Aug. 15, 1961 S. A. JORDAN, JR., ET AL 2,995,830

SIMULATED MISSILE HOMING SYSTEM

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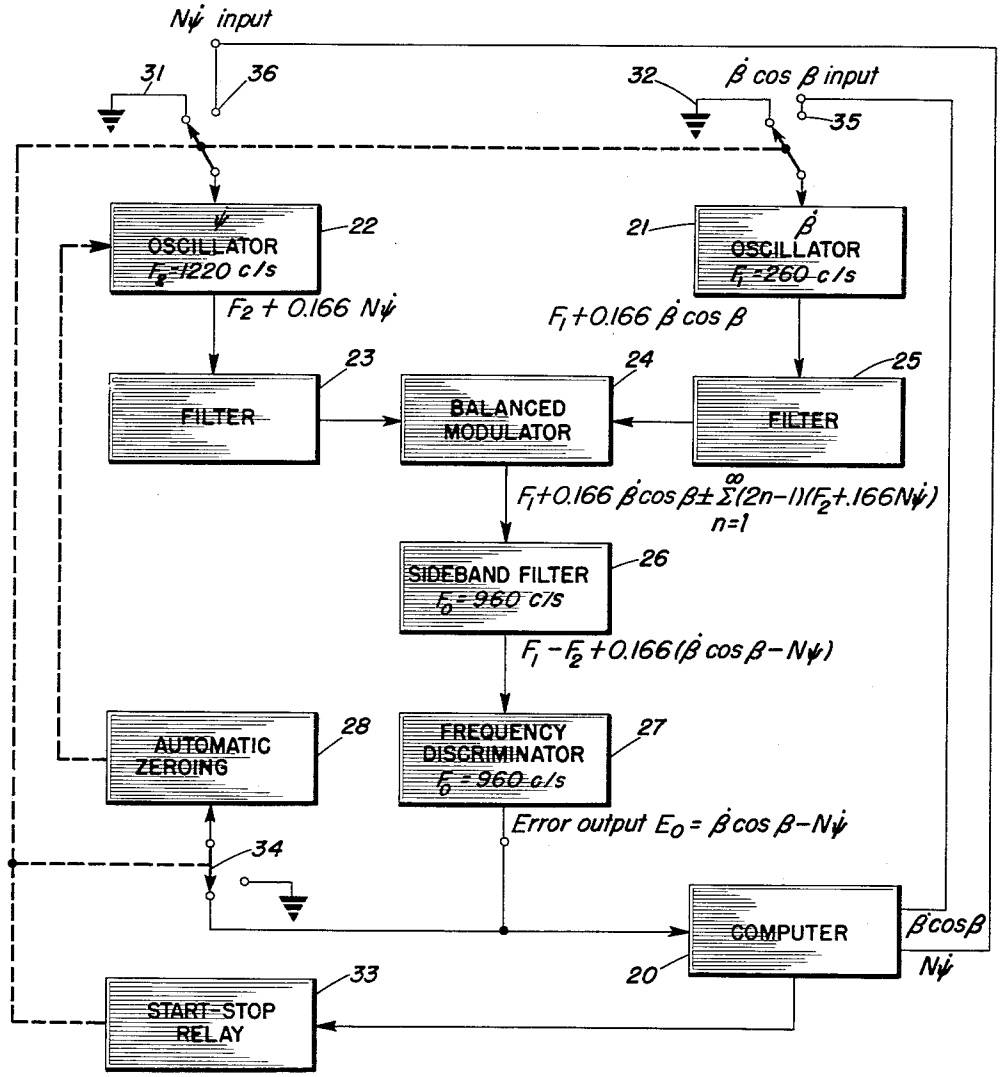


FIG. 1.

