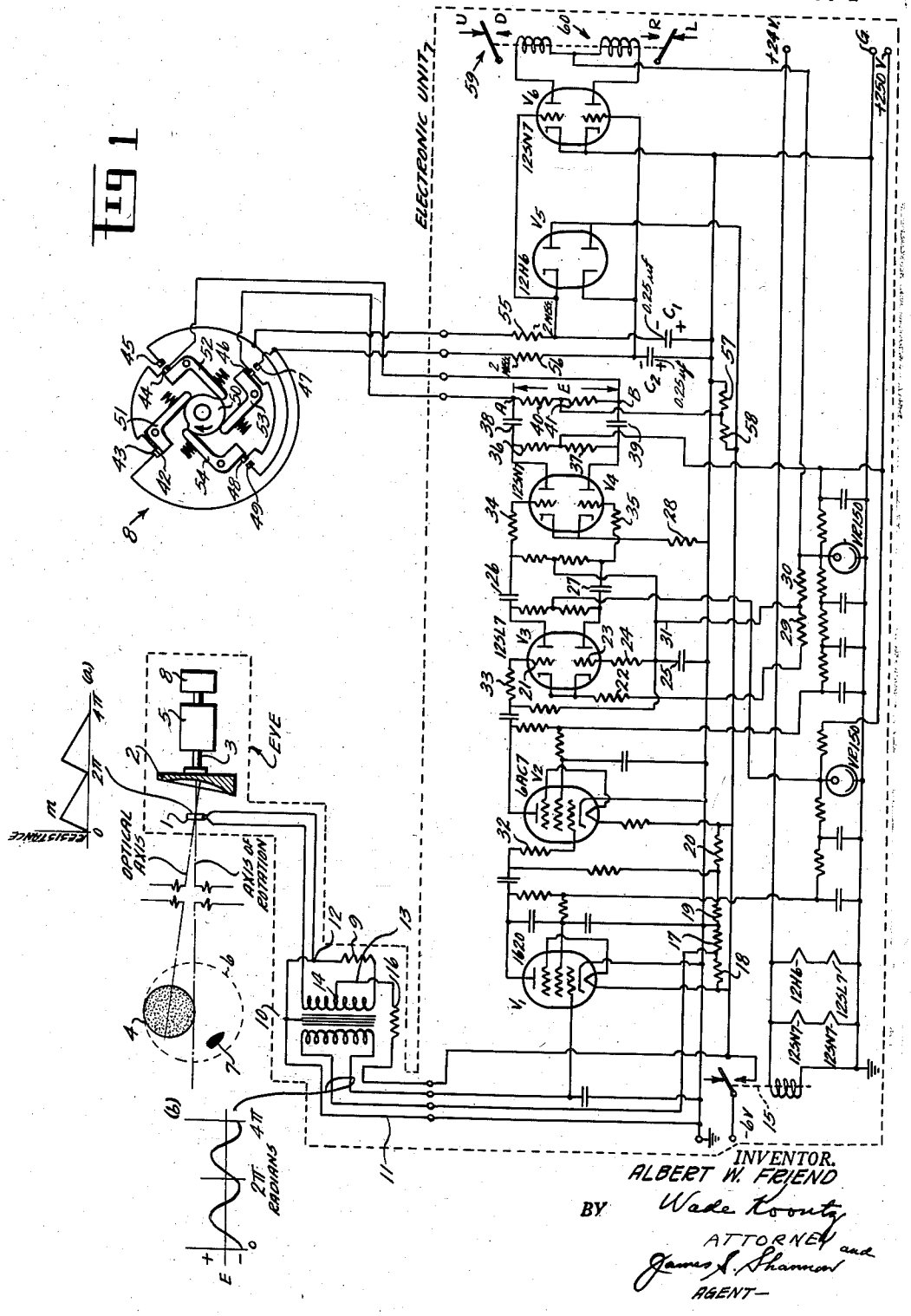
Feb. 25, 1958 A. W. FRIEND 2,825,021

CONTROL FOR HEAT-HOMING BOMB

Filed Nov. 21, 1946

2 Sheets-Sheet 1

Fig 1



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CONTROL FOR HEAT-HOMING BOMB

