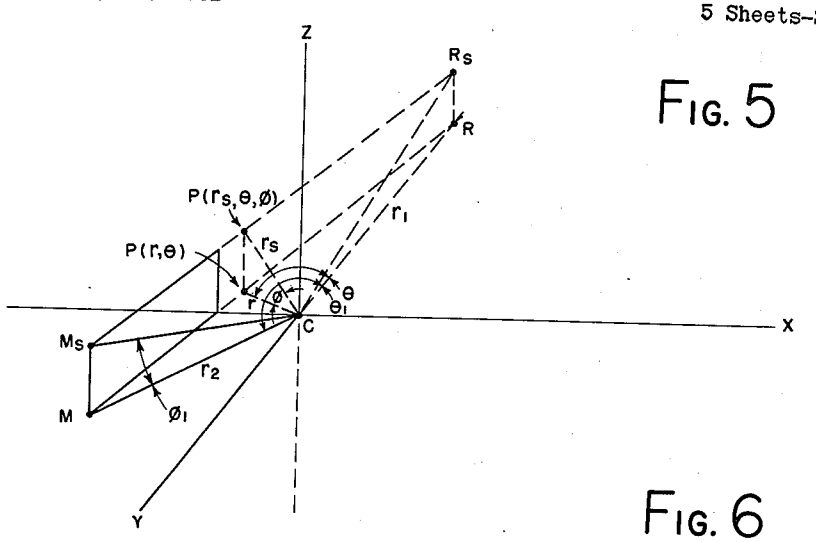
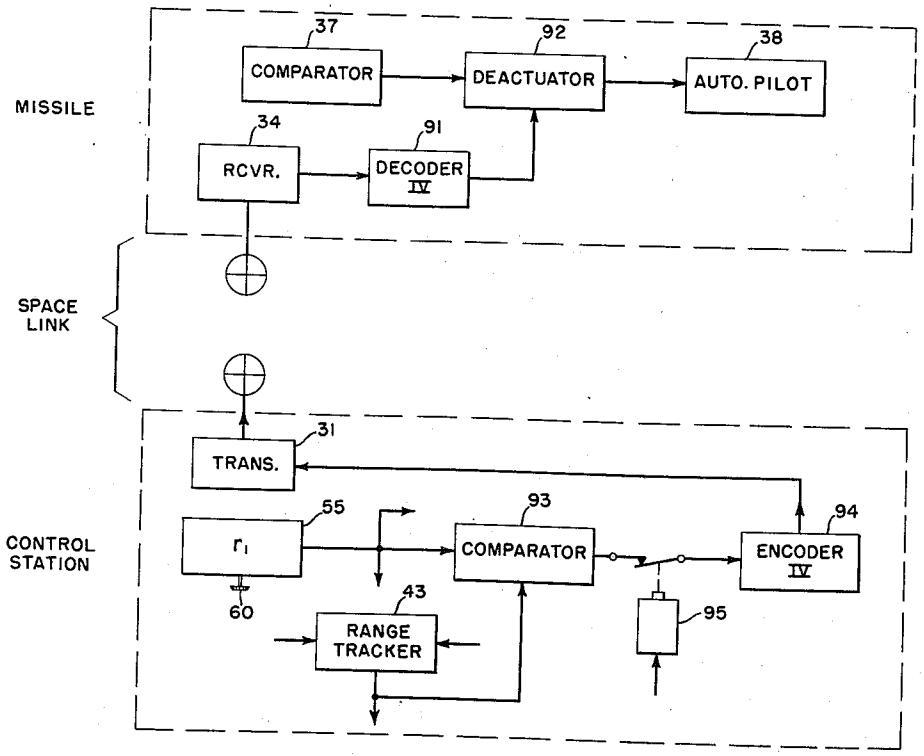


FIG. 6



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United States Patent Office

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2,923,496

SINGLE CONTROL MISSILE GUIDANCE

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Application July 25, 1952, Serial No. 300,868

5 Claims. (Cl. 244—14)

This invention relates generally to a method and means for guiding a moving vehicle and more particularly to the problem of mid-course guidance from a control station for a long range vehicle such as a missile or the like.

