March 13, 1962 J. W. B. BARGHAUSEN 3,025,023

MISSILE GUIDANCE SYSTEM

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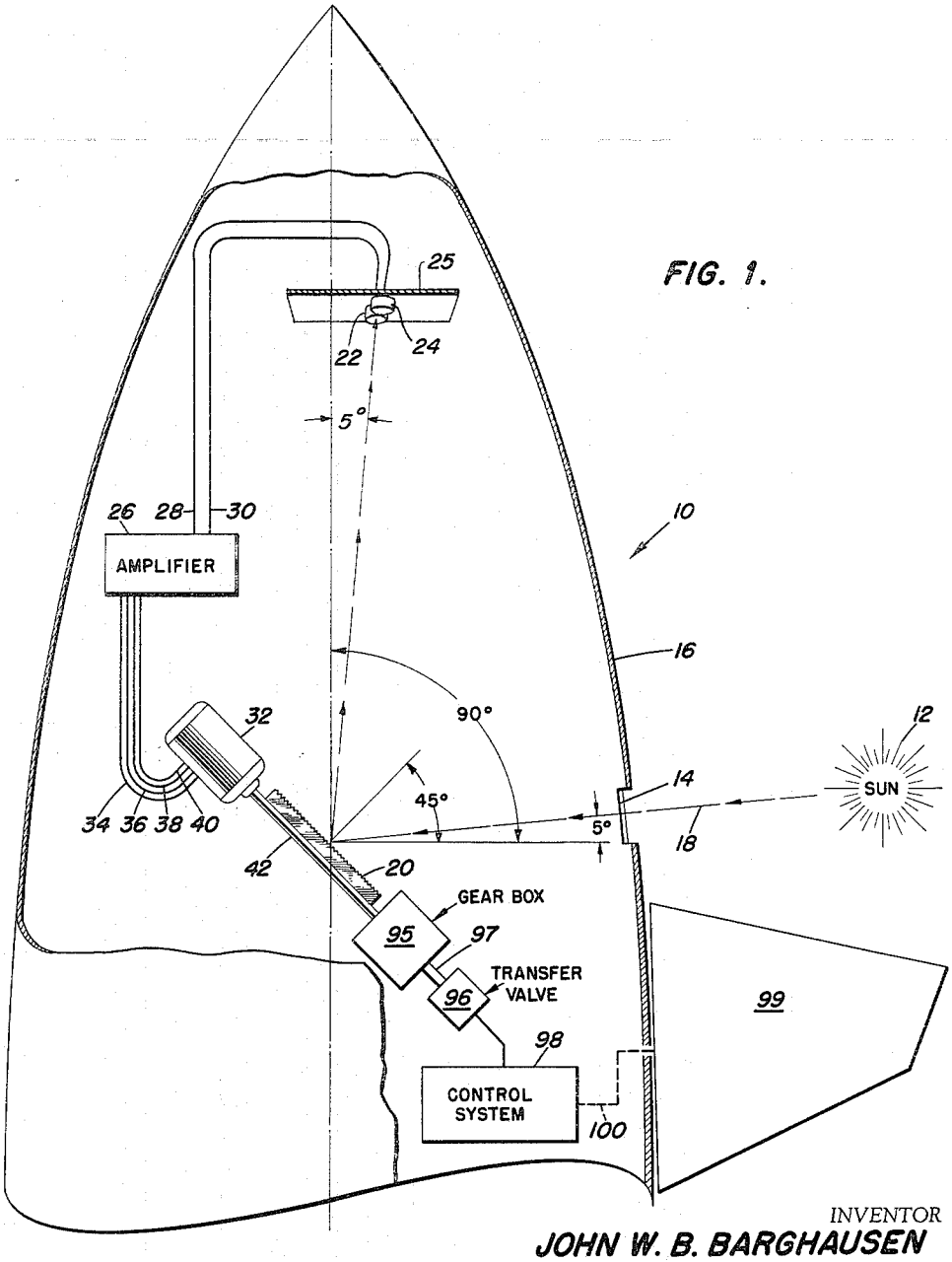


FIG. 1.

INVENTOR
JOHN W. B. BARGHAUSEN

BY G. D. O'Brien
Q. Baxter Warner
ATTORNEYS

March 13, 1962 J. W. B. BARGHAUSEN 3,025,023

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FIG. 2.

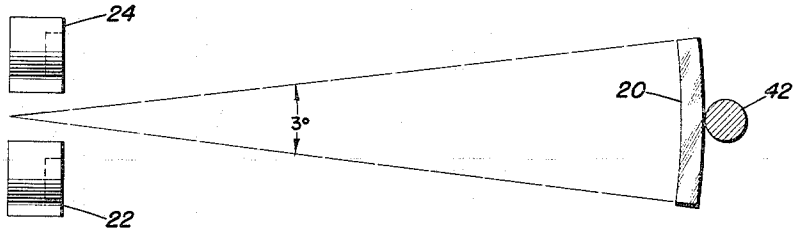


FIG. 3.

