

Jan. 5, 1965

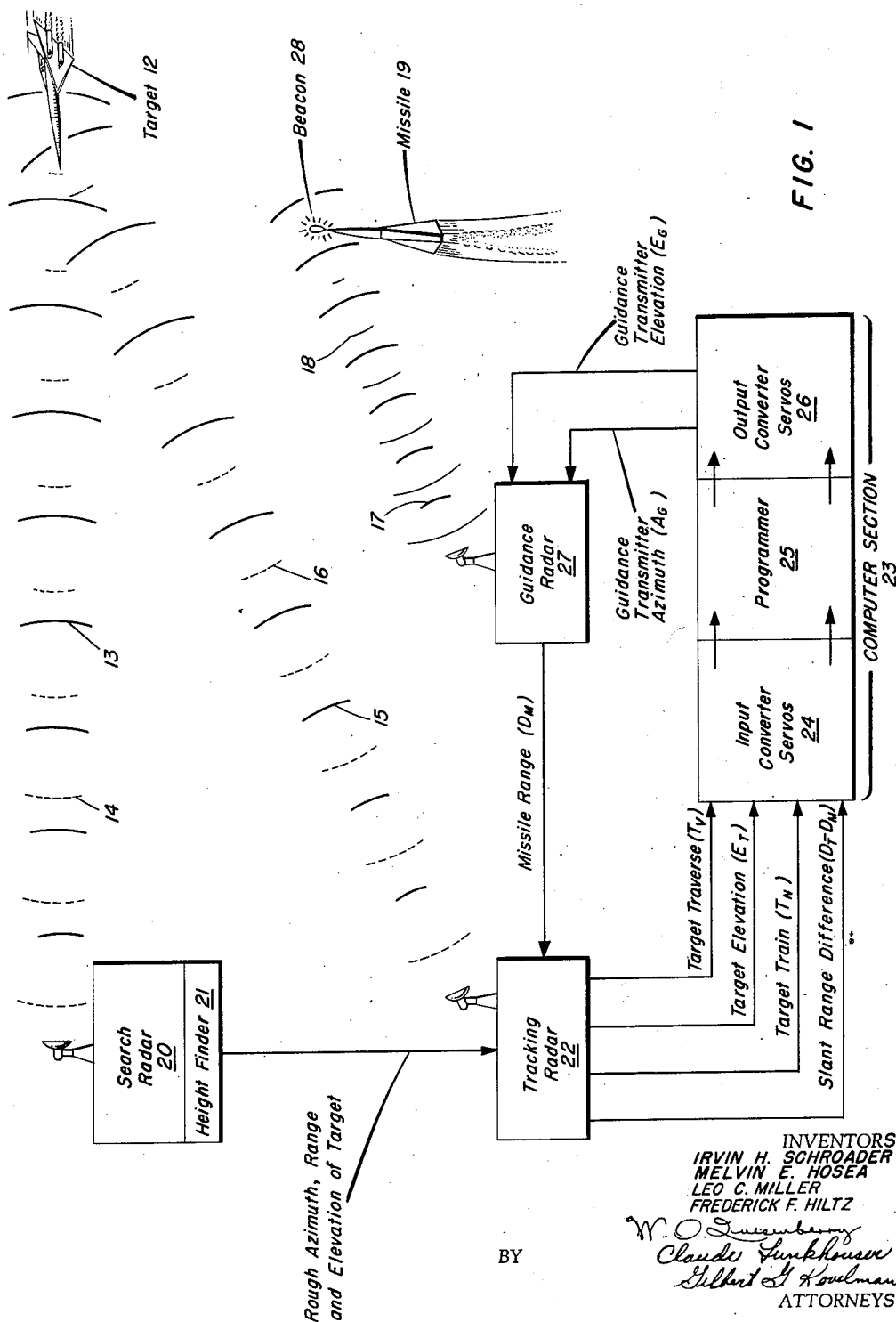
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3,164,339

MISSILE PROGRAMMER COAST MODE PROVISION

Filed Jan. 31, 1961

4 Sheets-Sheet 1



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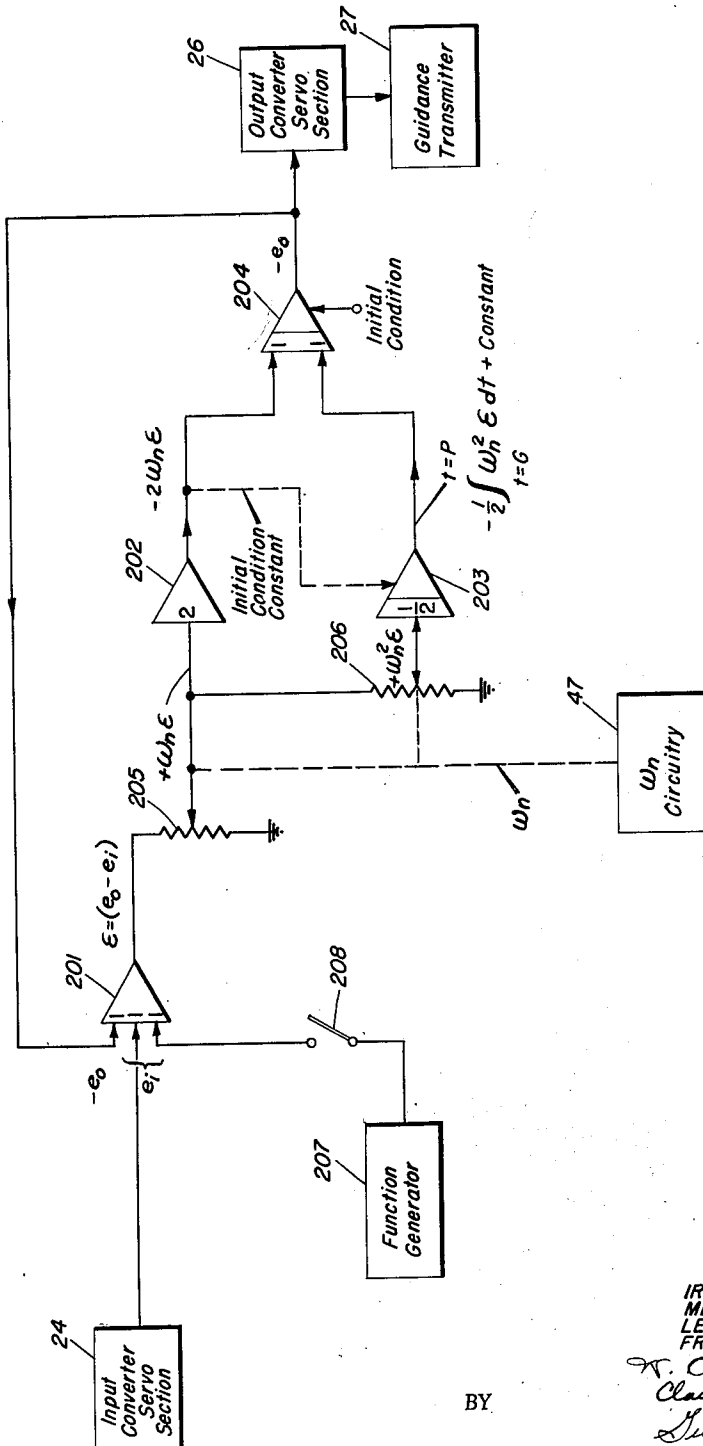
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MISSILE PROGRAMMER COAST MODE PROVISION

