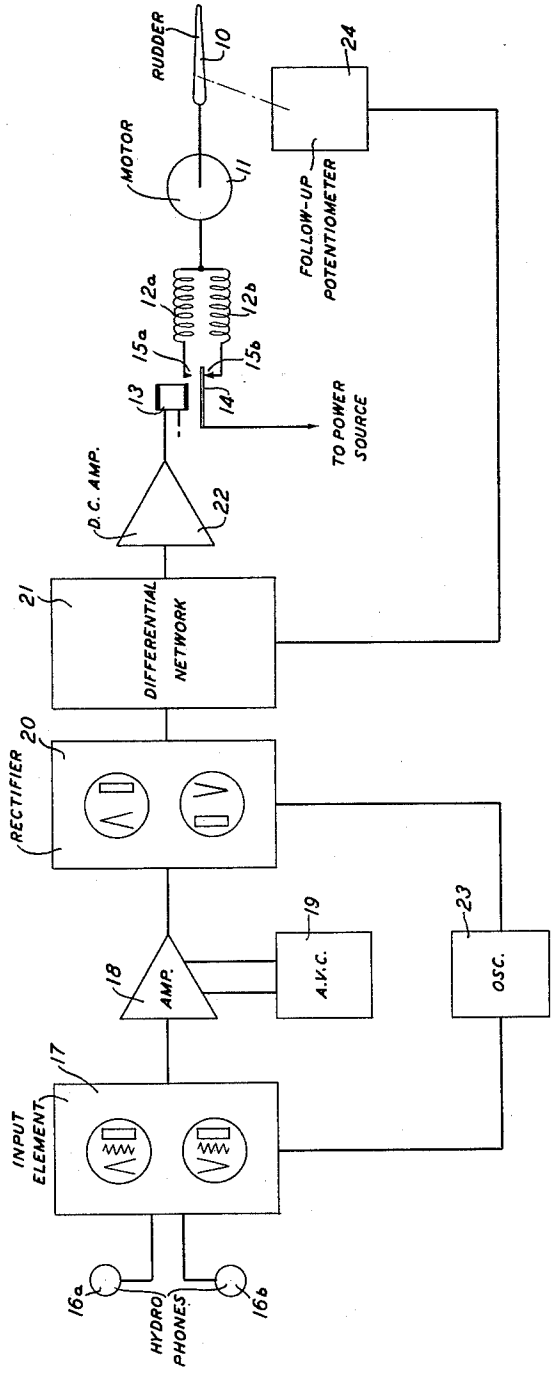
Nov. 2, 1965 D. D. ROBERTSON 3,215,110

SIGNAL CONTROLLED STEERING APPARATUS

Filed June 22, 1943 3 Sheets-Sheet 1

FIG. 1



INVENTOR
D. D. ROBERTSON
BY
Walter C. Kiesel
ATTORNEY

Nov. 2, 1965 D. D. ROBERTSON 3,215,110

SIGNAL CONTROLLED STEERING APPARATUS

Filed June 22, 1943 3 Sheets-Sheet 2

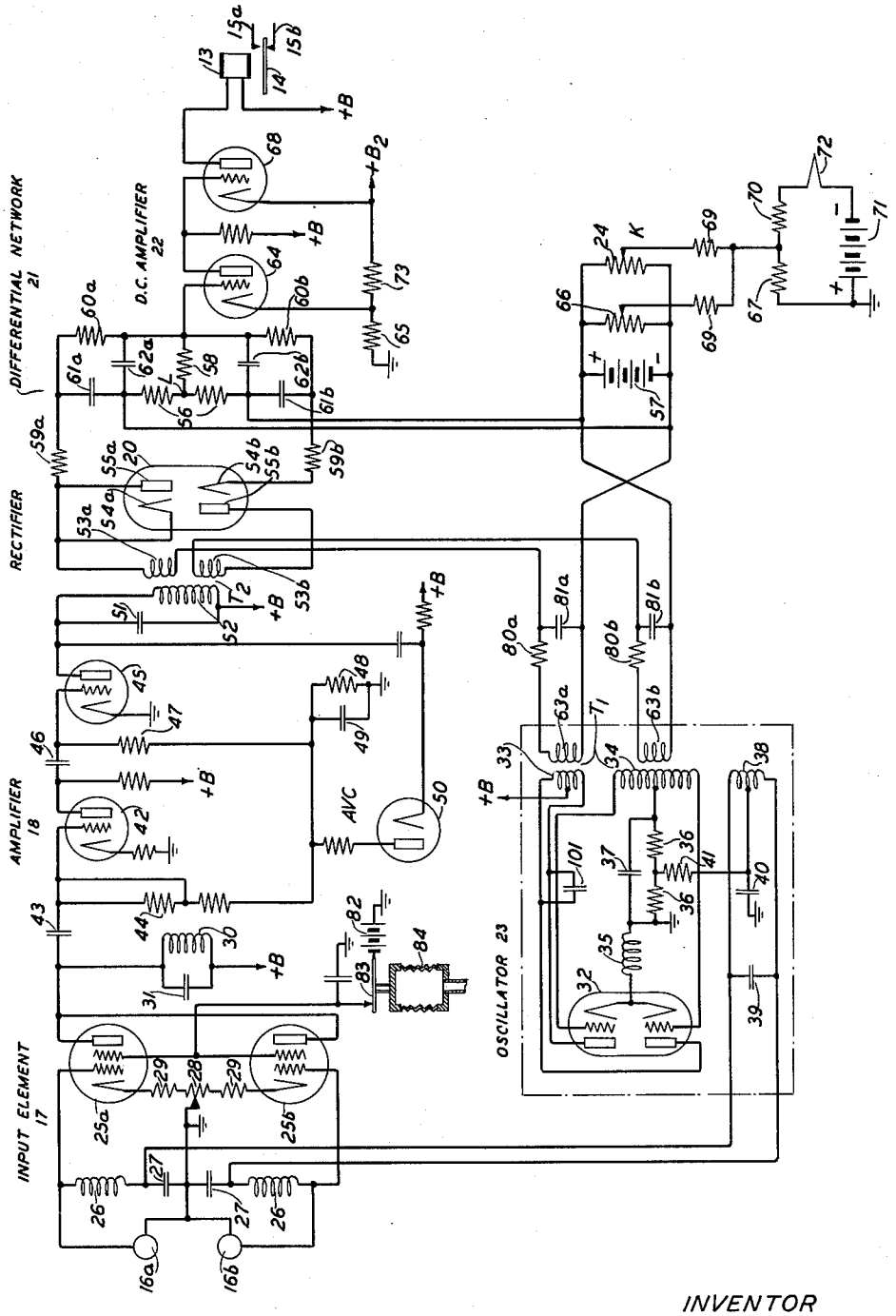


FIG. 2

INVENTOR
D.D. ROBERTSON
BY
Walter C. Kiesel
ATTORNEY

Nov. 2, 1965 D. D. ROBERTSON 3,215,110

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Filed June 22, 1943 3 Sheets-Sheet 3

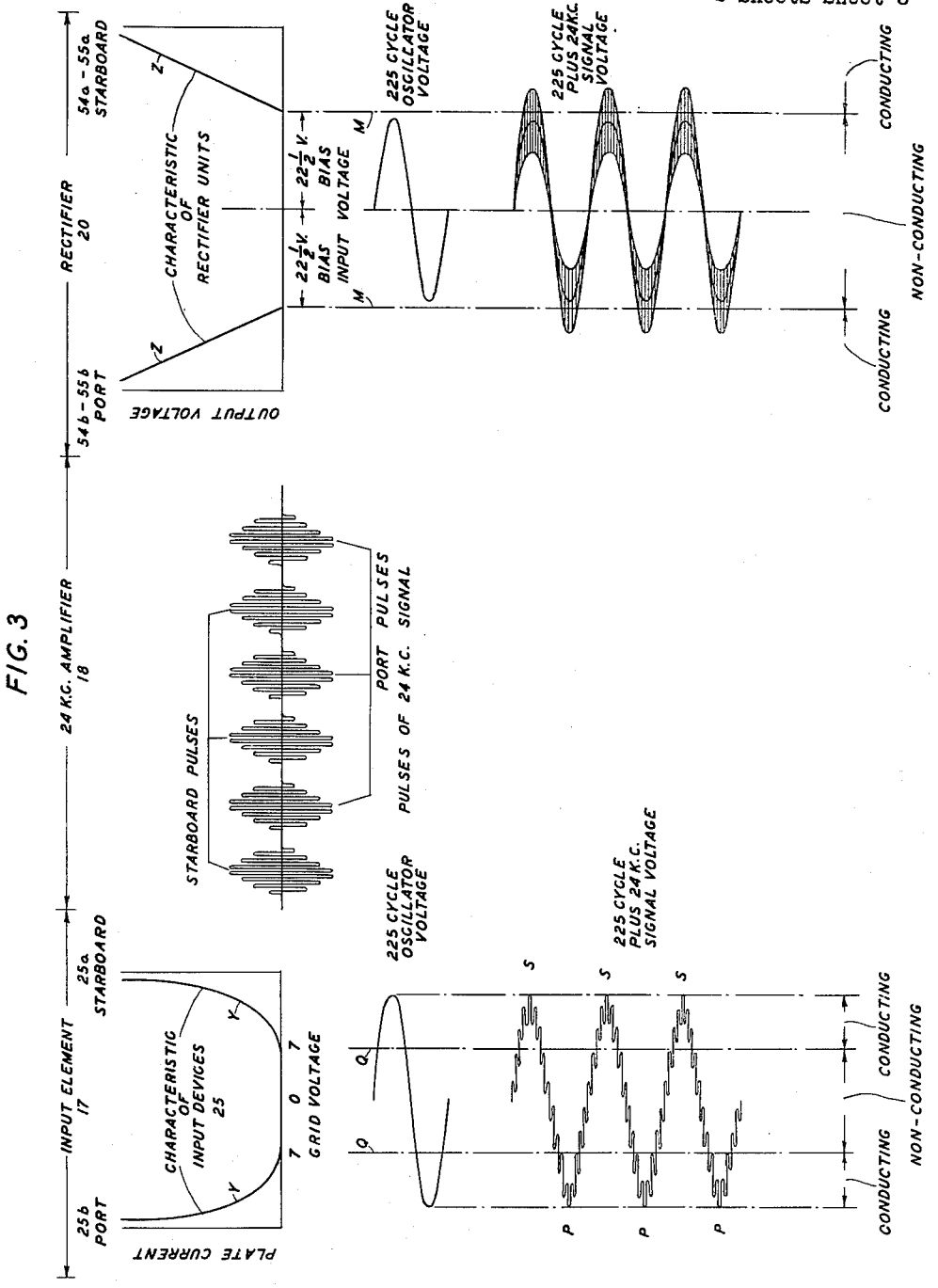

FIG. 3

INVENTOR
D.D. ROBERTSON
BY
Walter C. Kiesel
ATTORNEY

United States Patent Office 3,215,110
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3,215,110

SIGNAL CONTROLLED STEERING APPARATUS

Donald D. Robertson, Hartsdale, N.Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

Filed June 22, 1943, Ser. No. 491,795
11 Claims. (Cl. 114—23)

This invention relates to signal controlled steering apparatus for moving bodies and more particularly to steering control systems for sonically guided torpedoes, such, for example, as control systems of the general configuration disclosed in the application Serial No. 491,796 filed June 22, 1943, of Lester M. Ilgenfritz and Hilbert B. Moore and in the application Serial No. 491,794 filed June 22, 1943, of Hugh K. Dunn.