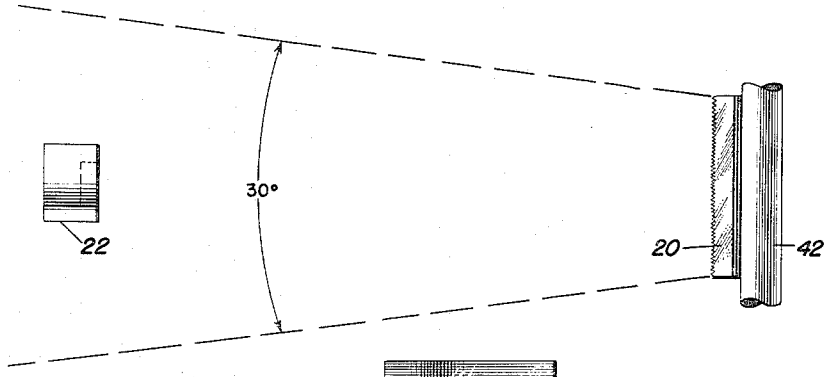


FIG. 4.

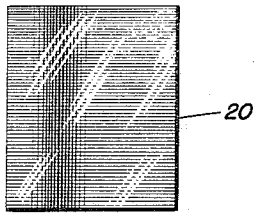
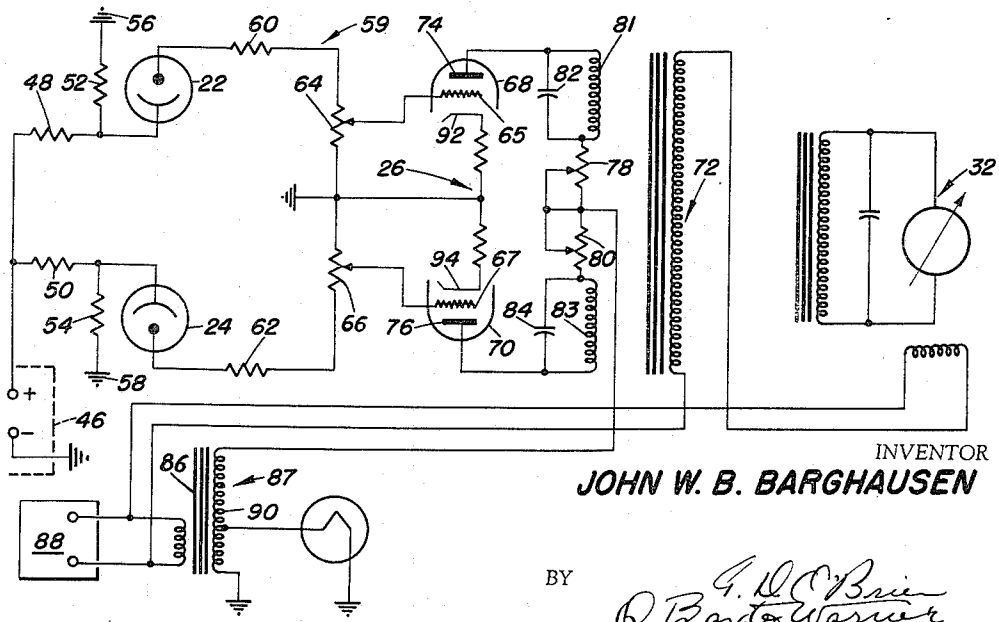


FIG. 5.



INVENTOR

JOHN W. B. BARGHAUSEN

BY

G. D. O'Brien
R. Baxter Warner

ATTORNEYS

March 13, 1962 J. W. B. BARGHAUSEN 3,025,023

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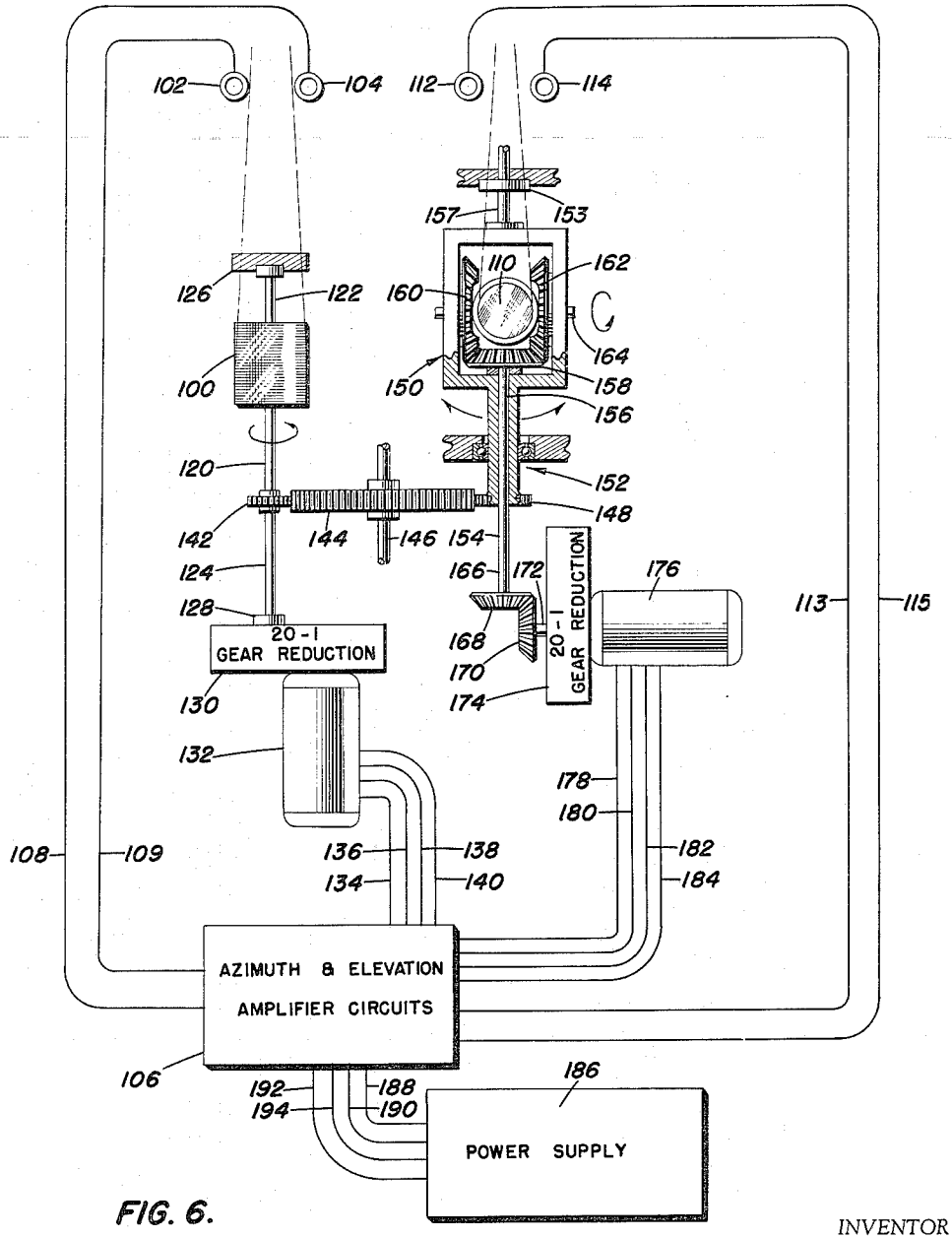