The problem of long range guidance of the flight of a missile from the point at which it is launched to its ultimate destination at a target is usually separated into three distinct phases when the distance to be traveled by the missile is of such great magntiude that no single location adjacent the course line can be in control of the missile throughout the complete flight. The phases for the flight of such a missile are usually designated as the launching phase, the mid-course guidance phase and the terminal phase. With this general plan there is provided in the launching phase some means for getting the missile into the air and started on a flight path in the general direction of the target. At some advance position intermediate the point of launching and the ultimate target there is setup a control station, the purpose of which is to intercept control of the missile as soon as it appears on the radio horizon from the launching site and control its flight past the control station to an ultimate release point which is generally on an opposite horizon. The function of the control station is completed once it has maneuvered the missile to the predetermined release point, whereupon the control of the flight of the missile is released to a homing guidance system in the missile itself or such other control as may be provided for terminal guidance in the final phase of the missile flight. While many arrangements have been provided heretofore for mid-course guidance, they have been relatively complex and have been limited in their application by a lack of flexibility for the various situations which are encountered. For example, many of the prior art systems have required that certain information with regard to the course to be flown be set in the missile before launching and, therefore, these settings may not be altered during the flight of the missile to meet any changing conditions or other unpredictable events which may occur.

It is the object of the present invention to provide method and means for guiding a missile in azimuth which are simple and reliable and readily adaptable to changing conditions encountered in the field.

A further object is the provision of missile guidance arrangements in which pre-set data, which is not subject to alteration during flight to compensate for unexpected irregularities, is not required to be supplied to the missile.

Another object is to provide mid-course guidance in which the guidance path is placed to agree with the position of the missile at the start of the guidance and the flight path from that point to the target is established as a straight line.

A still further object is the provision of such a system in which the flight path may be reestablished for a new missile position in the event that guidance control is lost momentarily.

Another object is the provision of a simple arrangement for comparing the actual missile position with the desired position therefor and manual means for supplementing the guidance information, if desired.

These and other objects of the invention will be more readily understood from the following detailed description, taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a plan view of an azimuth control arrangement;

Fig. 2 is a block diagram of a complete system for accomplishing azimuth guidance in accordance with the invention;

Fig. 3 is a block diagram functionally indicating the operation of the computer of the present invention;

Fig. 4 is a pulse timing diagram useful in explaining the operation of the invention;

Fig. 5 is a view showing the guidance relationships in three dimension; and,

Fig. 6 is a partial block diagram showing a modification.

Referring now to Fig. 1, the azimuth control situation is shown wherein a control station C is located a fixed distance r_1 from a release point R, which is in the vicinity of the target. In any tactical situation the distance CR and the direction thereof, in some reference systems, are known. The control station C is capable of measuring the range and bearing of a missile M continuously. The distance from C to M, r_2, and the angle θ_1 between r_1 and r_2 are determined at the control station C for the position of the missile M at some point, for example, where it is first detected with suitable signal strength after being launched. Upon the determination of the quantities r_2 and θ_1 for a given point in space, the control station C computes the path MR by solution of the triangle CMR. The path MR, as thus computed, is a straight line and coincides at one end thereof with the actual position of the missile M and the other end of the path is the release point R. The information thereafter required from the control station C is merely that which will maintain the missile at the range r of points P (r,θ) on the line MR for all subsequent values of θ.