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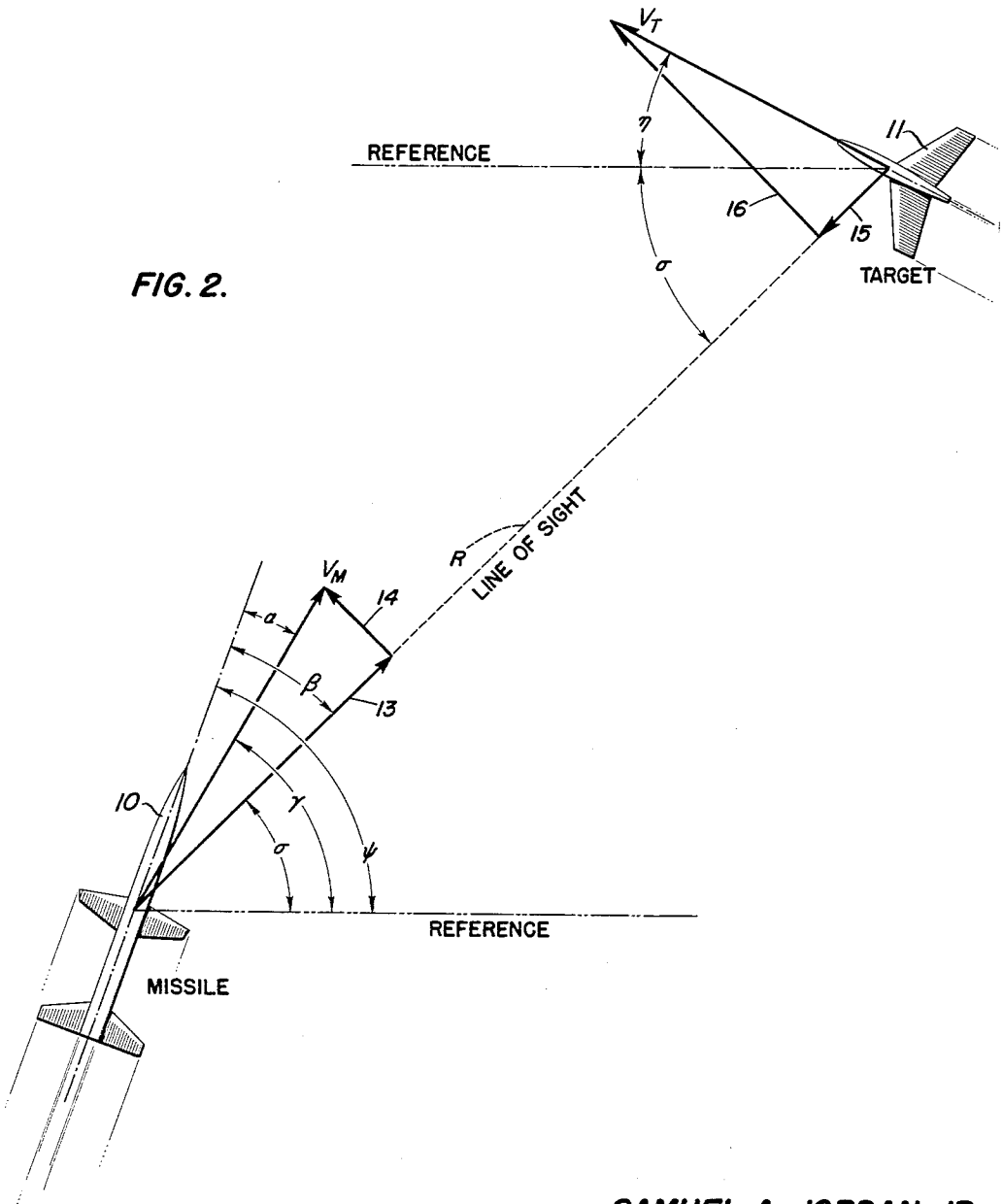


FIG. 2.

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SIMULATED MISSILE HOMING SYSTEM

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7 Claims. (Cl. 35—10.2)

The present invention relates to a simulated homing system for steering an aerial missile to a point of collision with a distant target.

This invention is intended to synthesize the characteristics of an interferometer-type homing system such as is disclosed in patent application Serial No. 319,624, filed November 10, 1952, for a "Scanning Interferometer-Beam Rider Guidance System," by Carl W. Brown et al.

Briefly, the interferometer homing system includes a device wherein a first signal having a frequency variable according to the rate of change in the orientation of the missile axis with an arbitrary reference is combined with a second signal whose frequency varies according to the rate of change in the orientation of the missile's axis to a line-of-sight between the missile and the target. Whenever the missile is proceeding along a course which would not result ultimately in collision with the target, the combination of the first and second signals gives rise to an error signal which causes the missile to correct its direction of flight. In this manner the missile is caused to home on a target and to steer itself along a collision course.