FIG. 6.

INVENTOR
JOHN W. B. BARGHAUSEN

BY G. O. O'Brien
Q. Baxter Warren
ATTORNEYS

March 13, 1962 J. W. B. BARGHAUSEN 3,025,023

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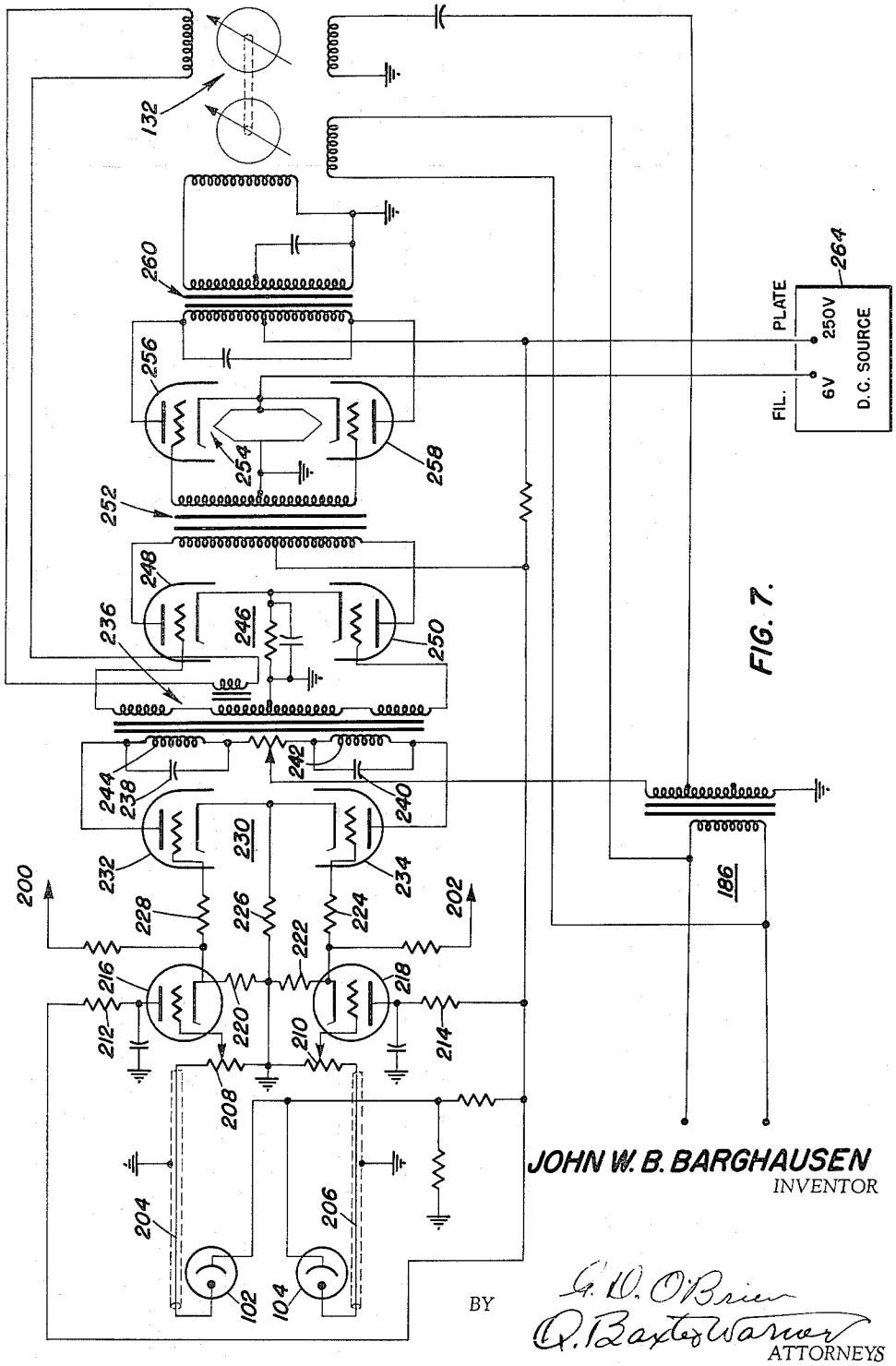


FIG. 7.