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Fig 2

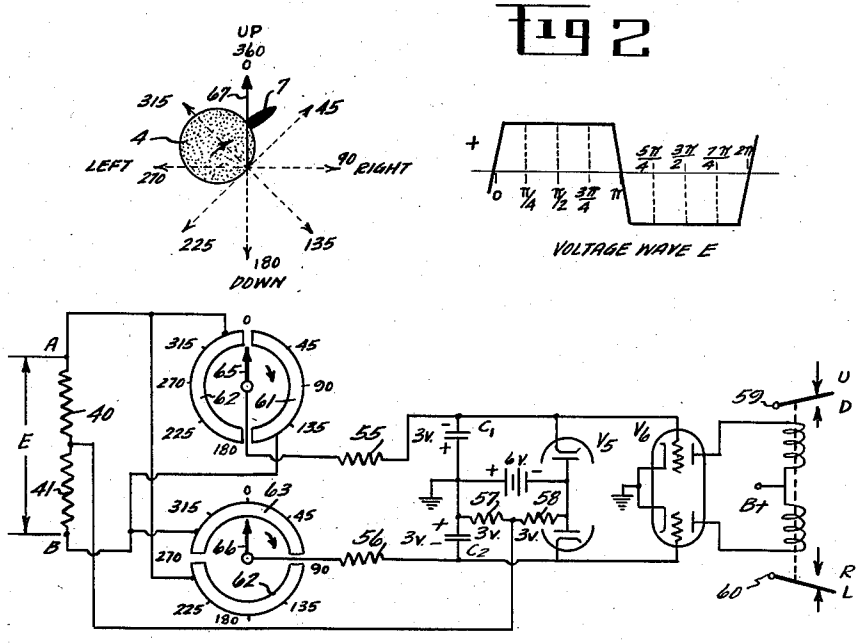


Fig 3

ANGLE OF LAG BETWEEN ARROW 67 AND VOLTAGE WAVE-E

POSITION OF ARROW 67 AND CONTACTS 65 AND 66

	0		45		90		135		180		225		270		315	
	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
0-45	−	−	−	−	−	+	−	+	+	+	+	+	+	−	+	−
45-90	−	−	−	+	−	+	+	+	+	+	+	−	+	−	−	−
90-135	−	+	−	+	+	+	+	+	+	−	+	−	−	−	−	−
135-180	−	+	+	+	+	+	+	−	+	−	−	−	−	−	−	+
180-225	−	−	−	−	−	+	−	+	+	+	+	+	+	−	+	−
225-270	−	−	−	+	−	+	+	+	+	+	+	−	+	−	−	−
270-315	−	+	−	+	+	+	+	+	+	−	+	−	−	−	−	−
315-360	−	+	+	+	+	+	+	−	+	−	−	−	−	−	−	+
CORRECTION PRODUCED	U	L	U	R	U	R	D	R	D	L	D	L	U	L	U	L

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CONTROL FOR HEAT-HOMING BOMB

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Application November 21, 1946, Serial No. 711,456

4 Claims. (Cl. 318—489)

The invention described herein may be manufactured and used by or for the Government for governmental purposes without payment to me of any royalty thereon.

This invention relates to the control system for a heat-homing bomb of the type designed to be dropped at a high angle with the aid of a bombsight in the same manner as a freely falling bomb, and capable of steering itself toward that part of the target area from which the greatest amount of long wave length infrared radiation is being emitted. The steering of the bomb is accomplished by small elevator and rudder surfaces which are located in the tail and serve to angularly displace the axis of the bomb with respect to its velocity vector, the resulting "lift" produced by the body of the bomb being sufficient to change the course of its fall. The bomb is stabilized as to roll by gyroscopically controlled ailerons also located in the tail.

The control system of the bomb comprises an infrared sensitive "eye" located in the nose of the bomb, an electronic control circuit and a servo-mechanism for operating the control surfaces. The "eye" is capable of scanning an area toward which the bomb is moving of size commensurate with the manueverability of the bomb and of producing a signal from infrared radiations emanating from the area scanned. The electronic control circuit analyzes the signal from the "eye" and causes the servo-mechanism to operate the control surfaces in such a way as to steer the bomb toward the strongest source of infrared radiation in the scanned field.

It is the object of this invention therefore to provide a control system of the above described type that is simple and reliable, and that occupies a minimum amount of space.