The required relationship of the range r to the line MR for any angle θ may be obtained from the equation of the line MR in polar coordinates with C as the origin and CR the baseline for angular measurement. This equation of the line MR is

$$rr_1 \sin \theta - r_1 r_2 \sin \theta_1 + rr_2 \sin (\theta_1 - \theta) = 0$$

from which the range r as a function of θ is

$$r = \frac{r_1 r_2 \sin \theta_1}{r_1 \sin \theta + r_2 \sin (\theta_1 - \theta)} \quad (1)$$

With the relation (1) future values of r may be computed for any θ after the missile has reached a point M for which r_2 and θ_1 can be established. If sufficient time is available during the mid-course flight the range may be computed manually for a number of points along the desired course MR and corrections applied to the missile as required upon comparing the computed and actual ranges for each angle. For example, if for the angle θ the computed range is r and the measured range r' at this angle discloses a missile position M' a command must be given causing the missile to turn toward the control station C and decrease the measured range. In general, manual computation and control will not provide sufficiently rapid and continuous data for a high speed missile. To overcome this deficiency continuous and automatic computation and control may be employed.

In Fig. 2 a system for automatic computation and control in accordance with the present invention is disclosed. In the missile any desired form of propelling and steering mechanisms are provided. For controlling and correct-

ing the course upon which the missile flies there is provided therein a precise time reference, such as a crystal oscillator **11**. The frequency of the oscillator **11** is applied to a divider **12** for producing a submultiple frequency having a period sufficiently along to accommodate the control cycle for a particular application, as herein explained. The output of the divider **12** is applied to a pulse generator **13** which produces accurately spaced timing pulses **14** at a predetermined point in the cycle of the waves from the divider **12**. The pulses **14** are encoded by an encoder **15** which characterizes the signals produced thereby in response to the pulses **14** in accordance with a predetermined code I. It will be understood that the encoding and decoding operations described herein may be of a conventional type and may include such characteristics, for example, as pulse width, pulse number, pulse spacing or the like, and signals so encoded only operate the channels which are equipped with a corresponding decoder. The encoder **15** produces code I signals **16** which are selectively passed by a gating circuit **17** to a pulse modulator **18** which characterizes the transmission of a radar transmitter **19** from an antenna **21** in accordance therewith.

At the control station C transmission from the missile antenna **21** is received by an antenna **22** and detected and amplified to a useable level by a radar receiver **23**. Code I signals from the receiver **23** are detected in a decoder **24** and passed to a pulse amplifier **25** from which they are applied to a controlled delay circuit **26**. The delay circuit **26** provides a selectively controlled delay time between the input and output pulses thereof in accordance with a control signal applied thereto, as will be presently explained. The delayed code I signal **27** from the delay circuit **26** is applied via a switch **30** to an encoder **28**, wherein the signal is characterized by code II. The character of the code II signals from encoder **28** is transmitted to the missile by means of a pulse modulator **29**, radar transmitter **31** and radar transmitting antenna **32**.

The code II signal from the control station C is received at the missile by a receiving antenna **33** and a radar receiver **34**. Signals from the receiver **34** are applied to a decoder **35** which passes code II signals **36** to the output circuit thereof. Code II signals **36** from the decoder **35** are applied to a pulse time comparator **37** under the control of gating circuits **17**. The pulse time comparator **37** also receives the timing pulse signals **14** from the generator **13** and provides an output control signal, the amplitude and polarity of which represent the relative time positions of the two input pulse signals **14** and **36**. This control signal from the comparator **37** is applied to an automatic pilot **38** which steers the missile in azimuth in response thereto. As will be more fully explained with reference to Fig. 4, the automatic pilot **38** provides left and right steering forces to the missile in response to opposite polarity control signals from the comparator **37** and maintains zero turning forces in response to zero magnitude control signals.