JOHN W. B. BARGHAUSEN
INVENTOR

BY G. W. O'Brien
R. Baxter Warner
ATTORNEYS

March 13, 1962 J. W. B. BARGHAUSEN 3,025,023

MISSILE GUIDANCE SYSTEM

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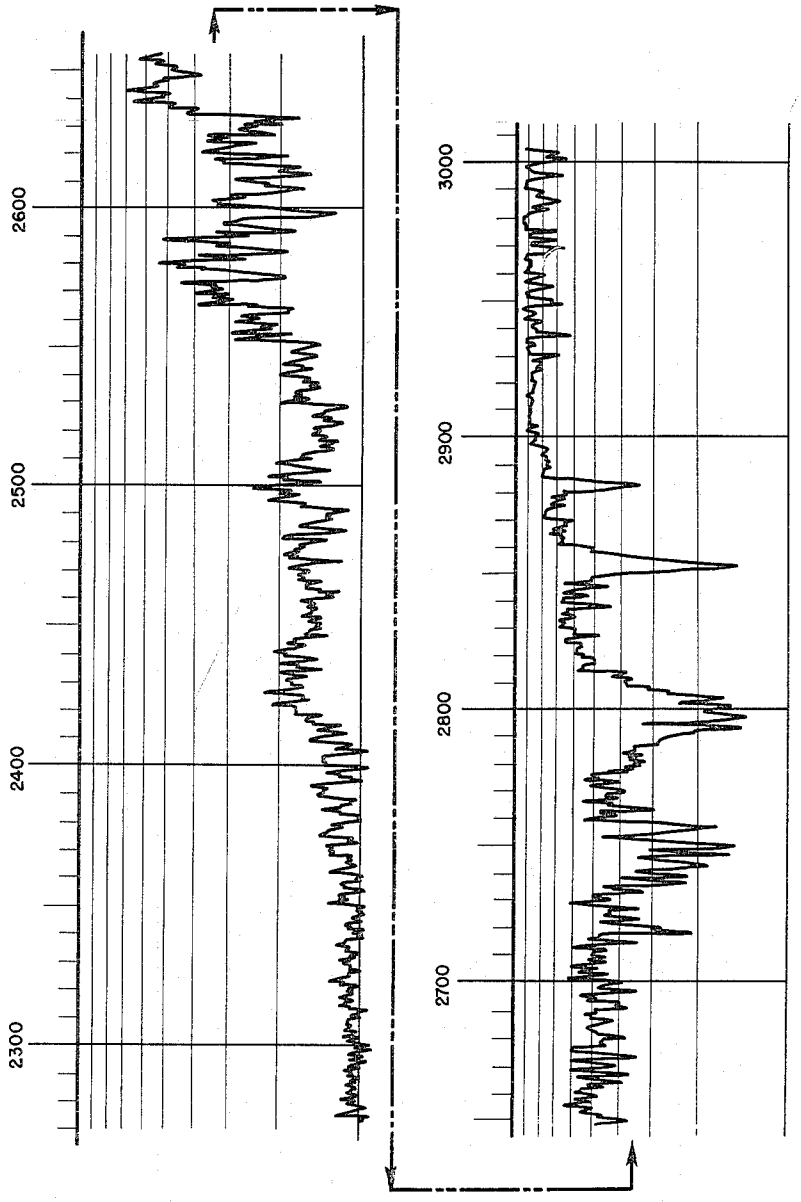


FIG. 8.

SOLAR SPECTRUM FROM V-2 ROCKET
HEIGHT 135 KM (84 MILES)

JOHN W. B. BARGHAUSEN
INVENTOR

BY E. D. O'Brien
R. Baxter Warner.
ATTORNEYS

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3,025,023

MISSILE GUIDANCE SYSTEM

John W. B. Barghausen, West Hyattsville, Md., assignor to the United States of America as represented by the Secretary of the Navy

Filed Sept. 14, 1954, Ser. No. 456,350
4 Claims. (Cl. 244—14)

This invention relates generally to missile guidance, and more particularly it relates to arrangements for controlling the flight of an aerial missile by celestial navigation.

It is one of the objects of this invention to provide an arrangement for controlling the flight of an aerial missile in one plane, such as azimuth, by reference to a natural or artificial celestial body.

It is another object of this invention to provide an arrangement for controlling the flight of an aerial missile in two planes, such as azimuth as well as in elevation, by reference to a natural or artificial celestial body.

It is still another object of this invention to provide electronic and mechanical arrangements in an aerial missile so that the latter will effectively sight and lock on a natural or artificial celestial body and thus will be able to be guided a sufficient distance along a course to a target.

And other objects of this invention are to provide electronic and mechanical arrangements for missile guidance which are economical to manufacture, efficient and reliable in operation, and which are compact.