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4 Sheets-Sheet 2

FIG. 2



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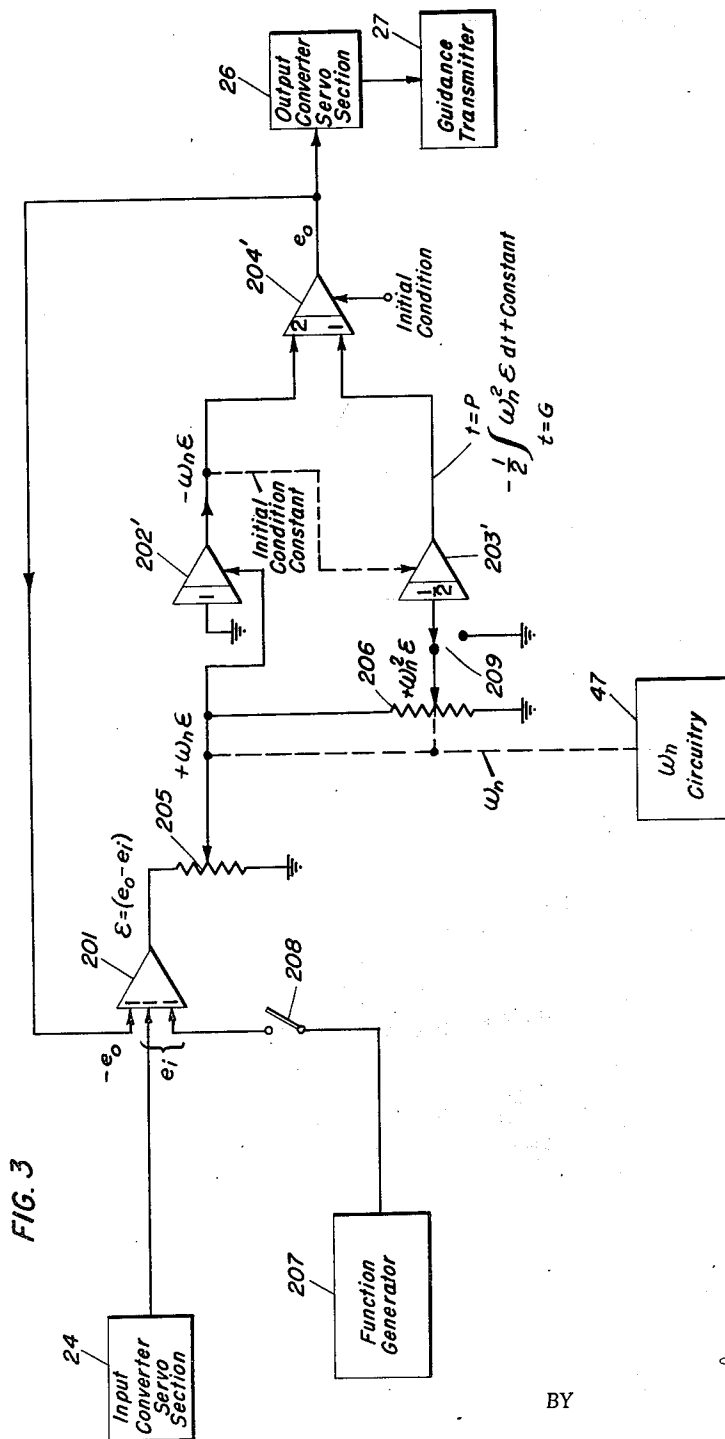
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MISSILE PROGRAMMER COAST MODE PROVISION

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4 Sheets-Sheet 4

FIG. 5

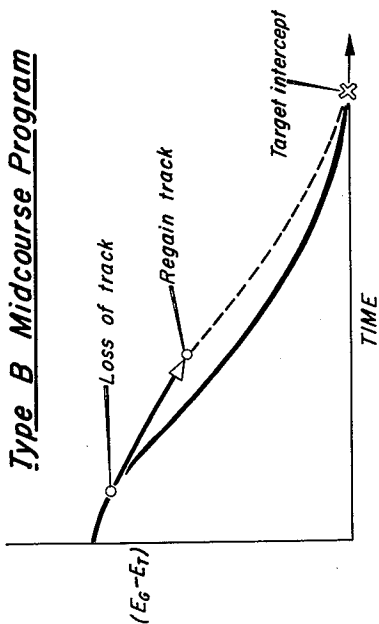


FIG. 4

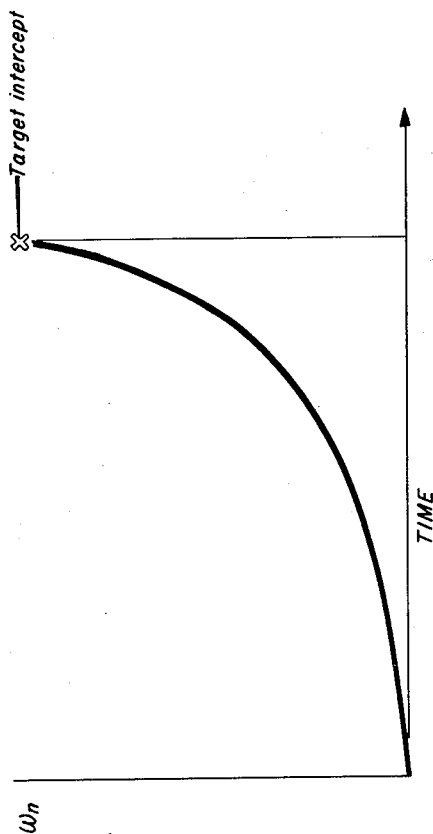
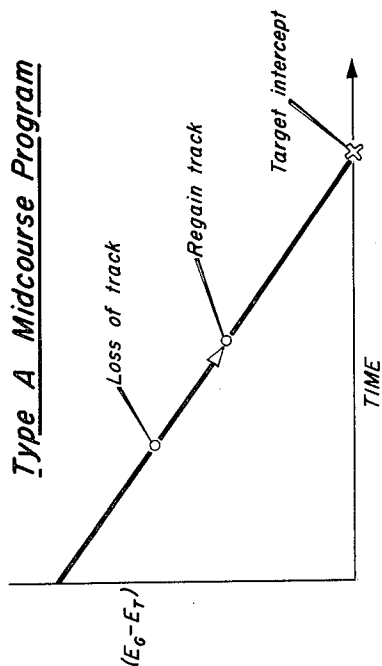