Sonically guided torpedoes of the type disclosed in the above-identified applications comprise, in general, a rudder, an elevator, two pairs of hydrophones, and circuits associated with the hydrophones for translating the signals received thereby into control signals for causing deflection of the rudder and elevator to steer the torpedo toward the source of the signals received by the hydrophones. More specifically, the hydrophones of one pair are mounted on opposite sides of the torpedo body so that the torpedo produces a shadow effect between the two hydrophones whereby the relative intensities of the signals at the two hydrophones vary in accordance with the angle of incidence of the signals upon the torpedo. The rudder is controlled in accordance with the difference of the signal intensities to steer the torpedo horizontally toward the side thereof on which the hydrophone receiving the greater signal is mounted. Similarly, the hydrophones of the other pair are mounted on the top and bottom of the torpedo and the outputs thereof are resolved to effect control of the elevator in accordance with the difference of the signal intensities at these two hydrophones to steer the torpedo vertically in the direction of the signal source with respect to the torpedo.

One general object of this invention is to improve steering control systems for signal guided moving bodies such as sonically guided torpedoes.

More specifically, one object of this invention is to simplify and facilitate manufacture of circuits for translating signals received by hydrophones in a sonically guided torpedo or similar moving body into electrical signals for controlling the operation of a rudder in accordance with the hydrophone signals.

Another object of this invention is to enable resolution of the sonic signals received by a pair of spaced hydrophones into a single electrical potential the magnitude and polarity of which is accurately related to the relative intensities of the sonic signals at the two hydrophones.

A further object of this invention is to realize, in a sonically guided torpedo or similar body, sensitive and accurate resolution of the signals received at the torpedo or body into information to steer the body automatically toward the source of the signals.

In one illustrative embodiment of this invention, a control circuit for associating a pair of hydrophones with a rudder on a sonicaly guided torpedo or similar body to effect operation of the rudder in accordance with the signals received by the hydrophones comprises an amplifier, an input element for associating the hydrophones with the amplifier, a translating element for resolving the output of the amplifier into a control signal, and a relay adapted for operation in accordance with the control signal to cause operation of a motor for deflecting the rudder.

In accordance with one feature of this invention, the input element comprises a pair of electron discharge devices having their anodes connected in common to the amplifier and each associated with a corresponding one of the hydrophones, and the translating element includes a pair of electronic rectifier units in parallel opposing relation and associated with the amplifier, and includes also a differential or resolving network for resolving the outputs of the rectifier units in combination into a potential for controlling the operation of the relay. An electronic oscillator is associated with both the input electron discharge devices and the electronic rectifiers and is effective to control these devices and rectifier units in such manner that the hydrophones are operatively connected in alternation to the input of the amplifier and the rectifier units are operatively associated with the output of the amplifier alternately and in synchronism with the alternate connection of the hydrophones to the amplifier. Hence, the difference in the outputs of the rectifier units is proportional to the difference in the signal intensities at the two hydrophones.

In accordance with another feature of this invention, the differential or resolving network comprises two substantially identical branches each associated with a corresponding one of the rectifier units and including substantially identical condensers adapted to be charged in accordance with the current passed by the respective rectifier unit, and a resistance bridged across both of the condensers. The condensers are charged in opposite directions relative to the resistance and in combination establish a potential difference across the resistance which is proportional to the difference of the rectifier unit outputs and, hence, to the difference in signal intensities at the two hydrophones. Means are provided for operating the rudder control relay in accordance with the polarity of this potential difference.

The invention and the above-noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

FIG. 1 is a block schematic of a steering system illustrative of one embodiment of this invention;

FIG. 2 is a detailed circuit diagram of the control circuit in the system illustrated in FIG. 1; and

FIG. 3 is a diagram illustrating the operation of the control circuit shown in FIG. 2.

The system illustrated in the drawing is adapted for utilization in a sonically steered or guided body such as, for example, a torpedo of the general construction and organization disclosed in the application Serial No. 491,797 filed June 22, 1943, of John C. Steinberg. It may be employed for steering the body either horizontally or vertically to guide it toward the object, for example a submarine, from which the compressional wave signals in accordance with which the steering is effected, emanate.

Referring now to the drawing, the system illustrated in FIG. 1 comprises a rudder **10**, which may be either the vertical rudder or the elevator of the body, e.g. torpedo, to be steered and a motor **11** mechanically coupled, as by suitable gearing, to the rudder **10**. The motor **11** is of the reversible type and may be of the series type having a pair of field windings **12***a* and **12***b* constructed and arranged so that when one winding is energized the motor is driven in one direction and when the other winding is energized, the motor is driven in the opposite direction. The energization of the windings is controlled by a relay **13** having an armature **14** connected to a suitable power supply source, not shown, and a pair of contacts **15***a* and **15***b* each connected to a corresponding one of the windings **12**.

The system comprises also a pair of substantially identical hydrophones **16***a* and **16***b* mounted on opposite sides, e.g. port and starboard or top and bottom, of the torpedo and a control circuit for resolving the combined

outputs of the hydrophones into a signal for actuating the relay in accordance with the relative intensities of the signals receive by the two hydrophones. The hydrophones may be of any one of a number of well-known types and, in a particularly advantageous construction, are designed to be specially sensitive at a preassigned frequency and are spaced from one another a distance large in comparison to the wavelength of this frequency. In one illustrative construction, the hydrophones may be of the piezoelectric type and resonant at a frequency of 24 kilocycles per second.

The control circuit comprises an input element **17**, which advantageously is tuned to the resonant frequency of the hydrophone **16**, connecting the hydrophones to a high frequency amplifier **18** provided with automatic gain control **19**. The output of the amplifier **18** is supplied to a two-unit rectifier **20** having its output connected to a differential or resolving network **21** which operates to resolve the rectifier output into a direct current potential impressed upon the control electrode of a direct current amplifier **22**. The amplifier **22** energizes the relay **13**. The input element **17** and rectifier **20** are controlled by an oscillator **23** in such manner that the hydrophones **16*a*** and **16*b*** are operatively associated in alternation with the amplifier **18** and the two units of the rectifier **20** are similarly associated with the amplifier **20** in alternation and in synchronism with the alternate operative association of the hydrophones with the amplifier. Thus, conductive channels are established alternately between the hydrophone **16*a*** and one unit of the rectifier **20** and between the hydrophone **16*b*** and the other unit of the rectifier **20**. The oscillator frequency advantageously is low in comparison to the frequency of the signals to be translated by the hydrophones. For example, if the hydrophones are resonant at 24 kilocycles per second, the oscillator frequency may be of the order of 225 cycles per second.