In the drawings:

Fig. 1 is a schematic diagram of the electronic control circuit;

Fig. 2 is a simplified diagram of Fig. 1 for explaining the operation of the electronic control circuit; and

Fig. 3 is an analysis of the operation of the circuit of Fig. 2 through one scanning cycle for various target positions.

Referring to Fig. 1, the "eye" comprises a bolometer **1** located at the primary focus of parabolic reflector **2** which is mounted on shaft **3** in such a way that its optical axis makes an angle of about 5 degrees with the axis of the shaft and so that its primary focus falls on the axis of the shaft. The sensitive area of the bolometer is made circular and of such size as to subtend an angle at the optical center of the reflector that is twice the angle between the optical axis and the axis of the shaft, in this case about 10 degrees. With this arrangement the area on a plane perpendicular to the axis of the shaft, or axis of rotation, from which radiations are caused to fall on the sensitive area of the bolometer is defined by a circle centered on the optical axis and having a radius practically equal to the distance in the plane from the optical axis to the axis of rotation. This circular scanning area is shown

at **4**, the plane having been rotated 90 degrees from its true position for illustrative purposes. The shaft **3** is rotated at a constant speed of about 32 revolutions per second by constant speed motor **5**. This causes the scanning circle **4** to rotate and scan an area defined by the circle **6**. When the scanning circle includes a source of infrared radiation such, for example, as the ship target **7**, the radiation from the target falls on the bolometer **1** and a signal is produced. Also mounted on shaft **3** is a commutator **8**, the details of which are shown to the right of the "eye." The function of the commutator is to distinguish between signals received from the upper, lower, left and right semicircles of the scanned area as will be explained later.

The bolometer **1** is an element whose electrical resistance changes with the amount of infrared radiation falling on it. This element may be made of a material having a high temperature coefficient of resistance with the resistive material coated with a black substance to convert the long wave length radiations into heat. The bolometer forms one arm of a bridge circuit, the other three arms of which are composed of balancing resistor **9** and the two halves of the primary winding of transformer **10**. The resistor **9** should have a value as nearly equal as possible to the resistance of bolometer **1** at its normal operating temperature in the absence of a signal. Operating current for the bridge is obtained through grounded lead **11** which is connected to point **12** of the bridge, and through lead **13** which is connected between opposite point **14** of the bridge and the —6 v. terminal through relay **15** when this relay is energized by application of voltage to the +24 v. terminal. The resistor **16** serves to limit the bridge current to the proper operating value.

When the scanning area **4** includes the target, infrared radiation therefrom falls on the bolometer **1** and causes its resistance to increase. This increase is represented by the *o–m* portion of the wave shown in Fig. 1 at (*a*). During the time when the scanning area does not include the target, the bolometer cools and its resistance decreases as represented by the $m–2\pi$ portion of the wave. Thus a saw tooth wave of resistance change is produced at the scanning frequency of about 32 cycles per second. This change in resistance causes an unbalance between the currents in the two halves of the primary winding and the resultant flux produced by the unbalance induces a voltage in the secondary winding. Due to the filtering action of the transformer and its inability to pass the direct component of a wave, an alternating voltage is produced in the secondary which approaches a sine wave in shape as shown at (*b*). The frequency of this voltage is likewise 32 cycles per second.

The secondary voltage is applied between the grid and cathode of amplifier tube V_1. The necessary grid bias for this tube is supplied by the drop across resistor **17** which is connected in series with resistor **18** between the —6 v. terminal and ground. The amplified signal in the output of V_1 is applied to the grid of V_2 where it is further amplified and applied to the grid of the upper section of dual triode V_3. The necessary grid bias for V_2 is supplied by the voltage drop across resistor **19** which is connected in series with resistor **20** between the —6 v. terminal and ground.