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 illustrates a schematic of an aerial missile having one embodiment of the invention mounted therein;

FIG. 2 is a schematic representation of the scan pattern of the azimuth mirror with respect to the photoelectric cells which form part of the invention;

FIG. 3 is a side view of the arrangement illustrated in FIG. 2;

FIG. 4 is a front view of the corrugated aluminized mirror illustrated in FIGS. 2 and 3;

FIG. 5 is a wiring diagram of the circuitry utilized in connection with the first embodiment of the invention;

FIG. 6 is a schematic of a second embodiment of the invention;

FIG. 7 is a schematic of the circuitry utilized in connection with the second embodiment of the invention; and

FIG. 8 illustrates a solar spectrum taken by spectrographic equipment mounted in a missile at a height of approximately 84 miles above the surface of the earth.

In accordance with one embodiment of the invention, an arrangement is provided for controlling the flight of an aerial missile in one plane by guiding on a celestial body, such as the sun, an artificial earth satellite, or a fixed star of sufficient light intensity, or even a high altitudte aircraft having a beam of light directed on the missile which the missile would follow as the prescribed course set by the aircraft. The invention hereinafter will be limited in description to the sun, although it is to be emphasized that it can be used in conjunction with an artificial satellite, a fixed star, or an aircraft, as previously indicated, to give positive night control of a missile. This arrangement comprises means including a corrugated aluminized mirror for receiving and reflecting the rays of light from the sun, a plurality of photoelectric cells for receiving the reflected rays of light, an amplifier which is actuated by the photoelectric cells, and servo motor means, which, in turn, are actuated by the output

of the amplifier and are phase sensitive so as to control the direction of movement of the missile in one plane.

In a second embodiment of the invention, an arrangement is provided for controlling the flight of the missile in two planes, such as azimuth and elevation, by guiding on a celestial body, such as the sun. This arrangement includes azimuth and elevation mirrors for reflecting the rays of light from the sun, a pair of photoelectric cells for each mirror for receiving the reflected rays of light therefrom, means for locking the azimuth mirror on the sun prior to the hunting of the sun by the elevation mirror, azimuth and elevation amplifiers, which, in turn, are actuated by the respective pairs of photoelectric cells, and separate phase sensitive servo means controlled by the amplifiers for moving the missile in azimuth as well as in elevation so as to control the direction of movement of the missile in two planes.

Referring now to FIG. 1 of the drawings, there is illustrated an aerial missile **10** of the rocket type, which has incorporated therein an electronic and mechanical arrangement for guiding on a celestial body, such as the sun **12**. It is to be noted that although this invention is illustrated in conjunction with a rocket type missile, it can readily be adapted for use with other types of missiles, such as a ramjet missile, or rocket-ramjet missiles. This aerial missile **10** has a window **14** provided in its wall surface **16** for receiving and passing rays of light, such as rays **18** from the sun **12**. The window **14** is arranged so that it will receive the rays from the sun through an angle of 10°, with a horizon sector angle of 90°.

The rays of light **18** are reflected from a corrugated aluminized concave mirror **20**, which is positioned at an angle to the longitudinal axis of the missile **10**, to a pair of photoelectric cells **22** and **24**, mounted on suitable structure **25**. These cells **22** and **24** are connected to an amplifier **26** by means of leads **28** and **30**. The signal from the photoelectric cells **22** and **24** actuates the amplifier **26** with sufficient power to drive a small motor **32**. This motor is phase sensitive as to direction of rotation, and it is connected to amplifier **26** by leads **34**, **36**, **38**, and **40**.

Shaft **42** of motor **26** is connected through a suitable reduction gear arrangement (not shown) to the mirror **20**. This reduction gear arrangement will be described more in detail hereinafter, with respect to the second embodiment of the invention.

As shown in FIG. 2, the concave mirror **20** is designed to reflect a ribbon of light having a width of approximately 3 degrees. The concave mirror **20** is corrugated with approximately 24 corrugations per inch (1") lying in planes perpendicular to the axis of curvature, as shown in FIGS. 3 and 4, and has a light cell scan of approximately 30 degrees. The reason for the corrugations is to give a multiplicity of light reflections forming a ribbon band of light having a width capable of creating a dead spot between the two cells **22** and **24**. Mirror **20** thus gives a rather wide beam of light in a plane perpendicular to the line connecting cells **22** and **24**. The light scatters rapidly as it departs from the image center, with the result that the intensity of light is not constant.

Due to spacing between the light cells **22** and **24**, a movement of the mirror **20** causes the reflected light to flip between them, that is, the light reflection from the concave mirror **20** is flipped from one to the other of the cells, thus causing a flutter motion of small amplitude having a frequency of approximately 15 to 20 cycles per second.

Referring now to FIG. 5 of the drawings, there is illustrated a flutter circuit which has some of the characteristics of a servo system, that is, in effect for a given signal

input with respect to phase, the signal output is controlled proportionally.

In the instant case, the light intensity of a celestial body, such as the sun 12, is applied to the photoelectric cell 22, causing the output torque motor 32 to move in one favored direction. If the light intensity is applied to photoelectric cell 24, the motor 32 will move in the opposite direction from the direction of rotation when the light intensity is applied to cell 22. If the light intensity is applied to both cells 22 and 24, the motor 32 will seek a point therebetween and will stop, depending upon the intensity of the light as distributed across the photoelectric cells 22 and 24. A balance point will be created, thus canceling the energizing force on the torque motor 32.