In order that the guidance commands supplied from the coincidence type comparator just described to the automatic pilot **38** in the missile shall call for the desired course to the release point R the delay circuit **26** must introduce a time delay having a value which, when added to the round trip echo time for the instantaneous range r, is equal to the period between the timing pulses **14** in the missile. The delay introduced by the circuit **26** is, therefore, controlled by a computer **41** and selectively by supplementary control signals from a manual component device **42**. The computer **41** is supplied with range data from an automatic range tracker **43**, which compares the time interval between the transmission of code II signals from the antenna **32**, by means of a detector **44** and a decoder **45**, with the return from the missile of a code III signal. Code III signals in the missile originate in an encoder **46** in response to the code II signals **36** and are detected after transmission from the radar transmitter **19** by the receiver **23** and a decoder **47**. Since the transmission of code II from the control station C to the missile and the reception of the code III signal in response thereto involves no delays other than that taken for signals to traverse the space path, the comparison of the time interval therebetween in the range tracker **43** provided an accurate measure of the missile range r. To obtain the azimuth angle position of the missile, a tracking antenna is employed and for this purpose one of the control station antennas **22**, **32** may be of the type which automatically follows the angular position of a particular target. With such an antenna an angle data take-off device **48** coupled thereto supplies output data representing the angle θ. Angle data from the device **48** and range data from the tracker **43** are supplied to the computer **41**.

The operation of the computer as employed in the present invention will now be described with reference to Fig. 3. It will be understood that the range r and the azimuth angle θ which are supplied to the computer **41** may be in the form of a mechanical motion or an electrical quantity or both. Accordingly, the mathematical operations indicated in Fig. 3 may be performed as mechanical motions or transformations of electrical quantities in accordance with the type data which is supplied in any particular embodiment. Since the devices, both mechanical and electrical, which are available for performing the indicated mathematical functions in Fig. 3 are varied and well known, no particular choice of these devices is herein specified. The assemblage of these computer components will be dictated by design factors in a particular application.

Range data are applied in the computer **41** to an input coupling **51** which supplies a visual range indicator **52** and, through a switch **53**, goes to a range keeping device **54** which reproduces the range data input as long as switch **53** remains closed. A manually operated range data device **55** is provided with a manual control **60**. The device **55** is capable of receiving set values corresponding to the distance r_1 which include the distances CR normally encountered. The outputs of the range keepers **54**, **55** are applied to a multiplier **56** which produces as an output the product r_1r_2.

The azimuth angle data θ are applied to an input coupling **57**, from which they are supplied through a switch **58** to a sine function generator **59**. The sine generator **59** provides in its output the sine of the angle θ continuously for closed positions of the switch **58** and maintains the last established value upon the opening of switch **58**. The opening of switch **58** establishes the angular constant θ_1. Upon reclosing the switch **58** new values are established according to the present value of θ at the coupling **57**. The sine output of generator **59** and the product r_1r_2 from the multiplier **56** are applied to a multiplier **61** to provide the output product thereof $r_1r_2 \sin \theta_1$.

The angular data θ are also applied to a subtraction device **62** as is the selected value thereof θ_1 from the right hand side of the switch **58**. The difference $\theta_1-\theta$ from the subtractor **62** is applied to a sine generator **63** and the sine of the difference angle is applied to a multiplier **64**. The value of r_2 from the range keeper **54** is also applied to the multiplier **64** and the output product thereof is $r_2 \sin (\theta_1-\theta)$. Another sine function generator **65** operates on the angle data θ and supplies a multiplier **66** which also is supplied with the constant value r_1 from the range set device **55**. The output of the multiplier **66**, therefore, is $r_1 \sin \theta$.

The outputs of the multipliers **64** and **66** are applied to an adder **67** to produce the sum of these quantities. The outputs of the multiplier **61** and the adder **67** are applied to a divider **68** as numerator and denominator, respectively, and the quotient produced at output **69** thereof is the functional value for the range r according to Equa-

tion 1. The computed value of range r is indicated by a visual indicator 71 in Fig. 2.