The dual triode V_3 acts as an amplifier and also as a phase inverter for coupling the unbalanced output circuit of tube V_2 to the input circuit of V_4, which is balanced with respect to ground. Considering the upper section of V_3, the signal from the output circuit of V_2 is applied between the control grid **21** and ground. The cathodes of the two sections are connected together and to ground through resistor **22**. The grid **23** of the lower section is connected through resistor **24**, the lower end of which is

at ground potential as far as the signal is concerned because of the filter condenser **25**. Assume that the signal causes the potential of grid **21** to increase in a positive direction, then the current flowing in resistor **22** due to the upper section increases and the cathodes of the two sections become more positive with respect to ground or, in other words, grid **23** becomes more negative with respect to its cathode. The signal potentials on grids **21** and **23** are therefore 180 degrees out of phase and likewise the anode currents in the two sections of V_3 are 180 degrees out of phase. Since the anode currents of both sections flow through resistor **22**, the voltage drop across this resistor, which constitutes the signal applied to grid **23**, is the voltage drop produced by the difference in these two currents. The circuit therefore must adjust itself to a slightly unbalanced condition in which the anode current of the lower section is less than that of the upper section by an amount just sufficient to provide the proper signal voltage on grid **23**. The degree of unbalance is an inverse function of the amplification of the lower section of V_3.

The output signal of V_3 is applied to the grids of tube V_4 through coupling condensers **26** and **27**. The tube V_4 is part of a conventional resistance coupled push-pull stage having a feedback resistor **28** common to the anode and grid circuits of both sections of the tube. If the stage is perfectly balanced, the two anode currents flowing through resistor **28** are of equal amplitudes and 180 degrees out of phase. The resultant current is therefore zero and no signal is developed across resistor **28**. However, if the currents in the two sections tend to become unequal, a signal is developed across resistor **28** proportional to the difference in the two currents. This signal is fed back to the two grids in such phase as to increase the signal on the grid of the section having the lesser current and to decrease the signal on the grid having the greater current. The effect of resistor **28** therefore is to maintain a balance between the anode signal currents of the two sections of tube V_4.

A positive potential obtained from the drop across resistor **29** is applied to the grids of tubes V_3 and V_4 by means of conductor **31**. Resistor **29** is connected in series with resistor **30** between a source of positive direct potential and ground. The potential across resistor **29** is adjusted to such a value that the difference between this potential and that produced across resistors **22** and **28** by the steady direct component of the anode currents of tubes V_3 and V_4 gives the proper biasing potential for these tubes.

In order to convert the sine wave output of transformer **10** to substantially a square wave, resistors **32**, **33**, **34** and **35** having values of from one to two megohms are inserted in series with the grids of tubes V_2, V_3 and V_4. Sufficient amplification is provided so that the signals applied to the input circuits of these tubes are of considerably greater amplitude than that required to drive the grids positive. Since the grids can go only slightly positive due to the drop in resistors **32** through **35** when grid current begins to flow, the result is a squaring of the positive half cycle of the signal. Due to the phase reversals produced by the tubes, both half cycles of the signal are subjected to this squaring action. Any inequality in the amplitudes of the two half cycles of the signal appearing across resistors **36** and **37** is removed by condensers **38** and **39** through their inability to pass the direct current component of the signal, so that there appears across resistors **40** and **41** a symmetrical alternating voltage E substantially square in form as shown in Fig. 2.

The commutator **8** comprises four sets of contacts **42—43**, **44—45**, **46—47** and **48—49**, and a cam **50** mounted on shaft **3**. Cam followers **51**, **52**, **53** and **54** are arranged to open and close the contacts and to contact the cam at points 90 degrees apart. The cam is cut so that each set of contacts is closed for about 175 degrees of the cam's rotation. Contacts **42** and **44** are connected together as are also contacts **46** and **48**, and the voltage E is applied between these two pairs of common contacts. Contacts **45** and **49** are connected together and through resistor **55** to one side of condenser C_1, the other side of which is connected to ground. Likewise contacts **43** and **47** are connected together and through resistor **56** to one side of condenser C_2, the other side of which is connected to ground. When either contacts **44—45** or **48—49** are closed, the condenser C_1 is subjected to a potential that acts to charge or discharge the condenser depending upon the charge already in the condenser when the contacts close and the polarity of points B or A during the time the contacts are closed. Similarly a potential is applied to condenser C_2 through resistor **56** when contacts **42—43** or **46—47** are closed, the effect on the condenser being determined by the previous condition of charge and the polarity of point B or A during the time the contacts are closed. Therefore, when the cam **50** rotates, a series of voltage pulses is applied to condensers C_1 and C_2. These pulses will be all positive, all negative, or mixed positive and negative depending upon the phase relationship between the voltage wave E and some reference point on the cam **50** or the scanning cycle.