FIG. 6

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3,164,339 MISSILE PROGRAMMER COAST MODE PROVISION

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America as represented by the Secretary of the Navy
Filed Jan. 31, 1961, Ser. No. 86,267
14 Claims. (Cl. 244-14)

The present invention relates generally to improvements in missile guidance systems and the like and more particularly to a new and improved missile guidance system for beam-riding missiles which enables a programmed missile to coast in an approximate ballistic trajectory to a designated target during periods of temporary loss of target track and to subsequently return to a standard program trajectory when target track is reacquired.

This application presents an improvement in the missile guidance system set forth in copending application Serial No. 38,408, filed June 23, 1960, for Multiple Flight Course Second Order Programmer, by Irvin H. Schroader, Melvin E. Hosea and Leo C. Miller and assigned to the same assignee as the instant application.

In the field of missile guidance systems development, it has been the general practice to employ ground computing devices in conjunction with cooperating guidance transmitters to guide various beam-riding missiles to their targets. Although such devices have generally served their purpose, they have not proved entirely satisfactory under all conditions of service and operation. In this regard, considerable difficulty has been experienced in minimizing the deleterious effects of noisy radar input data upon both the computer and resulting programmed missile trajectory, with consequent effects upon missile fuel consumption, missile range, and probability of successful target kill. A further and perhaps more critical problem confronting designers of missile programmers has been the loss of control or "wild running" of beam-riding missiles during even momentary losses of target track by ground radar and associated guidance transmitter equipment. In such instances, even after reacquisition of target track, beam-riders so lost cannot readily be recaptured by the guidance beam. Furthermore, even in those few instances where recapture of the stray is accomplished, the missile generally cannot be caused to return to a standard program trajectory to the target since the latter would usually require a hard maneuver on the missile far beyond its design capabilities.

The general purpose of this invention, therefore, is to provide a guided missile programmer which embraces substantially all of the advantages of previously employed missile guidance systems and yet possesses none of the aforescribed disadvantages. To attain the latter, the instant invention contemplates provision of a missile programming system capable of guiding beam-riding missiles along prescribed trajectories most suited to considerations of missile performance characteristics and target threat. The latter programming system performs in a manner insuring maximum efficiency through the smoothing of input radar data in the computing stages of the programmer itself, and simultaneously minimizes the probability of loss of a programmed missile, with consequent failure of target kill, due to intermittent loss of target track during programmed flight. To accomplish the latter, the missile guidance system of the instant invention contemplates the provision of a novel second order programmer computing section of the type disclosed in copending application Serial No. 38,408, filed June 23, 1960, for Multiple Flight Course Second Order Programmer, by Irvin H. Schroader, Melvin E. Hosea and Leo C. Miller. In the instant in-

vention, the second order smoothing circuitry set forth in the latter application is modified to include a novel coast mode provision, the latter provision enabling a linear extrapolation for the program trajectory existing at the instant the coast mode is initiated. Means are also contemplated within the scope of the invention to enable the programmer to revert from coast programming mode to its normal programming mode, upon reacquisition of radar target track, and to correct any trajectory error developed during the coast period within a time interval determined by the amount of computer damping then in effect.

Accordingly, one object of the present invention is the provision of a new and improved missile guidance system.

Another object is to provide a new and improved missile guidance system capable of preventing loss of a programmed missile during periods of target track loss by guidance equipment.

A further object of the instant invention is the provision of a new and improved missile guidance system enabling programmed missiles to coast during periods of target track loss by guidance equipment and thereafter to return to a normal program flight mode.

Still another object resides in the provision of a new and improved missile programmer which minimizes missile fuel consumption, increases missile range, and insures maximum probability of target kill through the maintenance of missile flight control during temporary periods of target track loss by guidance equipment.

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

FIG. 1 is a schematic representation by block diagram of a typical missile guidance and control system in which the device of the instant invention is to be utilized;

FIG. 2 illustrates a second order missile programmer computing circuit without the coast mode provision of the instant invention;

FIG. 3 illustrates a novel second order missile programmer computing circuit embodying coast mode provisions in accordance with the instant invention;

FIGS. 4 and 5 are illustrative of the manner in which the coast mode provision of the instant invention operates in two instances of standard programs obtainable with the second order missile programmers set forth in FIGS. 2 and 3;

FIG. 6 is a graph illustrating the manner in which computer guidance sensitivity may be varied in the second order missile programmers disclosed.

The second order missile programmer shown in FIG. 2 of the drawings is of the type shown and described in copending application Serial No. 38,408, filed June 23, 1960, for Multiple Flight Course Second Order Programmer, by Irvin H. Schroader et al. In the latter application, a guidance computer was disclosed which incorporated a second order smoothing circuit having variable gain sensitivity to the end result that effects of noisy input radar data were minimized and trajectories of maximum efficiency and accuracy were obtained for any set of input position parameters, in accordance with master generalized programming equations. The device of the instant invention deals with an improvement in the circuitry of the second order smoother.

Second order missile programmers of the type disclosed in the aforementioned application Serial No. 38,408 contemplate the manipulation of various input data to the computer in accordance with generalized systems equations, the constants of which are chosen in accordance with missile characteristics and target considerations to bring the missile to its target in the prescribed manner.

The second order computing system accomplishes the latter by the same functional manipulations performed upon any and all input data irrespective of whatever input parameters such data may represent. Therefore, such programmers enable a great variety of flight programs to be obtained for any given missile merely by varying the nature of the input data and constants for the generalized system equation manipulations in the programming computer section.

Referring now to the drawings, which illustrate one embodiment of the invention, there is shown in FIG. 1 a schematic representation by block diagram of a complete missile guidance system adaptable to second order smoothing and coast techniques.