Associated mechanically with the rudder **10** and electrically with the differential or resolving network **21** is a follow-up potentiometer **24**, the function of which will be described hereinafter.

The operation of the system, assuming the source of the compressional wave signals to be located other than along the longitudinal axis of the torpedo, is briefly as follows: Inasmuch as the signal source is located unequal distances from the two hydrophones and because of the shadow or diffraction effect of the torpedo, the signal intensities at the two hydrophones will be different. Because of the switching operation due to the oscillator **23**, the outputs of the hydrophones are fed, as amplified by the amplifier **18**, in alternation to the respective units of the rectifier **20**. The automatic gain control **19** controls the gain of the amplifier **18** in accordance with the greater of the two signal intensities at the hydrophones so that the same gain for the amplifier **18** is established for both signals and the outputs of the two hydrophones are amplified to the same extent. The output of each rectifier unit is determined by the signal intensity at the corresponding hydrophone and the outputs of the two rectifier units are in the same ratio as the intensities of the signals at the two hydrophones. In the differential network **21**, the outputs of the two rectifier units are combined differentially and resolved into a direct current potential which is impressed upon the control electrode of the direct current amplifier **22**. The magnitude and polarity of the potential are determined by the relative intensities of the signals at the two hydrophones.

Assume, for example, that the hydrophone **16*a*** is on the starboard side of the torpedo, the hydrophone **16*b*** is on the port side, that when the signal intensity at the hydrophone **16*a*** is greater than that at hydrophone **16*b*** the resultant direct current potential supplied by the network **21** is negative, and that when the signal intensity at the hydrophone **16*b*** is the greater, the potential noted is positive. If, under the conditions postulated, the source of the compressional wave signals is to the starboard side of the torpedo, the signal intensity at the hydrophone **16*a*** is greater than that at hydrophone **16*b***. Hence, the resultant potential impressed upon the direct current amplifier **22** will be negative, and the relay **13** will be operated to close the contact **15*a*** whereby the motor will revolve to produce starboard rudder, i.e. to steer the torpedo to the starboard side and toward the signal source. Conversely, when the signal intensity at the hydrophone **16*b*** is the greater, the resultant potential supplied to the amplifier **22** will be positive and port rudder will be produced.

When the torpedo is traveling directly toward the source of the compressional wave signals, the rudder remains substantially in central position, as described hereinafter, to maintain the torpedo on course.

If the hydophones **16** are mounted on the top and bottom of the torpedo the control circuit would operate in the manner described above to control the elevator in accordance with the relative intensities of the signals at the two hydrophones to steer the torpedo vertically toward the source of the signals.

It will be understood, of course, that in a torpedo two steering systems, one for vertical and one for horizontal steering, may be employed, each system being of the configuration shown in FIG. 1 described hereinabove and the two systems operating concurrently whereby the torpedo is steered against the object from which the signals emanate. A single oscillator **23** may be employed to perform the switching operations in both systems.

The input element **17**, as shown in FIG. 2, comprises a pair of substantially identical electron discharge devices **25*a*** and **25*b***, the input circuits of which are tuned to the resonant frequency of the hydrophones **16** by suitable similar inductances **26** and condensers **27** in association with the hydrophones. Each hydrophone **16**, it will be noted, is included in the grid circuit of the corresponding discharge device **25**. A potentiometer **28** is connected in the cathode circuit and is adjusted to balance the grid circuits of the two devices. Also included in these circuits is a pair of equal resistors **29**, for example of the order of 1,000 ohms each, which, in combination with the potentiometer **28**, provides negative feedback to stabilize the operation of the devices **25**. The anodes of the two devices **25** are connected in common to an output circuit which also is tuned to the resonant frequency of the hyrophones **16** by a suitable inductance **30** and condenser **31** combination.

The oscillator **23** comprises an electron discharge device **32** including two substantially identical triode or multigrid units connected in push-pull relation and having a tuned anode circuit including a condenser **101** and a winding **33** of a transformer T_1. The oscillator is tuned to a relatively low frequency, such, for example, as of the order of 225 cycles per second as noted heretofore. The grid circuit of the oscillator **23** includes another winding **34** of the transformer T_1, the mid-point of this winding being connected to the cathodes of the device **32** by way of an inductance **35** and resistors **36** shunted by a condenser **37**. One end of the resistor **36**-condensor **37** combination is grounded as shown.

The oscillator **23** supplies both a negative direct current bias and a low frequency switching potential to the control grids of the input electron discharge devices **25**. The switching potential is supplied by way of a coil **38** coupled to the winding **34**, connected across the condensers **27** in the grid circuit of the input devices **25**. The mid-point of the coil **38** is connected to ground by way of a condenser **40** and is connected also to the mid-point between the resistors **36** by way of a high resistance **41**. When the oscillator is operating, a direct current potential appears across the resistors **36** in series because of grid current flow. A portion of this potential is impressed upon the grids of the input devices **25**, the circuit being from ground, through the left-hand resistor **36** (in FIG. 2) and thence by way of resistance **41** and the winding **38** to the

grids of the devices **25**, the cathodes of the devices **25** being connected to ground as shown. The parameters of this circuit are made such that the negative direct current bias applied to the grids of the devices **25** is above the cut-off point whereby, in the absence of switching potentials in the grid circuit of the input devices **25**, these devices are blocked or nonconducting. The switching potential, supplied in the manner described above, is sufficiently high to overcome the bias noted so that the devices **25** are rendered conductive alternately and, thus, the hydrophones **16***a* and **16***b* are operatively associated alternately with the amplifier **18**.