Prior to the present invention, it was common practice to employ computing machines for the solution of problems involving missile flight. In such machines, missile elements were represented merely in terms of time delays or gain factors. The solutions thereby obtained were broadly representative of an actual flight, but they were lacking in many important details necessary for a complete systhesis of the missile. It has been determined that in order to achieve satisfactory transmission of intelligence signals by means of a frequency modulation system, all components transmitting a frequency varying signal must possess a certain minimum bandwidth. In the case of broadcasting by means of frequency modulation it is possible, on the bases of certain reasonable assumptions, to compute the bandwidth required.

In the case of a guided missile, reasonable assumptions as to various missile-target relationships do not permit an analysis to be made without resorting to the most tedious and time consuming methods of computation. Moreover, the problem of determining satisfactory band pass characteristics for missile components cannot be ignored. A missile cannot arbitrarily be designed with narrow band pass characteristics, nor with overly wide band pass characteristics, for the reasons that in the former case the missile would tend to be unstable in operation, and in the latter case, noise might appear at such a level as to mask the steering signals.

It is therefore an object of this invention to provide a convenient means for evaluating the probable performance of a guided missile when the band pass characteristics of the missile homing system are altered.

A further object of the present invention is to provide a simulated interferometer homing system which utilizes frequency modulated signals having spectra corresponding to the actual case.

Still another object of the present invention is to provide a simulated missile homing system adapted to use with an electronic analogue computer.

Other objects and many of the attendant advantages of the present invention will be readily appreciated as the same becomes better understood when considered in connection with the accompanying drawings.

Briefly, the present invention comprises a pair of frequency modulated audio frequency oscillators, the frequency of one being controlled by a voltage corresponding to the quantity measured by a rate gyroscope mounted on the missile, the frequency of the other being controlled by a voltage corresponding to the quantity measured by a radio frequency interferometer. Means are provided for combining the oscillator signals and demodulating the combined signal in a manner which simulates the actual missile installation.

In the drawings:

FIG. 1 is a functional block diagram of the simulated homing system of the present invention; and

FIG. 2 is a diagram illustrating the geometry applicable to an interferometer type homing system in the yaw or pitch plane.

FIG. 1 is a block diagram of the simulated interferometer type homing system which is the subject of the present invention. An electronic analogue computer **20** is provided to solve simultaneous differential equations representing missile motion, target motion, and the dynamic performances of a rate gyro. The computer **20** provides an output voltage $\dot{\beta}\cos\beta$ which controls a frequency modulated oscillator **21**. The computer also provides an output voltage $N\dot{\psi}$ to control a second frequency modulated oscillator **22**.

Oscillator **21** has a center frequency F_1 of 260 c.p.s. from which the output deviates .166 c.p.s. per volt of applied control voltage $\dot{\beta}\cos\beta$. The output of oscillator **21** is filtered by means of a filter **23** and supplied as one input to a balanced modulator **24**.

Oscillator **22** is similar generally to oscillator **21** except that the center frequency of oscillator **22** is 1220 c.p.s. The output of oscillator **22** deviates .166 c.p.s. per volt of applied control voltage $N\dot{\psi}$. The output of oscillator **22** is filtered by means of a filter **25** and supplied as a second input to the balanced modulator **24**. The oscillators may be any conventional type which will provide a frequency deviation in the output in response to an applied control voltage. Also, the filters and balanced modulator are conventional, and need not be given detailed consideration.

The output of the balanced modulator is a complex wave comprising components having frequencies equal to the sum of the frequencies of oscillator **21** and oscillator **22**, the difference in frequencies of oscillator **21** and oscillator **22** and the sum and the difference of harmonics of the outputs of oscillators **21** and **22**. A filter **26** removes from the output of the balanced modulator all components other than the component having a frequency equal to the difference in the frequency of the outputs of oscillators **21** and **22**. The filter **26** eliminates sidebands which are not effective in supplying information to the discriminator and thereby improves the efficiency of the system.