FIGURE 1 shows a search radar 20, incorporating a separate height finder 21, which sends out a radar search beam 13 to a target 12 and in turn receives a reflected signal 14 from the target. Many types of search radar instrumentation are suitable for utilization in carrying out the latter functions, including search radars having built in height finders or those which incorporate such units separately. The output of the search radar 20 and height finder 21 consists of information relating to rough values of target range and azimuth and an even rougher value of target elevation. The latter output data is then conveyed as input information to a tracking radar 22, which may take a great variety of forms but is here illustrated as incorporating a three-coordinate system utilizing train, traverse, and elevation axes.

The target azimuth, target range and target elevation information from the search radar 20 and height finder 21 enables the operator of the tracking radar 22 to either actually "lock on" the target 12 or to throw the tracking radar into "search" operation, which is essentially a scan raster of plus or minus a discrete number of degrees about a position which is believed by the operator of the tracking radar 22 to be the approximate target position as indicated by the rough information received from the search radar system. Other modes of radar systems for feeding input data to the tracking radar 22 might include such systems as the Air Force "SAGE" type concentrated network of defense radars.

The tracking radar 22 transmits its own radar beam 15 to the target 12 and receives a reflected signal 16 therefrom. The output data from the tracking radar 22 consists of target elevation, target train, target traverse, and slant range from the tracking radar 22 to the target 12. The latter output information from tracking radar 22 is derived for further use through synchro devices physically located at the tracking radar unit itself. Shaft rotations about the various axes of the tracking radar 22 are converted by means of such synchro devices to synchro signals, three-wire lines being conventionally embodied for each synchro, to provide outputs from each synchro which are directly proportional to the number of degrees of radar shaft rotation from an established zero reference position.

The synchro output data from the tracking radar 22 is in turn fed to a computer section 23. The latter tracking data is first directed to the input converter servo section 24 of the computer 23 wherein the synchro input information is converted by means of servomechanism devices to electrical signals in the form of D.C. voltages proportional to the original radar shaft rotation from which the input synchro signals were derived. Such D.C. voltage signal form is required for use by the programmer section 25 of the computer 23. The programmer section 25 utilizes the latter D.C. voltage outputs of the input converter servos as electrical voltage inputs to a computing section which manipulates such input voltages on the basis of prescribed generalized trajectory equations, and produces D.C. output voltages which are then fed to an output converter servo section 26.

The output converter servo section 26 of computer 23 reconverts the D.C. output voltage signals from the pro-

grammer section 25 to synchro signal form for transmission to and utilization by the guidance radar transmitters denoted generally as 27 in FIG. 1 of the drawings. The latter guidance radar transmitters 27 are physically located near the tracking and search radars 22 and 20, respectively, or at least within a few hundred feet of the latter radars to avoid the introduction of severe parallax errors.

The guidance radar 27 transmits a radar signal 17 to the missile 19, but only in a single direction, that is, guidance radar 27 receives absolutely no reflected signal from the missile in the guidance system embodiment illustrated. The major distinction, therefore, between the guidance radar transmitter 27 and tracking radar 22 is that the guidance transmitter is commanded into position by the output elevation and azimuth signals from the ground computer 23 as opposed to the complete lack of such control over the tracking radar. For some types of program trajectories, however, the guidance radar transmitter 27 may track in range. In such instances, the tracking accomplished by the guidance transmitter 27 is distinguished from the operation of the tracking radar 22 in that tracking is not accomplished by the conventional method of receiving a signal from the missile constituting a reflection of an original signal generated in the guidance transmitter itself. On the contrary, missiles utilizing those types of program trajectories which require tracking in range by the guidance transmitter 27 carry a beacon 28, incorporated into the missile itself, and which is triggered by the guidance beam 17 from the guidance transmitter 27 to generate a beacon signal 18 of its own. The latter beacon signal 18 is directed from the missile 19 to the guidance transmitter 27, the time of delay of arrival of the beacon signal 18 at the guidance transmitter 27 being a measure of the slant range to the missile.

Missiles utilizing multiple flight course programmers of the type shown in FIG. 1 must, of necessity, be beam-riders. Such a missile is captured by the radar beam 17 emanating from the guidance transmitter 27 so that the missile 19 is caused to follow the guidance beam as the beam moves in accordance with the program flight trajectory equation. Servomechanism devices within the missile 19 itself steer the missile in accordance with the transmitted guidance signals so that the missile is caused to always remain within the guidance beam after capture, provided the guidance beam moves in such a manner that the missiles capabilities of linear velocity and lateral acceleration are not exceeded.

In actual operation utilizing multiple flight course programmers of the type disclosed, prior to launching, the tactical operator elects in accordance with the nature of the missile to be fired and the target to be intercepted, one of the standard program trajectories within the scope of the programmer. The operator then proceeds to manipulate various switches in the guidance transmitter, e.g., for tracking in missile range or not, depending upon the nature of the program trajectory chosen, and simultaneously operate switches in the programmer section 25 of the computer 23 to select proper constants and input data channels for the desired program. All of the latter operations for multiple flight course second order programmers are set forth in the aforementioned copending application, Serial No. 38,408.

After the missile is initially fired, a discrete period of time elapses before capture of the missile 19 by the guidance beam 18 is accomplished. Thereafter, E_G , the elevation of the guidance transmitter, must approach E_T , the elevation of the target, in a manner determined by the prescribed programming equations set up in the programmer section 25 of computer 23. FIGS. 4 and 5 of the drawings illustrate the form of $E_G - E_T$ found desirable in instances where two standard programs, arbitrarily designated type "A" and type "B," are utilized. It will be noted from FIGS. 4 and 5 that, whereas the type "A"

program illustrated causes the missile to dive on the target in a nearly linear collision course, the type "B" program is of a nature which causes the missile to approach asymptotically to the line of sight from the tracking radar to the target prior to collision.

The type "A" program is the more accurate of the two types of flight programs illustrated as being obtainable with the Multiple Flight Course Second Order Programmer. Although the generalized system equations for both the type "A" and type "B" programs are similar, the type "A" program trajectory is varied from that of the type "B" program by varying the nature of the parameters which are fed into the computer section as input data.

The type "A" program with its direct intercept collision course is generally chosen for multiple target and wherever the potential threat is very great, as where the target may be carrying a thermonuclear device. On the other hand, the type "B" program trajectory is usually chosen only for single targets and for minimum multiple target threats since, as previously pointed out, the type "B" program contemplates a homing type of asymptotic collision course, such homing systems being susceptible to serious confusion where multiple targets are engaged.