The operation of the system of Figs. 2 and 3 in guiding a missile in accordance with the maneuver of Fig. 1 will now be described with reference to the timing diagram of Fig. 4. In the launching phase the flight of the missile is established to come within the range of the control station C and the various propelling, navigational and control devices are rendered operative. The crystal oscillator 11 accurately establishes a time reference in the missile in the form of pulses 14. The pulses 14 interrogate over the code I signals 16 seeking to establish guidance from the control station. At the control station C the tracking radar is alert and waiting for the missile to come into some suitable range r_2 at the point M where guidance is to be established. During this interval range and azimuth angle data are continuously supplied to computer 41 for a period of time before guidance is established. The manual component of the delay signal supplied by the device 42 is normally set to zero or such other constant value as the unavoidable circuit delays may require. The control delay circuit 26, therefore, is calling for the correct delay in the code I, code II round trip signal period for the instantaneous position of the missile but the guidance control remains unestablished due to the open position of switch 30.

When the missile has reached some suitable position, such as point M, the operator in the control station opens switches 53, 58 and closes switch 30 to initiate guidance along the path MR. Since the missile is at point M, opening switch 53 establishes the value r_2 in the range keeper 54 and the opening of switch 58 establishes the angle θ_1 to the sine generator 59 and these values remain unchanged for the duration of the maneuver. Switch 30 which is simultaneously closed permits the code II transmission to be completed in response to the delayed code I signal 27. The code II signal reaches the missile after a further delay due to the distance traveled over the space path and the decoded signal 36 will be in time coincidence with the next timing pulse 14 for the "on course" condition which obtains, by definition, at the point M. For all subsequent times the position of the missile, such as the position M', will determine whether or not the pulses 14 are in time coincidence with the code II pulses 36 received at the missile. The total time for such coincidence is determined by the transmission delays over the space path of the code I and code II signals and the delay introduced by the circuit 26. The total of these delays would produce coincidence if the missile range were r for the angle θ. If the missile range is other than r, say r', the total delay as sensed by the comparator 37 will be other than that for which coincidence obtains and a corresponding steering correction signal of the correct polarity will be applied to the automatic pilot 38 to turn the missile toward the path MR.

The code III signals 72 returned from the missile to the control station provide on the range indicator 52 a visual indication of the actual range r' to the missile which may be used for comparison with the desired range r as read from the indicator 71. If required, manual over-ride of the automatic steering control may be introduced by means of the device 42. If at any point, as a result of uncontrollable conditions, the missile position M' is so far from the course MR that the reacquisition of the course would be difficult or impossible, a new course may be readily established by reclosing switches 53, 58 and opening switch 30 until the system stabilizes upon the missile's present position. A new course to the release point R may then be established from the present missile position by reinitiating guidance as herein described with a new value of r_2 and θ_1 for the new missile position.

In order that the operation of the circuit may occur as above described, the gate circuit 17 in the missile supplies a gating wave 73 which prevents transmitter 19 from transmitting on alternate ones of the pulses 14 and likewise prevents the comparator 37 from utilizing any signals which occur during the transmission periods for the transmitter 19. The wave 73 will normally embrace the period on each side of a pulse 14 equal to the maximum change in controlled delay from the circuit 26 that is expected to occur. The characteristics of the comparator 37 preferably include a memory for supplying continuous output data to the pilot 38 during the intervals between the gates 73 when no data are received.

The system as hereinbefore described provides midcourse guidance control which is adequate for many applications. In some situations, however, it may be desirable to practice the invention with compensation for the altitude at which the missile travels. The three dimensional situation is depicted in Fig. 5, wherein the azimuth projection in the XY plane corresponds to Fig. 1. For this arrangement it is apparent that the slant range CM_S is greater than r_2 and that r_2 is equal to the product $CM_S \cos \phi_1$. Likewise the azimuth range r for any point P (r, θ) is obtained by multiplying the slant range to the point P (r, θ, ϕ) by $\cos \phi$. The maneuver of Fig. 1, therefore may be performed irrespective of the initial altitude of the missile by correcting the slant range measured by the system by a factor of $\cos \phi$. This operation is shown in Fig. 3 wherein a multiplier 75 is supplied with range data from the range input 51 and the value of $\cos \phi$ from a cosine generator 76. The generator 76 is supplied with elevational angle ϕ data from the tracking antennas 22, 32. For this purpose these antennas may be of the type providing a thin pencil shaped beam with automatic tracking in both azimuth and elevation. The output of the multiplier 75 is available at a terminal 77 and may be selectively supplied to the subsequent portions of the computer by means of a switch 78. Such selection interrupts the transmission of slant range data from the terminal 51 to the units 52, 54. It will be understood that the data supplied to the units 52, 54 for either position of the switch 78 is the range data from which the computation is made and for situations in which the difference between slant range and the azimuth projection thereof becomes large, the connection to the terminal 77 is preferred.