As shown in FIG. 5, a conventional voltage source 46, such as a D.C. battery, is connected to the photoelectric cells 22 and 24 through the resistors 48, 50, 52, and 54. One end of each of the resistors 52 and 54 is grounded as indicated by reference numerals 56 and 58, respectively. The resistors 48 and 50 are current regulating and voltage feed resistors for the photoelectric cells 22 and 24, respectively, while the resistors 52 and 54 are load resistors.

The photoelectric cells 22 and 24 are connected through a network 59, including fixed resistors 60 and 62 and variable resistors 64 and 66, to the grids 65 and 67 of the two dual triode vacuum tubes 68 and 70. Vacuum tubes 68 and 70 are a part of the amplifier 26.

The resistors 60 and 62 are necessary to attenuate the signals from the photoelectric cells 22 and 24, and thereby attenuate the input or overshooting effect of the signals from the cells. Resistors 64 and 66 are used for biasing the grids 65 and 67 of the dual triode tubes 68 and 70, respectively. The signal produced across the resistors 60 and 64, or resistors 62 and 66, is a varying bias control signal which limits the plate current flowing in each half of the amplifier tube circuit. Amplifier 26 is coupled to a coupling transformer 72 of the saturable reactor type, and this transformer is, in turn, magnetically coupled to the 400 cycle torque motor 32.

Without any energizing source, amplifier 26 is balanced electronically to a zero output, in which case the motor 32 will not move due to the fact that there is a cancellation of the driving voltage. Balance of the circuit is achieved by means of the variable resistors 78 and 80 which are connected to the plates 74 and 76 of the dual triodes 68 and 70, respectively, through the condensers 82 and 84, and the inductance coils 81 and 83, which are connected in parallel with the condensers 82 and 84, respectively. Condensers 82 and 84 are utilized for tuning the plate circuits of the dual triodes 68 and 70.

However, when the two plates 74 and 76 of the dual triode tubes 68 and 70, respectively, are energized, the effect is to throw the circuit off-balance by a ratio of the input energized voltages from the photoelectric cells 22 and 24. This ratio is determined by the resistors 60 and 62. The motor 32 is then influenced to move in one direction or the other. The attempt at all times is for the motor 32 to run in the direction that it is influenced, and the speed thereof is determined by the amplitude or voltage off-balance of resistors 60 and 62. However, this voltage is that which is a function of the light intensity as applied to light cells 22 or 24. The circuitry is tuned to 400 cycles because of a 400 cycle per second power supply 87.

A power transformer 86, which is an integral part of the power supply 87, is energized from a 400 cycle input generator 88, with the secondary or output side 90 of the transformer 86 developing the necessary voltage to energize the plates 74 and 76 and light the filaments 92 and 94 of the dual triodes 68 and 70, respectively, of the amplifier 26.

When the photoelectric cells 22 and 24 see a light source, such as the rays from the sun, the output of either or both of these cells 22 and 24 is in the form of a short-term control pulse which causes the system to continuously hunt back and forth to establish a point where both of the cells 22 and 24 are able to see the sun equally well by the positioning of the concave mirror 20.

In operation, the signal from either photoelectric cell 22 or 24 is fed to the amplifier 26, and hence to the motor 32, as previously described. The common shaft 42 of the motor 32 can be connected to a suitable gear box 95, and thence to a transfer valve 96 through a take-off shaft 97. Transfer valve 96 is the sense control for a hydraulic or mechanical-electrical power control system 98, which is suitably linked to control surfaces 99 (only one of which is shown) of the missile 10 by a suitable mechanical linkage 100 for controlling the flight of the missile 10 in a single plane.

Instead of connecting from the common shaft 42 of motor 32, the signal from the photoelectric cell 22 or 24 can be fed into an independent amplifier and phase sensitive motor (no shown) for an independent control of the missile surfaces 99. This is particularly true where the amount of space available is not adequate to house the necessary components in the vicinity of the mirror 20.

In FIG. 8, there is illustrated an actual solar spectrum taken from a flight of an aerial missile 10 of the rocket type, in which the beam of light which actuated the photoelectric cells 22 and 24 also injected light into a spectrograph camera having its aperture 101 located in the support 25, shown in FIG. 1. This light was reflected again from an internal grating to a special type of film which was later processed after recovery of the missile 10.

Referring now to FIGS. 6 and 7 of the drawings, there is illustrated another embodiment of the invention which represents a considerable improvement over the embodiment of the invention illustrated in FIGS. 1 through 5 in that the arrangement illustrated here is used to control the flight of an aerial missile 10 in two planes, that is, in azimuth as well as in elevation, by guiding on a celestial body, such as the sun. This embodiment of the invention, therefore, has two distinct planes for reference on the sun. In this embodiment of the invention, use is made of a clear, concave, spot focusing type of reflecting mirror in the elevation portion of the system, which will be described more fully hereinafter, and also the corrugated mirror 20 as illustrated in connection with the first embodiment of the invention.

As shown in FIG. 6, the rays of light having passed through the window 14 in the wall 16 of missile 10 are reflected from a corrugated aluminized mirror 100 to a pair of photoelectric cells 102 and 104. These cells 102 and 104 are connected to azimuth and elevation amplifier circuits 106 by means of leads 108 and 109. The mirror 100 is similar to the mirror 20 used in the first embodiment of the invention, and the photoelectric cells 102 and 104 also correspond to cells 22 and 24 in the first embodiment of the invention. This mirror 100 is used only to position a slave differential frame mounting 150, through a gear arrangement, which mounts a vertical homing concave clear mirror 110 so that it will hunt its proper angle and then reflect the light rays to a second pair of control photoelectric cells 112 and 114, which are electrically connected to the azimuth and elevation amplifier circuits 106 by leads 113 and 115. This second arrangement is independent of the azimuth system in that it has its own set of photoelectric cells 112 and 114 to work against.