It will be noted that the bias supplied to the grids of the input devices **25** is proportional to the grid currents in the oscillator device **32** and that the switching potentials for the devices **25** are derived from the grid circuit of the oscillator. Hence, a substantially fixed ratio obtains between the bias and switching potentials and, consequently, if the characteristics of the oscillator device **32** should vary, for example because of variations in the anode potential, the switching potential always will be sufficiently great to overcome the bias applied to the grids of the devices **25**.

Features of the oscillator-input element combination described above are disclosed and claimed in the application Serial No. 491,798 filed June 22, 1943 of Alton C. Dickieson now Patent No. 2,866,680.

The anodes of the input devices **25** are connected to the control grid of the first electron discharge device **42** of the amplifier **18** by way of a condenser **43** and resistor **44** and the anode of the device **42** is connected to the control grid of the second stage device **45** of the amplifier **18** by way of a similar condenser **46** and resistor **47**. The devices **42** and **45** may be triodes as shown or of the multi-grid type. The grid circuits of both devices include a biasing resistance-condenser combination **48**, **49**. Connected between the grids of the devices **42** and **45** and the anode of the device **45** is a diode **50** which provides automatic gain control for the amplifier **18**.

The cathode of the diode **50** normally is biased at a moderate positive potential with respect to the anode thereof. This bias may be overcome by the peak portions of the varying component of the potential appearing upon the anode of the device **45**. When this occurs, the diode becomes conducting and the bias upon the control grids of the devices **42** and **45** is varied in accordance with the diode current, by the action of the resistance-condenser combination **48**, **49**. The greater the output of the amplifier, the greater will be the diode current and, consequently the greater will be the negative bias applied to the control grids of the devices **42** and **45**. Hence, the diode **50** is effective to establish a substantially constant gain for the amplifier **18**, the output level being substantially independent of the amplitude of the input to the amplifier, supplied by the devices **25**. The parameters of the gain control circuit are made such as to provide holdover sufficient to relate the gain control action to the greater of the two hydrophone outputs at any time whereby a constant gain level is established.

The output circuit of the amplifier **18** includes the primary winding **52** of the transformer T_2 and a tuning condenser **51**, and is tuned to the resonant frequency of the hydrophones **16**. From what has been said heretofore, it will be appreciated that the output of the amplifier **18** is composed of pulses, e.g. of 225 cycle frequency, of high frequency, e.g. 24 kilocycle, signals, one group of alternate pulses being related in amplitude to the signal intensity at the hydrophone **16***a* and the other alternate pulses being related in amplitude to the signal intensity of the hydrophone **16***b*.

The pulses noted are impressed upon the rectifier **20** by way of two balanced secondary windings **53***a* and **53***b* of the transformer T_2. The rectifier includes two similar units connected in parallel opposing relation, each associated with one of the windings **53**. Each unit includes a cathode **54** and an anode **55**, cooperating electrodes being designated in the drawing by the same letter, *a* or *b*, as the identifying letter of the associated secondary winding **53**. The outputs of the two units of the rectifier are supplied to the differential network **21**.

This network comprises a central section including a pair of equal resistors **56**, across which a potential is impressed by a battery **57**, a resistance **58** connected to the mid-point between the resistors **56** and two substantially identical end sections each associated with a corresponding one of the rectifier units. One end section includes a resistance **59***a* connected to the anode **55***a* and a resistance **60***a* and a blocking condenser **61***a* having one terminal connected in common to the resistance **59***a* and the other terminals connected by a condenser **62***a*. The other end section includes a resistance **59***b* connected to the cathode **54***b*, and a resistance **60***b* and a blocking condenser **61***b* having one terminal connected in common to the resistance **59***b* and the other terminals connected by a condenser **62***b*. Corresponding elements of the two end sections are of equal impedance so that the two end sections are balanced. The cathode-to-anode circuits of the two rectifier units are completed by balanced secondary windings **63***a* and **63***b* respectively of the transformer T_1, it being understood that the potentials induced in these windings by the oscillator **23** are equal. The circuit for one rectifier unit may be traced as follows: From the cathode **54***a*, through winding **53***a*, resistance **80***a* and winding **63***a*, and then through the resistive path composed of the upper resistance **56** and the resistances **58**, **60***a* and **59***a* to the anode **55***a*. The circuit for the other rectifier unit may be traced similarly from the anode **55***b* through the winding **53***b*, resistance **80***b* and winding **63***b*, and then through the resistive path composed of the lower resistance **56** and resistances **58**, **60***b* and **59***b* to the cathode **54***b*.

It will be noted that the resistance **58** is common to the output circuits of the two rectifier units and that it is bridged by two identical resistor-condenser combinations **56**, **62***a* and **56**, **62***b*. It will be noted further that the battery **57**, in the absence of other controls to be described hereinafter, impresses equal direct current potentials between the anode and cathode of the two rectifier units and that the potential supplied to each rectifier unit by the associated winding **63** is in series with that supplied by the battery **57**. The direct current potential supplied by the battery **57** is of such magnitude as to bias the anode of each unit beyond the cut-off point and the low frequency potentials supplied by the windings **63** are made such that the peak value thereof when superimposed upon the direct current biasing potential results in a potential slightly below the value requisite to render the rectifier units conductive. Hence, in the absence of signal potentials in the windings **53**, both the rectifier units are non-conducting. When signal energy is supplied from the amplifier **18** to the windings **53**, the combination of the signal and low frequency potentials is sufficiently great to overcome the bias and render the rectifier units conductive. The two units are connected in opposing relation and the low frequency and signal potentials supplied to the two units are phasically related in such manner that the two units become conductive alternately and in synchronism with the alternate operative association of the devices **25***a* and **25***b*, and, hence, the hydrophones **16***a* and **16***b* respectively, with the amplifier **18**.