In order that the computed value of r appearing at the terminal 69 may be correct for any elevation angle ϕ along the path, a further modification may be provided in Fig. 3. The elevation angle ϕ data is applied selectively through a switch 97 to a secant generator 98. The output of the generator 98 is applied to a multiplier 99. The other factor for the multiplier 99 is the output of the divider 68, obtained selectively by switch means 101. The output of the multiplier 99 alternatively supplies the output terminal 69 via a switch 102 when the divider 68 is disconnected therefrom by the switch 101. The output of the multiplier 99 is the product of the computed "on course" range r and the secant of the angle ϕ. Therefore, the range data from the multiplier 99 supplied to the unit 26 of Fig. 2 will always be greater than the value of r computed by (1) except when the angle ϕ is zero. The inverse range input-delay output function of the unit 26 provides a corresponding decrease in delay introduced into the code I, code II signal round trip period thereby placing the "on course" signal at the point P (r, θ, ϕ) for a computed point P (r, θ). The missile, therefore, is guided to fly the space path $M_S R_S$ upon establishing the course MR thereof and in accordance with any desired altitude requirements established by well known means, not shown.

In Fig. 6 one arrangement suitable for releasing control of the vehicle upon its arrival at the release point R is indicated. The units now first described are shown as they would be applied to the system of Figs. 2 and 3. At the control station, data of the set range r_1 from the unit 55 and the range from the range tracker 43 is supplied to a comparator 93. When the measured range is equal to r_1 the comparator actuates an encoder 94 which provides a code IV signal transmission from the trans-

mitter 31. In the missile a decoder 91 passes code IV signals from the receiver 34 to a deactuator 92, which interrupts control of the automatic pilot 38 by the comparator 37 upon receipt of a signal from the decoder 91 and may switch into operation the means for terminal phase guidance which is provided in the missile. In the event that the initial range r_2 is greater than r_1 a time or angle θ operated lock-out device 95 may be employed to disable the generation of a code IV signal for a period until the measured range is less than r_1.

It will be understood that small time delays are inevitable in a system of this type and in the calibration of the system will be accounted for. As an example, the range indicator 52 actually measures the time interval $2r+d$ between the pulse 74 at the start of code II and the pulse 75 at the end of code III. The value indicated, however, is merely the actual range with the value d and the factor of two suitably calibrated out of the indication.

The present invention is well adapted to automatic operation at the control station as well as in the vehicle. For example, for wartime use automatic control stations may be planted in enemy territory on land or in water and arranged to operate after a predetermined period for guiding missiles or occupied aircraft to a release point established at the time the station is planted. These stations would then operate for some useful period while an attack was carried out with the aid of guidance signals therefrom.

Many equivalents of the present system will now be apparent for practicing the invention as here described and other embodiments may be devised for practicing the method thereof and are to be understood as within the scope hereof.