That is, the azimuth control for the aerial missile 10 has its own two photoelectric cells 102 and 104 to control the angle of the reflected light so that the slave differential frame mounting can be assured of the proper angle in azimuth only. If it is assumed that the system is sighting and locked on a celestial body, such as the sun, in azimuth, then the vertical mirror 110 hunts around and reflects the light in the vertical plane to its own two photoelectric cells 112 and 114. The above is accom-

plished by two servo systems each operating from its separate circuit in proper sequence, as will be explained more fully hereinafter.

Mirror **100** is mounted on a rotatable shaft **120**, which, in turn, has its ends **122** and **124** supported in suitable bearing arrangements **126** and **128**. End **124** of shaft **120** is connected to a 20:1 reduction gearing arrangement contained in gear reduction housing **130**, and this gearing arrangement, in turn, is mechanically connected to a 5,000 r.p.m. selsyn motor **132**. Motor **132** is electrically connected to the azimuth and elevation amplifier circuits **106** by leads **134**, **136**, **138**, and **140**.

Shaft **120** has mounted thereon a gear **142** which meshes with an idler gear **144**, which, in turn, is mounted on a suitable rotatable supporting shaft **146**. Idler gear **144** meshes with a second gear **148** contained at one end of the differential housing **150**. Housing **150** is supported by two bearings **152** and **153** and a shaft **154** which passes through the differential housing **150**. A shaft element **157**, attached to differential housing **150**, operates in bearing arrangement **153** and thus helps to support differential housing **150**. The end **156** of shaft **154** has mounted thereon a beveled gear **158** for meshing with two other beveled gears **160** and **162** which are mounted on an idler drift shaft **164** that passes through housing **150** for moving mirror **110**.

On end **166** of shaft **154**, there is located a beveled gear **168** for meshing with a second beveled gear **170**. Gear **170**, in turn, is mounted on shaft **172**, which is mechanically coupled to a 20:1 gear reduction arrangement contained in a housing **174**. The gear reduction arrangement contained in housing **174** is mechanically coupled to a 5,000 r.p.m. selsyn motor **176**, similar to the type of motor **132** used in the azimuth control. Selsyn motor **176** is electrically connected to the azimuth and elevation amplifier circuits **106** by means of leads **178**, **180**, **182**, and **184**. A suitable power supply **186**, including a 400 cycle inverter, is also electrically connected to the azimuth and elevation amplifier circuits by leads **188**, **190**, **192**, and **194**, as illustrated in FIGS. 6 and 7.

The amplifier circuits **106** for both azimuth and elevation control are identical, so that only one need be explained hereinafter, such as the azimuth control circuit as illustrated in FIG. 7. The amplifier shown in FIG. 7 has four stages, instead of one stage as previously described with respect to the embodiment of the invention illustrated in FIGS. 1 through 5. The reason for this is to build up the signal voltage from the photoelectric cells **102** and **104** to a higher amplitude, and eventually obtain more power and operating torque on motor **132**, thereby giving also a better response time to the function of control of the aerial missile **10**. Leads **200** and **202** are connected to the amplifier circuit **106** to supply a signal to an external telemetering system, which, in turn, supplies information to a station located either on the ground or in an aircraft to indicate the function of the circuitry receiving the light beam or light path, as previously indicated, for cells **102** and **104**.

Cells **102** and **104** are electrically connected to triode, cathode followers **216** and **218** through variable resistors **208** and **210** for setting the amplitude of the signals from the cells **102** and **104**, respectively. The cathode followers **216** and **218** offer a much better impedance match to both the light cells **102** and **104**, and the succeeding circuitry and stages. From the cathodes of tubes **216** and **218**, the signals are fed through limiting resistors **228** and **224** to the stages **232** and **234** of the dual-triode amplifier **230**, the plates of which are tuned to 400 cycles by capacitors **238** and **240** and inductances **244** and **242** of an interstage coupling transformer **236**. Resistors **220** and **222** are utilized as load resistors for the cathode follower tubes **216** and **218**. Resistor **226** is used as a common load resistor for the two stages **232** and **234** of amplifier **230**. The signal from transformer **236** needs further amplification through the two stages **248** and **250** of dual-triode amplifier **246**. The signals from stages **248** and **250** of amplifier **246** are then fed through a coupling transformer **252** to the power stages **256** and **258** of dual-triode amplifier **254**. In these stages, the voltage gain is not as high. However, more power is realized from the stages **256** and **258** of amplifier **254**. The output signals from stages **256** and **258** of amplifier **254** are fed to the common output transformer **260**, which drives the phase sensitive motor **132**. The input phase of motor **132** is fed constantly to one set of windings from the power supply **186**, while the controlling phase of motor **132** is fed from the output transformer **260** of the amplifier.

Cathode followers **216** and **218**, dual-triode amplifier **246**, and the output stages of dual-triode amplifier **254** have their filament and plate circuits energized by 6 volts and 250 volts from a D.C. voltage source **264**, respectively. Dual-triode amplifier **230** is fed with an A.C. voltage from power supply inverter **186** in order to establish the A.C. pulse and phase sense necessary to couple energy through transformer **236**.