The alternate association of the input devices **25** with the respective rectifier units is illustrated pictorially in FIG. 3. In this figure, the frequencies and voltages indicated are illustrative, the hydrophone **16***a* is considered as the starboard hydrophone and the hydrophone **16***b* is considered as the port hydrophone. For simplicity of illustration, the signal intensities at the two hydrophones have been assumed to be equal.

The input devices **25** have similar grid voltage-plate current characteristics Y and the rectifier units have similar input voltage-output current characteristics Z. The grids of the input devices **25** are biased beyond cut-off, indicated at Q and the rectifier units are biased beyond cut-off, indicated at M. The oscillator supplies voltage of 225 cycle frequency to the input devices **25** and the rectifier units. The oscillator voltage supplied to the devices **25** overcomes the grid bias so that the devices **25***a* and **25***b* are rendered conductive alternately. Simultaneously, the oscillator voltages supplied to the rectifier units reduce the bias to slightly beyond the cut-off point.

When signals are received by the hydrophones **16** the 225 cycle output of the respective devices **25** are modulated in accordance with the respective 24 kilocycle signal. Hence, 24 kilocycle signal pulses are supplied to the amplifier **18**, the port and starboard signal pulses being in alternate relation. At the rectifier **20**, the 24 kilocycle signal pulses are superimposed upon the 225 cycle potential being supplied to the rectifier unit. That is, the 24 kilocycle port signal is superimposed upon the 225 cycle potential being supplied to the unit **54***b*, **55***b* and this unit is rendered conducting, and the starboard signal is superimposed upon the 225 cycle potential being supplied to the unit **54***a*, **55***a* and this unit is rendered conducting. The two rectifier units become conducting alternately and in synchronism with the input devices **25**.

The resistance **58** has one terminal connected to the control grid of the input electron discharge device **64** of the direct current amplifier **22**. The cathode of the device **64** is connected to ground through a resistance **65**. The input circuit of the device **64** is completed through the resistance **58**, resistances **56** and potentiometers **66** and **24**, the function and operation of which will be described hereinafter, the contact arms of the two potentiometers being connected in common to a point between resistances **67** and **70**, one end of which is connected to ground as shown. The output of the device **64** is supplied to a second electron discharge device **68** in the output circuit of which the winding of the relay **13** is connected.

When signals are received by the hydrophones **16**, the two rectifier units are rendered conductive alternately as described heretofore and rectified currents flow in the output circuits thereof. As a result of current flow in the output circuit of the rectifier unit **54***a*, **55***a*, the condenser **62***a* will receive a charge which is determined by the signal intensity at the hydrophone **16***a*. This charge is dissipated through the resistance **58** and the upper resistance **56**. The time constant of this condenser-resistance combination is made such that the discharge time is long in comparison with the oscillator frequency so that a potential difference is established across the resistance **58**. Similarly, when the unit **54***b*, **55***b* is conducting, the condenser **62***b* receives a charge and a potential difference determined by the signal intensity at the hydrophone **16***b* is established across the resistance **58**. As has been pointed out heretofore, the two rectifier units are in opposing relation. Consequently, the two potential differences impressed upon the resistance **58** are of opposite polarity and the resultant of the two, therefore, is proportional to the difference in the intensities of the signals at the two hydrophones **16**.

Thus, when the signal intensity at hydrophone **16***a* is greater than that at hydrophone **16***b*, the potential applied to the grid of the device **64** is of one polarity; when the signal intensity at the hydrophone **16***b* is the greater, the potential noted will be of the opposite polarity. Hence, the amplifier **22** will operate the relay **13** in accordance with the difference in signal intensities. If, for example, the hydrophone **16***a* is on the starboard side of the torpedo and the grid of the device **64** becomes negative when this hydrophone receives the greater signal, the relay **13** will operate to close contact **15***a* and produce starboard rudder. Conversely, if the hydrophone **16***b* receives the stronger signal, the grid of device **64** will become positive and the contact **15***b* will be closed whereby port rudder is produced.

The magnitude of the several impedance elements included in the differential or resolving network **21** will be determined in any case by the time constants and currents desired. In an illustrative system wherein the rectifier units are biased beyond cut-off at 22.5 volts and the oscillator frequency is 225 cycles per second, the following impedances have been found satisfactory.

Resistances **59***a* and **59***b*	0.1 megohm each.
Resistances **56**	10,000 ohms each.
Resistances **60***a* and **60***b*	0.1 megohm each.
Resistance **58**	1 megohm.
Condensers **61***a* and **61***b*	0.1 microfarad each.
Condensers **62***a* and **62***b*	0.1 microfarad each.

In a system having these constants, a change of about 0.75 volt in the potential of the grid of the device **64** may be obtained for each decibel difference in signal intensities at the two hydrophones **16**.

In order to prevent undesired singing in the control system, suitable filters composed of resistance **80** and condensers **81** may be provided in association with the oscillator as shown.

The potentiometer **66** may be utilized to balance the differential network, that is, it may be set so that for the condition when no signals are received by the hydrophones **16**, the two potential differences established across the resistance **58** are substantially equal and opposite. The potentiometer **24** is the rudder follow-up potentiometer the contact arm of which, as noted hereinabove, is coupled mechanically to the rudder. The operation of this potentiometer **24** will be understood from the following considerations. Normally, i.e. when no signals are being received by the hydrophones **16** the contact arm of the potentiometer **24** is in the center position, the rudder likewise being in the center position. Hence, assuming the contact arm of potentiometer **66** to be in center position, no potential difference appears between the points K and L, K being the contact point of the arm on the potentiometer **24**, and no potential, due to the battery **57**, is impressed upon the grid of the device **65**. If the rudder is deflected to one side or the other, the contact arm of the potentiometer **24** moves accordingly and a potential difference, proportional to the rudder deflection, is established between the points K and L. A corresponding potential is impressed upon the grid of the device **64** and the relay **13** operates to cause operation of the motor **11** in such manner as to tend to bring the rudder back to the no potential position. As the rudder deflects, the contact arm of the potentiometer moves accordingly and a corresponding change occurs in the potential of the grid of the device **64**. In the absence of a signal at the hydrophones **16**, it will be appreciated that the rudder will oscillate about its center position. The parameters involved advantageously are correlated so that the rudder deflection is small, for example a few degrees to each side of the center position and the period of oscillation is moderate, for example approximately 2 to 3 oscillations per second for a torpedo having a traveling speed of the order of 12 knots.