A discriminator **27** having a center frequency of 960 c.p.s. provides a D.C. signal E_0 proportional to the difference in the control voltages $N\psi$ and $\dot{\beta}\cos\beta$ when the elements of the simulated homing system are linear in operation. If the elements are not linear, a distorted signal is produced which will affect the behavior of the simulated missile. Intentional distortions can be introduced which closely resemble those occurring in the actual missile, and the effect of those distortions can be observed in the solutions provided by the computer **20**.

An automatic zeroing servomotor **28** is provided to remove biases from the output of the discriminator **27** when the simulator is in a stand-by condition. The biases arise because imperfections in the oscillators **21** and **22** cause the oscillators to drift from their center frequencies and thus undesirably shift the input frequency to the discriminator. The inputs to the oscillators are grounded through

contacts 31 and 32 of start-stop relay 33. Relay 33 is energized by a common circuit with the computer start-stop relays. During the grounded or stand-by condition of the oscillators, the output of the discriminator 27 is applied through a contact 34 of relay 33 to the servomotor 28 input. The servomotor 28 moves to adjust the frequency determining element of oscillator 22 in the proper direction to remove the output bias. When the computer is performing a solution, control voltage is applied to oscillators 21 and 22 through contacts 35 and 36 of relay 33, and the input to servomotor 28 is grounded through contact 34.

FIG. 2 illustrates the geometry applicable to an interferometer type homing system. A missile 10 is shown oriented in the general direction of a target 11. The missile is proceeding with a velocity V_m generally in the direction of the target 11 which may be proceeding in any direction with a velocity V_t. When the missile is oriented in such a way that the component of the relative velocity between the missile and target transverse to a line-of-sight between the missile and target is zero, the missile is on a course which eventually will result in a collision between the missile and the target.

The various angles appearing in FIG. 1 are defined as follows:

σ is the angle between the line-of-sight from the missile to the target and an arbitrary reference.
γ is the angle between the missile's velocity vector V_m and the reference.
ψ is the angle between the missile axis and the reference.
β is the angle between the missile axis and the line-of-sight.
η is the angle between the target velocity and the reference.
R is the range from the missile to the target.

The following relationships can be derived from FIG. 1 by inspection:

$$\sigma=\psi-\beta \quad (1)$$
$$\psi=\gamma+\alpha \quad (2)$$

and by differentiating Equation 1

$$\dot{\sigma}=\dot{\psi}-\dot{\beta} \quad (3)$$

where the dot notation indicates differentiation with respect to time.

The missile velocity V_m can be resolved into a component 13 of velocity along the line-of-sight and a component 14 perpendicular to the line-of-sight. Likewise, the velocity V_t of the target can be resolved into a component 15 along the line-of-sight and a component 16 perpendicular to the line-of-sight. The velocity components 14 and 16 are equal when the missile is proceeding along a collision course, otherwise, the line-of-sight will rotate at a rate depending upon the difference between the components. The linear rate of rotation of the line-of-sight, as measured at the missile, is equal to the angular rate $\dot{\sigma}$ of rotation multiplied by the range R. This may be more satisfactorily expressed mathematically as

$$\dot{\sigma}R=V_m \sin(\gamma-\sigma)-V_t \sin(\eta+\sigma) \quad (4)$$

Also from FIG. 2 the range rate is obtained as

$$\dot{R}=V_m \cos(\gamma-\sigma)+V_t \cos(\eta+\sigma) \quad (5)$$

and the following two equations represent the aerodynamics of the missile

$$\dot{\gamma}=A\alpha+B\delta \quad (6)$$
$$\ddot{\psi}+D\psi+C\alpha=E\delta \quad (7)$$

where A, B, C, D, and E are parameters which depend upon the characteristics of a particular missile, and δ is the deflection of the missile control surface.

The preceding equations are solved simultaneously in the computer 20 in accordance with well known techniques. The control voltages necessary to operate oscillators 21 and 22 are readily available as part of the solution.

The simulated homing system is equivalent to the actual interferometer homing system since in the interferometer a scanning type antenna system together with a receiver provides a signal output in the form of a frequency modulated carrier whose deviation from its center frequency is proportional to $\dot{\beta}\cos\beta$. A rate gyro mounted on the missile controls the deviation of a second signal from its center frequency according to the term $N\dot{\psi}$. The two signals are combined in a balanced modulator and detected by a discriminator to provide steering information proportional to $\dot{\beta}\cos\beta-N\dot{\psi}$.