The condenser C_1 is connected between the grid and cathode of the upper section of V_6 and the condenser C_2 is connected between the grid and cathode of the lower section of this tube. Hence, the potentials across these condensers determine the potentials between the grids and cathodes of the two sections of V_6. Resistors **57** and **58** have equal values and are connected between the —6 v. terminal and ground. The resulting 3 volt drop across resistor **57** is applied through resistors **40** and **41**, the contacts of commutator **8** and resistors **55** and **56** to the condensers C_1 and C_2. Therefore, in the absence of a signal, these condensers are charged to a potential of 3 volts with the ungrounded sides negative, which potential supplies the operating bias for the two sections of tube V_6. The cathode of the upper diode section of V_5 is connected to the ungrounded side of condenser C_1 and the cathode of the lower diode section to the ungrounded side of condenser C_2. The anodes of the two diodes are connected together and to ground through the —6 v. source of potential. The anodes of the two diodes are therefore biased 6 volts negative with respect to their cathodes. With this arrangement, the condensers C_1 and C_2 may charge to a potential of 6 volts with the ungrounded side negative but any further charging will be prevented by the shunting effect of the diodes which become conductive at this point; also the condensers C_1 and C_2 may discharge to zero potential but any recharging with reversed polarity is prevented by the shunting effect of the grid-cathode paths of the two sections of V_6 which becomes conductive at this point. Hence potential variations across condensers C_1 and C_2 are limited to a maximum of 3 volts in either direction from the 3 volt potential normally existing thereacross in the absence of a signal, and as a result the potential variations of the grids of tube V_6 are limited to a maximum of 3 volts either side of the bias potential of —3 volts.

Considering again the series of voltage pulses applied to condensers C_1 and C_2, if all the pulses are positive or if the positive pulses predominate in number, the condensers discharge and the grid potentials are raised; if all pulses are negative or if negative pulses predominate in number, the condenser charges are increased and the grid potentials are lowered; if there are equal numbers of positive and negative pulses, their net effect on the condenser charges is zero and the condensers either remain at or return to their normal no-signal charge, depending upon whether the condensers were previously at their normal charge or had been charged or discharged to a voltage greater or less than 3 volts. The values of condensers C_1 and C_2 and resistors **55** and **56** are such that the time constants of

the two condenser circuits are sufficiently long to require a signal to remain for about six cycles of the scanning system in order to appreciably change the charge on the condensers.

The coils of relays **59** and **60** are connected in the anode circuits of the upper and lower sections respectively of V_6. These relays are adjusted so as to operate when the grid potentials reach a value slightly above —3 volts. For grid voltages below this value, the anode currents are insufficient to operate the relays. The contacts of these relays are in circuit with the servomotors operating the control surfaces of the bomb. Thus when relay **59** is operated the "D" contact is closed and a "down" correction is made in the bomb's direction of travel; likewise, when relay **60** is operated, the R contact is closed and a "right" correction is applied. In the deenergized condition, the U contact of relay **59** and the L contact of relay **60** are closed so that in the absence of a signal the bomb is made to follow an up and to the left course. Thus the bomb follows a sinuous path toward the target.

The operation of the commutator may be more clearly understood by reference to Fig. 2. In the simplified diagram of this figure the semicircular conductive strips **61, 62, 63** and **64** each extend for about 175 degrees and with contacts **65** and **66** which rotate together, form an arrangement that is the electrical equivalent of commutator **8** in Fig. 1. The scanning area **4** and arrow **67** also rotate with contacts **65** and **66**. The arrow **67** represents the angular position of the point at which the scanning area begins to include the target, which is the point at which voltage wave E is initiated. As previously shown the period of voltage wave E is the same as that of a complete scanning cycle. The intersection of the Up-Down and the Right-Left axes represents the point toward which the bomb is travelling. Hence if the target is above the Left-Right axis, an "up" correction is needed and if to the right of the Up-Down axis, a "right" correction is needed, etc.