When signals are received by the hydrophones, the potentiometer **24** operates in like manner to vary the potential applied to the grid of the device **64** in relation to the amplitude of the rudder deflection so that, as will be appreciated, the potentiometer **24** tends to maintain balance in the differential network and continuous steering of the torpedo is obtained.

The relative sensitivities of the signal and rudder follow-up controls may be adjusted as desired by resistances **69** in the contact arm circuits of the potentiometers **24** and **66**.

As noted in the aforementioned application of Hugh

K. Dunn, other controls may be provided in addition to the rudder follow-up. For example, when the rudder is mounted upon the torpedo in such manner as to steer the torpedo vertically, i.e. when it operates as an elevator, depth and trim controls may be provided in addition to the follow-up controls. Such additional controls are effected conveniently by potentiometers in parallel with the potentiometers **24** and **66**, resistances similar to the resistances **69** being provided in association with each additional potentiometer to establish a desired relative sensitivity of the several controls.

In order to prevent the torpedo from rising to above a prescribed depth due, for example, to sounds emanating from surface ships or to reflections at the sea surface of submarine signals, means may be provided to render the signal control of the elevator inoperative whenever the torpedo rises above this depth. This may be effected conveniently by impressing a blocking potential upon the screen grids of the devices **25** from a suitable source **82** by way of a switch **83**. The switch is controlled hydrostatically as by a bellows **84** the interior of which is in communication with the sea by way of a port in the torpedo body. When the torpedo is below the prescribed depth, the switch is open. When the torpedo is submerged to less than this depth, the switch is closed by operation of the bellows and a blocking potential is applied to the screen grids thus disabling the hydrophone circuits.

The cathodes of the several electron discharge devices included in the system shown and described may be of the indirectly heated type. The heating current for the cathodes heater filaments may be supplied from a battery **71**. The cathodes or heater filaments indicated generally as a matter of simplification of the drawing at **72** in FIG. 2, may be connected in series with one another and with the battery **71** and resistances **67** and **70**.

In a particularly advantageous arrangement, the direct current amplifier **22** is constructed so that the operating characteristics thereof are substantially unaffected by variations in the voltages of the sources, e.g. batteries, supplying the potentials to the electrodes of the discharge devices included in the amplifier. As has been pointed out heretofore, the grid circuit of the device **64** includes resistances **65** and **67**. The latter, in series with the resistance **70** and cathodes or heater filaments **72** is bridged across the battery **71**. Hence, a component of bias is produced upon the grid of the device **64** equal to the drop across the resistance **67**. The positive terminal of the battery **71** is grounded so that the bias noted is negative. The magnitude of this bias component is made such, by correlation of the voltage of battery **71** and the resistances **67** and **70**, that it substantially neutralizes the contact potential appearing between the cathode and grid of the device **64** when the cathode is emitting. Both the bias and the contact potential vary as the voltage supplied by the battery **71** varies and changes in the contact potential are substantially neutralized by changes in the bias.

The resistance **65** is connected in series with the resistance **73** to a positive terminal of the anode supply battery for the device **64**, the potential of this terminal being considerably lower than the potential supplied to the anode. Hence, it will be seen that another component of bias is introduced into the grid circuit of the device **64**. The magnitude of this bias component is dependent upon the voltage of the anode supply battery and varies with changes in this voltage. Thus, the anode current of the device **64** and the potential applied to the grid of the device **68** are maintained substantially independent of changes in the voltage of the anode supply battery.

It will be noted that the two bias components above mentioned are of the same polarity and the sum of the two may be of a magnitude different from the operating bias desired upon the grid of the device **64**. The desired bias may be obtained in such case by adjustment of the

potentiometer **66**. For example, the desired bias on the grid of the device **64** may be 2 volts negative. The bias component due to the resistance **67** may be of the order of 2 volts negative and the component of bias due to the resistance **65** may be of the order of 1.5 volts negative. The desired grid bias is obtained, then, by adjusting the potentiometer **66** off center to introduce a positive component of bias of 1.5 volts positive. The net of the several bias components is, then, 2 volts negative, which is the desired operating grid bias.

Although a specific embodiment of this invention has been shown and described, it will be understood that it is but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. A signal controlled steering system for moving bodies comprising a pair of signal translating devices, a rudder, means for deflecting said rudder, and means for operating said deflecting means in accordance with the relative intensities of signals received by said translating devices, said last means comprising an amplifier, an input element for said amplifier including a pair of electronic devices each associated with a corresponding one of said translating devices, a second pair of electronic devices adapted to be connected in parallel opposing relation to the output of said amplifier, means for combining the outputs of said second electronic devices differentially to control said operating means, and switching means for rendering said first electronic devices conducting alternately and said second electronic devices conducting alternately and in synchronism with said first electronic devices.

2. A signal controlled steering system in accordance with claim **1** comprising means biasing said first and second electronic devices beyond the cut-off point thereof and wherein said switching means comprises an electronic oscillator associated with said first and second electronic devices to overcome the bias applied thereto by said biasing means.

3. A signal controlled steering system for moving bodies comprising a pair of similar signal translating devices, an amplifier, an input element including a pair of similar electron discharge devices having their outputs connected in parallel to said amplifier and each having a control grid connected to a corresponding one of said translating devices, means biasing said control grids beyond the cut-off potential thereof, a pair of similar electronic rectifier units adapted to be connected in parallel opposing relation to the output of said amplifier, means biasing said rectifier units beyond the cut-off potential thereof, differential network means associated with said units for resolving the combined outputs thereof into a direct current potential the polarity of which is dependent upon the relative magnitudes of said rectifier unit outputs, a rudder, means for deflecting said rudder in opposite directions in accordance with the polarity of said potential, and electronic means associated with said electron discharge devices and said rectifier units for overcoming the bias on the control grids of said devices alternately and substantially neutralizing the bias on said units alternately and in synchronism with the overcoming of the bias on said control grids.