The Multiple Flight Course Second Order Programmer disclosed in copending application Serial No. 38,408 teaches a second order smoothing circuit which performs in accordance with the equation

$$\dot{e}_o = \int_{t=G}^{t=P} \dot{e}_o dt \quad (1)$$

where G and P denote the times of guidance initiation and the present, respectively, and e_o represents the generalized system equation, the variation of the constants and input data of which enables the wide variety of programs obtainable with such second order programmers. The second order system equation is expressed in terms of $\dot{e}_o$, the first derivative of e_o , rather than conventional e_o form for sake of simplicity as will be subsequently made evident. Thus, the behavior of the second order equation computing circuit set forth in the aforementioned copending application Serial No. 38,408 is uniquely described in terms of the following generalized system equation:

$$\dot{e}_o = -2\omega_n(e_o - e_i) - \sigma \int_{t=G}^{t=P} \omega_n^2(e_o - e_i) dt + \text{constant} \quad (2)$$

where

e_o is the output data from the computer,

e_i is the input data to the computer,

$\dot{e}_o$ is the first derivative of e_o ,

ω_n is the gain sensitivity factor of the computer, and σ is a constant.

An important feature of the circuitry utilized in the multiple flight second order programmer for computing the various program trajectories in accordance with the above equations, is the manner in which the value of ω_n , the gain sensitivity factor, is varied. A low value of ω_n allows e_o to change only slowly and to be relatively insensitive to changes in e_i , the input data. On the other hand, a high value of ω_n allows e_o to change rapidly and to be more sensitive to fluctuations in e_i . Therefore, the manner in which ω_n , the gain sensitivity factor, is programmed is a major aspect of second order programming computer operation.

It has been determined empirically that adequate smoothing of noisy input data and desired flight trajectory accuracy will be realized if the gain sensitivity factor, ω_n is programmed in accordance with the equation

$$\omega_n = \frac{c}{T_{P1} + c} \quad (3)$$

where T_{P1} is the time remaining until intercept of the target by the missile and c is a constant. Such an empirical programming equation for ω_n insures values of

gain sensitivity lying between zero and unity and eliminates the situation where a gain sensitivity of infinity would be required, the later case being one which would obtain if the gain sensitivity constant " c " were omitted from Equation 3. The constant c in Equation 3 is also related to the constant σ in Equation 2 by the relation

$$\sigma = \frac{c-2}{c} \quad (4)$$

The specific value of the constant c in Equation 3 for ω_n is generally determined for any particular missile by means of simulator analysis, values of c between 3.5 and 4.5 being fairly common for typical modern missiles presently in use. The value of c , however, may assume any desired form for presently existing or subsequently developed future missiles and, therefore, the variability of c —values provides for a wide range of adaptability. By way of example, a value of $c=4$ is chosen to illustrate the principles of operation of the programming computer in conjunction with the type "A" and type "B" programmed flight trajectories depicted in FIGS. 4 and 5 of the drawings. Setting $c=4$, the value of ω_n in Equation 3 is expressed by

$$\omega_n = \frac{4}{T_{P1} + 4} \quad (5)$$

and according to Equation 4,

$$\sigma = \frac{4-2}{4} = \frac{1}{2} \quad (6)$$

Thus, Equation 2 for the generalized system equation becomes

$$\dot{e}_o = -2\omega_n e - \frac{1}{2} \int_{t=G}^{t=P} \omega_n^2 e dt \quad (7)$$

where $e = e_o - e_i$.

The value of the constant c is varied in accordance with the type of trajectory to be programmed and practical embodiments of the Multiple Flight Course Second Order Programmer incorporate means for varying this quantity as desired.

Referring now to FIG. 2 of the drawings, there is illustrated a novel second order computing circuit for a missile programmer substantially as disclosed in copending application Serial No. 38,408 filed June 23, 1960 by Irvin H. Schroader, Melvin E. Hosea and Leo C. Miller. The latter circuitry will be described in detail here in order to make more readily apparent the distinctions between such circuitry unmodified and as modified by the coast mode improvement of the instant invention.

FIG. 2 shows a second order computing or smoothing circuit comprising a series of four amplifiers indicated as 201, 202, 203 and 204, respectively. Amplifiers 201 and 202 are conventional D.C. analog type summing amplifiers, well known in the art and commercially available. Amplifiers 203 and 204 are conventional integrating amplifiers. The input to amplifier 204 is $\dot{e}_o$, the first derivative of e_o , the output of amplifier 204 being $-e_o$. The latter quantity is directed to the output converter servo section 26 prior to transmission to the guidance transmitter 27 and is also simultaneously fed back as an additional input to amplifier 201, which receives the input data e_i , the nature of which is determined by the desired flight trajectory program. The input to amplifier 201 is thus $e_i - e_o$ and the output, in view of the 180° phase shift which takes place in the amplifier 201, with resultant reversal in sign, is therefore $e_o - e_i$ or e . For purposes of solving Equation 7, the quantities $\omega_n e$ and $\omega_n^2 e$ must be obtained. The latter is accomplished as described below.

The output of amplifier 201, which is e , is directed to a potentiometer 205, the shaft position of which is equal in value to ω_n , the gain sensitivity factor. Hence, since the input to potentiometer 205 is a voltage corresponding to the value of e , the output therefrom is equal to $\omega_n e$ multiplied by e or $\omega_n e^2$. The latter quantity is fed as an

input to amplifier 202 and is also simultaneously directed to a second potentiometer 206 whose shaft position is likewise adjusted to the value of ω_n , the output from potentiometer 206, therefore, being $\omega_n^2 e$. The latter quantity is, in turn, directed as an input to integrating amplifier 203. The manner in which the output voltage proportional to ω_n is obtained to control the shaft positions of potentiometers 205 and 206, in accordance with Equation 7, forms no basis of the instant invention and, hence, is referred to only generally in FIG. 2 as the ω_n circuitry section 47. A suitable embodiment of the latter ω_n circuitry section 47 is adequately set forth in the aforementioned compending application Serial No. 38,408. For purposes of the instant discussion, it will suffice to say that ω_n is limited to values between zero and unity, in accordance with Equation 3, and since the shaft positions of both potentiometers 205 and 206 are at all times set to the value of ω_n , therefore the respective outputs from the latter potentiometers are functions of the input voltages across the potentiometers and directly proportional to ω_n . It is to be noted, of course, that the use of the second potentiometer 206 connected in the manner shown to obtain ω_n^2 is merely a close approximation method since the effect of the second potentiometer 206 is to load the first potentiometer 205. Hence, to increase the accuracy of such an approximation approach, the second potentiometer 206 is supplied with a somewhat higher value of total resistance than that of the first potentiometer 205.