What is claimed is:

1. A control system for guiding a radio controlled vehicle from a first point in space to a second point, said system functioning on signals passing between said vehicle and a third point, where said first point is the location of said vehicle when said method of guiding commences and where said third point is not colinear with said first and second points, comprising: means for producing, in said vehicle, a reference signal; means for transmitting said signal from said vehicle; means at said third point for receiving said transmitted signal; means for delaying said received signal; means for transmitting said delayed signal; means in said vehicle for receiving said second transmitted signal; means for retransmitting said second signal; means at said third point for receiving said retransmitted second signal; means at said third point for determining range of said vehicle by comparing said retransmitted second signal with said second transmitted signal; means at said third point for measuring the successive angles between said vehicle and said second point; means at said third point functioning on data consisting of the location of said second point, the initial range of said ranges, the initial angle of said angles, and said successive angles of said angles to produce an output to vary said delay means; and means comparing said second transmitted signal received at said vehicle with said reference signal; said comparing means producing an effect tending to maintain said vehicle on said course.

2. A control system for guiding a radio controlled vehicle from a first point in space to a second point, said system functioning on signals passing between said vehicle and a third point, where said third point is not colinear with said first and second points, comprising: means for producing, in said vehicle, a reference signal; means for transmitting said signal from said vehicle; means at said third point for receiving said transmitted signal; means for delaying said received signal; means for transmitting said delayed signal; means in said vehicle for receiving said second transmitted signal; means for retransmitting said second signal; means at said third point for receiving said retransmitted second signal; means at said third point for determining range of said vehicle by comparing said retransmitted second signal with said second transmitted signal; means at said third point for measuring the successive angles between said vehicle and said second point; means at said third point functioning on data consisting of the location of said second point, the initial range of said ranges, the initial angle of said angles, and said successive angles of said angles to produce an output to vary said delay means; and means comparing said second transmitted signal received at said vehicle with said reference signal; said comparing means producing an effect tending to maintain said vehicle on said course.

3. A control system for guiding a radio controlled vehicle over a course from a first point to a second point, said system functioning on signals passing between said vehicle and a third point, where said first point is the location of said vehicle when said guiding commences and where said third point is not colinear with said first and second points, comprising: means in said vehicle for producing a periodic time reference signal; a round trip communication data link between said vehicle and said third point for signals synchronized with said time reference signal; range and direction finder means for determining the range and bearing of said vehicle from said third point; means responsive to the range and bearing of said first point and predetermined data of said second point to determine said course; computer means utilizing data of said course and the successive bearings of said vehicle to provide outputs representative of the respective ranges of said course from said third point; delay means responsive to said outputs to introduce delay in said communication link representative of said ranges; and means in said vehicle comparing said communication link transmission interval, including said delay, with said reference signal, said comparing means producing an effect tending to maintain said vehicle on said course.

4. A control system for guiding a radio controlled vehicle over a course from a first point to a second point, said system functioning on signals passing between said vehicle and a third point, where said first point is the location of said vehicle when said guiding commences and where said third point is not colinear with said first and second points, comprising: means for producing a periodic time reference signal; a communication data link between said vehicle and said third point for signals synchronized with said time reference signal; range and direction finder means for determining the range and bearing of said vehicle from said third point; means responsive to the range and bearing of said first point and predetermined data of said second point to determine said course; computer means utilizing data of said course and the successive bearings of said vehicle to provide outputs representative of the respective ranges of said course from said third point; delay means responsive to said outputs to introduce delay in said communication link representative of said ranges; and means comparing said communication link transmission interval, including said delay, with said reference signal, said comparing means producing an effect tending to maintain said vehicle on said course.

5. A control system for guiding a radio controlled vehicle over a course from a first point to a second point, said system functioning on signals passing between said vehicle and a third point, where said first point is the location of said vehicle when said guiding commences and where said third point is not colinear with said first and second points, comprising: means for producing a periodic time reference signal; a communication data link between said vehicle and said third point for signals synchronized with said time reference signal; direction finder means for determining the bearing of said vehicle from said third point; means for setting said course relative to

said third point; computer means utilizing data of said course and the successive bearings of said vehicle to provide outputs representative of the respective ranges of said course from said third point; delay means responsive to said outputs to introduce delay in said communication link representative of said ranges; and means comparing said communication link transmission interval, including said delay, with said reference signal, said comparing means producing an effect tending to maintain said vehicle on said course.

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