4. A torpedo having a rudder, a motor for driving said rudder, a source for energizing said motor, and a control system for determining the direction of rotation of said motor in response to sounds emanating from an object thereby to guide the torpedo to said object, said control system comprising a pair of similar hydrophones, an amplifier, means for connecting each of said hydrophones to the input of said amplifier, rectifying means having two similar independently operable units, means for controlling said connecting means and said rectifying means to connect said hydrophones to said amplifier alternately and to operatively associate said two units to the output of said amplifier alternately and in synchronism with the

connection of said hydrophones to said amplifier, means for translating the combined outputs of said two units into a potential the polarity of which at any instant is determined by the relative magnitudes of the individual outputs of said hydrophones, and means controlled in accordance with the polarity of said potential for determining the direction of energization of said motor by said source.

5. A torpedo comprising a rudder, a motor for driving said rudder and having two field windings effective to drive said motor in opposite directions, an energizing source for said motor, relay means for connecting said source to either of said windings, a direct current amplifier for energizing said relay and having a control element, said relay when not energized connecting said source to one of said windings and when energized connecting said source to the other of said windings, and means for controlling said amplifier in response to sounds emanating from an object thereby to actuate said relay and steer the torpedo toward the object, said controlling means comprising two similar rectifier units, a differential network connecting said two units to said control element and effective to resolve the combined outputs of said two units into a potential upon said control element, the polarity of which at any instant is dependent upon the relative outputs of said units, said control element being adapted to render said amplifier operative only when said potential is of one polarity, a pair of hydrophones, and means supplying the output of each hydrophone to a corresponding one of said units.

6. A torpedo in accordance with claim 5 wherein said last means comprises an alternating current amplifier, means for connecting each of said hydrophones to the input of said alternating current amplifier, means for connecting each of said units to the output of said alternating current amplifier, and means for operating said first and second connecting means to operatively associate said hydrophones alternately with said alternating current amplifier and to operatively associate said units with said alternating current amplifier alternately and in synchronism with the association of said hydrophones with said amplifier.

7. An electrical circuit comprising a pair of electron discharge devices having individual input circuits, an amplifier, said devices having their outputs connected in parallel to said amplifier, a rectifier having two similar electronic units connected in parallel to the output of said amplifier, a utilization circuit connected to the outputs of said rectifier units, and means for closing said input circuits alternately and for energizing said units alternately and in synchronism with the closing of said input circuits, said last means comprising a low frequency electronic oscillation generator and means for supplying energy from said oscillator to said input circuits and said units.

8. In combination, a pair of similar electron discharge devices each having a control grid, an amplifier, means connecting the outputs of said devices in parallel to said amplifier, a pair of similar diodes connected in parallel opposing to the output of said amplifier, an electronic oscillator, means connecting said oscillator to said diodes to impress thereon alternately voltages slightly above the cut-off point thereof, means for combining the outputs of said diodes, means impressing upon said control grids biasing potentials substantially equal to the cut-off voltage thereof, and means connecting said oscillator to said control grids to impress thereon alternately and in synchronism with the impressing of voltages upon said diodes voltages to drive the potentials of said grids above the cut-off value.

9. A control circuit comprising a relay, means controlled by said relay, a pair of signal translating devices, and means for controlling operation of said relay in accordance with the relative signal intensities at said devices, said means comprising a pair of similar rectifier units, means for alternately connecting one of said devices to one of said units and the other of said devices to the other of said units, an output circuit for said one unit and including a condenser adapted to be charged in accordance with current flow in said circuit, a similar output circuit for said other unit and including a similar condenser adapted to be charged in accordance with current flow in said second circuit, a single resistance bridged by both of said condensers, said condensers being arranged to be charged in opposite directions relative to said resistance whereby the potential difference across said resistance is proportional to the difference in charges received by said condensers, and an energizing circuit for said relay including said resistance.

10. A signal controlled steering system for a moving body comprising a rudder, reversible means for deflecting said rudder, a pair of signal translating devices, and means for controlling said deflecting means in accordance with the relative intensities of signals received by said translating devices, said controlling means comprising energizing means for said deflecting means, a relay for controlling the direction of energization of said deflecting means, an energizing circuit for said relay including a direct current amplifier having an input circuit, said input circuit including a biasing resistance, a pair of condensers bridged across said resistance, means for charging said condensers in opposite directions including a pair of similar rectifier units each associated with one of said devices and one of said condensers and means for operatively connecting said devices alternately to the respective rectifier units.

11. In a torpedo, means for guiding the torpedo toward an object in accordance with sounds emanating from said object, said guiding means comprising a pair of similar spaced hydrophones, a rudder, means for deflecting said rudder in opposite directions, a relay for controlling said deflecting means to determine the direction of deflection of said rudder, and means for operating said relay in accordance with the relative signal intensities at said devices, said operating means comprising a direct current amplifier for energizing said relay and having an input circuit, an alternating current amplifier, an input element for said amplifier including a pair of electron discharge devices having their outputs connected to said alternating current amplifier and each having its inputs associated with a corresponding one of said hydrophones, a pair of similar electronic rectifier units, a differential network including a bias controlling resistance in the input circuit of said direct current amplifier and including also a pair of substantially equal condensers each in the output circuit of a corresponding rectifier unit and adapted to be charged in accordance with the current flow therein, said condensers being bridged across said resistance and arranged to be charged in opposite directions relative to said resistance, and means including an electronic oscillation generator for rendering said devices conductive alternately and for operatively associating said rectifier units with said alternating current amplifier alternately and in synchronism with the rendering of said devices conductive.

No references cited.

BENJAMIN A. BORCHELT, *Primary Examiner.*

BURNHAM YUNG KWAI, *Examiner.*