It has been established that the input to amplifier 202 is $\omega_n e$ while the input to integrating amplifier 203 is $\omega_n^2 e$. The gain of amplifier 202 is adjusted to provide the multiplication factor of 2, called for in Equations 2 and 7, as well as the usual reversal in sign through inherent phase shift. Similarly, the gain of amplifier 203 is adjusted to provide multiplication by the factor σ in Equation 2, which in the illustrative example is set equal to one-half. Thus, the output of amplifier 202 is equal to $-2\omega_n e$ whereas the output of integrating amplifier 203 is

$$-\frac{1}{2} \int_{t=G}^{t=P} \omega_n^2 e \, dt + \text{constant}$$

It will be noted that the sum of the outputs from amplifiers 202 and 203 is equal to the first derivative of e_0 , or $\dot{e}_0$, in accordance with Equation 7. Thus, the outputs of amplifier 202 and integrating amplifier 203 are fed directly as input to integrating amplifier 204 whose gain is set to unity, to produce an output from amplifier 204 equal to $-e_0$.

By varying the nature of the input data e_1 to amplifier 201 and the value of the constant initially fed to the integrating amplifier 203 prior to commencement of integration at the "compute" signal, the nature of the output flight trajectories represented by e_0 can be varied to suit various missile and target conditions. Input data is varied by means of selective exploitation of output data available from an input converter servo section 24 and also through suitable utilization of a variety of function generators designated generally as 207 in FIG. 2 of the drawings and which may be selectively placed either in or out of the input circuit to amplifier 201 by means of a single switch 208 or a plurality of such switches controlling a plurality of possible input function generators.

It is to be noted that the second order computing circuit described above allows e_0 to gradually approach e_1 , until actual intercept with the target, in a manner and degree dependent upon the rapidity with which e_0 can change, the latter being controlled by the magnitude of the gain sensitivity factor ω_n which also controls the shaft position settings of the potentiometers 205 and 206. If ω_n is allowed to reach its maximum value of unity, then e_0 can approach e_1 very rapidly since the feedback loop gain is very high, whereas if the ω_n settings of potentiometers 205 and 206 are near their lower limits that is with ω_n considerably less than unity, then the feedback loop

gain is very low and e_0 will follow input data e_1 rather slowly, and with a substantial lag. A primary purpose, therefore, of the second order smoothing programmer circuitry is to cause e_0 to approach e_1 from an initial value of e_0 and proceed through a transient midcourse phase whose nature and time duration is controlled by the manner in which the gain sensitivity factor, ω_n , is programmed. A large value of ω_n increases the tightness of following of e_0 and reduces the transient error due to rapid variation in the input voltages. On the other hand, a low value of ω_n provides heavy smoothing of noisy radar data. In practice, therefore, the manner of programming ω_n is a compromise between the suppression of noise on the input data e_1 , to prevent vibration of the missile wing flaps and consequent increased drag and possible damage to missile wing servos, and yet maintain maximum probability of target kill. Thus, ω_n is programmed in time in such a manner as to enable e_0 to follow e_1 to an extremely close tolerance as actual collision with the target approaches, that is, a large value of ω_n is utilized to increase the tightness of following during the latter portion of the programmed flight trajectory, when the missile is closed to the target, whereas a small value of ω_n is utilized for the initial portion of the programmed flight trajectory to provide heavy smoothing of noisy radar input data. The latter serves to minimize missile wing vibration, servo damage and air drag, and enhance fuel economy. FIG. 6 illustrates the manner in which the ω_n is varied during a typical flight program in accordance with Equation 3 with the value of c arbitrarily set equal to four.

Referring now to FIG. 3 of the drawings, which illustrates a second order computing circuit for a missile programmer incorporating the novel coast provisions of the instant invention, there is shown a guidance computer circuit comprising a series of four amplifiers 201, 202', 203' and 204' in an arrangement which allows for ready switching from the normal programming mode to the coast programming mode whenever required. The major distinctions between the circuitry illustrated in FIG. 3 of the drawings as opposed to that of FIG. 2 of the drawings is in the modification to amplifiers 202, 203 and 204 of FIG. 2 which have been replaced by new amplifiers 202', 203' and 204', respectively, in FIG. 3.

In essence, the summing amplifier 202 in FIG. 2 has been changed to the integrating amplifier 202' in FIG. 3 while amplifier 203 has been modified in that the new integrating amplifier 203' has been provided with a switching arrangement 209 for selectively grounding the input to the integrating amplifier 203'. It will be noted that the input circuitry to amplifier 202' in FIG. 3 is short-circuited to ground and the $\omega_n e$ voltage obtained from potentiometer 205 is directed to the initial condition circuit of amplifier 202'. This is the normal programming mode for integrating amplifier 202'. The latter arrangement insures that the output of amplifier 202' will follow the input $\omega_n e$ but with the usual phase inversion previously provided by amplifier 202 in FIG. 2 to provide reversal in sign. Amplifier 204 has been modified in FIG. 3 by substituting amplifier 204' which receives the output signals from both amplifiers 202' and 203'. However, the input channel of amplifier 204', which receives output from amplifier 202', has been modified to raise the gain of that channel to two in order to compensate for the reduction in gain in new amplifier 202' to unity, as opposed to the previous gain of two in the unmodified amplifier 202 shown in FIG. 2.

Switching arrangement 209 of amplifier 203' as well as the internal initial condition-compute condition switch (not shown) of integrating amplifier 202' are exclusively under the control of a relay system in the ground tracking radar 22 of FIG. 1. In the event target track is lost at any time after a programmed missile has been launched, relays in the tracking radar 22 are actuated to place the

radar 22 in the "search" condition. The same relays in tracking radar 22 which effect the change from "track" to "search" condition simultaneously switch integrating amplifier 202' from the "initial condition" to the "compute" state and also operate switch 209 to short-circuit to ground the input to integrating amplifier 203'. This is in contrast to operation during a normal programming mode when these relays are in the "initial condition" state for amplifier 202' and the ungrounded input state for integrating amplifier 203'. When target track is lost and the coast mode is in effect, both 202' and 203' are in the "integrate" state with their inputs grounded. Therefore, whatever charge has accumulated on the integrating capacitors of amplifiers 202' and 203' during the normal programming mode is held at a fixed value equal to the value it had at coast mode initiation. In essence, therefore, $\dot{e}_0$, the rate of change of the program, is held constant at the value it had at coast initiation. Thus, the program continues at the same rate of change it had at loss of target track since $\dot{e}_0$ is stored continuously for use during the interval when radar target track is interrupted. Since the input $\dot{e}_0$ to integrating amplifier 204' is held constant, the effect, therefore, is to continue the rate of change of missile position during intervals of loss of track at the same rate at which it was changing when loss of target track first occurred. The latter is an attempt to extrapolate during tracking loss intervals between the program trajectory in effect at loss of track and that which is to be expected when track is regained.