Summarizing the above, the sequence of operation of this embodiment of the invention is as follows: The azimuth control, in its normal hunt and as previously described, will lock onto the light path as soon as it has made a rotation so that the mirror **100** will position at the correct angle to project light to the cells **102** and **104**, thus establishing the position of the missile **10** in one plane. At the same time, the rotation of shaft **120** has positioned, through the associated gear arrangement **142**, **144**, and **148**, the differential slave frame **150**, thereby allowing the mirror **110** to hunt for its proper vertical angle. As soon as the mirror **110** has rotated sufficiently far to project the light at the correct angle to cells **112** and **114**, for vertical control, mirror **110** locks on the light source and establishes control of the missile **10** in a second plane through a suitable linkage similar to that previously illustrated for the embodiment of the invention in FIGS. 1 through 5, with the control surfaces of the missile being located in this second plane.

As previously stated, this embodiment of the invention as well as the first embodiment of the invention can be used for night flying control in connection with a high flying aircraft having a beam directed at the missile. When used in this manner, it would not be affected by any other lights which might be projected from other angles for the purposes of countermeasures, and provided the control aircraft can reach sufficient altitude.

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 caims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. In combination with an aerial missile having structure including at least one pair of control surfaces mounted thereon, with said structure having an opening in its surface for passing radiation from a light projecting body, a navigational device for controlling the flight of said missile in at least one plane by the radiation from said light projecting body, said device including a corrugated mirror for receiving radiation through said opening from said light projecting body and reflecting a vertical ribbon of radiation therefrom, means for detecting said vertical ribbon of radiation, circuit means including an amplifier for receiving the outputs from said detecting means, mean including a phase sensitive motor controllable by the output of said amplifier and including a shaft element for rotating said mirror, and a missile control system mechanically linked to said shaft element for controlling the actuation of said pair of control surfaces.

2. In combination with an aerial missile having structure including at least one pair of control surfaces mounted thereon, with said structure having an opening

in its surfaces for passing radiation from a light projecting body, a device for controlling the flight of said missile in at least one plane by guiding on the radiation from said light projecting body, said device including a concave corrugated mirror for receiving radiation through said opening from said light projecting body and reflecting a vertical ribbon of radiation therefrom, means including a pair of spaced photoelectric cells for receiving said vertical ribbon of radiation between said cells, circuit means including an amplifier for receiving the outputs of said photoelectric cells, means including a phase sensitive motor controllable by the output of said amplifier and including a shaft element for rotating said mirror, and a missile control system including a transfer valve mechanically linked to said shaft element for controlling the actuation of said pair of control surfaces.

3. In combination with an aerial missile having structure including at least two pairs of control surfaces mounted thereon and an opening in its surfaces for passing radiation from a light projecting body, a device for controlling the flight of said missile in two planes by guiding on the radiation from said light projecting body, said device including a first corrugated mirror for receiving radiation through said opening from said light projecting body and reflecting a vertical ribbon of radiation therefrom, means for detecting said vertical ribbon of radiation, means including a differential slave frame having a second mirror mounted thereon, a second means for detecting said radiation from said light projecting body, means including azimuth and elevation circuits for receiving the outputs from both of said detecting means, a first means including a phase sensitive motor controllable by the output of the azimuth amplifier circuit and including a first shaft element for rotating said first mirror, a second means including a second phase sensitive motor controllable by the output of said elevation amplifier circuit and including a second shaft element for rotating said second mirror, means for mechanically coupling said first and second shaft elements, and a missile control system including a transfer valve mechanically linked to each said shaft element for controlling the actuation of said two pairs of control surfaces in both the azimuth and elevation planes, whereby said first mirror by locking onto said radiation from said light projecting body establishes the position of said missile in said azimuth plane, said first shaft element simultaneously positioning said differential slave frame through said mechanical coupling means to allow said mirror to hunt for its proper vertical angle, with said second mirror locking on said light projecting body to establish control of said missile in said elevation plane.

4. In combination with an aerial missile having structure including at least two pairs of control surfaces mounted thereon and an opening in its surfaces for passing radiation from a light projecting body, a device for controlling the flight of said missile in two planes by guiding on the radiation from said light projecting body, siad device including a first concave corrugated mirror for receiving radiation through said opening from said light projecting body and reflecting a vertical ribbon of radiation therefrom, means including a pair of spaced photoelectric cells for receiving said vertical ribbon of radiation between said cells, means including a differential slave frame having a second concave mirror mounted thereon, a second means including a second pair of spaced photoelectric cells, means including azimuth and elevation circuits for receiving the outputs from said two pairs of photoelectric cells, a first means including a phase sensitive motor controllable by the output of the azimuth amplifier circuit and including a first shaft element for rotating said first concave mirror, a second means including a second phase seensitive motor controllable by the output of said elevation amplifier circuit and including a second shaft element for rotating said second concave mirror, means for mechanically coupling said first and second shaft elements, and a missile control system including a transfer valve mechanically linked to each said shaft element for controlling the actuation of said two pairs of control surfaces in both the azimuth and elevation planes, whereby said first concave mirror by locking onto said radiation from said light projecting body establishes the position of said missile in said azimuth plane, said first shaft element simultaneously positioning said differential slave frame through said mechanical coupling means to allow said second concave mirror to hunt for its proper vertical angle, with said second concave mirror locking on said light projecting body to establish control of said missile in said elevation plane.

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