Fig. 3 gives a tabulation of the polarities of the voltage pulses applied to condensers C_1 and C_2 for eight points on the scanning cycle and for various angles of lag between the arrow **67** and the voltage wave E. The angle of lag is the angle through which arrow **67** rotates from the zero position before voltage wave E is initiated and is determined by the position of the target. The first column of the table shows the pulse polarities for zero phase angle which is the condition in which the voltage wave E is initiated when the arrow **67** is in the zero position, and is the condition shown in Fig. 2. Therefore for 180 degrees of the scanning cycle the point A, Fig. 2, will be positive and the point B negative. Since strip **61** is connected to point B and since contact **65** is on this strip for approximately 180 degrees, the potential applied to C_1 from 0 to 180 degrees is negative as shown under "C_1." Since contact **63** is also connected to point B, the potential applied to C_2 from 0 to 90 degrees is also negative as shown under "C_2." However, from 90 to 180 degrees, contact **66** is on strip **64** which is connected to point A and therefore the potential applied to C_2 during this interval is positive. From 180 to 360 degrees, the point A is negative and the point B positive due to the reversal in polarity of E at 180 degrees. Therefore the voltage applied to C_1 through contact **65** during the 180–360 degree interval is also negative, whereas the voltage applied to C_2 through contact **66** is negative from 180 to 270 and positive from 270 to 360 since this contact changes from strip **64** to strip **63** at 270 degrees. Therefore it is seen that for this phase angle the charge of C_1 is increased and the grid of the upper section of V_6 becomes more negative so that relay **59** is not operated; and since the voltage applied to C_2 alternates equally between positive and negative polarity with neither polarity persisting long enough to appreciably change the charge of this condenser, the grid voltage of the lower section remains at —3 volts and the relay **60** is likewise not operated. The correction produced for this target position is therefore "up" and "left."

A similar analysis of the operation of the circuit for lag angles from 45 to 315 degrees is given in the remaining columns of the table in Fig. 3, with the correction produced in each case given at the bottom. It will be noted that whenever the target is on the Up-Down axis, a "left" correction is given and whenever it is on the Right-Left axis, an "up" correction is given. If the target is at the intersection of the two axes, an "up" and "left" correction is given. This is due to the previously mentioned fact that in the deenergized condition the "U" and "L" contacts of relays **59** and **60** are closed and is the reason for the aforementioned sinuous path taken by the bomb in travelling toward the target.

What I claim is:

1. A control system for a target seeking bomb comprising a circular scanning device and a thermal infrared sensitive device the resistance of which changes with temperature changes due to changes in the amount of infrared radiation falling thereon, said scanning device and said infrared sensitive device cooperating to produce a cyclic variation in the resistance of the infrared sensitive device at the frequency of the scanning cycle whenever a source of infrared radiation appears in the scanned field, the phase relation between said cyclic resistance variation and said scanning cycle being determined by the position of the source of infrared radiation in the scanned field, means for changing said cyclic resistance variation into substantially a sine wave of voltage having the same frequency as the resistance variation, said changing means having an output circuit that is unbalanced with respect to ground, means for amplifying said voltage wave and converting said unbalanced output circuit into a circuit that is balanced with respect to ground, said amplifying and converting means also containing means for clipping the sine wave of voltage so that a substantially square of voltage is produced in said balanced circuit, commutating means comprising a cam and four sets of contacts, cam follower means contacting said cam at points ninety degrees apart and arranged to open and close said contacts, said cam being shaped to close each set of contacts for slightly less than one hundred and eighty degrees of the cam's rotation, two condensers with one side of each connected to ground, means connecting the electrical center of said balanced circuit to ground through a source of constant direct voltage, means connecting one side of said balanced circuit through two of said sets of contacts operated by adjacent cam followers to the ungrounded side of each of said condensers, means connecting the other side of said balanced circuit through the remaining two of said sets of contacts to the ungrounded side of each of said condensers, a plurality of control circuits associated with the steering mechanism of the bomb, relay means for opening and closing said control circuits, and means utilizing the voltage across said condensers to control the operation of said relay means.

2. Apparatus as claimed in claim 1 in which each of said condensers has a resistor connected in series therewith of such value as to require any change in signal to persist for several scanning cycles in order to appreciably change the voltage across said condensers.

3. Apparatus as claimed in claim 1 in which said utilizing means comprises two electron tubes each having the coil of one of said relay means in its anode circuit and each having one of said condensers connected between its grid and cathode, and in which each of said condensers is shunted by a diode biased by a voltage equal to twice the voltage of said source of contant direct voltage whereby voltage variations across said condensers

are held within equal limits on either side of the no-signal voltages.

4. Apparatus as claimed in claim 1 in which said commutating means is mechanically coupled to said scanning means so as to provide a fixed relationship between the scanning cycle and the commutating cycle.

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