Accuracy of extrapolation by means of a coast mode provision is limited primarily by three factors. These are: (1) lack of linearity of target motion during coast intervals; (2) inherent non-linearity of the standard program trajectory prior to loss; (3) integrator instability or drift. All three of these factors are functions of time in the sense that increased coast intervals will result in increased trajectory deviations. However, it has been determined empirically that the apparatus of the instant invention, when used even with the most non-linear of standard programs, limits deviations in program elevation and azimuth angles to no more than one half a degree, even for coast intervals of as long as two minutes' duration.

Referring now to FIGS. 4 and 5 of the drawings, plots of $E_G - E_T$ against time are shown for two types of standard second order programs previously designated as type "A" and type "B." These graphs illustrate the manner in which the missile trajectory is varied after initiation of the coast mode. It will be observed that for the type "A" midcourse program shown in FIG. 4, which is of the linear variety, extrapolation error during the coast interval is virtually nill, since program rate of change is constant over the entire duration of the standard trajectory and would remain so during any coast interval. For the type "B" midcourse program, on the other hand, depicted in FIG. 5 of the drawings, it is noted that the extrapolation error is somewhat greater due to inherent non-linearity of the manner in which $E_G - E_T$ varies with time. However, even in this instance, it will be noted that the return to the normal programming mode is accomplished with minimal error. These situations are in contrast to that which would prevail in the event such a second order programming computer were not provided with the novel coast mode provisions of the instant invention. In such an instance, the missile would "run wild" and, in the event recapture could be accomplished after reacquisition of target track, return of the missile to the normal programming mode would generally require a hard maneuver upon the missile far beyond its design capabilities.

Hence, the improved second order missile programmer with coast mode provision not only provides the versatility of a wide variety of programmed flight trajectories, the inherent advantage of the second order programmer, but also adds profoundly to the economy and probability

of successful target kill by way of preventing loss or "wild running" of programmed missiles during momentary losses of target track, frequently encountered with distant targets.

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. Apparatus for controlling the flight course of a guided missile to a target comprising a guidance computer, a source of D.C. voltage signals relating to target and missile position data for use by said guidance computer, said computer including input amplifiers for receiving said D.C. voltage signals, amplifier and integration circuit means responsive to the respective output signals from said input amplifier for acting upon said output signals in accordance with the relations

$$e_o = \int_{t=G}^{t=P} \dot{e}_0 dt$$

and

$$\dot{e}_0 = 2\omega_n(e_o - e_i) - \sigma \int_{t=G}^{t=P} \omega_n^2(e_o - e_i) dt + \text{constant}$$

where

e_o is the output data from said computer,

e_i is the input data to said computer,

$\dot{e}_0$ is the first derivative of e_o ,

ω_n is the gain sensitivity factor of the computer,

σ is a constant,

P is the present time, and

G is the time of guidance initiation,

to produce output voltage signals proportional to desired guidance transmitter positions, means to vary the magnitude of the computer gain sensitivity factor ω_n in accordance with the relation

$$\omega_n = \frac{C}{T_{P1} + C}$$

where T_{P1} is the time remaining until intercept of the target by the missile

and C is a constant,

means to feed back the D.C. output signals from said computer to the inputs of said input amplifiers, normally inactivated means to hold the value of $\dot{e}_0$ constant in the active state during periods of loss of target track by a tracking radar.

2. Apparatus for controlling the flight course of a guided missile to a target comprising a guidance computer, a source of voltage signals relating to target and missile position data for use by said guidance computer, said computer including input amplifiers for receiving said voltage signals, amplifier and integration circuit means responsive to the respective output signals from said input amplifiers for acting upon said output signals in accordance with the relations

$$e_o = \int_{t=G}^{t=P} \dot{e}_0 dt$$

and

$$\dot{e}_0 = 2\omega_n(e_o - e_i) - \sigma \int_{t=G}^{t=P} \omega_n^2(e_o - e_i) dt + \text{constant}$$

where

e_o is the output data from said computer,

e_i is the input data to said computer,

$\dot{e}_0$ is the first derivatives of e_o ,

ω_n is the gain sensitivity factor of the computer,

σ is a constant,

P is the present time, and

G is the time of guidance initiation

to produce output signals proportional to desired guidance transmitter positions, means to vary the magnitude of the computer gain sensitivity factor ω_n as a function of predicted time to go to target intercept to smooth noisy target and missile input data until maximum maneuverability of the missile is required, means to feed back the output signals from said computer to the inputs of said input amplifiers, normally inactivated means in said guidance computer to hold the value of $\dot{e}_0$ constant in the active state during periods of loss of target track by a tracking radar.

3. Apparatus for controlling the flight trajectory of guided missile to its target comprising a guidance computer, means to supply input voltages to said computer proportional to target and missile position parameters, means within said guidance computer to manipulate said parameters in accordance with the relations

$$e_o = \int_{t=G}^{t=P} \dot{e}_o dt$$

and

$$\dot{e}_o = -2\omega_n(e_o - e_i) - \sigma \int_{t=G}^{t=P} \omega_n^2(e_o - e_i) dt + \text{constant}$$

where

e_o is the output data from said computer,
 e_i is the input data to said computer,
 $\dot{e}_o$ is the first derivatives of e_o ,
 ω_n is the gain sensitivity factor of the computer,
 σ is a constant,
 P is the present time, and
 G is the time of guidance initiation

means to feed back the output voltages from said guidance computer to its input, normally inactivated means in said guidance computer to hold the value of $\dot{e}_o$ constant in the active state during periods of loss of target track by a tracking radar, and means delaying maximum gain sensitivity of said computing circuit until the missile is close to the target, whereby noisy radar input data is smoothed until maximum maneuverability of the missile is required and loss of missile control due to loss of target track is avoided.

4. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising elevation and azimuth computing sections, each of said computing sections including input summing amplifier means for receiving a plurality of input functions relating to missile and target position data and whose output consists of a voltage proportional to the sum of said input functions, a first potentiometer, means to direct the output voltage from said summing amplifier means across said first potentiometer, a first integrating amplifier whose input is grounded, a second potentiometer, means to derive a voltage from said first potentiometer proportional to the gain sensitivity factor of the guidance computer and to direct said voltage to the initial condition circuit of said first integrating amplifier and simultaneously across said second potentiometer, a second integrating amplifier, means to derive a voltage from said second potentiometer proportional to the square of the gain sensitivity factor of the guidance computer and to direct said voltage as input to said second integrating amplifier, third integrating amplifier means for receiving as inputs the output voltages from said first and second integrating amplifiers, normally inactivated means for maintaining the inputs to said third integrating amplifier means constant during periods of loss of target track by a tracking radar by switching said first integrating amplifier from the "initial condition" state to the "compute" state and by grounding the input to said second integrating amplifier.

5. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising elevation and azimuth computing sections, each of said computing sections including input summing amplifier means

for receiving a plurality of input functions relating to missile and target position data and whose output consists of a voltage proportional to the sum of said input functions, a first integrating amplifier whose input is grounded, a second integrating amplifier, means to derive a first voltage from the output of said summing amplifier means proportional to the gain sensitivity factor of the guidance computer and to direct said voltage to the initial condition circuit of said first integrating amplifier, means to derive a second voltage from the output of said input summing amplifier means proportional to the square of the gain sensitivity factor of the guidance computer and to direct said second voltage as input to said second integrating amplifier, third integrating amplifier means for receiving as inputs the output voltages from said first and second integrating amplifiers, normally inactivated means for maintaining said output voltages from said first and second integrating amplifiers constant during periods of loss of target track by a tracking radar by switching said first integrating amplifier from the "initial condition" state to the "compute" state and by grounding the input to said second integrating amplifier.

6. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising elevation and azimuth computing sections, each of said computing sections including input summing amplifier means for receiving a plurality of input functions relating to missile and target position data and whose output consists of a voltage proportional to the sum of said input functions, a first integrating amplifier whose input is grounded, a second integrating amplifier, means to derive a first voltage function from the output of said input summing amplifier means and to direct said first voltage function to the initial condition circuit of said first integrating amplifier, means to derive a second voltage function from the output of said input summing amplifier means and to direct said second voltage function as input to said second integrating amplifier, third integrating amplifier means for receiving as inputs the output voltages from said first and second integrating amplifiers, normally inactivated means for maintaining said output voltages from said first and second integrating amplifiers constant during periods of loss of target track by a tracking radar by switching said first integrating amplifier from the "initial condition" state to the "compute" state and by short-circuiting to ground the input to said second integrating amplifier.

7. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising input summing amplifier means for receiving a plurality of input functions relating to missile and target position data and whose output consists of a voltage proportional to the sum of said input functions, a first integrating amplifier whose input is grounded, said first integrating amplifier being provided with an "initial condition" circuit, a second integrating amplifier, means to derive a first voltage function from the output of said input summing amplifier means and to direct said first voltage function to the initial condition circuit of said first integrating amplifier, means to derive a second voltage function from the output of said input summing amplifier means and to direct said second voltage function as input to said second integrating amplifier, third integrating amplifier means for receiving as inputs the output voltages from said first and second integrating amplifiers, normally inactivated means for maintaining the inputs to said third integrating amplifier means constant during periods of loss of target track by a tracking radar by switching said first integrating amplifier from the "initial condition" state to the "compute" state and by simultaneously short-circuiting to ground the input to said second integrating amplifier.

8. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising a first integrating amplifier whose input is grounded and having an initial condition circuit, a second integrating amplifier, means to provide a first voltage function relat-

ing to missile and target position data as input to the initial condition circuit of said first integrating amplifier, means to provide a second voltage function relating to missile and target position data as input to said second integrating amplifier, third integrating amplifier means for receiving as inputs the output voltages from said first and second integrating amplifiers, normally inactivated means for maintaining the inputs to said third integrating amplifier means constant during periods of loss of target track by a tracking radar by switching said first integrating amplifier from the "initial condition" state to the "compute" state and by simultaneously short-circuiting to ground the input to said second integrating amplifier.

9. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising input summing amplifier means for receiving a plurality of input functions relating to missile and target position data and whose output consists of a voltage proportional to the sum of said input functions, first and second integrating amplifiers, means to derive a first voltage function from the output of said input summing amplifier means and to direct said first voltage function as input to said first integrating amplifier, means to derive a second voltage function from the output of said input summing amplifier means and to direct said second voltage function as input to said second integrating amplifier, third integrating amplifier means for receiving as inputs the output voltages from said first and second integrating amplifiers, normally inactivated means to maintain the voltage outputs from said first and second integrating amplifiers constant during loss of target track.

10. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising input summing amplifier means for receiving a plurality of input functions relating to missile and target position data and whose output consists of a voltage proportional to the sum of said input functions, first and second integrating amplifiers, means to derive a first voltage function from the output of said input summing amplifier means and to direct said first voltage function as input to said first integrating amplifier, means to derive a second voltage function from the output of said input summing amplifier means and to direct said second voltage function as input to said second integrating amplifier, third integrating amplifier means for receiving as inputs the output voltages from said first and second integrating amplifiers, and whose output is an electrical signal relating to programmed missile position, and normally inactivated means to maintain the rate of change of output electrical signals from said third integrating amplifier means constant during periods of loss of target track.

11. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising first and second integrating amplifiers, a third integrating amplifier for receiving as inputs the output voltages from said first and second integrating amplifiers, normally inactivated means to maintain the rate of change of output signals from said third integrating amplifier constant during periods of loss of target track.

12. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising a first integrating amplifier whose input is grounded and having an initial condition circuit, a second integrating amplifier, a third integrating amplifier for receiving as inputs the output signals from said first and second integrating amplifiers and whose output is an electrical signal relating to programmed missile position, normally inactivated means to switch said first integrating amplifier from the "initial condition" state to the "compute" state and to short-circuit to ground the input circuit to said second integrating amplifier during periods of loss of target track.

13. In an apparatus for controlling the flight trajectory of a guided missile, a guidance computer comprising a first integrating amplifier, a second integrating amplifier, a third integrating amplifier for receiving as inputs the output voltages from said first and second integrating amplifiers and whose output is an electrical signal relating to programmed missile position, normally inactivated means to maintain the output voltages from said first and second integrating amplifiers constant during periods of loss of target track.

14. A missile guidance computer which acts upon signal outputs from a target tracking means comprising first and second integrating amplifiers coupled to receive outputs from the tracking means; a third integrating amplifier for receiving as inputs the output electrical signals from said first and second integrating amplifiers; and condition responsive means activated upon loss of target signal to maintain the rate of change of output electrical signals from said third integrating amplifier constant during periods of loss of target signal.

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