A collision course is obtained when $\dot{\sigma}$ is equal to zero. The actual interferometer detects steering errors by approximating the value of $\dot{\sigma}$ from the difference between $\dot{\beta}\cos\beta$ and $N\dot{\psi}$. By employing $\dot{\beta}\cos\beta$ and $N\dot{\psi}$ as the control voltage for the oscillators 21 and 22 a frequency modulated signal closely approximating the actual signal is provided.

In use, appropriate initial conditions representing the missile velocity, the target velocity and the attitude of the missile with respect to target are set into the computer. The computer performs mathematical operations upon these initial conditions to supply an $N\dot{\psi}$ and a $\dot{\beta}\cos\beta$ signal to the oscillators of the simulated homing system.

Either filter 23, filter 25, or filter 26 is adjusted to represent a desired band pass characteristic. The filter limits the bandwidth of the signal passing through it and so ultimately affects the quality of the error signal E_0. The error signal E_0 enters the computer which calculates a new value for N and $\dot{\psi}\beta\cos\beta$.

This process is carried out continuously until the computer signals the end of the flight. The effects of altering the band pass characteristics of the missile homing system can be determined by comparing the miss distances as calculated by the computer for various settings of filters 23, 25, and 26.

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 simulator for predicting the performance of a homing system for steering a guided missile into collision with a target, comprising, a computing machine for solving the differential equations of motion applicable to the missile and target and for representing the time delays inherent in said missile, said machine providing a first control voltage output representing the rate of missile rotation about its center of gravity and a second control voltage representing the rate of change of the missile heading angle measured with respect to the line-of-sight between the missile center of gravity and the target, a first frequency modulated oscillator receiving said first control voltage and providing a frequency deviation proportional thereto, a first adjustable filter for altering the output of said first oscillator, a second frequency modulated oscillator receiving said second control voltage and providing a frequency deviation proportional thereto, a second adjustable filter for altering the output of said second oscillator means for combining the outputs of said first and second filters, and means for detecting said combined outputs of said filters to provide a signal simulating the steering signal in an actual missile, said simulated steering signal being entered in said computer to alter said first and second control voltages.

2. A simulator as claimed in claim 1 wherein said first and second oscillators have outputs of different frequencies.

3. A simulator as claimed in claim 2 wherein said

means for combining the outputs of said first and second filters comprises, a balanced modulator arranged to receive the output of said first and said second oscillator to provide a signal having a frequency equal to the difference in frequency between the outputs of said first and second oscillators.

4. A simulator as claimed in claim 2 wherein said means for detecting said combined outputs comprises, a discriminator having a center frequency equal to the difference in frequency between the outputs of said first and second oscillators.

5. A simulator as claimed in claim 4 with additionally, means receiving the output of said discriminator and coupled to one of said oscillators for adjusting the frequency of said one of said oscillators to remove unwanted bias from the output of said discriminator.

6. A simulator for predicting the performance of a missile homing system, comprising an electronic analogue computer having a first control voltage output and a second control voltage output, a first frequency modulated oscillator and a second frequency modulated oscillator, said oscillators being responsive to said first and said second control voltages respectively, a first adjustable filter for altering the output of said first oscillator, a second adjustable filter for altering the output of said second oscillator, a balanced modulator for obtaining a signal having a frequency equal to the difference in the frequencies of the outputs of said first and second oscillators, a filter to remove unwanted components from the output of said

modulator, a discriminator to provide a simulated steering signal according to the filtered output of said modulator, means for removing unwanted bias from the output of said discriminator, and means for entering the output of said discriminator into said computer, so constructed and arranged that effects of altering the band pass characteristics of an actual missile homing system can be observed by altering the characteristics of said first and second filters.

7. A simulator as claimed in claim 6 wherein said means for removing unwanted bias comprises an automatic zeroing servomotor including a relay for applying the output of said discriminator to the servomotor input and operative upon the commencement of computation of said computer to disconnect said discriminator input and thereby render said servomotor inoperative, said servomotor being mechanically coupled to an adjustable frequency determining element in said first oscillator.

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